1-1-2015

Utilization of BIOSCREEN to Calculate Retardation Factor of Petroleum Contaminants, and Biodegradation Rate for a Site in Montpelier, Indiana

Brittany M. Garner

Utilization of BIOSCREEN to calculate retardation factor of petroleum contaminants, and biodegradation rate for a site in Montpelier, Indiana

By

Brittany M. Garner

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Geoscience- Environmental Geosciences
in the Department of Geosciences

Mississippi State, Mississippi

December 2015

Utilization of BIOSCREEN to calculate retardation factor of petroleum contaminants, and biodegradation rate for a site in Montpelier, Indiana

By

Brittany M. Garner

Approved:

Darrel W. Schmitz
(Major Professor)

Renee M. Clary
(Co-Major Professor)

Ashli Brown-Johnson
(Committee Member)

Michael E. Brown
(Graduate Coordinator)

R. Gregory Dunaway
Professor and Dean
College of Arts & Sciences

Name: Brittany M. Garner

Date of Degree: December 11, 2015

Institution: Mississippi State University

Major Field: Geoscience- Environmental Geosciences

Major Professor: Darrel Schmitz and Renee Clary

Title of Study: Utilization of BIOSCREEN to calculate retardation factor of petroleum contaminants, and biodegradation rate for a site in Montpelier, Indiana

Pages in Study: 96

Candidate for Degree of Master of Science

In March 1994, a report was issued to the Indiana Department of Environmental Management after Jim Allen Maintenance, Inc. found levels of total petroleum hydrocarbons (TPH) exceeding the level appropriate for action (100 parts per million) during an underground storage tank closure report assessment. Creek Run L.L.C Environmental Engineering was contracted by Jay Petroleum to complete an initial site characterization. Through quarterly monitoring of benzene, toluene, ethyl benzene, and methyl tert-butyl ether for 11 years, Creek Run L.L.C determined that biodegradation was occurring.

Upon using BIOSCREEN, a contaminant transport modeling software that simulates natural attenuation over time, it was determined that the retardation factor was 1.4, and the biodegradation rate constant was 4.6 per year. This indicates that the contaminant migration is slow in comparison to groundwater flow, and the rate of biodegradation is at an appropriate value to allow natural attenuation to occur on its own.

ACKNOWLEDGEMENTS

I could not have survived graduate school without all of those I love. Thank you to my grandmothers Wahid Duncan and Bobbie Tate, my parents Jeff Garner and Judy Garner, my sisters Gabriella and Anastasia, and the rest of my family and many friends who have supported me through this whole process. I could not have done any of this without your continued love, patience, and words of encouragement.

To Dr. Darrel Schmitz and Dr. Renee Clary, thank you for accepting me during my most troubled time. Your patience and support in helping me understand this new area of research is invaluable. All professors and mentors should embody the spirit and advocacy for their students like you have shown for me.

To Dr. Ashli Brown-Johnson, thank you for taking the time to serve on my committee in a whirlwind state. Your time serving on my committee is greatly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

1.1 Introduction

Usage of petroleum as an energy source in the United States has increased exponentially since 1935, where the main employment has been fuel sources (United States Energy Information Administration, 2011). Subsequently, consuming petroleum brought forth innovative technology for the development of many items that are used worldwide. However, with the increase in the employment of petroleum, there was also increases in sought out crude oil to sustain the demand for these products, which led to the increase in hazards affecting the environment where petroleum is utilized.

In the United States, petroleum is the most frequent cause of contamination, whereby soil and ground water are exposed to organic compounds that would otherwise not be present naturally (Das, 2011; United States Environmental Protection Agency, 2007). Most common is the gradual release of contaminants from underground storage tanks (Kao, 2006). These contaminants are problematic because benzene, toluene, ethyl benzene, xylenes, and methyl tert-butyl ether, often found in proximity to service stations, have been linked to the prevention of protein synthesis, cancer, and respiratory irritations (Prescott, 1996; Short, 1997; Kaladumo, 1996). Prolonged exposure to these compounds can ultimately lead to death. Furthermore, these organic compounds are volatile, or they evaporate at low temperatures, which not only increases the risk of the contaminants being released in the atmosphere, but also increases the risk of ingestion through respiration, and fire or explosion (Afifi, 2004). Accordingly, a substantial body of research focused on remediation of these risks has been generated by researchers in fields of engineering, medicine, and the natural sciences (Stroud, 2007).

1.2 Petroleum Release in Montpelier, Indiana

In Montpelier, Indiana at Pak-A-Sak #5, located at 204 East Huntington Street, a release was reported by Jim Allen Maintenance, Inc. to the Indiana Department of Environmental Management (IDEM) in March 1994. This release occurred via underground storage tank (UST), and was discovered after a backfill sample was collected from a UST cavity during a UST Closure Assessment conducted by Jim Allen Maintenance, Inc. Total petroleum hydrocarbons (TPH) exceeded 100 parts per million (ppm), which is the IDEM level appropriate for action on site. Creek Run L.L.C. Environmental Engineering (Creek Run) was contracted by Jay Petroleum, the owner of the Pak-A-Sak, to further investigate and report on the site.

Pak-A-Sak #5 is a gasoline/convenience store located in a commercial/residential area, and is owned by Jay Petroleum. Ownership of this site by Jay Petroleum began May 13, 1972, following previous ownership by the Sunoco Oil Company. The former UST system and current kerosene UST and dispenser were present on site during the time of purchase by Jay petroleum. According to the Initial Site Characterization reported by Creek Run in 2003, as of the year 1993 there were four fiberglass reinforced plastic tanks registered on site, with two 8,000-gallon (30,283.29 L) gasoline USTs and one 6,000-gallon (22712.47 L) gasoline UST. In 1998, one 2,000-gallon (7570.824 L) kerosene

UST, which existed prior to purchase by Jay Petroleum, was upgraded with fiberglass lining.

In March 1994, Jim Allen Maintenance, Inc. reported a release to IDEM following an assessment for a UST closure report. This release was discovered when a backfill sample was collected from the UST cavity and was found to contain TPH above 100 ppm which is the IDEM action level. Since gasoline and kerosene were the only products known to be on site, it was clear that the release was from either one of these UST systems. However, analytical results indicated that methyl tert-butyl ether (MTBE) was present in groundwater samples, which led to the conclusion that gasoline was released on site since MTBE is an additive to gasoline. Previously, the UST system that was present at the time of purchase by Jay Petroleum included three 6000-gallon (22,712.47 L) gasoline USTs, one 2000-gallon (7570.82 L) UST, one unregistered 550-gallon (2081.98 L) UST, three fuel dispensers, and piping. All were removed and replaced with the current UST system in 1993. The IDEM assigned the release as incident number 199403537, and as a medium priority.

The site is located in central Indiana, Tipton Till Plain, which is the glaciated area of Indiana. Eight hundred feet (243.84 m) above mean sea level is where bedrock is present, and it is composed of Silurian-age carbonates (Gray 1982; Gray 1987). At depths of 7-123 feet (2.13-37.49 m), below grade, water wells near the site came in contact with bedrock. Surface soil around the site is classified as Glynwood-Bount-Pewamo, which is level to sloping, moderately well-drained to poorly drained, silty, loamy, clayey soils that come from glacial till sources (Kluess, 1986).

The site is located close to a few sensitive areas that include Montpelier Elementary and Middle School which is located approximately 825 feet (251.46 m) south, East Creek located approximately 970 feet (295.66 m) northeast, Salamonie River located approximately 1,650 feet (502.92 m) north, and Lake Blue Water located approximately 0.75 mile (1207 m) northeast. Creek Run approximated these sensitive area distances by inspecting the local topographic map (figure 1.2), and by employing a drive-by survey around the site. Figure 1.1 shows a map created by Creek Run, and the map includes, the location of monitor wells that were put in place. It was determined that subsurface groundwater was impacted by petroleum hydrocarbons, however, the contaminated backfill was removed from site and, through laboratory analysis, TPH has not been detected in soil since then. Groundwater flow was determined to flow toward the west after groundwater elevations were collected on September 5, 2003. Figure 1.3 shows the general topography of the area in addition to the groundwater flow direction.

Through quarterly monitoring of natural attenuation parameters for approximately 10 years, it was observed that electron acceptors were being converted through reduction reactions over time. In addition, the dissolved oxygen content on site was also decreasing over time. This led to the conclusion that biodegradation was occurring on site, and a possibly plan of action could be to allow natural attenuation be the main proponent for remediation of the petroleum contamination.

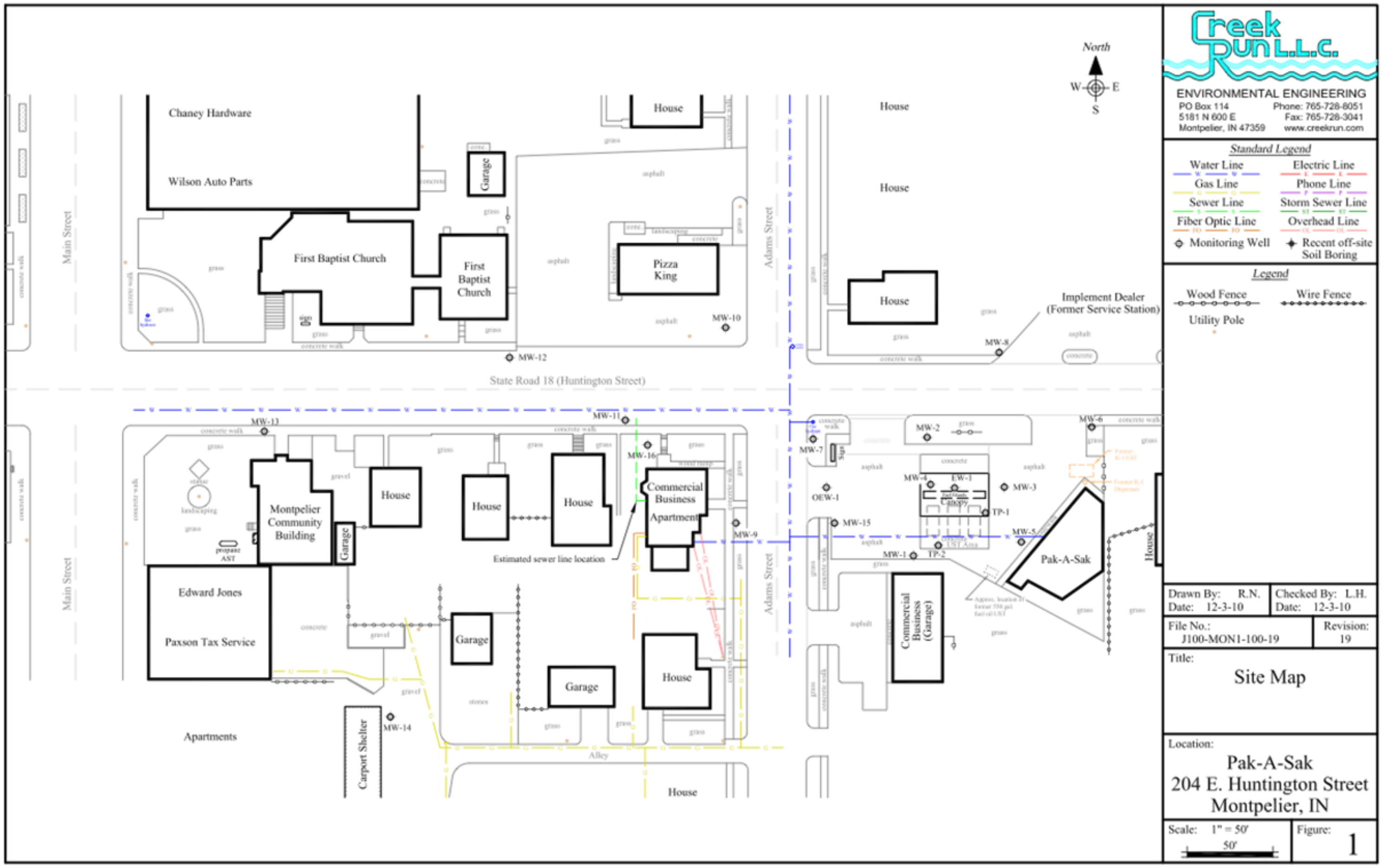


Figure 1.1 Map of Area in Montpelier, Indiana Impacted by Petroleum Contamination

(Map used with permission, Creek Run L.L.C. Environmental Engineering)

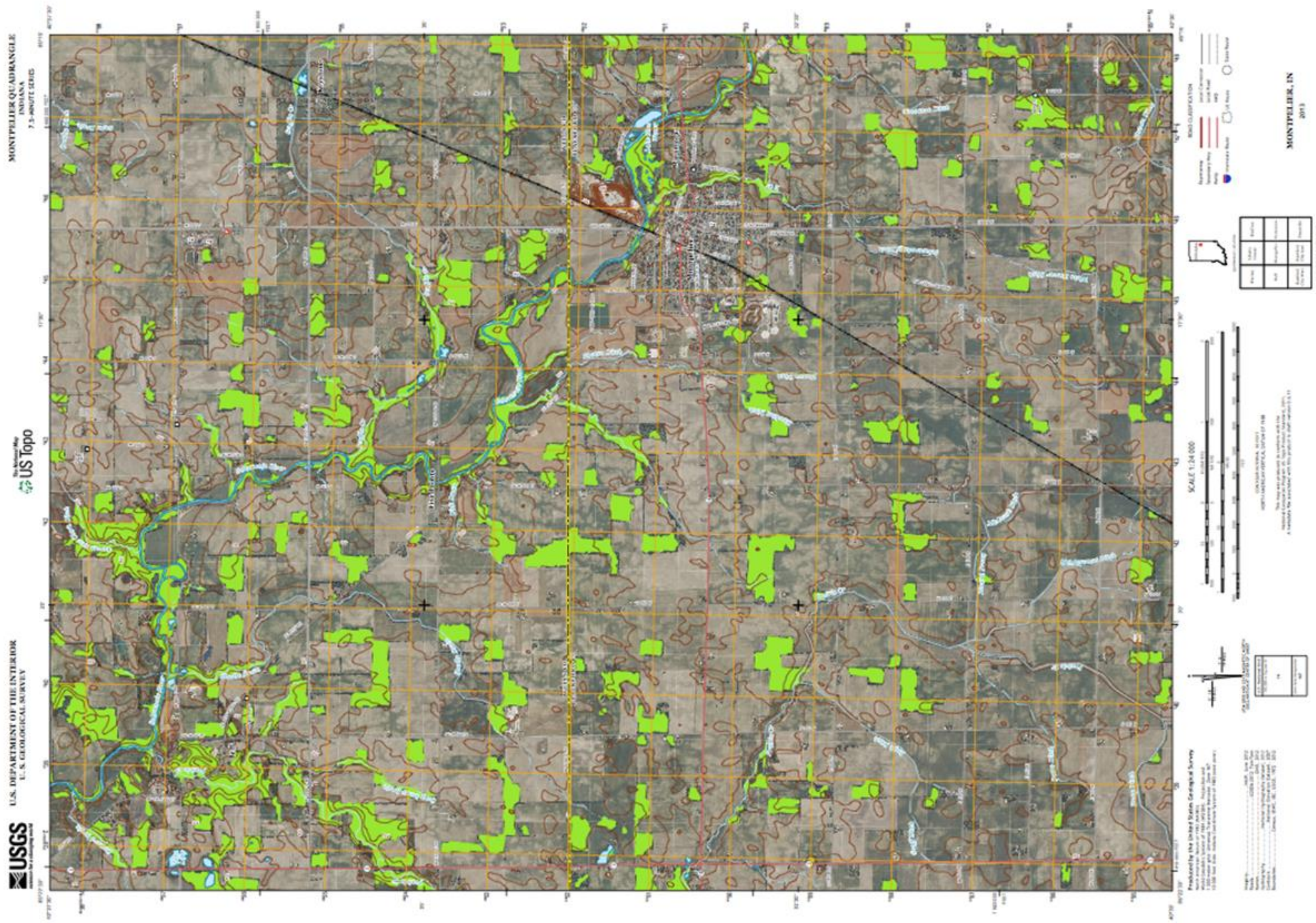


Figure 1.2 Topographic map of Montpelier, Indiana; developed by USGS

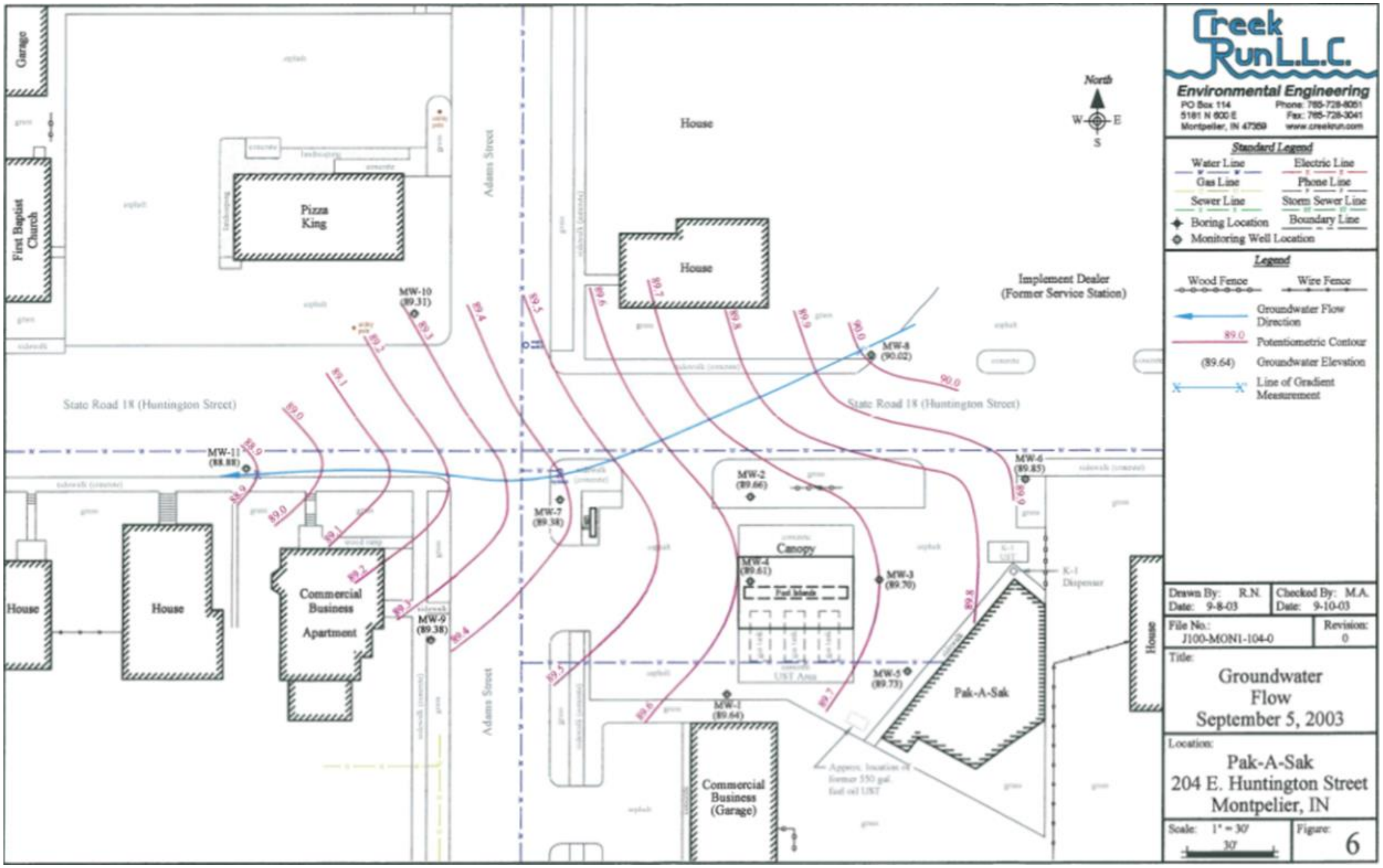


Figure 1.3 Map created by Creek Run that illustrates the directional flow of groundwater on site

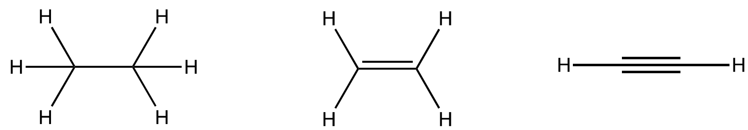
(Map used with permission, Creek Run L.L.C Environmental Engineering)

CHAPTER II

LITERATURE REVIEW

2.1 Organic Contaminants from Petroleum

Organic compounds contain carbon atoms that are predominately bound to hydrogen, oxygen, and nitrogen atoms (Bruice, 2007, p. 2). However, these carbon atoms can also form bonds with other atoms like bromine, sulfur, and silicon. The type of atoms present, in addition to the molecular structure, determine the correct nomenclature for the particular compound. For clarity, the focus will be upon hydrocarbon compounds, or those containing only carbon and hydrogen atoms incorporated in the molecular structure (Bruice, 2007, p. 71). These compounds can have many different structural geometries, and physical and chemical properties depending on the electronics that exist within the structure (Carey, 2007; Fleming, 2009). For example, in figure 2.1 are examples of three different compounds (ethane, ethylene, and acetylene) that only differ in the type of bond between two carbon atoms, and the amount of hydrogen atoms bound to each carbon atom. Their different structures influence the physical properties and reactivity of each compound. Understanding the structure/reactivity relationships can aid in understanding the complexities of petroleum contamination, especially since petroleum consists of many different types of chemical compounds.



Ethane Ethylene Acetylene

Figure 2.1 Structures of ethane, ethylene, and acetylene

Carbons are not shown but are illustrated at the point in which lines meet. All of these structures have two carbons.

Ethane, ethylene, and acetylene are hydrocarbon compounds that exist as gases at standard temperature and pressure (Bruice, 2007). They each have their own unique smell, and they each display different reaction pathways when subjected to the chemical reagent. Their differences in reactivity are due to the electronics that exist within each molecule (Bruice, 2007; Carey, 2007; Fleming, 2009). These differences are apparent when comparing the types of bonds between the two carbons. The more bonds there are between two atoms, the more electron density between them, thus they have differences in electronics. Figure 2.2 presents example syntheses of these compounds being subjected to the same reaction conditions, but yielding different results. This shows that even though compounds are very similar in structure and atoms present, there will be differences in product formation since they possess different chemical properties individually. It is important to note that ethylene is the simplest alkene, or compound containing a double bond. Knowing this information leads to the understanding of how complicated organic reactions can become. As compounds become more complex, the results of organic reactions also become more complex. This is an important point to make since petroleum consists of many different organic compounds that range from very simple to complex molecular structures. In addition, hydrocarbons are not the only type of compounds present in petroleum, and understanding the influences of structure on reactivity can help with future work in remediation.

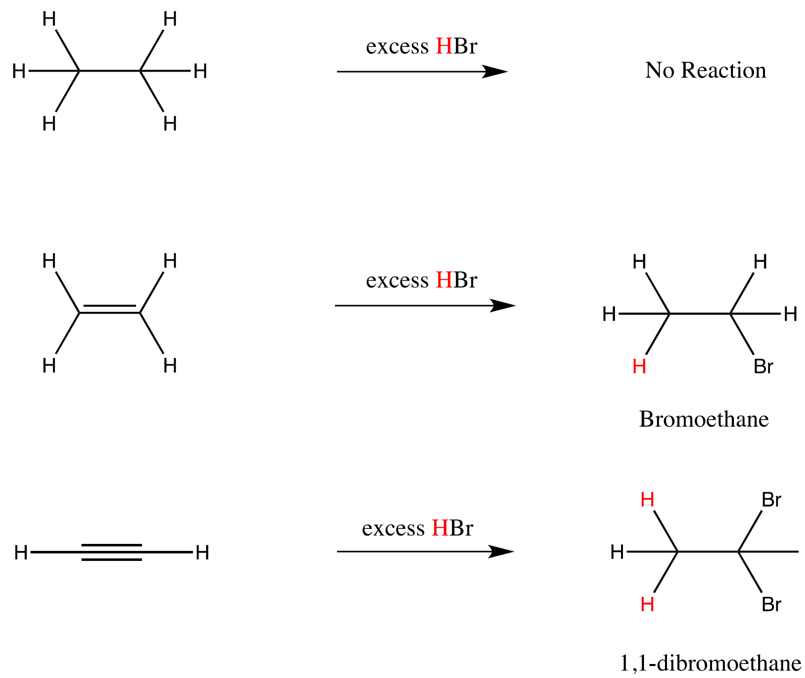


Figure 2.2 Example syntheses of ethane, ethylene, and acetylene under the same reaction conditions

illustrations adapted from Bruice, 2007

Petroleum consists of hydrocarbons that vary in size and molecular weight (United States Department of Health and Human Services, 1999). Examples of these hydrocarbons can be described as aliphatic, aromatic, or polycyclic aromatic. This nomenclature is dependent on the types of atoms present in addition to the geometry exhibited in the molecule (Bruice, 2007). Nevertheless, no matter how simple or complex, most of these compounds have adverse effects on the health of surrounding inhabitants and the environment if consistent exposure occurs (Center for Disease Control and Prevention, 2014; International Programme on Chemical Safety, 1993).

These adverse effects are unique to the particular compound that causes them and will be explained further throughout the text.

Because of the various organic compounds that may be present in petroleum, this section will focus its attention on the organic compounds relevant to this research. These compounds of interest are benzene, toluene, ethyl benzene, xylenes, and methyl tert-butyl ether (BTEX/ MTBE), which are compounds more commonly found in petroleum-contaminated areas (Bedient, 1999). Their structures can be seen in figure 2.3, and it can be noted that BTEX are similar in structure. However, these compounds exhibit dissimilar properties similar to ethane, ethylene, and acetylene previously discussed in this section. Their differences in physical and chemical properties have a great influence on how the compounds are metabolized in the body, and how they react in nature.

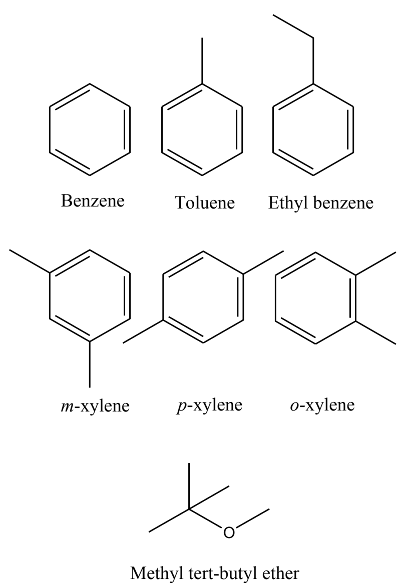


Figure 2.3 Illustrations of BTEX/MTBE molecular structures

Hydrocarbon compounds come in many sizes and shapes, which influence their chemical and physical properties. Knowing how atoms and bonds influence the electronics of the molecular structure can also help with identifying possible pathways of reaction to product formation or working backwards to identify possible starting reactants. Understanding the relationship between structure and reactivity can help tremendously in comprehending and predicting reactions, which will also help to assessing the risk associated with contamination.

2.1.1 Aliphatic Hydrocarbons

When a hydrocarbon compound is referred as aliphatic, it means the compound being described is straight-chained with single, double, and/or triple bonds present in the molecular structure (Bruice, 2007 p. 640). In addition, nitrogen, oxygen, sulfur, and chlorine are commonly found as part of these compounds; however, other elements can also exist in the molecular structure. The reactivity of these compounds, like all other compounds, is dependent on electron distribution within the molecule, which can either be influenced by the type of atoms or the types of bonds present (Carey, 2007; Fleming, 2009). For example, if a more electronegative atom, or an atom that has a high affinity for electrons, is present within the molecule there will be a higher electron density near that atom, and a smaller electron density on the other atom bound to the electronegative one. As in the case of the type of bond, the more bonds there are, such as with a triple bond, the more electron density there is between those two atoms, which causes that part of the molecule to be more reactive. The nature of these compounds affects the reactivity in many different ways, and because of the many possible combinations of atoms for these types of compounds, in-depth explanations of the effects of the structure on reactivity will be omitted due to the complexities of the topic.

2.1.2 Aromatic Hydrocarbons

An aromatic compound is usually defined as a compound that is planar and cyclic in structure with delocalized π-electrons (conjugated double bonds), which add to the overall stability of the compound (Bruice, 2007 p. 640; Carey, 2007 p. 713). Of course, stability is relative and depends on the conditions to which the compound is subjected, but overall aromatic compounds have a slight benefit when it comes to stability. This is because the conjugated double bonds are part of a system in which the electrons are evenly distributed throughout the ring system, a condition known as resonance. The most commonly known aromatic compound that exhibits these characteristics is benzene.

Quantitatively, aromatic compounds can be described using Hückel's rule, where molecular orbital (MO) theory is used to describe the structure and aromaticity of a compound (Bruice, 2007 p. 642). The rule states that if a planar cyclic structure has $(4n+2)\pi$ electrons, equal to a positive integer, then this compound is aromatic. In benzene, for example, there are 3 doubles bonds, which contribute to 2 π-electrons each. This means that there are 6 π-electrons, so when the Hückel equation is set equal to 6, the n value is a positive integer, which is indicative of aromaticity. Knowing whether a compound is aromatic or not is very important in terms of understanding the reaction pathways of these types of compounds because these types of compounds exhibit very different reactivity patterns than aliphatic compounds.

Aromatic compounds can undergo substitution reactions in which a substituent, or functional group, is replaced on the ring through different reaction mechanisms. These reaction mechanisms can be utilized to predict the results of synthetic problems, and can be divided in to four categories: electrophilic, transition metal catalyzed, nucleophilic, and radical reactions (Carey, 2007 p. 771). These are not the only categories for aromatic substitutions, but are the most commonly seen for this category of reactions. Being able to understand, identify, and predict these types of reactions can lead to a better overall understanding of biodegradation.

2.1.3 Health and Environmental Hazards

Because of the many types of chemical compounds in petroleum, in addition to their individual properties, the hazards associated with contamination can affect both the health of inhabitants and the environment. Health impacts are unique to each compound because of their physical and chemical properties, and how they are metabolized in the body; however, their common physical property of having a low evaporation temperature can lead to atmospheric infiltration and environmental damage. The reasoning behind the differences in health hazards despite their similar structures can be explained using the previous example of ethane, ethylene, and acetylene in figure 2.2. However, the complexities of the topic are out of scope of this research (For more fundamental and in-depth descriptions of metabolic pathways in humans, and why they occur, the reader can direct focus on Principles of Biochemistry and The Organic Chemistry of Drug Design and Drug Action (Nelson, 2008; Silverman, 2004). These textbooks are complementary in which one contains fundamental concepts of chemistry within the body, while the other explains how molecular structure influences metabolic pathways in the body.

Benzene is an aromatic compound, and is naturally found in gasoline, crude oil, and cigarette smoke (Center for Disease Control and Prevention, 2013). Because of its physical properties, it is less dense than water and absorbs through skin; however, the most common source of exposure is inhalation because of its volatility (International Programme on Chemical Safety, 1993). Benzene has been linked to many short and long-term health effects. Some effects include dizziness, blurred vision, leukemia, convulsions, and death (Centers for Disease Control and Prevention, 2013).

Toluene is an aromatic compound similar to benzene except it has an added functional group called a methyl group (-CH_3), which can be seen in figure 2.3. However, this added methyl group changes not only the physical properties, but also the reactivity, and thus the way it is metabolized in the body (United States Environmental Protection Agency, 1994). Inhalation can cause kidney, liver, and heart problems if exposure is in high concentration, even for a short period of time. Additionally, if exposure occurs during pregnancy, there can be negative effects towards the fetus.

Ethyl benzene is a colorless liquid used for many chemical processes such as the development of styrene, and can be found in fuel and other petroleum related materials like asphalt (Agency for Toxic Substances and Disease Registry (ATSDR), 1999). Acute exposure can lead to eye and respiratory irritation, shortness of breath, and dizziness. In a study done with mice, it was found that exposure to this compound through inhalation led to the development of tumors in the liver and kidneys; however, carcinogenic properties of this compound are unknown.

Xylenes are isomers of the chemical compound xylene, which are usually found together in nature if chemical separations were not performed to get a pure form of xylene (ATSDR, 1993). Found in most laboratories, xylene is a common solvent used in chemical reactions to produce items such as rubber or paint. Found in gasoline and cigarette smoke, xylenes can cause headaches, nausea, vomiting, and dizziness if acute exposure occurs. Chronic exposure can lead to irritability, depression, tiredness, and insomnia.

Used as an additive in gasoline, methyl tert-butyl ether is a colorless liquid that can cause acute effects such as nausea, sleepiness, and vomiting (ATSDR, 1996). If exposure over a period of time occurs, one may experience coughing, dizziness, headache, and the possibility of testicular tumors and leukemia.

Although the health hazards associated with BTEX/MTBE are worrisome, one must be more aware of how their physical properties can lead to exposure. These compounds are volatile, which means they evaporate at low temperatures. Because of this, the risks associated with them can expand to a bigger category where the environment will be affected through evaporation, and the compounds will infiltrate the atmosphere (Afifi, 2004). Once this occurs, their flammability leads to a greater risk for fire and extreme environmental damage.

2.2 Biodegradation

Studies focused on microorganisms' ability to survive amongst aromatic hydrocarbons have been occurring since the early 1900s, where the first study by Söhngen showed microbes utilizing hydrocarbon compounds for energy (Söhngen, 1913). Since then, biodegradation studies on hydrocarbon degradation have increased exponentially, which has added to the understanding of general degradation pathways (Gibson, 1984). There are two types of biodegradation reaction pathways: aerobic degradation and anaerobic degradation. The difference in these types of reactions is whether or not oxygen is utilized by the microbes to metabolize the organic contaminants present on site. When biodegradation occurs, there are two categories of methods, specific and nonspecific, that can be utilized for multiple purposes; such as methods in order to determine the types of compounds present, for example. The difference between the two is the level of analytical attention given to each method (Gibson, 1984 p. 30).

Aerobic degradation is the process by which a microbial degradation of organic compounds takes place, but can only occur if oxygen is present for utilization by microbes (Gibson, 1984). Consumption of oxygen leads to the dispelling of carbon dioxide and methane as products. Conversely, anaerobic degradation is the microbial degradation of organic compounds in the absence of oxygen; however the dispelling of carbon dioxide and methane is the same. The pathways of these reactions are dependent on the contaminant being consumed, which means there are a multitude of combinations for conversion. Because of this, the complexities of reaction pathways are out of the scope of this research. Detailed descriptions of aerobic and anaerobic degradations can be found in (Gibson, 1984), which contains all research published through 1984 on a multitude of degradation pathways.

If an analytical approach for characterizing biodegradation is required, research should be focused on more specific techniques where the structure, biological activity, and physical properties of the compounds can be determined (These methods are thin-layer chromatography, high-pressure liquid chromatography, ultraviolet-visible spectroscopy, and mass spectrometry.

A more feasible option for characterizing biodegradation is to use the nonspecific approach. This is because the approach is quick and applicable on site rather than requiring laboratory analysis. There are three main measurements than can be done on site: biochemical oxygen demand (BOD) chemical oxygen demand (COD) and dissolved organic carbon (DOC).

BOD measures the consumption of oxygen during biodegradation, which can help with determining level of biodegradability of the microbial population (Howard, 1975). This measurement is usually stated as a percentage of theoretical oxygen consumption. COD can be determined in the place of BOD by oxidizing a sample using potassium dichromate in 50% sulfuric acid in conjunction with a catalytic amount of silver sulfate (Pitter, 1976). It measures the decrease in chemical oxygen demand during biodegradation. DOC measures the decrease in the dissolved organic carbon by using instruments that measure the concentration of methane and carbon dioxide since these are the products to which DOCs are converted (Gibson, 1984 p. 31). These methods can be employed on site, which make them a better option in terms of quickly obtaining the information needed to draw conclusions.

2.2.1 Bioremediation

As early as 1913, microbes were shown to utilize hydrocarbons for energy (Söhngen, 1913), and through the years studies have evolved into more applied research of microbes present in soil and groundwater and their remedial properties (Johnson, 1964; Suflita, 2000). According to Practical Environmental Bioremediation: The Field Guide by R. Barry King et al., there are three methods for bioremediation treatment. These treatments are biostimulation, bioaugmentation, and intrinsic treatment, and all are related to each other in that one treatment is a more intrusive method than the other.

Biostimulation is the act of allowing native microbes to remediate the impacted area, and aiding in these processes by providing the proper resources for the microbes to work (King, 1998 p. 7). If through testing it is determined that biostimulation will not achieve the required results, bioaugmentation will possibly be employed. In bioaugmentation, microbes will be added to the impacted area. Lastly, if both biostimulation and bioaugmentation do not achieve desired results, intrinsic treatment will be implemented where the contaminants are allowed to degrade naturally over time. However, in order to know which option is best suited for a particular site, it is essential to understand degradation pathways as well as bioremedial design.

Bacteria discovered in soil and groundwater were shown to have the unique capacity to digest petroleum contaminants and convert them in to less harmful products (King, 1998). This process is known as biodegradation, and has been used for a variety of applications, with the most prevalent being the mitigation of petroleum contamination. This field of research encompasses a number of lines of inquiry including the fate of hydrocarbons in soil, which has led to the proposal of specific carbon transformations, and potential soil-hydrocarbon interactions (Stroud, 2007). These studies have contributed to an improved understanding of biodegradation as well as bioremediation, and there are a multitude of other pathways that have been taken to maximize processes. However, because of the large volume of bioremedial strategies, the aforementioned strategies were only cited as examples.

Concentrations of benzene, found in soil and groundwater samples collected beneath a manufacturing facility, were observed to decrease over time (Davis, 1994; Johnson, 2003). To determine whether the decreased concentrations were due to physical processes or biodegradation processes, samples were taken and subjected to analysis. The authors concluded that biodegradation was the responsible mechanism because the measured dissolved oxygen content decreased over time, in addition to the conversion of electron acceptors, via redox reactions, present on site. Furthermore, the biodegradation occurred in the presence and absence of oxygen, which could create many pathways for research regarding this subject. This is because researchers can utilize the reaction pathways in order to develop laboratory strategies to speed up processes and make bioremediation more efficient. For example, research on the interactions of iron in clay with indigenous microbes were studied (Kuhn, 2012). These interactions were anaerobic processes because oxygen was not required for degradation to take place; however, the researchers found that the energy barrier for the reaction to take place was too high to occur on its own, so this research group employed the use of siderophores, or iron chelators, to push the reaction forward. In addition, other research groups pumped pure oxygen in to samples, via hydrogen peroxide, to take advantage of aerobic processes (Davis, 1994).

2.2.2 Retardation factor

Overall, the retardation factor determines how the soil affects the flow of contaminants relative to the flow of groundwater, since certain types of soils can affect the flow of contaminants through molecular interactions (Koestel, 2012). Quantitatively, the retardation factor is determined by completing flow experiments in a laboratory setting, or it can be calculated using modeling software (Bouwer, 1991; Li, 1997). When calculated, it gives an indication of how far contaminants have migrated, or how far they can go over time. This will give a better idea of how the soil and sediment affect the movement of contaminants, and how much of a decrease of concentration in groundwater can be contributed to biodegradation. Since retardation factor is a ratio of the distance of contaminants traveled versus the distance of groundwater traveled, a higher number calculated for this factor indicates a faster flow of contaminants with little adsorption to ground material.

Mathematically, retardation factor can be calculated using the formula:

$$R = 1 + (\rho\ k)/\ \theta \qquad (2.1)$$

where R is defined as the retardation factor. This equation is derived from the convection-dispersion model employed by Hoffman and coworkers in addition to Jardine (Hoffman 1980; Jardine, 1992). The variable ρ is the porous medium bulk density, k is an empirical distribution coefficient (mL/g), and θ is the volumetric water content.

2.2.3 Biodegradation rate

As microbes metabolize hydrocarbons in soil and groundwater, the rate of degradation is dependent on the rate of contaminant movement, and assimilative capacity of the soil material on site. This rate can be determined by calculating the rate of the biodegradation reaction using 1st order kinetics (United States Environmental Protection Agency, 2002). The United States Environmental Protection Agency published a well-written article on the use of first-order rate constants for studying natural attenuation. In the article, three types of first-order rate attenuation constants were described (concentration versus time, concentration versus distance, and biodegradation constant). The previous citation provides the information regarding this subject, as well as the relevant data analysis to determine these constants.

Determination of the biodegradation rate constant can be achieved by performing tracer tests on site and graphing contaminant transport versus tracer transport. The slope of the line is the biodegradation constant, and is usually expressed in inverse years. In addition, the employment of a solute transport model can also calculate biodegradation rate based on field data. Also, calculations of biodegradation rate can be achieved by using laboratory methods (Baker, 2000; Cho, 2013; Oya, 1998). The information gathered from these calculations can help estimate the concentration of contaminants being consumed, and a possible time when all of the contaminants will be fully consumed.

2.3 BIOSCREEN

Developed by Groundwater Services, Inc. for the Air Force Center for Environmental Excellence Technology Transfer Division at Brooks Air Force Base, BIOSCREEN is a useful tool for modeling remediation through natural attenuation, where it can simulate dispersion, advection, adsorption, and aerobic/anaerobic reactions (Newell, 1997). Based on the Domenico analytical transport model, this software was programmed in Microsoft® Excel which makes it easy to use and compatible with any computer that has Microsoft® Office. Within the software is automatic conversion of units of measurement, which increases applicability to field work and decreases time used for analysis. Comparable software, like BIOPLUME III, can somewhat achieve the same results as BIOSCREEN; however, it does not use the Domenico Model for analysis. Although this software is free to use and easy to download from the internet, there were some limitations to its use for this research.

BIOSCREEN includes three model types that can simulate aerobic and anaerobic biodegradation processes. Features of this software include the ability to calculate mass flux of contaminants and to convert kilogram to gallons in order to give a volume to the

Actual Plume Mass. BIOPLUME II and III, use the instantaneous reaction superposition method for calculations, rather than the Domenico Model, where the instantaneous reaction is dependent on the amount of oxygen available for biodegradation to occur (Ollila, 1996). There are a few comparative studies of BIOSCREEN versus BIOPLUME, and it was found that BIOSCREEN gave more accurate results by using the Domenico model for calculations (Nevin, 1997; Ollila, 1996; Rifai, 1997). However, BIOPLUME seems to have more features and animations to help with analysis of the contaminated site. Eventually, it would be interesting to see BIOSCREEN incorporate more features as well.

BIOSCREEN is able to determine to biodegradation of BTEX on a contaminated site. However, it is unable to determine biodegradation of MTBE. Since MTBE can be just as prevalent on a petroleum-contaminated site as BTEX, it is important to also know how natural attenuation will eventually degrade this compound. There are some studies focused on using BIOSCREEN for calculating biodegradation of MTBE that give somewhat accurate results, but laboratory analysis shows that there are still some slight discrepancies, and conclusions do not give a sure indication that the method could be employed (Wilson, 1999). Nevertheless, since BIOSCREEN is free and easy to use, it is a better option for modeling natural attenuation.

CHAPTER III

PROBLEM STATEMENT

3.1 Problem Statement

In Montpelier, Indiana, a petroleum release was discovered in March 1994 after a backfill sample was found to contain concentrations of BTEX/MTBE. Since MTBE is an additive in gasoline, it was concluded that the release was a result of a gasoline underground storage tank leak. The volume of contaminants released is unknown. Since data suggest that biodegradation is occurring on site, it is of interest to determine if allowing natural attenuation is a feasible option.

3.1.1 Hypothesis

Using retardation and biodegradation rate calculated by BIOSCREEN, the rate of flow of contaminants and the rate of metabolic conversion will document that natural attenuation via microbial degradation is occurring on site.

3.1.2 Objectives

BIOSCREEN will be used for

1. Calculation of retardation factor to determine the flow of contaminants relative to groundwater flow.
2. Calculation of biodegradation rate to determine if natural attenuation will give an idea of the rate at which the microbes on site are metabolizing

BTEX/MTBE, and if that rate is appropriate allow natural attenuation, intrinsic bioremediation, to be the main source of remediation.

CHAPTER IV

METHODOLOGY

4.1 Data Collection

In November 1993, Jim Allen Maintenance, Inc. collected six soils samples for an underground storage tank (UST) closure report. Of those six soil samples, the backfill sample was found to contain levels of total petroleum hydrocarbons (TPH) exceeding the Indiana Department of Environmental Management (IDEM) action level of 100 ppm. Three 6,000-gallon (22,712.47 L) gasoline USTs and one 550-gallon (2081.98 L) unregistered UST were removed, in addition to the backfill, and three fiberglass reinforced plastic USTs were installed in their place.

During the initial site characterization employed by Creek Run in 2003, soil borings were drilled using a truck-mounted Geoprobe, and soil samples were collected in four foot increments using a hydraulically-driven, stainless steel sampling tube equipped with a clear, co-polyester liner. Ten soil borings (SB-5 through SB-14) were drilled to a depth of 16 to 20 feet (4.88 – 6.10 m) below grade. Figure 4.1 shows the locations of all soil borings on site, and boring logs can be seen in Appendix B. After soil samples were collected, soil borings were backfilled with granular bentonite.

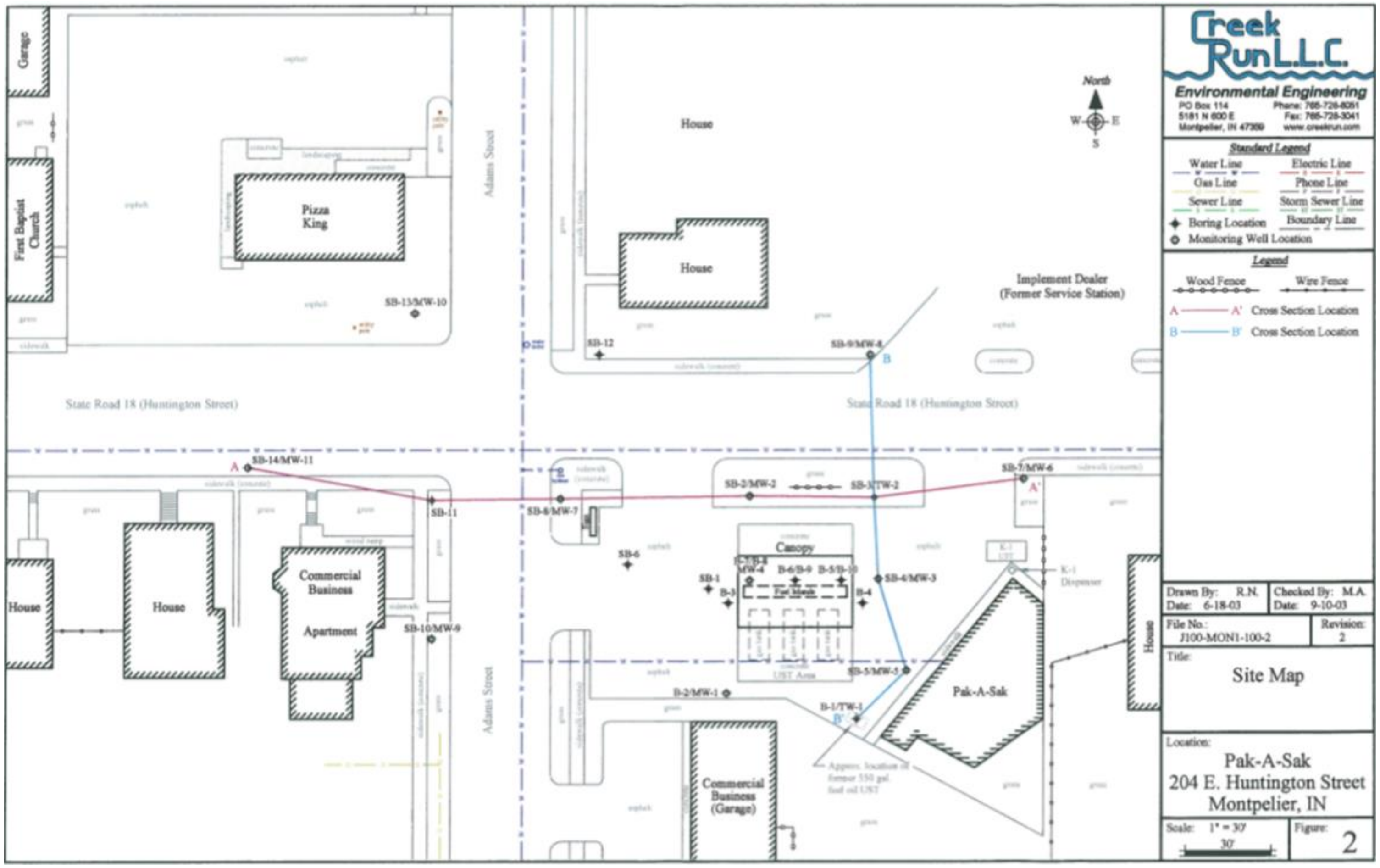


Figure 4.1 Locations of Soil Borings in Montpelier, Indiana

(Map used with permission, Creek Run L.L.C. Environmental Engineering)

Eleven monitor wells were installed, and construction diagrams for the monitoring wells can be seen in Appendix B. All were equipped with locking well caps and protected by flush mounted protected assembly. Depths of wells were in the range of 13.5-16.18 feet below grade, and they were constructed with 10 feet of two-inch diameter, factory slotted, 0.01-inch PVC screen. The annular space from bottom to one to three feet above the screen interval was filled with sand, and bentonite was placed above the sand pack approximately one foot of depth below the top of the riser.

Before collecting groundwater samples, three well volumes of water were purged from each well, and samples were collected in to a disposable bailer and cooled to 39.2 ^{o}F (4 ^{o}C) in an ice-filled cooler. Samples from wells MW-1 through MW-3 were sent to Severn Trent Laboratories, while samples from MW-4 through MW-11 were sent to Pace Analytical®. Monitor wells 12-16 and EW-1, OEW-1, TP-1, and TP-2 sample analysis locations were not specified by Creek Run. All samples were analyzed for BTEX and MTBE and the results can be seen in tables 4.1-4.20.

In addition, natural attenuation parameters were measured on site by Creek Run, the data can be seen in tables 4.21-4.37. Additionally, the dissolved oxygen content of the wells was also measured on site. Dissolved oxygen, oxidation/reduction potential, and temperature were all measured using an Oakton pH 10 series meter equipped with a DO meter and a platinum ORP electrode. Specific conductivity and pH measurements were measured using an Oakton pH/conductivity 10 series meter. Hydrogen sulfide was measured with a CHEMets kit and ferrous iron concentrations were measured with a LaMotte Iron Ferric/Ferrous test kit.

Table 4.1 Elevations and Analytical Results for Monitoring Well 1

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-1	4/1/03	9.12	90.92	<5.0	<5.0	<5.0	<5.0	23
	1/12/04	9.64	90.4	3	5.1	5.1	17	19
	4/15/04	10.72	89.32	<1.0	<5.0	<5.0	<10.0	5.5
	7/21/04	11.92	88.12	<1.0	<5.0	<5.0	<10.0	6.4
	10/21/04	12.07	87.97	<1.0	<5.0	<5.0	<10.0	14
	1/19/05	9.32	90.72	<1.0	<5.0	<5.0	<10.0	18
	4/13/05	10.16	89.88	<1.0	<5.0	<5.0	<10.0	7.7
	7/6/05	11.27	88.77	<1.0	<5.0	<5.0	<10.0	6.4
	10/11/05	12.1	87.94	<1.0	<5.0	<5.0	<10.0	16
	1/18/06	9.63	90.41	<1.0	<5.0	<5.0	<10.0	16
	4/19/06	9.71	90.33	<1.0	<5.0	<5.0	<10.0	9.3
	7/11/06	11.76	88.28	<1.0	<5.0	<5.0	<10.0	5.6
	10/18/06	11.08	88.96	<1.0	<5.0	<5.0	<10.0	8.2
	1/18/07	8.89	91.15	<1.0	<5.0	<5.0	<10.0	6.1
	4/18/07	9.61	90.43	<1.0	<5.0	<5.0	<10.0	9.5
	7/24/07	12.73	87.31	<1.0	<5.0	<5.0	<10.0	5.7
	10/24/07	12.62	87.42	<1.0	<5.0	<5.0	<10.0	10
	1/23/08	10.94	89.1	<1.0	<5.0	<5.0	<10.0	12.1
	4/17/08	10.14	89.9	<1.0	<5.0	<5.0	<10.0	7.3
	7/16/08	11.15	88.89	<1.0	<5.0	<5.0	<10.0	5.7
	10/16/08	13.27	86.77	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	11.47	88.57	<1.0	<5.0	<5.0	<10.0	8.3
	4/7/09	8.96	91.08	<1.0	<5.0	<5.0	<10.0	6.5
	7/1/09	11.38	88.59	<1.0	<5.0	<5.0	<10.0	<4.0
	10/1/09	12.68	87.29	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	10.28	89.69	<1.0	<5.0	<5.0	<10.0	6.8
	4/1/10	9.33	90.64	<1.0	<5.0	<5.0	<10.0	4.6
	7/6/10	11.14	88.83	<1.0	<5.0	<5.0	<10.0	4.4
	10/19/10	12.88	87.09	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	11.4	88.57	<1.0	<5.0	<5.0	<10.0	7
	5/9/11	9.28	90.69	<1.0	<5.0	<5.0	<10.0	4.4
	8/16/11	11.82	88.15	<1.0	<5.0	<5.0	<10.0	<4.0
	11/1/11	11.44	88.53	<1.0	<5.0	<5.0	<10.0	4.3
	1/23/12	9.21	90.76	<1.0	<5.0	<5.0	<10.0	5
	4/5/12	10.97	89	<1.0	<5.0	<5.0	<10.0	4.3
	7/10/12	13.05	86.92	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	11.34	88.54	<1.0	<5.0	<5.0	<10.0	4.6
	1/9/13	10.85	89.03	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	9.08	90.8	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	10.53	89.35	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	11.66	88.22	<1.0	<5.0	<5.0	<10.0	4.4
	1/14/14	9.54	90.34	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.2 Elevations and Analytical Results for Monitoring Well 2

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-2	4/1/03	8.12	90.9	<5.0	<5.0	<5.0	<5.0	16
	1/12/04	8.61	90.41	<1.0	<5.0	<5.0	<10.0	<4.0
	4/15/04	9.69	89.33	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	10.89	88.13	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	11.03	87.99	<1.0	<5.0	<5.0	<10.0	23
	1/19/05	5.3	93.72	<1.0	<5.0	<5.0	<10.0	7.1
	4/13/05	9.11	89.91	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	10.22	88.8	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	11.07	87.95	<1.0	<5.0	<5.0	<10.0	23
	1/18/06	8.58	90.44	<1.0	<5.0	<5.0	<10.0	30
	4/19/06	8.66	90.36	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	10.71	88.31	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	10.04	88.98	<1.0	<5.0	<5.0	<10.0	16
	1/18/07	7.85	91.17	<1.0	<5.0	<5.0	<10.0	<4.0
	4/18/07	8.64	90.38	<1.0	<5.0	<5.0	<10.0	<4.0
	7/24/07	11.7	87.32	<1.0	<5.0	<5.0	<10.0	<4.0
	10/24/07	11.59	87.43	<1.0	<5.0	<5.0	<10.0	**42.8**
	1/23/08	9.91	89.11	<1.0	<5.0	<5.0	<10.0	21.9
	4/17/08	9.07	89.95	<1.0	<5.0	<5.0	<10.0	<4.0
	7/16/08	10.1	88.92	<1.0	<5.0	<5.0	<10.0	<4.0
	10/16/08	12.22	86.8	<1.0	<5.0	<5.0	<10.0	34.6
	1/14/09	10.41	88.61	1.2	<5.0	<5.0	<10.0	**56**
	4/7/09	7.86	91.16	<1.0	<5.0	<5.0	<10.0	20.7
	7/1/09	10.4	88.62	<1.0	<5.0	<5.0	<10.0	<4.0
	10/1/09	11.7	87.32	<1.0	<5.0	<5.0	<10.0	30.3
	1/4/10	9.3	89.72	<1.0	<5.0	<5.0	<10.0	29.9
	4/1/10	8.32	90.7	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/10	10.16	88.86	<1.0	<5.0	<5.0	<10.0	<4.0
	10/19/10	11.87	87.15	<1.0	<5.0	<5.0	<10.0	22.3
	1/27/11	10.36	88.66	<1.0	<5.0	<5.0	<10.0	**71.7**
	5/9/11	8.23	90.79	<1.0	<5.0	<5.0	<10.0	<4.0
	8/16/11	10.77	88.25	<1.0	<5.0	<5.0	<10.0	4.6
	11/1/11	10.4	88.62	<1.0	<5.0	<5.0	<10.0	38.9
	1/23/12	8.16	90.86	<1.0	<5.0	<5.0	<10.0	8.8
	4/5/12	9.91	89.11	<1.0	<5.0	<5.0	<10.0	<4.0
	7/10/12	12.02	87	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	10.29	88.56	<1.0	<5.0	<5.0	<10.0	39.6
	1/9/13	9.82	89.03	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	8.03	90.82	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	9.5	89.35	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	10.34	88.51	<1.0	<5.0	<5.0	<10.0	22.4
	1/14/14	8.51	90.34	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.3 Elevations and Analytical Results for Monitoring Well 3

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-3	4/1/03	8.08	90.92	<5.0	<5.0	<5.0	<5.0	**129**
	1/12/04	8.55	90.45	<1.0	<5.0	<5.0	<10.0	**140**
	4/15/04	9.64	89.36	<1.0	<5.0	<5.0	<10.0	**190**
	7/21/04	10.82	88.18	<1.0	<5.0	<5.0	<10.0	**180**
	10/21/04	10.97	88.03	<1.0	<5.0	<5.0	<10.0	**110**
	1/19/05	8.25	90.75	<1.0	<5.0	<5.0	<10.0	**85**
	4/13/05	9.08	89.92	<1.0	<5.0	<5.0	<10.0	**190**
	7/6/05	10.17	88.83	<1.0	<5.0	<5.0	<10.0	**230**
	10/11/05	10.99	88.01	<1.0	<5.0	<5.0	<10.0	**83**
	1/18/06	8.51	90.49	<1.0	<5.0	<5.0	<10.0	**52**
	4/19/06	8.6	90.4	<1.0	<5.0	<5.0	<10.0	**87**
	7/11/06	10.65	88.35	<1.0	<5.0	<5.0	<10.0	**52**
	10/18/06	9.96	89.04	<1.0	<5.0	<5.0	<10.0	38
	1/18/07	7.8	91.2	<1.0	<5.0	<5.0	<10.0	**40**
	4/18/07	8.55	90.45	<1.0	<5.0	<5.0	<10.0	30.5
	7/24/07	11.66	87.34	<1.0	<5.0	<5.0	<10.0	24.2
	10/24/07	11.52	87.48	<1.0	<5.0	<5.0	<10.0	23.9
	1/23/08	9.86	89.14	<1.0	<5.0	<5.0	<10.0	37.7
	4/17/08	9.05	89.95	<1.0	<5.0	<5.0	<10.0	**46.2**
	7/16/08	10.07	88.93	<1.0	<5.0	<5.0	<10.0	**51.7**
	10/16/08	12.19	86.81	<1.0	<5.0	<5.0	<10.0	13.6
	1/14/09	10.39	88.61	<1.0	<5.0	<5.0	<10.0	**40.8**
	4/7/09	7.85	91.15	<1.0	<5.0	<5.0	<10.0	14.1
	7/1/09	10.41	88.59	<1.0	<5.0	<5.0	<10.0	29.8
	10/1/09	11.7	87.3	<1.0	<5.0	<5.0	<10.0	9.9
	1/4/10	9.32	89.68	<1.0	<5.0	<5.0	<10.0	21.9
	4/1/10	8.36	90.64	<1.0	<5.0	<5.0	<10.0	18.1
	7/6/10	10.17	88.83	<1.0	<5.0	<5.0	<10.0	14
	10/19/10	11.88	87.12	<1.0	<5.0	<5.0	<10.0	7.5
	1/27/11	10.38	88.62	<1.0	<5.0	<5.0	<10.0	7.1
	5/9/11	8.24	90.76	<1.0	<5.0	<5.0	<10.0	8.3
	8/16/11	10.78	88.22	<1.0	<5.0	<5.0	<10.0	7.4
	11/1/11	7.4	91.6	<1.0	<5.0	<5.0	<10.0	5.7
	1/23/12	9.18	89.82	<1.0	<5.0	<5.0	<10.0	13.8
	4/5/12	9.94	89.06	<1.0	<5.0	<5.0	<10.0	**59.9**
	7/10/12	12.02	86.98	<1.0	<5.0	<5.0	<10.0	25.1
	10/4/12	10.29	88.67	<1.0	<5.0	<5.0	<10.0	10.2
	1/9/13	9.85	89.11	<1.0	<5.0	<5.0	<10.0	7.8
	4/15/13	8.06	90.9	<1.0	<5.0	<5.0	<10.0	35.7
	7/10/13	9.52	89.44	<1.0	<5.0	<5.0	<10.0	35.9
	10/8/13	10.63	88.33	<1.0	<5.0	<5.0	<10.0	6.3
	1/14/14	8.55	90.41	<1.0	<5.0	<5.0	<10.0	4.6

Table 4.4 Elevations and Analytical Results for Monitoring Well 4

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
	5/23/03	9.48	89.94	**29**	<5.0	5.8	<10.0	**1,800**
	1/12/04	9.04	90.38	**71**	<5.0	5.1	<10.0	**2,100**
	4/15/04	10.15	89.27	**93**	<5.0	5.3	<10.0	**1,700**
	7/21/04	11.35	88.07	**270**	6.4	7.3	13.8	**3,500**
	10/21/04	11.51	87.91	**28**	<5.0	<5.0	<10.0	**2,700**
	1/19/05	8.78	90.64	**76**	8.8	5.9	17.5	**2,400**
	4/13/05	9.61	89.81	**230**	<5.0	11	6.4	**2,000**
	7/6/05	10.71	88.71	**110**	11	4.4	14.2	**2,200**
	10/11/05	11.53	87.89	**34**	<5.0	<5.0	<10.0	**1,700**
	1/18/06	9.08	90.34	**43**	<5.0	<5.0	<10.0	**1,600**
	4/19/06	9.67	89.75	**79**	<5.0	<5.0	<10.0	**2,000**
	7/11/06	11.2	88.22	**390**	<5.0	8.7	<10.0	**2,200**
	10/18/06	10.54	88.88	**36**	<5.0	<5.0	<10.0	**1,900**
	1/18/07	8.36	91.06	**49**	<5.0	<5.0	<10.0	**1,400**
	4/18/07	9.16	90.26	**169**	<5.0	10.5	<10.0	**1,860**
	7/24/07	12.23	87.19	**22**	<5.0	<5.0	<10.0	**3,000**
	10/24/07	12.1	87.32	**6.9**	<5.0	<5.0	<10.0	**1,660**
	1/23/08	10.44	88.98	**13.8**	<5.0	<5.0	<10.0	**1,550**
	4/17/08	9.63	89.79	**92.2**	<5.0	<5.0	<10.0	**2,250**
	7/16/08	10.62	88.8	**67.6**	<5.0	8	<10.0	**1,990**
MW-4	10/16/08	12.73	86.69	1.2	<5.0	<5.0	<10.0	**2,080**
	1/14/09	10.92	88.5	**30.1**	<5.0	<5.0	<10.0	**1,590**
	4/7/09	8.32	91.1	**31.4**	<5.0	<5.0	<10.0	**1,130**
	7/1/09	10.92	88.5	**59.9**	8.3	6.7	<10.0	**1,600**
	10/1/09	12.22	87.2	**27.6**	<5.0	<5.0	<10.0	**1,550**
	1/4/10	9.81	89.61	3.4	<5.0	<5.0	<10.0	**820**
	4/1/10	8.85	90.57	**251**	13	186	18.1	**665**
	7/6/10	10.66	88.76	**110**	<25.0	58.9	<50.0	**975**
	10/19/10	4.47	94.95	**167**	<25.0	14.9 J	<50.0	**112**
	1/27/11	10.49	88.93	**273**	87.2	25	<50.0	**809**
	5/9/11	8.39	91.03	**210**	80.1	27.3	<50.0	**635**
	8/16/11	11.06	88.36	**169**	42.7	28.2	<50.0	**923**
	11/1/11	10.73	88.69	**110**	32.2	19.7 J	<50.0	**723**
	1/23/12	8.71	90.71	**89.1**	64.6	20.2 J	<50.0	**649**
	4/5/12	10.29	89.13	**32.5**	9	5	<10.0	**178**
	7/10/12	12.45	86.97	**136**	19.4	15.6	23.7	**989**
	10/4/12	10.73	88.63	**47.7**	<25.0	13.7 J	<50.0	**659**
	1/9/13	10.2	89.16	**40.7**	16.3 J	<25.0	<50.0	**660**
	4/15/13	8.43	90.93	**133**	<25.0	<25.0	<50.0	**771**
	7/10/13	9.91	89.45	**73.4**	<25.0	<25.0	<50.0	**744**
	10/8/13	11.23	88.13	**20.6**	<25.0	<25.0	<50.0	**735**
	1/14/14	9.05	90.31	**23.7**	8.4	5.2	<10.0	**665**

Table 4.5 Elevations and Analytical Results for Monitoring Well 5

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-5	5/23/03	15.71	83.71	<1.0	<5.0	<5.0	<10.0	5.6
	1/12/04	8.86	90.56	<1.0	<5.0	<5.0	<10.0	**99**
	4/15/04	10.04	89.38	<1.0	<5.0	<5.0	<10.0	14
	7/21/04	11.23	88.19	<1.0	<5.0	<5.0	<10.0	27
	10/21/04	11.35	88.07	<1.0	<5.0	<5.0	<10.0	7.5
	1/19/05	8.66	90.76	<1.0	<5.0	<5.0	<10.0	20
	4/13/05	9.48	89.94	<1.0	<5.0	<5.0	<10.0	34
	7/6/05	10.56	88.86	<1.0	<5.0	<5.0	<10.0	32
	10/11/05	11.37	88.05	<1.0	<5.0	<5.0	<10.0	9.7
	1/18/06	8.92	90.5	<1.0	<5.0	<5.0	<10.0	28
	4/19/06	9	90.42	<1.0	<5.0	<5.0	<10.0	34
	7/11/06	11.08	88.34	<1.0	<5.0	<5.0	<10.0	19
	10/18/06	10.35	89.07	<1.0	<5.0	<5.0	<10.0	11
	1/18/07	8.2	91.22	<1.0	<5.0	<5.0	<10.0	22
	4/18/07	8.92	90.5	<1.0	<5.0	<5.0	<10.0	24
	7/24/07	12.04	87.38	<1.0	<5.0	<5.0	<10.0	39.4
	10/24/07	11.89	87.53	<1.0	<5.0	<5.0	<10.0	8
	1/23/08	10.23	89.19	<1.0	<5.0	<5.0	<10.0	13.1
	4/17/08	9.43	89.99	<1.0	<5.0	<5.0	<10.0	37.2
	7/16/08	10.43	88.99	<1.0	<5.0	<5.0	<10.0	17
	10/16/08	12.55	86.87	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	10.75	88.67	<1.0	<5.0	<5.0	<10.0	9.7
	4/7/09	8.21	91.21	<1.0	<5.0	<5.0	<10.0	20.6
	7/1/09	10.76	88.66	<1.0	<5.0	<5.0	<10.0	25.5
	10/1/09	12.03	87.39	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	9.67	89.75	<1.0	<5.0	<5.0	<10.0	<4.0
	4/1/10	8.68	90.74	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/10	10.51	88.91	<1.0	<5.0	<5.0	<10.0	<4.0
	10/19/10	12.21	87.21	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	10.71	88.71	<1.0	<5.0	<5.0	<10.0	<4.0
	5/9/11	8.58	90.84	<1.0	<5.0	<5.0	<10.0	<4.0
	8/16/11	11.1	88.32	<1.0	<5.0	<5.0	<10.0	<4.0
	11/1/11	10.73	88.69	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	9.55	89.87	<1.0	<5.0	<5.0	<10.0	4.5
	4/5/12	10.28	89.14	<1.0	<5.0	<5.0	<10.0	4.6
	7/10/12	12.37	87.05	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	10.71	88.71	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	10.3	89.12	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	8.49	90.93	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	9.93	89.49	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	11.04	88.38	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	8.96	90.46	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.6 Elevations and Analytical Results for Monitoring Well 6

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-6	5/23/03	13.45	83.81	<1.0	<5.0	<5.0	<10.0	10
	1/12/04	6.72	90.54	1.9	<5.0	<5.0	<10.0	<4.0
	4/15/04	7.8	89.46	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	9	88.26	<1.0	<5.0	<5.0	<10.0	5.3
	10/21/04	9.11	88.15	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	6.3	90.96	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	7.24	90.02	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	8.32	88.94	1.6	<5.0	<5.0	<10.0	<4.0
	10/11/05	9.15	88.11	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	6.38	90.88	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	6.57	90.69	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	8.83	88.43	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	7.8	89.46	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	5.75	91.51	NS-1	NS-1	NS-1	NS-1	NS-1
	4/18/07	6.65	90.61	NS-1	NS-1	NS-1	NS-1	NS-1
	7/24/07	9.83	87.43	NS-1	NS-1	NS-1	NS-1	NS-1
	10/24/07	9.56	87.7	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	8.02	89.24	NS-1	NS-1	NS-1	NS-1	NS-1
	4/17/08	7.11	90.15	NS-1	NS-1	NS-1	NS-1	NS-1
	7/16/08	8.25	89.01	NS-1	NS-1	NS-1	NS-1	NS-1
	10/16/08	10.36	86.9	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	8.57	88.69	NS-1	NS-1	NS-1	NS-1	NS-1
	4/7/09	5.12	92.14	NS-1	NS-1	NS-1	NS-1	NS-1
	7/1/09	8.55	88.71	NS-1	NS-1	NS-1	NS-1	NS-1
	10/1/09	9.83	87.43	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	7.45	89.81	NS-1	NS-1	NS-1	NS-1	NS-1
	4/1/10	6.16	91.1	NS-1	NS-1	NS-1	NS-1	NS-1
	7/6/10	8.23	89.03	NS-1	NS-1	NS-1	NS-1	NS-1
	10/19/10	9.13	88.13	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	8.51	88.75	NS-1	NS-1	NS-1	NS-1	NS-1
	5/9/11	4.31	92.95	NS-1	NS-1	NS-1	NS-1	NS-1
	8/16/11	8.25	89.01	NS-1	NS-1	NS-1	NS-1	NS-1
	11/1/11	7.87	89.39	<1.0	<5.0	<5.0	<10.0	<4.0

Table 4.7 Elevations and Analytical Results for Monitoring Well 7

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
	1/23/12	3.45	93.81	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	7.93	89.33	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	10.05	87.21	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	3.04	94.22	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	7.91	89.35	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	1.14	96.12	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	7.12	90.14	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	1.71	95.55	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	1.23	96.03	NS-1	NS-1	NS-1	NS-1	NS-1
	5/23/03	10.21	89.73	<1.0	<5.0	<5.0	<10.0	**210**
	1/12/04	9.76	90.18	<1.0	<5.0	<5.0	<10.0	**61**
	4/15/04	10.8	89.14	<1.0	<5.0	<5.0	<10.0	36
	7/21/04	12	87.94	<1.0	<5.0	<5.0	<10.0	**53**
	10/21/04	12.17	87.77	<1.0	<5.0	<5.0	<10.0	**50**
	1/19/05	9.46	90.48	<1.0	<5.0	<5.0	<10.0	33
	4/13/05	10.26	89.68	<1.0	<5.0	<5.0	<10.0	15
	7/6/05	11.38	88.56	<1.0	<5.0	<5.0	<10.0	26
	10/11/05	12.18	87.76	<1.0	<5.0	<5.0	<10.0	36
	1/18/06	9.74	90.2	<1.0	<5.0	<5.0	<10.0	**40**
	4/19/06	9.84	90.1	1.2	<5.0	<5.0	<10.0	38
	7/11/06	11.84	88.1	<1.0	<5.0	<5.0	<10.0	19
	10/18/06	11.21	88.73	1.8	<5.0	<5.0	<10.0	**57**
	1/18/07	9.05	90.89	<1.0	<5.0	<5.0	<10.0	**49**
	4/18/07	9.78	90.16	1.2	<5.0	<5.0	<10.0	37.2
	7/24/07	12.81	87.13	1.1	<5.0	<5.0	<10.0	31.5
MW-7	10/24/07	12.73	87.21	1.4	<5.0	<5.0	<10.0	31.7
	1/23/08	11.03	88.91	1.7	<5.0	<5.0	<10.0	**52.5**
	4/17/08	10.27	89.67	1.6	<5.0	<5.0	<10.0	**70.4**
	7/16/08	11.25	88.69	1.5	<5.0	<5.0	<10.0	**71**
	10/16/08	13.35	86.59	1.5	<5.0	<5.0	<10.0	**49.4**
	1/14/09	11.56	88.38	1.6	<5.0	<5.0	<10.0	**57.4**
	4/7/09	9.13	90.81	<1.0	<5.0	<5.0	<10.0	**75**
	7/1/09	11.6	88.34	<1.0	<5.0	<5.0	<10.0	**58.8**
	10/1/09	12.9	87.04	<1.0	<5.0	<5.0	<10.0	12
	1/4/10	10.49	89.45	<1.0	<5.0	<5.0	<10.0	24.6
	4/1/10	9.57	90.37	<1.0	<5.0	<5.0	<10.0	**49.8**
	7/6/10	11.34	88.6	<1.0	<5.0	<5.0	<10.0	**44**
	10/19/10	4.07	95.87	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	6.24	93.7	<1.0	<5.0	<5.0	<10.0	<4.0
	5/9/11	5.18	94.76	<1.0	<5.0	<5.0	<10.0	<4.0
	8/16/11	10.02	89.92	<1.0	<5.0	<5.0	<10.0	<4.0
	11/1/11	10.33	89.61	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	8.64	91.3	<1.0	<5.0	<5.0	<10.0	<4.0
	4/5/12	10.2	89.74	<1.0	<5.0	<5.0	<10.0	<4.0
	7/10/12	12.31	87.63	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	11.41	88.53	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	10.41	89.53	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	9.07	90.87	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	10.6	89.34	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	11.95	87.99	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	9.64	90.3	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.8 Elevations and Analytical Results for Monitoring Well 8

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-8	5/23/03	7.89	90.29	<1.0	<5.0	<5.0	<10.0	<4.0
	1/12/04	7.47	90.71	1.2	<5.0	<5.0	<10.0	<4.0
	4/15/04	8.58	89.6	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	9.86	88.32	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	9.99	88.19	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	7.14	91.04	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	7.98	90.2	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	9.13	89.05	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	9.9	88.28	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	7.45	90.73	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	7.5	90.68	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	9.68	88.5	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	8.91	89.27	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	6.62	91.56	NS-1	NS-1	NS-1	NS-1	NS-1
	4/18/07	7.42	90.76	NS-1	NS-1	NS-1	NS-1	NS-1
	7/24/07	10.73	87.45	NS-1	NS-1	NS-1	NS-1	NS-1
	10/24/07	10.49	87.69	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	8.76	89.42	NS-1	NS-1	NS-1	NS-1	NS-1
	4/17/08	7.93	90.25	NS-1	NS-1	NS-1	NS-1	NS-1
	7/16/08	9.05	89.13	NS-1	NS-1	NS-1	NS-1	NS-1
	10/16/08	11.25	86.93	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	9.33	88.85	NS-1	NS-1	NS-1	NS-1	NS-1
	4/7/09	4.59	93.59	NS-1	NS-1	NS-1	NS-1	NS-1
	7/1/09	9.37	88.81	NS-1	NS-1	NS-1	NS-1	NS-1
	10/1/09	10.7	87.48	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	8.13	90.05	NS-1	NS-1	NS-1	NS-1	NS-1
	4/1/10	7.03	91.15	NS-1	NS-1	NS-1	NS-1	NS-1
	7/6/10	9.11	89.07	NS-1	NS-1	NS-1	NS-1	NS-1
	10/19/10	10.87	87.31	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	9.28	88.9	NS-1	NS-1	NS-1	NS-1	NS-1
	5/9/11	6.27	91.91	NS-1	NS-1	NS-1	NS-1	NS-1
	8/16/11	9.71	88.47	NS-1	NS-1	NS-1	NS-1	NS-1
	11/1/11	9.25	88.93	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	2.86	95.32	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	8.86	89.32	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	11.05	87.13	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	9.14	88.81	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	8.73	89.22	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	2.47	95.48	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	8.37	89.58	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	9.51	88.44	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	2.71	95.24	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.9 Elevations and Analytical Results for Monitoring Well 9

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-9	8/12/03	11.6	88.82	<1.0	<5.0	<5.0	<10.0	<4.0
	1/12/04	10.23	90.19	<1.0	<5.0	<5.0	<10.0	<4.0
	4/15/04	11.28	89.14	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	12.47	87.95	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	12.65	87.77	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	9.92	90.5	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	10.7	89.72	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	11.81	88.61	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	12.65	87.77	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	10.18	90.24	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	10.3	90.12	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	12.28	88.14	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	11.65	88.77	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	9.45	90.97	<1.0	<5.0	<5.0	<10.0	<4.0
	4/18/07	10.22	90.2	<1.0	<5.0	<5.0	<10.0	<4.0
	7/24/07	13.27	87.15	<1.0	<5.0	<5.0	<10.0	<4.0
	10/24/07	13.18	87.24	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	11.44	88.98	<1.0	<5.0	<5.0	<10.0	<4.0
	4/17/08	10.67	89.75	<1.0	<5.0	<5.0	<10.0	<4.0
	7/16/08	11.66	88.76	<1.0	<5.0	<5.0	<10.0	<4.0
	10/16/08	13.76	86.66	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	11.99	88.43	<1.0	<5.0	<5.0	<10.0	<4.0
	4/7/09	9.48	90.94	<1.0	<5.0	<5.0	<10.0	<4.0
	7/1/09	12.01	88.41	<1.0	<5.0	<5.0	<10.0	<4.0
	10/1/09	13.31	87.11	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	10.93	89.49	<1.0	<5.0	<5.0	<10.0	<4.0
	4/1/10	9.98	90.44	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/10	11.75	88.67	<1.0	<5.0	<5.0	<10.0	<4.0
	10/19/10	13.47	86.95	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	11.96	88.46	<1.0	<5.0	<5.0	<10.0	<4.0
	5/9/11	9.87	90.55	<1.0	<5.0	<5.0	<10.0	<4.0
	8/16/11	12.43	87.99	<1.0	<5.0	<5.0	<10.0	<4.0
	11/1/11	12.03	88.39	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	9.62	90.8	<1.0	<5.0	<5.0	<10.0	<4.0
	4/5/12	11.52	88.9	<1.0	<5.0	<5.0	<10.0	<4.0
	7/10/12	13.59	86.83	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	12.81	87.61	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	11.51	88.91	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	9.84	90.58	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	11.22	89.2	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	12.37	88.05	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	10.12	90.3	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.10 Elevations and Analytical Results for Monitoring Well 10

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-10	8/12/03	11.06	88.78	<1.0	<5.0	<5.0	<10.0	<4.0
	1/12/04	9.73	90.11	<1.0	<5.0	<5.0	<10.0	<4.0
	4/15/04	10.73	89.11	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	11.82	88.02	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	12.1	87.74	1.2	<5.0	<5.0	<10.0	<4.0
	1/19/05	9.4	90.44	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	10.12	89.72	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	11.24	88.6	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	12.1	87.74	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	9.71	90.13	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	9.77	90.07	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	11.71	88.13	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	11.17	88.67	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	9.02	90.82	NS-1	NS-1	NS-1	NS-1	NS-1
	4/18/07	9.8	90.04	NS-1	NS-1	NS-1	NS-1	NS-1
	7/24/07	12.64	87.2	NS-1	NS-1	NS-1	NS-1	NS-1
	10/24/07	12.66	87.18	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	10.94	88.9	NS-1	NS-1	NS-1	NS-1	NS-1
	4/17/08	10.19	89.65	NS-1	NS-1	NS-1	NS-1	NS-1
	7/16/08	11.14	88.7	NS-1	NS-1	NS-1	NS-1	NS-1
	10/16/08	13.23	86.61	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	11.47	88.37	NS-1	NS-1	NS-1	NS-1	NS-1
	4/7/09	9.22	90.62	NS-1	NS-1	NS-1	NS-1	NS-1
	7/1/09	11.45	88.39	NS-1	NS-1	NS-1	NS-1	NS-1
	10/1/09	12.74	87.1	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	10.38	89.46	NS-1	NS-1	NS-1	NS-1	NS-1
	4/1/10	9.48	90.36	NS-1	NS-1	NS-1	NS-1	NS-1
	7/6/10	11.19	88.65	NS-1	NS-1	NS-1	NS-1	NS-1
	10/19/10	12.92	86.92	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	11.46	88.38	NS-1	NS-1	NS-1	NS-1	NS-1
	5/9/11	9.42	90.42	NS-1	NS-1	NS-1	NS-1	NS-1
	8/16/11	11.88	87.96	NS-1	NS-1	NS-1	NS-1	NS-1
	11/1/11	11.52	88.32	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	9.32	90.52	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	10.99	88.85	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	13.01	86.83	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	11.59	88.25	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	11.02	88.82	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	9.94	89.9	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	10.69	89.15	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	11.94	87.9	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	9.83	90.01	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.11 Elevations and Analytical Results for Monitoring Well 11

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-11	8/12/03	9.91	88.39	<1.0	<5.0	9.9	30	**190**
	1/12/04	8.67	89.63	2.6	<5.0	89	180	**190**
	4/15/04	9.62	88.68	3.1	<5.0	120	200	**160**
	7/21/04	10.68	87.62	**5.3**	<5.0	190	275.5	**240**
	10/21/04	10.87	87.43	<1.0	<5.0	<5.0	<10.0	**240**
	1/19/05	8.39	89.91	**5.6**	<5.0	160	300	**180**
	4/13/05	9.11	89.19	**5.3**	<5.0	160	350	**190**
	7/6/05	10.1	88.2	2.1	<5.0	52	100	**230**
	10/11/05	10.82	87.48	<1.0	<5.0	<5.0	<10.0	**270**
	1/18/06	5.62	92.68	<1.0	<5.0	9.7	20	**200**
	4/19/06	8.71	89.59	3.4	<5.0	69	140	**270**
	7/11/06	10.52	87.78	2.4	<5.0	45	81	**250**
	10/18/06	9.95	88.35	<1.0	<5.0	<5.0	<10.0	**260**
	1/18/07	7.98	90.32	3.5	<5.0	52	110	**200**
	4/18/07	8.66	89.64	2.9	<5.0	36.2	67.6	**171**
	7/24/07	11.41	86.89	<1.0	<5.0	6.6	13.1	**232**
	10/24/07	11.31	86.99	1.2	<5.0	<5.0	<10.0	**235**
	1/23/08	9.76	88.54	1.3	<5.0	5	<10.0	**161**
	4/17/08	9.01	89.29	2	<5.0	19.3	37	**181**
	7/16/08	9.96	88.34	1.5	<5.0	12.3	23.6	**181**
	10/16/08	11.84	86.46	<1.0	<5.0	<5.0	<10.0	**191**
	1/14/09	10.21	88.09	<1.0	<5.0	<5.0	<10.0	**171**
	4/7/09	8.03	90.27	<1.0	<5.0	<5.0	<10.0	**161**
	7/1/09	10.24	88.06	<1.0	<5.0	7.1	12.6	**172**
	10/1/09	11.4	86.9	<1.0	<5.0	<5.0	<10.0	**196**
	1/4/10	9.24	89.06	<1.0	<5.0	<5.0	<10.0	**172**
	4/1/10	8.41	89.89	1.3	<5.0	17.1	31.8	**167**
	7/6/10	10.01	88.29	1.8	<5.0	12.9	25.6	**178**
	10/19/10	DRY	DRY	NS-2	NS-2	NS-2	NS-2	NS-2
	1/27/11	10.23	88.07	<1.0	<5.0	<5.0	<10.0	**157**
	5/9/11	8.52	89.78	<1.0	<5.0	<5.0	<10.0	**107**
	8/16/11	10.81	87.49	<1.0	<5.0	<5.0	<10.0	**131**
	11/1/11	10.43	87.87	<1.0	<5.0	<5.0	<10.0	**100**
	1/23/12	8.47	89.83	NS-2	NS-2	NS-2	NS-2	NS-2
	4/5/12	9.93	88.37	<1.0	<5.0	<5.0	<10.0	**91.7**
	7/10/12	11.78	86.52	<1.0	<5.0	<5.0	<10.0	**95.3**
	10/4/12	10.35	87.7	<1.0	<5.0	<5.0	<10.0	**106**
	1/9/13	9.81	88.93	1.4	<5.0	<5.0	<10.0	**76.3**
	4/15/13	8.11	89.94	<1.0	<5.0	<5.0	<10.0	**62.4**
	7/10/13	9.64	88.41	<1.0	<5.0	<5.0	<10.0	**69.2**
	10/8/13	10.68	87.37	<1.0	<5.0	<5.0	<10.0	**81.5**
	1/14/14	8.59	89.46	<1.0	<5.0	<5.0	<10.0	**62.2**

Table 4.12 Elevations and Analytical Results for Monitoring Well 12

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-12	4/29/04	9.71	86.56	<1.0	<5.0	<5.0	<10.0	6.9
	7/21/04	10.14	86.13	<1.0	<5.0	<5.0	<10.0	6
	10/21/04	10.26	86.01	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	9.3	86.97	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	9.5	86.77	<1.0	<5.0	<5.0	<10.0	4.6
	7/6/05	9.92	86.35	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	10.2	86.07	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	9.47	86.8	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	9.4	86.87	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	10.16	86.11	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	9.99	86.28	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	9.19	87.08	<1.0	<5.0	<5.0	<10.0	<4.0
	4/18/07	9.42	86.85	<1.0	<5.0	<5.0	<10.0	<4.0
	7/24/07	10.82	85.45	<1.0	<5.0	<5.0	<10.0	<4.0
	10/24/07	10.88	85.39	2	<5.0	<5.0	<10.0	<4.0
	1/23/08	10.07	86.2	1.2	<5.0	<5.0	<10.0	<4.0
	4/17/08	9.72	86.55	<1.0	<5.0	<5.0	<10.0	<4.0
	7/16/08	10.11	86.16	<1.0	<5.0	<5.0	<10.0	<4.0
	10/16/08	11.02	85.25	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	10.21	86.06	<1.0	<5.0	<5.0	<10.0	<4.0
	4/7/09	9.35	86.92	1	<5.0	<5.0	<10.0	<4.0
	7/1/09	10.2	86.07	<1.0	<5.0	<5.0	<10.0	<4.0
	10/1/09	10.83	85.44	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	9.85	86.42	<1.0	<5.0	<5.0	<10.0	<4.0
	4/1/10	9.49	86.78	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/10	10.13	86.14	<1.0	<5.0	<5.0	<10.0	<4.0
	10/19/10	10.98	85.29	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	10.21	86.06	<1.0	<5.0	<5.0	<10.0	<4.0
	5/9/11	9.42	86.85	<1.0	<5.0	<5.0	<10.0	<4.0
	8/16/11	10.34	85.93	<1.0	<5.0	<5.0	<10.0	<4.0
	11/1/11	10.23	86.04	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	9.37	86.9	<1.0	<5.0	<5.0	<10.0	<4.0
	4/5/12	10	86.27	<1.0	<5.0	<5.0	<10.0	<4.0
	7/10/12	10.88	85.39	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	10.29	86.01	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	10.05	86.22	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	9.45	86.82	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	9.88	86.39	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	10.46	85.81	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	9.65	86.62	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.13 Elevations and Analytical Results for Monitoring Well 13

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-13	4/29/04	6.65	85.84	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	7	85.49	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	8.84	83.65	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	5.5	86.99	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	6.01	86.48	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	6.62	85.87	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	8.41	84.08	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	5.91	86.58	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	5.57	86.92	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	6.65	85.84	<1.0	<5.0	<5.0	<10.0	<4.0
	10/18/06	6.69	85.8	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	4.72	87.77	NS-1	NS-1	NS-1	NS-1	NS-1
	4/18/07	5.25	87.24	NS-1	NS-1	NS-1	NS-1	NS-1
	7/24/07	7.28	85.21	NS-1	NS-1	NS-1	NS-1	NS-1
	10/24/07	8.25	84.24	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	7.28	85.21	NS-1	NS-1	NS-1	NS-1	NS-1
	4/17/08	5.49	87	NS-1	NS-1	NS-1	NS-1	NS-1
	7/16/08	5.87	86.62	NS-1	NS-1	NS-1	NS-1	NS-1
	10/16/08	8.91	83.58	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	7.43	85.06	NS-1	NS-1	NS-1	NS-1	NS-1
	4/7/09	5.26	87.23	NS-1	NS-1	NS-1	NS-1	NS-1
	7/1/09	6.24	85.96	NS-1	NS-1	NS-1	NS-1	NS-1
	10/1/09	8.58	83.62	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	6.45	85.75	NS-1	NS-1	NS-1	NS-1	NS-1
	4/1/10	5.07	87.13	NS-1	NS-1	NS-1	NS-1	NS-1
	7/6/10	5.96	86.24	NS-1	NS-1	NS-1	NS-1	NS-1
	10/19/10	8.51	83.69	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	7.56	84.64	NS-1	NS-1	NS-1	NS-1	NS-1
	5/9/11	4.9	87.3	NS-1	NS-1	NS-1	NS-1	NS-1
	8/16/11	6.72	85.48	NS-1	NS-1	NS-1	NS-1	NS-1
	11/1/11	6.64	85.56	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	4.57	87.63	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	6.32	85.88	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	8.35	83.85	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	8.36	83.84	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	7	85.2	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	5.57	86.63	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	5.91	86.29	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	6.34	85.86	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	6.37	85.83	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.14 Elevations and Analytical Results for Monitoring Well 14

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-14	4/29/04	4.98	89.06	<1.0	<5.0	<5.0	<10.0	<4.0
	7/21/04	6.02	88.02	<1.0	<5.0	<5.0	<10.0	<4.0
	10/21/04	5.84	88.2	<1.0	<5.0	<5.0	<10.0	<4.0
	1/19/05	3.66	90.38	<1.0	<5.0	<5.0	<10.0	<4.0
	4/13/05	4.2	89.84	<1.0	<5.0	<5.0	<10.0	<4.0
	7/6/05	5.11	88.93	<1.0	<5.0	<5.0	<10.0	<4.0
	10/11/05	6.14	87.9	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/06	3.44	90.6	<1.0	<5.0	<5.0	<10.0	<4.0
	4/19/06	3.71	90.33	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	5.7	88.34	<1.0	<5.0	<5.0	<10.0	4.1
	10/18/06	4.41	89.63	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	3.06	90.98	NS-1	NS-1	NS-1	NS-1	NS-1
	4/18/07	3.63	90.41	NS-1	NS-1	NS-1	NS-1	NS-1
	7/24/07	6.58	87.46	NS-1	NS-1	NS-1	NS-1	NS-1
	10/24/07	6.12	87.92	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	4.71	89.33	NS-1	NS-1	NS-1	NS-1	NS-1
	4/17/08	4.16	89.88	NS-1	NS-1	NS-1	NS-1	NS-1
	7/16/08	4.86	89.18	NS-1	NS-1	NS-1	NS-1	NS-1
	10/16/08	6.65	87.39	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/09	5.33	88.71	NS-1	NS-1	NS-1	NS-1	NS-1
	4/7/09	3.02	91.02	NS-1	NS-1	NS-1	NS-1	NS-1
	7/1/09	5.27	88.77	NS-1	NS-1	NS-1	NS-1	NS-1
	10/1/09	6.52	87.52	<1.0	<5.0	<5.0	<10.0	<4.0
	1/4/10	4.36	89.68	NS-1	NS-1	NS-1	NS-1	NS-1
	4/1/10	3.53	90.51	NS-1	NS-1	NS-1	NS-1	NS-1
	7/6/10	5.04	89	NS-1	NS-1	NS-1	NS-1	NS-1
	10/19/10	6.4	87.64	<1.0	<5.0	<5.0	<10.0	<4.0
	1/27/11	5.37	88.67	NS-1	NS-1	NS-1	NS-1	NS-1
	5/9/11	3.3	90.74	NS-1	NS-1	NS-1	NS-1	NS-1
	8/16/11	5.45	88.59	NS-1	NS-1	NS-1	NS-1	NS-1
	11/1/11	5.07	88.97	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	2.91	91.13	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	4.76	89.28	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	6.55	87.49	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	5.75	88.29	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	4.63	89.41	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	3.44	90.6	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	4.46	89.58	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	5.27	88.77	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	2.87	91.17	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.15 Elevations and Analytical Results for Monitoring Well 15

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-15	1/18/06	9.72	90.29	<1.0	<5.0	<5.0	<10.0	31
	4/19/06	9.83	90.18	<1.0	<5.0	<5.0	<10.0	<4.0
	7/11/06	11.86	88.15	<1.0	<5.0	<5.0	<10.0	4.1
	10/18/06	11.2	88.81	<1.0	<5.0	<5.0	<10.0	<4.0
	1/18/07	9	91.01	<1.0	<5.0	<5.0	<10.0	4.9
	4/18/07	9.72	90.29	<1.0	<5.0	<5.0	<10.0	6.5
	7/24/07	12.84	87.17	<1.0	<5.0	<5.0	<10.0	14.8
	10/24/07	12.77	87.24	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/08	11.03	88.98	<1.0	<5.0	<5.0	<10.0	30.7
	4/17/08	10.24	89.77	<1.0	<5.0	<5.0	<10.0	13.1
	7/16/08	11.24	88.77	<1.0	<5.0	<5.0	<10.0	10.9
	10/16/08	13.36	86.65	<1.0	<5.0	<5.0	<10.0	36.1
	1/14/09	11.53	88.48	<1.0	<5.0	<5.0	<10.0	14.1
	4/7/09	9.06	90.95	<1.0	<5.0	<5.0	<10.0	13.7
	7/1/09	11.56	88.45	<1.0	<5.0	<5.0	<10.0	17.1
	10/1/09	12.87	87.14	<1.0	<5.0	<5.0	<10.0	21.5
	1/4/10	10.46	89.55	<1.0	<5.0	<5.0	<10.0	12
	4/1/10	9.51	90.5	<1.0	<5.0	<5.0	<10.0	10.3
	7/6/10	11.31	88.7	<1.0	<5.0	<5.0	<10.0	12.1
	10/19/10	13.06	86.95	<1.0	<5.0	<5.0	<10.0	**41.5**
	1/27/11	11.53	88.48	<1.0	<5.0	<5.0	<10.0	13.8
	5/9/11	9.43	90.58	<1.0	<5.0	<5.0	<10.0	10.6
	8/16/11	11.98	88.03	<1.0	<5.0	<5.0	<10.0	18.2
	11/1/11	11.59	88.42	<1.0	<5.0	<5.0	<10.0	**133**
	1/23/12	9.31	90.7	<1.0	<5.0	<5.0	<10.0	9.8
	4/5/12	11.07	88.94	<1.0	<5.0	<5.0	<10.0	8.7
	7/10/12	13.37	86.64	<1.0	<5.0	<5.0	<10.0	27.3
	10/4/12	11.61	88.4	<1.0	<5.0	<5.0	<10.0	**87.1**
	1/9/13	11.08	88.93	<1.0	<5.0	<5.0	<10.0	15.5
	4/15/13	9.8	90.21	<1.0	<5.0	<5.0	<10.0	12
	7/10/13	10.78	89.23	<1.0	<5.0	<5.0	<10.0	8.5
	10/8/13	11.93	88.08	<1.0	<5.0	<5.0	<10.0	**77**
	1/14/14	9.79	90.22	<1.0	<5.0	<5.0	<10.0	17.8

Table 4.16 Elevations and Analytical Results for Monitoring Well 16

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
MW-16	4/7/09	9.86	90.43	**35.6**	29.2	84.1	393	**113**
	7/1/09	12.06	88.23	**168**	57.3	205	423	**267**
	10/1/09	13.36	86.93	**16.9**	10.4	38.4	128	**48**
	1/4/10	11.12	89.17	**68.1**	9.1	85.3	208	**162**
	4/1/10	10.28	90.01	**22.6**	13	75	164	**64**
	7/6/10	11.92	88.37	**32**	10.8	71.5	135	**105**
	10/19/10	13.5	86.79	3.7	<5.0	14.3	22	**64.4**
	1/27/11	12.13	88.16	**17.4**	8.9	35.2	105	**84.4**
	5/9/11	10.19	90.1	**17.3**	10	44.1	92.6	**91.7**
	8/16/11	12.53	87.76	**20.8**	11.4	45.3	91.9	32.7
	11/1/11	12.19	88.1	**15.3**	9.1	32.4	82.3	**86.9**
	1/23/12	10.05	90.24	**13.9**	7.8	30	78	**82.8**
	4/5/12	11.71	88.58	**35.1**	9.9	65.5	119	**50.9**
	7/10/12	13.61	86.68	**19.8**	7.3	10.9	36	**53.4**
	10/4/12	12.26	88.03	**21.7**	7.4	22.8	55.6	**64.4**
	1/9/13	11.73	88.56	**52.6**	<5.0	28.4	56.5	**186**
	2/5/13	10.97	89.32	**66.4**	7.5	49.3	87.8	**159**
	4/15/13	10.15	90.14	**31.8**	9.2	48.3	97.6	**86.3**
	7/10/13	11.48	88.81	**32.2**	7.1	50.5	106	**85.1**
	10/8/13	12.55	87.74	**5.2**	5.3	53.9	176	**108**
	1/14/14	10.55	89.74	**7.8**	6.8	25.3	76.9	**93.6**

Table 4.17 Elevations and Analytical Results for Monitoring Well EW-1

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
EW-1	4/13/05	9.37	89.91	**1,700**	67	48	103	**5,700**
	7/6/05	10.52	88.76	NS-2	NS-2	NS-2	NS-2	NS-2
	10/11/05	11.31	87.97	NS-2	NS-2	NS-2	NS-2	NS-2
	1/18/06	8.9	90.38	NS-2	NS-2	NS-2	NS-2	NS-2
	4/19/06	9.97	89.31	**200**	<5.0	5.1	<10.0	**5,800**
	7/11/06	11.01	88.27	**56**	<5.0	<5.0	<10.0	**3,100**
	10/18/06	10.33	88.95	**14**	6.5	<5.0	<10.0	**1,300**
	1/18/07	8.18	91.1	**54**	<5.0	<5.0	<10.0	**2,400**
	4/18/07	8.9	90.38	**1,410**	21.5	54.2	22.6	**3,680**
	7/24/07	12.02	87.26	NS-2	NS-2	NS-2	NS-2	NS-2
	10/24/07	11.88	87.4	NS-2	NS-2	NS-2	NS-2	NS-2
	1/23/08	10.22	89.06	NS-2	NS-2	NS-2	NS-2	NS-2
	4/17/08	9.46	89.82	NS-2	NS-2	NS-2	NS-2	NS-2
	7/16/08	10.41	88.87	NS-2	NS-2	NS-2	NS-2	NS-2
	10/16/08	12.53	86.75	NS-2	NS-2	NS-2	NS-2	NS-2
	1/14/09	10.7	88.58	NS-2	NS-2	NS-2	NS-2	NS-2
	4/7/09	8.17	91.04	NS-2	NS-2	NS-2	NS-2	NS-2
	7/1/09	10.71	88.57	NS-2	NS-2	NS-2	NS-2	NS-2
	10/1/09	NM	NM	NS-2	NS-2	NS-2	NS-2	NS-2
	1/4/10	9.61	89.67	NS-2	NS-2	NS-2	NS-2	NS-2
	4/1/10	8.65	90.63	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/10	10.46	88.82	NS-2	NS-2	NS-2	NS-2	NS-2
	10/19/10	12.17	87.11	NS-2	NS-2	NS-2	NS-2	NS-2
	1/27/11	NM	NM	NS-2	NS-2	NS-2	NS-2	NS-2
	5/9/11	8.53	90.75	NS-2	NS-2	NS-2	NS-2	NS-2
	8/16/11	11.07	88.21	NS-2	NS-2	NS-2	NS-2	NS-2
	11/1/11	10.69	88.59	**118**	<5.0	<5.0	<10.0	**895**
	1/23/12	8.51	90.77	NS-2	NS-2	NS-2	NS-2	NS-2
	4/5/12	10.22	89.06	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	12.31	86.97	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	10.61	88.59	**86.8**	<25.0	<25.0	<50.0	**590**
	1/9/13	10.14	89.06	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	8.36	90.84	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	9.81	89.39	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	10.93	88.27	**148**	<25.0	<25.0	<50.0	**843**
	1/14/14	8.82	90.38	NS-1	NS-1	NS-1	NS-1	NS-1

Table 4.18 Elevations and Analytical Results for Monitoring Well OEW-1

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
OEW-1	1/18/06	9.7	90.24	<1.0	<5.0	<5.0	<10.0	**170**
	4/19/06	9.78	90.16	<1.0	<5.0	<5.0	<10.0	**240**
	7/11/06	11.81	88.13	<1.0	<5.0	<5.0	<10.0	**64**
	10/18/06	11.15	88.79	<1.0	<5.0	<5.0	<10.0	**130**
	1/18/07	9.02	90.92	<1.0	<5.0	<5.0	<10.0	**160**
	4/18/07	9.73	90.21	<1.0	<5.0	<5.0	<10.0	**171**
	7/24/07	12.78	87.16	NS-2	NS-2	NS-2	NS-2	NS-2
	10/24/07	12.68	87.26	NS-2	NS-2	NS-2	NS-2	NS-2
	1/23/08	10.99	88.95	NS-2	NS-2	NS-2	NS-2	NS-2
	4/17/08	10.21	89.73	NS-2	NS-2	NS-2	NS-2	NS-2
	7/16/08	11.17	88.77	NS-2	NS-2	NS-2	NS-2	NS-2
	10/16/08	13.29	86.65	NS-2	NS-2	NS-2	NS-2	NS-2
	1/14/09	11.47	88.47	NS-2	NS-2	NS-2	NS-2	NS-2
	4/7/09	9.02	90.92	NS-2	NS-2	NS-2	NS-2	NS-2
	7/1/09	11.49	88.45	NS-2	NS-2	NS-2	NS-2	NS-2
	10/1/09	12.8	87.14	NS-2	NS-2	NS-2	NS-2	NS-2
	1/4/10	10.38	89.56	NS-2	NS-2	NS-2	NS-2	NS-2
	4/1/10	9.45	90.49	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/10	11.23	88.71	NS-2	NS-2	NS-2	NS-2	NS-2
	10/19/10	12.97	86.97	NS-2	NS-2	NS-2	NS-2	NS-2
	1/27/11	11.45	88.49	NS-2	NS-2	NS-2	NS-2	NS-2
	5/9/11	9.35	90.59	NS-2	NS-2	NS-2	NS-2	NS-2
	8/16/11	11.85	88.09	NS-2	NS-2	NS-2	NS-2	NS-2
	11/1/11	11.05	88.89	<1.0	<5.0	<5.0	<10.0	6.6
	1/23/12	9.25	90.69	<1.0	<5.0	<5.0	<10.0	**58.8**
	4/5/12	11	88.94	<1.0	<5.0	<5.0	<10.0	**60.8**
	7/10/12	13.08	86.86	<1.0	<5.0	<5.0	<10.0	<4.0
	10/4/12	11.55	88.39	<1.0	<5.0	<5.0	<10.0	10.7
	1/9/13	11.02	88.92	<1.0	<5.0	<5.0	<10.0	17.7
	4/15/13	9.31	90.63	<1.0	<5.0	<5.0	<10.0	24.6
	7/10/13	10.71	89.23	<1.0	<5.0	<5.0	<10.0	<4.0
	10/8/13	11.88	88.06	<1.0	<5.0	<5.0	<10.0	4.4
	1/14/14	9.72	90.22	<1.0	<5.0	<5.0	<10.0	25

Table 4.19 Elevations and Analytical Results for Monitoring Well TP-1

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
TP-1	1/19/05	1.1	98.07	**10**	<5.0	<5.0	<10.0	14
	4/13/05	1.01	98.16	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/05	1.2	97.97	NS-2	NS-2	NS-2	NS-2	NS-2
	10/11/05	1.3	97.87	NS-2	NS-2	NS-2	NS-2	NS-2
	1/18/06	0.8	98.37	NS-2	NS-2	NS-2	NS-2	NS-2
	4/19/06	1.18	97.99	NS-2	NS-2	NS-2	NS-2	NS-2
	7/11/06	5.05	94.12	NS-2	NS-2	NS-2	NS-2	NS-2
	10/18/06	1.24	97.93	NS-2	NS-2	NS-2	NS-2	NS-2
	1/18/07	1.38	97.79	NS-2	NS-2	NS-2	NS-2	NS-2
	4/18/07	1.15	98.02	NS-2	NS-2	NS-2	NS-2	NS-2
	7/24/07	1.29	97.88	NS-2	NS-2	NS-2	NS-2	NS-2
	10/24/07	1.02	98.15	NS-2	NS-2	NS-2	NS-2	NS-2
	1/23/08	1.86	97.31	NS-2	NS-2	NS-2	NS-2	NS-2
	4/17/08	1.09	98.08	NS-2	NS-2	NS-2	NS-2	NS-2
	7/16/08	1.28	97.89	NS-2	NS-2	NS-2	NS-2	NS-2
	10/16/08	1.28	97.89	NS-2	NS-2	NS-2	NS-2	NS-2
	1/14/09	1.32	97.85	NS-2	NS-2	NS-2	NS-2	NS-2
	4/7/09	1.22	97.95	NS-2	NS-2	NS-2	NS-2	NS-2
	7/1/09	1.19	97.98	NS-2	NS-2	NS-2	NS-2	NS-2
	10/1/09	1.28	97.89	NS-2	NS-2	NS-2	NS-2	NS-2
	1/4/10	1.27	97.9	NS-2	NS-2	NS-2	NS-2	NS-2
	4/1/10	1.14	98.03	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/10	1.25	97.92	NS-2	NS-2	NS-2	NS-2	NS-2
	10/19/10	1.28	97.89	NS-2	NS-2	NS-2	NS-2	NS-2
	1/27/11	1.5	97.67	NS-2	NS-2	NS-2	NS-2	NS-2
	5/9/11	1.09	98.08	NS-2	NS-2	NS-2	NS-2	NS-2
	8/16/11	1.25	97.92	NS-2	NS-2	NS-2	NS-2	NS-2
	11/1/11	1.29	97.88	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	1.07	98.1	NS-2	NS-2	NS-2	NS-2	NS-2
	1/23/12	1.07	98.1	NS-1	NS-1	NS-1	NS-1	NS-1
	4/5/12	1.35	97.82	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	1.35	97.82	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	1.16	98.01	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	1.3	97.87	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	1.14	98.03	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	1.15	98.02	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	1.19	97.98	**31.3**	<5.0	25.1	192	<4.0
	1/14/14	1.28	97.89	<1.0	<5.0	<5.0	<10.0	<4.0

Table 4.20 Elevations and Analytical Results for Monitoring Well TP-2

Well Number	Date	Depth to Water	Groundwater Elevation	Benzene	Toluene	Ethylbenzene	Xylenes	MTBE
TP-2	1/19/05	1.94	98.03	<1.0	<5.0	<5.0	<10.0	9.4
	4/13/05	1.81	98.16	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/05	2.01	97.96	NS-2	NS-2	NS-2	NS-2	NS-2
	10/11/05	2.12	97.85	NS-2	NS-2	NS-2	NS-2	NS-2
	1/18/06	1.66	98.31	NS-2	NS-2	NS-2	NS-2	NS-2
	4/19/06	1.93	98.04	NS-2	NS-2	NS-2	NS-2	NS-2
	7/11/06	5.79	94.18	NS-2	NS-2	NS-2	NS-2	NS-2
	10/18/06	1.74	98.23	NS-2	NS-2	NS-2	NS-2	NS-2
	1/18/07	2.12	97.85	NS-2	NS-2	NS-2	NS-2	NS-2
	4/18/07	1.9	98.07	NS-2	NS-2	NS-2	NS-2	NS-2
	7/24/07	2.04	97.93	NS-2	NS-2	NS-2	NS-2	NS-2
	10/24/07	1.78	98.19	NS-2	NS-2	NS-2	NS-2	NS-2
	1/23/08	2.61	97.36	NS-2	NS-2	NS-2	NS-2	NS-2
	4/17/08	1.87	98.1	NS-2	NS-2	NS-2	NS-2	NS-2
	7/16/08	2.01	97.96	NS-2	NS-2	NS-2	NS-2	NS-2
	10/16/08	2.02	97.95	NS-2	NS-2	NS-2	NS-2	NS-2
	1/14/09	2.09	97.88	NS-2	NS-2	NS-2	NS-2	NS-2
	4/7/09	1.66	98.31	NS-2	NS-2	NS-2	NS-2	NS-2
	7/1/09	2.86	97.11	NS-2	NS-2	NS-2	NS-2	NS-2
	10/1/09	2	97.97	NS-2	NS-2	NS-2	NS-2	NS-2
	1/4/10	2.01	97.96	NS-2	NS-2	NS-2	NS-2	NS-2
	4/1/10	1.81	98.16	NS-2	NS-2	NS-2	NS-2	NS-2
	7/6/10	1.99	97.98	NS-2	NS-2	NS-2	NS-2	NS-2
	10/19/10	2.01	97.96	NS-2	NS-2	NS-2	NS-2	NS-2
	1/27/11	2.26	97.71	NS-2	NS-2	NS-2	NS-2	NS-2
	5/9/11	NM	NM	NS-2	NS-2	NS-2	NS-2	NS-2
	8/16/11	1.99	97.98	NS-2	NS-2	NS-2	NS-2	NS-2
	11/1/11	2.02	97.95	<1.0	<5.0	<5.0	<10.0	<4.0
	1/23/12	1.81	98.16	NS-2	NS-2	NS-2	NS-2	NS-2
	4/5/12	2.07	97.9	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/12	2.05	97.82	NS-1	NS-1	NS-1	NS-1	NS-1
	10/4/12	1.99	97.98	<1.0	<5.0	<5.0	<10.0	<4.0
	1/9/13	2.1	97.87	NS-1	NS-1	NS-1	NS-1	NS-1
	4/15/13	1.87	98.1	NS-1	NS-1	NS-1	NS-1	NS-1
	7/10/13	1.88	98.09	NS-1	NS-1	NS-1	NS-1	NS-1
	10/8/13	1.94	98.03	<1.0	<5.0	<5.0	<10.0	<4.0
	1/14/14	1.86	98.11	NS-1	NS-1	NS-1	NS-1	NS-1

In addition, natural attenuation parameters were measured on site by Creek Run, the data can be seen in tables 4.21-4.37. Additionally, the dissolved oxygen content of the wells was also measured on site. Dissolved oxygen, oxidation/reduction potential, and temperature were all measured using an Oakton pH 10 series meter equipped with a DO meter and a platinum ORP electrode. Specific conductivity and pH measurements were measured using an Oakton pH/conductivity 10 series meter. Hydrogen sulfide was measured with a CHEMets kit and ferrous iron concentrations were measured with a LaMotte Iron Ferric/Ferrous test kit.

Table 4.21 Natural Attenuation Parameters for Monitor Well 1

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-1	4/13/05	<0.500	125	132	0	1	1.69	11.9	NM
	4/7/09	<0.100	86.4	-16	0	0	3.36	10	7.06

Table 4.22 Natural Attenuation Parameters for Monitor Well 2

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-2	4/13/05	1.47	70	147	0	0.3	2.49	12.3	NM
	4/7/09	1.11	60.8	-2	0	0	1.98	9.6	7.17
	1/27/11	0.181	59.8	103	0.4	0.1	1.91	13	7.16
	5/9/11	0.523	75.5	108.2	0	0	3.13	10.6	7.4
	8/16/11	0.302	65.2	252	0	0	3.22	16.3	NM
	11/1/11	0.143	58	72.6	0	0	2.55	16.96	7.25
	1/23/12	0.17	55	NM	0	0.1	0.47	14.6	7.04
	4/5/12	<0.100	56	152	0.2	0.1	1.76	11.6	7.12
	7/10/12	0.12	57.5	107	0.2	0	4.18	15.1	7

Table 4.23 Natural Attenuation Parameters for Monitor Well 3

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-3	4/13/05	<0.500	58.6	148	0.8	0.5	1.97	12.9	NM
	4/7/09	<0.1	104	2	0	0	2.64	9.7	7.15
	1/27/11	0.113	99.8	201	0	0	0.65	13.2	7.14
	5/9/11	<0.1	74.5	66.3	0	0	0.43	10.9	7.26
	8/16/15	<0.1	93.9	190	0	0	0.69	15.9	NM
	11/1/11	<0.1	102	70	0	0	4.93	12.67	6.75
	1/23/12	0.137	49.5	NM	0	0	1.86	13.3	7.03
	4/5/12	<0.1	52	102	0.4	0	1.06	11.4	7.08
	7/10/12	0.11	84.8	121	0.6	0	0.31	15.1	6.72
	10/4/12	<0.1	93	-17.8	0.4	0	0.38	19	7.02
	1/9/13	<0.1	90.9	-10	0	0	0.17	15.2	7.29
	4/15/13	<0.1	42.9	-0.2	0	0.1	0.49	10.7	7
	7/10/13	<0.1	39.3	858.8	0	0	8.8	14.8	5.91
	10/8/13	<0.1	55.5	25.2	0	0.1	0.68	18.6	6.95
	1/14/14	<0.1	64.5	NM	0.4	0	1	13	NM

Table 4.24 Natural Attenuation Parameters for Monitor Well 4

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-4	4/13/05	<0.500	16.8	-3	6.1	0	1.96	12.2	NM
	4/7/09	<0.1	18.1	2	1.8	0.1	1.62	9.2	7.21
	1/27/11	0.153	24.1	90	0.4	0	>20.0	12.6	12.95
	5/9/11	<0.1	32.5	-177.1	0	0.1	23.42	10.4	12.41
	8/16/11	<0.1	<5.0	-54	0.4	0	>20	16.2	NM
	11/1/11	<0.1	<5.0	-112	0.2	0.1	>20	17.4	12.01
	1/23/12	0.185	17.9	NM	0.2	0.1	>20	13.8	10.02
	4/5/12	<0.1	<5.0	-14	0.6	0.1	>20	11.7	8.38
	7/10/12	0.11	<5.0	-33.5	0	0.2	26.21	15.3	12.15
	10/4/12	0.102	<5.0	-78.6	0.8	0.1	30.31	18.5	12.57
	1/9/13	<0.100	17.7	-112	0	0	36.5	15.2	12.74
	4/15/13	<0.100	12	-171.5	0	0	41.46	10.3	12.1
	7/10/13	<0.100	13.4	777.3	0	0	40.69	14.7	10.66
	10/8/13	<0.100	12.1	-85.2	0	0	15.19	17.5	12.09
	1/14/14	<0.1	14.5	NM	0.8	0	10.88	14	NM

Table 4.25 Natural Attenuation Parameters for Monitor Well 5

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-5	4/13/05	<0.500	141	147	0	0.1	1.97	13	NM
	4/7/09	0.122	124	-11	0.1	0	1.49	10.4	6.98
	1/27/11	0.135	128	102	0	0.1	3.21	13	7.18
	5/9/11	<0.100	118	32.3	0	0	3.31	11.2	7.39
	8/16/11	<0.100	111	130	0.1	0	2.02	15.9	NM
	11/1/11	0.177	121	161	0.1	0	0.43	16.2	7.35
	1/23/12	0.385	94.5	NM	0	0	0.32	13.6	7.08
	4/5/12	<0.1	138	16	1.8	0	0.42	12	7.03
	7/10/12	0.13	148	98	1.8	0	1.55	15.3	6.77

Table 4.26 Natural Attenuation Parameters for Monitor Well 6

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-6	4/13/05	<0.500	67.4	154	0	0.1	2.65	11.7	NM
	4/7/09	0.996	29.9	-16	0	0	4.58	8.1	7.13

Table 4.27 Natural Attenuation Parameters for Monitor Well 7

MW-7	4/13/05	<0.5	113	159	0	0	1.98	13.3	NM
	4/7/09	<0.1	106	12	0	0	1.26	10.5	7.14

Table 4.28 Natural Attenuation Parameters for Monitor Well 8

MW-8	4/13/05	<0.5	111	83	0.6	0.3	2.05	12.4	NM
	4/7/09	0.718	36.5	-24	0	0	4.43	9.1	7.18

Table 4.29 Natural Attenuation Parameters for Monitor Well 9

MW-9	4/13/05	<0.5	47.6	27	0.5	0.3	2.21	12.9	NM
	4/7/09	3.15	21	30	0	0	8.03	9.4	7.23

Table 4.30 Natural Attenuation Parameters for Monitor Well 10

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-10	4/13/05	<0.5	95.1	58	0.8	1	2.61	11.6	NM
	4/7/09	<0.100	82.8	-16	0.4	0	1.7	11.5	7.09

Table 4.31 Natural Attenuation Parameters for Monitor Well 11

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-11	4/13/05	<0.5	41.3	-17	5.1	0.3	1.92	12.8	NM
	4/7/09	<0.1	83.8	3	1	0	0.63	10.6	7.16
	1/27/11	0.198	64.5	-15	0	1	>20.0	12.6	12.73
	5/9/11	0.215	49	-50.2	0	0	24.29	11.6	12.39
	8/16/11	0.247	50.8	36	0.2	0	>20.0	16.2	NM
	11/1/11	0.422	17.2	70.5	0	0	>20.0	16.5	12.44
	1/23/12	NS	NS	NM	NM	NM	NM	NM	NM
	4/5/12	0.723	35.8	-66	1	0	>20.0	12	8.63
	7/10/12	0.61	21.9	-46.1	0.4	0	41.02	15.6	12.01
	10/4/12	0.365	31.8	-82.6	1.2	0.1	32.73	17.7	12.62
	2/5/13	0.51	43.2	-74.2	0	0	40.95	12.77	25.67
	4/15/13	0.613	32.6	-91.3	0	0	47.93	10.9	12.21
	7/10/13	0.46	36.4	840.3	0	0.1	45.88	15	10.9
	10/8/13	0.35	33.2	-48	0	0	14.18	17.2	12.21
	1/14/14	0.27	33.6	NM	0.4	0	11.24	13.7	NM

Table 4.32 Natural Attenuation Parameters for Monitor Well 12

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-12	4/13/05	<0.500	97	-33	4.5	0.5	2.55	11.3	NM
	4/7/09	<0.100	72.5	-20	2.8	0	0.88	10.9	7.05
	1/27/11	0.105	65	45	4	0	0.94	13.3	8.02
	5/9/11	<0.100	69	-83.3	1.5	0	0.31	11.8	7.5
	8/16/11	<0.100	45.4	79	3	0	0.89	16.3	NM
	11/1/11	<0.100	56	-87	2	0.1	0.15	17.8	7.17
	1/23/12	<0.100	47	NM	2	0	0.22	14.5	7.03
	4/5/12	<0.100	62.2	36	2	0	0.32	12.4	7.27
	7/10/12	0.13	31.4	-65	3.4	0	0.2	17.8	6.78

Table 4.33 Natural Attenuation Parameters for Monitor Well 13

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-13	4/13/05	<0.500	30.4	69	0	0	3.21	11.2	NM
	4/7/09	0.559	34.9	14	0	0	1.31	8.9	7.14

Table 4.34 Natural Attenuation Parameters for Monitor Well 14

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-14	4/13/05	<0.500	79.6	124	0	0	1.71	11.6	NM
	4/7/09	0.375	69.8	3	0	0	1.3	8.4	7

Table 4.35 Natural Attenuation Parameters for Monitor Well 15

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-15	4/7/09	<0.100	97.2	-12	0	0	1.18	10.5	7.1
	4/5/12	<0.100	100	163	0.2	0.1	0.94	12.4	6.96
	1/9/13	<0.100	91.5	-6.2	0.4	0	0.16	15.7	7.39
	4/15/12	<0.100	93.1	-3.5	0	0	0.46	11.8	7.12
	7/10/13	<0.100	97.4	839.8	0	0	0.5	14.7	6.29
	10/8/13	<0.100	102	20.1	0	0	0.7	17.7	7.09
	1/14/14	<0.100	51.1	NM	0.4	0	0.29	14.2	NM

Table 4.36 Natural Attenuation Parameters for Monitor Well 16

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
MW-16	4/7/09	<0.100	37.4	-11	0.4	0	4.64	10.7	7.06
	1/27/09	0.123	27.3	231	0.2	0.1	1.04	13.2	7.91
	5/9/11	<0.100	29	-74.3	2.5	0.1	1.47	11.3	10.27
	8/16/11	<0.100	11.5	183	0.8	0.3	1.2	14.2	NM
	11/1/11	<0.100	26.8	-70.2	2.2	0	0.64	15.3	8.41
	1/23/12	0.118	30.2	NM	2.4	0.1	0.22	13.7	7.07
	4/5/12	<0.100	17.5	-72	2.6	0.1	0.49	12.1	7.03
	7/10/12	<0.100	21.2	-60.1	2.4	0	7.37	14.2	6.95
	10/4/12	<0.100	98	-106	3.4	0.1	0.31	16.2	7.18
	1/9/13	0.11	47	-94.9	2.4	0.1	0.15	14.3	7.39
	2/5/13	<0.100	32.5	-173.4	2.8	0	0.48	12.03	19.97
	4/15/13	<0.100	27.5	-182.3	2	0.3	0.3	11.1	9.18
	7/10/13	<0.100	21.1	666.3	2	0.1	0.36	13.5	7.9
	10/8/13	<0.100	96.1	-96.3	2.2	0	2.15	15.6	9.57
	1/14/13	<0.100	35.9	NM	2.4	0	0.43	13.7	NM

Table 4.37 Natural Attenuation Parameters for Monitor Well OEW-1

Well No.	Date	Nitrate	Sulfates	*ORP	*Ferrous Iron	*Hydrogen Sulfide	*DO	*Temperature	*pH
OEW-1	11/1/11	0.124	105	70.8	0	0.1	3.14	17.9	8.18
	1/23/12	0.117	77.5	NM	0	0	5.23	14.9	6.89
	4/5/12	<0.1	114	108	0.4	0	4.34	12.6	7.35
	7/10/12	0.14	127	116	0.4	0	4.31	16.4	7.12
	10/4/12	0.159	102	73.4	0.6	0	4.69	19.9	7.08
	1/9/13	0.12	128	-33.2	0	0	3.9	16.3	7.18
	4/15/13	0.117	96.9	12.6	0	0	6.84	12.1	6.92
	7/10/13	<0.1	107	864.5	0	0.1	6.83	15.5	5.88
	10/8/13	<0.1	100	25.1	0	0	4.31	18.9	6.93
	1/14/14	<0.1	62.1	NM	0.4	0	5.14	14.9	NM

Table 4.38 Dissolved Oxygen Content in Monitor Wells

Date	MW-1	MW-2	MW-3	MW-4	MW-5	MW-6	MW-7	MW-8	MW-9	MW-10	MW-11	MW-12	MW-13	MW-14	MW-15	MW-16	EW-1	OEW-1	TP-1	TP-2
1/12/04	2.01	2.79	2.67	3.1	2.89	10.64	2.71	3.08	3.71	4.86	2.76	NM	NM	NM	NM	NM	NM	NM	NM	NM
4/13/05	1.69	2.49	1.97	1.96	1.97	2.65	1.98	2.05	2.21	2.61	1.92	2.55	3.21	1.71	NM	NM	NM	NM	NM	NM
4/7/09	3.36	1.98	2.64	1.62	1.49	4.58	1.26	4.43	8.03	1.7	0.63	0.88	1.31	1.3	1.18	4.64	NM	NM	NM	NM
7/1/09	1.31	2.68	1.25	0.5	1.34	1.39	1.46	0.59	1.34	1.92	0.54	0.58	0.8	3.87	1.03	0.48	0.56	5.57	0.54	0.68
10/1/09	5.15	1.64	1.97	3.23	1.31	1.07	1.43	0.77	1.23	4.36	0.32	0.99	0.93	1.22	0.42	0.36	NM	2.37	0.91	3.36
1/4/10	1.41	1.98	1.16	0.98	1.25	1.8	3.38	3.37	2.06	2.43	0.52	0.51	0.64	0.87	1.09	0.65	0.48	4.54	0.64	3.19
4/1/10	1.92	2.32	2.39	1.01	3.58	2.9	0.73	3.13	3.83	2.36	0.4	0.47	0.83	3.98	1.58	0.43	0.51	5.52	0.81	3.85
7/6/10	0.71	1.22	2.3	0.51	1.62	1.09	0.88	0.45	0.75	1.7	0.39	0.48	0.65	0.73	1.05	0.42	NM	NM	NM	NM
10/19/10	0.59	1.26	0.45	>20.0	0.83	4.5	>20.0	0.62	3.63	1.01	NM	0.55	0.69	0.82	0.57	0.81	NM	NM	NM	NM
1/27/11	0.81	1.91	0.65	>20.0	3.21	4.31	>20.0	0.97	3.5	1.2	>20.0	0.94	0.82	0.97	0.76	1.04	NM	NM	NM	NM
5/9/11	1.98	3.13	0.43	23.42	3.31	0.96	17.55	2.07	3.34	0.56	24.29	0.31	0.42	4.54	0.42	1.47	NM	NM	NM	NM
8/16/11	0.74	3.22	0.69	>20.0	2.02	2.25	>20.0	0.98	2.61	0.81	>20.0	0.89	0.78	0.85	1.05	1.2	0.87	4.5	1.53	4.09
11/1/11	0.36	2.55	4.39	>20.0	0.43	2.6	15.02	0.33	1.79	1.87	>20.0	0.15	0.48	1.02	0.23	0.64	0.57	3.14	0.09	3.12
1/23/12	1.41	0.47	1.86	>20.0	0.32	3.68	16.5	7.34	7.13	0.88	>20.0	0.22	0.35	0.33	0.46	0.22	0.3	5.23	0.84	3.5
4/5/12	0.65	1.76	1.06	>20.0	0.42	2.18	9.01	0.42	0.74	0.82	>20.0	0.32	0.44	0.37	0.94	0.49	0.34	4.34	NM	NM
7/10/12	0.15	4.18	0.31	26.21	1.55	0.18	9.28	1.02	1.92	0.41	41.02	0.2	0.75	0.54	0.46	7.37	0.16	4.31	0.2	0.43
10/4/12	0.75	4.47	0.38	30.31	0.85	1.68	12.41	0.69	3.44	0.87	32.73	0.42	0.52	0.58	0.38	0.31	4.12	4.69	0.7	4.31
1/9/13	0.37	3.03	0.17	36.5	0.31	1.38	12.26	0.25	2.14	1.73	NM	0.21	0.35	0.43	0.16	0.15	1.57	3.9	0.43	3.14
2/5/13	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	40.95	NM	NM	NM	NM	0.48	NM	NM	NM	NM
4/15/13	5.22	3.1	0.49	41.46	0.46	5.49	25.99	3.19	3.12	1.57	47.93	0.23	0.43	0.65	0.46	0.3	0.24	6.84	0.56	2.9
7/10/13	0.48	3.71	8.8	40.69	1.24	0.46	6.72	0.68	0.7	0.67	45.88	0.25	0.31	0.4	0.5	0.36	0.39	6.83	0.28	0.25
10/8/13	0.67	3.37	0.68	15.19	0.54	3.46	5.14	0.48	4.69	0.73	14.18	0.62	0.65	0.91	0.7	2.15	3.54	4.31	0.6	4.6
1/14/14	0.86	1.78	1	10.88	2.24	8.29	5.13	7.83	8.61	0.98	11.24	0.39	0.62	0.83	0.29	0.43	0.41	5.14	0.39	4.43

Analysis of monitor wells showed that MW-1, MW-2, MW-4, MW-5, MW-7, MW-10, MW-11, and MW-12 were non-impacted based on the concentrations of BTEX/MTBE being below detection limit. In addition, although the electron acceptors show variations, which are indicative of biodegradation, the great variations lie with the dissolved oxygen content. These data suggest that aerobic degradation is the dominating pathway for degradation of BTEX/MTBE.

4.2 Analysis Using BIOSCREEN

Using BIOSCREEN, data were input in to the Excel file and pre-programmed calculations gave output data to aid in analysis of natural attenuation on site. The following section describes how data were input, and what steps were necessary to achieve results. Figure 4.2 shows the input screen where data were inserted.

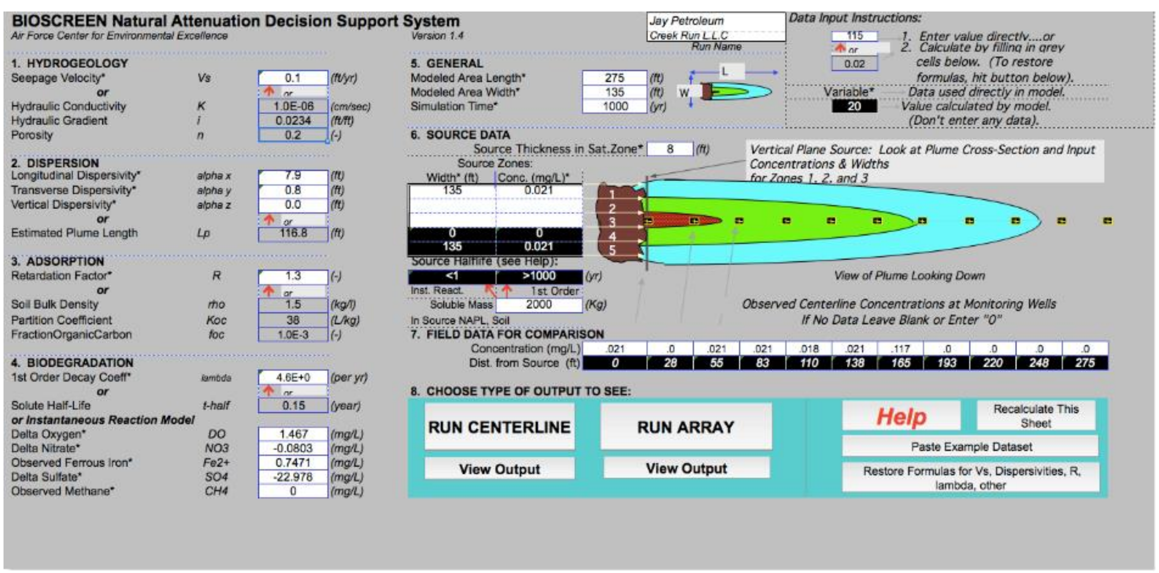


Figure 4.2 BIOSCREEN Input Screen

For data input, white boxes are for data input/calculation output, gray boxes are calculated values done by BIOSCREEN or another place for data input, and black boxes are boxes that cannot be altered. An advantage of BIOSCREEN is that both the white boxes and the gray boxes can be used to input data, so if a specific variable is unknown, the gray boxes can be used to input known variables and BIOSCREEN will calculate the value of the white box. Variables needed for the analysis of a site are seepage velocity (ft/yr), longitudinal/transverse/vertical dispersivities (ft), retardation factor, biodegradation rate (per year), length of area, width of area, and a simulation time.

Seepage velocity is the velocity that can be calculated using Darcy's Law, which is

$$v = Ki/\eta_e \tag{4.1}$$

where v is the linear velocity, K is the proportionality constant (cm/s), *i* is the gradient, and η_e is the effective porosity (Domenico, 1998). Because Creek Run calculated the linear groundwater flow velocity to be approximately 5.26×10^{-6} to 5.26×10^{-3} m/yr, this value was converted to the units ft/yr (1.73×10^{-5} to 1.73×10^{-2} ft/yr). The average of the range was taken and input in to the appropriate box. As a note, calculations were done using the English system, but metric equivalents will be provided.

Longitudinal dispersivity, transverse dispersivity, and vertical dispersivity, which are the estimated spread of contaminants on site, were calculated by BIOSCREEN by using estimated plume length. This value was measured by using the map provided by Creek Run (figure 2.1), and finding the length from the source to the furthest contaminated monitor well.

Retardation factor was the variable needed for section 3, so soil bulk density (kg/L), partition coefficient (L/kg), and fraction organic carbon (FOC) were input into the spreadsheet. These values were previously calculated based on soil type, and can be found in literature (Weidemeier, 1995; United States Department of Agriculture, 2015).

Source thickness of saturated zone was calculated by BIOSCREEN after width (ft) and concentration (mg/L) were input in to the spreadsheet. Width was measured by using the map provided by Creek Run (figure 2.1) to estimate the width of the plume by measuring the widest distance between impacted wells, and concentration (mg/L) was taken from the measured value of benzene at widest point of the estimated plume. Simulation time was set to 1000 years, because BIOSCREEN would not give an output for any values less than this. Concentrations of BTEX components were reported in parts per billion by Creek Run, so those values were converted to mg/L so that they could be input in to the spreadsheet (table 4.40). However, BIOSCREEN uses BTEX concentrations for calculations instead of individual concentration, so each concentration at the particular distance from source is the sum of benzene, toluene, ethylbenzene, and xylenes; table 4.40. These concentrations were determined by correlating the distance from the source with a monitor well, and subsequently the concentrations at that particular well. All input data can be seen in table 4.39.

Table 4.39 Input Data for BIOSCREEN Excel Spreadsheet

Hydrogeology	
Seepage Velocity (ft/yr)	0.3
Hydraulic Conductivity (cm/sec)	1.00E-06
Hydraulic Gradient (ft/ft)	0.05
Porosity	0.2

Dispersion	
Longitudinal Dispersivity (ft)	7.9
Transverse Dispersivity (ft)	0.8
Vertical Dispersivity (ft)	0
Estimated Plume Length (ft)	116.8

Adsorption	
Retardation Factor	1.3
Soil Bulk Density (kg/L)	1.5
Partition Coefficient (L/kg)	38
FractionOrganicCarbon	1.00E-03

Biodegradation	
1st Order Decay Coefficient (per y	4.6
Solute Half-Life	0.15

General	
Modeled Area Length (ft)	275
Modeled Area Width (ft)	135
Simulation Time (yr)	1000

Source Data	
Source Thickness in Sat. Zone (ft)	8
Source Zones:	
Width (ft)	135
Concentration (mg/L)	0.021

Field Data for Comparison	
Distance from Source (ft)	Concentration (mg/L)
0	0.021
28	0
55	0.021
83	0.021
110	0.018
138	0.021
165	0.117
193	0
220	0
248	0
275	0

Table 4.40 Sum of Benzene, Toluene, Ethylbenzene, and Xylenes in ppb and mg/L

	BTEX (ppb)	mg/L	Date Measured
MW-1	21	0.021	1/14/14
MW-2	NS-1	NS-1	1/14/14
MW-3	21	0.021	1/14/14
MW-4	18.4	0.0184	1/14/14
MW-5	21	0.021	1/14/14
MW-6	21	0.021	1/14/14
MW-7	NS-1	NS-1	1/14/14
MW-8	NS-1	NS-1	1/14/14
MW-9	NS-1	NS-1	1/14/14
MW-10	NS-1	NS-1	1/14/14
MW-11	21	0.021	1/14/14
MW-12	NS-1	NS-1	1/14/14
MW-13	NS-1	NS-1	1/14/14
MW-14	NS-1	NS-1	1/14/14
MW-15	21	0.021	1/14/14
MW-16	116.8	0.1168	1/14/14
EW-1	NS-1	NS-1	1/14/14
OEW-1	21	0.021	1/14/14
TP-1	21	0.021	1/14/14
TP-2	NS-1	NS-1	1/14/14

CHAPTER V

RESULTS AND DISCUSSION

The calculations employed by BIOSCREEN were ultimately used to determine retardation factor and biodegradation rate. Both were calculated by the programmed equations in the spreadsheet, and those values in addition to the complete spreadsheet, can be seen in figure 5.1. The small retardation rate value indicated that there was adsorption of organic contaminants occurring on the ground material. This is a positive result because it indicates that the flow of contaminants was less than the groundwater flow, and there will not be contamination into the sensitive areas around the site. In addition, the input of the solute half-life led to the spreadsheet calculation of 1^{st} order biodegradation rate to be 4.6 per year, which is an indication that there was a fair amount of biodegradation occurring to impede the flow of contaminants on site.

After calculating the entire spreadsheet to obtain a simulation of the site's natural attenuation, it was determined that after 1000 years, contamination would be almost completely gone and biodegradation would remove 0.1 kg of mass from 2000 kg starting mass (figures 5.2 and 5.3). Unfortunately, the limitation of BIOSCREEN to only allow 1000 years for simulation does not give a clear picture of how natural attenuation would occur through the years. In addition, the mass 0.1 kg degraded through biodegradation seems like an extremely small number for a 1000 year simulation. However, the main reason for using this software was to determine retardation factor and biodegradation rate, and both of those values were calculated.

After retardation factor and biodegradation rate were determined to be appropriate values that would allow natural attenuation to occur on site, it can be concluded that the appropriate action on site would be to let intrinsic bioremediation continue to occur without interference, and no further action is needed.

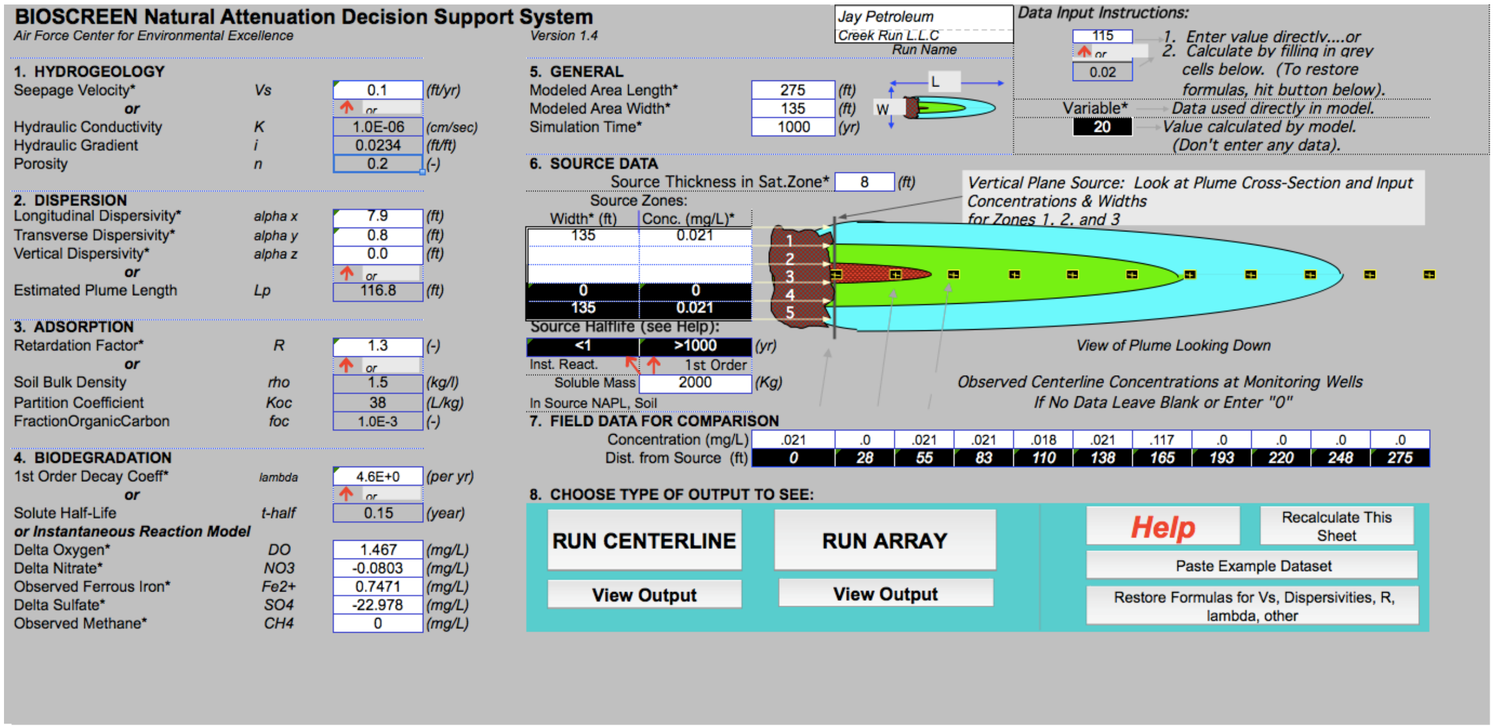
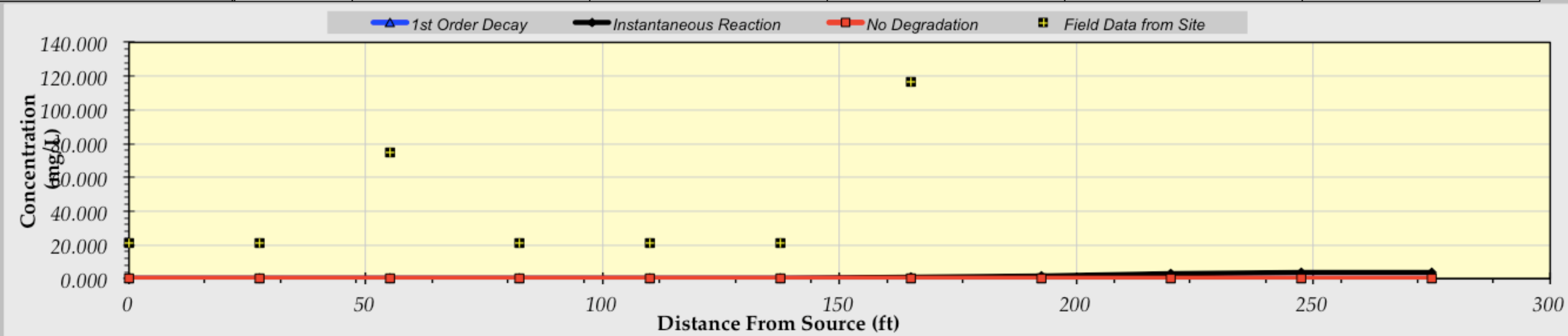


Figure 5.1 BIOSCREEN Input Spreadsheet

DISSOLVED HYDROCARBON CONCENTRATION ALONG PLUME CENTERLINE (mg/L at Z=0)

Distance from Source (ft)

TYPE OF MODEL	0	28	55	83	110	138	165	193	220	248	275
No Degradation	0.021	0.021	0.021	0.021	0.020	0.018	0.016	0.012	0.008	0.004	0.002
1st Order Decay	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Inst. Reaction	0.000	0.000	0.019	0.079	0.237	0.575	1.154	1.939	2.783	3.502	3.987
Field Data from Site	21.000	21.000	74.600	21.000	21.000	21.000	116.800				



Calculate Animation | nestep | nestep

Time: 6 Years

Return to Input

Recalculate This Sheet

Figure 5.2 Dissolved Hydrocarbon Concentration Along Plume Centerline (mg/L)

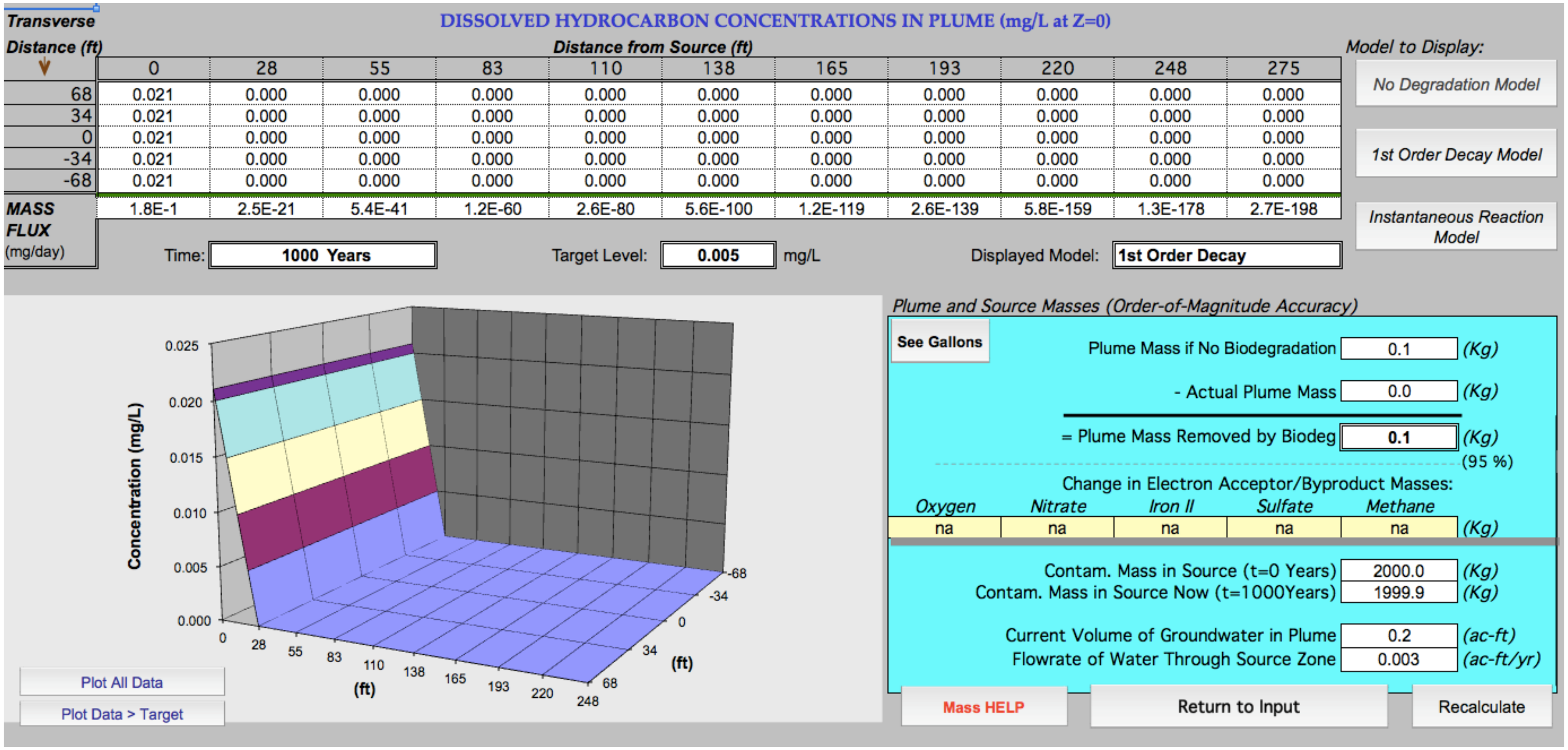


Figure 5.3 Output Screen on BIOSCREEN Showing 1st Order Decay Model

CHAPTER VI

CONCLUSION

Petroleum contamination is most commonly caused the slow release of contaminants from underground storage tanks. Because of their health and environmental hazards, BTEX/MTBE compounds pose a threat to sensitive areas around a site that may have experienced contamination. Proper action must be taken to ensure the exposure to these contaminants does not occur.

In Montpelier, Indiana, Creek Run L.L.C Environmental Engineering was contracted by Jay Petroleum to complete an initial site characterization of an impacted area around Pak-A-Sak #5. From March 2003-August 2003, boring samples were taken and monitor wells were put in to place to determine if the flow of contaminants was a threat to inhabitants by infiltrating drinking water. It was determined, after natural attenuation parameters were measured, that biodegradation was occurring on site; more prevalently aerobic degradation was taking place

BIOSCREEN was utilized to calculate retardation factor and biodegradation rate in order to determine the rate of contaminants relative to groundwater flow, and to determine if natural attenuation occurring on site was appropriate to allow it to continue. Retardation factor was calculated to be 1.4, which is indicative of adsorption occurring on ground material, and biodegradation rate was calculated to be 4.6 per year. The adsorption of the contaminants in addition to the biodegradation rate of 4.6 per year indicates that intrinsic remediation is an appropriate plan of action for this site, and no further action is needed.

Limitations for this research were far from few. Data received from Creek Run L.L.C Environmental Engineering had many measurements below detection limit, which made it difficult to understand what had been occurring on site by an outsider. In addition, many of these values that were below detection limit, or not measured at all were at impacted monitor wells. This could be problematic in terms of the overall results of this research. Also since BIOSCREEN was unable to calculate below 1000 years, there could not be a simulation for a timeline closer to modern time. Although the desired values were calculated, it would have been a nice touch to include a simulation.

For future work, one may find this site useful in microbial studies. It seemed as though there was a large span of land that had biodegradation occurring, and this could be a microbiologist's dream. Although Creek Run has since gotten approval to close this site for monitoring, someone may still find this area useful for research.

REFERENCES

Afifi, S., 2004, Petroleum Hydrocarbon Contamination of Groundwater in Suez: Causes Severe Fire Risk: *Hydrology Days*

Agency for Toxic Substances and Disease Registry (ATSDR), 1993. *Toxicological Profile for Xylene*. Public Health Service, U.S Department of Health and Human Services, Atlanta, GA.

Agency for Toxic Substances and Disease Registry (ATSDR), 1996. *Toxicological Profile for Methyl t-Butyl Ether*. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.

Agency for Toxic Substances and Disease Registry (ATSDR), 1999. *Toxicological Profile for Ethylbenzene* (Update). Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA.

Baker, R.J., A.L. Baehr, M.A. Lahvis, 2000. Estimation of biodegradation rates in gasoline-contaminated sediment from measured respiration rates. *Journal of Contaminant Hydrology* v. 41 p. 175-192

Bedient, P., H.S. Rifai, C.J. Newell, 1999, Ground Water Contamination.

Bruice, P., 2007. Organic Chemistry. Upper Saddle River, New Jersey: Prentice Hall.

Center for Disease Control and Prevention, 2013. Facts about Benzene. <www.bt.cdc.gov/agent/benzene/basics/facts.asp on October 9, 2013>.

Center for Disease Control and Prevention, 2014. Water-related Diseases and Contaminants in Public Water Systems, Atlanta, Ga, <http://www.cdc.gov/healthywater/drinking/public/water_diseases.html#asterisk>

Cho, Y., K. Han, N. Kim, 2013. Estimating In Situ Biodegradation Rates of Petroleum Hydrocarbons and Microbial Population Dynamics by Performing Single-Well Push-Pull Tests in a Fractured Bedrock Aquifer. *Water, Air, & Soil Pollution* v. 224 p. 1-14.

Creek Run L.L.C. Environmental Engineering, 2002, *Summary Report-Intrinsic Bioremediation Evaluation*

Davis, J.W, N. Klier, C. Carpenter, 1994, Natural Biological Attenuation of Benzene in Ground Water Beneath a Manufacturing Facility. *Ground Water*, v. 32, p. 215-226.

Das, N., P. Chandran, 2011. Microbial Degradation of Petroleum Hydrocarbon Contaminants: An Overview. *Biotechnology Research International*. vol. 2011

Domenico, P.A., F.W. Schwartz, 1987. Physical and Chemical Hydrogeology, New York, New York: Wiley

Fleming, I., 2009. Molecular Orbitals and Organic Chemical Reactions. United Kingdom: John Wiley and Sons Ltd.

Gibson, D., 1984. Microbial Degradation of Organic Compounds. Microbioloy Series, Volume 13. New York, New York: Marcel Dekker Inc.

Gray, H.H., 1982. Map of Indiana Showing the Topography of the Bedrock Surface, Indiana Department of Natural Resources, Geological Survey, Miscellaneous Map 36.

Gray, H.H., C.H. Ault, S.J. Keller, 1987. Bedrock geological Map of Indiana, Indiana Department of Natural Resources, Geological Survey. Miscellaneous Map 48.

Hoffman, D.L., D.E. Rolston, 1980. Transport of organic phosphate in soil as affected by soil type. *Soil Science Society of America Journal.* 44, 46-52.

Howard, P.H., J. Saxena, P.R. Durkin, L.T. Ou, 1975. Review and evaluation of available techniques for determining persistence and routes of degradation of chemical substances in the environment. *Environmental Protection Agency*. 560/5-75-006

International Programme on Chemical Safety, 1993. *Benzene*. Geneva, World Health Organization, International Programme on Chemical Safety. <http://www.inchem.org/documents/ehc/ehc/ehc150.htm>.

Jardine, P.M., F.M. Dunnivant, H.M. Selim, J.F. McCarthy, 1992. Comparison of models for describing the transport of dissolved organic carbon in aquifer columns. *Soil Science Society of America Journal*. 56, 393-401.

Johnson, L.F., 1964. Utilization of hydrocarbons by micro-organisms. *Chemistry and Industry* v. 36 p. 1532.

Johnson S.J., K.J. Woolhouse, H. Prommer, D.A. Barry, N. Christofi, 2003, Contribution of anaerobic microbial activity to natural attenuation of benzene in groundwater, *Engineering Geology*, v. 70, p. 343-349.

Kaladumo, C.O.K., 1996. *The implications of gas flaring in the Niger Delta Environment.* Proceedings of the 8th Biennial International NNPC Seminar. In: The Petroleum Industry and the Nigerian Environment, Port Harcourt, Nigeria, 277-290.

Kao, 2006. Application of monitored natural attenuation to remediate a petroleum-hydrocarbon spill site. *Water Science and Technology* vol. 53, p. 321-328.

King, B., G.M. Long, J.K. Sheldon, 1997. Practical Environmental Remediation: The Field Guide.

Kluess, S., 1986. Soil survey of Blackford and Jay Counties, Indiana.

Koestel, J.K., J. Moeys, N.J. Jarvis, 2012, Meta-analysis of the effects of soil properties, site factors, and experimental conditions on solute transport. *Hydrology and Earth System Sciences* v. 16 p. 147-1655.

Kuhn, K., J. DuBois, P. Maurice, 2013, Strategies of aerobic microbial Fe acquisition from Fe-bearing montomorillonite clay: Geochemica et *Cosmochimica Acta*, v. 117, 191-202.

Li, Zhenbin, L.M. Shuman, 1997. Estimation of retardation factor of dissolved carbon in sandy soils using batch experiments. *Geoderma* v. 78 p. 197-206.

Murray, W.A., R.C. Lunardini, F.J. Ullo, M.E. Davidson, 2000. Site 5 air sparging pilot test. Naval Air Station Cecil Field, Jacksonville, Florida. *Journal of Hazardous Materials*, v. 72, p. 121-145.

Nelson, D., M. Cox, 2008. Principles of Biochemistry (5th ed.). New York, New York: W.H. Freeman and Company

Nevin, J.P., J.A. Connor, C.J. Newell, J.B. Gustafon, K.A. Lyons, 1997. "Fate 5: A Natural Attenuation Calibration Tool for Groundwater Fate and Transport Modeling," Petroleum Hydrocarbons and Organic Chemicals in Groundwater Conference, NGWA, Houston, Texas, November 1997.

Newell, C.J., 1996. *BIOSCREEN: Natural Attenuation Decision Support System*. User's Manual 1.3

Newell, C.J., 1997. *BIOSCREEN: Natural Attenuation Decision Support System*. User's Manual 1.4 Revisions.

Newell, C.J., H.S. Rifai, J.T. Wilson, J.A. Connor, J.A. Aziz, M.P. Suarez, 2002. *Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies*. Cincinnati, Ohio: United States Environmental Protection Agency.

Ollila, P.W., 1996. Evaluating Natural Attenuation with Spreadsheet Analytical Fate and Transport Models. *Ground Water Monitoring and Remediation*, Vol. XVI, No. 24, p. 69-75.

Oya, S., A.J. Valocchi, 1998. Analytical approximation of biodegradation rate for in situ bioremediation of groundwater under ideal radial flow conditions. *Journal of Contaminant Hydrology* v. 31 p. 275-293.

Pitter, P 1976. Determination of biological degradability of organic substances. *Water Resources*. v. 10 p. 231- 235.

Prescott, M.L., J.P. Harley, A.D. Klan, 1996. Industrial Microbiology and Biotechnology. In: Microbiology. 3rd Ed. Wim C Brown Publishers, Chicago, 923-927.

Rifai, H.S., C.J. Newell, J.R. Gonzales, S. Dendrou, L. Kennedy, J. Wilson, 1997. BIOPLUME III Natural Attenuation Decision Support System Version 1.0 User's Manual. Air Force Center for Environmental Excellence, Brooks AFB, Texas

Short, J.W., M.R. Lindeberg, P.M. Harris, J. Maslko, S.D. Rice, 2002. *Vertical oil distribution within intertidal zone 12 years after Exxon Valdez oil spill in Prince William Sound, Alaska. Proceedings*, 25th Arctic and Marine Oilspill Program. Calgary, Alberta, Canada. June, 11-13, p. 57-72

Silverman, R., 2004. <u>The Organic Chemistry of Drug Design and Drug Action</u> (2nd ed.). Burlington, Massachusetts: Elsevier Academic Press

Stroud, J.L., G.I. Paton, K.T. Semple, 2007. Microbe-aliphatic hydrocarbon interactions in soil: implications for biodegradation and bioremediation. *Journal of Applied Microbiology*, v. 102, p. 1239-1253

Söhngen, N.L. 1913. *Benzin, Petroleum, Paraffinol and Paraffin als Kohlenstoff und Energiequelle fur Mikroben.* Zentr. Bakt. Parasitenk. II v. 37 p595-609

Suflita, J.M., 2000. *Intrinsic bioremediation of complex hydrocarbon mixtures: Novel mechanisms and geochemical consequences*. Groundwater 2000: proceedings of the International Conference on Groundwater Research, Copenhagen, Denmark, 6-8 June 2000 p. 293-295.

United Nations Environment Programme, 2006. <u>Challenges to International Waters: Regional Assessments in a Global Perspective</u>, pg. 38-53.

United States Department of Agriculture, 2015. Estimating Moist Bulk Density by Texture. <http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/office/ssr10/tr/?cid=nrcs144p2_074844>.

United States Energy Information Administration, 2014. What are the products and uses of petroleum? <http://www.eia.gov/tools/faqs/faq.cfm?id=41&t=6>.

United States Environmental Protection Agency, 1994. *Chemicals in the Environment: Toluene (CAS NO. 108-88-3)*. OPPT Chemical Fact Sheet. EPA 794-F-94-021

United States Environmental Protection Agency, 2007. UST Program Facts, Washington DC., <http://www.epa.gov/oust/pubs/ustfacts.pdf>.

United States Department of Health and Human Sciences, 1999. Toxilogical Profile for Total Petroleum Hydrocarbons (TPH). Agency for Toxic Substances and Disease Registry, Atlanta, Ga.

Walton, W.C., 1988. Practical Aspects of Groundwater Modeling: Natural Water Well Association, Worthington, Ohio

Weidemeier, T.H., J.T. Wilson, D.H., Kampbell, 1995. "Technical Protocol for Implementing Intrinsic Remediation With Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater (Revision 0)", Air Force Center for Environmental Excellence, April, 1995.

Wilson, B., H. Shen, J. Cho, J. Vardy, 1999. Use of BIOSCREEN to Evaluate Natural Attenuation of MTBE. *Petroleum Hydrocarbons and MTBE*. vol. 5 p. 115-12.

APPENDIX A

MONITOR WELL CONSTRUCTION DIAGRAMS, BORING LOGS, AND SLUG TESTS

A.1 Monitor- Well Diagrams and Boring Logs

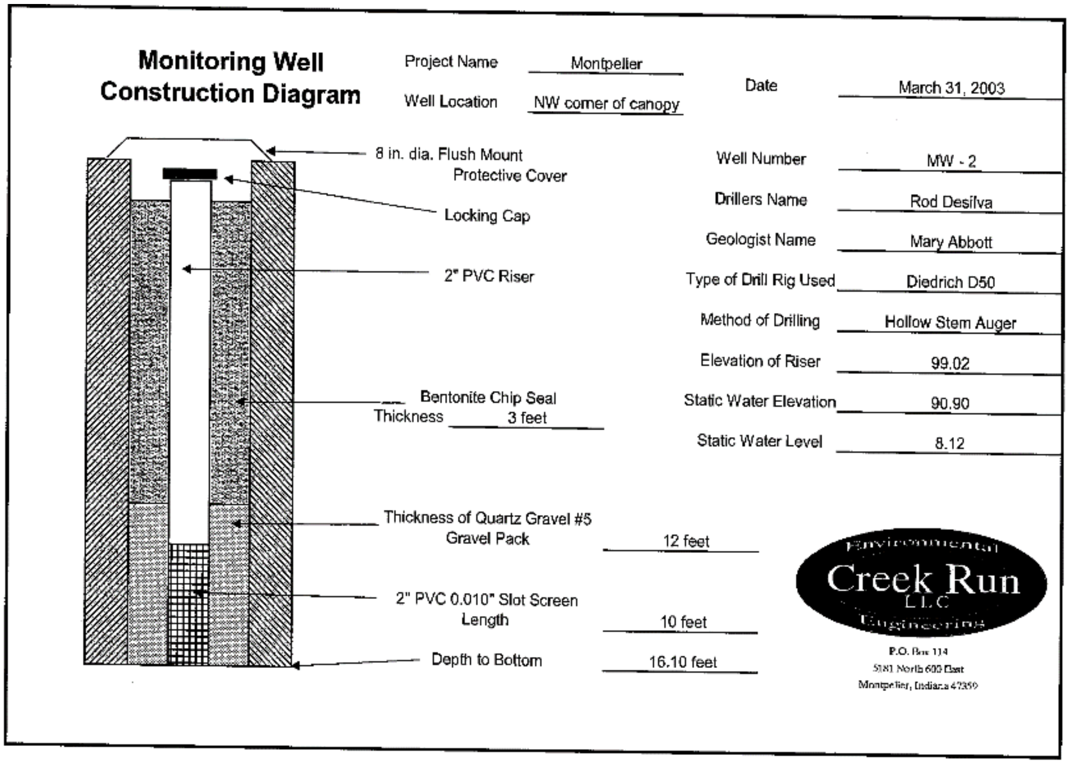
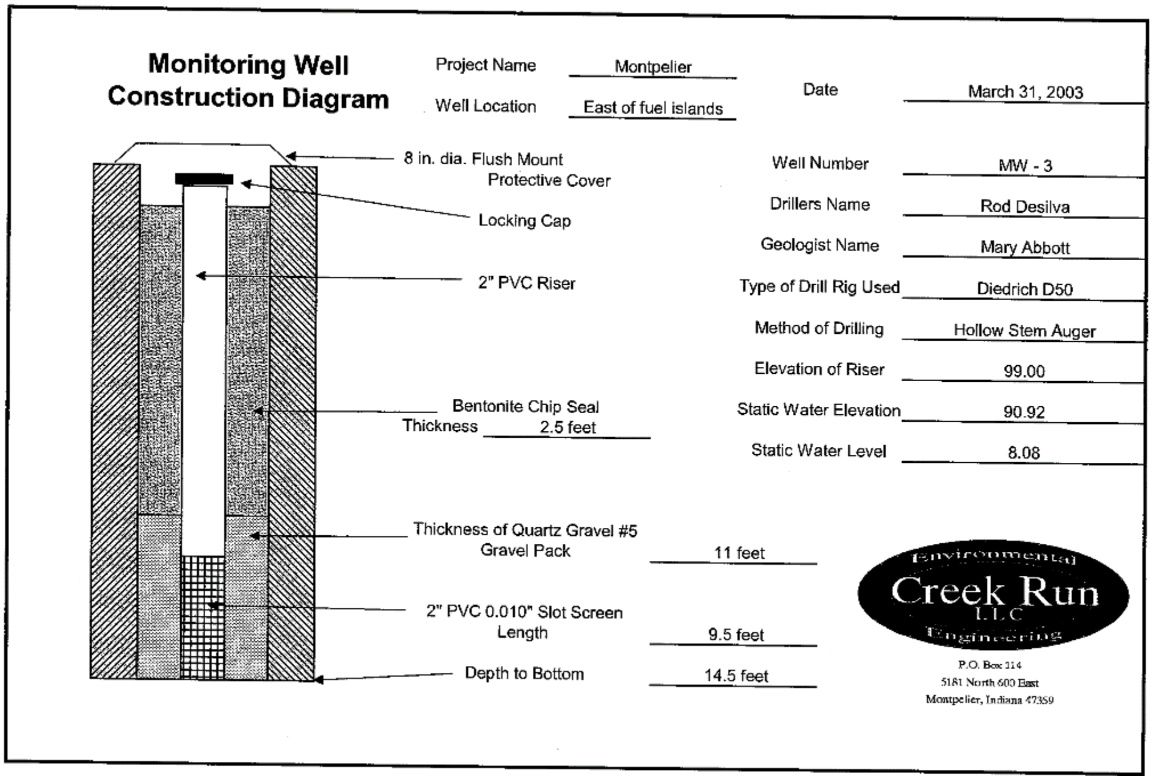


Figure A.1 Monitoring Well Construction Diagram for MW-2



Monitoring Well Construction Diagram

Project Name: Montpelier

Well Location: East of fuel islands

Date: March 31, 2003

8 in. dia. Flush Mount Protective Cover

Locking Cap

2" PVC Riser

Bentonite Chip Seal Thickness: 2.5 feet

Thickness of Quartz Gravel #5 Gravel Pack: 11 feet

2" PVC 0.010" Slot Screen Length: 9.5 feet

Depth to Bottom: 14.5 feet

Well Number	MW - 3
Drillers Name	Rod Desilva
Geologist Name	Mary Abbott
Type of Drill Rig Used	Diedrich D50
Method of Drilling	Hollow Stem Auger
Elevation of Riser	99.00
Static Water Elevation	90.92
Static Water Level	8.08

Environmental Creek Run LLC Engineering

P.O. Box 314
5181 North 600 East
Montpelier, Indiana 47359

Figure A.2 Monitoring Well Construction Diagram for MW-3

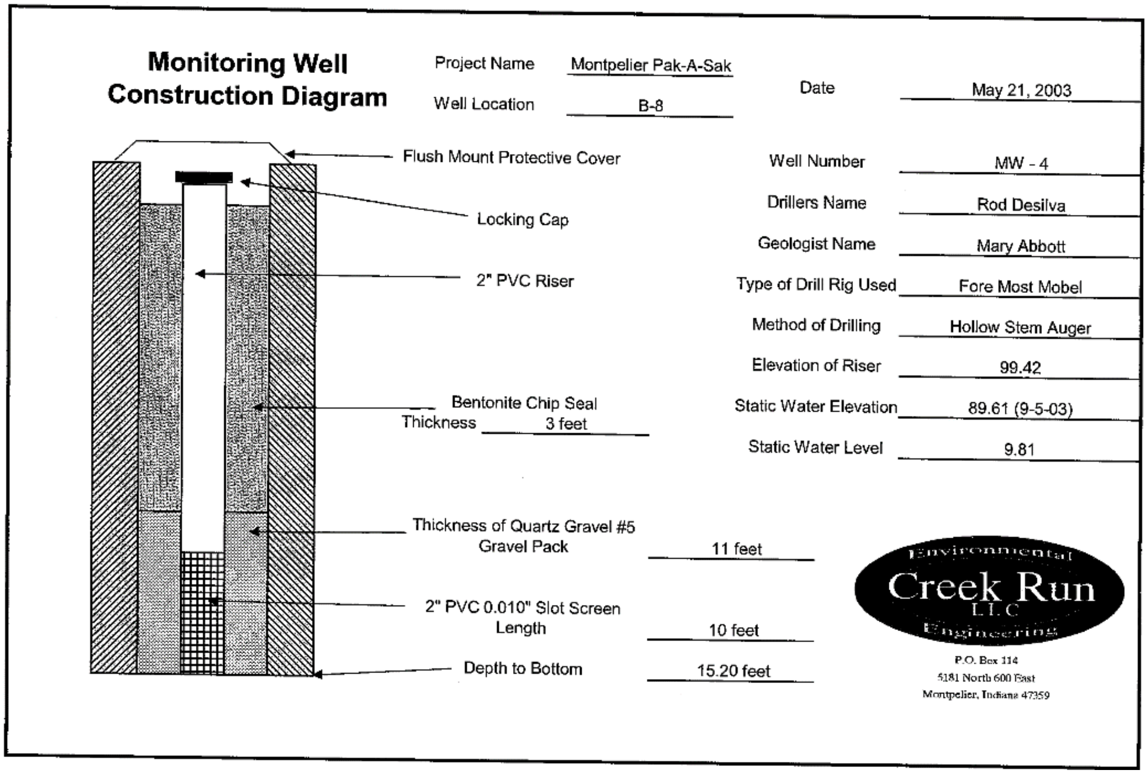


Figure A.3 Monitoring Well Construction Diagram for MW-4

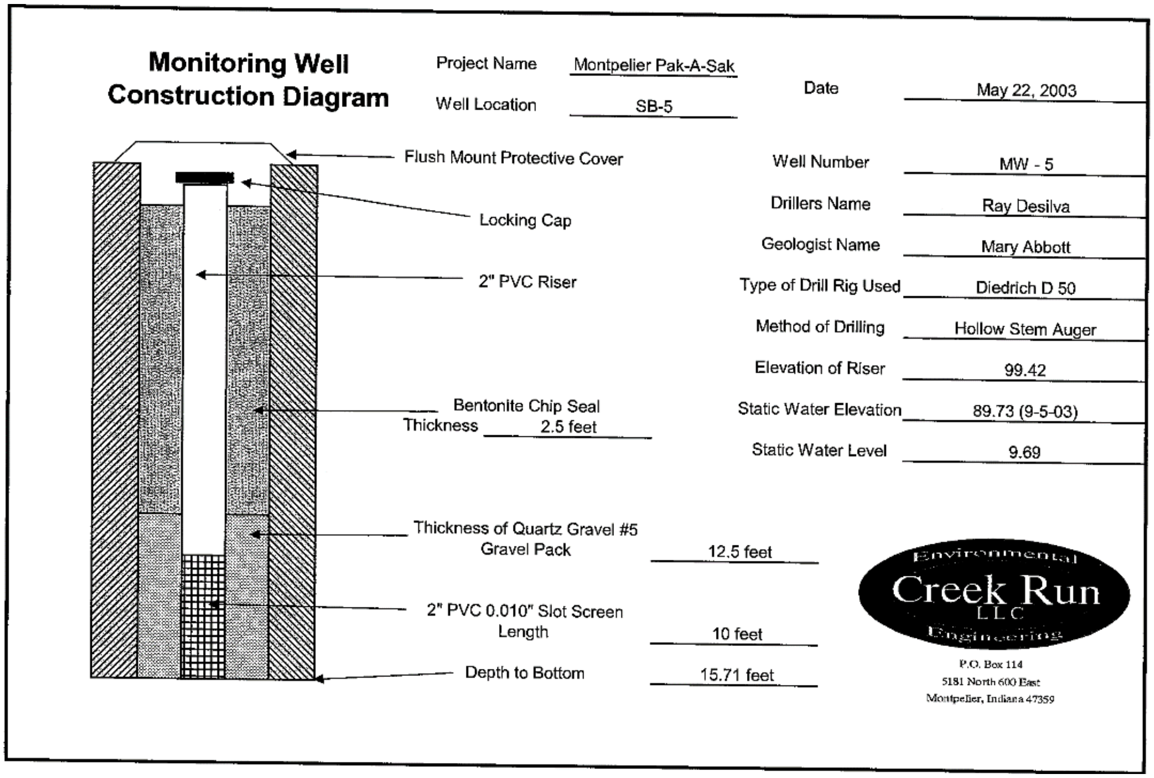


Figure A.4 Monitoring Well Construction Diagram for MW-5

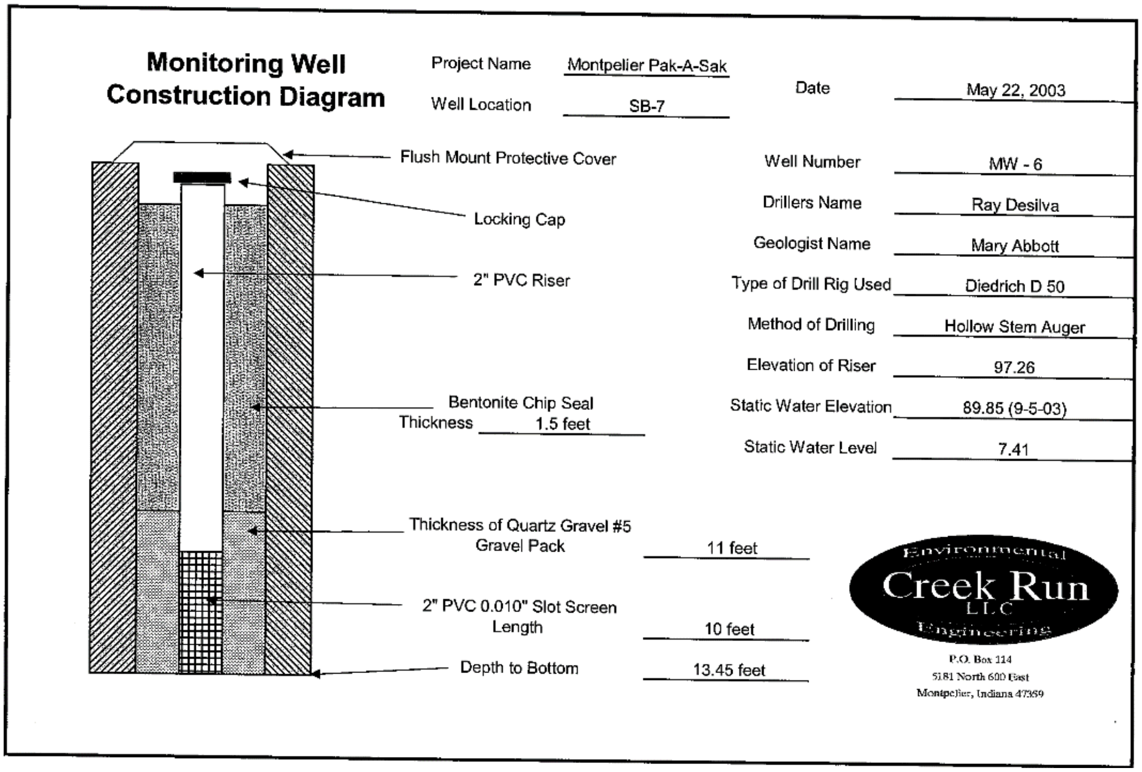


Figure A.5 Monitoring Well Construction Diagram for MW-6

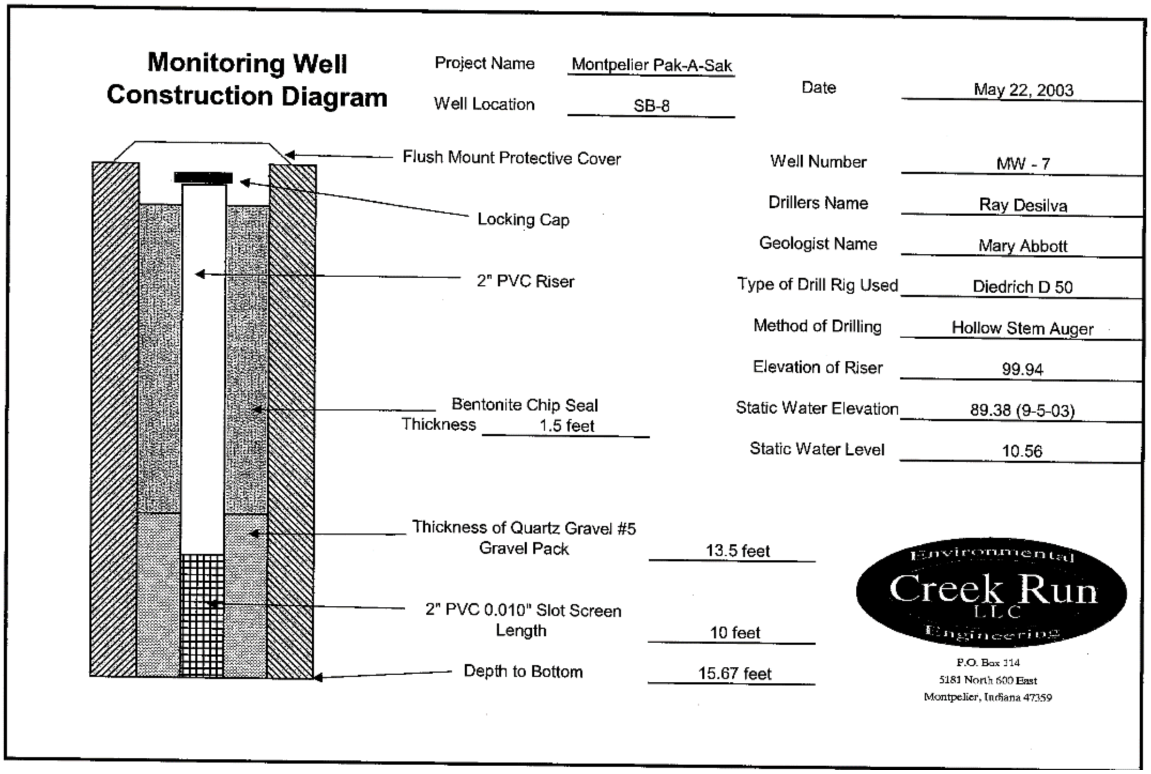


Figure A.6 Monitoring Well Construction Diagram for MW-7

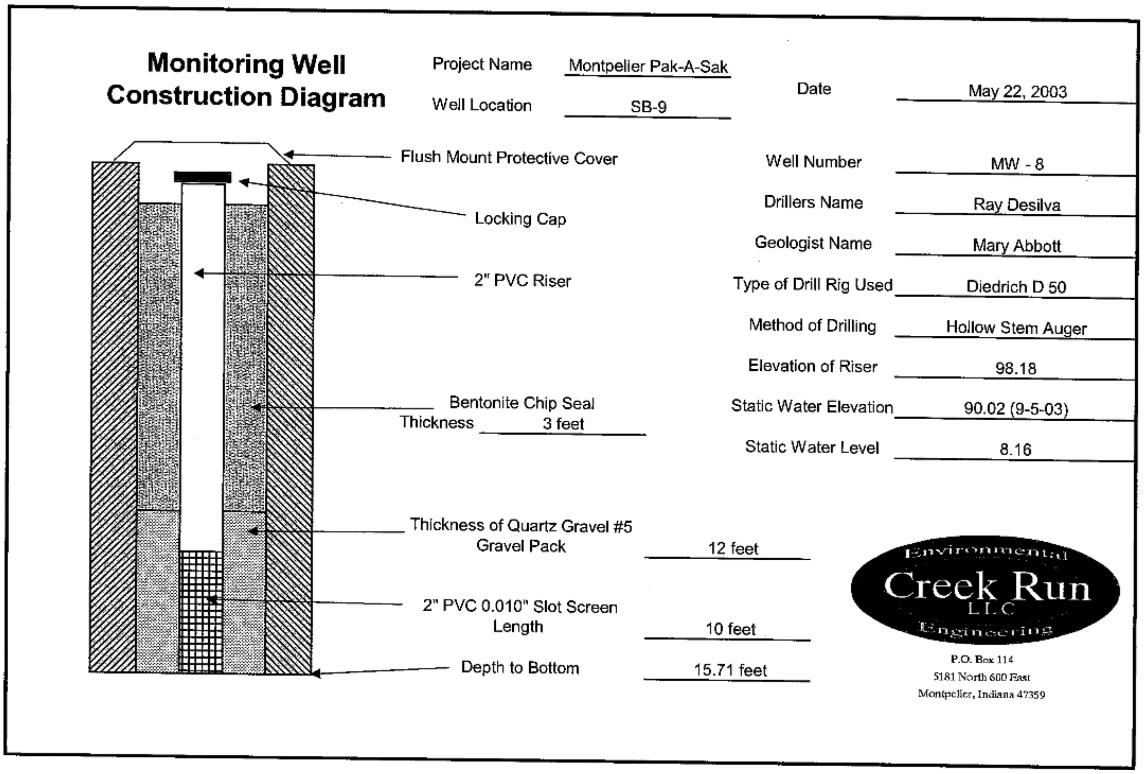


Figure A.7 Monitoring Well Construction Diagram for MW-8

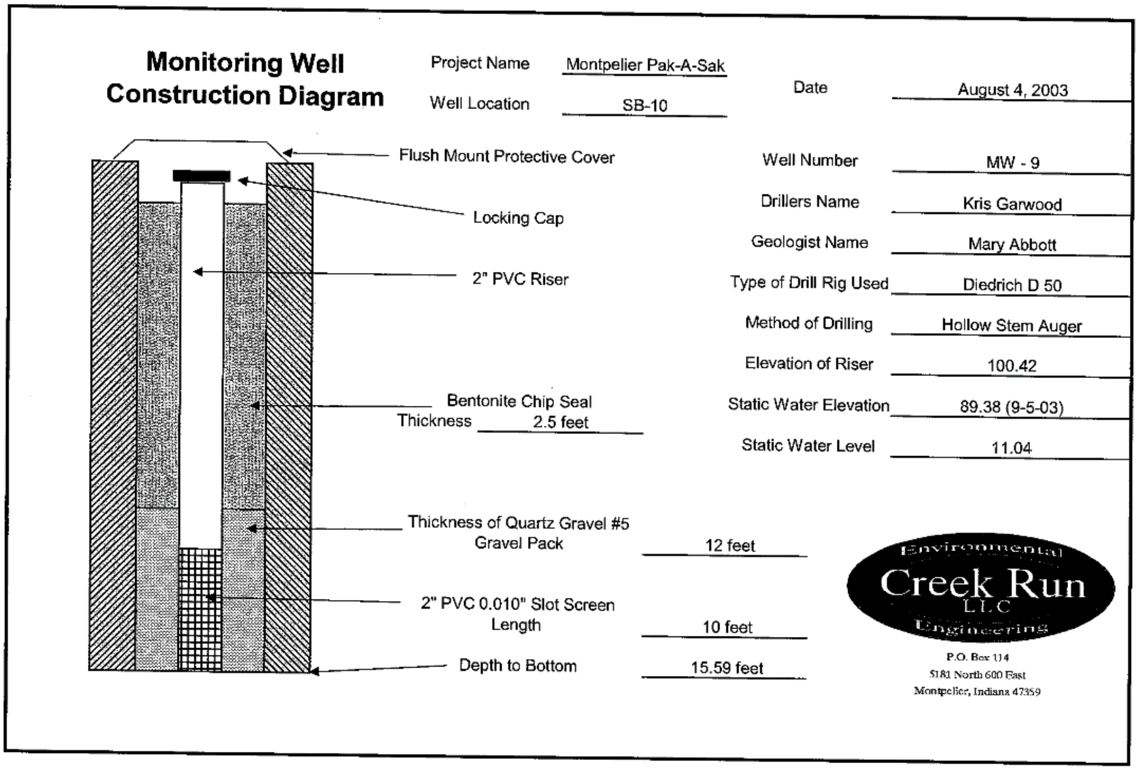


Figure A.8 Monitoring Well Construction Diagram for MW-9

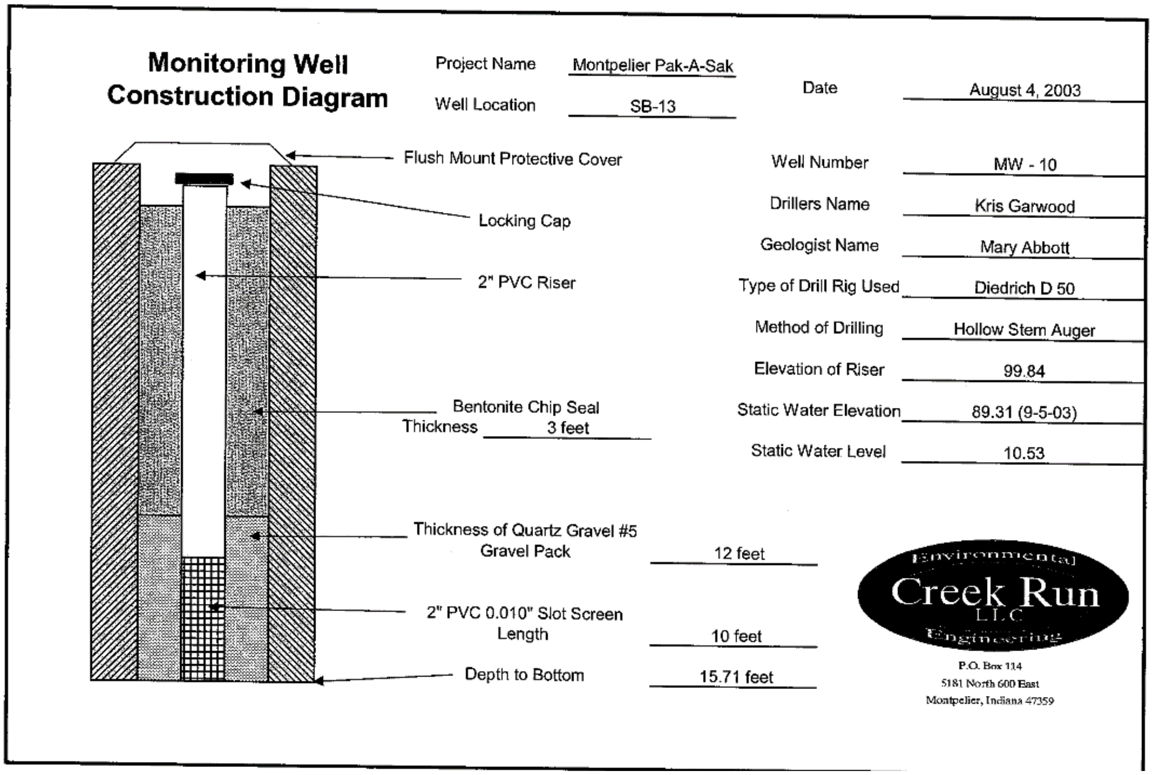


Figure A.9 Monitoring Well Construction Diagram for MW-10

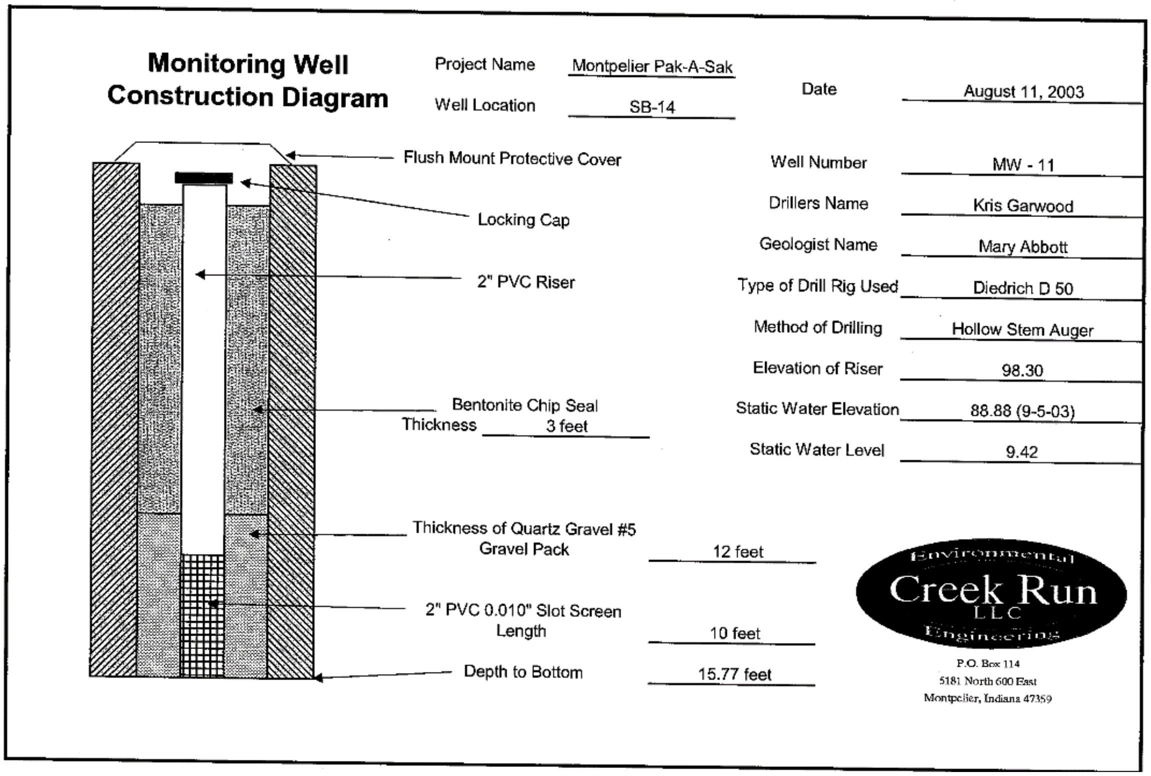


Figure A.10 Monitoring Well Construction Diagram for MW-11

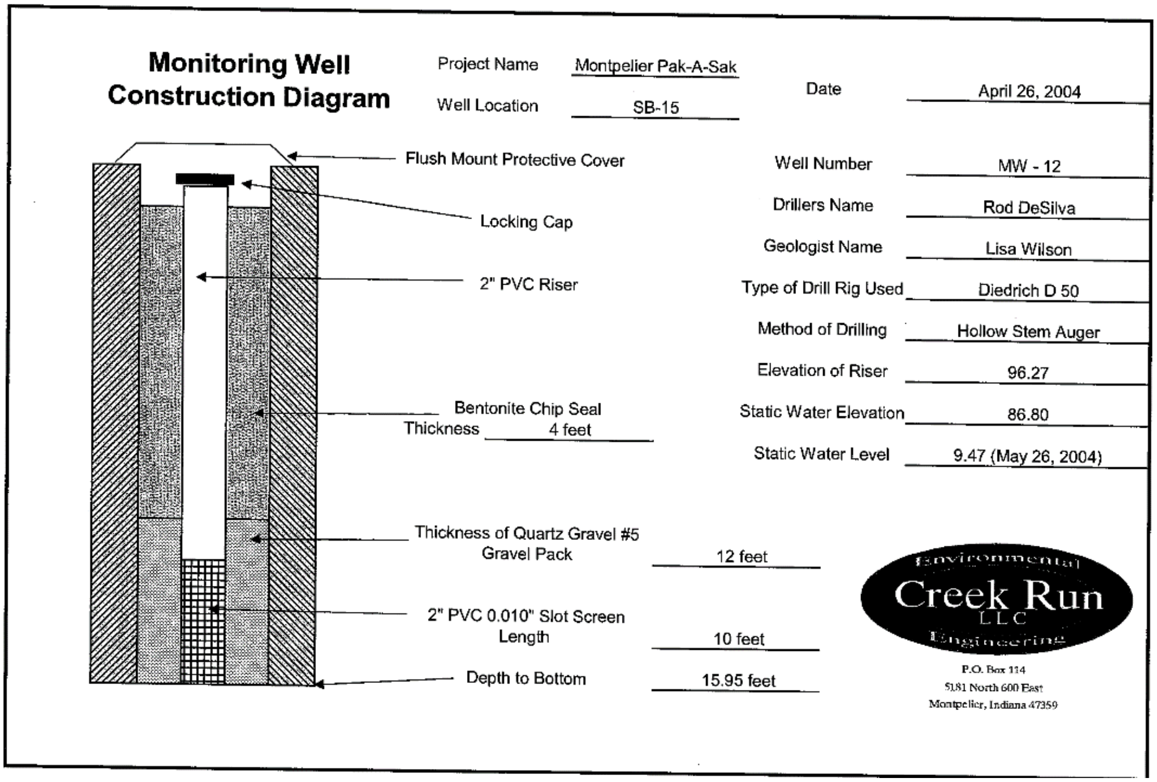


Figure A.11 Monitoring Well Construction Diagram for MW-12

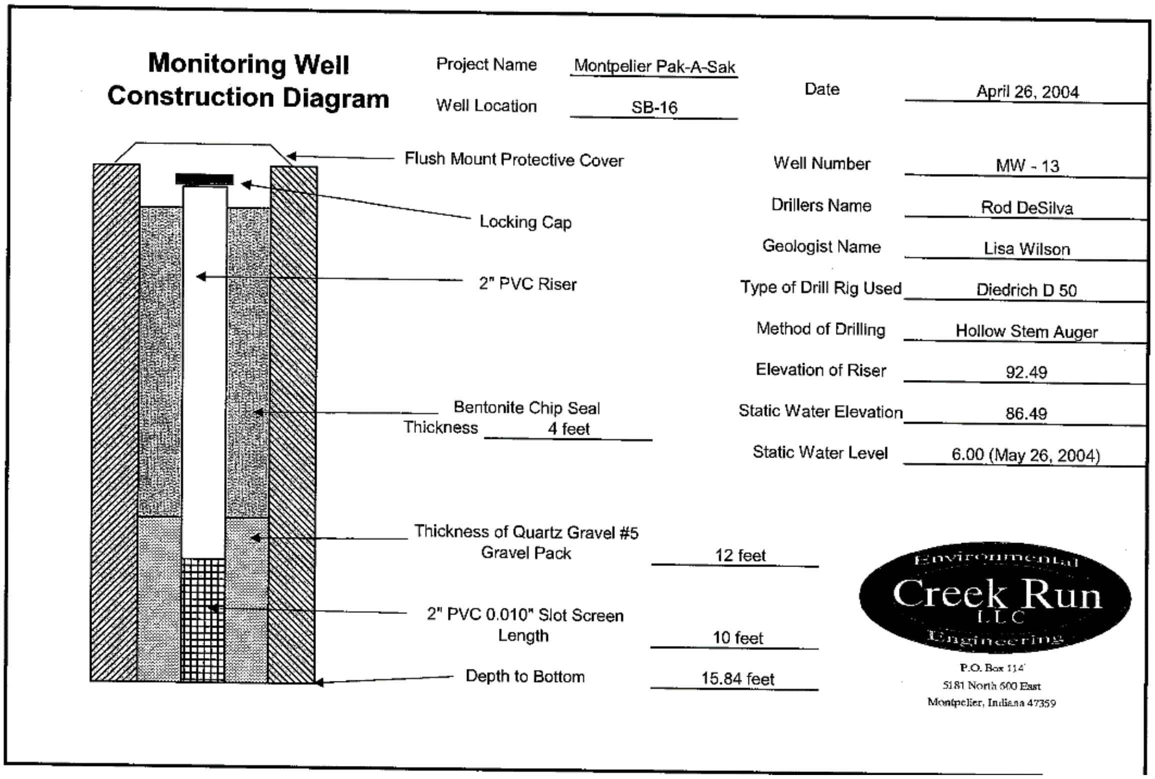


Figure A.12 Monitoring Well Construction Diagram for MW-13

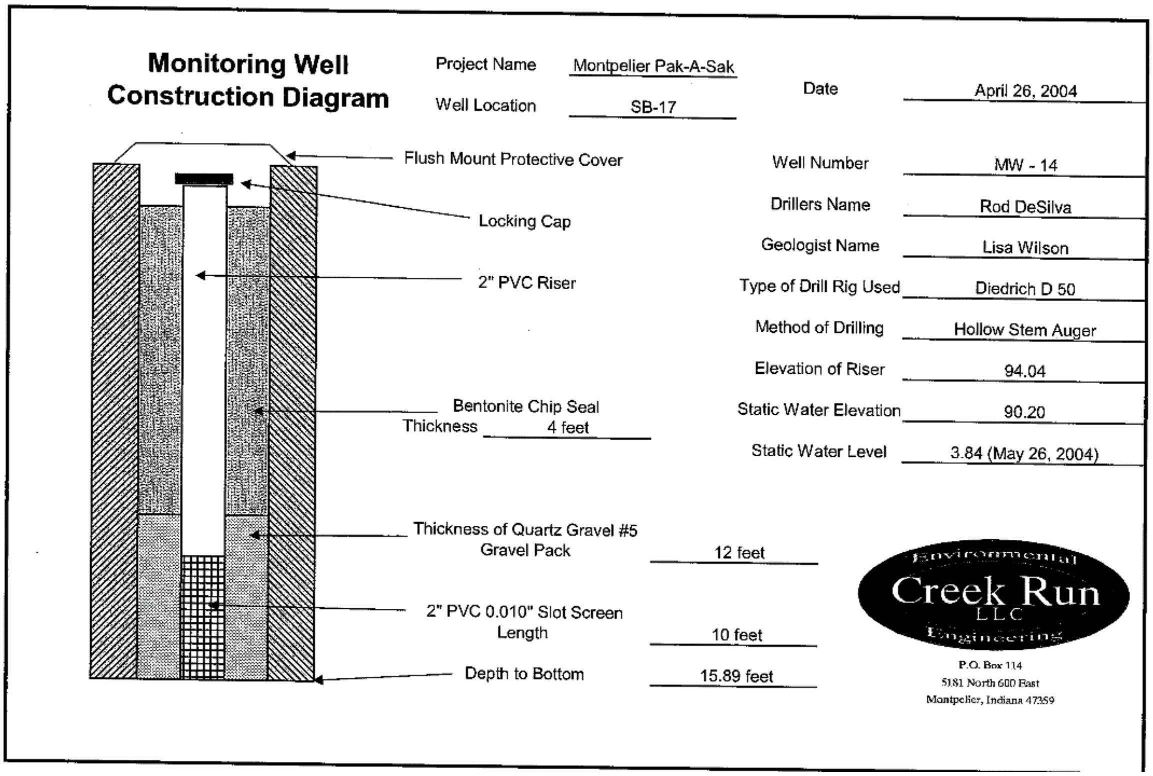
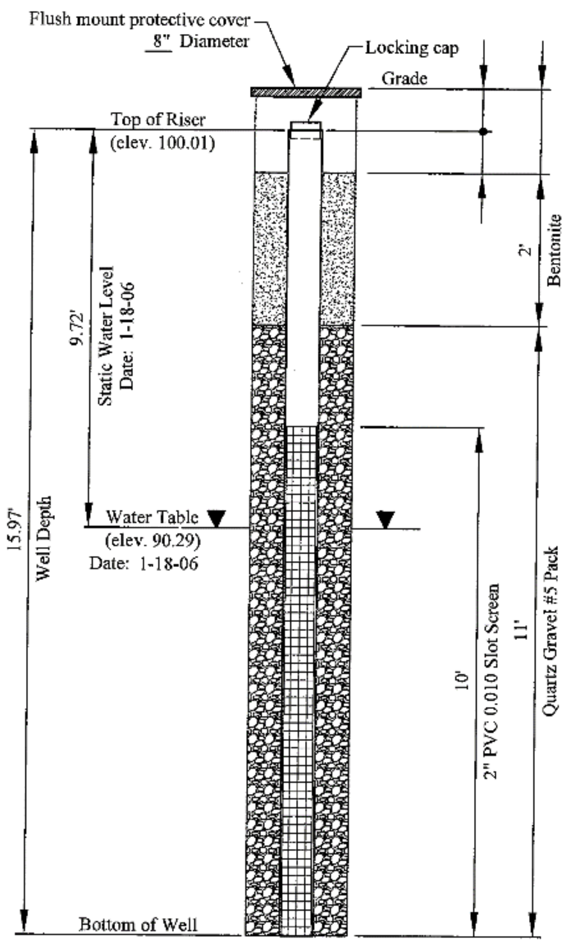


Figure A.13 Monitoring Well Construction Diagram for MW-14

WELL NUMBER: MW-15



PROJECT INFORMATION:

Installation Date: 1-11-06
Well Location: SB-22
Field Supervisor: Lisa Wilson
Drilling Contractor: SCS
Drillers Name: Rod DeSilva
Drill Rig: D-120
Method of Drilling: Hollow Stem Auger

WELL SPECIFICATIONS:

Bentonite Thickness: 2 feet
Gravel Pack Thickness: 11 feet
Riser Material: 2" Diameter PVC
Screen Length: 10 feet
Riser Elevation: 100.01
Static Water Level: 9.72 Date: 1-18-06
Static Water Elevation: 90.29 Date: 1-18-06
Well Depth: 15.97 feet

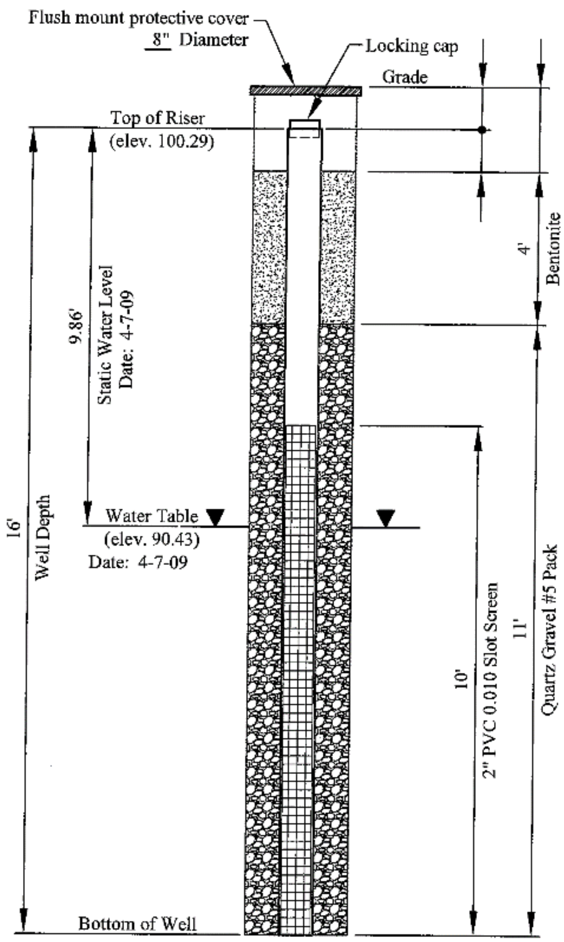
Creek Run L.L.C.
ENVIRONMENTAL ENGINEERING
PO Box 114
5181 N 600 E
Montpelier, IN 47359
Phone: 765-728-8051
Fax: 765-728-3041
www.creekrun.com

Monitoring Well Construction Diagram

Client: Jay Petroleum
Project Name: Pak-A-Sak
Address: 204 E. Huntington Road
City/State: Montpelier, IN
Project Manager: Lisa Wilson

Figure A.14 Monitoring Well Construction Diagram for MW-15

WELL NUMBER: MW-16



PROJECT INFORMATION:

Installation Date: 3-17-09
Well Location: B-26
Field Supervisor: Missy Ehrhart
Drilling Contractor: SCS
Drillers Name: Dana Booth (#1954)
Drill Rig: Geoprobe 6620 DT
Method of Drilling: Hollow Stem Auger

WELL SPECIFICATIONS:

Bentonite Thickness: 4 feet
Gravel Pack Thickness: 11 feet
Riser Material: 2" Diameter PVC
Screen Length: 10 feet
Riser Elevation: 100.29
Static Water Level: 9.86 Date: 4-7-09
Static Water Elevation: 90.43 Date: 4-7-09
Well Depth: 16 feet

Creek Run L.L.C.
ENVIRONMENTAL ENGINEERING
PO Box 114
5181 N 600 E
Montpelier, IN 47359
Phone: 765-728-8051
Fax: 765-728-3041
www.creekrun.com

Monitoring Well Construction Diagram

Client: Jay Petroleum
Project Name: Pak-A-Sak
Address: 204 E. Huntington Road
City/State: Montpelier, IN
Project Manager: Lisa Hendershot

Figure A.15 Monitoring Well Construction Diagram for MW-16

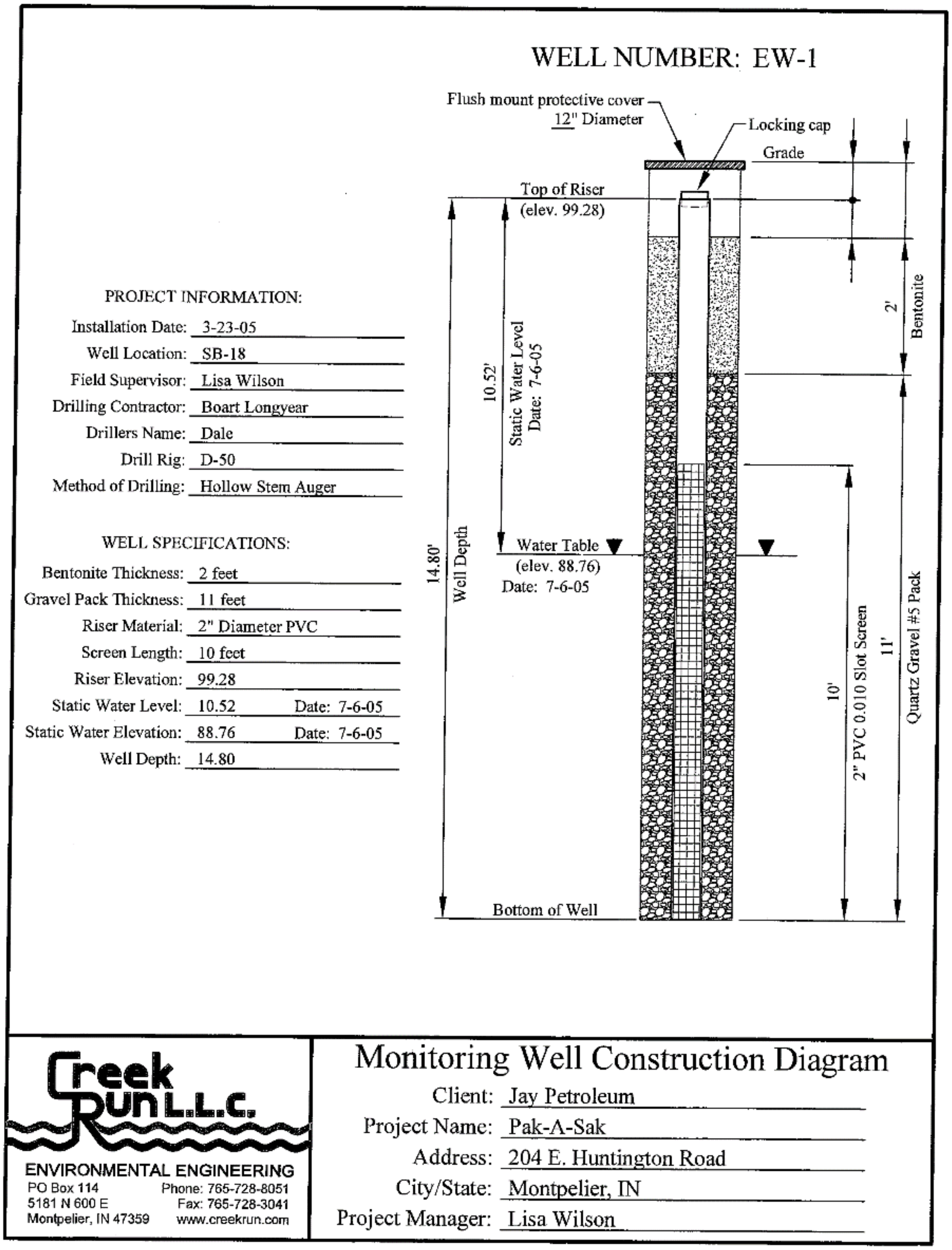
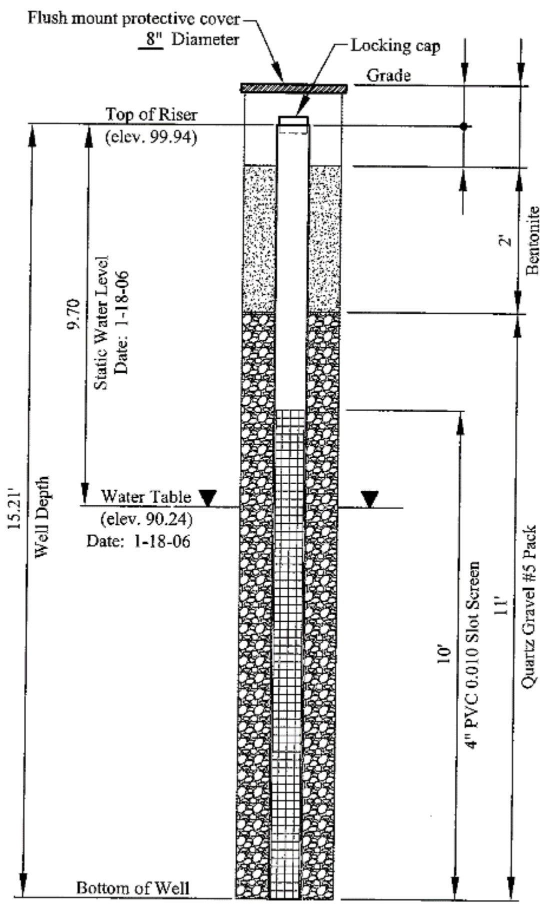


Figure A.16 Monitoring Well Construction Diagram for EW-1

WELL NUMBER: OEW-1



PROJECT INFORMATION:

Installation Date: 1-11-06
Well Location: SB-21
Field Supervisor: Lisa Wilson
Drilling Contractor: SCS
Drillers Name: Rod DeSilva
Drill Rig: D-120
Method of Drilling: Hollow Stem Auger

WELL SPECIFICATIONS:

Bentonite Thickness: 2 feet
Gravel Pack Thickness: 11 feet
Riser Material: 4" Diameter PVC
Screen Length: 10 feet
Riser Elevation: 99.94
Static Water Level: 9.70 Date: 1-18-70
Static Water Elevation: 90.24 Date: 1-18-06
Well Depth: 15.21 feet

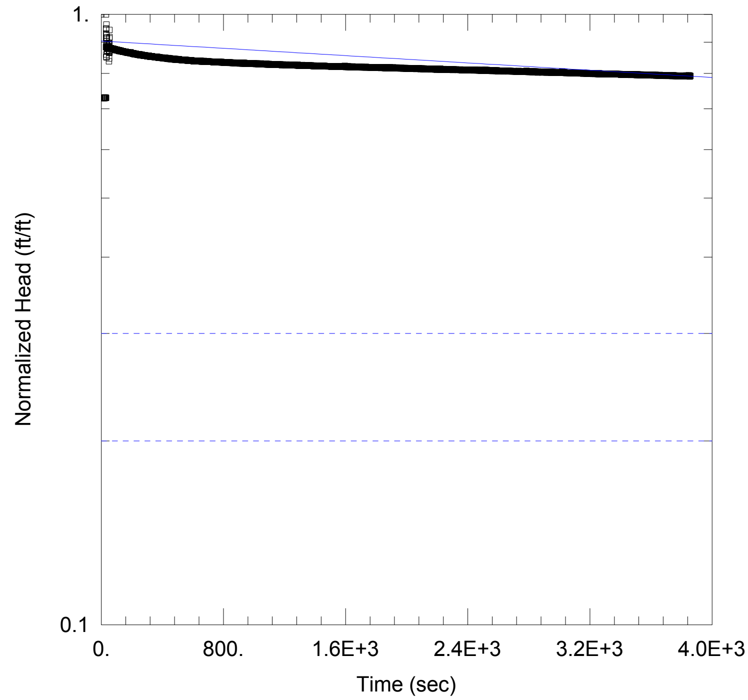
Creek Run L.L.C.
Environmental Engineering
PO Box 114
5181 N 600 E
Montpelier, IN 47359
Phone: 765-728-8051
Fax: 765-728-3041
www.creekrun.com

Monitoring Well Construction Diagram

Client: Jay Petroleum
Project Name: Pak-A-Sak
Address: 204 E. Huntington Road
City/State: Montpelier, IN
Project Manager: Lisa Wilson

Figure A.17 Monitoring Well Construction Diagram for OEW-1

A.2 Slug Tests



WELL TEST ANALYSIS

Data Set: C:\Users\stat021.CRENET\Desktop\MW-6 10-7-11.aqt
Date: 01/02/13 Time: 13:17:27

PROJECT INFORMATION

Company: Creek Run LLC
Client: Jay Petroleum
Project: 1
Location: 204 E Huntington, Montpelier
Test Well: MW-6
Test Date: 10-7-11

AQUIFER DATA

Saturated Thickness: 8. ft
Anisotropy Ratio (Kz/Kr): 1.

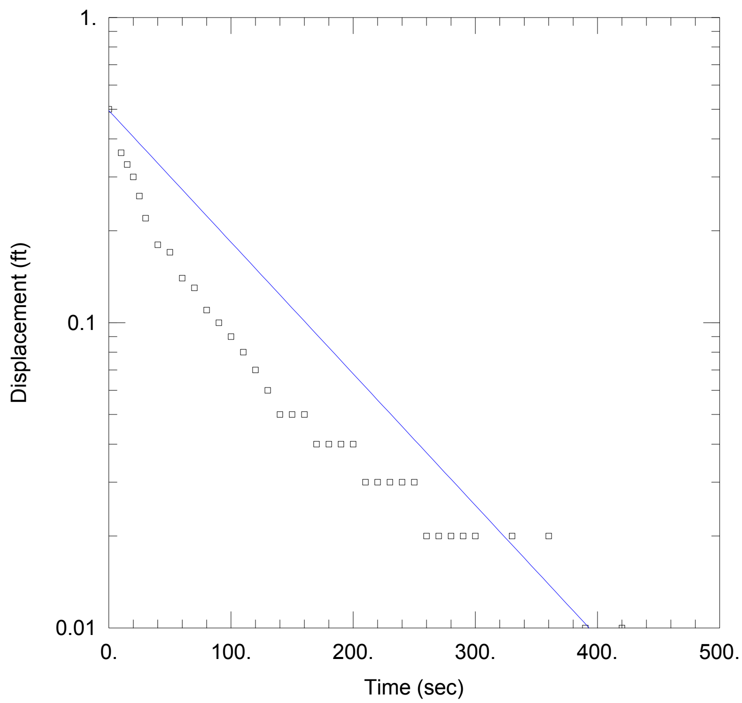
WELL DATA (MW-6)

Initial Displacement: 2.48 ft
Total Well Penetration Depth: 13.45 ft
Casing Radius: 0.083 ft
Static Water Column Height: 8.65 ft
Screen Length: 10. ft
Well Radius: 0.083 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.00492 ft/day
y0 = 2.242 ft

Figure A.18 Slug Test for Monitoring Well 6



WELL TEST ANALYSIS

Data Set: G:\Jay Petroleum\Montpelier\204 E. Huntington Rd\AquiferTests\MW-9 1-9-13.aqt
Date: 01/16/13 Time: 09:32:21

PROJECT INFORMATION

Company: Creek Run LLC
Client: Jay Petroleum
Location: 204 E Huntington Rd.
Test Well: MW-9
Test Date: 1-9-13

AQUIFER DATA

Saturated Thickness: 4.06 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-9)

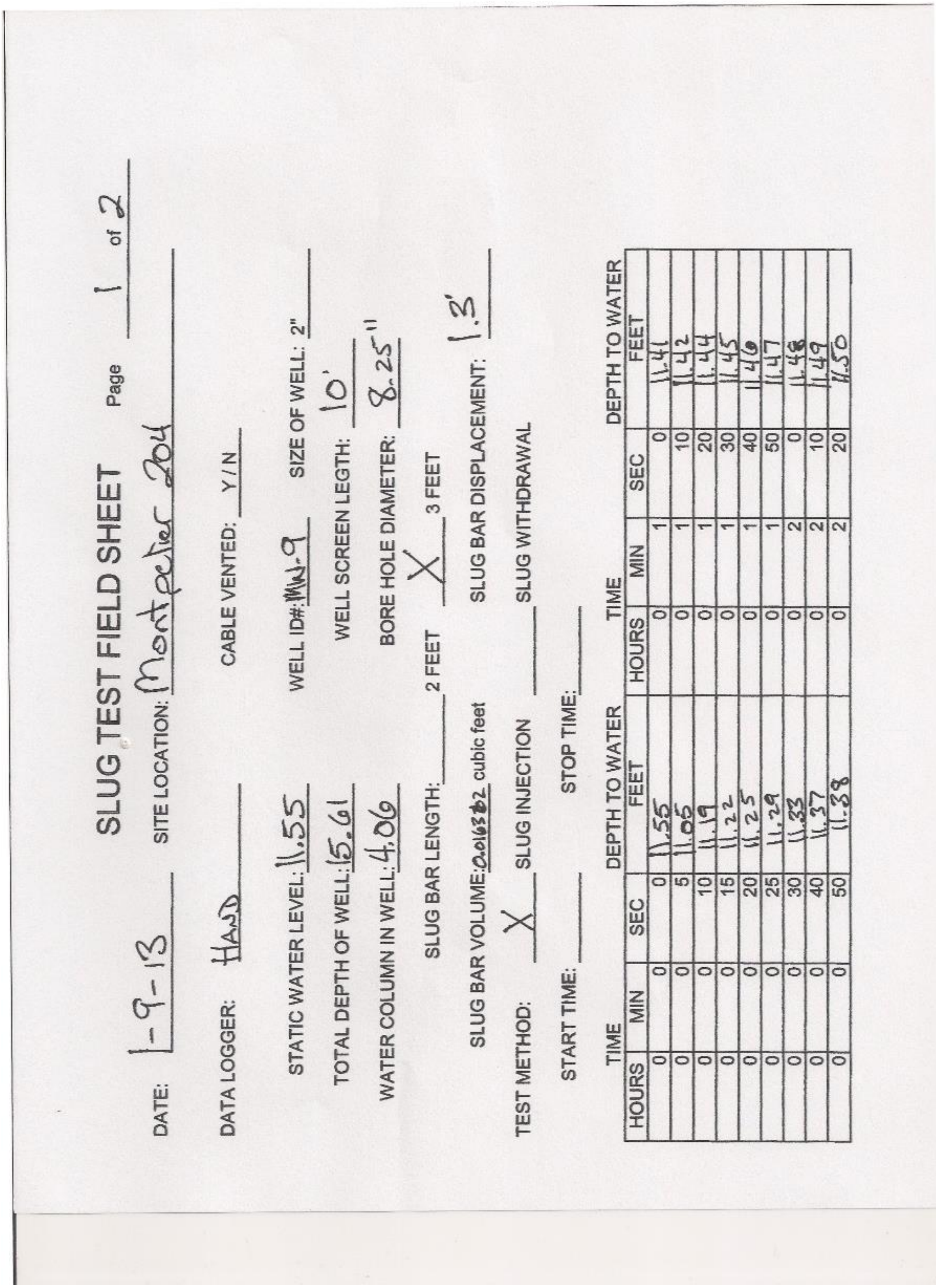
Initial Displacement: 0.5 ft
Total Well Penetration Depth: 15.61 ft
Casing Radius: 0.083 ft
Static Water Column Height: 11.55 ft
Screen Length: 10. ft
Well Radius: 0.083 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 2.764 ft/day y0 = 0.4952 ft

Figure A.19 Slug Test Data for Monitoring Well 9



SLUG TEST FIELD SHEET

Page 1 of 2

DATE: 1-9-13 SITE LOCATION: Montpelier 204

DATA LOGGER: HAND CABLE VENTED: Y / N

STATIC WATER LEVEL: 11.55 WELL ID#: MW-9 SIZE OF WELL: 2"

TOTAL DEPTH OF WELL: 15.61 WELL SCREEN LEGTH: 10'

WATER COLUMN IN WELL: 4.06 BORE HOLE DIAMETER: 8.25"

SLUG BAR LENGTH: ____ 2 FEET X 3 FEET

SLUG BAR VOLUME: 0.016362 cubic feet SLUG BAR DISPLACEMENT: 1.3'

TEST METHOD: X SLUG INJECTION ____ SLUG WITHDRAWAL

START TIME: ____ STOP TIME: ____

TIME			DEPTH TO WATER	TIME			DEPTH TO WATER
HOURS	MIN	SEC	FEET	HOURS	MIN	SEC	FEET
0	0	0	11.55	0	1	0	11.41
0	0	5	11.05	0	1	10	11.42
0	0	10	11.19	0	1	20	11.44
0	0	15	11.22	0	1	30	11.45
0	0	20	11.25	0	1	40	11.46
0	0	25	11.29	0	1	50	11.47
0	0	30	11.33	0	2	0	11.48
0	0	40	11.37	0	2	10	11.49
0	0	50	11.38	0	2	20	11.50

Figure A.19 (continued)

SLUG TEST FIELD SHEET

Page 1 of 2

DATE: 1-9-13 SITE LOCATION: Montpelier 204

DATA LOGGER: HAND CABLE VENTED: Y / N

STATIC WATER LEVEL: 11.55 WELL ID#: MW-9 SIZE OF WELL: 2"

TOTAL DEPTH OF WELL: 15.61 WELL SCREEN LEGTH: 10'

WATER COLUMN IN WELL: 4.06 BORE HOLE DIAMETER: 8.25"

SLUG BAR LENGTH: ____ 2 FEET X 3 FEET

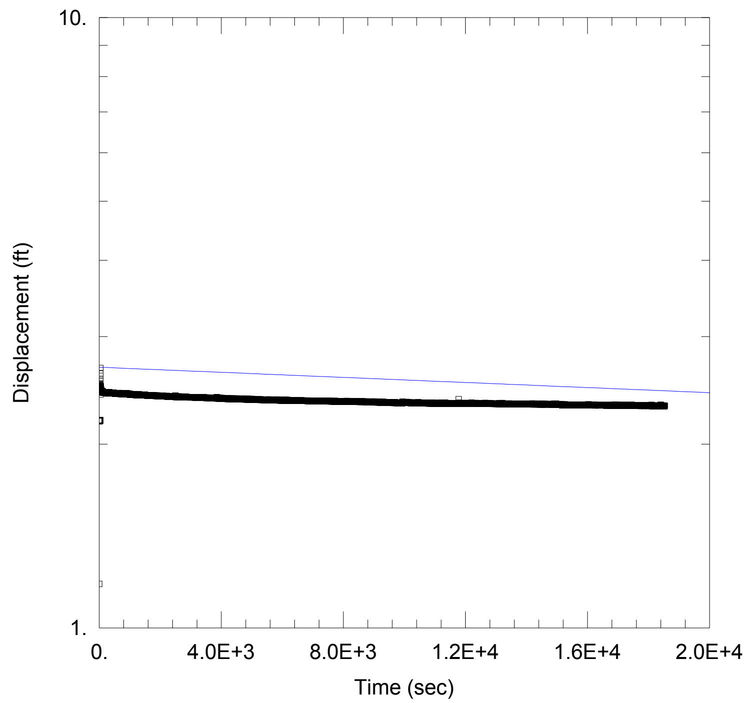
SLUG BAR VOLUME: 0.01632 cubic feet SLUG BAR DISPLACEMENT: 1.3'

TEST METHOD: X SLUG INJECTION ____ SLUG WITHDRAWAL

START TIME: ____ STOP TIME: ____

TIME			DEPTH TO WATER	TIME			DEPTH TO WATER
HOURS	MIN	SEC	FEET	HOURS	MIN	SEC	FEET
0	0	0	11.55	0	1	0	11.41
0	0	5	11.05	0	1	10	11.42
0	0	10	11.19	0	1	20	11.44
0	0	15	11.22	0	1	30	11.45
0	0	20	11.25	0	1	40	11.46
0	0	25	11.29	0	1	50	11.47
0	0	30	11.33	0	2	0	11.48
0	0	40	11.37	0	2	10	11.49
0	0	50	11.38	0	2	20	11.50

Figure A.19 (continued)



WELL TEST ANALYSIS

Data Set:
Date: 01/16/13 Time: 11:44:34

PROJECT INFORMATION

Company: Creek Run LLC
Client: Jay Petroleum
Location: 204 E Huntington Rd.
Test Well: MW-11
Test Date: 1-9-13

AQUIFER DATA

Saturated Thickness: 5.66 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (New Well)

Initial Displacement: 1.18 ft
Total Well Penetration Depth: 15.47 ft
Casing Radius: 0.083 ft
Static Water Column Height: 9.91 ft
Screen Length: 10. ft
Well Radius: 0.083 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined Solution Method: Bouwer-Rice

K = 0.0009762 ft/day y0 = 2.673 ft

Figure A.20 Slug Test Data for Monitoring Well 11

SLUG TEST FIELD SHEET

Page 1 of 1

DATE: 1-9-13 SITE LOCATION: Montpelier 204

DATA LOGGER: Win-Situ CABLE VENTED: Y / N

STATIC WATER LEVEL: 9.91 WELL ID#: 11 SIZE OF WELL: 2"

TOTAL DEPTH OF WELL: 15.47 WELL SCREEN LEGTH: 10

WATER COLUMN IN WELL: 5.66 BORE HOLE DIAMETER: 8.25

SLUG BAR LENGTH: X 2 FEET ____ 3 FEET

SLUG BAR VOLUME: 0.010908 cubic feet SLUG BAR DISPLACEMENT: ____

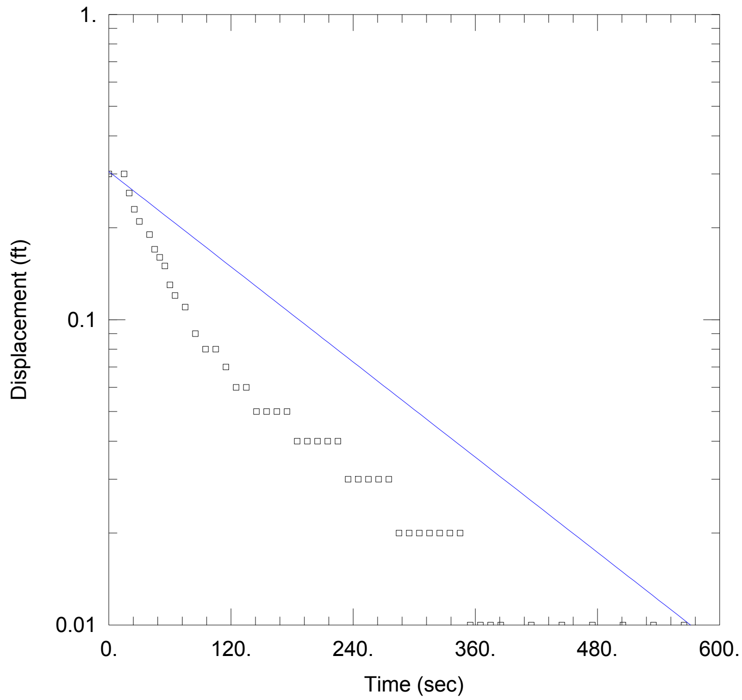
TEST METHOD: X SLUG INJECTION ____ SLUG WITHDRAWAL

START TIME: 9:48 STOP TIME: ____

TIME			DEPTH TO WATER	TIME			DEPTH TO WATER
HOURS	MIN	SEC	FEET	HOURS	MIN	SEC	FEET
0	0	0		0	1	0	
0	0	5		0	1	10	
0	0	10		0	1	20	
0	0	15		0	1	30	
0	0	20		0	1	40	
0	0	25		0	1	50	
0	0	30		0	2	0	
0	0	40		0	2	10	
0	0	50		0	2	20	

Time	WL
9:48	9.91
9:50	9.35
10:30	9.42
10:50	9.45
12:35	9.55
13:30	9.58
13:50	9.60
14:30	9.61
14:50	9.61

Figure A.20 (continued)



WELL TEST ANALYSIS

Data Set: G:\Jay Petroleum\Montpelier\204 E. Huntington Rd\AquiferTests\MW-16 1-9-13.aqt
Date: 01/16/13 Time: 12:53:12

PROJECT INFORMATION

Company: Creek Run LLC
Client: Jay Petroleum
Location: 204 E Huntington Rd.
Test Well: MW-16
Test Date: 1-9-13

AQUIFER DATA

Saturated Thickness: 4.19 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-16)

Initial Displacement: 0.3 ft
Total Well Penetration Depth: 15.89 ft
Casing Radius: 0.083 ft
Static Water Column Height: 11.72 ft
Screen Length: 10. ft
Well Radius: 0.083 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 1.623 ft/day
y0 = 0.3056 ft

Figure A.21 Slug Test Data for Monitoring Well 16

SLUG TEST FIELD SHEET

Page 1 of 2

DATE: 1-9-13 SITE LOCATION: Montpelier 204

DATA LOGGER: HAND CABLE VENTED: Y / N

STATIC WATER LEVEL: 11.72 WELL ID#: 16 SIZE OF WELL: 2"

TOTAL DEPTH OF WELL: 15.89 WELL SCREEN LEGTH: 10'

WATER COLUMN IN WELL: 4.19 BORE HOLE DIAMETER: 8.25"

SLUG BAR LENGTH: ____ 2 FEET X 3 FEET

SLUG BAR VOLUME: 0.016362 cubic feet SLUG BAR DISPLACEMENT: 1.3'

TEST METHOD: X SLUG INJECTION ____ SLUG WITHDRAWAL

START TIME: 11:22 STOP TIME: ____

TIME			DEPTH TO WATER	TIME			DEPTH TO WATER
HOURS	MIN	SEC	FEET	HOURS	MIN	SEC	FEET
0	0	0	11.72	0	0 ~~1~~	45 ~~0~~	11.55
0	0	5	NM	0	0 ~~1~~	50 ~~10~~	11.56
0	0	10	NM	0	0 ~~1~~	55 ~~20~~	11.57
0	0	15	11.42	0	1	00 ~~30~~	11.59
0	0	20	11.46	0	1	05 ~~40~~	11.60
0	0	25	11.49	0	1	15 ~~50~~	11.61
0	0	30	11.51	0	1 ~~2~~	25 ~~0~~	11.63
0	0	35 ~~40~~	11.52	0	1 ~~2~~	35 ~~10~~	11.64
0	0	40 ~~50~~	11.53	0	1 ~~2~~	45 ~~20~~	11.64

Figure A.21 (continued)

MW-16

Page 2 of 2

TIME			DEPTH TO WATER	TIME			DEPTH TO WATER	
HOURS	MIN	SEC	FEET	HOURS	MIN	SEC	FEET	
0	1 2	55 45 30	11.65	0	7 15	55 Ø	11.71	
0	2 2	05 50 40	11.66	0	8 20	25 Ø	11.71	
0	2 2	15 50	11.66	0	9 25	55 Ø	11.71	
0	2 3	25 Ø	11.67	0	9 30	25 Ø	11.71	
0	2 3	35 10	11.67	0	10 40	25 Ø	11.72	1 min
0	2 3	45 20	11.67	0	50	Ø		
0	2 3	55 30	11.67	0 1	Ø	Ø		
0	3 3	05 40	11.68					
0	3 3	15 50	11.68					
0	3 4	25 Ø	11.68					
0	3 4	35 10	11.68					
0	3 4	45 20	11.68					
0	3 4	55 30	11.69					
0	4 4	05 40	11.69					
0	4 4	15 50	11.69					
0	4 5	25 Ø	11.69					
0	4 5	35 30	11.69					
0	4 6	45 Ø	11.70					
0	4 6	55 30	11.70					
0	5 7	05 Ø	11.70					
0	5 7	15 30	11.70					
0	5 8	25 Ø	11.70					
0	5 8	25 30	11.70					
0	5 9	45 Ø	11.70					
0	5 9	55 30	11.71					
0	6 10	05 Ø	11.71					
0	6 11	15 Ø	11.71					
0	6 12	25 Ø	11.71					
0	6 13	55 Ø	11.71	30 sec				
0	7 14	25 Ø	11.71					

Figure A.21 (continued)