Summer 2007

The importance and influence of groundwater fluctuations in phytoremediation

Jeff A. Weishaar

THE IMPORTANCE AND INFLUENCE OF GROUNDWATER FLUCTUATIONS IN PHYTOREMEDIATION

by

JEFF WEISHAAR

A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

2007

Approved by

Joel G. Burken, Advisor

Mark W. Fitch

Melanie R. Mormile

ABSTRACT

Volatile hydrocarbons have multiple potential fates in phytoremediation. This research investigated the relationship between biodegradation and plant uptake of BTEX in laboratory and field settings. Studies were performed to evaluate the BTEX and oxygen transport to the vadose zone as a result of diurnal fluctuations in the groundwater caused by evapotranspiration. At a former refinery, inspections discovered contaminated groundwater and a BTEX contaminant seep in one impoundment. Phytoremediation was chosen to lower the groundwater table and remove the contaminants. Phytomonitoring methods were used to evaluate groundwater contamination throughout the site. Failure to detect BTEX in native trees led to an interest in microbial degradation occurring in the vadose zone. Hydrocarbon-degrader enumeration studies performed in the impoundment area indicated BTEX degrader populations up to 2.4 x 10^4 CFU/g. Reactors were constructed using site soils and DN34 hybrid poplar trees watered with contaminated and un-contaminated water. Water input and levels in each reactor were monitored and used to calculate oxygen diffusion and advection into the reactors. The contaminated planted reactor had BTEX degrader populations of 6 x 10^5 CFU/g, the uncontaminated planted reactor contained BTEX degrader populations of 5 x 10^4 CFU/g while unplanted reactors had populations 2 x 10^3 CFU/g. Oxygen input levels in planted reactors using natural soil were at least 2 times higher than in sterilized reactors and 3 to 5 times higher than in unplanted reactors. Results indicate that phytoremediation can aid microbial degradation by increasing oxygen levels in the soil as well as by transporting contaminants to the microbes by creating groundwater diurnal fluctuations.

ACKNOWLEDGMENTS

I would like thank my advisor, Dr. Joel G. Burken for his friendship and guidance and his unending dedication to my education, as well as the use of his house for 8 months. Wow, what a party! Also want to thank Dr. Mark Fitch for his help in all aspects of my academic career, from getting me though my undergraduate degree to getting me through my graduate degree and research and for all his off-the-wall suggestions and comments in the classroom, priceless. I will never forget that it is inappropriate to give a presentation in a bikini or Speed-o®. I would thank Dr. Curt Elmore for his advice and willingness to sit down and listen to my research ramblings. Also, thanks to Dr. Mormile for filling in last minute on my committee. Thank you to David Tsao and British Petroleum as well as EPA Midwest HSRC at Purdue University for the financial support to complete the research, hopefully the results are worth the investment.

Unending thank you's to my parents, for all their love, understanding and unending support. Without them, I wouldn't be where, or who, I am today. To my wonderful Monica and our beautiful Audrey, I love you both and I am finishing this so we can spend our weekends at the beach together. To all my labmates and classmates over the past few semesters, thanks for all the fun times in the lab, in the classroom and in the Grotto. To Amanda, Sally and Emily, it was fun being one of the girls of 309, thanks for including me. It's been fun, y'all.

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NOMENCLATURE

Symbol	Description
e	Void Ratio
CFU	Coliform Forming Units
P	Pressure
V	Volume
T	Temperature
R	Ideal Gas Constant
n	Number of Moles
J	Flux
T	Tortuosity
D	Diffusion Coefficient for Oxygen in Soil
$\frac{\partial C}{dx}$	Change in Concentration over Change in Depth
C_0	Surface Concentration
erfc	Error Function
$D_{p,g}$	Gas Diffusion Coefficient in Soil
$D_{o,g}$	Gas Diffusion Coefficient in Air
Φ	Total Porosity or Porosity
ε	Air Filled Porosity
α	ε for gas diffusion
t	Time
x	Depth
M_{O_2}	Oxygen Mass due to Diffusion
C	Oxygen Concentration at time determined by Fick's Second Law
A_R	Reactor Surface Area
D_U	Depth of Unsaturated Zone in Reactor after Watering
D_W	Depth of Water Table Drop after Time, t

1. INTRODUCTION

1.1. BACKGROUND

Phytoremediation is the use of natural or engineered vegetation to remove chemicals from contaminated soil and groundwater and offers an established remediation alternative for the removal of volatile organic compounds (VOCs) in shallow groundwater settings. Phytoremediation offers the advantage of a low energy technology as a biological process with no pumps, wells or machinery required. It also offers other advantages including low implementation and maintenance costs, low site impact and noise due to the lack of heavy machinery, and the ascetic value offered by using a natural remediation technology.

A former refinery located near Kansas City had fuel and oil releases during refinery operations. In 1980, the refinery underwent a demolition period in which the refining operations were suspended and multiple tanks were removed and the area was allowed to re-forest. The site, which featured many above-ground tanks, used natural berms to isolate the tanks and any accidental spills. Past site inspections uncovered leaching groundwater within a specific impoundment, herein referred to as Berm 156. Sampling of the seep resulted in detection of methyl-tertiary butyl ether (MTBE), as well as detection of benzene, toluene, ethyl-benzene, and xylenes (BTEX). Subsequent sampling demonstrated a decrease in contaminant concentrations; however, remedial action was considered necessary to remove the potential risk for human and ecological exposure

Due to the large amount of vegetation in the area and the associated difficulty in providing large equipment and power to the area, phytoremediation was chosen for remedial action within the berm. Phytoremediation uses vegetation which act as biological pumps. The vegetation utilizes groundwater for growth and survival and can be used to act as a hydraulic control for groundwater and contaminant mobility. Phytoremediation provides for contaminant removal through various mechanisms dependent on both the plant and the chemical properties. These mechanisms include phytovolatilization, phytostabilization, phytoextraction, rhizofiltration, and rhizodegradation. Contaminants are removed through uptake into the plant where they can be volatilized into the atmosphere or accumulated into the plant biomass or by biodegradation in the vadose zone surrounding the roots.

The main objective of the phytoremediation effort was to lower the groundwater level within the impoundment and prevent further seepage. Contaminant uptake was also a goal within the phytoremediation area, which consisted of native willow trees as well as nonnative poplar trees planted in a portion of the berm. Contaminant uptake throughout the natural growing re-forested area became another point of interest for the remediation effort. In order to evaluate the impact and contaminant concentrations in the area, contaminant concentrations within trees were requested to be determined. This would allow for a low-cost, low impact method of tracking the contaminant plume. This is termed "phyto-mapping" and has been used in the past for detection of VOC's in natural vegetation and at engineered phytoremediation sites.

Benzene, toluene, and xylene were detected in small quantities in a number of the trees samples; however, the low concentrations could not explain the lack of detection in tree cores throughout the site and in close proximity to the phytoremediation area. The possibility of other removal pathways was considered a factor in this finding. There are numerous pathways that could reduce the probability of uptake occurring, including natural biodegradation, soil sorption, mobility in the soil structure, and sorption to root surfaces without uptake occurring were all viewed as viable pathways

The possibility of microbial degradation aided by phytoremediation became an interesting hypothesis after the analysis of several soil cores for microbial populations capable of degrading BTEX. This led to an increased interest in microbial populations within the subsurface capable of degrading hydrocarbons and their role and interaction with poplar trees and the phytoremediation process. Biodegradation of BTEX compounds is a well established remediation technology in laboratory studies as well as in industry. Rhizosphere conditions are known to create an enhanced bioremediation atmosphere in some cases, where microbial populations around the root zone thrive due to exudates produced within the plants and released though the roots. What remains to be understood is how these processes interact with the diurnal process of groundwater fluctuation caused by transpiration. This study attempts to observe these interactions in an effort to better understand the relationship between phytoremediation and bioremediation of VOCs.

1.2. GOALS AND OBJECTIVES

The primary purpose of this research is to study the relationship between microbial degradation and plant uptake of volatile hydrocarbons, such as benzene, toluene, ethylbenzene and xylene. While these compounds are known to biodegrade and are capable of transport into plant tissue, any relationship between the two removal mechanisms remains largely unknown. The goal of this work is to better understand the interactions of these multiple biological processes within a phytoremediation effort.

The underlying hypothesis is: groundwater use by trees acts to concurrently provide significant amounts of atmospheric oxygen as well as biodegradable contaminants to soil microbial populations in the vadose zone, and particularly the rhizosphere. The availability of these is influenced by depth and the zone of influence of the diurnal fluctuations. Specific objectives include:

1. Construct laboratory reactors to mimic site conditions and isolate tree and water impacts on microbial populations within soil.
2. Determine possible VOC uptake by trees.
3. Measure VOC concentrations in soil and tree tissues to evaluate impacts on microbial growth.
4. Estimate oxygen input to soil microorganisms directly caused by water addition and fluctuations in the water table.
5. Determine and compare microbial populations with soil depth in planted reactors, unplanted reactors and field site soils.

Completion of the above objectives will allow for a better understanding of phytoremediation. The interactions between plant species and microbial populations are of increasing importance to the field of phytoremediation. The results may also lead to a better understating of the aerobic degradation of organic contaminants. The effect of groundwater fluctuations caused by phytoremediation may have a larger influence on microbial degradation than previously considered. The results of this study may have an impact on future decisions regarding the implementation of phytoremediation at field sites and may enhance the attractiveness of phytoremediation and bioremediation as a combined process for site clean-up. The potential benefits of this study could lead to faster and more efficient contaminant removal at a lower cost than current studies may suggest, as well as an increased cost benefit for phytoremediation when compared to other remediation strategies.

2. REVIEW OF LITERATURE

2.1. PHYTOREMEDIATION

Phytoremediation is the use of vegetation, including trees, grasses, and reeds, to remediate contaminated soil and groundwater in-situ. Remediation occurs through a variety of mechanisms including contaminant uptake and transformation, rhizodegradation, phytostabilization and hydraulic control, phytoextraction, rhizofiltration, and phytovolatilization (Schnoor, 2002). Phytoextraction involves contaminant uptake and accumulation with the plant biomass and applies mostly to inorganics (Pivets, 2001). Phytostabilization utilizes soil and plant roots to immobilize metal contaminants within the soil preventing movement into the atmosphere and groundwater (Pierzynski, 2002 and Schnoor, 2000). Rhizofiltration utilizes plant roots to adsorb and precipitate metals and radionucleids onto plant roots (Salt et al., 1997 and Dushenkov et al., 1997). The uptake and transformation of contaminants within the plant biomass is known as phytodegradation. Phytovolatilization is the release of contaminant into the atmosphere after uptake has occurred. Rhizodegradation refers to increased microbial biodegradation occurring near the plant root zone with microbial growth enhanced by root exudates. Phytodegradation, phytovolatilization and rhizodegradation are possible mechanisms for the removal and destruction of organic compounds and often act together as a combined process (Pivetz, 2001 and Schnoor, 2002).

Phytodegradation of organics has been studied for a variety of compounds. Uptake is dependent on the compound's affinity to water with moderately hydrophobic compounds (log K_{ow} = 1-3.5) best suited for uptake (Collins, 2002 and Schnoor, 2002). The use of hybrid poplar trees for contaminant uptake has been reported for numerous compounds including the herbicide atrazine (Burken and Schnoor, 1997) and trinitrotoluene (Thompson, 1998). The presence of trichloroethene (TCE) and TCE metabolites were found in poplar trees exposed to TCE contaminated groundwater (Newman et al., 1997 and 1999). Schnoor and Burken studied the uptake and translocation of numerous organic compounds, including BTEX and TCE, and developed an equation to relate the octanol-water partition coefficient (log K_{ow}) to chemical uptake (Burken and Schnoor, 1998). The same study reported high recovery rates of the studied compounds and indicated translocation and transpiration from the leaves to the atmosphere as the main pathway for volatile organic compounds (Burken and Schnoor, 1998). Future studies revealed that volatilization of volatile organic compounds (VOC's) will occur through both leaves and plant stems and that transpiration stream concentrations decrease with tree height (Ma and Burken, 2002 and 2003). Modeling of VOC volatilization from the transpiration stream to the atmosphere resulted in the determination of the diffusivities of multiply VOC's including TCE, benzene, toluene and *o*-xylene (Ma and Burken, 2004). The work performed by Ma and Burken has increased the viability of using phytoremediation to monitor contaminant plumes in groundwater, known as phyto-mapping. At the Aberdeen Proving Grounds, Maryland, tree core samples were used to successfully identify the borders and extent of contamination of the TCE plume (Burken, 2001a).

The use of phytoremediation to remediate hydrocarbons has been shown effective for a variety of plant species. Muratova et al. showed the ability of alfalfa and ditch reed to remediate hydrocarbon contaminated soils by plant stimulation of the microbial population (Muratova et al., 2003). A review by Frick et al. cited numerous studies which have proven the effective use of grasses and legumes to remediate petroleum hydrocarbons from contaminated soils (Frick et al., 1999). Willow trees have successfully been used to remediate ethanol-blended gasoline. Benzene and ethanol reductions of more than 99% were attributed to plant uptake and root adsorption (Corseuil and Moreno, 2001). The use of hybrid poplars to remove benzene from soils has been shown in laboratory conditions. In the study, benzene removal was attributed to the combined processes of uptake and volatilization and microbial degradation (Burken et al., 2001). The use of hybrid poplar trees in contaminated soil was seen to support BTEX degrader populations 5 times higher than in unplanted soils (Jordahl et al., 1997). At an industrial site in Wisconsin, hybrid poplars and willows were planted to remediate soil contaminated with a range of diesel fuel organics by stimulation of the soil microbial populations (Carman, 1998).

2.2. BIODEGRADATION OF BTEX

Aerobic biodegradation of BTEX is known to occur through two main pathways that lead to mineralization. The *tod* pathway requires a dioxygenase reaction with the aromatic ring. In the *tol* pathway, the methyl groups are attacked by monooxygenase (Mikesell, 1993). Benzene is mineralized only along the *tod* pathway, while ethylbenzene, toluene and the xylenes can be mineralized along either pathway. It has been noted that mineralization of toluene and xylene can lead to catechols and methylcatechols that will polymerize and become part of the soil humus. However, the resultant soil make-up was not found to be any more toxic than non-contaminated soils (Tsao et al., 1998).

There are a variety of microbial strains known to utilize BTEX as a carbon source in soils. Strains of *Pseudomonas* sp., *Alcaligenes* sp., *Rhodococcus* sp., *Microbacterium* sp., and *Arthrobacter* sp. have been separated and identified as capable of degrading hydrocarbon mixtures in field contaminated sites (Greene et al., 2000). The findings suggest that diverse microbial communities are present in contaminated soils that are capable of mineralizing the BTEX compounds. The same study found that different communities thrived in different contamination conditions. Furthermore, it has been revealed that in identical contamination conditions, the same microbial communities will develop, regardless of the soils contamination history (Shi et al., 1999 and Greene et al., 2000). Franzmann et al. reported the presence and ability of soil microorganisms to control hydrocarbon movement in the vadose zone and dissolved toluene, ethylbenzene and xylene movement in the groundwater at a BTEX contaminated site as long as gas transport was not impeded (Franzmann, 2002). Many other studies have been performed to separate and identify BTEX degrading bacteria (Shen, 1998, Shi, 1999, and Hubert, 1999). The use of fungi to degrade BTEX has also been studied. Prenafeta-Boldu et al. reported the degradation of toluene, ethylbenzene and xylene in contaminated soil by a fungal *Cladophialophora* sp. strain, however, degradation of benzene did require the presence of the indigenous microorganisms (Prenafeta-Boldu, 2004).

The rates of BTEX biodegradation are known to vary based on whether the compounds are present individually or as a mixture. In the case of gasoline spills, where the BTEX compounds are present as a mixture, ethylbenzene is degraded most rapidly, followed by toluene, benzene and xylenes (Deeb and Alvarez-Cohen, 1999). However, the use of natural attenuation is still a slow process that requires time and is most often used only at sites with little public importance.

Rhizodegradation refers to microbial degradation of contaminants on and around the root zone of plants. Coupled with phytoremediation, it can offer a more rapid remedial action than natural attenuation. Sugars, acids and alcohols present in root exudates help to stimulate microbial activity and increase population (Vancura and Hovadik, 1965). A review written by Kuiper et al., cites many studies which found that the use of plants and the associated rhizosphere can improve the chemical and physical properties of contaminated soils and increase contact between contaminants and the degrading microbial population (Kuiper et al., 2003). Studies have also shown microbial populations surrounding the root zone to be as high as 100 times greater than in bulk soil (Schnoor, 2002).

While a universal definition of the rhizosphere zone around the roots does not exist, it is generally considered to be the soil within a few millimeters radius of the root. Hojberg and Sorenson describe the rhizosphere as being within 5 mm of the roots (Hojberg and Sorenson, 1993). The same study found microbial respiration rates to be much higher in the rhizosphere than in surrounding bulk soils. It has also been suggested that plant roots may add oxygen to the soil as a root exudate (Frick et al., 1999). This is primarily thought to occur in wetland plants, which live in saturated conditions and have a higher capacity for oxygen transport to the roots.

A limited number of studies have successfully demonstrated the ability of rhizosphere microbes to successfully degrade the BTEX compounds and serve as an aid in the overall phytoremediation process. Jordahl et al. (1997) found significantly higher populations of denitrifiers, pseudomonads, and monoaromatic petroleum hydrocarbon (BTX) degraders in rhizosphere soils of hybrid poplar trees as compared to the bulk soil populations (Jordahl et al., 1997). Rhizodegradation of fuel and oil contamination has been studied at a much higher level (Muratova et al., 2003, Carman, 1998, Corseuil and Moreno, 2001). The use of phytoremediation to remediate these sites often focuses on the use of plants to enhance degrading microbial populations. Over one hundred strains of BTEX degrading bacteria have been isolated from the roots, stems and leaves of poplar.

The study found that within the diverse population a number of isolated bacteria were also capable of growing in the presence of TCE (Moore et al., 2006). The range of capabilities exhibited by rhizosphere microbial populations illustrates the potential of combining phytodegradation and rhizodegradation.

Overall, the use and implementation of phytoremediation has been successfully demonstrated over a variety of compounds, plants, soils and groundwater conditions. The knowledge base continues to expand as the various mechanisms of phytoremediation are studied more closely, making the overall process more acceptable as a remedial action. There does seem to be a lack of information regarding the phytoremediation of the BTEX compounds. Laboratory studies have shown uptake and volatilization but there seems to be little information on field site studies of uptake. Rhizodegradation seems to be accepted as the main pathway for BTEX destruction in phytoremediation efforts, however, there is a lack of documented field studies. The interactions of uptake, volatilization and rhizodegradation are almost completely un-documented.

2.3. GROUNDWATER IMPACTS OF PHYTOREMEDIATION

The use of phytoremediation for hydraulic control has been the purpose of a number of field implementations. Utilizing plants with high transpiration rates, it is possible to create a cone of depression in the groundwater and prevent contaminant transport. The planting of hybrid poplars, eastern cottonwoods and willows at a contaminated site in Orlando, Florida, resulted in the successful containment of the contaminated groundwater (Spriggs, 2003). Hong et al. demonstrated the ability of deep rooting trees to effectively contain groundwater contaminated with MTBE (Hong, 2001). The use of poplar trees at the Aberdeen Proving Grounds, Maryland, to contain TCE-contaminated groundwater resulted in transpiration rates of 45 to 80 L/day/tree. A cone of depression was seen to exist from May to November, effectively preventing movement of the contaminated groundwater. Daily water table fluctuations were observed at a peak of 7.6 cm. This diurnal fluctuation was seen throughout the growing season and occurred as the overall water table continued to fall (Schneider, 2002). Figure 2.1 shows the effects of transpiration by the poplar trees on the groundwater table at the site. The fall of the groundwater table over the growing season is clearly indicated. Also, the diurnal fluctuations can be seen on a daily basis (Schneider, 2000).

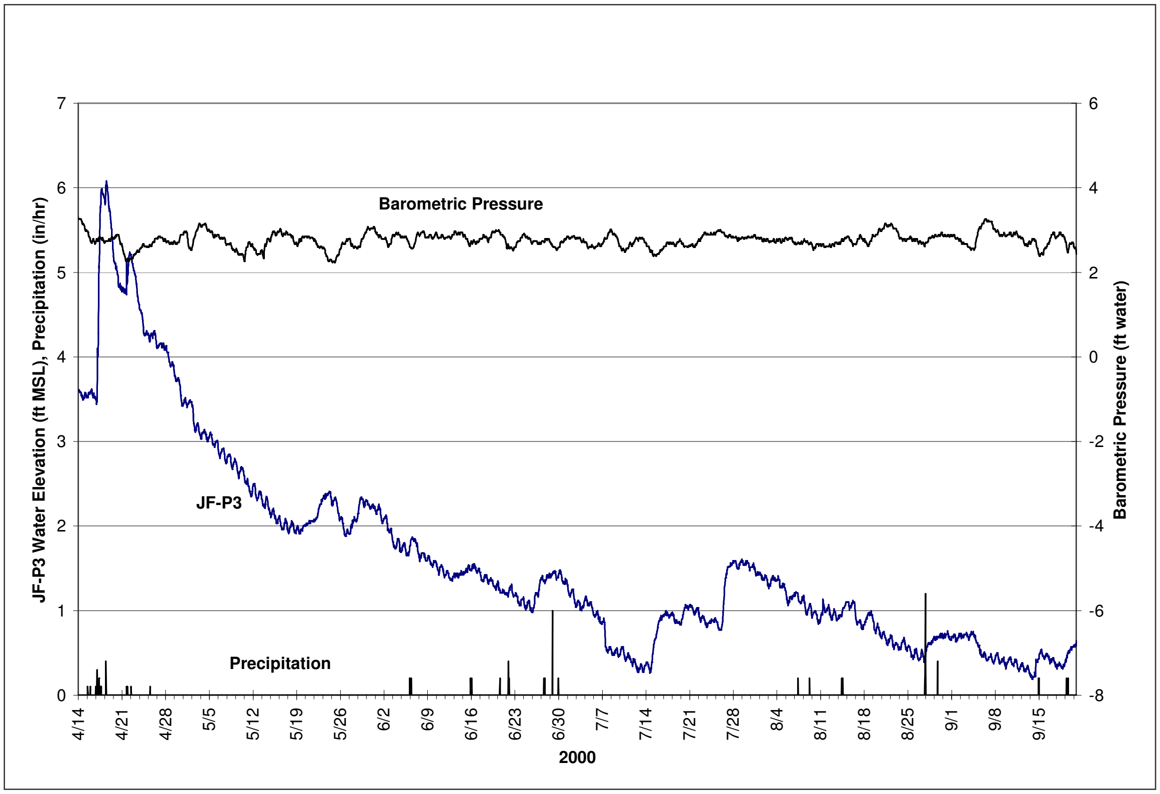

Figure 2.1. Water table draw-down and diurnal fluctuations caused by poplar tree transpiration at the phytoremediation site at Aberdeen Proving Grounds, Maryland (Adopted from Schneider, 2000).

3. MATERIALS AND METHODS

3.1. REACTOR SET-UP

3.1.1. Soil Characteristics. Soil for the experiment was obtained from the phytoremediation area within Berm 156. The soil was a mixture of the natural soil present throughout the site and a top soil that was placed during planting of the phytoremediation plot. Two soil cores were taken using a Shelby tube sampler 7.6 cm in diameter during removal of the bulk soil for analysis of soil properties. The core sleeves were capped and the cores were placed on ice for transport to UMR. A sample of the soil was also sent to the soil testing lab at the University of Missouri – Columbia for agronomic analysis. The results are listed in Table 3.1 and Table 3.2. After removal from the site, the soil was allowed to air dry before being mixed and crushed. Any stones larger than ¼ inches were removed. The total dry soil was weighed at approximately 112 kg and divided into 5 groups of 20.4 kg for use in the reactors.

Table 3.1. Soil properties.

Sample	Visual Observations	Water Content (%)	Water Content at Saturation (%)	Void Ratio (e)	Porosity (n)
SC-SC-1	silty	29	45.36	1.36	0.58
SC-SC-2	clayey	24.2	32.55	0.83	0.45

Table 3.2 Agronomic properties.

						Particle Size Analysis		
pH	Phosphorus (lbs/a)	Potassium (lbs/a)	Calcium (lbs/a)	Magnesium (lbs/a)	Organic Matter (%)	% Clay	% Silt	% Sand
5.9	29.0	367.0	7249.0	704.0	3.8	22.5	55.0	22.5

3.1.2. Reactor Conditions and Arrangement. Five reactors were constructed to approximate different field conditions as listed in Table 3.3. Each reactor was constructed in a glass fish aquarium approximately 20 cm (8 in.) wide, 38 cm (15 in.) long, and 26 cm (10 in.) deep with a total volume of 20.6 Liters. The aquariums, as well as all other reactor components, were disinfected with ethanol and water before construction. Each reactor was loosely packed with 2.5 cm (1 in.) of sand with soil placed above. Each reactor contained 20.4 kg of soil with an average soil depth of 19 cm (7.5 in.).

Table 3.3. Reactors arrangement.

Reactor #	Reactor ID	Reactor Description	Poplar Trees	Sterile Soil	Contaminated Water
1	PC	Planted Contaminated	Yes	No	Yes
2	UC	Unplanted Contaminated	No	No	Yes
3	PUC	Planted Uncontaminated	Yes	No	No
4	PSC	Planted Sterile Contaminated	Yes	Yes	Yes
5	USC	Unplanted Sterile Contaminated	No	Yes	Yes

Sterile soil was conditioned by autoclaving three times, for a total of 2.25 hours. For Reactor 4, poplar trees were disinfected, prior to planting, by soaking in a 5% bleach solution for 5 minutes; however, this was later changed to wiping the trees with a paper towel wetted with a 5% bleach solution in an effort to increase survival rates in Reactor 4.

Sixteen poplar cuttings (*Populus Deltoides x Nigra* Clone #34, DN34) were planted in each planted reactor (1,3, and 4). Prior to planting, cuttings were allowed to begin rooting hydroponically, at the initial sign of rooting the cuttings were then planted to a depth of 15 cm. The cuttings were planted in four rows of four trees with each row being assigned a letter (A,B,C,D) and each tree given a number (1,2,3,4), as illustrated in Figure 3.1. The cuttings averaged 39 cm in length with an average mass of 23.3 grams.

A 30.5 cm glass tube, 10 mm in diameter, was positioned in the center of each reactor and extended to the bottom of the aquarium to serve as a feed pipe. Glass wool was placed in the bottom of the tube to prevent clogging. Water for each reactor was

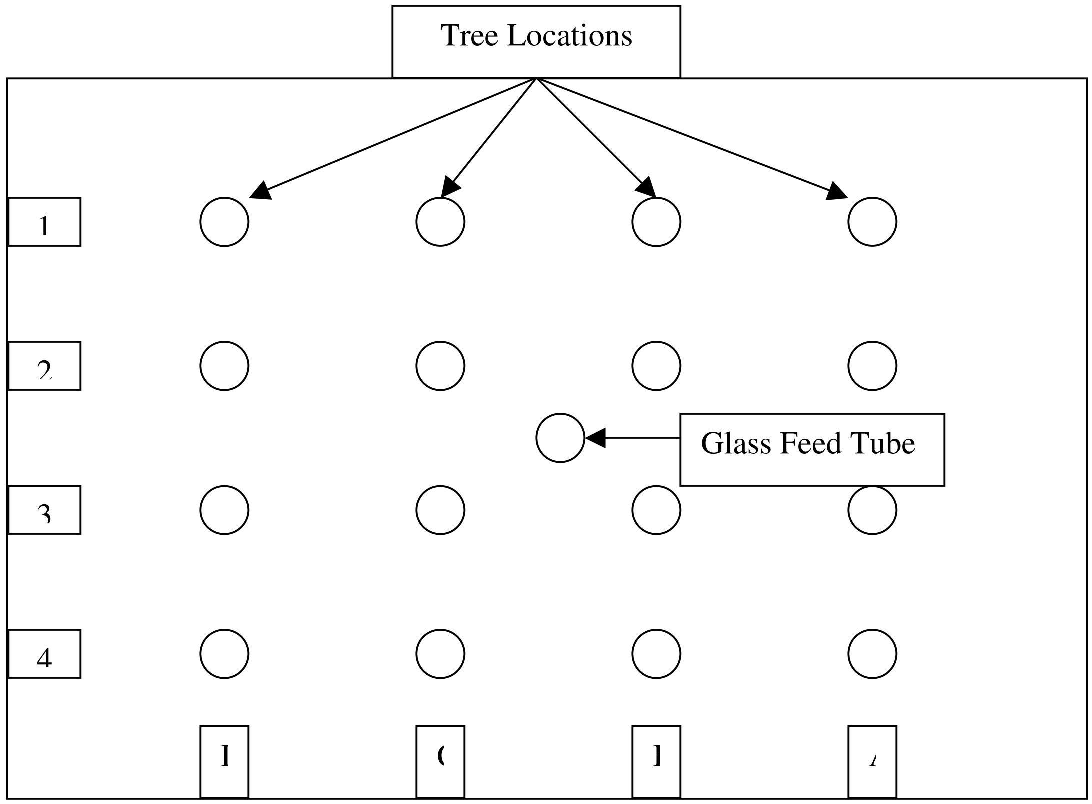

Figure 3.1. Tree locations in Reactors 1, 3, and 4. (Not to Scale).

gravity fed through the tube and introduced into the bottom of the reactor. Each reactor was fitted with a galvanized sheet metal cover to reduce direct evaporation of soil water or contaminants into the greenhouse. The cover was not sealed to allow air flow into reactor. Each cover had two hatches that allowed access to the top soil. Holes were cut to into the cover to allow the poplars to pass through. Reactors 2 and 5 contained no such holes. Figure 3.2 illustrates the construction and set-up of the reactors.

After the initial watering period, Reactor 2 developed a crack in the aquarium glass. The crack was caulked and the reactor was wrapped with duct tape in an effort to seal the crack. The reactor remained water tight for approximately 30 days when leaking was noticed. Numerous attempts to reseal the reactor failed so the reactor was rebuilt. The glass of the original reactor was removed and the wet soil was removed in layers. The soil was removed wet to maintain the original soil profile as best as possible. The layers were then placed into a new aquarium. By replacing the soil wet and in layers, it

Figure 3.2 Picture of Reactor 1 after construction and planting were complete. Note the one liter Erlenmeyer flask attached to the centered glass feed tube by Teflon lined tubing for water addition.

was not possible to regain the same level of soil compaction that was obtained by placing dry soil into the original aquarium. Air gaps were noticeable in places and an increase in porosity was expected. The importance of maintaining the existing soil profile was seen as more important than maintaining compaction. The reactor experiment time was reset to correspond with the rebuilding as the amount of water lost through the crack was unknown.

3.2. REACTOR WATERING

The use of tap water instead of de-ionized water was chosen for the reactors due to the micro-nutrients and minerals present in tap water. The nutrients and minerals, absent in de-ionized water, are necessary for proper growth of trees and microbial populations. Furthermore, in an effort to mimic site conditions, tap water was a better representation of groundwater. De-ionized water may also cause a leaching of ions from the soil which would alter the soil conditions unfavorably. Tap water was filter-sterilized using a 0.45 µM filter to prevent contamination of the reactors with unwanted microbial populations. The filtered water was then deemed suitable for use and either fed to Reactor 3 or further spiked with BTEX for use in the other reactors.

Spiked water was created by creating a saturated solution of each compound (benzene, toluene, ethylbenzene and xylene) and diluting with filter sterilized tap water. Concentrations of the compounds were chosen to mimic site conditions. Final concentrations in the contaminated feed water were 4.4 mg/L benzene, 1.3 mg/L toluene, 0.4 mg/L ethylbenzene and 0.4 mg/L total xylene.

Water levels in the reactors were monitored and recorded daily. A wooden dowel was placed into the glass feed tube of each reactor and a mark was placed on the dowel at the end of the tube, creating a benchmark. By placing the dowel into the feed tube when the reactor was holding water, a water mark was left that could then be measured against the benchmark in order to determine the potentiometric water level.

3.3. REACTOR SAMPLING

3.3.1. Soil Sampling During Experiment. Soil cores were taken at three times throughout the experiment, with the intent to plate these samples to enumerate BTEX degrading microorganisms. Soil samples were taken to represent the soil conditions at three times:

1) Prior to planting

2) 60 days after planting
3) 120 days after planting

The initial samples prior to planting were collected as random samples from the bulk soil and the sterilized soil. The 60 day and 120 day samples were taken from each reactor. Figure 3.3 shows the location of the 120 day sample in Reactor 3 between columns A and B and rows 2 and 3. The 60 day sample was taken on the opposite side of the feed tube between columns C and D and rows 2 and 3. Continuous vertical cores were collected using a hollow steel pipe with an inner diameter of 1.1 cm. The cores were then extruded with a solid bar. Cores were collected, wrapped in aluminum foil and placed in a freezer until final analysis.

3.3.2. Diffusion Sampling During Experiment. In order to determine if contaminant uptake was occurring during the experiment, select trees were fitted with diffusion collars developed at UMR by Ma and Burken (2003). A hollow glass tube, 7.6 cm long with an inner diameter of 2.7 cm, was fitted around the tree trunk. A Teflon cap, with the center cut out to fit around the trunk, was placed on the ends of the tube and sealed with Teflon tape. The trunk was wrapped with Teflon tape at the point of contact with each cap. Parafilm was then used on both ends to seal the collar. A thermal desorption (TD) tube packed with Tenax was connected to a syringe needle which penetrated the bottom cap of the collar. A needle connected to a syringe packed with activated carbon was placed through the top cap, allowing filtered air into the collar. Tubing was used to connect the opposite end of the TD tube to a vacuum pump. Air was then drawn thru the collar, at a rate of 5mL/min., and through the tube, thus sampling for volatilized contaminant diffusion released from the trees. Two sampling events occurred on day 86 and day 134. Figure 3.4, below, illustrates the sampling set-up.

3.3.3. Final Sampling. Final sampling of the reactors consisted of multiple steps. Trees were cut at the soil surface, dissected into new leaf growth, stem growth and trunk and weights were recorded for each tissue. Portions of each tissue were placed into 22 mL glass vials, sealed and analyzed via GC/FID for headspace concentrations using previously published methods (Ma and Burken, 2003).

Two sides of the aquarium glass were broken away and 2 cm of soil were removed and discarded from the exposed sides and the surface. This was done so that soil

Figure 3.3. The location of the soil core taken on day 120 in Reactor 3.

samples taken would not be adversely affected by side wall effects. Soil samples were then taken for microbial enumeration. In the unplanted reactors, bulk soil samples were collected and their location was recorded. All soil samples for enumeration studies were collected using sterilized spatulas and tweezers and were placed 1.5mL micro-centrifuge tubes and stored at 4°C. Location was determined by creating a 3 dimensional grid of the reactor soil with the bottom corner near tree D-4 being labeled 0, 0, 0 in an x,y,z-

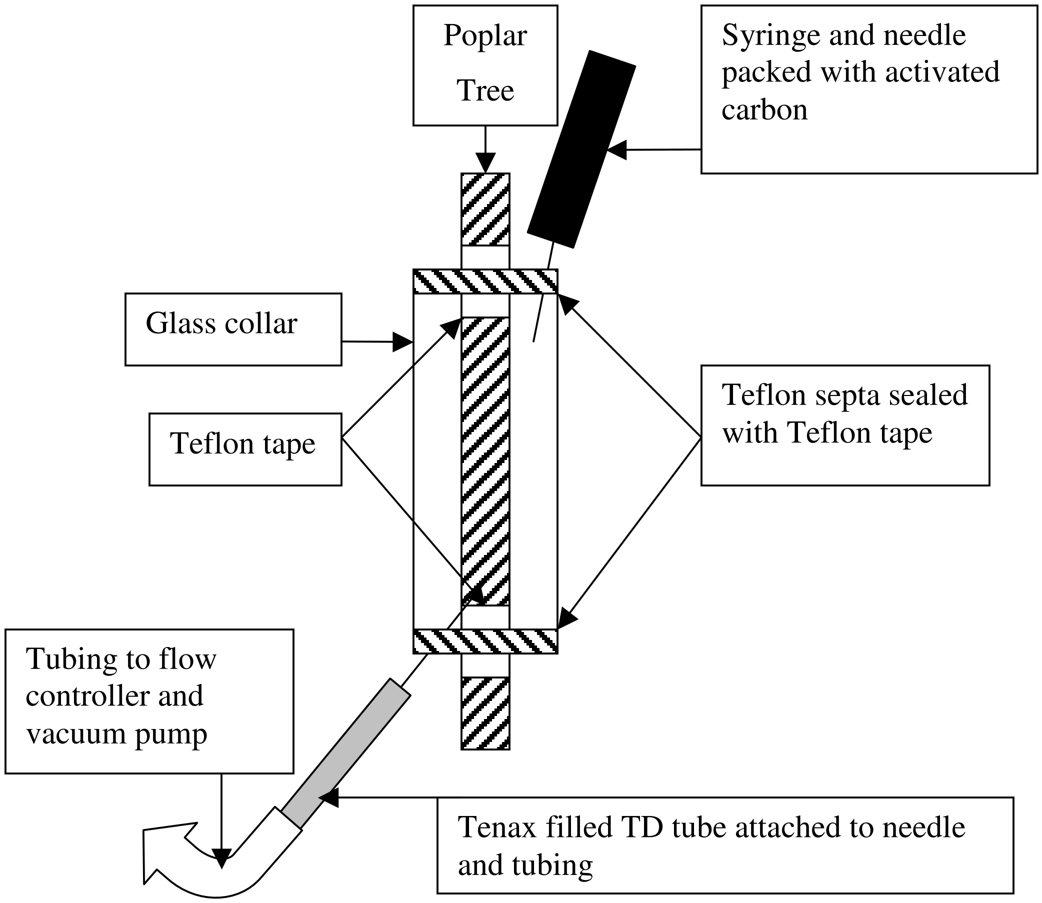

Figure 3.4. Schematic of diffusion collar, adopted from Ma and Burken (2003).

coordinate system. Location was measured in centimeters using a ruler. Soil samples were collected followed by the removal of 2 – 4 cm of soil and another round of sample collection. Sampling continued in this manner to the bottom of the soil. The sand layer was not sampled. For the planted reactors, positioned-bulk samples were collected as described above, with a coordinate system for each reactor. Figure 3.5 illustrates how each layer was measured and removed.

Rhizosphere and section-bulk samples were collected from each 2 – 4 cm section of soil removed before discarding the soil. Roots were separated from the soil using tweezers and shaken vigorously to remove bulk soil. Any soil adhering to the root was

Figure 3.5. An example of the reactor sampling. The measurement of each soil layer is done using a ruler before removal using sterilized spatulas. The dowels mark the location of the soil cores taken throughout the experiment.

considered rhizosphere soil. Rhizosphere soil was typically seen as being less than 1 mm thick soil adhering to the roots. Rhizosphere soil was removed from the roots using a sterile brush. Section-bulk samples were collected by separating loose soil from roots. Samples were collected in each section of soil until the sand layer was reached.

Throughout sampling of all reactors, random soil samples were collected for headspace analysis and moisture content analysis. For headspace samples, approximately 5 g of soil were placed in a 22mL glass vial and sealed. Moisture content samples were placed in a pre-weighed, labeled weigh boat and placed in an oven at 150^{o}C until the weight was stable. Dry weight was then recorded and used to determine the moisture content.

3.4. SITE SAMPLING

Two sampling events occurred at the contaminated former refinery site in the summer and fall of 2004, with subsequent sampling trips in the summers of 2005 and 2006. The first event, on July 13th, 2004, allowed for preliminary sampling and consisted

Figure 3.6. Example of rhizosphere sampling. After removing loose bulk soil by vigorous shaking, the adhering rhizosphere soil is removed from the root. The process was repeated on multiple roots for each sample collected.

of taking tree core samples from five native trees located near the berm. Poplar trees, planted for the phytoremediation effort, were not sampled as they had yet to reach a maturity level where core sampling will not affect their health.

Tree core sampling consists of using a standard increment borer to remove a small core of the trees, approximately two to three inches long and 0.2 inch in diameter. The tree core is then placed in a 20 mL glass vial, sealed with a Teflon cap and aluminum seal, and placed on ice in a cooler for shipment to UMR. Bright tape was used to mark the trees and GPS equipment was used to record location. All samples were obtained and transported to UMR by UMR personnel. Methods used for tree core analysis had previously been developed at UMR (Ma and Burken, 2002). The cores were allowed to equilibrate to room temperature for 24 – 36 hours before being analyzed using the GC/FID method previously described.

The second sampling event occurred on October 22, 2004. Cores were obtained from 24 native trees along the path of the plume extending south from Berm 156. In addition to coring, five poplar trees, located in Berm 156, were fitted with air diffusion sampling devices to determine if contaminants are being translocated in the poplar trees. Soil cores were also taken from the poplar plot located within Berm 156 to investigate the possibility of BTEX degraders present in the vadose zone.

Soil cores were obtained using a hammer-driven, split spoon sampler, five centimeters in diameter. Four 15 cm cores were taken to achieve a total core depth of 61 cm. Observations during coring revealed that groundwater was present before obtaining the final 15 cm of soil. Core sleeves were capped, labeled and put on ice for transport to UMR facilities. Cores were allowed to equilibrate to room temperature for 24 to 36 hours before being analyzed for microbial growth as previously described.

Air sampling consists of fitting a tree with a PVC collar, lined with Tedlar sheeting. A small strip of foam padding is placed between the tree and the bag on both ends of the collar. The Tedlar is then held tight against the foam pads using locking nylon cinch straps. A small Teflon tube is placed through the top foam pad and attached to a thermal desorber (TD) tube and small air pump. Another small Teflon tube is placed through the bottom foam pad for air circulation. As air is drawn through the TD tube by the pump, compounds are retained on the Tenax packing material within the tube. After sampling is complete, the TD tubes are capped to prevent contamination during transport to UMR. Analysis is performed using the TD/GC method described previously. The pumps were allowed to run for a total of 286 minutes (4.8 hours).

On April 11 of 2005, another sampling event occurred. Cores were obtained from 10 native trees within and near Berm 156. Six soil cores were obtained from within Berm 156 to further investigate the abundance of BTEX degrading microbes throughout the area. Two to three cores were taken at each sampling location to achieve total core depths ranging from 14 to 34 inches. Depths ranged due to variations in soil saturation levels at individual locations, as did indications of groundwater. Rain prevented the use of air diffusion collars.

A fourth sampling event occurred on June 30, 2005. The primary purpose of this trip was to obtain more bulk soil necessary for the reactors. Two soil cores from within the poplar plot were collected in Shelby tubes to investigate soil properties. These properties were listed in Table 3.1. Heavy thunderstorms hampered sampling efforts and once again prevented sampling with air diffusion collars.

The final sampling trip occurred on August 29, 2006. Seven trees cores were taken from trees within the phytoremediation plot as described above. Two continuous 10 inch soil cores were taken; one from within the phytoremediation area and the other from the berm slope in order to investigate microbial populations with depth from the different areas. The cores were taken using an open-faced hand sampler with an inner diameter of 2 cm. Cores were removed from the sampler, wrapped securely in foil and placed on ice for transport to UMR for degrader analysis. Bulk and rhizosphere soil samples were also taken from within the phytoremediation plot. The soil was taken from a number of locations within the plot in order to obtain a representative sample of the area. After removal of the top soil, the soil samples were taken from exposed soil. Three bulk and three rhizosphere samples were taken from three locations at a depth of approximately 15 centimeters. Four samples for bulk and rhizosphere each were taken from two other locations at a depth range of 0 to 15 cm, for the first two samples, and 16 to 30cm for the final two samples. Rhizosphere soil was obtained by vigorously shaking exposed roots; soil adhering to the roots was termed rhizosphere soil and was brushed off of the root into a sterile plastic vial, before being placed on ice. Bulk soil was that soil separate from the roots, which was also placed in a sterile plastic vial and placed on ice. Samples were returned to UMR and analyzed for BTEX degraders.

3.5. MICROBIAL ENUMERATION

Soil samples collected from the reactors and the refinery site were analyzed to enumerate BTEX degrading microorganisms. The procedure used was adapted from Bakken (1985) and Hubert et al. (1999). Approximately 1 gram of sample was weighed and mixed with 10 ml of de-ionized water, vortexed for 15 minutes and then centrifuged in a 50 mL centrifuge tube at 10,000*G for 20 minutes to separate the bacteria from the soil. Using a sterile pipette, 100 µL of the supernatant was then added to 50mm plates containing a minimal salts media, MM30, with no carbon source. The media consisted of the following: 6 g/L $NaHPO_4$, 3 g/L K_2HPO_4, 1 g/L $NaNO_3$, 0.005 g/L $CaCO_3$, 0.05 g/L $MgSO_4$, 0.05 g/L $MnSO_4$, 0.025 g/L $FeSO_4$, 15g/L Agar, and 10 mL/L Cyclohexamide (Sylvestre, 1980). The plates were placed in a desiccator containing a 1% solution (by volume) of vacuum pump oil (vpo) and BTEX. Vacuum pump oil was used in order to control the vaporization rate and concentration of vapor-phase BTEX inside the desiccator. The desiccator was then placed in an incubator at 35^0C for 14 days. A headspace analysis was performed after 7 days to determine the vapor-phase concentrations. Benzene, toluene, ethyl benzene and xylene concentrations were found to be 4.0 mg/L, 1.1 mg/L, 2.1 mg/L, and 2.7 mg/L, respectively. After 14 days, the plates were removed, and a colony count was performed. Colony forming units (CFU) are reported as CFU per gram of soil sample and were calculated using the following equation:

$$\frac{CFU}{g\ soil} = \frac{\left(\frac{CFU_i}{Sample\ Volume\ Plated\,(mL)}\right) \times Total\ Sample\ Volume\ (mL)}{Soil\ Sample\ Mass\ (g)} \qquad (1)$$

Plates with a CFU_i greater than 200 were deemed as too many to count (TMC) and were diluted before repeating the enumeration procedure.

3.6. GAS CHROMATOGRAPHY

3.6.1. Thermal Desorption. Thermal desorption tubes were analyzed using a Markes International Limited Ultra TD and Unity TD and an Agilent 6890N Network GC System. Tube desorption was set at 10 minutes at 250°C. The flow rate through the thermal desorber was a split flow, set at 50 ml/min at a temperature of 120°C. The gas chromatography system used 0.25 micron, 30m x 0.32mm, HP-5 column, with a flame ionization detector (FID) detector. Inlet temperature was set at 150°C and oven temperature was set to 40°C with a column flow rate of 3.2 ml/min. The detector temperature was set at 200°C.

Five standards were prepared to generate standard curves. An aqueous solution of known concentration was transferred to a 40 mL glass vial, capped and allowed to equilibrate. A TD tube was attached to Teflon tubing with a needle at the opposite end of the tubing. The needle was inserted through the cap of the 40 mL vial and the opposite end of the TD tube was attached to a vacuum. By drawing a vacuum of 0.1 L/min through the tubing and TD tube, a known mass of contaminant was then loaded onto the

TD tube. This was repeated to generate five standard samples for each contaminant. Standard curves were obtained before sample analysis and used to relate peak area to total contaminant mass captured in the TD tubes and were accepted if the R^2 was greater than 0.98. Mass per unit time was then calculated to determine contaminant diffusion over the sampling period.

3.6.2. Headspace Analysis. All tree and soil samples were allowed to equilibrate to room temperature for 24 hours before analysis. Samples were analyzed using a Tekmar 7000 Headspace autosampler and a Hewlett Packard 5890 Series II gas chromatograph (GC) using a 3 micron J & W Scientific DB-1 column (15m x 0.53mm) with an FID. The autosampler used a platen temperature of 40°C with an sample equilibration time of 60 minutes. The line temperature and sample loop temperature were both 40°C. The GC oven temperature was set at 40°C. Inlet temperature was set at 250°C and the detector temperature was set at 250°C.

Peak areas obtained from the GC analysis were used to determine headspace concentrations relative to vapor phase concentrations in known standards. Linear, 5-point standard curves were generated before analysis and were accepted if the R^2 was greater than 0.98.

4. RESULTS AND DISCUSSION

4.1. FIELD STUDIES

4.1.1. Tree Core Results. A total of 50 tree cores were taken at the former refinery site. Cores were taken from native trees and non-native trees planted for the phytoremediation effort. The same native trees were sampled at every sampling event. The trees were based on their size, their proximity to the phytoremediation area and their elevation relative to the phytoremediation area and the surrounding berms. Most of the native trees were located on top of the berm or along the berm slope. Non-native trees within the phytoremediation area were chosen for sampling based on their size and their location within the phytoremediation area. Headspace analysis of the cores resulted in no positive detections of the contaminants present in the soil. The tree core samples are listed in Appendix D.

4.1.2. Tree Diffusion Results. Diffusion sampling of trees in the phytoremediation plot resulted in detection of low masses of benzene, toluene and xylene. Ethylbenzene was not detected in any sample. The results are listed in Table 4.1 below.

Table 4.1. Contaminant concentration results for diffusion sampling.

Sample	Sample ID	Benzene Conc. (µg/day)	Toluene Conc. (µg/day)	Ethylbenzene Conc. (µg/day)	Xylene Conc. (µg/day)
Tree 1	33851	0.00	4.21	0.00	0.00
Tree 2	39944	30.40	25.69	0.00	3.68
Tree 3	38878	0.00	4.99	0.00	3.94
Tree 4	38737	0.00	6.82	0.00	4.09
Tree 5	39506	0.00	3.54	0.00	3.55
Blank	39506	0.00	0.00	0.00	0.00

The low detections indicate the presence of BTEX in the non-native trees planted for the purpose of phytoremediation and may explain the lack of detection in tree cores. Diffusion sampling is capable of detecting lower masses of contaminant than headspace analysis. However, the low detections do not account for the mass of contaminant known to have been released into the subsurface area. Groundwater sampling in 2004 revealed concentrations of 15,000 µg/L benzene, 4,900 µg/L toluene, 22,000 µg/L ethylbenzene and 22,000 µg/L total xylenes. The low detection led to the investigation of possible BTEX degraders in the soil. An abundant population of BTEX degrading microorganisms intercepting the BTEX prior to uptake in the tree roots would explain the low concentration seen in the diffusion sampling and the lack of detection in the tree cores.

4.1.3. BTEX Degraders in Site Soils. The initial sample taken to investigate the presence of BTEX degraders in the soil presented clear evidence of their presence. The results can be seen in Figure 4.1 below. During sampling, groundwater was encountered at 46 cm below the surface. The results indicate an increase in degrader population between the ground surface and groundwater at 25 – 40 cm below the surface.

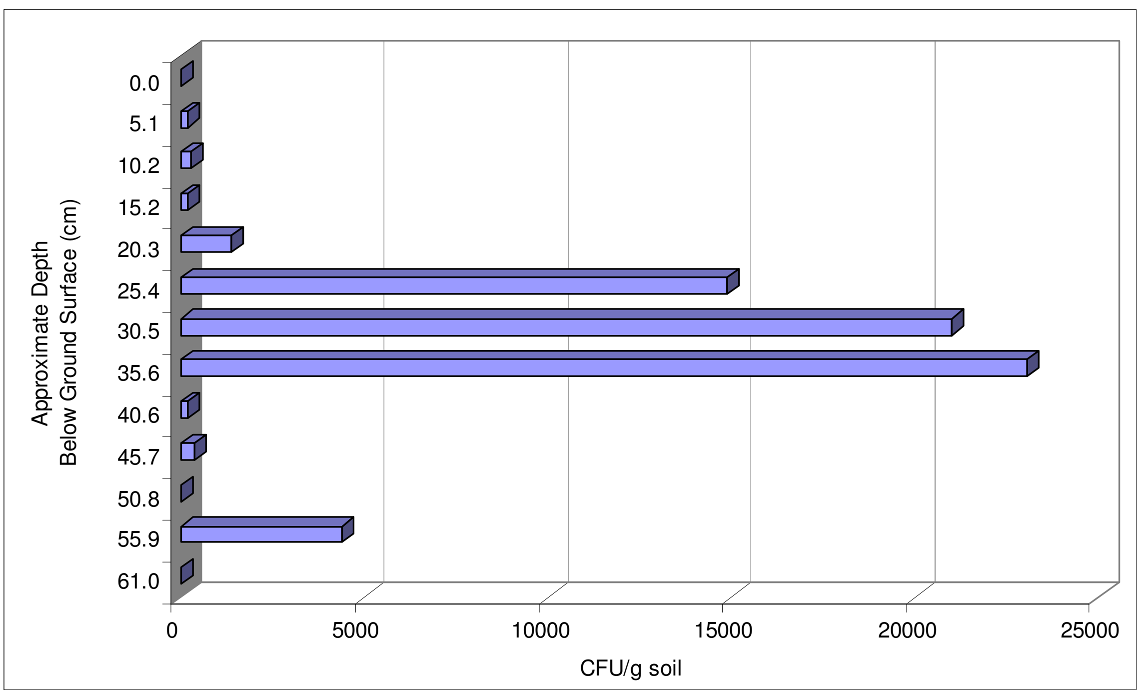

Figure 4.1. BTEX degrader enumeration results for initial site sample.

The spike seen in population may represent the depth of optimal growth where oxygen levels and contaminant levels will support growth of the microbial community. It is the optimal mix of oxygen and BTEX that allow the microbial population to thrive and continue to degrade the contaminants. This depth would be specific to each sample taken would vary with groundwater depth and soil characteristics. Shallower depths likely do not allow for contact with the contaminant while greater depths likely lack sufficient oxygen levels.

Samples taken during the final sampling trip reveal a significant difference in microbial populations between bulk and rhizosphere soils. Figure 4.2 illustrates enumeration results for the soil cores taken within the phytoremediation area and along the berm slope. The spike in microbial numbers, at a depth of 10 cm, is similar in both samples and to the spike seen in Figure 4.1. Soil from the phytoremediation area showed a significant difference in microbial numbers over the berm soil except in the first few centimeters of depth. Indications of groundwater were not evident during the sampling.

Figure 4.3 shows the enumeration results for bulk and rhizosphere samples taken within the phytoremediation plot. The results are the average for at least two samples taken at each depth at different location within the plot. A significant difference can be seen between the rhizosphere and bulk samples. The increased population seen in the rhizosphere samples is expected. A spike in microbial population is seen in the rhizosphere samples at a depth of 15 cm. It should also be noted that the bulk samples from the phytoremediation plot hold higher microbial populations than the bulk sample taken from the berm, approximately 15 feet away from the phytoremediation plot. The 15-cm berm soil core sample from Figure 4.2 contained 6.4×10^2 CFU/g of soil, while the 15-cm bulk soil sample from the phytoremediation plot contained 3.8×10^3 CFU/g of soil. This shows that even bulk soils within a planted area and not in direct contact with roots can be impacted, likely by oxygen and groundwater.

4.2. REACTOR STUDIES TREE GROWTH AND WATER USAGE

The trees in each reactor were monitored and visually inspected on a daily basis for health and growth. Dead trees were replaced during two replanting events in an attempt to maintain survival. Reactor 1 and 3 maintained adequate survival, similar or

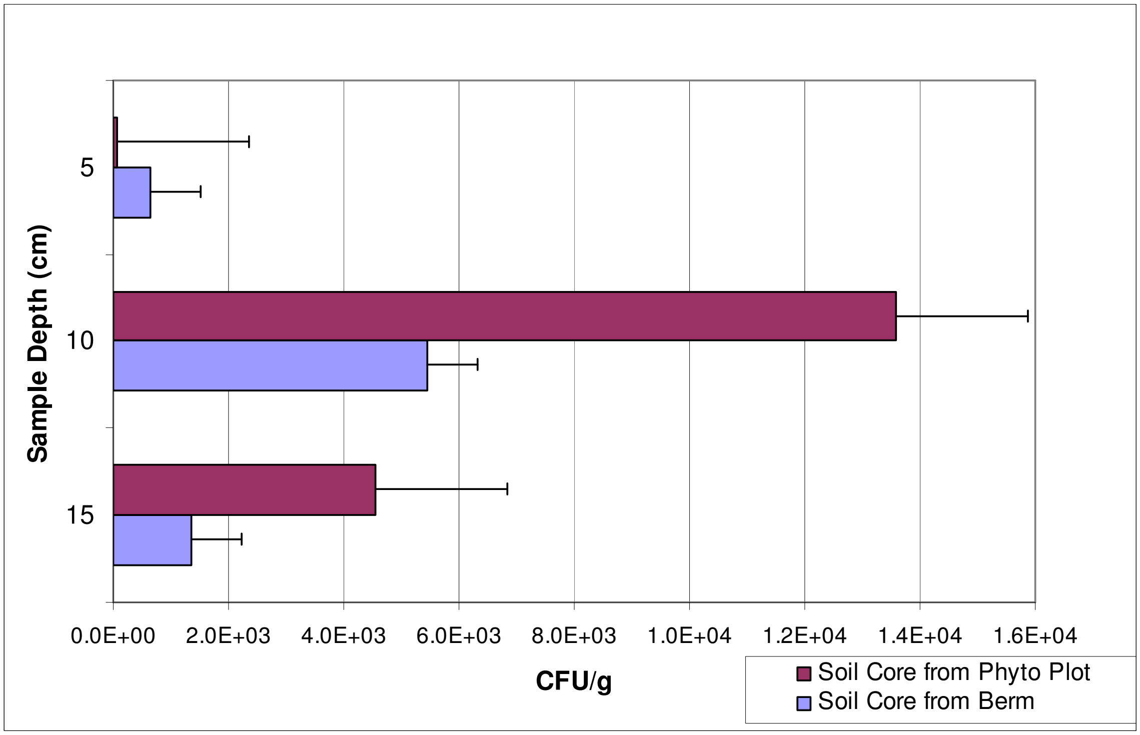

Figure 4.2. Enumeration results from two bulk soil cores taken August 29, 2006 at the former refinery site. One core was taken from within the phytoremediation plot while the other was taken along the berm slope away from any trees. Standard error bars are shown.

better to what is expected in field conditions. Survival was low in Reactor 4 where none of the trees survived after the initial planting, likely due to the aggressive disinfection methods described in Section 3.1.2. Table 4.2 lists the number of trees replanted and the survival rates for each reactor.

In an effort to increase survival in Reactor 4, trees replanted during the second event were wiped with a 5% bleach solution as opposed to being soaked. While this allowed for a slight increase in survival, it did not fully explain the lack of survival. The change in soil characteristics, brought about by autoclaving the soil, is believed to have been the main factor for lack of tree survival. The chemical properties of the autoclaved soil are not known, however, visual inspection of the soil revealed a much darker, almost black, soil that seemed to compact much tighter.

During final sampling, both Reactors 4 and 5 gave off a distinct anaerobic odor as sampling depth and revealed a grey-colored soil. The physical properties of Reactor 4,

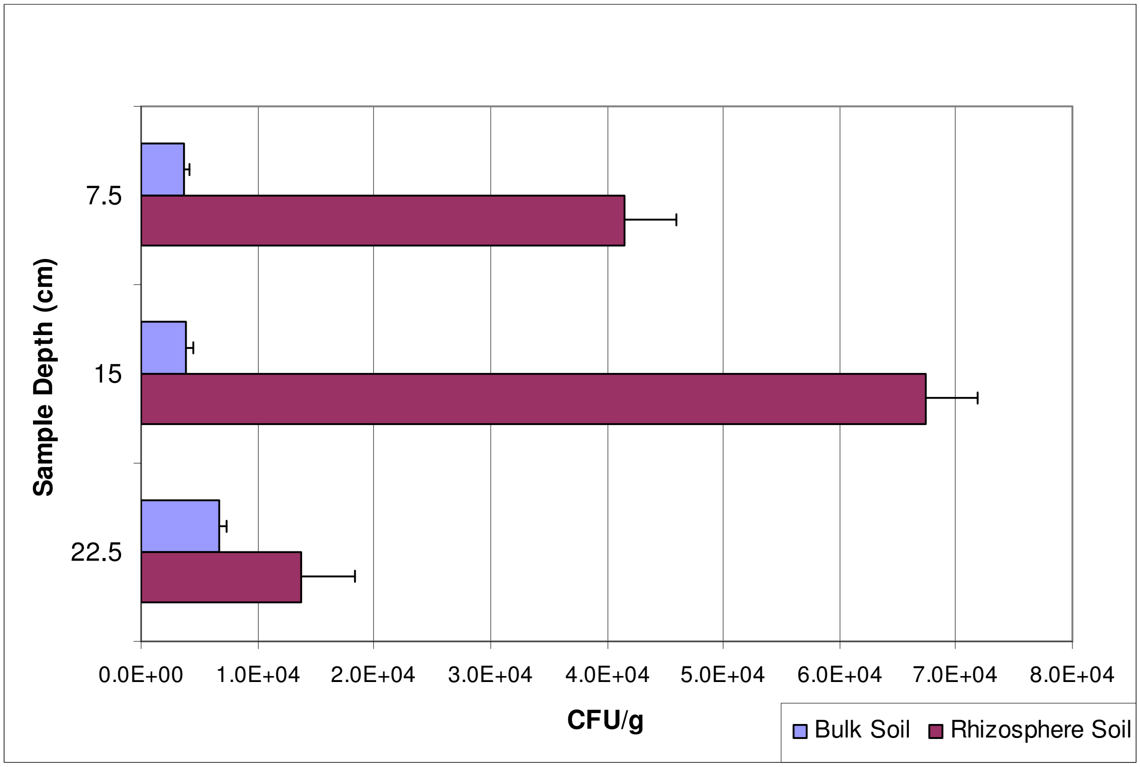

Figure 4.3. Enumeration results for soil samples taken within the phytoremediation plot at different depths. Standard error bars are shown.

Table 4.2. Tree survival data in Reactors 1, 3, & 4.

Reactor	Number of Trees Planted			Total Trees Planted	Trees Alive at Experiment Conclusion	Survival Rate (%)
	Initial Planting	First Replant	Second Replant			
1	16	8	3	27	16	59%
3	16	10	3	29	13	45%
4	16	16	12	44	5	11%

listed in Table 4.3 with those of the other reactors, do not reveal any significant difference from the other planted reactors. However, the comparatively lower porosity and void ratio of Reactor 5 suggest that the soil was much more compact than Reactor 1 & 3, which had dense root structures throughout each reactor. Furthermore, plants are known to increase soil tilth and improve porosity (Angers, 1998). The high porosity and void ratio in Reactor 2 is attributed to the rebuilding required after the reactor glass broke.

Table 4.3. Physical properties of reactor soils at experiment conclusion.

Reactor	Dry Density (g/cm^3)	Moisture Content	Porosity	Void Ratio
1	1.89	0.40	0.29	0.40
2	2.11	0.45	0.33	0.49
3	1.76	0.43	0.26	0.34
4	1.93	0.39	0.28	0.38
5	1.77	0.40	0.19	0.23

Reactors 1 and 3, both having higher survival rates, required water on a daily basis. Reactor 4 was watered every 1 to 3 days, while Reactors 2 and 5 were water very infrequently, some times going as long as 5 days before being watered. The total measured water usage in each reactor was used to determine that reactor's evapotranspiration rate. Figure 4.4, below illustrates each reactor's water demand and the significant difference between the reactors with high survival rates, 1 and 3, and those with little survival or no trees, Reactors 5, 2 and 4. Note that Reactor 1, which was fed with contaminated water, had the highest survival rate as well as the highest water consumption.

The higher transpiration rate seen in Reactor 1 resulted in a greater contaminant mass delivered relative to the other spiked reactors. The amount of BTEX delivered to Reactor 1 was more than 10 times the mass delivered to the unplanted reactors. Reactor 3, fed with uncontaminated water, displayed a similar evapotranspiration rate to Reactor 1. Evapotranspiration rates and the mass of BTEX delivered to each reactor are listed in Table 4.4.

The high evapotranspiration rate seen in Reactors 1 and 3 created a fluctuating water table of approximately 9 inches that changed hourly, often dropping from the soil surface to the soil bottom over the course of a few hours. The flux was desired in order to bring soil microbes in contact with the BTEX compounds as water levels rose. As the

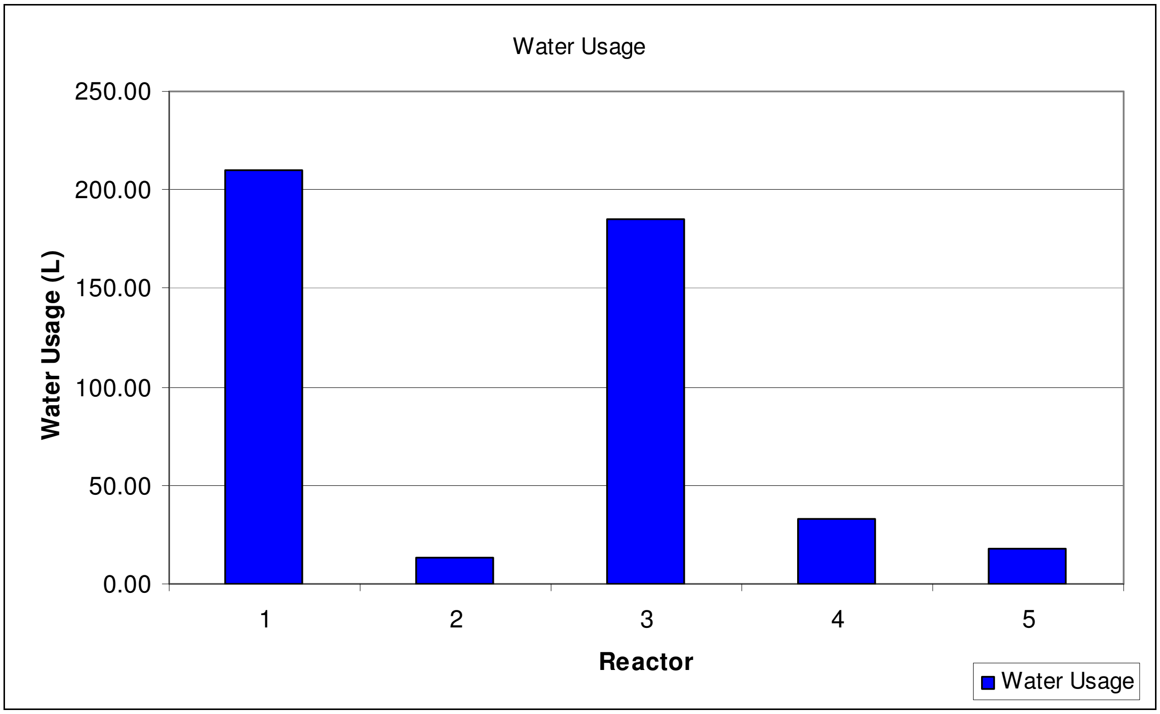

Figure 4.4. Evapotranspiration from reactors as measured by total water usage over the experiment duration.

Table 4.4. Evapotranspiration rate and contaminant mass delivered to each reactor.

Reactor	Total Time (d)	Total Water (L)	Evapo-transpiration Rate (L/d)	Total Benzene Delivered (mg)	Total Toluene Delivered (mg)	Total Ethylbenzene Delivered (mg)	Total Xylene Delivered (mg)
1	150	210	1.40	929	269	87	91
2	102	14	0.14	61	18	6	6
3	150	185	1.24	0	0	0	0
4	146	33	0.23	145	42	14	14
5	141	18	0.13	79	23	7	8

trees used water, they act as pumps to remove water and to also bring oxygen from the atmosphere into the soil structure. Daily water levels over a 7 day period are shown in Figure 4.5 below. The rapid, daily drop in water level can be clearly seen in Reactors 1 and 3 against the slower, step-wise drop in Reactors 2 and 5. Reactor 4 is seen to have a both the rapid drop and the step-wise drop, which illustrates the changing health in the trees. The daily rise and fall of water levels in Reactors 1 clearly illustrates the delivery of BTEX and oxygen throughout the reactor in a constant alternating pattern. The stepped drop seen in Reactors 2 and 5 indicates that BTEX is delivered throughout the reactors, but oxygen delivery is slower and more dependent on diffusion through the soil pore space. Also, as the water level is stagnant for a period of time, it may be limiting oxygen levels and inducing anaerobic conditions.

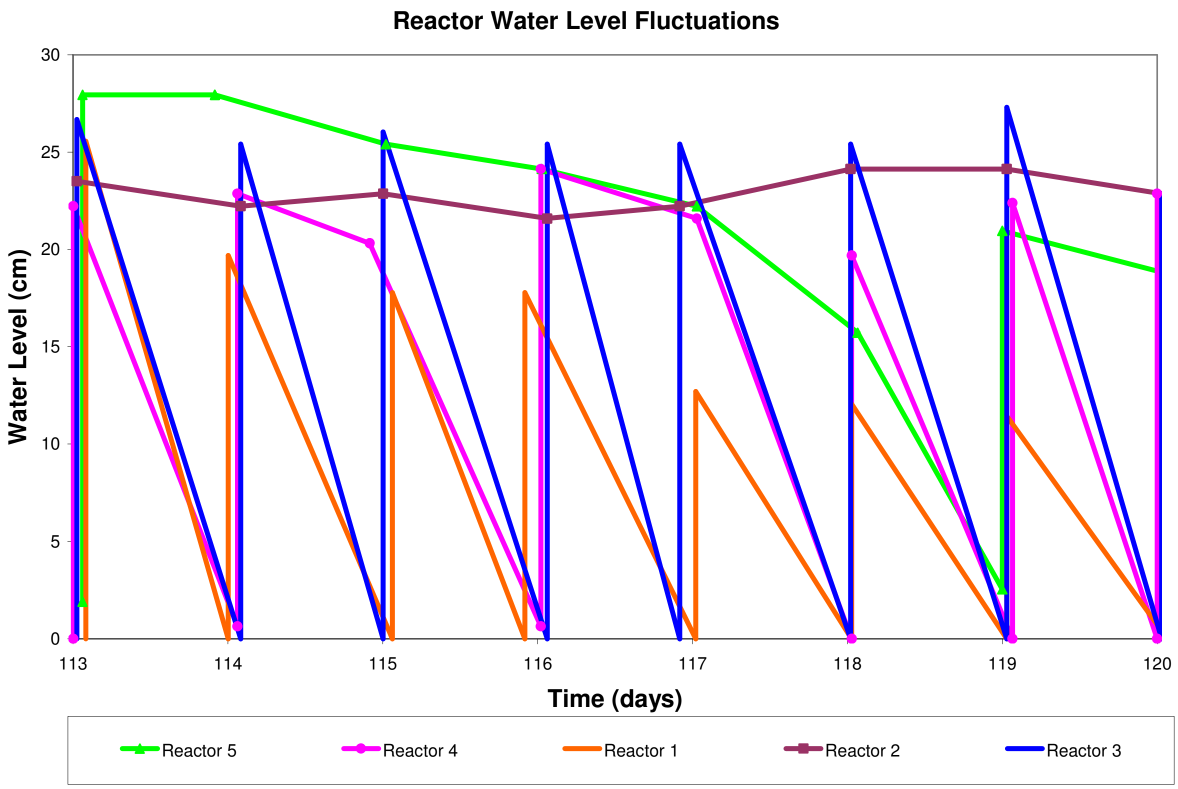

Figure 4.5. Comparison of water levels in reactors over a 7 day period, from day 113 to day 120 of the 150 day experiment.

The pattern seen in the planted reactors has been observed at full scale phytoremediation field sites. Figure 4.6 below shows daily groundwater fluctuations observed over a three day period at the Aberdeen Proving Grounds, MD (Schneider, 2002). The daily draw-down of the groundwater followed by the nightly recharge can clearly be seen. Furthermore, the overall reduction of the water table can be seen, showing the hydraulic impacts of phytoremediation.

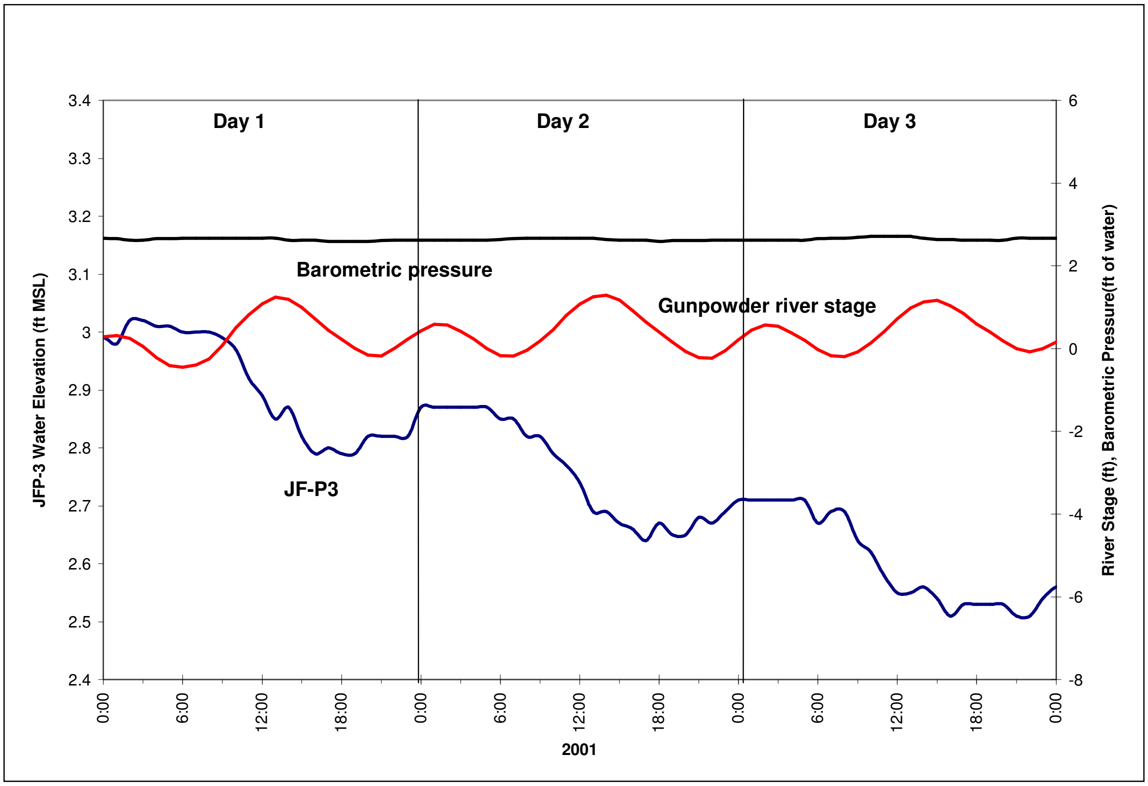

Figure 4.6. Groundwater fluctuation at a full scale phytoremediation site. The blue line shows the groundwater level fluctuations over a three day period (Schneider, 2002).

4.3. OXYGEN ADDITION

As discussed previously, the addition of oxygen into the system is accomplished through three possible entry pathways. When microbial populations are present and consuming oxygen, an oxygen gradient is present and diffusion occurs as air passes from the atmosphere and into the soil structure via the unsaturated soil pore space. The second pathway is through advection caused by the pumping action of the diurnal fluctuation of the water levels. The final pathway is by the dissolved oxygen present in the water added to the reactor. At field sites, groundwater will contain little, if any, dissolved oxygen and diffusion pathways will be longer. This will increase the importance of advective oxygen input through diurnal fluctuations of the groundwater table.

Oxygen input into each reactor is determined from three sources: the dissolved oxygen in the volume of water added daily (representing resurgence in groundwater) and the loss of water which occurs between two watering events (representing the loss of groundwater due to transpiration or evapotranspiration) and diffusion from the atmosphere. Oxygen input by water addition is calculated based on the dissolved oxygen (DO) present in the feed water. Test show approximately 1.8 mg/L of DO present in uncontaminated feed water and 3.6 mg/L of DO in contaminated feed water. Therefore, the following equation is used to estimate oxygen input:

$$O_2\,(mol) = DO\left(\frac{mg}{L}\right) \times H_2O\ Addition\,(L) \times \frac{mol\,O_2}{32\,mg} \qquad (2)$$

Oxygen input through water loss is calculated using the ideal gas law and the daily drop in the water table:

$$n\,(mol\,O_2) = 0.20\frac{PV}{RT} \qquad (3)$$

Where

n = *Number of Moles of Oxygen*

$P = 1\,atm$

$R = 0.08206\left(\frac{L\,atm}{mol\,K}\right)$

$T = \left(273 + {}^{o}C\right)K$

$V = Tank\ Area\,(sq\,in) \times \Delta Water\ Height\,(in.) \times 0.016387\left(\frac{L}{in^3}\right) \times \Phi$

Where

$\Phi = porosity$

The daily water fluctuations illustrated above translates into a daily addition of oxygen from both water addition and water loss. In order to validate the effect of diurnal fluctuations as an aid to increased bioremediation through elevated oxygen levels, it is necessary to include oxygen addition through natural diffusion as governed by Fick's law. Fick's first law describes one-dimensional flux as:

$$J = -\left(\frac{D}{\tau}\right)\frac{\partial c}{\partial x} \tag{5}$$

Where

$J = \textit{flux of oxygen into the soil} \left(\frac{mol}{m^2 s}\right)$

$\tau = \textit{tortuosity factor for the soil}$

$D = \textit{the diffusion coefficient for oxygen in soil} \left(\frac{cm^2}{s}\right)$

$\frac{dc}{dx} = \textit{change in concentration over a depth, } x$

The negative sign indicates that the flux is occurring into the soil. Integration of equation 5 yields the following:

$$J = -\left(\frac{D}{\tau}\right)\left(\frac{C_0 - C_t}{x_o - x_t}\right) \tag{6}$$

Where

$C_0 = \textit{Initial oxygen concentration } (mol/m^3)$

$C_t = \textit{Oxygen concentration at depth, } x\textit{, at time, } t\ (mol/m^3)$

$x_0 = \textit{Initial depth } (m)$

$x_t = \textit{Depth at time, } t\ (m)$

Diffusion occurs from the atmosphere into the soil, therefore, the initial depth is zero and the initial oxygen concentration, C_0, is the concentration of oxygen in air. Air is known to consist of 20.95% oxygen. Using the ideal gas law at standard pressure and a temperature of 60℉, the concentration of oxygen in one cubic meter of air is 8.84 mol/m^3. The oxygen concentration, C_t, is the oxygen concentration in the soil just above the groundwater table. Due to the long, tortuous path of diffusion and the limited supply of oxygen near the groundwater table, the assumption is made that any diffused oxygen reaching the groundwater table is being consumed and is approximately zero. The depth is measured over the time period between water level readings.

Diffusion in soil is known to be a factor of multiple soil properties, including water content, porosity, temperature and other factors. Various studies and equations have been developed to predict gaseous diffusion in soil. Moldrup et al. has studied and published numerous findings on gas and liquid diffusion in various soil media (Moldrup et al., 1998, 1999, 2000, 2000a, and 2001). Most notably, he has critiqued and adjusted numerous equations developed in the past. His work on diffusion in wet soil has allowed for more accurate predictions by developing a model which considers the effect of decreased diffusion pathways caused by water in the soil pore space. By adjusting an equation first developed by Marshall (1959), Moldrup (2000a) developed the following for a sieved and repacked soil at different water contents and total porosities:

$$\frac{D_{p,g}}{D_{0,g}} = \varepsilon^{1.5} \frac{\varepsilon}{\Phi} \tag{7}$$

Where

$D_{p,g}$ = *gas diffusion coefficient in soil (cm^2/s)*

$D_{o,g}$ = *gas diffusion coefficient in air (cm^2/s)*

Φ = *total porosity*

ε = *air filled porosity = total porosity – water content*

Moldrup (2001) also relates tortuosity and diffusion by defining tortuosity as

$$\tau = \sqrt{\frac{\alpha D_o}{D_p}} \qquad (8)$$

Where α = ε for gas diffusion. By assuming an oxygen diffusion coefficient in air of 2.09 x 10^{-5} cm^2/s at 25°C (Denny, 1993) and an average reactor depth of 21.5 cm solutions of Equations 7 and 8 can be obtained. The results are listed in Table 4.5 below.

Table 4.5. Soil diffusion coefficient, tortuosity and flux in reactors.

	Reactor				
	1	2	3	4	5
Water Content	0.40	0.45	0.43	0.39	0.40
Total Porosity (Φ)	0.29	0.33	0.26	0.28	0.19
Air Filled Porosity (ε)	0.11	0.12	0.17	0.11	0.21
O_2 Diffusion Coefficient in Soil @ 25°C (m^2/s)	2.9E-07	3.2E-07	9.6E-07	3.0E-07	2.2E-06
Tortuosity	2.82	2.82	1.93	2.77	1.41

By substituting the tortuosity and oxygen diffusion coefficient into equation 6, it is then possible to solve for the oxygen flux occuring in each reactor. The depth is considered to be the unsaturated zone above the water table after a watering event plus the depth of water table drop that occurs before the next watering event. The time between watering events is used and the flux is computed. The mass of oxygen in each reactor accumulated over that time can then be determined by equation 9. Table 4.6 lists the daily mass input of oxygen through the three pathways.

$$M_{O_2} = J \times A_R \times t \qquad (9)$$

Where

$M_{O_2} = \textit{Oxygen mass due to diffusion} \ (mol)$

$J = \textit{Flux of oxygen into reactor soil} \ (mol/m^3)$

$A_R = \textit{Reactor surface area} \ (m^2)$

$t = \textit{Time elapsed between watering events} \ (s)$

Table 4.6. Oxygen mass input in each reactor through the three pathways: diffusion, advection and dissolved oxygen.

Reactor	Reactor Description	Average Daily Oxygen Diffusion (mol)	Average Daily Oxygen Advection (mol)	Average Daily Dissolved Oxygen Input (mol)
1	Planted Contaminated	1.35E-03	3.21E-02	1.93E-01
3	Planted Uncontaminated	2.69E-03	3.17E-02	8.40E-02
4	Planted Sterile	5.00E-03	2.32E-02	3.15E-02
2	Unplanted	8.87E-03	1.61E-02	1.77E-02
5	Unplanted Sterile	1.18E-03	9.37E-03	1.83E-02

As diurnal fluctuations continue, a cumulative addition of oxygen into the system creates conditions much more favorable to microbial degradation than in the systems with more stagnant water levels and lower oxygen input. Figure 4.7 presents the cumulative oxygen mass diffused into each reactor. The influence of the diurnal fluctuations are clear: as the trees grow and transpire more water, the mass of oxygen being brought into the system increases versus those systems with no trees. Even the unhealthy trees in Reactor 4 have an impact compared to unplanted Reactors 2 and 5. Oxygen input in the unplanted reactors increases very slowly, responding only to slight changes in water level and increased oxygen input due to the dissolved oxygen content in feed water. In field settings, where dissolved oxygen in the groundwater is limited, the impact of dissolved oxygen in the groundwater would be even less. The effects of dissolved oxygen are also seen in the planted reactors. Reactors 1 and 3 consumed similar amounts of water on a daily basis, which, in a field setting, would result in similar oxygen input. However, due to the dissimilarity in dissolved oxygen concentration in the spiked and un-spiked feed water, Reactor 1 shows a higher oxygen mass input. This is an artifact of the reactor and experiment design and was not observed until well into the experiment. The difference between Reactor 1, fed with contaminated water, and Reactor 3 fed with uncontaminated water, can be explained by the dissolved oxygen concentration in the spiked feed water (3.2 mg/L), which was twice the concentration in the un-spiked feed water (1.6 mg/L).

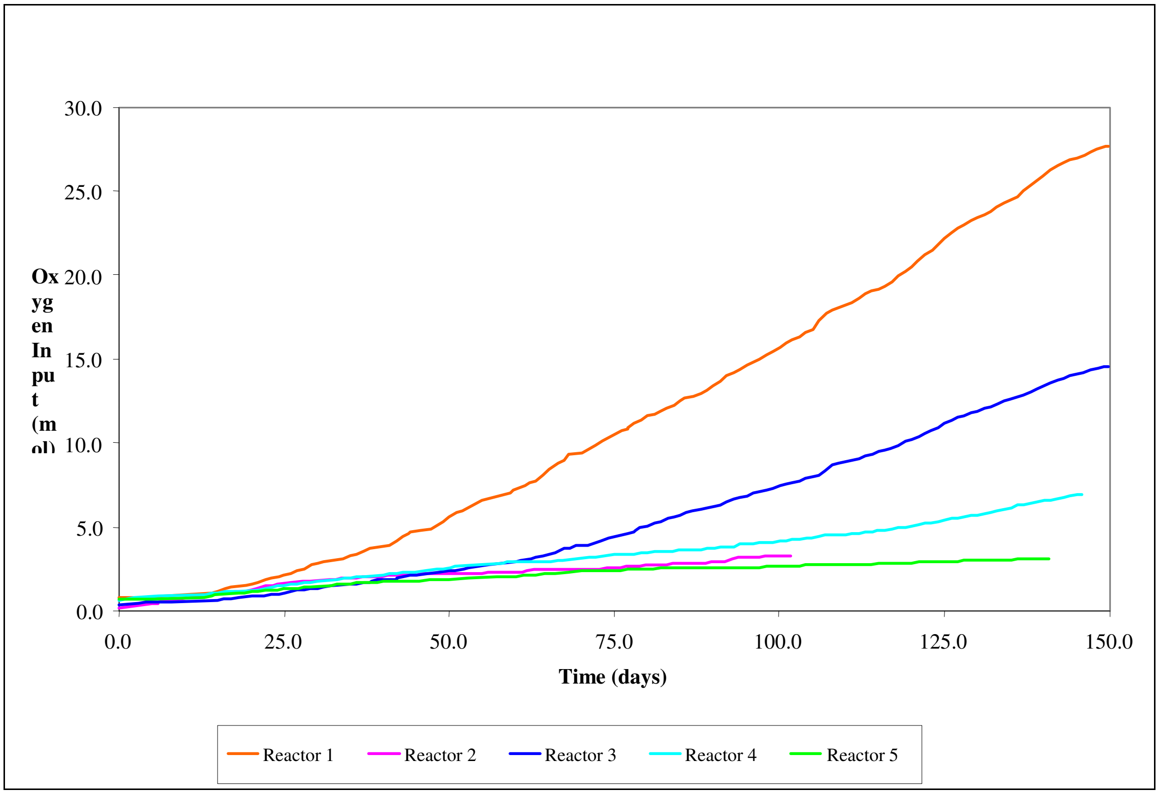

Figure 4.7. Cumulative oxygen input in reactors through the three pathways.

4.4. BTEX DEGRADER ENUMERATIONS

The soil samples taken from reactors as well as those taken from the field site during the final sampling event were plated using the method previously described. Figure 4.8 illustrates the plating results for the samples taken during the course of the experiment. A clear increase in population can be seen in the planted reactors, Reactors 1 and 3, versus the unplanted reactors, Reactors 2 and 5, and the sterilized reactors, Reactors 4 and 5. The BTEX degrader population at 120 days for Reactor 1 is 5 times that in the uncontaminated Reactor 3 at 120 days, which is expected due to the increased carbon source the microbial population was given.

Plating results for the soil samples taken during the final reactor sampling as well as those taken at the field site during the final sampling event are shown in Figures 4.9 thru 4.11. Figure 4.9 illustrates the average BTEX degrading population in bulk soil and Figure 4.10 shows the average BTEX degrading population in rhizosphere soil. Figure 4.11 is a combination of the previous two for comparative purposes.

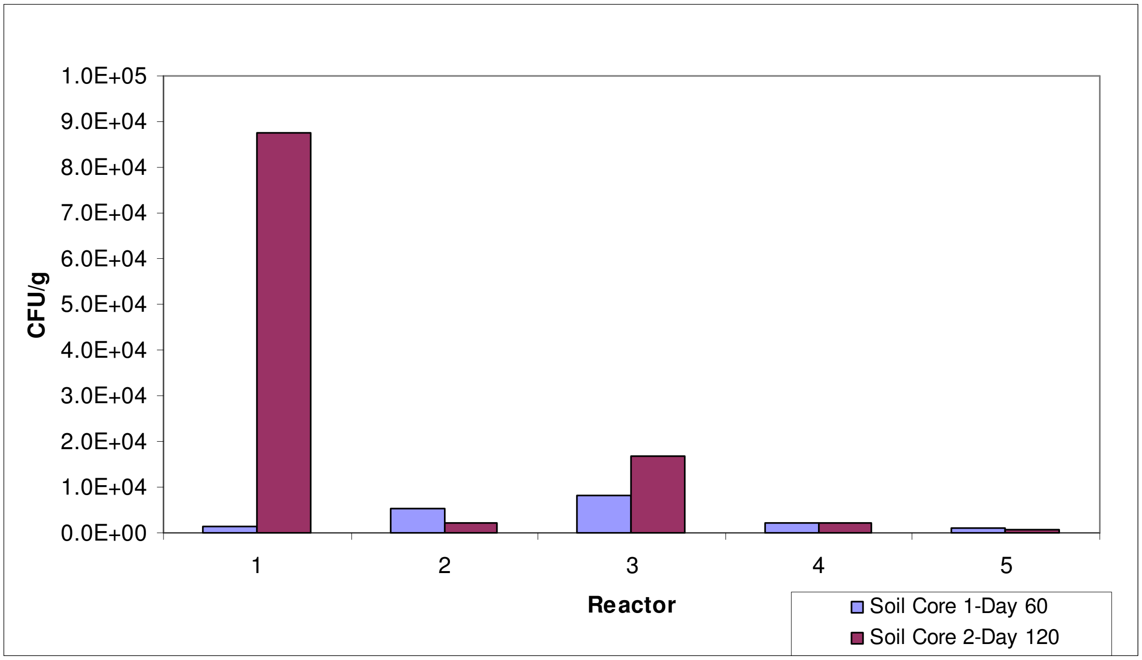

Figure 4.8. Microbial growth results for soil cores taken from reactors during the experiment. Soil core 1 was taken on day 60 and soil core 2 was taken on day 120 for reactors 1, 3, 4 and 5. Standard error bars are not shown as only one composite sample was plated from each core sample.

The higher populations seen in Reactors 1 and 3 indicate the role the trees have in aiding the BTEX degrading microbial population even within the bulk soil. The large degrader population seen in Reactor 3 samples illustrates the importance of the plant-microbe relationship. The rhizosphere degrader population seen indicates that the rhizosphere can promote BTEX degrading organisms even in the absence of BTEX. The significant difference seen between degrader populations in Reactor 1 versus Reactor 2 is clear evidence of the impact trees have on supporting degrader populations. This is also seen when comparing Reactors 4 and 5, both containing sterilized soil. By the end of the experiment, 3 to 4 trees in Reactor 4 were showing clear signs of thriving within the sterile soil. The degrader populations seen in Reactor 4 indicate that trees capable of surviving in a harsh, contaminated environment can help support a microbial population if a nearby carbon source is available. The similarity between the uncontaminated Reactor 3 and the Site Soil is an indication of decreased contamination levels at the site

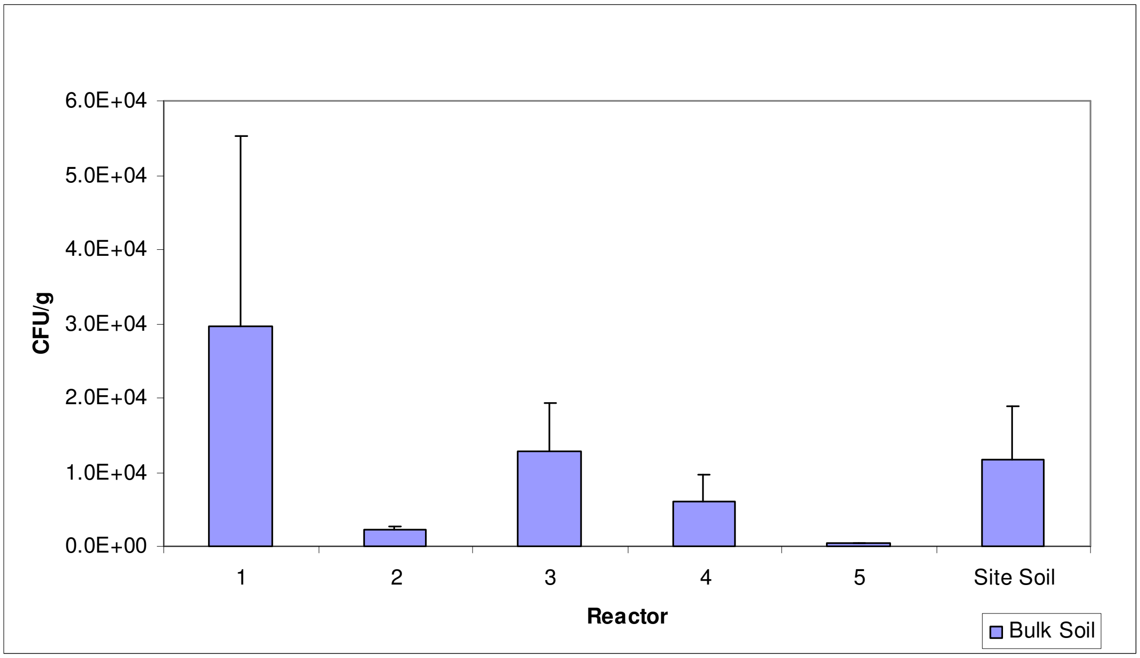

Figure 4.9. Average microbial growth results for all bulk soil samples taken from reactors as well as soil samples taken at the field site. Standard error bars are shown.

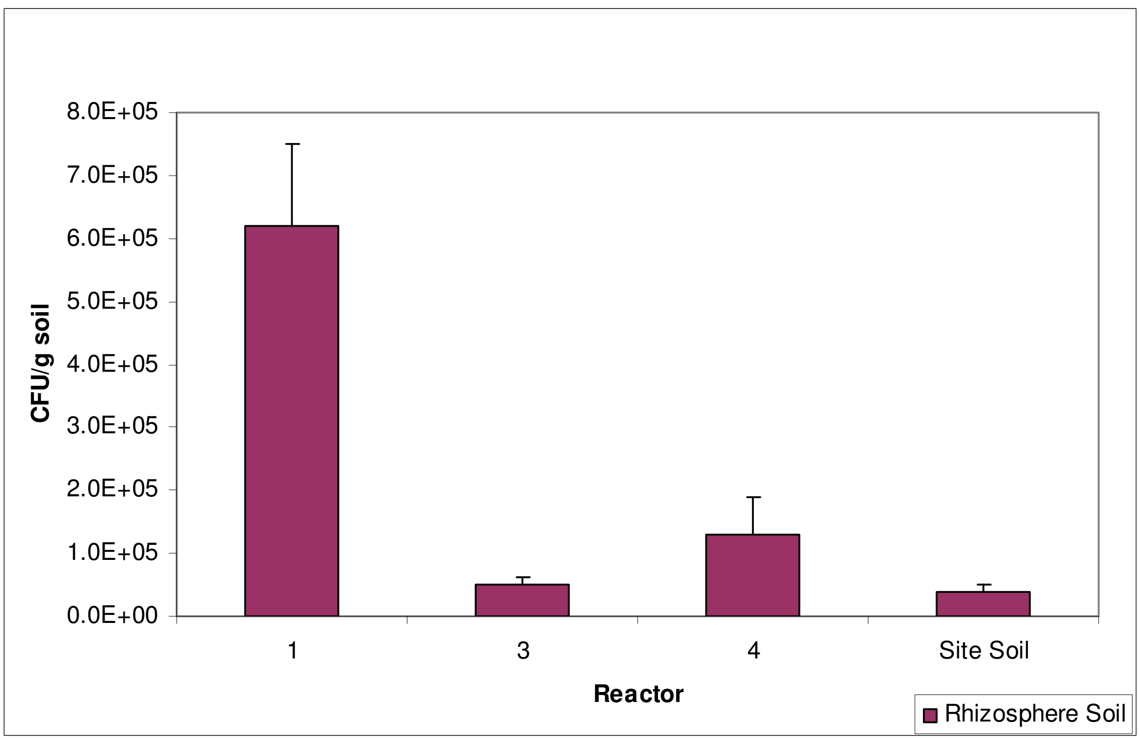

Figure 4.10. Average microbial growth results for all rhizosphere soil samples taken from reactors as well as soil samples taken at the field site. Standard error bars are shown.

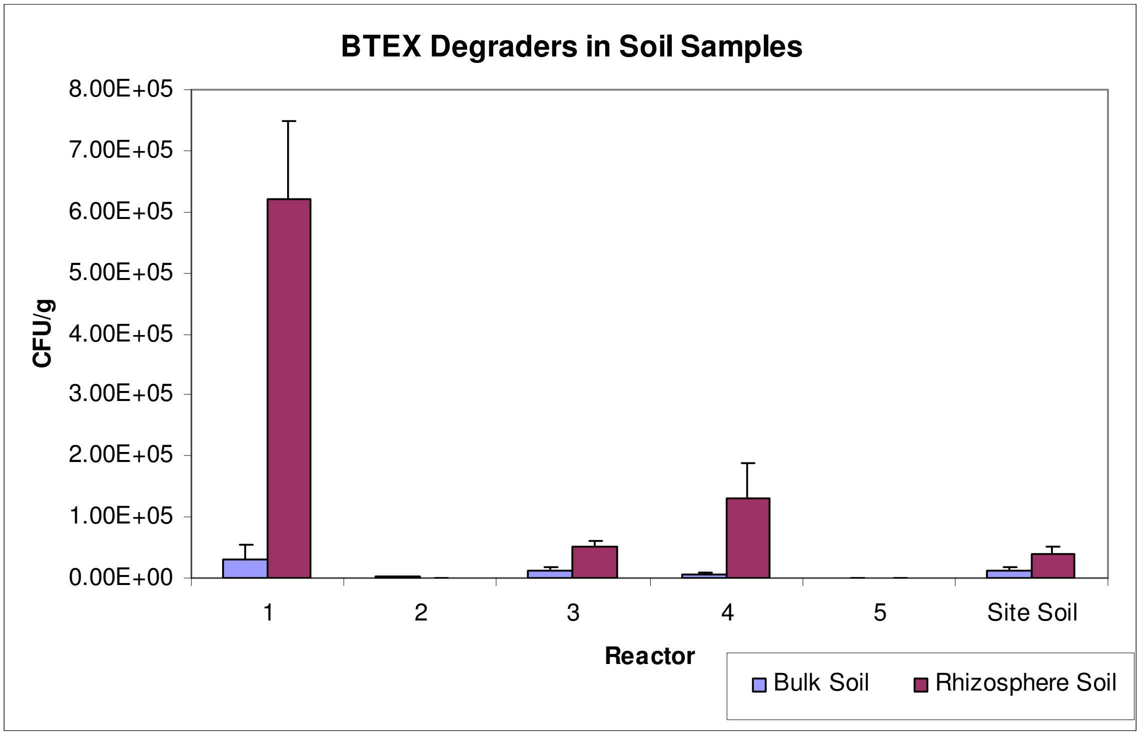

Figure 4.11. Comparison of the average bulk and average rhizosphere soil microbial population for samples taken from the reactors and the field site during final sampling events. Standard error bars are shown.

that explain the lack of detection in tree cores at the site. Comparing Reactor 3 and the Site Soil rhizosphere samples, evidence is again seen to explain the lack of detections in tree cores tested from the site. Overall, rhizosphere samples in the contaminated reactors contained degrader populations 20 times higher than the bulk samples, while rhizosphere samples from the uncontaminated reactor and the site had populations only 3 times higher than the bulk samples. The bulk soil from the planted reactors also contains higher BTEX degrader populations than unplanted reactors, indicating that the increased oxygen input due to plant transpiration is affecting the bulk soil as well as the rhizosphere. This is important considering the large volume of bulk soil versus rhizosphere soil and the degrader population that could be contained within the bulk soil.

Reactor trees were sampled and analyzed to determine BTEX uptake by trees in contaminated reactors. Reactor soils were analyzed to evaluate soil contamination in the reactors and the possible effects of tree uptake and microbial degradation of BTEX within the reactors. Soil BTEX concentrations are listed in Table 4.7. BTEX concentrations are listed as microgram per liter of vapor as the soil samples were wet when taken and it is not possible to separate the soil and soil water for headspace analysis. BTEX concentrations were seen only in the unplanted sterilized Reactor 5. The remaining reactors had no BTEX detections in soil samples taken over the soil depth. This indicates that BTEX was leaving the system through multiple pathways including microbial degradation and uptake into the trees for the planted reactors. Diffusion into the atmosphere is also a viable pathway as the reactors were not sealed.

Table 4.7. BTEX concentrations in reactor soils.

Reactor	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Total Xylene (µg/Lv)
1	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00
5	8.57	34.01	81.95	70.34

Contaminant concentrations detected in the trees of the planted reactors are listed in Table 4.8. Detections of benzene, toluene and ethylbenzene in trees of Reactors 1 and 4 reaffirm BTEX uptake by poplar trees. The lower detections in Reactor 4 are a result of the younger, less developed trees that were planted after the failed survival of previous trees. However, the uptake does show that the trees in Reactor 4 were transpiring, influencing the groundwater and microbial population. The detections seen in trees samples from Reactor 1 are low compared with the total mass input listed in Table 4.4. The low concentrations detected represent the apparent difficulty in BTEX uptake that is seen in the field. Coupled with the lack of detection in the reactor soil, the low detections in the trees sampled are a clear indication of the importance of microbial degradation as a pathway for removal of BTEX from contaminated groundwater and soil.

Table 4.8. BTEX concentration in trees of planted reactors.

Reactor	Benzene (μg/Lv)	Toluene (μg/Lv)	Ethylbenzene (μg/Lv)	Total Xylene (μg/Lv)
1	3.04	0.32	0.44	0.00
2	Unplanted Reactor			
3	0.00	0.00	0.00	0.00
4	0.07	0.12	0.00	0.00
5	Unplanted Reactor			

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. CONCLUSIONS

The results presented in this study clearly show that diurnal fluctuations in groundwater levels can increase microbial degradation of contaminants in groundwater and soils. The increased population of microbial degraders in the presence of trees has been reaffirmed along with the groundwater impacts associated with the presence of trees. The ability of trees to create diurnal fluctuations in the groundwater can produce higher oxygen levels in the vadose zone as the falling water table will draw in oxygen from the atmosphere. When trees cease transpiration during nocturnal hours, the water table will recharge, bringing increased contaminant flux into the soil profile and into contact with microbial populations. Over an extended time period, the overall elevation of the groundwater will be reduced as trees consume groundwater, creating a larger vadose zone for microbial populations to flourish as well.

Specific findings of this study include numerous first time observations. The increased populations of BTEX degraders in the contaminated bulk soil indicates the ability of plant roots to influence microbial populations that are not in direct contact with the root system. The number of BTEX degraders in the rhizosphere versus the bulk soil of planted contaminated reactors was as much as 20 times higher. The increased number of BTEX degrader populations is a result of the increased oxygen input into the soil as a direct result of tree transpiration. The data presented herein clearly shows that diurnal fluctuations caused by transpiration will increase oxygen flux into the vadose zone. The results of this study also find that BTEX degrader populations were seen to increase in planted reactor even in the absence of BTEX.

For field sites, the combined strategy of phytoremediation and enhanced biodegradation has many advantages. The combined strategy would allow for a low cost, low maintenance remedy to what would otherwise be a costly clean-up. The combined strategy could also offer a more rapid closure date compared to the use of phytoremediation or natural attenuation as stand alone strategies. Much work will be necessary to demonstrate the combined strategy in the field however, the advantages should be significant. The combined strategy is most likely already occurring in phytoremediation field sites where soils contain microbial populations capable degrading the contaminants aerobically.

5.2. RECOMMENDATIONS

Future work should focus on phytoremediation field sites and direct measurements of oxygen levels in the vadose zone and contaminant degrading microbial populations. Laboratory research can continue to increase knowledge of this process by implementing increased monitoring. Directly measuring oxygen levels and redox conditions in the soil, monitoring contaminant levels in the atmosphere to detect contaminant diffusion out of the system, and enhanced microbial assay techniques will help to further enhance the knowledge and acceptability of phytoremediation and enhanced biodegradation as a combined remedial strategy.

APPENDIX A.
REACTOR WATERING DATA

Reactor 1 - Trees with BTEX water								
Date	Time (hr)	Total Time (hr)	Total Time (days)	H2O Height (in)	Water Added (mL)	Total Water Added (mL)	H2O Final Height (in)	H2O Final Height (cm)
3/21/06 12:00		0:00:00	0.00	0	7449	7449	0.00	0.00
3/24/06 15:00	75:00:00	75:00:00	3.13	2.5	0	7449	2.50	6.35
3/28/06 12:00	93:00:00	168:00:00	7.00				0.00	0.00
3/28/06 12:00	0:00:00	168:00:00	7.00	0	250	7699	2.38	6.03
4/4/06 12:30	168:30:00	336:30:00	14.02				0.00	0.00
4/4/06 12:30	0:00:00	336:30:00	14.02	0	1250	8949	8.50	21.59
4/5/06 10:30	22:00:00	358:30:00	14.94				0.00	0.00
4/5/06 10:30	0:00:00	358:30:00	14.94	0	500	9449	8.38	21.27
4/6/06 12:00	25:30:00	384:00:00	16.00				0.00	0.00
4/6/06 12:00	0:00:00	384:00:00	16.00	0	750	10199	8.25	20.96
4/7/06 12:30	24:30:00	408:30:00	17.02				0.00	0.00
4/7/06 12:30	0:00:00	408:30:00	17.02	0	500	10699	9.25	23.50
4/9/06 16:00	51:30:00	460:00:00	19.17				0.00	0.00
4/9/06 16:00	0:00:00	460:00:00	19.17	0	500	11199	9.00	22.86
4/10/06 14:40	22:40:00	482:40:00	20.11				0.00	0.00
4/10/06 14:40	0:00:00	482:40:00	20.11	0	554	11753	9.44	23.97
4/11/06 10:30	19:50:00	502:30:00	20.94				0.00	0.00
4/11/06 10:30	0:00:00	502:30:00	20.94	0	500	12253	8.00	20.32
4/12/06 15:40	29:10:00	531:40:00	22.15				0.00	0.00
4/12/06 15:40	0:00:00	531:40:00	22.15	0	1000	13253	9.00	22.86
4/13/06 14:00	22:20:00	554:00:00	23.08				0.00	0.00
4/13/06 14:00	0:00:00	554:00:00	23.08	0	500	13753	8.25	20.96
4/14/06 17:00	27:00:00	581:00:00	24.21				0.00	0.00
4/14/06 17:00	0:00:00	581:00:00	24.21	0	500	14253	8.50	21.59
4/15/06 11:00	18:00:00	599:00:00	24.96				0.00	0.00
4/15/06 11:00	0:00:00	599:00:00	24.96	0	500	14753	6.50	16.51
4/16/06 11:00	24:00:00	623:00:00	25.96				0.00	0.00
4/16/06 11:00	0:00:00	623:00:00	25.96	0	500	15253	5.31	13.49
4/17/06 10:30	23:30:00	646:30:00	26.94				0.00	0.00
4/17/06 10:30	0:00:00	646:30:00	26.94	0	1000	16253	8.81	22.38
4/18/06 10:30	24:00:00	670:30:00	27.94				0.00	0.00
4/18/06 10:30	0:00:00	670:30:00	27.94	0	450	16703	8.50	21.59
4/19/06 15:00	28:30:00	699:00:00	29.13				0.00	0.00
4/19/06 15:00	0:00:00	699:00:00	29.13	0	1500	18203	10.06	25.56
4/20/06 11:00	20:00:00	719:00:00	29.96				0.00	0.00
4/20/06 11:00	0:00:00	719:00:00	29.96	0	500	18703	8.38	21.27
4/21/06 12:00	25:00:00	744:00:00	31.00				0.00	0.00
4/21/06 12:00	0:00:00	744:00:00	31.00	0	750	19453	6.38	16.19
4/24/06 12:00	72:00:00	816:00:00	34.00				0.00	0.00
4/24/06 12:00	0:00:00	816:00:00	34.00	0	1500	20953	4.38	11.11
4/25/06 12:45	24:45:00	840:45:00	35.03				0.00	0.00
4/25/06 12:45	0:00:00	840:45:00	35.03	0	750	21703	7.56	19.21
4/26/06 11:00	22:15:00	863:00:00	35.96				0.00	0.00

4/26/06 11:00	0:00:00	863:00:00	35.96	0	1000	22703	11.06	28.10
4/27/06 12:45	25:45:00	888:45:00	37.03				0.00	0.00
4/27/06 12:45	0:00:00	888:45:00	37.03	0	1000	23703	5.00	12.70
4/28/06 13:00	24:15:00	913:00:00	38.04				0.00	0.00
4/28/06 13:00	0:00:00	913:00:00	38.04	0	1000	24703	5.06	12.86
5/1/06 12:00	71:00:00	984:00:00	41.00				0.00	0.00
5/1/06 12:00	0:00:00	984:00:00	41.00	0	1750	26453	8.31	21.11
5/2/06 12:30	24:30:00	1008:30:00	42.02				0.00	0.00
5/2/06 12:30	0:00:00	1008:30:00	42.02	0	1750	28203	5.13	13.02
5/3/06 13:30	25:00:00	1033:30:00	43.06				0.00	0.00
5/3/06 13:30	0:00:00	1033:30:00	43.06	0	2250	30453	10.19	25.88
5/4/06 10:30	21:00:00	1054:30:00	43.94				0.00	0.00
5/4/06 10:30	0:00:00	1054:30:00	43.94	0	1000	31453	9.63	24.45
5/4/06 16:30	6:00:00	1060:30:00	44.19				0.00	0.00
5/4/06 16:30	0:00:00	1060:30:00	44.19	0	500	31953	10.75	27.31
5/6/06 5:00	36:30:00	1097:00:00	45.71				0.00	0.00
5/6/06 5:00	0:00:00	1097:00:00	45.71	0	750	32703	0.00	0.00
5/7/06 21:00	40:00:00	1137:00:00	47.38				0.00	0.00
5/7/06 21:00	0:00:00	1137:00:00	47.38	0	750	33453	2.00	5.08
5/9/06 13:30	40:30:00	1177:30:00	49.06				0.00	0.00
5/9/06 13:30	0:00:00	1177:30:00	49.06	0	3250	36703	10.25	26.04
5/10/06 11:30	22:00:00	1199:30:00	49.98				0.00	0.00
5/10/06 11:30	0:00:00	1199:30:00	49.98	0	1750	38453	7.25	18.42
5/11/06 15:00	27:30:00	1227:00:00	51.13				0.00	0.00
5/11/06 15:00	0:00:00	1227:00:00	51.13	0	1750	40203	8.50	21.59
5/12/06 11:00	20:00:00	1247:00:00	51.96				0.00	0.00
5/12/06 11:00	0:00:00	1247:00:00	51.96	0	1500	41703	0.00	0.00
5/15/06 11:00	72:00:00	1319:00:00	54.96				0.00	0.00
5/15/06 11:00	0:00:00	1319:00:00	54.96	0	4500	46203	9.63	24.45
5/19/06 16:30	101:30:00	1420:30:00	59.19				0.00	0.00
5/19/06 16:30	0:00:00	1420:30:00	59.19	0	3980	50183	3.75	9.53
5/20/06 6:45	14:15:00	1434:45:00	59.78				0.00	0.00
5/20/06 6:45	0:00:00	1434:45:00	59.78	0	1750	51933	2.00	5.08
5/21/06 23:45	41:00:00	1475:45:00	61.49				0.00	0.00
5/21/06 23:45	0:00:00	1475:45:00	61.49	0	1250	53183	9.75	24.77
5/22/06 16:03	16:18:00	1492:03:00	62.17				0.00	0.00
5/22/06 16:03	0:00:00	1492:03:00	62.17	0	1250	54433	8.75	22.23
5/23/06 15:30	23:27:00	1515:30:00	63.15				0.00	0.00
5/23/06 15:30	0:00:00	1515:30:00	63.15	0	1250	55683	4.00	10.16
5/24/06 15:30	24:00:00	1539:30:00	64.15				0.00	0.00
5/24/06 15:30	0:00:00	1539:30:00	64.15	0	2500	58183	0.00	0.00
5/25/06 14:00	22:30:00	1562:00:00	65.08				0.00	0.00
5/25/06 14:00	0:00:00	1562:00:00	65.08	0	2900	61083	9.00	22.86
5/26/06 21:00	31:00:00	1593:00:00	66.38				0.00	0.00
5/26/06 21:00	0:00:00	1593:00:00	66.38	0	3000	64083	12.00	30.48
5/27/06 21:00	24:00:00	1617:00:00	67.38				0.00	0.00
5/27/06 21:00	0:00:00	1617:00:00	67.38	0	1000	65083	0.00	0.00
5/28/06 14:00	17:00:00	1634:00:00	68.08				0.00	0.00

5/28/06 14:00	0:00:00	1634:00:00	68.08	0	2750	67833	7.13	18.10
5/30/06 14:00	48:00:00	1682:00:00	70.08				0.00	0.00
5/30/06 14:00	0:00:00	1682:00:00	70.08	0	1250	69083	2.00	5.08
6/1/06 14:30	48:30:00	1730:30:00	72.10				0.00	0.00
6/1/06 14:30	0:00:00	1730:30:00	72.10	0	3500	72583	0.00	0.00
6/2/06 15:00	24:30:00	1755:00:00	73.13				0.00	0.00
6/2/06 15:00	0:00:00	1755:00:00	73.13	0	2500	75083	0.00	0.00
6/5/06 16:00	73:00:00	1828:00:00	76.17				0.00	0.00
6/5/06 16:00	0:00:00	1828:00:00	76.17	0	5000	80083	7.44	18.89
6/6/06 12:00	20:00:00	1848:00:00	77.00				0.00	0.00
6/6/06 12:00	0:00:00	1848:00:00	77.00	0	1000	81083	11.00	27.94
6/6/06 14:45	2:45:00	1850:45:00	77.11				8.31	21.11
6/6/06 14:45	0:00:00	1850:45:00	77.11	8.31	0	81083	8.31	21.11
6/7/06 11:00	20:15:00	1871:00:00	77.96			81083	0.00	0.00
6/7/06 11:00	0:00:00	1871:00:00	77.96	0	2000	83083	9.44	23.97
6/8/06 13:30	26:30:00	1897:30:00	79.06			83083	0.00	0.00
6/8/06 13:30	0:00:00	1897:30:00	79.06	0	1500	84583	9.88	25.08
6/9/06 13:25	23:55:00	1921:25:00	80.06			84583	0.00	0.00
6/9/06 13:25	0:00:00	1921:25:00	80.06	0	1500	86083	9.88	25.08
6/10/06 13:30	24:05:00	1945:30:00	81.06			86083	0.00	0.00
6/10/06 13:30	0:00:00	1945:30:00	81.06	0	1000	87083	9.44	23.97
6/11/06 15:30	26:00:00	1971:30:00	82.15			87083	0.00	0.00
6/11/06 15:30	0:00:00	1971:30:00	82.15	0	1000	88083	8.44	21.43
6/12/06 12:10	20:40:00	1992:10:00	83.01			88083	0.00	0.00
6/12/06 12:10	0:00:00	1992:10:00	83.01	0	1000	89083	9.50	24.13
6/13/06 13:00	24:50:00	2017:00:00	84.04			89083	0.00	0.00
6/13/06 13:00	0:00:00	2017:00:00	84.04	0	1250	90333	8.50	21.59
6/14/06 10:50	21:50:00	2038:50:00	84.95			90333	0.00	0.00
6/14/06 10:50	0:00:00	2038:50:00	84.95	0	1750	92083	5.88	14.92
6/15/06 6:30	19:40:00	2058:30:00	85.77			92083	0.00	0.00
6/15/06 6:30	0:00:00	2058:30:00	85.77	0	1250	93333	8.56	21.75
6/16/06 14:00	31:30:00	2090:00:00	87.08			93333	0.00	0.00
6/16/06 14:00	0:00:00	2090:00:00	87.08	0	1000	94333	2.75	6.99
6/17/06 13:10	23:10:00	2113:10:00	88.05			94333	0.00	0.00
6/17/06 13:10	0:00:00	2113:10:00	88.05	0	1500	95833	2.00	5.08
6/18/06 14:15	25:05:00	2138:15:00	89.09			95833	0.00	0.00
6/18/06 14:15	0:00:00	2138:15:00	89.09	0	1500	97333	0.50	1.27
6/19/06 13:20	23:05:00	2161:20:00	90.06			97333	0.00	0.00
6/19/06 13:20	0:00:00	2161:20:00	90.06	0	2000	99333	1.00	2.54
6/20/06 14:15	24:55:00	2186:15:00	91.09			99333	0.00	0.00
6/20/06 14:15	0:00:00	2186:15:00	91.09	0	2500	101833	7.00	17.78
6/21/06 12:50	22:35:00	2208:50:00	92.03			101833	0.00	0.00
6/21/06 12:50	0:00:00	2208:50:00	92.03	0	2750	104583	6.75	17.15
6/22/06 13:30	24:40:00	2233:30:00	93.06			104583	0.00	0.00
6/22/06 13:30	0:00:00	2233:30:00	93.06	0	1500	106083	0.25	0.64
6/23/06 14:00	24:30:00	2258:00:00	94.08			106083	0.00	0.00
6/23/06 14:00	0:00:00	2258:00:00	94.08	0	1500	107583	0.25	0.64
6/24/06 14:00	24:00:00	2282:00:00	95.08			107583	0.00	0.00

6/24/06 14:00	0:00:00	2282:00:00	95.08	0	2000	109583	1.25	3.18
6/25/06 13:45	23:45:00	2305:45:00	96.07			109583	0.00	0.00
6/25/06 13:45	0:00:00	2305:45:00	96.07	0	1500	111083	0.25	0.64
6/26/06 12:55	23:10:00	2328:55:00	97.04			111083	0.00	0.00
6/26/06 12:55	0:00:00	2328:55:00	97.04	0	2000	113083	1.75	4.45
6/27/06 12:50	23:55:00	2352:50:00	98.03			113083	0.00	0.00
6/27/06 12:50	0:00:00	2352:50:00	98.03	0	2000	115083	1.00	2.54
6/28/06 13:30	24:40:00	2377:30:00	99.06			115083	0.00	0.00
6/28/06 13:30	0:00:00	2377:30:00	99.06	0	2000	117083	1.25	3.18
6/29/06 13:00	23:30:00	2401:00:00	100.04			117083	0.00	0.00
6/29/06 13:00	0:00:00	2401:00:00	100.04	0	2000	119083	1.00	2.54
6/30/06 13:40	24:40:00	2425:40:00	101.07			119083	0.00	0.00
6/30/06 13:40	0:00:00	2425:40:00	101.07	0	2000	121083	0.25	0.64
7/1/06 13:00	23:20:00	2449:00:00	102.04			121083	0.00	0.00
7/1/06 13:00	0:00:00	2449:00:00	102.04	0	2000	123083	1.00	2.54
7/2/06 13:27	24:27:00	2473:27:00	103.06			123083	0.00	0.00
7/2/06 13:27	0:00:00	2473:27:00	103.06	0	1500	124583	0.50	1.27
7/3/06 13:00	23:33:00	2497:00:00	104.04			124583	0.00	0.00
7/3/06 13:00	0:00:00	2497:00:00	104.04	0	2000	126583	0.75	1.91
7/4/06 15:00	26:00:00	2523:00:00	105.13			126583	0.00	0.00
7/4/06 15:00	0:00:00	2523:00:00	105.13	0	1500	128083	0.75	1.91
7/5/06 11:30	20:30:00	2543:30:00	105.98			128083	0.00	0.00
7/5/06 11:30	0:00:00	2543:30:00	105.98	0	5180	133263	0.00	0.00
7/6/06 13:00	25:30:00	2569:00:00	107.04			133263	0.00	0.00
7/6/06 13:00	0:00:00	2569:00:00	107.04	0	3500	136763	9.69	24.61
7/7/06 12:00	23:00:00	2592:00:00	108.00			136763	0.00	0.00
7/7/06 12:00	0:00:00	2592:00:00	108.00	0	1000	137763	8.88	22.54
7/10/06 13:45	73:45:00	2665:45:00	111.07			137763	0.00	0.00
7/10/06 13:45	0:00:00	2665:45:00	111.07	0	3750	141513	6.75	17.15
7/11/06 12:37	22:52:00	2688:37:00	112.03			141513	0.00	0.00
7/11/06 12:37	0:00:00	2688:37:00	112.03	0	1750	143263	9.00	22.86
7/12/06 14:00	25:23:00	2714:00:00	113.08			143263	0.00	0.00
7/12/06 14:00	0:00:00	2714:00:00	113.08	0	1750	145013	10.06	25.56
7/13/06 12:04	22:04:00	2736:04:00	114.00			145013	0.00	0.00
7/13/06 12:04	0:00:00	2736:04:00	114.00	0	1000	146013	7.75	19.69
7/14/06 13:30	25:26:00	2761:30:00	115.06			146013	0.00	0.00
7/14/06 13:30	0:00:00	2761:30:00	115.06	0	1000	147013	7.00	17.78
7/15/06 10:00	20:30:00	2782:00:00	115.92			147013	0.00	0.00
7/15/06 10:00	0:00:00	2782:00:00	115.92	0	1250	148263	7.00	17.78
7/16/06 12:30	26:30:00	2808:30:00	117.02			148263	0.00	0.00
7/16/06 12:30	0:00:00	2808:30:00	117.02	0	2000	150263	5.00	12.70
7/17/06 12:40	24:10:00	2832:40:00	118.03			150263	0.00	0.00
7/17/06 12:40	0:00:00	2832:40:00	118.03	0	2750	153013	4.75	12.07
7/18/06 12:40	24:00:00	2856:40:00	119.03			153013	0.00	0.00
7/18/06 12:40	0:00:00	2856:40:00	119.03	0	2500	155513	4.50	11.43
7/19/06 13:35	24:55:00	2881:35:00	120.07			155513	0.00	0.00
7/19/06 13:35	0:00:00	2881:35:00	120.07	0	2000	157513	4.94	12.54
7/20/06 12:00	22:25:00	2904:00:00	121.00			157513	0.00	0.00

7/20/06 12:00	0:00:00	2904:00:00	121.00	0	2750	160263	8.75	22.23
7/21/06 13:35	25:35:00	2929:35:00	122.07			160263	0.00	0.00
7/21/06 13:35	0:00:00	2929:35:00	122.07	0	2750	163013	9.75	24.77
7/22/06 14:00	24:25:00	2954:00:00	123.08			163013	0.00	0.00
7/22/06 14:00	0:00:00	2954:00:00	123.08	0	2000	165013	9.25	23.50
7/23/06 13:40	23:40:00	2977:40:00	124.07			165013	0.00	0.00
7/23/06 13:40	0:00:00	2977:40:00	124.07	0	2500	167513	7.19	18.26
7/24/06 12:40	23:00:00	3000:40:00	125.03			167513	0.00	0.00
7/24/06 12:40	0:00:00	3000:40:00	125.03	0	2750	170263	8.00	20.32
7/25/06 12:30	23:50:00	3024:30:00	126.02			170263	0.00	0.00
7/25/06 12:30	0:00:00	3024:30:00	126.02	0	3000	173263	10.75	27.31
7/26/06 13:30	25:00:00	3049:30:00	127.06			173263	0.00	0.00
7/26/06 13:30	0:00:00	3049:30:00	127.06	0	1750	175013	10.13	25.72
7/27/06 13:00	23:30:00	3073:00:00	128.04			175013	0.00	0.00
7/27/06 13:00	0:00:00	3073:00:00	128.04	0	1000	176013	10.63	26.99
7/28/06 12:35	23:35:00	3096:35:00	129.02			176013	0.00	0.00
7/28/06 12:35	0:00:00	3096:35:00	129.02	0	1750	177763	10.44	26.51
7/29/06 13:00	24:25:00	3121:00:00	130.04			177763	0.00	0.00
7/29/06 13:00	0:00:00	3121:00:00	130.04	0	1250	179013	9.50	24.13
7/30/06 13:30	24:30:00	3145:30:00	131.06			179013	0.00	0.00
7/30/06 13:30	0:00:00	3145:30:00	131.06	0	1000	180013	10.50	26.67
7/31/06 13:30	24:00:00	3169:30:00	132.06			180013	0.00	0.00
7/31/06 13:30	0:00:00	3169:30:00	132.06	0	1500	181513	6.50	16.51
8/1/06 12:00	22:30:00	3192:00:00	133.00			181513	0.00	0.00
8/1/06 12:00	0:00:00	3192:00:00	133.00	0	2000	183513	6.25	15.88
8/2/06 11:03	23:03:00	3215:03:00	133.96			183513	0.00	0.00
8/2/06 11:03	0:00:00	3215:03:00	133.96	0	2150	185663	6.00	15.24
8/4/06 13:35	50:32:00	3265:35:00	136.07			185663	0.00	0.00
8/4/06 13:35	0:00:00	3265:35:00	136.07	0	3000	188663	8.25	20.96
8/5/06 13:45	24:10:00	3289:45:00	137.07			188663	0.00	0.00
8/5/06 13:45	0:00:00	3289:45:00	137.07	0	2500	191163	9.88	25.08
8/6/06 13:20	23:35:00	3313:20:00	138.06			191163	0.00	0.00
8/6/06 13:20	0:00:00	3313:20:00	138.06	0	2500	193663	10.06	25.56
8/8/06 12:00	46:40:00	3360:00:00	140.00			193663	0.00	0.00
8/8/06 12:00	0:00:00	3360:00:00	140.00	0	4250	197913	10.13	25.72
8/9/06 14:00	26:00:00	3386:00:00	141.08			197913	0.00	0.00
8/9/06 14:00	0:00:00	3386:00:00	141.08	0	3000	200913	10.50	26.67
8/10/06 15:00	25:00:00	3411:00:00	142.13			200913	0.00	0.00
8/10/06 15:00	0:00:00	3411:00:00	142.13	0	1750	202663	9.75	24.77
8/11/06 13:00	22:00:00	3433:00:00	143.04			202663	0.00	0.00
8/11/06 13:00	0:00:00	3433:00:00	143.04	0	1500	204163	10.06	25.56
8/12/06 13:30	24:30:00	3457:30:00	144.06			204163	2.50	6.35
8/12/06 13:30	0:00:00	3457:30:00	144.06	2.5	1000	205163	11.25	28.58
8/13/06 13:30	24:00:00	3481:30:00	145.06			205163	5.06	12.85
8/13/06 13:30	0:00:00	3481:30:00	145.06	5.06	500	205663	10.25	26.04
8/14/06 16:00	26:30:00	3508:00:00	146.17			205663	0.00	0.00
8/14/06 16:00	0:00:00	3508:00:00	146.17	0	1000	206663	10.50	26.67
8/15/06 17:00	25:00:00	3533:00:00	147.21			206663	0.00	0.00

8/15/06 17:00	0:00:00	3533:00:00	147.21	0	1000	207663	10.50	26.67
8/16/06 16:00	23:00:00	3556:00:00	148.17			207663	0.00	0.00
8/16/06 16:00	0:00:00	3556:00:00	148.17	0	1000	208663	10.38	26.35
8/17/06 20:00	28:00:00	3584:00:00	149.33			208663	0.00	0.00
8/17/06 20:00	0:00:00	3584:00:00	149.33	0	1000	209663	10.50	26.67
8/18/06 7:30	11:30:00	3595:30:00	149.81			209663	2.94	7.47
8/18/06 7:30	0:00:00	3595:30:00	149.81	2.94	0	209663	2.94	7.46
Reactor 2 - No trees with BTEX water								
Date	Time (hr)	Total Time (hr)	Total Time (days)	H2O Height (in)	Water Added (mL)	Total Water Added (mL)	H2O Final Height (in)	H2O Final Height (cm)
5/4/06 16:13	0:00:00	0:00:00	0.00			0	0.00	0.00
5/4/06 16:13	0:00:00	0:00:00	0.00	0.00	1000	1000	12.00	30.48
5/9/06 13:30	117:17:00	117:17:00	4.89			1000	0.00	0.00
5/9/06 13:30	0:00:00	117:17:00	4.89	0.00	2614	3614	6.50	16.51
5/10/06 11:30	22:00:00	139:17:00	5.80			3614	5.38	13.65
5/10/06 11:30	0:00:00	139:17:00	5.80	5.38	0	3614	5.38	13.65
5/10/06 12:00	0:30:00	139:47:00	5.82			3614	9.13	23.18
5/10/06 12:00	0:00:00	139:47:00	5.82	9.13	0	3614	9.13	23.18
5/11/06 15:00	27:00:00	166:47:00	6.95			3614	0.00	0.00
5/11/06 15:00	0:00:00	166:47:00	6.95	0.00	572	4186	10.63	26.99
5/12/06 11:00	20:00:00	186:47:00	7.78			4186	9.50	24.13
5/12/06 11:00	0:00:00	186:47:00	7.78	9.50	0	4186	9.50	24.13
5/15/06 11:00	72:00:00	258:47:00	10.78			4186	0.00	0.00
5/15/06 11:00	0:00:00	258:47:00	10.78	0.00	500	4686	12.00	30.48
5/19/06 16:30	101:30:00	360:17:00	15.01			4686	0.00	0.00
5/19/06 16:30	0:00:00	360:17:00	15.01	0.00	1750	6436	10.75	27.31
5/20/06 6:45	14:15:00	374:32:00	15.61			6436	4.31	10.95
5/20/06 6:45	0:00:00	374:32:00	15.61	4.31		6436	4.31	10.95
5/21/06 23:45	41:00:00	415:32:00	17.31			6436	0.00	0.00
5/21/06 23:45	0:00:00	415:32:00	17.31	0.00	250	6686	7.25	18.42
5/22/06 16:03	16:18:00	431:50:00	17.99			6686	4.00	10.16
5/22/06 16:03	0:00:00	431:50:00	17.99	4.00	0	6686	4.00	10.16
5/23/06 15:30	23:27:00	455:17:00	18.97			6686	0.00	0.00
5/23/06 15:30	0:00:00	455:17:00	18.97	0.00	250	6936	4.25	10.80
5/24/06 15:30	24:00:00	479:17:00	19.97			6936	0.00	0.00
5/24/06 15:30	0:00:00	479:17:00	19.97	0.00	250	7186	3.25	8.26
5/25/06 14:00	22:30:00	501:47:00	20.91			7186	0.00	0.00
5/25/06 14:00	0:00:00	501:47:00	20.91	0.00	1250	8436	10.25	26.04
5/26/06 21:00	31:00:00	532:47:00	22.20			8436	10.25	26.04
5/26/06 21:00	0:00:00	532:47:00	22.20	10.25	250	8686	11.25	28.58
5/27/06 21:00	24:00:00	556:47:00	23.20			8686	0.00	0.00
5/27/06 21:00	0:00:00	556:47:00	23.20	0.00	250	8936	0.00	0.00
5/28/06 14:00	17:00:00	573:47:00	23.91			8936	0.00	0.00
5/28/06 14:00	0:00:00	573:47:00	23.91	0.00	250	9186	9.13	23.18
5/30/06 14:00	48:00:00	621:47:00	25.91			9186	0.00	0.00
5/30/06 14:00	0:00:00	621:47:00	25.91	0.00	500	9686	2.50	6.35

6/1/06 14:30	48:30:00	670:17:00	27.93			9686	0.00	0.00
6/1/06 14:30	0:00:00	670:17:00	27.93	0.00	1000	10686	6.63	16.83
6/2/06 15:00	24:30:00	694:47:00	28.95			10686	6.50	16.51
6/2/06 15:00	0:00:00	694:47:00	28.95	6.50	0	10686	6.50	16.51
6/5/06 16:00	73:00:00	767:47:00	31.99			10686	1.13	2.86
6/5/06 16:00	0:00:00	767:47:00	31.99	1.13	500	11186	9.56	24.29
6/6/06 12:00	20:00:00	787:47:00	32.82			11186	7.81	19.84
6/6/06 12:00	0:00:00	787:47:00	32.82	7.81	0	11186	7.81	19.84
6/7/06 11:00	23:00:00	810:47:00	33.78			11186	7.13	18.11
6/7/06 11:00	0:00:00	810:47:00	33.78	7.13	0	11186	7.13	18.10
6/8/06 13:30	26:30:00	837:17:00	34.89			11186	2.81	7.14
6/8/06 13:30	0:00:00	837:17:00	34.89	2.81	250	11436	8.25	20.96
6/9/06 13:25	23:55:00	861:12:00	35.88			11436	9.25	23.50
6/9/06 13:25	0:00:00	861:12:00	35.88	9.25	0	11436	9.25	23.50
6/10/06 13:30	24:05:00	885:17:00	36.89			11436	7.00	17.78
6/10/06 13:30	0:00:00	885:17:00	36.89	7.00	0	11436	7.00	17.78
6/11/06 15:30	26:00:00	911:17:00	37.97			11436	1.38	3.51
6/11/06 15:30	0:00:00	911:17:00	37.97	1.38	250	11686	7.50	19.05
6/12/06 12:10	20:40:00	931:57:00	38.83			11686	6.00	15.24
6/12/06 12:10	0:00:00	931:57:00	38.83	6.00	0	11686	6.00	15.24
6/13/06 13:00	24:50:00	956:47:00	39.87			11686	7.50	19.05
6/13/06 13:00	0:00:00	956:47:00	39.87	7.50	0	11686	7.50	19.05
6/14/06 10:50	21:50:00	978:37:00	40.78			11686	6.44	16.36
6/14/06 10:50	0:00:00	978:37:00	40.78	6.44	0	11686	6.44	16.35
6/15/06 6:30	19:40:00	998:17:00	41.60			11686	1.25	3.18
6/15/06 6:30	0:00:00	998:17:00	41.60	1.25	250	11936	8.00	20.32
6/16/06 14:00	31:30:00	1029:47:00	42.91			11936	8.94	22.71
6/16/06 14:00	0:00:00	1029:47:00	42.91	8.94	0	11936	8.94	22.70
6/17/06 13:10	23:10:00	1052:57:00	43.87			11936	8.25	20.96
6/17/06 13:10	0:00:00	1052:57:00	43.87	8.25	0	11936	8.25	20.96
6/18/06 14:15	25:05:00	1078:02:00	44.92			11936	8.38	21.29
6/18/06 14:15	0:00:00	1078:02:00	44.92	8.38	0	11936	8.38	21.27
6/19/06 13:20	23:05:00	1101:07:00	45.88			11936	8.75	22.23
6/19/06 13:20	0:00:00	1101:07:00	45.88	8.75	0	11936	8.75	22.23
6/20/06 14:15	24:55:00	1126:02:00	46.92			11936	8.50	21.59
6/20/06 14:15	0:00:00	1126:02:00	46.92	8.50	0	11936	8.50	21.59
6/21/06 12:50	22:35:00	1148:37:00	47.86			11936	8.50	21.59
6/21/06 12:50	0:00:00	1148:37:00	47.86	8.50	0	11936	8.50	21.59
6/22/06 13:30	24:40:00	1173:17:00	48.89			11936	7.56	19.20
6/22/06 13:30	0:00:00	1173:17:00	48.89	7.56	0	11936	7.56	19.20
6/23/06 14:00	24:30:00	1197:47:00	49.91			11936	6.00	15.24
6/23/06 14:00	0:00:00	1197:47:00	49.91	6.00	0	11936	6.00	15.24
6/24/06 14:00	24:00:00	1221:47:00	50.91			11936	5.75	14.61
6/24/06 14:00	0:00:00	1221:47:00	50.91	5.75	0	11936	5.75	14.61
6/25/06 13:45	23:45:00	1245:32:00	51.90			11936	5.56	14.12
6/25/06 13:45	0:00:00	1245:32:00	51.90	5.56	0	11936	5.56	14.12
6/26/06 12:55	23:10:00	1268:42:00	52.86			11936	3.00	7.62
6/26/06 12:55	0:00:00	1268:42:00	52.86	3.00	0	11936	3.00	7.62

6/27/06 12:50	23:55:00	1292:37:00	53.86			11936	3.50	8.89
6/27/06 12:50	0:00:00	1292:37:00	53.86	3.50	0	11936	3.50	8.89
6/28/06 13:30	24:40:00	1317:17:00	54.89			11936	3.81	9.68
6/28/06 13:30	0:00:00	1317:17:00	54.89	3.81	0	11936	3.81	9.68
6/29/06 13:00	23:30:00	1340:47:00	55.87			11936	2.50	6.35
6/29/06 13:00	0:00:00	1340:47:00	55.87	2.50	250	12186	8.00	20.32
6/30/06 13:40	24:40:00	1365:27:00	56.89			12186	8.50	21.59
6/30/06 13:40	0:00:00	1365:27:00	56.89	8.50	0	12186	8.50	21.59
7/1/06 13:00	23:20:00	1388:47:00	57.87			12186	9.25	23.50
7/1/06 13:00	0:00:00	1388:47:00	57.87	9.25	0	12186	9.25	23.50
7/2/06 13:27	24:27:00	1413:14:00	58.88			12186	8.13	20.65
7/2/06 13:27	0:00:00	1413:14:00	58.88	8.13	0	12186	8.13	20.65
7/3/06 13:00	23:33:00	1436:47:00	59.87			12186	9.50	24.13
7/3/06 13:00	0:00:00	1436:47:00	59.87	9.50	0	12186	9.50	24.13
7/4/06 15:00	26:00:00	1462:47:00	60.95			12186	5.00	12.70
7/4/06 15:00	0:00:00	1462:47:00	60.95	5.00	0	12186	5.00	12.70
7/5/06 11:30	20:30:00	1483:17:00	61.80			12186	2.63	6.68
7/5/06 11:30	0:00:00	1483:17:00	61.80	2.63	500	12686	8.69	22.07
7/6/06 13:00	25:30:00	1508:47:00	62.87			12686	8.75	22.23
7/6/06 13:00	0:00:00	1508:47:00	62.87	8.75	0	12686	8.75	22.23
7/7/06 12:00	23:00:00	1531:47:00	63.82			12686	8.56	21.74
7/7/06 12:00	0:00:00	1531:47:00	63.82	8.56	0	12686	8.56	21.75
7/10/06 13:45	73:45:00	1605:32:00	66.90			12686	8.00	20.32
7/10/06 13:45	0:00:00	1605:32:00	66.90	8.00	0	12686	8.00	20.32
7/11/06 12:37	22:52:00	1628:24:00	67.85			12686	9.25	23.50
7/11/06 12:37	0:00:00	1628:24:00	67.85	9.25	0	12686	9.25	23.50
7/12/06 14:00	25:23:00	1653:47:00	68.91			12686	8.75	22.23
7/12/06 14:00	0:00:00	1653:47:00	68.91	8.75	0	12686	8.75	22.23
7/13/06 12:04	22:04:00	1675:51:00	69.83			12686	9.00	22.86
7/13/06 12:04	0:00:00	1675:51:00	69.83	9.00	0	12686	9.00	22.86
7/14/06 13:30	25:26:00	1701:17:00	70.89			12686	8.50	21.59
7/14/06 13:30	0:00:00	1701:17:00	70.89	8.50	0	12686	8.50	21.59
7/15/06 10:00	20:30:00	1721:47:00	71.74			12686	8.75	22.23
7/15/06 10:00	0:00:00	1721:47:00	71.74	8.75	0	12686	8.75	22.23
7/16/06 12:30	26:30:00	1748:17:00	72.85			12686	9.50	24.13
7/16/06 12:30	0:00:00	1748:17:00	72.85	9.50	0	12686	9.50	24.13
7/17/06 12:40	24:10:00	1772:27:00	73.85			12686	9.50	24.13
7/17/06 12:40	0:00:00	1772:27:00	73.85	9.50	0	12686	9.50	24.13
7/18/06 12:40	24:00:00	1796:27:00	74.85			12686	9.00	22.86
7/18/06 12:40	0:00:00	1796:27:00	74.85	9.00	0	12686	9.00	22.86
7/19/06 13:35	24:55:00	1821:22:00	75.89			12686	8.75	22.23
7/19/06 13:35	0:00:00	1821:22:00	75.89	8.75	0	12686	8.75	22.23
7/20/06 12:00	22:25:00	1843:47:00	76.82			12686	7.00	17.78
7/20/06 12:00	0:00:00	1843:47:00	76.82	7.00	0	12686	7.00	17.78
7/21/06 13:35	25:35:00	1869:22:00	77.89			12686	2.56	6.50
7/21/06 13:35	0:00:00	1869:22:00	77.89	2.56	250	12936	9.44	23.97
7/22/06 14:00	24:25:00	1893:47:00	78.91			12936	8.50	21.59
7/22/06 14:00	0:00:00	1893:47:00	78.91	8.50	0	12936	8.50	21.59

7/23/06 13:40	23:40:00	1917:27:00	79.89			12936	7.75	19.69
7/23/06 13:40	0:00:00	1917:27:00	79.89	7.75	0	12936	7.75	19.69
7/24/06 12:40	23:00:00	1940:27:00	80.85			12936	8.00	20.32
7/24/06 12:40	0:00:00	1940:27:00	80.85	8.00	0	12936	8.00	20.32
7/25/06 12:30	23:50:00	1964:17:00	81.85			12936	9.00	22.86
7/25/06 12:30	0:00:00	1964:17:00	81.85	9.00	0	12936	9.00	22.86
7/26/06 13:30	25:00:00	1989:17:00	82.89			12936	7.00	17.78
7/26/06 13:30	0:00:00	1989:17:00	82.89	7.00	0	12936	7.00	17.78
7/27/06 13:00	23:30:00	2012:47:00	83.87			12936	1.75	4.45
7/27/06 13:00	0:00:00	2012:47:00	83.87	1.75	250	13186	9.25	23.50
7/28/06 12:35	23:35:00	2036:22:00	84.85			13186	7.75	19.69
7/28/06 12:35	0:00:00	2036:22:00	84.85	7.75	0	13186	7.75	19.69
7/29/06 13:00	24:25:00	2060:47:00	85.87			13186	9.00	22.86
7/29/06 13:00	0:00:00	2060:47:00	85.87	9.00	0	13186	9.00	22.86
7/30/06 13:30	24:30:00	2085:17:00	86.89			13186	8.38	21.29
7/30/06 13:30	0:00:00	2085:17:00	86.89	8.38	0	13186	8.38	21.29
7/31/06 13:30	24:00:00	2109:17:00	87.89			13186	8.50	21.59
7/31/06 13:30	0:00:00	2109:17:00	87.89	8.50	0	13186	8.50	21.59
8/1/06 12:00	22:30:00	2131:47:00	88.82			13186	7.38	18.75
8/1/06 12:00	0:00:00	2131:47:00	88.82	7.38	0	13186	7.38	18.75
8/2/06 11:03	23:03:00	2154:50:00	89.78			13186	7.25	18.42
8/2/06 11:03	0:00:00	2154:50:00	89.78	7.25	0	13186	7.25	18.42
8/4/06 13:35	50:32:00	2205:22:00	91.89			13186	2.31	5.87
8/4/06 13:35	0:00:00	2205:22:00	91.89	2.31	250	13436	9.19	23.34
8/5/06 13:45	24:10:00	2229:32:00	92.90			13436	8.19	20.80
8/5/06 13:45	0:00:00	2229:32:00	92.90	8.19	0	13436	8.19	20.80
8/6/06 13:20	23:35:00	2253:07:00	93.88			13436	8.25	20.96
8/6/06 13:20	0:00:00	2253:07:00	93.88	8.25	0	13436	8.25	20.96
8/8/06 12:00	46:40:00	2299:47:00	95.82			13436	6.88	17.48
8/8/06 12:00	0:00:00	2299:47:00	95.82	6.88	0	13436	6.88	17.48
8/9/06 14:00	26:00:00	2325:47:00	96.91			13436	7.19	18.26
8/9/06 14:00	0:00:00	2325:47:00	96.91	7.19	0	13436	7.19	18.26
8/10/06 15:00	25:00:00	2350:47:00	97.95			13436	2.50	6.35
8/10/06 15:00	0:00:00	2350:47:00	97.95	2.50	250	13686	9.25	23.50
8/11/06 9:45	18:45:00	2369:32:00	98.73			13686	6.63	16.84
8/11/06 9:45	0:00:00	2369:32:00	98.73	6.63	0	13686	6.63	16.84
8/12/06 13:30	27:45:00	2397:17:00	99.89			13686	9.75	24.77
8/12/06 13:30	0:00:00	2397:17:00	99.89	9.75	0	13686	9.75	24.77
8/13/06 13:30	24:00:00	2421:17:00	100.89			13686	8.75	22.23
8/13/06 13:30	0:00:00	2421:17:00	100.89	8.75	0	13686	8.75	22.23
8/14/06 9:00	19:30:00	2440:47:00	101.70			13686	7.75	19.69
8/14/06 9:00	0:00:00	2440:47:00	101.70	7.75	0	13686	7.75	19.69
Reactor 3 - Trees with uncontaminated water								
Date	Time (hr)	Total Time (hr)	Total Time (days)	H2O Height (in)	Water Added (mL)	Total Water Added (mL)	H2O Final Height (in)	H2O Final Height (cm)
3/20/06 12:00	0:00:00	0:00	0.00	0.00	6835		0.00	0.00

3/23/06 12:00	72:00:00	72:00:00	3.00	0.00	800	7635	9.38	23.81
3/24/06 15:00	27:00:00	99:00:00	4.13			7635	8.44	21.44
3/24/06 15:00	0:00:00	99:00:00	4.13	8.44	0	7635	8.44	21.43
3/28/06 12:00	93:00:00	192:00:00	8.00			7635	0.00	0.00
3/28/06 12:00	0:00:00	192:00:00	8.00	0.00	250	7885	7.00	17.78
4/4/06 12:30	168:30:00	360:30:00	15.02			7885	0.00	0.00
4/4/06 12:30	0:00:00	360:30:00	15.02	0.00	1000	8885	6.88	17.46
4/5/06 10:30	22:00:00	382:30:00	15.94			8885	0.00	0.00
4/5/06 10:30	0:00:00	382:30:00	15.94	0.00	775	9660	12.00	30.48
4/6/06 12:00	25:30:00	408:00:00	17.00			9660	8.63	21.92
4/6/06 12:00	0:00:00	408:00:00	17.00	8.63	0	9660	8.63	21.91
4/7/06 12:30	24:30:00	432:30:00	18.02			9660	8.63	21.92
4/7/06 12:30	0:00:00	432:30:00	18.02	8.63	0	9660	8.63	21.91
4/9/06 16:00	51:30:00	484:00:00	20.17			9660	0.00	0.00
4/9/06 16:00	0:00:00	484:00:00	20.17	0.00	500	10160	8.00	20.32
4/10/06 14:40	22:40:00	506:40:00	21.11			10160	0.00	0.00
4/10/06 14:40	0:00:00	506:40:00	21.11	0.00	500	10660	12.00	30.48
4/11/06 10:30	19:50:00	526:30:00	21.94			10660	7.50	19.05
4/11/06 10:30	0:00:00	526:30:00	21.94	7.50	0	10660	7.50	19.05
4/12/06 15:40	29:10:00	555:40:00	23.15			10660	0.00	0.00
4/12/06 15:40	0:00:00	555:40:00	23.15	0.00	500	11160	9.06	23.02
4/13/06 14:00	22:20:00	578:00:00	24.08			11160	5.50	13.97
4/13/06 14:00	0:00:00	578:00:00	24.08	5.50	0	11160	5.50	13.97
4/14/06 17:00	27:00:00	605:00:00	25.21			11160	0.00	0.00
4/14/06 17:00	0:00:00	605:00:00	25.21	0.00	500	11660	3.44	8.73
4/15/06 11:00	18:00:00	623:00:00	25.96			11660	0.00	0.00
4/15/06 11:00	0:00:00	623:00:00	25.96	0.00	500	12160	12.00	30.48
4/16/06 11:00	24:00:00	647:00:00	26.96			12160	0.00	0.00
4/16/06 11:00	0:00:00	647:00:00	26.96	0.00	500	12660	12.00	30.48
4/17/06 10:30	23:30:00	670:30:00	27.94			12660	0.00	0.00
4/17/06 10:30	0:00:00	670:30:00	27.94	0.00	500	13160	10.38	26.35
4/18/06 10:30	24:00:00	694:30:00	28.94			13160	8.75	22.23
4/18/06 10:30	0:00:00	694:30:00	28.94	8.75	0	13160	8.75	22.23
4/19/06 15:00	28:30:00	723:00:00	30.13			13160	0.00	0.00
4/19/06 15:00	0:00:00	723:00:00	30.13	0.00	500	13660	7.56	19.21
4/20/06 11:00	20:00:00	743:00:00	30.96			13660	0.00	0.00
4/20/06 11:00	0:00:00	743:00:00	30.96	0.00	200	13860	11.13	28.26
4/21/06 12:00	25:00:00	768:00:00	32.00			13860	0.00	0.00
4/21/06 12:00	0:00:00	768:00:00	32.00	0.00	500	14360	11.50	29.21
4/24/06 12:00	72:00:00	840:00:00	35.00			14360	0.00	0.00
4/24/06 12:00	0:00:00	840:00:00	35.00	0.00	1000	15360	10.56	26.83
4/25/06 12:45	24:45:00	864:45:00	36.03			15360	4.25	10.80
4/25/06 12:45	0:00:00	864:45:00	36.03	4.25	0	15360	4.25	10.80
4/26/06 11:00	22:15:00	887:00:00	36.96			15360	0.00	0.00
4/26/06 11:00	0:00:00	887:00:00	36.96	0.00	500	15860	11.50	29.21
4/27/06 12:45	25:45:00	912:45:00	38.03			15860	4.06	10.31
4/27/06 12:45	0:00:00	912:45:00	38.03	4.06	0	15860	4.06	10.32
4/27/06 15:00	2:15:00	915:00:00	38.13			15860	1.25	3.18

4/27/06 15:00	0:00:00	915:00:00	38.13	1.25	250	16110	12.00	30.48
4/28/06 13:00	22:00:00	937:00:00	39.04			16110	0.00	0.00
4/28/06 13:00	0:00:00	937:00:00	39.04	0.00	500	16610	12.00	30.48
5/1/06 12:00	71:00:00	1008:00:00	42.00			16610	0.00	0.00
5/1/06 12:00	0:00:00	1008:00:00	42.00	0.00	500	17110	11.81	30.00
5/1/06 13:30	1:30:00	1009:30:00	42.06			17110	8.25	20.96
5/1/06 13:30	0:00:00	1009:30:00	42.06	8.25	0	17110	8.25	20.96
5/2/06 12:30	23:00:00	1032:30:00	43.02			17110	0.00	0.00
5/2/06 12:30	0:00:00	1032:30:00	43.02	0.00	500	17610	11.63	29.53
5/3/06 13:30	25:00:00	1057:30:00	44.06			17610	0.00	0.00
5/3/06 13:30	0:00:00	1057:30:00	44.06	0.00	500	18110	10.44	26.51
5/4/06 10:30	21:00:00	1078:30:00	44.94			18110	0.00	0.00
5/4/06 10:30	0:00:00	1078:30:00	44.94	0.00	500	18610	9.38	23.81
5/6/06 5:00	42:30:00	1121:00:00	46.71			18610	0.00	0.00
5/6/06 5:00	0:00:00	1121:00:00	46.71	0.00	750	19360	0.00	0.00
5/7/06 21:00	40:00:00	1161:00:00	48.38			19360	0.00	0.00
5/7/06 21:00	0:00:00	1161:00:00	48.38	0.00	500	19860	10.00	25.40
5/9/06 13:30	40:30:00	1201:30:00	50.06			19860	0.00	0.00
5/9/06 13:30	0:00:00	1201:30:00	50.06	0.00	1000	20860	12.00	30.48
5/10/06 11:30	22:00:00	1223:30:00	50.98			20860	8.63	21.92
5/10/06 11:30	0:00:00	1223:30:00	50.98	8.63	0	20860	8.63	21.92
5/11/06 15:00	27:30:00	1251:00:00	52.13			20860	0.00	0.00
5/11/06 15:00	0:00:00	1251:00:00	52.13	0.00	500	21360	10.69	27.15
5/12/06 11:00	20:00:00	1271:00:00	52.96			21360	0.00	0.00
5/12/06 11:00	0:00:00	1271:00:00	52.96	0.00	1000	22360	10.38	26.35
5/15/06 11:00	72:00:00	1343:00:00	55.96			22360	0.00	0.00
5/15/06 11:00	0:00:00	1343:00:00	55.96	0.00	1875	24235	9.50	24.13
5/19/06 16:30	101:30:00	1444:30:00	60.19			24235	0.00	0.00
5/19/06 16:30	0:00:00	1444:30:00	60.19	0.00	3000	27235	10.88	27.62
5/20/06 6:45	14:15:00	1458:45:00	60.78			27235	5.69	14.45
5/20/06 6:45	0:00:00	1458:45:00	60.78	5.69	500	27735	11.50	29.21
5/21/06 23:45	41:00:00	1499:45:00	62.49			27735	0.00	0.00
5/21/06 23:45	0:00:00	1499:45:00	62.49	0.00	1000	28735	3.88	9.84
5/22/06 16:03	16:18:00	1516:03:00	63.17			28735	0.00	0.00
5/22/06 16:03	0:00:00	1516:03:00	63.17	0.00	500	29235	4.75	12.07
5/23/06 15:30	23:27:00	1539:30:00	64.15			29235	0.00	0.00
5/23/06 15:30	0:00:00	1539:30:00	64.15	0.00	1000	30235	10.50	26.67
5/24/06 15:30	24:00:00	1563:30:00	65.15			30235	0.00	0.00
5/24/06 15:30	0:00:00	1563:30:00	65.15	0.00	1000	31235	6.25	15.88
5/25/06 14:00	22:30:00	1586:00:00	66.08			31235	0.00	0.00
5/25/06 14:00	0:00:00	1586:00:00	66.08	0.00	2000	33235	9.13	23.18
5/26/06 21:00	31:00:00	1617:00:00	67.38			33235	0.00	0.00
5/26/06 21:00	0:00:00	1617:00:00	67.38	0.00	2900	36135	12.00	30.48
5/27/06 21:00	24:00:00	1641:00:00	68.38			36135	0.00	0.00
5/27/06 21:00	0:00:00	1641:00:00	68.38	0.00	1000	37135	0.00	0.00
5/28/06 14:00	17:00:00	1658:00:00	69.08			37135	0.00	0.00
5/28/06 14:00	0:00:00	1658:00:00	69.08	0.00	1500	38635	9.25	23.50
5/30/06 14:00	48:00:00	1706:00:00	71.08			38635	0.00	0.00

5/30/06 14:00	0:00:00	1706:00:00	71.08	0.00	750	39385	2.00	5.08
6/1/06 14:30	48:30:00	1754:30:00	73.10			39385	0.00	0.00
6/1/06 14:30	0:00:00	1754:30:00	73.10	0.00	3000	42385	4.25	10.80
6/2/06 15:00	24:30:00	1779:00:00	74.13			42385	0.00	0.00
6/2/06 15:00	0:00:00	1779:00:00	74.13	0.00	2500	44885	7.00	17.78
6/5/06 16:00	73:00:00	1852:00:00	77.17			44885	0.00	0.00
6/5/06 16:00	0:00:00	1852:00:00	77.17	0.00	5000	49885	10.75	27.31
6/6/06 12:00	20:00:00	1872:00:00	78.00			49885	0.00	0.00
6/6/06 12:00	0:00:00	1872:00:00	78.00	0.00	1000	50885	8.38	21.27
6/6/06 14:45	2:45:00	1874:45:00	78.11			50885	0.00	0.00
6/6/06 14:45	0:00:00	1874:45:00	78.11	0.00	500	51385	9.31	23.65
6/7/06 11:00	20:15:00	1895:00:00	78.96			51385	0.00	0.00
6/7/06 11:00	0:00:00	1895:00:00	78.96	0	2000	53385	9.50	24.13
6/8/06 13:30	26:30:00	1921:30:00	80.06			53385	0.00	0.00
6/8/06 13:30	0:00:00	1921:30:00	80.06	0	1500	54885	9.63	24.45
6/9/06 13:25	23:55:00	1945:25:00	81.06			54885	0.00	0.00
6/9/06 13:25	0:00:00	1945:25:00	81.06	0	1500	56385	6.25	15.88
6/10/06 13:30	24:05:00	1969:30:00	82.06			56385	0.00	0.00
6/10/06 13:30	0:00:00	1969:30:00	82.06	0	2000	58385	7.38	18.73
6/11/06 15:30	26:00:00	1995:30:00	83.15			58385	0.00	0.00
6/11/06 15:30	0:00:00	1995:30:00	83.15	0	1500	59885	8.93	22.68
6/12/06 12:10	20:40:00	2016:10:00	84.01			59885	0.00	0.00
6/12/06 12:10	0:00:00	2016:10:00	84.01	0	1000	60885	9.63	24.45
6/13/06 13:00	24:50:00	2041:00:00	85.04			60885	0.00	0.00
6/13/06 13:00	0:00:00	2041:00:00	85.04	0	1500	62385	8.25	20.96
6/14/06 10:50	21:50:00	2062:50:00	85.95			62385	0.00	0.00
6/14/06 10:50	0:00:00	2062:50:00	85.95	0	2000	64385	2.13	5.40
6/15/06 6:30	19:40:00	2082:30:00	86.77			64385	0.00	0.00
6/15/06 6:30	0:00:00	2082:30:00	86.77	0	1500	65885	9.25	23.50
6/16/06 14:00	31:30:00	2114:00:00	88.08			65885	0.00	0.00
6/16/06 14:00	0:00:00	2114:00:00	88.08	0	1500	67385	2.25	5.72
6/17/06 13:10	23:10:00	2137:10:00	89.05			67385	0.00	0.00
6/17/06 13:10	0:00:00	2137:10:00	89.05	0	1000	68385	2.25	5.72
6/18/06 14:15	25:05:00	2162:15:00	90.09			68385	0.00	0.00
6/18/06 14:15	0:00:00	2162:15:00	90.09	0	1500	69885	0.25	0.64
6/19/06 13:20	23:05:00	2185:20:00	91.06			69885	0.00	0.00
6/19/06 13:20	0:00:00	2185:20:00	91.06	0	2000	71885	2.00	5.08
6/20/06 14:15	24:55:00	2210:15:00	92.09			71885	0.00	0.00
6/20/06 14:15	0:00:00	2210:15:00	92.09	0	2500	74385	9.50	24.13
6/21/06 12:50	22:35:00	2232:50:00	93.03			74385	0.00	0.00
6/21/06 12:50	0:00:00	2232:50:00	93.03	0	2500	76885	6.38	16.19
6/22/06 13:30	24:40:00	2257:30:00	94.06			76885	0.00	0.00
6/22/06 13:30	0:00:00	2257:30:00	94.06	0	1950	78835	0.25	0.64
6/23/06 14:00	24:30:00	2282:00:00	95.08			78835	0.00	0.00
6/23/06 14:00	0:00:00	2282:00:00	95.08	0	1500	80335	0.25	0.64
6/24/06 14:00	24:00:00	2306:00:00	96.08			80335	0.00	0.00
6/24/06 14:00	0:00:00	2306:00:00	96.08	0	2000	82335	1.25	3.18
6/25/06 13:45	23:45:00	2329:45:00	97.07			82335	0.00	0.00

6/25/06 13:45	0:00:00	2329:45:00	97.07	0	1500	83835	0.25	0.64
6/26/06 12:55	23:10:00	2352:55:00	98.04			83835	0.00	0.00
6/26/06 12:55	0:00:00	2352:55:00	98.04	0	2000	85835	1.50	3.81
6/27/06 12:50	23:55:00	2376:50:00	99.03			85835	0.00	0.00
6/27/06 12:50	0:00:00	2376:50:00	99.03	0	2000	87835	1.00	2.54
6/28/06 13:30	24:40:00	2401:30:00	100.06			87835	0.00	0.00
6/28/06 13:30	0:00:00	2401:30:00	100.06	0	2000	89835	1.06	2.70
6/29/06 13:00	23:30:00	2425:00:00	101.04			89835	0.00	0.00
6/29/06 13:00	0:00:00	2425:00:00	101.04	0	2000	91835	1.00	2.54
6/30/06 13:40	24:40:00	2449:40:00	102.07			91835	0.00	0.00
6/30/06 13:40	0:00:00	2449:40:00	102.07	0	1250	93085	0.19	0.48
7/1/06 13:00	23:20:00	2473:00:00	103.04			93085	0.00	0.00
7/1/06 13:00	0:00:00	2473:00:00	103.04	0	2000	95085	0.75	1.91
7/2/06 13:27	24:27:00	2497:27:00	104.06			95085	0.00	0.00
7/2/06 13:27	0:00:00	2497:27:00	104.06	0	2500	97585	0.81	2.06
7/3/06 13:00	23:33:00	2521:00:00	105.04			97585	0.00	0.00
7/3/06 13:00	0:00:00	2521:00:00	105.04	0	2500	100085	0.75	1.91
7/4/06 15:00	26:00:00	2547:00:00	106.13			100085	0.00	0.00
7/4/06 15:00	0:00:00	2547:00:00	106.13	0	1500	101585	0.75	1.91
7/5/06 11:30	20:30:00	2567:30:00	106.98			101585	0.00	0.00
7/5/06 11:30	0:00:00	2567:30:00	106.98	0	3460	105045	8.75	22.23
7/6/06 13:00	25:30:00	2593:00:00	108.04			105045	0.00	0.00
7/6/06 13:00	0:00:00	2593:00:00	108.04	0	5500	110545	10.00	25.40
7/7/06 12:00	23:00:00	2616:00:00	109.00			110545	0.00	0.00
7/7/06 12:00	0:00:00	2616:00:00	109.00	0	1000	111545	7.75	19.69
7/10/06 13:45	73:45:00	2689:45:00	112.07			111545	0.00	0.00
7/10/06 13:45	0:00:00	2689:45:00	112.07	0	4000	115545	6.94	17.62
7/11/06 12:37	22:52:00	2712:37:00	113.03			115545	0.00	0.00
7/11/06 12:37	0:00:00	2712:37:00	113.03	0	2500	118045	10.50	26.67
7/12/06 14:00	25:23:00	2738:00:00	114.08			118045	0.00	0.00
7/12/06 14:00	0:00:00	2738:00:00	114.08	0	1000	119045	10.00	25.40
7/13/06 12:04	22:04:00	2760:04:00	115.00			119045	0.00	0.00
7/13/06 12:04	0:00:00	2760:04:00	115.00	0	1500	120545	10.25	26.04
7/14/06 13:30	25:26:00	2785:30:00	116.06			120545	0.00	0.00
7/14/06 13:30	0:00:00	2785:30:00	116.06	0	1000	121545	10.00	25.40
7/15/06 10:00	20:30:00	2806:00:00	116.92			121545	0.00	0.00
7/15/06 10:00	0:00:00	2806:00:00	116.92	0	1250	122795	10.00	25.40
7/16/06 12:30	26:30:00	2832:30:00	118.02			122795	0.00	0.00
7/16/06 12:30	0:00:00	2832:30:00	118.02	0	2750	125545	10.00	25.40
7/17/06 12:40	24:10:00	2856:40:00	119.03			125545	0.00	0.00
7/17/06 12:40	0:00:00	2856:40:00	119.03	0	2500	128045	10.75	27.31
7/18/06 12:40	24:00:00	2880:40:00	120.03			128045	0.00	0.00
7/18/06 12:40	0:00:00	2880:40:00	120.03	0	2000	130045	9.00	22.86
7/19/06 13:35	24:55:00	2905:35:00	121.07			130045	0.00	0.00
7/19/06 13:35	0:00:00	2905:35:00	121.07	0	2500	132545	4.88	12.38
7/20/06 12:00	22:25:00	2928:00:00	122.00			132545	0.00	0.00
7/20/06 12:00	0:00:00	2928:00:00	122.00	0	2500	135045	10.00	25.40
7/21/06 13:35	25:35:00	2953:35:00	123.07			135045	0.00	0.00

7/21/06 13:35	0:00:00	2953:35:00	123.07	0	2500	137545	9.63	24.45
7/22/06 14:00	24:25:00	2978:00:00	124.08			137545	0.00	0.00
7/22/06 14:00	0:00:00	2978:00:00	124.08	0	2500	140045	10.25	26.04
7/23/06 13:40	23:40:00	3001:40:00	125.07			140045	0.00	0.00
7/23/06 13:40	0:00:00	3001:40:00	125.07	0	2500	142545	9.13	23.18
7/24/06 12:40	23:00:00	3024:40:00	126.03			142545	0.00	0.00
7/24/06 12:40	0:00:00	3024:40:00	126.03	0	2500	145045	10.25	26.04
7/25/06 12:30	23:50:00	3048:30:00	127.02			145045	0.00	0.00
7/25/06 12:30	0:00:00	3048:30:00	127.02	0	2500	147545	10.50	26.67
7/26/06 13:30	25:00:00	3073:30:00	128.06			147545	0.00	0.00
7/26/06 13:30	0:00:00	3073:30:00	128.06	0	1950	149495	9.31	23.65
7/27/06 13:00	23:30:00	3097:00:00	129.04			149495	0.00	0.00
7/27/06 13:00	0:00:00	3097:00:00	129.04	0	965	150460	8.50	21.59
7/28/06 12:35	23:35:00	3120:35:00	130.02			150460	0.00	0.00
7/28/06 12:35	0:00:00	3120:35:00	130.02	0	1500	151960	10.19	25.88
7/29/06 13:00	24:25:00	3145:00:00	131.04			151960	0.00	0.00
7/29/06 13:00	0:00:00	3145:00:00	131.04	0	2000	153960	10.25	26.04
7/30/06 13:30	24:30:00	3169:30:00	132.06			153960	0.00	0.00
7/30/06 13:30	0:00:00	3169:30:00	132.06	0	1200	155160	10.88	27.62
7/31/06 13:30	24:00:00	3193:30:00	133.06			155160	0.00	0.00
7/31/06 13:30	0:00:00	3193:30:00	133.06	0	2000	157160	9.00	22.86
8/1/06 12:00	22:30:00	3216:00:00	134.00			157160	0.00	0.00
8/1/06 12:00	0:00:00	3216:00:00	134.00	0	1850	159010	9.50	24.13
8/2/06 11:03	23:03:00	3239:03:00	134.96			159010	0.00	0.00
8/2/06 11:03	0:00:00	3239:03:00	134.96	0	2000	161010	8.25	20.96
8/4/06 13:35	50:32:00	3289:35:00	137.07			161010	0.00	0.00
8/4/06 13:35	0:00:00	3289:35:00	137.07	0	3750	164760	8.75	22.23
8/5/06 13:45	24:10:00	3313:45:00	138.07			164760	0.00	0.00
8/5/06 13:45	0:00:00	3313:45:00	138.07	0	2500	167260	9.38	23.81
8/6/06 13:20	23:35:00	3337:20:00	139.06			167260	0.00	0.00
8/6/06 13:20	0:00:00	3337:20:00	139.06	0	2500	169760	10.13	25.72
8/8/06 12:00	46:40:00	3384:00:00	141.00			169760	0.00	0.00
8/8/06 12:00	0:00:00	3384:00:00	141.00	0	4500	174260	10.38	26.35
8/9/06 14:00	26:00:00	3410:00:00	142.08			174260	0.00	0.00
8/9/06 14:00	0:00:00	3410:00:00	142.08	0	2500	176760	9.44	23.97
8/10/06 15:00	25:00:00	3435:00:00	143.13			176760	0.00	0.00
8/10/06 15:00	0:00:00	3435:00:00	143.13	0	2000	178760	10.50	26.67
8/11/06 13:00	22:00:00	3457:00:00	144.04			178760	0.00	0.00
8/11/06 13:00	0:00:00	3457:00:00	144.04	0	1400	180160	10.75	27.31
8/12/06 13:30	24:30:00	3481:30:00	145.06			180160	0.00	0.00
8/12/06 13:30	0:00:00	3481:30:00	145.06	0	1200	181360	10.75	27.31
8/13/06 13:30	24:00:00	3505:30:00	146.06			181360	0.00	0.00
8/13/06 13:30	0:00:00	3505:30:00	146.06	0	900	182260	10.50	26.67
8/14/06 16:00	26:30:00	3532:00:00	147.17			182260	0.00	0.00
8/14/06 16:00	0:00:00	3532:00:00	147.17	0	1000	183260	10.75	27.31
8/15/06 17:00	25:00:00	3557:00:00	148.21			183260	0.00	0.00
8/15/06 17:00	0:00:00	3557:00:00	148.21	0	1000	184260	10.50	26.67
8/16/06 16:00	23:00:00	3580:00:00	149.17			184260	0.00	0.00

8/16/06 16:00	0:00:00	3580:00:00	149.17	0	915	185175	10.25	26.04
8/17/06 8:30	16:30:00	3596:30:00	149.85			185175	0.00	0.00
8/17/06 8:30	0:00:00	3596:30:00	149.85	0	0	185175	0.00	0.00
Reactor 4 - Disinfected Trees with BTEX water in Autoclaved Soil								
Date	Time (hr)	Total Time (hr)	Total Time (days)	H2O Height (in)	Water Added (mL)	Total Water Added (mL)	H2O Final Height (in)	H2O Final Height (cm)
3/22/06 12:00	0:00:00	0:00:00	0.00	0.00	5732		0.00	0.00
3/23/06 12:00	24:00:00	24:00:00	1.00				0.00	0.00
3/23/06 12:00	0:00:00	24:00:00	1.00	0.00	1000	6732	8.13	20.64
3/24/06 17:10	29:10:00	53:10:00	2.22				8.13	20.65
3/24/06 17:10	0:00:00	53:10:00	2.22	8.13	0	6732	8.13	20.64
3/28/06 12:00	90:50:00	144:00:00	6.00				0.00	0.00
3/28/06 12:00	0:00:00	144:00:00	6.00	0.00	250	6982	7.00	17.78
4/4/06 12:30	168:30:00	312:30:00	13.02				0.00	0.00
4/4/06 12:30	0:00:00	312:30:00	13.02	0.00	500	7482	8.50	21.59
4/5/06 10:30	22:00:00	334:30:00	13.94				1.50	3.81
4/5/06 10:30	0:00:00	334:30:00	13.94	1.50	350	7832	10.38	26.35
4/6/06 12:00	25:30:00	360:00:00	15.00				3.50	8.89
4/6/06 12:00	0:00:00	360:00:00	15.00	3.50	0	7832	3.50	8.89
4/7/06 12:30	24:30:00	384:30:00	16.02				8.50	21.59
4/7/06 12:30	0:00:00	384:30:00	16.02	8.50	0	7832	8.50	21.59
4/9/06 16:00	51:30:00	436:00:00	18.17				0.00	0.00
4/9/06 16:00	0:00:00	436:00:00	18.17	0.00	0	7832	0.00	0.00
4/12/06 14:30	70:30:00	506:30:00	21.10				0.00	0.00
4/12/06 14:30	0:00:00	506:30:00	21.10	0.00	1000	8832	8.75	22.23
4/13/06 14:00	23:30:00	530:00:00	22.08				0.00	0.00
4/13/06 14:00	0:00:00	530:00:00	22.08	0.00	250	9082	8.75	22.23
4/14/06 17:00	27:00:00	557:00:00	23.21				0.00	0.00
4/14/06 17:00	0:00:00	557:00:00	23.21	0.00	250	9332	6.94	17.62
4/15/06 11:00	18:00:00	575:00:00	23.96				0.00	0.00
4/15/06 11:00	0:00:00	575:00:00	23.96	0.00	500	9832	9.00	22.86
4/16/06 11:00	24:00:00	599:00:00	24.96				9.13	23.19
4/16/06 11:00	0:00:00	599:00:00	24.96	9.13	0	9832	9.13	23.19
4/17/06 10:30	23:30:00	622:30:00	25.94				0.00	0.00
4/17/06 10:30	0:00:00	622:30:00	25.94	0.00	250	10082	8.75	22.23
4/18/06 10:30	24:00:00	646:30:00	26.94				6.31	16.03
4/18/06 10:30	0:00:00	646:30:00	26.94	6.31	0	10082	6.31	16.03
4/19/06 15:00	28:30:00	675:00:00	28.13				0.00	0.00
4/19/06 15:00	0:00:00	675:00:00	28.13	0.00	500	10582	9.00	22.86
4/20/06 11:00	20:00:00	695:00:00	28.96				3.06	7.77
4/20/06 11:00	0:00:00	695:00:00	28.96	3.06	0	10582	3.06	7.77
4/21/06 12:00	25:00:00	720:00:00	30.00				0.00	0.00
4/21/06 12:00	0:00:00	720:00:00	30.00	0.00	500	11082	9.63	24.45
4/24/06 12:00	72:00:00	792:00:00	33.00				0.00	0.00
4/24/06 12:00	0:00:00	792:00:00	33.00	0.00	286	11368	9.00	22.86
4/25/06 12:45	24:45:00	816:45:00	34.03				0.00	0.00

4/25/06 12:45	0:00:00	816:45:00	34.03	0.00	250	11618	9.00	22.86
4/26/06 11:00	22:15:00	839:00:00	34.96			11618	7.56	19.20
4/26/06 11:00	0:00:00	839:00:00	34.96	7.56	0	11618	7.56	19.21
4/27/06 12:45	25:45:00	864:45:00	36.03			11618	1.56	3.96
4/27/06 12:45	0:00:00	864:45:00	36.03	1.56	250	11868	9.88	25.08
4/28/06 13:00	24:15:00	889:00:00	37.04			11868	1.63	4.14
4/28/06 13:00	0:00:00	889:00:00	37.04	1.63	250	12118	9.38	23.81
5/1/06 12:00	71:00:00	960:00:00	40.00			12118	1.88	4.78
5/1/06 12:00	0:00:00	960:00:00	40.00	1.88	250	12368	9.31	23.65
5/2/06 12:30	24:30:00	984:30:00	41.02			12368	8.19	20.80
5/2/06 12:30	0:00:00	984:30:00	41.02	8.19	0	12368	8.19	20.80
5/3/06 13:30	25:00:00	1009:30:00	42.06			12368	0.00	0.00
5/3/06 13:30	0:00:00	1009:30:00	42.06	0.00	500	12868	9.25	23.50
5/4/06 10:30	21:00:00	1030:30:00	42.94			12868	7.13	18.11
5/4/06 10:30	0:00:00	1030:30:00	42.94	7.13	0	12868	7.13	18.10
5/6/06 5:00	42:30:00	1073:00:00	44.71			12868	0.00	0.00
5/6/06 5:00	0:00:00	1073:00:00	44.71	0.00	250	13118	8.00	20.32
5/7/06 21:00	40:00:00	1113:00:00	46.38			13118	4.25	10.80
5/7/06 21:00	0:00:00	1113:00:00	46.38	4.25	0	13118	4.25	10.80
5/9/06 13:30	40:30:00	1153:30:00	48.06			13118	0.00	0.00
5/9/06 13:30	0:00:00	1153:30:00	48.06	0.00	500	13618	9.38	23.81
5/10/06 11:30	22:00:00	1175:30:00	48.98			13618	9.13	23.19
5/10/06 11:30	0:00:00	1175:30:00	48.98	9.13	0	13618	9.13	23.18
5/11/06 15:00	27:30:00	1203:00:00	50.13			13618	8.00	20.32
5/11/06 15:00	0:00:00	1203:00:00	50.13	8.00	0	13618	8.00	20.32
5/12/06 11:00	20:00:00	1223:00:00	50.96			13618	1.25	3.18
5/12/06 11:00	0:00:00	1223:00:00	50.96	1.25	500	14118	11.31	28.73
5/15/06 11:00	72:00:00	1295:00:00	53.96			14118	0.00	0.00
5/15/06 11:00	0:00:00	1295:00:00	53.96	0.00	250	14368	9.06	23.02
5/19/06 16:30	101:30:00	1396:30:00	58.19			14368	0.00	0.00
5/19/06 16:30	0:00:00	1396:30:00	58.19	0.00	1250	15618	9.31	23.65
5/20/06 6:45	14:15:00	1410:45:00	58.78			15618	9.50	24.13
5/20/06 6:45	0:00:00	1410:45:00	58.78	9.50	0	15618	9.50	24.13
5/21/06 23:45	41:00:00	1451:45:00	60.49			15618	9.25	23.50
5/21/06 23:45	0:00:00	1451:45:00	60.49	9.25	0	15618	9.25	23.50
5/22/06 16:03	16:18:00	1468:03:00	61.17			15618	9.50	24.13
5/22/06 16:03	0:00:00	1468:03:00	61.17	9.50	0	15618	9.50	24.13
5/23/06 15:30	23:27:00	1491:30:00	62.15			15618	9.50	24.13
5/23/06 15:30	0:00:00	1491:30:00	62.15	9.50	0	15618	9.50	24.13
5/24/06 15:30	24:00:00	1515:30:00	63.15			15618	9.50	24.13
5/24/06 15:30	0:00:00	1515:30:00	63.15	9.50	0	15618	9.50	24.13
5/25/06 14:00	22:30:00	1538:00:00	64.08			15618	9.50	24.13
5/25/06 14:00	0:00:00	1538:00:00	64.08	9.50	0	15618	9.50	24.13
5/26/06 21:00	31:00:00	1569:00:00	65.38			15618	3.50	8.89
5/26/06 21:00	0:00:00	1569:00:00	65.38	3.50	0	15618	11.00	27.94
5/27/06 21:00	24:00:00	1593:00:00	66.38			15618	0.00	0.00
5/27/06 21:00	0:00:00	1593:00:00	66.38	0.00	250	15868	10.00	25.40
5/28/06 14:00	17:00:00	1610:00:00	67.08			15868	10.00	25.40

5/28/06 14:00	0:00:00	1610:00:00	67.08	10.00	0	15868	10.00	25.40
5/30/06 14:00	48:00:00	1658:00:00	69.08			15868	0.00	0.00
5/30/06 14:00	0:00:00	1658:00:00	69.08	0.00	500	16368	12.00	30.48
6/1/06 14:30	48:30:00	1706:30:00	71.10			16368	7.69	19.53
6/1/06 14:30	0:00:00	1706:30:00	71.10	7.69	0	16368	7.69	19.53
6/2/06 15:00	24:30:00	1731:00:00	72.13			16368	8.31	21.11
6/2/06 15:00	0:00:00	1731:00:00	72.13	8.31	0	16368	8.31	21.11
6/5/06 16:00	73:00:00	1804:00:00	75.17			16368	0.00	0.00
6/5/06 16:00	0:00:00	1804:00:00	75.17	0.00	1000	17368	11.00	27.94
6/6/06 12:00	20:00:00	1824:00:00	76.00			17368	9.13	23.19
6/6/06 12:00	0:00:00	1824:00:00	76.00	9.13	0	17368	9.13	23.18
6/7/06 11:00	23:00:00	1847:00:00	76.96			17368	10.38	26.37
6/7/06 11:00	0:00:00	1847:00:00	76.96	10.38	0	17368	10.38	26.37
6/8/06 13:30	26:30:00	1873:30:00	78.06			17368	7.88	20.02
6/8/06 13:30	0:00:00	1873:30:00	78.06	7.88	0	17368	7.88	20.02
6/9/06 13:25	23:55:00	1897:25:00	79.06			17368	2.25	5.72
6/9/06 13:25	0:00:00	1897:25:00	79.06	2.25	250	17618	8.50	21.59
6/10/06 13:30	24:05:00	1921:30:00	80.06			17618	7.75	19.69
6/10/06 13:30	0:00:00	1921:30:00	80.06	7.75	0	17618	7.75	19.69
6/11/06 15:30	26:00:00	1947:30:00	81.15			17618	0.00	0.00
6/11/06 15:30	0:00:00	1947:30:00	81.15	0.00	250	17868	8.56	21.75
6/12/06 12:10	20:40:00	1968:10:00	82.01			17868	6.50	16.51
6/12/06 12:10	0:00:00	1968:10:00	82.01	6.50	0	17868	6.50	16.51
6/13/06 13:00	24:50:00	1993:00:00	83.04			17868	7.75	19.69
6/13/06 13:00	0:00:00	1993:00:00	83.04	7.75	0	17868	7.75	19.69
6/14/06 10:50	21:50:00	2014:50:00	83.95			17868	4.50	11.43
6/14/06 10:50	0:00:00	2014:50:00	83.95	4.50	250	18118	8.38	21.27
6/15/06 6:30	19:40:00	2034:30:00	84.77			18118	6.31	16.03
6/15/06 6:30	0:00:00	2034:30:00	84.77	6.31	250	18368	11.75	29.85
6/15/06 13:00	6:30:00	2041:00:00	85.04			18368	9.56	24.28
6/15/06 13:00	0:00:00	2041:00:00	85.04	9.56	0	18368	9.56	24.28
6/16/06 14:00	25:00:00	2066:00:00	86.08			18368	9.38	23.83
6/16/06 14:00	0:00:00	2066:00:00	86.08	9.38	0	18368	9.38	23.83
6/17/06 13:10	23:10:00	2089:10:00	87.05			18368	7.50	19.05
6/17/06 13:10	0:00:00	2089:10:00	87.05	7.50	0	18368	7.50	19.05
6/18/06 14:15	25:05:00	2114:15:00	88.09			18368	7.25	18.42
6/18/06 14:15	0:00:00	2114:15:00	88.09	7.25	0	18368	7.25	18.42
6/19/06 13:20	23:05:00	2137:20:00	89.06			18368	6.00	15.24
6/19/06 13:20	0:00:00	2137:20:00	89.06	6.00	0	18368	6.00	15.24
6/20/06 14:15	24:55:00	2162:15:00	90.09			18368	0.25	0.64
6/20/06 14:15	0:00:00	2162:15:00	90.09	0.25	250	18618	8.50	21.59
6/21/06 12:50	22:35:00	2184:50:00	91.03			18618	7.69	19.53
6/21/06 12:50	0:00:00	2184:50:00	91.03	7.69	0	18618	7.69	19.53
6/22/06 13:30	24:40:00	2209:30:00	92.06			18618	0.00	0.00
6/22/06 13:30	0:00:00	2209:30:00	92.06	0.00	240	18858	7.75	19.69
6/23/06 14:00	24:30:00	2234:00:00	93.08			18858	6.50	16.51
6/23/06 14:00	0:00:00	2234:00:00	93.08	6.50	0	18858	6.50	16.51
6/24/06 14:00	24:00:00	2258:00:00	94.08			18858	0.25	0.64

6/24/06 14:00	0:00:00	2258:00:00	94.08	0.25	500	19358	9.50	24.13
6/25/06 13:45	23:45:00	2281:45:00	95.07			19358	9.25	23.50
6/25/06 13:45	0:00:00	2281:45:00	95.07	9.25	0	19358	9.25	23.50
6/26/06 12:55	23:10:00	2304:55:00	96.04			19358	9.00	22.86
6/26/06 12:55	0:00:00	2304:55:00	96.04	9.00	0	19358	9.00	22.86
6/27/06 12:50	23:55:00	2328:50:00	97.03			19358	7.00	17.78
6/27/06 12:50	0:00:00	2328:50:00	97.03	7.00	0	19358	7.00	17.78
6/28/06 13:30	24:40:00	2353:30:00	98.06			19358	0.25	0.64
6/28/06 13:30	0:00:00	2353:30:00	98.06	0.25	0	19358	7.69	19.53
6/29/06 13:00	23:30:00	2377:00:00	99.04			19358	4.00	10.16
6/29/06 13:00	0:00:00	2377:00:00	99.04	4.00	0	19358	4.00	10.16
6/30/06 13:40	24:40:00	2401:40:00	100.07			19358	0.00	0.00
6/30/06 13:40	0:00:00	2401:40:00	100.07	0.00	250	19608	5.31	13.49
7/1/06 13:00	23:20:00	2425:00:00	101.04			19608	0.25	0.64
7/1/06 13:00	0:00:00	2425:00:00	101.04	0.25	250	19858	9.00	22.86
7/2/06 13:27	24:27:00	2449:27:00	102.06			19858	0.56	1.42
7/2/06 13:27	0:00:00	2449:27:00	102.06	0.56	250	20108	7.88	20.00
7/3/06 13:00	23:33:00	2473:00:00	103.04			20108	4.00	10.16
7/3/06 13:00	0:00:00	2473:00:00	103.04	4.00	0	20108	4.00	10.16
7/4/06 15:00	26:00:00	2499:00:00	104.13			20108	0.25	0.64
7/4/06 15:00	0:00:00	2499:00:00	104.13	0.25	250	20358	3.75	9.53
7/5/06 11:30	20:30:00	2519:30:00	104.98			20358	0.00	0.00
7/5/06 11:30	0:00:00	2519:30:00	104.98	0.00	500	20858	8.94	22.70
7/6/06 13:00	25:30:00	2545:00:00	106.04			20858	7.75	19.69
7/6/06 13:00	0:00:00	2545:00:00	106.04	7.75	0	20858	7.75	19.69
7/7/06 12:00	23:00:00	2568:00:00	107.00			20858	2.94	7.47
7/7/06 12:00	0:00:00	2568:00:00	107.00	2.94	250	21108	8.50	21.59
7/10/06 13:45	73:45:00	2641:45:00	110.07			21108	0.00	0.00
7/10/06 13:45	0:00:00	2641:45:00	110.07	0.00	250	21358	3.13	7.94
7/11/06 12:37	22:52:00	2664:37:00	111.03			21358	0.25	0.64
7/11/06 12:37	0:00:00	2664:37:00	111.03	0.25	250	21608	8.50	21.59
7/12/06 14:00	25:23:00	2690:00:00	112.08			21608	6.25	15.88
7/12/06 14:00	0:00:00	2690:00:00	112.08	6.25	0	21608	6.25	15.88
7/13/06 12:04	22:04:00	2712:04:00	113.00			21608	0.00	0.00
7/13/06 12:04	0:00:00	2712:04:00	113.00	0.00	250	21858	8.75	22.23
7/14/06 13:30	25:26:00	2737:30:00	114.06			21858	0.25	0.64
7/14/06 13:30	0:00:00	2737:30:00	114.06	0.25	250	22108	9.00	22.86
7/15/06 10:00	20:30:00	2758:00:00	114.92			22108	8.00	20.32
7/15/06 10:00	0:00:00	2758:00:00	114.92	8.00	0	22108	8.00	20.32
7/16/06 12:30	26:30:00	2784:30:00	116.02			22108	0.25	0.64
7/16/06 12:30	0:00:00	2784:30:00	116.02	0.25	400	22508	9.50	24.13
7/17/06 12:40	24:10:00	2808:40:00	117.03			22508	8.50	21.59
7/17/06 12:40	0:00:00	2808:40:00	117.03	8.50	0	22508	8.50	21.59
7/18/06 12:40	24:00:00	2832:40:00	118.03			22508	0.00	0.00
7/18/06 12:40	0:00:00	2832:40:00	118.03	0	250	22758	7.75	19.69
7/19/06 13:35	24:55:00	2857:35:00	119.07			22758	0.00	0.00
7/19/06 13:35	0:00:00	2857:35:00	119.07	0.00	250	23008	8.81	22.38
7/20/06 12:00	22:25:00	2880:00:00	120.00			23008	0.00	0.00

7/20/06 12:00	0:00:00	2880:00:00	120.00	0.00	250	23258	9.00	22.86
7/21/06 13:35	25:35:00	2905:35:00	121.07			23258	0.00	0.00
7/21/06 13:35	0:00:00	2905:35:00	121.07	0.00	250	23508	7.44	18.89
7/22/06 14:00	24:25:00	2930:00:00	122.08			23508	0.25	0.64
7/22/06 14:00	0:00:00	2930:00:00	122.08	0.25	250	23758	8.50	21.59
7/23/06 13:40	23:40:00	2953:40:00	123.07			23758	0.00	0.00
7/23/06 13:40	0:00:00	2953:40:00	123.07	0.00	250	24008	8.69	22.07
7/24/06 12:40	23:00:00	2976:40:00	124.03			24008	0.25	0.64
7/24/06 12:40	0:00:00	2976:40:00	124.03	0.25	250	24258	9.00	22.86
7/25/06 12:30	23:50:00	3000:30:00	125.02			24258	0.00	0.00
7/25/06 12:30	0:00:00	3000:30:00	125.02	0.00	250	24508	9.00	22.86
7/26/06 13:30	25:00:00	3025:30:00	126.06			24508	0.00	0.00
7/26/06 13:30	0:00:00	3025:30:00	126.06	0.00	250	24758	5.13	13.02
7/27/06 13:00	23:30:00	3049:00:00	127.04			24758	0.00	0.00
7/27/06 13:00	0:00:00	3049:00:00	127.04	0.00	250	25008	5.13	13.02
7/28/06 12:35	23:35:00	3072:35:00	128.02			25008	0.00	0.00
7/28/06 12:35	0:00:00	3072:35:00	128.02	0.00	250	25258	7.31	18.57
7/29/06 13:00	24:25:00	3097:00:00	129.04			25258	0.00	0.00
7/29/06 13:00	0:00:00	3097:00:00	129.04	0.00	250	25508	7.25	18.42
7/30/06 13:30	24:30:00	3121:30:00	130.06			25508	0.00	0.00
7/30/06 13:30	0:00:00	3121:30:00	130.06	0.00	250	25758	4.75	12.07
7/31/06 13:30	24:00:00	3145:30:00	131.06			25758	0.00	0.00
7/31/06 13:30	0:00:00	3145:30:00	131.06	0.00	400	26158	5.25	13.34
8/1/06 12:00	22:30:00	3168:00:00	132.00			26158	0.00	0.00
8/1/06 12:00	0:00:00	3168:00:00	132.00	0.00	500	26658	5.88	14.92
8/2/06 11:03	23:03:00	3191:03:00	132.96			26658	0.00	0.00
8/2/06 11:03	0:00:00	3191:03:00	132.96	0.00	500	27158	7.00	17.78
8/4/06 13:35	50:32:00	3241:35:00	135.07			27158	0.00	0.00
8/4/06 13:35	0:00:00	3241:35:00	135.07	0.00	1000	28158	8.50	21.59
8/5/06 13:45	24:10:00	3265:45:00	136.07			28158	0.00	0.00
8/5/06 13:45	0:00:00	3265:45:00	136.07	0.00	1000	29158	9.50	24.13
8/6/06 13:20	23:35:00	3289:20:00	137.06			29158	3.56	9.04
8/6/06 13:20	0:00:00	3289:20:00	137.06	3.56	250	29408	9.19	23.34
8/8/06 12:00	46:40:00	3336:00:00	139.00			29408	0.00	0.00
8/8/06 12:00	0:00:00	3336:00:00	139.00	0.00	750	30158	6.75	17.15
8/9/06 14:00	26:00:00	3362:00:00	140.08			30158	0.00	0.00
8/9/06 14:00	0:00:00	3362:00:00	140.08	0.00	490	30648	7.38	18.73
8/10/06 15:00	25:00:00	3387:00:00	141.13			30648	0.00	0.00
8/10/06 15:00	0:00:00	3387:00:00	141.13	0.00	250	30898	0.75	1.91
8/11/06 13:00	22:00:00	3409:00:00	142.04			30898	0.00	0.00
8/11/06 13:00	0:00:00	3409:00:00	142.04	0.00	500	31398	7.56	19.21
8/12/06 13:30	24:30:00	3433:30:00	143.06			31398	0.00	0.00
8/12/06 13:30	0:00:00	3433:30:00	143.06	0.00	400	31798	9.00	22.86
8/13/06 13:30	24:00:00	3457:30:00	144.06			31798	0.00	0.00
8/13/06 13:30	0:00:00	3457:30:00	144.06	0.00	500	32298	8.69	22.07
8/14/06 16:00	26:30:00	3484:00:00	145.17			32298	0.00	0.00
8/14/06 16:00	0:00:00	3484:00:00	145.17	0.00	500	32798	7.50	19.05
8/15/06 9:00	17:00:00	3501:00:00	145.88			32798	0.00	0.00

8/15/06 9:00	0:00:00	3501:00:00	145.88	0.00	0	32798	0.00	0.00
Reactor 5 - No Trees with BTEX water in autoclaved Soil								
Date	Time (hr)	Total Time (hr)	Total Time (days)	H2O Height (in)	Water Added (mL)	Total Water Added (mL)	H2O Final Height (in)	H2O Final Height (cm)
3/23/06 12:00	0:00:00	0:00:00	0.00	0.00	6346	6346	0.00	0.00
3/28/06 12:00	120:00:00	120:00:00	5.00			6346	0.00	0.00
3/28/06 12:00	0:00:00	120:00:00	5.00	0.00	250	6596	2.38	6.03
4/5/06 10:30	190:30:00	310:30:00	12.94			6596	0.00	0.00
4/5/06 10:30	0:00:00	310:30:00	12.94	0.00	312	6908	12.00	30.48
4/6/06 12:00	25:30:00	336:00:00	14.00			6908	0.00	0.00
4/6/06 12:00	0:00:00	336:00:00	14.00	0.00	250	7158	12.00	30.48
4/7/06 0:30	12:30:00	348:30:00	14.52			7158	0.00	0.00
4/7/06 0:30	0:00:00	348:30:00	14.52	0.00	500	7658	9.00	22.86
4/10/06 14:30	86:00:00	434:30:00	18.10			7658	0.00	0.00
4/10/06 14:30	0:00:00	434:30:00	18.10	0.00	1000	8658	12.00	30.48
4/11/06 10:30	20:00:00	454:30:00	18.94			8658	9.13	23.19
4/11/06 10:30	0:00:00	454:30:00	18.94	9.13	0	8658	9.13	23.18
4/12/06 15:40	29:10:00	483:40:00	20.15			8658	6.50	16.51
4/12/06 15:40	0:00:00	483:40:00	20.15	6.50	0	8658	6.50	16.51
4/13/06 14:00	22:20:00	506:00:00	21.08			8658	0.00	0.00
4/13/06 14:00	0:00:00	506:00:00	21.08	0.00	500	9158	12.00	30.48
4/14/06 17:00	27:00:00	533:00:00	22.21			9158	5.56	14.12
4/14/06 17:00	0:00:00	533:00:00	22.21	5.56	0	9158	5.56	14.13
4/15/06 11:00	18:00:00	551:00:00	22.96			9158	0.00	0.00
4/15/06 11:00	0:00:00	551:00:00	22.96	0.00	250	9408	8.44	21.43
4/16/06 11:00	24:00:00	575:00:00	23.96			9408	8.63	21.92
4/16/06 11:00	0:00:00	575:00:00	23.96	8.63	0	9408	8.63	21.91
4/17/06 10:30	23:30:00	598:30:00	24.94			9408	0.00	0.00
4/17/06 10:30	0:00:00	598:30:00	24.94	0.00	250	9658	8.13	20.64
4/18/06 10:30	24:00:00	622:30:00	25.94			9658	5.50	13.97
4/18/06 10:30	0:00:00	622:30:00	25.94	5.50	0	9658	5.50	13.97
4/19/06 15:00	28:30:00	651:00:00	27.13			9658	0.00	0.00
4/19/06 15:00	0:00:00	651:00:00	27.13	0.00	250	9908	5.88	14.92
4/20/06 11:00	20:00:00	671:00:00	27.96			9908	0.00	0.00
4/20/06 11:00	0:00:00	671:00:00	27.96	0.00	250	10158	11.50	29.21
4/21/06 12:00	25:00:00	696:00:00	29.00			10158	6.19	15.72
4/21/06 12:00	0:00:00	696:00:00	29.00	6.19	0	10158	6.19	15.72
4/24/06 12:00	72:00:00	768:00:00	32.00			10158	0.00	0.00
4/24/06 12:00	0:00:00	768:00:00	32.00	0.00	500	10658	9.44	23.97
4/25/06 12:45	24:45:00	792:45:00	33.03			10658	0.00	0.00
4/25/06 12:45	0:00:00	792:45:00	33.03	0.00	500	11158	10.50	26.67
4/26/06 11:00	22:15:00	815:00:00	33.96			11158	10.25	26.04
4/26/06 11:00	0:00:00	815:00:00	33.96	10.25	0	11158	10.25	26.04
4/27/06 12:45	25:45:00	840:45:00	35.03			11158	9.38	23.83
4/27/06 12:45	0:00:00	840:45:00	35.03	9.38	0	11158	9.38	23.81
4/28/06 13:00	24:15:00	865:00:00	36.04			11158	0.00	0.00

4/28/06 13:00	0:00:00	865:00:00	36.04	0.00	250	11408	10.88	27.62
5/1/06 12:00	71:00:00	936:00:00	39.00			11408	5.06	12.85
5/1/06 12:00	0:00:00	936:00:00	39.00	5.06	0	11408	5.06	12.85
5/2/06 12:30	24:30:00	960:30:00	40.02			11408	0.00	0.00
5/2/06 12:30	0:00:00	960:30:00	40.02	0.00	250	11658	9.13	23.18
5/3/06 13:30	25:00:00	985:30:00	41.06			11658	0.00	0.00
5/3/06 13:30	0:00:00	985:30:00	41.06	0.00	500	12158	12.00	30.48
5/4/06 10:30	21:00:00	1006:30:00	41.94			12158	10.13	25.73
5/4/06 10:30	0:00:00	1006:30:00	41.94	10.13	0	12158	10.13	25.73
5/6/06 5:00	42:30:00	1049:00:00	43.71			12158	8.75	22.23
5/6/06 5:00	0:00:00	1049:00:00	43.71	8.75	0	12158	8.75	22.23
5/7/06 21:00	40:00:00	1089:00:00	45.38			12158	7.00	17.78
5/7/06 21:00	0:00:00	1089:00:00	45.38	7.00	0	12158	7.00	17.78
5/9/06 13:30	40:30:00	1129:30:00	47.06			12158	7.00	17.78
5/9/06 13:30	0:00:00	1129:30:00	47.06	7.00	0	12158	7.00	17.78
5/10/06 11:30	22:00:00	1151:30:00	47.98			12158	0.00	0.00
5/10/06 11:30	0:00:00	1151:30:00	47.98	0.00	250	12408	12.00	30.48
5/11/06 15:00	27:30:00	1179:00:00	49.13			12408	10.31	26.19
5/11/06 15:00	0:00:00	1179:00:00	49.13	10.31	0	12408	10.31	26.19
5/12/06 11:00	20:00:00	1199:00:00	49.96			12408	9.44	23.98
5/12/06 11:00	0:00:00	1199:00:00	49.96	9.44	0	12408	9.44	23.98
5/15/06 11:00	72:00:00	1271:00:00	52.96			12408	0.00	0.00
5/15/06 11:00	0:00:00	1271:00:00	52.96	0.00	250	12658	10.75	27.31
5/19/06 16:30	101:30:00	1372:30:00	57.19			12658	0.00	0.00
5/19/06 16:30	0:00:00	1372:30:00	57.19	0.00	750	13408	10.00	25.40
5/20/06 6:45	14:15:00	1386:45:00	57.78			13408	9.75	24.77
5/20/06 6:45	0:00:00	1386:45:00	57.78	9.75	0	13408	9.75	24.77
5/21/06 23:45	41:00:00	1427:45:00	59.49			13408	11.50	29.21
5/21/06 23:45	0:00:00	1427:45:00	59.49	11.50	0	13408	11.50	29.21
5/22/06 16:03	16:18:00	1444:03:00	60.17			13408	10.00	25.40
5/22/06 16:03	0:00:00	1444:03:00	60.17	10.00	0	13408	10.00	25.40
5/23/06 15:30	23:27:00	1467:30:00	61.15			13408	8.50	21.59
5/23/06 15:30	0:00:00	1467:30:00	61.15	8.50	0	13408	8.50	21.59
5/24/06 15:30	24:00:00	1491:30:00	62.15			13408	8.50	21.59
5/24/06 15:30	0:00:00	1491:30:00	62.15	8.50	0	13408	8.50	21.59
5/25/06 14:00	22:30:00	1514:00:00	63.08			13408	8.50	21.59
5/25/06 14:00	0:00:00	1514:00:00	63.08	8.50	0	13408	8.50	21.59
5/26/06 21:00	31:00:00	1545:00:00	64.38			13408	7.00	17.78
5/26/06 21:00	0:00:00	1545:00:00	64.38	7.00	250	13658	12.00	30.48
5/27/06 21:00	24:00:00	1569:00:00	65.38			13658	0.00	0.00
5/27/06 21:00	0:00:00	1569:00:00	65.38	0.00	200	13858	10.00	25.40
5/28/06 14:00	17:00:00	1586:00:00	66.08			13858	10.00	25.40
5/28/06 14:00	0:00:00	1586:00:00	66.08	10.00	0	13858	10.00	25.40
5/30/06 14:00	48:00:00	1634:00:00	68.08			13858	4.50	11.43
5/30/06 14:00	0:00:00	1634:00:00	68.08	4.50	0	13858	4.50	11.43
6/1/06 14:30	48:30:00	1682:30:00	70.10			13858	0.00	0.00
6/1/06 14:30	0:00:00	1682:30:00	70.10	0.00	750	14608	11.56	29.37
6/2/06 15:00	24:30:00	1707:00:00	71.13			14608	10.19	25.88

6/2/06 15:00	0:00:00	1707:00:00	71.13	10.19	0	14608	10.19	25.88
6/5/06 16:00	73:00:00	1780:00:00	74.17			14608	8.69	22.07
6/5/06 16:00	0:00:00	1780:00:00	74.17	8.69	0	14608	8.69	22.07
6/6/06 12:00	20:00:00	1800:00:00	75.00			14608	7.63	19.38
6/6/06 12:00	0:00:00	1800:00:00	75.00	7.63	0	14608	7.63	19.38
6/7/06 11:00	23:00:00	1823:00:00	75.96			14608	6.94	17.63
6/7/06 11:00	0:00:00	1823:00:00	75.96	6.94	0	14608	6.94	17.63
6/8/06 13:30	26:30:00	1849:30:00	77.06			14608	0.00	0.00
6/8/06 13:30	0:00:00	1849:30:00	77.06	0.00	250	14858	10.75	27.31
6/9/06 13:25	23:55:00	1873:25:00	78.06			14858	9.75	24.77
6/9/06 13:25	0:00:00	1873:25:00	78.06	9.75	0	14858	9.75	24.77
6/10/06 13:30	24:05:00	1897:30:00	79.06			14858	9.25	23.50
6/10/06 13:30	0:00:00	1897:30:00	79.06	9.25	0	14858	9.25	23.50
6/11/06 15:30	26:00:00	1923:30:00	80.15			14858	3.19	8.10
6/11/06 15:30	0:00:00	1923:30:00	80.15	3.19	0	14858	3.19	8.10
6/12/06 12:10	20:40:00	1944:10:00	81.01			14858	0.00	0.00
6/12/06 12:10	0:00:00	1944:10:00	81.01	0.00	500	15358	11.00	27.94
6/13/06 13:00	24:50:00	1969:00:00	82.04			15358	10.00	25.40
6/13/06 13:00	0:00:00	1969:00:00	82.04	10.00	0	15358	10.00	25.40
6/14/06 10:50	21:50:00	1990:50:00	82.95			15358	8.81	22.38
6/14/06 10:50	0:00:00	1990:50:00	82.95	8.81	0	15358	8.81	22.38
6/15/06 6:30	19:40:00	2010:30:00	83.77			15358	9.81	24.92
6/15/06 6:30	0:00:00	2010:30:00	83.77	9.81	0	15358	9.81	24.92
6/16/06 14:00	31:30:00	2042:00:00	85.08			15358	9.13	23.19
6/16/06 14:00	0:00:00	2042:00:00	85.08	9.13	0	15358	9.13	23.19
6/17/06 13:10	23:10:00	2065:10:00	86.05			15358	9.50	24.13
6/17/06 13:10	0:00:00	2065:10:00	86.05	9.50	0	15358	9.50	24.13
6/18/06 14:15	25:05:00	2090:15:00	87.09			15358	9.69	24.61
6/18/06 14:15	0:00:00	2090:15:00	87.09	9.69	0	15358	9.69	24.61
6/19/06 13:20	23:05:00	2113:20:00	88.06			15358	9.25	23.50
6/19/06 13:20	0:00:00	2113:20:00	88.06	9.25	0	15358	9.25	23.50
6/20/06 14:15	24:55:00	2138:15:00	89.09			15358	8.75	22.23
6/20/06 14:15	0:00:00	2138:15:00	89.09	8.75	0	15358	8.75	22.23
6/21/06 12:50	22:35:00	2160:50:00	90.03			15358	8.63	21.92
6/21/06 12:50	0:00:00	2160:50:00	90.03	8.63	0	15358	8.63	21.92
6/22/06 13:30	24:40:00	2185:30:00	91.06			15358	7.94	20.17
6/22/06 13:30	0:00:00	2185:30:00	91.06	7.94	0	15358	7.94	20.17
6/23/06 14:00	24:30:00	2210:00:00	92.08			15358	5.50	13.97
6/23/06 14:00	0:00:00	2210:00:00	92.08	5.50	0	15358	5.50	13.97
6/24/06 14:00	24:00:00	2234:00:00	93.08			15358	4.50	11.43
6/24/06 14:00	0:00:00	2234:00:00	93.08	4.50	0	15358	4.50	11.43
6/25/06 13:45	23:45:00	2257:45:00	94.07			15358	0.19	0.48
6/25/06 13:45	0:00:00	2257:45:00	94.07	0.19	250	15608	8.38	21.27
6/26/06 12:55	23:10:00	2280:55:00	95.04			15608	8.38	21.29
6/26/06 12:55	0:00:00	2280:55:00	95.04	8.38	0	15608	8.38	21.29
6/27/06 12:50	23:55:00	2304:50:00	96.03			15608	9.00	22.86
6/27/06 12:50	0:00:00	2304:50:00	96.03	9.00	0	15608	9.00	22.86
6/28/06 13:30	24:40:00	2329:30:00	97.06			15608	8.50	21.59

6/28/06 13:30	0:00:00	2329:30:00	97.06	8.50	0	15608	8.50	21.59
6/29/06 13:00	23:30:00	2353:00:00	98.04			15608	7.75	19.69
6/29/06 13:00	0:00:00	2353:00:00	98.04	7.75	0	15608	7.75	19.69
6/30/06 13:40	24:40:00	2377:40:00	99.07			15608	6.63	16.84
6/30/06 13:40	0:00:00	2377:40:00	99.07	6.63	0	15608	6.63	16.84
7/1/06 13:00	23:20:00	2401:00:00	100.04			15608	4.50	11.43
7/1/06 13:00	0:00:00	2401:00:00	100.04	4.50	0	15608	4.50	11.43
7/2/06 13:27	24:27:00	2425:27:00	101.06			15608	0.31	0.79
7/2/06 13:27	0:00:00	2425:27:00	101.06	0.31	250	15858	9.94	25.24
7/3/06 13:00	23:33:00	2449:00:00	102.04			15858	8.75	22.23
7/3/06 13:00	0:00:00	2449:00:00	102.04	8.75	0	15858	8.75	22.23
7/4/06 15:00	26:00:00	2475:00:00	103.13			15858	6.75	17.15
7/4/06 15:00	0:00:00	2475:00:00	103.13	6.75	0	15858	6.75	17.15
7/5/06 11:30	20:30:00	2495:30:00	103.98			15858	3.94	10.01
7/5/06 11:30	0:00:00	2495:30:00	103.98	3.94	250	16108	9.81	24.92
7/6/06 13:00	25:30:00	2521:00:00	105.04			16108	9.06	23.01
7/6/06 13:00	0:00:00	2521:00:00	105.04	9.06	0	16108	9.06	23.01
7/7/06 12:00	23:00:00	2544:00:00	106.00			16108	9.50	24.13
7/7/06 12:00	0:00:00	2544:00:00	106.00	9.50	0	16108	9.50	24.13
7/10/06 13:45	73:45:00	2617:45:00	109.07			16108	4.00	10.16
7/10/06 13:45	0:00:00	2617:45:00	109.07	4.00	0	16108	4.00	10.16
7/11/06 12:37	22:52:00	2640:37:00	110.03			16108	7.00	17.78
7/11/06 12:37	0:00:00	2640:37:00	110.03	7.00	0	16108	7.00	17.78
7/12/06 14:00	25:23:00	2666:00:00	111.08			16108	6.63	16.84
7/12/06 14:00	0:00:00	2666:00:00	111.08	6.63	0	16108	6.63	16.84
7/13/06 12:04	22:04:00	2688:04:00	112.00			16108	9.00	22.86
7/13/06 12:04	0:00:00	2688:04:00	112.00	9.00	0	16108	9.00	22.86
7/14/06 13:30	25:26:00	2713:30:00	113.06			16108	0.75	1.91
7/14/06 13:30	0:00:00	2713:30:00	113.06	0.75	250	16358	11.00	27.94
7/15/06 10:00	20:30:00	2734:00:00	113.92			16358	11.00	27.94
7/15/06 10:00	0:00:00	2734:00:00	113.92	11.00	0	16358	11.00	27.94
7/16/06 12:30	26:30:00	2760:30:00	115.02			16358	10.00	25.40
7/16/06 12:30	0:00:00	2760:30:00	115.02	10.00	0	16358	10.00	25.40
7/17/06 12:40	24:10:00	2784:40:00	116.03			16358	9.50	24.13
7/17/06 12:40	0:00:00	2784:40:00	116.03	9.50	0	16358	9.50	24.13
7/18/06 12:40	24:00:00	2808:40:00	117.03			16358	8.75	22.23
7/18/06 12:40	0:00:00	2808:40:00	117.03	8.75	0	16358	8.75	22.23
7/19/06 13:35	24:55:00	2833:35:00	118.07			16358	6.19	15.72
7/19/06 13:35	0:00:00	2833:35:00	118.07	6.19	0	16358	6.19	15.72
7/20/06 12:00	22:25:00	2856:00:00	119.00			16358	1.00	2.54
7/20/06 12:00	0:00:00	2856:00:00	119.00	1.00	250	16608	8.25	20.96
7/21/06 13:35	25:35:00	2881:35:00	120.07			16608	7.38	18.75
7/21/06 13:35	0:00:00	2881:35:00	120.07	7.38	0	16608	7.38	18.75
7/22/06 14:00	24:25:00	2906:00:00	121.08			16608	7.25	18.42
7/22/06 14:00	0:00:00	2906:00:00	121.08	7.25	0	16608	7.25	18.42
7/23/06 13:40	23:40:00	2929:40:00	122.07			16608	5.50	13.97
7/23/06 13:40	0:00:00	2929:40:00	122.07	5.50	0	16608	5.50	13.97
7/24/06 12:40	23:00:00	2952:40:00	123.03			16608	4.50	11.43

7/24/06 12:40	0:00:00	2952:40:00	123.03	4.50	0	16608	4.50	11.43
7/25/06 12:30	23:50:00	2976:30:00	124.02			16608	2.50	6.35
7/25/06 12:30	0:00:00	2976:30:00	124.02	2.50	250	16858	9.25	23.50
7/26/06 13:30	25:00:00	3001:30:00	125.06			16858	8.13	20.65
7/26/06 13:30	0:00:00	3001:30:00	125.06	8.13	0	16858	8.13	20.65
7/27/06 13:00	23:30:00	3025:00:00	126.04			16858	1.63	4.14
7/27/06 13:00	0:00:00	3025:00:00	126.04	1.63	250	17108	9.38	23.81
7/28/06 12:35	23:35:00	3048:35:00	127.02			17108	8.94	22.71
7/28/06 12:35	0:00:00	3048:35:00	127.02	8.94	0	17108	8.94	22.71
7/29/06 13:00	24:25:00	3073:00:00	128.04			17108	9.75	24.77
7/29/06 13:00	0:00:00	3073:00:00	128.04	9.75	0	17108	9.75	24.77
7/30/06 13:30	24:30:00	3097:30:00	129.06			17108	8.88	22.56
7/30/06 13:30	0:00:00	3097:30:00	129.06	8.88	0	17108	8.88	22.56
7/31/06 13:30	24:00:00	3121:30:00	130.06			17108	9.25	23.50
7/31/06 13:30	0:00:00	3121:30:00	130.06	9.25	0	17108	9.25	23.50
8/1/06 12:00	22:30:00	3144:00:00	131.00			17108	7.56	19.20
8/1/06 12:00	0:00:00	3144:00:00	131.00	7.56	0	17108	7.56	19.20
8/2/06 11:03	23:03:00	3167:03:00	131.96			17108	6.50	16.51
8/2/06 11:03	0:00:00	3167:03:00	131.96	6.50	0	17108	6.50	16.51
8/4/06 13:35	50:32:00	3217:35:00	134.07			17108	0.00	0.00
8/4/06 13:35	0:00:00	3217:35:00	134.07	0.00	250	17358	6.94	17.62
8/5/06 13:45	24:10:00	3241:45:00	135.07			17358	6.44	16.36
8/5/06 13:45	0:00:00	3241:45:00	135.07	6.44	0	17358	6.44	16.36
8/6/06 13:20	23:35:00	3265:20:00	136.06			17358	5.06	12.85
8/6/06 13:20	0:00:00	3265:20:00	136.06	5.06	0	17358	5.06	12.85
8/8/06 12:00	46:40:00	3312:00:00	138.00			17358	0.00	0.00
8/8/06 12:00	0:00:00	3312:00:00	138.00	0.00	250	17608	8.13	20.64
8/9/06 14:00	26:00:00	3338:00:00	139.08			17608	7.75	19.69
8/9/06 14:00	0:00:00	3338:00:00	139.08	7.75	0	17608	7.75	19.69
8/10/06 15:00	25:00:00	3363:00:00	140.13			17608	1.75	4.45
8/10/06 15:00	0:00:00	3363:00:00	140.13	1.75	250	17858	9.00	22.86
8/11/06 9:45	18:45:00	3381:45:00	140.91			17858	7.94	20.17
8/11/06 9:45	0:00:00	3381:45:00	140.91	7.94	0	17858	0.00	0.00

APPENDIX B.
ENUMERATION RESULTS

Reactor 1	
Sample	CFU/g soil
R1-B13	1.07E+05
R1-B17	7.07E+03
R1-B23	3.57E+03
R1-B24	1.20E+03
R1-R20	1.04E+06
R1-R24	7.99E+05
R1-R28	3.58E+05
R1-R30	4.65E+05
R1-R31	4.39E+05
R1-SC1	1.50E+03
R1-SC2	8.75E+04
Reactor 2	
Sample	CFU/g soil
R2-22A	2.20E+03
R2-25A	1.02E+03
R2-29A	0.00E+00
R2-32A	1.85E+03
R2-36A	2.08E+03
R2-39A	9.25E+02
R2-43A	1.47E+03
R2-44A	4.52E+03
R2-SC1	5.43E+03
R2-SC2	2.28E+03
Reactor 3	
Sample	CFU/g soil
R3-B11	3.14E+03
R3-B12	1.56E+04
R3-B3	5.85E+03
R3-B5	3.66E+04
R3-B9	3.33E+03
R3-R12	5.75E+04
R3-R16	9.87E+03
R3-R17	6.22E+04
R3-R18	4.38E+04
R3-R8	7.95E+04
R3-SC1	8.38E+03
R3-SC2	1.67E+04
Reactor 4	
Sample	CFU/g soil
R4-45A	0.00E+00
R4-51A	7.93E+03
R4-58A	1.98E+04
R4-62A	9.41E+02
R4-64A	1.60E+03

R4-R1	9.70E+04
R4-R3	2.88E+05
R4-R6	9.10E+03
R4-R7	1.23E+05
R4-SC1	2.17E+03
R4-SC2	2.24E+03
Reactor 5	
Sample	CFU/g soil
R5-1A	0.00E+00
R5-4A	9.15E+01
R5-8B	1.02E+02
R5-11A	6.82E+02
R5-15A	6.54E+02
R5-18A	3.89E+02
R5-SC1	8.95E+02
R5-SC2	6.43E+02
Former Refinery Site	
Sample	CFU/g soil
SC-B1	1.81E+03
SC-B2	5.36E+04
SC-B3	2.91E+03
SC-B4	8.78E+02
SC-B5	5.82E+03
SC-B6	4.29E+03
SC-B7	1.25E+04
SC-R1	8.80E+04
SC-R2	3.01E+04
SC-R3	6.68E+04
SC-R4	1.33E+04
SC-R5	4.67E+04
SC-R6	1.61E+04
SC-R7	1.43E+04

APPENDIX C.

GAS CHROMATOGRAPHY RESULTS

Reactor 1					
Sample	Sample Media	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Xylene (µg/Lv)
H1-S-1	Soil	0.00	0.00	0.00	0.00
H1-S-10	Soil	0.00	0.00	0.00	0.00
H1-S-11	Soil	0.00	0.00	0.00	0.00
H1-S-11	Soil	0.00	0.00	4.15	0.00
H1-S-2	Soil	0.00	0.00	0.00	0.00
H1-S-2	Soil	0.00	0.16	0.00	0.00
H1-S-3	Soil	0.00	0.00	0.00	0.00
H1-S-4	Soil	0.00	0.00	0.00	0.00
H1-S-6	Soil	0.00	0.35	0.00	0.00
H1-S-7	Soil	0.00	0.00	0.00	0.00
H1-S-7	Soil	0.00	0.00	0.00	0.00
H1-S-9	Soil	0.00	0.00	0.00	0.00
R1-A1-1	Tree	0.00	1.64	2.32	0.00
R1-A1-2	Tree	0.00	0.00	0.00	0.00
R1-A1-3	Tree	0.00	0.00	0.00	0.00
R1-A1-35	Tree	0.00	0.00	0.00	0.00
R1-A1-38	Tree	4.25	0.00	0.00	0.00
R1-A1-4	Tree	2.31	0.00	0.00	0.00
R1-A1-5	Tree	8.80	0.00	0.00	0.00
R1-A1-6	Tree	7.54	0.00	0.00	0.00
R1-A3-33	Tree	0.00	1.90	6.56	0.00
R1-A3-34	Tree	0.00	0.00	0.00	0.00
R1-A3-36	Tree	4.55	0.00	0.00	0.00
R1-A3-37	Tree	0.00	0.00	0.00	0.00
R1-A3-39	Tree	0.00	2.19	8.19	0.00
R1-A3-40	Tree	0.70	0.00	0.00	0.00
R1-A3-41	Tree	0.00	2.22	12.90	0.00
R1-A3-42	Tree	3.50	0.00	0.00	0.00
R1-A3-43	Tree	5.53	0.00	0.00	0.00
R1-A3-44	Tree	0.00	0.00	0.00	0.00
R1-A3-45	Tree	2.20	0.00	0.00	0.00
R1-A3-46	Tree	0.00	0.00	0.00	0.00
R1-A3-47	Tree	6.75	0.00	0.00	0.00
R1-A3-48	Tree	0.00	1.49	7.87	0.00
R1-A3-49	Tree	0.80	0.00	0.00	0.00
R1-A3-50	Tree	1.36	0.00	0.00	0.00
R1-A3-51	Tree	0.00	0.00	0.00	0.00
R1-A3-52	Tree	2.46	0.00	0.00	0.00
R1-A3-53	Tree	0.00	0.00	0.00	0.00
R1-A3-54	Tree	0.92	0.00	0.00	0.00
R1-A3-55	Tree	0.00	2.42	0.00	0.00
R1-A3-56	Tree	0.00	0.00	0.00	0.00
R1-A3-57	Tree	6.89	6.00	0.00	0.00
R1-A3-58	Tree	0.00	0.00	0.00	0.00
R1-A3-59	Tree	2.39	0.00	0.00	0.00

R1-A3-60A	Tree	0.00	0.00	0.00	0.00
R1-A3-60A	Tree	0.00	0.00	0.00	0.00
R1-A3-60B	Tree	0.00	0.00	0.00	0.00
R1-A3-61	Tree	0.00	0.00	0.00	0.00
R1-A3-62	Tree	8.73	0.83	0.00	0.00
R1-A3-63	Tree	12.71	0.00	0.00	0.00
R1-A3-64	Tree	4.65	0.00	0.00	0.00
R1-A3-7A	Tree	14.98	0.00	0.00	0.00
R1-A3-7B	Tree	12.87	0.00	0.00	0.00
R1-A3-8	Tree	19.52	0.43	0.00	0.00
R1-A3-9	Tree	13.29	0.00	0.00	0.00
R1-A4-24	Tree	0.00	1.77	0.09	0.00
R1-A4-25	Tree	0.00	2.03	3.62	0.00
R1-A4-26	Tree	0.00	0.00	0.00	0.00
R1-A4-27	Tree	0.81	0.00	0.00	0.00
R1-A4-28	Tree	2.88	0.00	0.00	0.00
R1-A4-28B	Tree	0.86	0.00	0.00	0.00
R1-A4-29	Tree	8.65	0.00	0.00	0.00
R1-A4-30	Tree	0.00	0.00	0.00	0.00
R1-A4-31	Tree	4.72	0.00	0.00	0.00
R1-A4-32	Tree	5.69	0.00	0.00	0.00
R1-B1-10	Tree	0.00	0.00	0.00	0.00
R1-B1-11	Tree	0.00	0.00	0.00	0.00
R1-B1-12	Tree	1.35	0.00	0.00	0.00
R1-B1-13	Tree	0.95	0.00	0.00	0.00
R1-B1-14	Tree	1.28	0.00	0.00	0.00
R1-C1-15	Tree	5.29	0.68	0.00	0.00
R1-C1-16	Tree	0.00	0.00	0.00	0.00
R1-C1-17	Tree	0.00	0.00	0.00	0.00
R1-C1-18	Tree	0.00	0.00	0.00	0.00
R1-C1-19	Tree	3.90	0.00	0.00	0.00
R1-C1-20	Tree	7.31	0.00	0.00	0.00
R1-C1-21	Tree	4.05	0.00	0.00	0.00
R1-C1-22	Tree	6.78	0.00	0.00	0.00
R1-C1-23	Tree	5.67	0.00	0.00	0.00
R1-D1-101	Tree	1.60	0.00	0.00	0.00
R1-D1-65	Tree	29.02	3.37	1.37	0.00
R1-D1-66	Tree	11.74	1.50	0.00	0.00
R1-D1-67	Tree	3.33	2.36	0.00	0.00
R1-D1-68	Tree	0.00	0.00	0.00	0.00
R1-D1-69A	Tree	0.00	0.00	0.00	0.00
R1-D1-69B	Tree	0.00	0.00	0.00	0.00
R1-D1-69C	Tree	0.00	0.00	0.00	0.00
R1-D1-70A	Tree	4.70	0.00	0.00	0.00
R1-D1-70B	Tree	2.63	0.00	0.00	0.00
R1-D1-71	Tree	12.82	1.54	0.00	0.00
R1-D1-72	Tree	0.00	0.00	0.00	0.00
R1-D1-73	Tree	0.00	2.34	4.28	0.00

R1-D1-74	Tree	1.30	0.00	0.00	0.00
R1-D1-75	Tree	8.89	0.00	0.00	0.00
R1-D1-76A	Tree	10.23	0.00	0.00	0.00
R1-D1-76B	Tree	9.02	0.00	0.00	0.00
R1-D1-77B	Tree	4.22	0.00	0.00	0.00
R1-D1-77B	Tree	6.59	0.00	0.00	0.00
R1-D1-78	Tree	8.38	0.00	0.00	0.00
R1-D1-79	Tree	0.00	0.00	0.00	0.00
R1-D1-89	Tree	0.00	0.00	0.00	0.00
R1-D2-100	Tree	1.65	0.00	0.00	0.00
R1-D2-102	Tree	0.00	0.00	0.00	0.00
R1-D2-82	Tree	0.00	0.00	0.00	0.00
R1-D2-83	Tree	0.00	0.00	0.00	0.00
R1-D2-84	Tree	0.00	0.00	0.00	0.00
R1-D2-86	Tree	0.00	0.00	0.00	0.00
R1-D2-87	Tree	0.00	0.00	0.00	0.00
R1-D2-90	Tree	0.00	0.00	0.00	0.00
R1-D2-91	Tree	0.00	0.00	0.00	0.00
R1-D2-92	Tree	0.00	0.00	0.00	0.00
R1-D2-93	Tree	0.00	0.00	0.00	0.00
R1-D2-95	Tree	0.00	0.00	0.00	0.00
R1-D2-95	Tree	0.00	0.00	0.00	0.00
R1-D2-96	Tree	0.00	0.00	0.00	0.00
R1-D2-97	Tree	0.00	0.00	0.00	0.00
R1-D2-98	Tree	1.66	0.00	0.00	0.00
R1-D2-99	Tree	0.00	0.00	0.00	0.00
Reactor 2					
Sample	Sample Media	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Xylene (µg/Lv)
H2-9	Soil	0.00	0.00	0.00	0.00
H2-10	Soil	0.00	0.00	0.00	0.00
H2-11	Soil	0.00	0.00	0.00	0.00
H2-12	Soil	0.00	0.00	0.00	0.00
H2-13	Soil	0.00	0.00	0.00	0.00
H2-14	Soil	0.00	0.00	0.00	0.00
H2-15	Soil	0.00	0.00	0.00	0.00
H2-16	Soil	0.00	0.00	0.00	0.00
H2-17	Soil	0.00	0.00	0.00	0.00
H2-18	Soil	0.00	0.00	0.00	0.00
H2-19	Soil	0.00	0.00	0.00	0.00
H2-20	Soil	0.00	0.00	0.00	0.00
Reactor 3					
Sample	Sample Media	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Xylene (µg/Lv)
H3-6	Soil	0.00	0.00	0.00	0.00
H3-5	Soil	0.00	0.00	0.00	0.00
R3-A2-8	Tree	0.00	0.00	0.00	0.00
R3-A2-6	Tree	0.00	0.00	0.00	0.00

H3-2	Soil	0.00	0.00	0.00	0.00
H3-4	Soil	0.00	0.00	0.00	0.00
A3-8	Tree	0.00	0.00	0.00	0.00
R3-A2-9	Tree	0.00	0.00	0.00	0.00
H3-3	Soil	0.00	0.00	0.00	0.00
R3-A2-7	Tree	0.00	0.00	0.00	0.00
R3-A2-5	Tree	0.00	0.00	0.00	0.00
R3-D2-1	Tree	0.00	0.00	0.00	0.00
R3-D2-3	Tree	0.00	0.00	0.00	0.00
R3-D2-8	Tree	0.00	0.00	0.00	0.00
R3-D1-7	Tree	0.00	0.00	0.00	0.00
R3-A1-3	Tree	0.00	0.00	0.00	0.00
R3-A1-1	Tree	0.00	0.00	0.00	0.00
R3-A2-1	Tree	0.00	0.00	0.00	0.00
R3-D2-10	Tree	0.00	0.00	0.00	0.00
R3-D2-7	Tree	0.00	0.00	0.00	0.00
R3-A1-5	Tree	0.00	0.00	0.00	0.00
R3-D1-2	Tree	0.00	0.00	0.00	0.00
R3-A1-4	Tree	0.00	0.00	0.00	0.00
R3-D2-2	Tree	0.00	0.00	0.00	0.00
R3-D1-8	Tree	0.00	0.00	0.00	0.00
R3-A1-8	Tree	0.00	0.00	0.00	0.00
R3-D2-5	Tree	0.00	0.00	0.00	0.00
R3-D2-9	Tree	0.00	0.00	0.00	0.00
R3-A2-2	Tree	0.00	0.00	0.00	0.00
R3-A1-7	Tree	0.00	0.00	0.00	0.00
R3-A1-2	Tree	0.00	0.00	0.00	0.00
R3-A1-9	Tree	0.00	0.00	0.00	0.00
R3-D1-1	Tree	0.00	0.00	0.00	0.00
R3-D1-5	Tree	0.00	0.00	0.00	0.00
R3-A1-6	Tree	0.00	0.00	0.00	0.00
R3-D1-9	Tree	0.00	0.00	0.00	0.00
R3-D2-4	Tree	0.00	0.00	0.00	0.00
R3-A2-3	Tree	0.00	0.00	0.00	0.00
R3-D1-6	Tree	0.00	0.00	0.00	0.00
R3-D2-11	Tree	0.00	0.00	0.00	0.00
R3-D2-6	Tree	0.00	0.00	0.00	0.00
R3-A2-4	Tree	0.00	0.00	0.00	0.00
R3-D1-3	Tree	0.00	0.00	0.00	0.00
R3-D1-4	Tree	0.00	0.00	0.00	0.00
Reactor 4					
Sample	Sample Media	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Xylene (µg/Lv)
A2-1	Tree	0.00	0.00	0.00	0.00
A2-2	Tree	0.00	0.46	0.00	0.00
A2-2	Tree	0.00	0.00	0.00	0.00
A2-3	Tree	0.31	0.00	0.00	0.00
A2-4	Tree	0.00	0.00	0.00	0.00

A2-5	Tree	0.00	0.00	0.00	0.00
A2-6	Tree	0.00	0.00	0.00	0.00
A2-6	Tree	0.00	0.00	0.00	0.00
A3-1	Tree	0.00	0.00	0.00	0.00
A3-10	Tree	0.35	0.00	0.00	0.00
A3-11	Tree	0.00	0.00	0.00	0.00
A3-11	Tree	0.00	0.00	0.00	0.00
A3-2	Tree	0.00	0.00	0.00	0.00
A3-3	Tree	0.00	0.00	0.00	0.00
A3-3	Tree	0.00	0.00	0.00	0.00
A3-4	Tree	0.00	0.00	0.00	0.00
A3-5	Tree	0.00	0.00	0.00	0.00
A3-6	Tree	0.00	0.00	0.00	0.00
A3-7	Tree	0.00	0.00	0.00	0.00
A3-7	Tree	0.00	0.00	0.00	0.00
A3-8	Tree	0.00	0.00	0.00	0.00
A3-8	Tree	0.00	0.00	0.00	0.00
A3-9	Tree	0.00	0.00	0.00	0.00
C2-1	Tree	0.00	0.00	0.00	0.00
C2-2	Tree	0.00	0.00	0.00	0.00
C2-3	Tree	0.00	0.00	0.00	0.00
C2-4	Tree	0.00	0.37	0.00	0.00
C2-4	Tree	0.00	0.00	0.00	0.00
C2-5	Tree	0.42	0.00	0.00	0.00
C2-6	Tree	0.65	0.00	0.00	0.00
C2-7	Tree	0.51	0.00	0.00	0.00
C2-8	Tree	0.00	0.00	0.00	0.00
C2-9	Tree	0.00	0.00	0.00	0.00
C3-1	Tree	0.00	0.00	0.00	0.00
C3-10	Tree	0.39	0.00	0.00	0.00
C3-11	Tree	0.00	0.00	0.00	0.00
C3-12	Tree	0.40	0.00	0.00	0.00
C3-13	Tree	0.28	0.00	0.00	0.00
C3-2	Tree	0.00	0.00	0.00	0.00
C3-3	Tree	0.00	0.00	0.00	0.00
C3-4	Tree	0.47	0.00	0.00	0.00
C3-5	Tree	0.00	0.00	0.00	0.00
C3-6	Tree	0.00	0.00	0.00	0.00
C3-7	Tree	0.00	0.00	0.00	0.00
C3-8	Tree	0.39	0.00	0.00	0.00
C3-9	Tree	0.00	0.00	0.00	0.00
D4-1	Tree	0.00	0.00	0.00	0.00
D4-10	Tree	0.00	0.55	0.00	0.00
D4-11	Tree	0.00	0.43	0.00	0.00
D4-2	Tree	0.00	0.00	0.00	0.00
D4-3	Tree	0.00	0.00	0.00	0.00
D4-4	Tree	0.00	0.00	0.00	0.00
D4-5	Tree	0.00	0.00	0.00	0.00

D4-6	Tree	0.00	0.00	0.00	0.00
D4-7	Tree	0.00	0.00	0.00	0.00
D4-8	Tree	0.00	0.44	0.00	0.00
D4-8	Tree	0.00	0.00	0.00	0.00
D4-9	Tree	0.00	4.99	0.00	0.00
H4-01	Soil	0.00	0.00	0.00	0.00
H4-10	Soil	0.00	0.00	0.00	0.00
H4-2	Soil	0.00	0.00	0.00	0.00
H4-3	Soil	0.00	0.00	0.00	0.00
H4-4	Soil	0.00	0.00	0.00	0.00
H4-5	Soil	0.00	0.00	0.00	0.00
H4-6	Soil	0.00	0.00	0.00	0.00
H4-7	Soil	0.00	0.00	0.00	0.00
H4-8	Soil	0.00	0.00	0.00	0.00
H4-9	Soil	0.00	0.00	0.00	0.00
Reactor 5					
Sample	Sample Media	Benzene (µg/Lv)	Toluene (µg/Lv)	Ethylbenzene (µg/Lv)	Xylene (µg/Lv)
H5-1	Soil	0.00	0.00	0	0.00
H5-2	Soil	0.00	0.00	0	0.00
H5-3	Soil	0.00	0.00	0	0.00
H5-4	Soil	0.49	1.49	0	0.00
H5-5	Soil	7.38	37.74	43.48	31.98
H5-6	Soil	0.00	0.21	17.42	20.17
H5-7	Soil	14.07	61.38	123.31	100.60
H5-8	Soil	25.76	107.99	216.65	182.27
H5-9	Soil	22.38	70.80	213.40	180.88
H5-10	Soil	15.58	60.47	205.27	187.55

APPENDIX D.

FORMER REFINERY SITE TREE CORE LIST

Sample	Sample ID	Sampling Date	Tree Sampled
1	SC-TC-1	7/13/2004	Native
2	SC-TC-2	7/13/2004	Native
3	SC-TC-3	7/13/2004	Native
4	SC-TC-4	7/13/2004	Native
5	SC-TC-5	7/13/2004	Native
6	Field Blank	7/13/2004	Field Blank
7	SC-TC-0	10/22/2004	Field Blank
8	SC-TC-1	10/22/2004	Native
9	SC-TC-2	10/22/2004	Native
10	SC-TC-3	10/22/2004	Native
11	SC-TC-4	10/22/2004	Native
12	SC-TC-5	10/22/2004	Native
13	SC-TC-6	10/22/2004	Native
14	SC-TC-7	10/22/2004	Native
15	SC-TC-8	10/22/2004	Native
16	SC-TC-9	10/22/2004	Native
17	SC-TC-10	10/22/2004	Native
18	SC-TC-11	10/22/2004	Native
19	SC-TC-12	10/22/2004	Native
20	SC-TC-13	10/22/2004	Native
21	SC-TC-14	10/22/2004	Native
22	SC-TC-15	10/22/2004	Native
23	SC-TC-16	10/22/2004	Native
24	SC-TC-17	10/22/2004	Native
25	SC-TC-18	10/22/2004	Native
26	SC-TC-19	10/22/2004	Native
27	SC-TC-20	10/22/2004	Native
28	SC-TC-21	10/22/2004	Native
29	SC-TC-22	10/22/2004	Native
30	SC-TC-23	10/22/2004	Native
31	SC-TC-24	10/22/2004	Native
32	Field Blank	10/22/2004	Field Blank
33	SC-TC-01	4/11/2005	Native
34	SC-TC-02	4/11/2005	Native
35	SC-TC-03	4/11/2005	Native
36	SC-TC-04	4/11/2005	Native
37	SC-TC-05	4/11/2005	Native
38	SC-TC-06	4/11/2005	Native
39	SC-TC-07	4/11/2005	Native
40	SC-TC-08	4/11/2005	Native
41	SC-TC-09	4/11/2005	Native
42	SC-TC-10	4/11/2005	Native
43	Field Blank	4/11/2005	Field Blank
44	SC-TC-01A	8/29/2006	Non-Native
45	SC-TC-01B	8/29/2006	Non-Native
46	SC-TC-2A	8/29/2006	Non-Native
47	SC-TC-03A	8/29/2006	Non-Native

48	SC-TC-03B	8/29/2006	Non-Native
49	SC-TC-04A	8/29/2006	Non-Native
50	SC-TC-05A	8/29/2006	Non-Native

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VITA

Jeff Weishaar was born in Omaha, Nebraska is 1980. He moved to St. Louis, Missouri in 1990 and graduated from high school there in 1999. He attended a few universities before deciding to study civil engineering at the University of Missouri-Rolla (UMR). He received his Bachelor of Science in Civil Engineering from UMR in 2004. He remained at UMR entering the Environmental Engineering graduate program studying Environmental Engineering and researching phytoremediation in the laboratory and at various field sites around the United States. In 2006, he accepted a job with Carollo Engineers in San Diego, California. He moved to San Diego in November, 2006, to start work and finish writing his thesis. On November 21, 2006, he became a father with the birth of his daughter, Audrey Alice Weishaar. He became engaged shortly thereafter, and plans to marry the love of his life, Monica Winters, even if she won't take his name. Jeff received his Master's Degree from UMR in August 2007.