Technology Demonstration Report
PolyGuardÄ
Guardian Environmental Technologies, Inc.

Prepared for

The Massachusetts Strategic
Envirotechnology Partnership
STEP

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Prepared by

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PREFACE

The STEP technology assessment process is designed to identify those technologies that will support the economic and environmental/energy goals of the Commonwealth of Massachusetts and may benefit from STEP assistance. The process is meant to be one of screening, in which technologies are evaluated by independent technical specialists. Recommendation from this process does not constitute an endorsement of the technology or of the absolute validity of the technology. STEP technical assessments attest only that, through the screening process, the reviewers feel there may be benefit to the Commonwealth of Massachusetts.

PROJECT FUNDING

This STEP Technology Assessment was funded by
The University of Massachusetts and The Massachusetts Division of Energy Resources

EXECUTIVE SUMMARY

Technology Innovation

PolyGuard™ is a granular absorption media used to remove hydrocarbon contaminants from liquid and vapor streams. PolyGuard's mode of action depends upon the ability of the active material to selectively absorb molecules with suitable solubility characteristics directly into its internal structure to form a stable, solid solution. Such a mechanism allows PolyGuard to absorb very large quantities of molecules, which have compatible solubility characteristics. Contaminants in water or air waste streams are partitioned into soft or glassy regions of the medium. These regions have a strong affinity for hydrocarbons, chlorinated hydrocarbons and many other non-polar organic compounds. PolyGuard has very little affinity for molecules whose solubility characteristics are very different from those of the active PolyGuard polymer. PolyGuard may not readily absorb inorganic compounds and some organic compounds that have high water solubility from aqueous streams.

Company Description and Projected Market Impact

Guardian Environmental Technologies (GET) is a Connecticut corporation, founded in 1992 by the present majority owner, and has been located in Kent, Connecticut, since that time. The basic technology was developed as a result of the development of families of polymeric absorbents, with a high affinity for hydrocarbons and chlorinated compounds.

GET estimates that the total U.S./Worldwide market potential, which uses absorption or adsorption technology, is in excess of $24 billion, with a predicted continued growth rate in selected market segments of 4% to 6% per year, through 2001. Because the most widely used method of environmental and industrial process water cleanup is carbon adsorption, GET has selected those industries where the use of carbon is most common. Of the leading types of volatile organic compound treatment equipment used for air pollution control, carbon is near the top in order of market share.

Prior Research Results

Lab testing has been performed on PolyGuard with several priority pollutants. Some of these unpublished studies demonstrate that PolyGuard absorbent can absorb more than twice its weight of diesel fuel or home heating fuel. Laboratory studies with iso-octane demonstrated a loading capacity for PolyGuard of greater than 4:1 (grams of contaminant per gram of PolyGuard).

Product Demonstration Objectives

This experimental pilot program was conducted in conjunction with the Commonwealth of Massachusetts Strategic Envirotechnology Partnership (STEP). The primary objectives of this pilot were: i) to demonstrate removal of organic compounds associated with gasoline contaminated ground water utilizing PolyGuard absorbent ii) to quantify the absorption potential of PolyGuard specifically for MTBE in conjunction with other organic contaminants associated with gasoline contaminated ground water, iii) to quantify the absorption potential of PolyGuard for BTEX compounds, iv) to evaluate the stability of the spent PolyGuard material providing information on disposal alternatives, and v) to monitor the hydraulic performance of PolyGuard under pump and treat remediation operation.

Experimental Methodology

The test demonstration methodology was designed in cooperation with GET and Environmental Compliance Services (ECS, Agawam, MA) the cleanup site operator. The demonstration site was a gasoline release at gas station located in Bellingham Massachusetts with high levels of MTBE and BTEX. Contaminant levels were reported for BTEX and MTBE as 75 and 125 mg/L respectively, prior to initialization of the demonstration. These concentrations decreased during the course of the experiment by a factor of 3 or more and were beyond the control of the site operator. The basic design premise of "Pump and Treat" was established by ECS and system configurations were established based on GET design criteria. The core design consideration used by GET to achieve its goals was a minimum residency time of 15 minutes. PolyGuard vessels were constructed in series to provide the minimum residency time and redundancy to lengthen the period between change outs at operating rates up to 3 GPM. Three PolyGuard system configurations were used at the option of ECS and GET. The design changes were attempts to assess changes in filter bed geometry on system performance.

The pretreatment system developed by ECS included a fractionation tank, diffuser and a Provectr iron removal system. Phase 1 of the pilot was conducted with two standard 110-gallon drums containing 11 cubic feet each or 418 pounds of PolyGuard (GET 1 and 2). The PolyGuard vessels constructed in Phase 2 included two 56-gallon fiberglass columns, 14" in diameter by 120" in length (N1 and N2). During this test one column was rebedded with fresh material resulting in three reported columns (N3). Phase 3 included eight absorber vessels constructed using 8" diameter by 120" long schedule 40 PVC pipe (ECS 1-8). Phase 3 operation included the Phase 2 vessels preceding the Phase 3 vessels, although the Phase 2 vessels were not freshly rebedded at the beginning of Phase 3. The pump and treat system was fully automated and required periodic maintenance compatible with the sampling regime.

Water samples were taken on the influent and effluent side of each set of contactors and the effluent side of the GAC filter beds when used. Sampling frequency was required to follow the minimum specified by the NPDES Permit exclusion. Upon startup, influent and effluent samples were to be taken every other day for the first week (3 samples). This level of sampling was necessary to establish that equilibrium conditions were met. After the first week, samples were to be taken every 5 days for the duration of the test. Water samples were analyzed using standard EPA methods for BTEX and MTBE.

Results

Results from this pilot demonstration are reported for the period between August 25, 1997 and December 24, 1998. During this period treated groundwater volume and contaminant concentrations were monitored to assess the removal efficiency and mass removal capacity of PolyGuard for BTEX and MTBE. The data from this period of monitoring is segregated into three phases, which reflect three distinct operating conditions on the site. In reporting the results from these tests, deviations from the original system configuration provide somewhat less detailed information on the properties of PolyGuard. These data, however, indicate trends that may be useful for developing additional field models. In this analysis the data are better described as qualitative, since the planned replication of operating conditions was not completed and data do not allow for controlled statistical comparisons.

Phase 1 of the pilot demonstration operated between August 25, 1997 and September 6, 1997. Mass flow to the system was 22,203 gallons. Average flow was 0.98 GPM over the duration of the test. Average MTBE influent concentration over the sampling period was 263 mg/L (standard deviation (s)=147 mg/L, sample number (n)=5). Removal efficiency for MTBE decreased during the course of the test from 100% to 71% at the close. Average column mass removal efficiency during this test was 56% and 78% for GET 1 and GET 2, respectively. The mass loading to the PolyGuard material was approximately 15% on a weight per weight basis. Average BTEX influent concentration over the sampling period was 36 mg/L (s=25.3 mg/L, n=5). Average mass removal efficiency during this test was 95% and 100% for GET 1 and GET 2, respectively. BTEX mass loading based on this method totaled 5.2 lbs. of which the PolyGuard columns removed 100%. The mass loading was approximately 1% on a weight per weight basis. Higher loading was specified in the protocol. However, the testing was terminated prematurely to comply with permitted discharge limitations. This problem occurred due to the failure of the operator to install GAC units as specified in the protocol.

Phase 2 of the pilot demonstration operated between October 27, 1997 and December 3, 1997. Mass flow to the system was 40,707 gallons. Average flow of 0.63 GPM over the duration of the test. Average MTBE influent concentration over the sampling period was 85.6 mg/L (24.8 mg/L, n=9). Removal efficiency for MTBE decreased during the course of the test from 100% to 21%. Average column mass removal efficiency during this test was 42%, 58% and 44% for N1, N2 and N3, respectively. MTBE mass loading during this test period totaled 28.1 lbs. of which the PolyGuard columns removed 15.1 lbs. The mass loading to the PolyGuard material was approximately 4% on a weight per weight basis. Average BTEX influent concentration over the sampling period was 30.3 mg/L (s=10.8 mg/L, n=9). Removal efficiency for BTEX decreased minimally and less than that observed for MTBE during the course of the test. Average column removal efficiency during this test was 98 to 100% for all three N columns. On one instance, November 18th, removal efficiency dropped to 81% in N2. However, it is unclear whether an analytical error occurred on that data rendering a sample concentration bias. Mass removal was calculated as previously described. BTEX mass loading based on this method totaled 10.35 lbs. of which the PolyGuard columns removed 99.6%. The GAC column removed BTEX, which passed through the N columns. The mass loading to the PolyGuard material was approximately 3% on a weight per weight basis. Higher loading was specified in the protocol. However, the testing was terminated prematurely to comply with permitted discharge limitations.

Phase 3 of the pilot demonstration was implemented June 17, 1998 and data is reported up until August 31, 1998. Total mass flow pumped though the system during this test was 51,951 gallon with an average flow of 0.44 GPM over the duration of the test. Average MTBE influent concentration over the sampling period was 38.3 mg/L (s=14.0 mg/L, n=11). Removal efficiency for MTBE decreased during the course of the test from 100% to 39%. The vessels from Phase 2 used in Phase 3 did not remove any appreciable amounts of MTBE during this test. Average system mass removal efficiency during this test was 82%. MTBE mass loading totaled 14.9 lbs. of which the ECS PolyGuard columns removed 13.1 lbs. The mass loading to the PolyGuard material in the ECS columns ranged from 1 to 7% on a weight per weight basis. Average BTEX influent concentration over the sampling period was 14.6 mg/L (s=7.0 mg/L, n=11). Removal efficiency for BTEX remained at 100% during the course of the test. Average column mass removal efficiency during this test ranged from 3% to 100%. BTEX mass loading based on this method totaled 6.82 lbs. of which the N columns removed 6.81 lbs. Based on the useful data, apart from the non-detects, it is estimated that the ECS columns removed 0.01 lbs. of BTEX. The mass loading to the PolyGuard material in the system was approximately 1% on a weight per weight basis. The N columns had a slightly higher mass loading rate of 3% on a weight per weight basis.

System performance demonstrated removal rates for BTEX up to 100% during the operation of each of the phases. The removal rates for MTBE were lower ranging from 3% to 100% for any individual column during each interval, while average system removal was 91, 41 and 82% for Phases 1, 2, and 3, respectively.

Under the study operating conditions system hydraulic performance did not present any limitations to use. A qualitative assessment of the hydraulic performance suggests that under the operating rates observed in this study, the system configuration and system construction, PolyGuard is capable of handling flows as high as 2 GPM or higher without significant effort to increase operating pressures.

No information regarding product stability or disposal costs were available from these studies. Disposal costs reported by GET indicate approximate costs of $275 to $325 per 55-gallon drum for hazardous material disposal and $89 per 55-gallon drum for non-hazardous material disposal. Proposed disposal may include fuel blending and or incineration.

A preliminary cost analysis was performed to assess the per pound cost to remove MTBE using PolyGuard. This analysis was made using total estimated contaminant removed and material cost of PolyGuard. Operational and capital cost were excluded from this analysis because under piloting conditions these cost do not reflect full commercial deployment of the technology. Lowest cost per pound of MTBE removed was realized during Phase 1 at $59/lb with the highest mass loading rate. Phase 2 and 3 costs were estimated at $229 and $262 per pound of MTBE removed. Cost per pound of MTBE removed with PolyGuard had a wide range due to problems associated with operation of the test. In particular, premature cessation of the test resulted in lower mass loading than was specified in the test protocol. These data suggest that PolyGuard may be cost competitive with GAC under conditions of high MTBE mass loading. Further cost analysis should be performed on properly operated PolyGuard systems developed in the future.

Conclusions

In this pilot one of the target contaminant was MTBE, which has a lower affinity for PolyGuard than other non-polar contaminants. As such, an absorption capacity 75% for MTBE was used as a goal in the design calculations. The absorption "rate" was estimated at 60%. A capacity of 150% was calculated for the BTEX portions of the influent with a removal rate of 99%.

The three tests conducted during this study reflect different operating conditions for the use of PolyGuard. The first test had the highest average flow rate, at 0.98 GPM and the highest average influent concentrations for MTBE, 263 mg/L. Under these conditions, PolyGuard demonstrated the highest absorption capacity of 15%. During this test removal efficiency was 93% on a mass basis. The second test had an average flow rate of 0.63 GPM and an average influent concentration of 86 mg/L MTBE. System absorption capacity for MTBE was 4% on a mass basis. The MTBE removal efficiency of this PolyGuard system was the lowest at 41%. Test three had the lowest average flow rate and influent MTBE concentration, at 0.48 GPM and 38 mg/L, respectively. In all test cases the PolyGuard system never reached capacity and continued to remove MTBE at 71%, 54% and 39% efficiency for tests 1, 2, and 3 respectively. Due permitted discharge limits all the tests were ended before capacity of the system was reached. In part, this was due to a failure of the operator to construct and maintain the safeguards specified in the test protocol.

With respect to BTEX removal, all three tests demonstrated excellent BTEX removal. Influent concentrations did not vary as much between tests with average influent concentrations of 36, 33, and 15 mg/L BTEX for tests 1, 2, and 3 respectively. Capacity for BTEX was never reached since system absorption of BTEX was 100% in each test. Due to the solubility characteristics of the BTEX constituents relative to MTBE, high absorption to PolyGuard was expected. Changes in system configuration, operating flow rates and influent concentrations add additional uncertainty to the results of these tests. Further, the applicability of the performance characteristics to operating conditions not defined by those in these studies is limited.

Data from this study suggests that PolyGuard has greater potential for MTBE removal when concentrations are greater than 100 mg/L. These data also indicate that, except with virgin PolyGuard, removal efficiencies are not suitable for treatment of MTBE in aqueous systems to concentrations at or near drinking water standards. This feature tends to suggest that PolyGuard is useful as a bulk contaminant remover and not a final polishing agent. One operational feature this demonstration was able to demonstrate was the need for a final polishing step such as GAC to achieve MTBE levels as required by the NPDES Permit exclusion.

It is useful to identify costs associated with remediation technologies. The USEPA provides guidance for documenting and cost and performance information for remediation projects under a similar title (USEPA, 1998). However, under piloting conditions it is difficult to develop accurate cost analysis for full deployment of a commercial application. The protocol for this demonstration was not developed with these guidelines and therefore does not conform to those standards. Cost data was not made readily available for this report and tests conducted under this study were not carried out to completion. Therefore capacity data do not reflect the ultimate capacity of PolyGuard or the minimum cost associated with contaminant removal. Because the cost analysis data is incomplete and true operations and maintenance data could not be collected in this demonstration of PolyGuard, it is difficult to quantify the competitive advantages of PolyGuard when compared to GAC systems, the current industry standard. However, qualitative evidence suggests performance and cost advantages under high MTBE concentrations and a range of BTEX concentrations

Further studies are recommended based on qualitative results from this study. Foremost, isotherm analysis under a variety of operating conditions will assist in quantifying absorption rates, especially where concentration varies. Furthermore, it is recommended that studies tests of PolyGuard absorption with complex solutions under controlled conditions may assist in understanding product performance. Additional investigation into system fouling and microbial activity is also recommended since they are problems in GAC systems. Field studies under alternative conditions to those reported in this study may assist in developing full scale operating parameters, but may be less useful for broader applicability to diverse sets of operating conditions.

The potential strengths and weaknesses of PolyGuard compared with GAC should also be further explored. Full life cycle costs, including capital costs, O&M, and disposal need to be more fully characterized for operational systems, following EPA methodologies.

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INTRODUCTION

Technology Innovation

PolyGuard™ is a granular absorption media used to remove hydrocarbon contaminants from liquid and vapor streams. PolyGuard's mode of action depends upon the ability of the active material to selectively absorb molecules with suitable solubility characteristics directly into its internal structure to form a stable, solid solution. Such a mechanism allows PolyGuard to absorb very large quantities of molecules, which have compatible solubility characteristics. Contaminants in water or air waste streams are partitioned into soft or glassy regions of the medium. These regions have a strong affinity for hydrocarbons, chlorinated hydrocarbons and many other non-polar organic compounds. PolyGuard has very little affinity for molecules whose solubility characteristics are very different from those of the active PolyGuard polymer. PolyGuard may not readily absorb inorganic and some organic compounds that have high water solubility from aqueous streams.

Granular activated carbon (GAC), molecular sieves and similar media depend upon the adsorption of contaminants onto the internal surfaces of the material. Contaminant selectivity is based upon several factors, including the chemical nature of the material to be adsorbed and the molecular size and shape of the compound. GAC has a broad range of selectivity towards various molecular types, and carbon will adsorb polar molecules (including water-soluble compounds) as well as non-polar molecules, such as hydrocarbons. The capacity of the carbon to adsorb different types of molecules, however, will vary from modest to low, again depending upon the characteristics of the contaminants and conditions such as temperature, pressure and concentration.

In contrast, PolyGuard's mode of action depends upon the ability of the active material to selectively absorb molecules with suitable solubility characteristics directly into its internal structure to form a stable, solid solution.

This mode of action distinguishes PolyGuard from other absorbents and adsorbents. These characteristics are; a) PolyGuard absorbs contaminants into its internal structure at weight to weight ratios of up to 4:1. b) Once contaminants are absorbed, organic compounds are "encapsulated" and cannot be easily released through pressure alone. c) The capacity of the absorption bed in vapor phase application is not affected by the presence of water vapor in the contaminant stream.

PolyGuard has a strong affinity for hydrocarbons (including components of: gasoline, diesel fuel, and heating oil), chlorinated hydrocarbons, chlorinated industrial solvents such as TCE and PCE, and polychlorinated biphenyls (PCBs). PolyGuard has applicability in treating industrial waste streams, pump and treat remediation of contaminated soil and ground water, and other applications where GAC is used. In previous laboratory studies PolyGuard demonstrated strong absorption potential for methyl-tertiary-butyl-ether (MTBE), a significant component of gasoline.

Company Description

Guardian Environmental Technologies (GET) is a Connecticut corporation, founded in 1992 by the present majority owner, and has been located in Kent, Connecticut, since that time. The basic technology was developed as a result of the development of families of polymeric absorbents, with a high affinity for hydrocarbons and chlorinated compounds.

GET's first product was first introduced in 1992 under the name PetroGuard™. The original product was meant purely as an oil spill control for surface oil removal. PetroGuard has been enhanced and improved over the years in both capacity and effectiveness to treat not only petroleum products, but also a wide range of chemical hydrocarbons.

GET used the same basic technology to develop a high-performance absorption media for the removal of dissolved hydrocarbon contamination from water and vapor streams. This technology is meant to fill a need worldwide for the treatment of polluted water and the vapor phase applications associated with that type of pollution. The product family developed for these applications was named PolyGuard™. A contract blender is used to manufacture PolyGuard™ and PetroGuard™ for GET.

Projected Market Impact

GET estimates that the total U.S./Worldwide market potential, which uses absorption or adsorption technology, is in excess of $24 billion, with a predicted continued growth rate in selected market segments of 4% to 6% per year, through 2001. Because the most widely used method of environmental and industrial process water cleanup is carbon adsorption, GET has selected those industries where the use of carbon is most common. Of the leading types of volatile organic compound treatment equipment used for air pollution control, carbon is near the top in order of market share.

Prior Research Results

Lab testing has been performed on PolyGuard with several priority pollutants. Some of these unpublished studies demonstrate that PolyGuard absorbent can absorb more than twice its weight of diesel fuel or home heating fuel. Laboratory studies with iso-octane demonstrated a loading capacity for PolyGuard of greater than 4:1 (grams of contaminant per gram of PolyGuard).

Closed loop experiments

Closed loop tests were performed to determine the maximum capacity of PolyGuard to absorb certain hydrocarbons. The total loading capacity was achieved in a closed loop system which allowed the analyte to be continuously circulated over a 24 or 48 hour period or until equilibrium was reached. These tests were not designed to demonstrate the rate of absorption. The tests were designed to minimize the time needed to reach capacity.

In these demonstrations, a 2-gram PolyGuard bed was subjected to a continuous flow system, at 30 ml/min, using a solution containing 4 grams of BTEX (34% benzene, 33% toluene, 33% xylene, and trace ethylbenzene) over the course of 24 hours. A schematic of the continuous flow system is shown in Figure 1. Results from this test indicated that PolyGuard had an absorption capacity of 1.97:1 for BTEX.

With addition of another 4 grams of BTEX to the solution, a total absorption ratio of 3.84:1 was recorded at 36 hours. Additional studies were conducted by an independent laboratory to determine PolyGuard absorption capacity in aqueous solutions for several commonly encountered hydrocarbon contaminants. In five-closed loop capacity tests, the total weight of the hydrocarbon absorbed per gram of PolyGuard used was determined over similar time frames. These data are presented in Table 1.

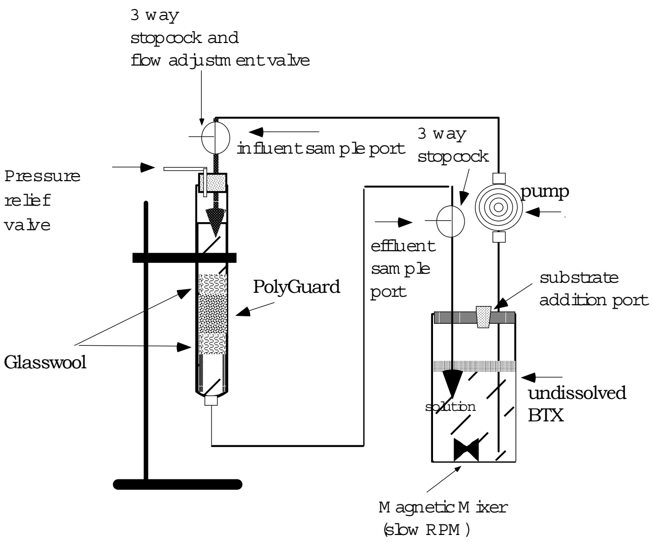

Figure 1: Schematic of closed loop capacity test apparatus. (After, GET, 1997).

Table 1. Test constituents, parameters and results from closed loop studies.

Beginning Contaminant Loading (grams)	Total PolyGuard (grams)	Final Loading Contaminant (ppm)	Absorption Capacity (grams/gram)
iso-Octane (2.0 grams)	1.0	2	2.0:1.0
MTBE (2.0 grams)	1.0	465	1.53:1.0
Trichloroethylene (2.0 grams)	1.0	5	1.99:1.0
BTEX (4.0 grams)	2.0	76	3.84:1.0
PCB's (Arochlor 1248) (2 grams)	2.0	5	0.99:1.0

Note: The experiment did not measure ultimate capacity-only performance at the measured capacity.

Controlled Flow Experiments

Additional tests were conducted to demonstrate the rate of absorption of contaminants from a controlled flow of water to simulate a specific residence time. These tests were run to determine the ability of PolyGuard to remove certain hydrocarbon contaminants in a single pass through, as would occur in the field. The apparatus used in these studies is shown in Figure 2. It should be noted that the maximum absorption capacity (weight to weight ratio) was not demonstrated in these tests, because the bed was not allowed to reach equilibrium.

In selecting an acceptable residence time, the most effective practical weight to weight ratio was calculated to prevent reaching maximum capacity. This is significant, since PolyGuard forms a "plug" resulting from the transformation of the granules into a solid glass-like mass, when completed saturated with hydrocarbons. In a field installation this would only occur if the bed was loaded with pure or near pure product or if a system was neglected and allowed to run beyond capacity. In field applications, this would be demonstrated by a large pressure drop. Operational devices, such as equilibration tanks, are capable of avoiding application of pure product onto the bed under field situations.

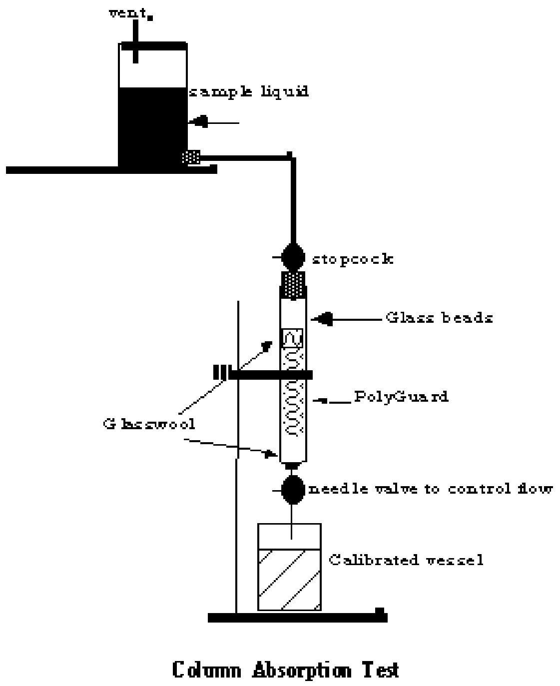

Figure 2: Schematic of single pass column absorption apparatus. (After, GET, 1997).

PolyGuard was packed into a 1-inch wide column giving a length to width ratio of 5:1. Five experiments were conducted with MTBE, TCE, Iso-Octane, Arochlor 1248, and a benzene-toluene-xylene mixture. Analyte solution was passed over the bed using a residence time of approximately 10-minutes, based on bed volume. The percent contaminant absorbed from the five tests are presented in Table 2. below:

Table 2. Results from absorption studies with residency time of 10 minutes.

Contaminants (20 mg/L)	% Absorbed
MTBE	87.8
TCE	98.9
Iso-Octane	98.5
PCB (Arochlor 1248)	87.4
Benzene	99.8
Toluene	99.8
Xylene	99.9

The results from bench scale studies suggest that PolyGuard may perform as efficiently as GAC under loading rates and residency times described in these studies. In these tests, comparisons to carbon efficiency were not performed. There are potential limitations to the application of results from single component studies. This is especially so, where the application of PolyGuard is typically with systems containing a mixture of contaminants. Further studies are recommended for this area of inquiry. Comparisons to GAC can be made once some of these unknowns are addressed. Furthermore, these data do not reflect changes in absorption rates relative to bed loads. Kinetic studies could enhance the developer's ability to predict absorption rates that may be affected by dual mode transfer processes and or concentration gradients.

These data indicate that additional bench scale testing is required. In particular, isotherm studies with priority contaminants, and complex solutions will provide performance data suitable for broader applications. Further work on retention times is needed to assess the full range of loading rates.

PILOT DEMONSTRATION

Participants

Guardian Environmental Technologies

Guardian Environmental Technologies provided all PolyGuard media and the primary columns for this test. The STEP PI and GET were to compile all relevant data into an overall analysis. GET was to support final report preparation along with the STEP PI. GET was to provide the STEP program with any additional available data for preparation of the final report of the pilot demonstration. William Litwin was the primary responsible individual at Guardian Environmental Technologies.

B & D Petroleum Corporation (Property Owner)

B & D Petroleum Corporation provided access to the site for maintenance, sampling, and monitoring the pilot study.

Environmental Compliance Services (Consulting Engineers)

Environmental Compliance Services, of Agawam and Brighton Massachusetts, was designated to operate and maintain the PolyGuard system for the duration of the pilot. ECS agreed to fabricate all secondary columns for Phase 3 and was responsible for installation and operation of the system as consulting engineers for the site. ECS was responsible for sampling and laboratory analysis. ECS was responsible for providing data to GET and to the STEP PI. ECS was responsible for supervising and or carry out the sampling protocols, transport samples to the analytical facilities, and provide for analysis of samples. ECS was responsible for assuring that standard operating procedures (SOPs) were followed and that changes were reported to the STEP PI. ECS was to be primarily responsible for assuring that sampling protocols and analytical methods adhered to the specifications of this pilot program and would notify Guardian Environmental Technologies or the STEP PI of any deviations of the specified protocols in a timely manner. ECS was also responsible for review of the final report.

University of Massachusetts – Amherst (STEP)

The Center for energy Efficiency and Renewable Energy in the Department of Mechanical and Industrial Engineering at the University of Massachusetts at Amherst (UMASS - Amherst) provided project oversight and reporting through the STEP Principal Investigator. The STEP P.I. was to ensure that technical, practical, and operational aspects of the study were documented and that objectives established for this pilot were completed. The STEP P.I. provided guidance on sampling protocols and technical guidance for the pilot. Oversight during the project included design and revisions to pilot test protocol, site visits during installation, initial sampling, dismantling, preparation of final report.

Executive Office of Environmental Affairs (STEP)

The Executive Office of Environmental Affairs was responsible for oversight and coordination of the evaluation and issuance of the final report. EOEA was responsible for coordination of project review and assistance in delivery and preparation of a demonstration project case study. Massachusetts DEP provided oversight on regulatory requirements through the regional BWSC coordinator. DEP participated in site visits and review of analytical results and report preparation.

Significance of Work

National attention to environmental pollution has led to new treatment technologies. In particular, removal of contaminants from groundwater is of significant importance as having immediate impact on other water quality issues. However much of the technology which has been developed requires significant capital investment, may be of uncertain efficacy, and may be labor intensive or impractical for certain applications. On-site incineration may not be a practical. Off-site incineration of collected PolyGuard has been identified as a suitable candidate for fuel blending at cogeneration and incineration facilities capable of handling these materials. Direct landfilling of spent PolyGuard would require special conditions as would be required for any adsorbent/absorbent containing similar contaminants.

The most common technique for treating contaminated groundwater is to pump the water out of the ground and treat through granulated activated carbon (GAC) beds either in liquid or vapor forms (US EPA, 1997). However, this method often has severe limitations when used in treating water-soluble organic compounds, biologically active groundwater systems and water with high iron or manganese concentrations. Numerous innovative treatment schemes are employed successfully for remediating contaminated groundwater. However, startup time, operation and maintenance, and user and regulatory acceptance are detractors to novel methodologies. The system utilized in this study is innovative since it capable of treating contaminants that GAC cannot and is operationally similar to GAC in setup and O&M. This affords rapid implementation and well defined performance characteristics, two key factors for user acceptance. Reduced cost per pound of removed contaminant and disposal are important for system utilization.

State Environmental Objectives

In Massachusetts, clean up of contaminated sites under the Massachusetts Contingency Plan (MCP) – 310 CMR 40.0000 is performance based. This allows innovative technologies to be utilized where their performance meets the minimum criteria. Pump and treat remediation of gasoline contamination is required to meet specific effluent concentrations prior to discharge. Under the conditions of a Release Abatement Measure (RAM), as was the case on this study site, discharge levels were set by the USEPA under a National Pollution Discharge Elimination Discharge System (NPDES) Permit Exclusion. Under this Exclusion Permit, limits are as follows: TPH (Total Petroleum Hydrocarbons)– 5000 ug/L, Benzene – 5 ug/L, BTEX (Benzene, Toluene, Ethyl Benzene, and Xylenes) - 100 ug/L, and MTBE (Methyl Tertiary Butyl Ether)– 70 ug/L.

Specific Project Environmental Objectives

Site Characterization

The site is a gasoline release at gas station (Figure 3) with high levels of MTBE and BTEX. Contaminant levels are reported in Table 3 below. Specific details of the proposed test site including the site plan and location, hydrology, complete groundwater organic and inorganic analysis are included in Appendix C, the Remediation Abatement Measure Proposal, date July, 1997. Details of the site status prior to and during the demonstration are included in Appendix C, Status update of the Remediation Abatement Measure Proposal, date April 1998. Contaminant concentrate levels are presented in Table 3.

Figure 3: Site of Gasoline spill in Bellingham, Massachusetts, 1997.

Table 3. Initial level of contaminants at proposed site.

Contaminant	Concentration (mg/L)
BTEX	75
MTBE	125
TPH	(Included in BTEX)

Site Description

Environmental Compliance Services, Inc. (ECS) prepared a Release Abatement Measure (RAM) status report summarizing activities which took place at the B & D Petroleum Sales Facility located at 220 South Main Street in Bellingham, Massachusetts (here-in-after referred to as the Site). This report discussed remedial operations associated with the groundwater recovery and treatment system (GTS), GTS sampling and analysis results, and monitoring of the groundwater quality at the Site since the implementation of the RAM modification in August, 1997.

Product Demonstration Objectives

This experimental pilot program was conducted in conjunction with the Commonwealth of Massachusetts Strategic Envirotechnology Partnership (STEP). The primary objectives of this pilot were: i) to demonstrate removal of organic compounds associated with gasoline contaminated ground water utilizing PolyGuard absorbent ii) to quantify the absorption potential of PolyGuard specifically for MTBE in conjunction with other organic contaminants associated with gasoline contaminated ground water, iii) to quantify the absorption potential of PolyGuard for BTEX compounds, iv) to evaluate the stability of the spent PolyGuard material providing information on disposal alternatives, and v) to monitor the hydraulic performance of PolyGuard under pump and treat remediation operation.

The final effluent concentration must be below the requirement mandated by the USEPA NPDES Permit Exclusion. This goal was to be achieved using PolyGuard in conjunction with a granulated activated carbon (GAC) finish filter or other equivalent technology. Performance of the PolyGuard system was judged on its ability to trap contaminants in large quantities and extend the life of the final polishing filter.

In this pilot, the target contaminant was MTBE, which has a lower affinity for PolyGuard than other non-polar contaminants. BTEX was a secondary target contaminant. As such, an absorption capacity 75% for MTBE was used as a goal in the design calculations. This value was based on previous laboratory tests. The absorption "rate" was estimated at 60%. A capacity of 150% was calculated for the BTEX portions of the influent with a removal rate of 99%. These rates were expected to vary due to fluctuations in flow rates and concentration levels, but are considered the target performance goals.

Experimental Methodology

The test demonstration methodology was designed in cooperation with GET and ECS. The basic design premise of "Pump and Treat" was established by ECS and system configurations were established based on GET design criteria. The core design consideration used by GET to achieve its goals was a minimum residency time of 15 minutes. This value came from lab studies conducted previously, which showed optimal removal in 10 minutes and a safety factor was added. For a system design flow rate of 3 GPM, a PolyGuard system would have volume of 90 gallons, which accounts for a 50% void volume. PolyGuard vessels were constructed in series to provide the minimum residency time and redundancy to lengthen the period between change outs. In some cases the serial system was designed to provide replication of the system where for example column 1 and column 2 could be considered sample replicates. It was recommended that all the systems be designed with a GAC bed as a final polish and to assure regulatory compliance. A typical PolyGuard bed is shown in Figure 4.

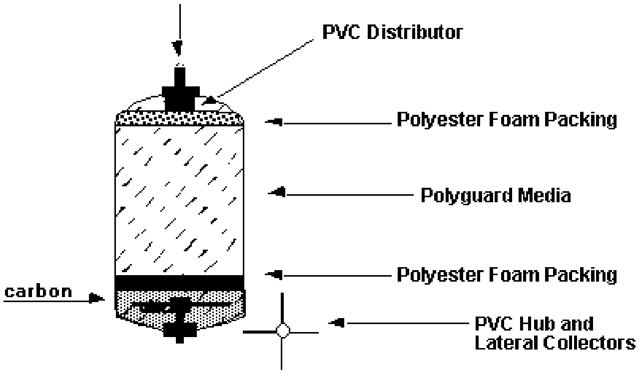

Figure 4: Typical fiberglass PolyGuard filter unit. (After GET, Inc. 1998)

The PolyGuard system configuration was modified two times after the initial design, hence Phase 2 and 3 are included. These changes occurred at points after which the system was shut down by ECS due to contaminant breakthrough. The design changes were later attempts to assess changes in filter bed geometry on system performance. Unfortunately, the changes in system design reduced the number of data points for any individual system configuration. The following sections describe the design considerations and provide descriptions of the different system configurations.

System Design Considerations

Each PolyGuard system design was configured and predicted absorption capacity was used to calculate bed life. The table in Appendix A illustrates the design calculations for the Phase 3 system configuration. Phase 1 and Phase 2 sizing was based on similar tables (not provided). Contaminant concentrations from the Bellingham site (Table 3) were used in the bed life calculations. The contaminant loading used for bed life prediction was calculated as the sum of MTBE, BTEX, plus 40% of the BTEX and MTBE concentrations (an estimate of TPH).

Consideration was given to potential competitive absorption, expected to occur at lower contaminant concentrations. Absorption capacity and rate were calculated separately. The removal efficiencies of PolyGuard for TPH, BTEX and MTBE were expected to be different, based on previous experience and known chemical characteristics. It was considered that performance of the absorption system, as measured by removal of BTEX or MTBE alone, would underestimate total hydrocarbon absorption capacity. However, under field test conditions, this factor could not be controlled.

In order to utilize the full capacity of the PolyGuard bed, the system configuration was to include vessels in series. The first column was expected to remove most of the BTEX constituents at a rate of 99% and at a capacity of 1.5 lbs./lb. BTEX and TPH fractions are readily absorbed by PolyGuard, more than MTBE, and should be removed first. Using this configuration, the first vessel or vessels were expected to remove BTEX and TPH and little MTBE. The subsequent columns were expected to be capable of removing a predicted amount of MTBE. As the initial vessels became exhausted, the subsequent columns were expected to experience shorter bed life. With the objective to describe mass loading capacity, the expended columns were not be rebedded until the last set of column had reached saturation.

A liquid phase carbon vessel in series was recommended for use after the PolyGuard vessels as a polisher and safeguard against exceeding the NPDES permit conditions should breakthrough occur prior to predicted bed life.

The calculations used in sizing the system are based on approximations of relative absorption capacity. Estimated bed life for MTBE, BTEX, and other constituents are listed in the Appendix A

Process Stream and Sampling Locations

Three configurations of PolyGuard were studied in what are referred to as Phase 1, 2, and 3. The pretreatment system developed by ECS included a fractionation tank, diffuser, Provectr iron removal system and final post treatment GAC unit (GAC was used in only in Phase 2 and Phase 3). The configuration depicted in Figure 5 indicates the pretreatment system, Phase 2 and Phase 3 columns. The only difference between that depicted in this figure and phase one is that two PolyGuard tanks follow pretreatment and GAC filters followed the PolyGuard. The sections below provide additional detail of the different PolyGuard configurations. The pretreatment process was to include an electric heater unit preceding the fractionation tank and PolyGuard vessels in Phases 2 and 3. The heating unit was to be installed to prevent temperatures from dropping below 60^{o}F. Final effluent discharge from the treatment system was to a storm drain.

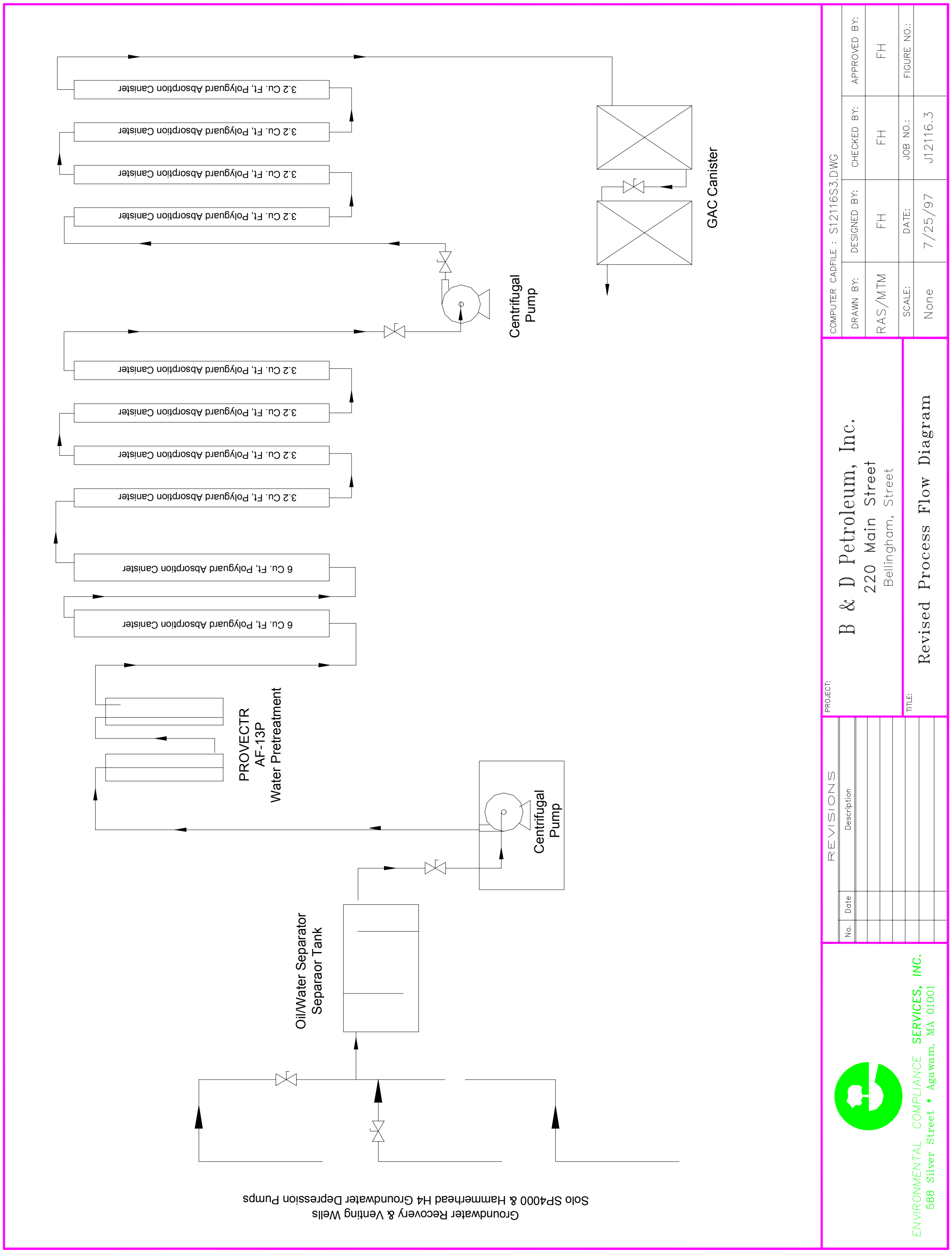

Figure 5: Schematic of treatment process train. (After ECS, Agawam, MA, 1998).

System Operation

The pump and treat system was fully automated and required periodic maintenance compatible with the sampling regime. Normal inspection included checking that pumps and timer programs were operational. Some issues regarding cold weather required more periodic inspections and system shut down was reported several times in the attached RAM reports (Appendix C and D). System checks occurred during sample collection. Pumping operations were designed to follow standard pumping rates for containment of the pollutant plume. Under this pilot, pumping volumes were controlled by groundwater elevations in the recovery wells. For this reason pump operation was periodic but total flows were monitored using a totalizer flow meter. Personnel responsible for operating the system also collected samples, transported samples to the analytical laboratory, and reported system operations.

A system operation milestone was considered when PolyGuard absorber influent and effluent concentrations were approximately equal, when static conditions were observed (i.e. no change in absorption rates or capacity) or when USEPA NPDES Permit Exclusion requirements mandated a change in the remedial action plan. The term "breakthrough" was loosely defined for the purposes of this study as the condition where influent and effluent concentrations were within 10% of each other on three consecutive sampling events or where analytical measures were insufficient to distinguish differences between samples.

The following are descriptions of the three system iterations used throughout the pilot demonstrations ultimately resulting in the flow system illustrated in Figure 5 above.

Phase 1

Phase 1 of the pilot was conducted with two standard 110-gallon drums containing 11 cubic feet each or a total of 418 pounds of PolyGuard. Hereafter these vessels are referred to as GET 1 and GET 2. The PolyGuard material was placed in the drums and held in place with a steel filter, which was held down by the steel tank cover, (Figure 6). Influent flow to the tanks was located near the bottom of the tank and effluent discharged through the top. Tubing into and out of the tanks was PVC SCH 40 or equivalent. Sampling ports were positioned at the outlet side of each tank, utilizing a brass valve. The system was constructed and operation began August 25, 1997. Samples were collected on 5 date between August 25 and September 6. The system was shut down after September 6, 1997 once analytical data showed the system was discharging beyond regulatory limits. This response was due in part to the contractor's failure to construct a GAC unit after the PolyGuard units as was specified in the pilot protocol.

Figure 6: Phase 1 test showing screen on top of PolyGuard Media.

Phase 2

The PolyGuard vessels constructed in Phase 2 included two high pressure 56-gallon fiberglass columns, 14" in diameter by 120" in length. The columns designated as N1 and N2 were provided by GET. These columns each contained 7 cubic feet of PolyGuard each or 133 pounds and a total volume 14 cubic feet with 265 pounds of PolyGuard. Phase 2 absorption columns, N1 ands N2 are shown in Figure 7, below. Vessels were constructed off sitebut were bedded with PolyGuard on site. Use of this system began October 27, 1997. Six (6) sampling events were conducted between October 27, and November 18, 1997. On November 18, the second vessel (N2), was re-plumbed as the primary column and N1 was emptied and rebedded with fresh PolyGuard. This change occurred upon request from ECS and was not specified in the test protocol. This system configuration included one GAC unit after the PolyGuard columns. The new configuration was then sampled on two additional dates until December 3, 1997, after which the system was shut down for winter. Since the heating unit was not installed, as specified, the system was shut down for a period of 6 months.

Figure 7: Phase 2 showing two 56-gallon fiberglass PolyGuard units (N1 and N2), prior to wrapping units with insulation.

Phase 3

Preliminary results from Phase 2 suggested that the primary absorbers (N1 and N2) were not providing optimal removal of MTBE. It was hypothesized that insufficient residency time may be the cause of early MTBE break through. BTEX removal continued to be satisfactory. GET and ECS decided to reconfigure the system further with, a new treatment train added to the Phase 2 vessels, hence providing additional capacity to the system. Eight absorber vessels were constructed using 8" diameter by 120" long schedule 40 PVC pipe. These vessels were placed in series after the Phase 2 vessels. These vessels are referred to as E1 through E8 and are shown in Figure 8. Each PVC column had a bed load volume of 2.8 cubic feet filled with 52.8 pounds of PolyGuard. A stainless steel booster pump was installed between vessels E4 and E5 to provide additional linear velocity lost due to pressure drops. This system configuration also included two GAC units installed after the PolyGuard columns, as was recommended in the test protocol. It was anticipated that during this phase multiple columns could be considered replicates for the purposes of quantifying absorption rates and capacities. However, loading rates would be an additional variable for which there would be no control. Each vessel therefore was fitted with sampling ports at the inlet and one at the outlet of E8 and the GAC units.

Figure 8: Phase 3 pilot absorption beds shown in mounting rack during construction.

Bed size was calculated for the design flow rate and a residency time of at least 15 to 20 minutes based on bed volume. The total bed size in Phase 3 of this test was 41 cubic feet or 779 pounds, including the N columns, 473 pounds in the ECS columns. The two N columns (N2 and N3) were left online since they continued to provide effective BTEX removal.

Sampling and Analysis

The sampling protocol specified that influent and effluent contaminant concentrations would be quantified at multiple positions in the treatment train. These data were to be used to calculate the absorption capacity of PolyGuard (Objectives 1, 2, and 3). These data were also to be used to characterize the relative rates of absorption and suitability of residency time specified for the material. The sampling frequency was designed to establish when absorption equilibrium is reached as well as changes in absorption as the PolyGuard material became saturated. Instantaneous flow rate (gal/min) were monitored at each sampling event and mass flow (total gallons) was monitored using a continuous flow meter (totalizer) and recorded at each sampling period (Objective 5). Flow rates reported in this study do not reflect the instantaneous flow rates since these data were unreliable. The flow rates reported are averages, calculated from the mass flow volume divided by the total time (including on and off pumping cycles. This result suggests that instantaneous flow rates are likely to be higher than average flow rates.

Sample Locations

Water samples were taken on the influent and effluent side of each set of contactors and the effluent side of the GAC filter beds when used (Phase 2 and 3). Phase 1 sampling was at the inlet side of the PolyGuard beds (GET1), between the two beds, and at the outlet of the second PolyGuard bed (GET2). Phase 2 sampling was at the inlet to the first N bed (N1), between the two N beds, at the outlet of the second N bed (N2) and at the outlet of the GAC unit. Phase 3 sampling was modified to allow for fewer samples initially. The influent samples were taken prior to N1 (influent), after N2, after the ECS columns E1, E2, E4 (to include E3 and E4), E7, E8, and after the GAC unit. Initial analysis during Phase 3 was limited to influent, N2 and ECS 1, 4, 7 for the initial sampling periods since breakthrough was not observed. Sampling E2 began on the third sample date and E8 on the eighth sampling period. Sampling between the N beds never occurred during Phase 3.

Sample Frequency

Sampling frequency was required to follow the minimum specified by the USEPA NPDES Permit Exclusion. Upon startup, influent and effluent samples will be taken every other day for the first week (3 samples). This level of sampling was necessary to establish that equilibrium conditions were met. After the first week, samples were to be taken every 5 days for the duration of the test. The 5-day interval was determined to provide an acceptable relative error in calculating the absorption ratio using sensitivity analysis described below.

Calculations were performed to assess the error associated with periodic sampling over a range of absorption ratios. In addition, consideration was also given to potential error associated with variability in contaminant concentration. Initial system sizing for Phase 1 and subsequent system sizing was based on preliminary data estimates from ECS. The daily load to the PolyGuard absorbers (N1) in Phase 3 was estimated to be approximately 1.8 lbs. BTEX per day. Percent error in absorption capacity was tabulated for sampling intervals 1, 2, 3, 5, and 7 days with predicted absorption ratios 100%, 150% and 200%. Additional error due to variations in mass loading (+/- 35%) are included in brackets and summarized in Table 4 below for BTEX removal. Table 5 evaluates the range in error associated with 75% expected removal efficiency for MTBE after the initial BTEX removal in treatment trains 2 - 5, (N1, ECS1-2-3, ECS 4-5-6, and ECS 7-8, respectively). These data are based on daily loads of 3, 1.2, 0.5, and 0.2 lbs. MTBE per day, respectively. The percentages as shown give the error associated with the absorption capacity as a result of periodic sampling and additional error associated with concentration variation. Using the highest variation in concentration assumes a worse case situation. Analysis of these data suggests that larger variation in concentration would result in increased error in absorption ratio. The table below illustrates that as the absorption ratio increases the error decreases since the mass loading as a percentage of the total mass load decreases. Frequent sampling would provide the lowest degree of error. However, it also requires more resources. Sampling on a daily basis has the potential to reduce error by as much as 5 times, compared to 5-day sampling.

Table 4. Summary table of associated errors with sampling intervals and variation in BTEX contaminant concentration.

Absorption Ratio lb/lb	Percent Error in Absorption Ratio by Sampling Frequency				
	1 day	2 day	3 day	5 day	7 day
100%	1.0(0.4)	2.0(0.7)	4.1(1.1)	5.1(1.8)	7.2(2.5)
150%	0.7(0.2)	1.4(0.4)	2.0(0.7)	3.4(1.2)	4.8(1.7)
200%	0.5(0.5)	1.0(0.4)	1.5(0.5)	2.6(0.9)	3.6(1.3)

(+/- for mass loading variability)

Table 5. Summary table of associated errors with sampling intervals and variation in MTBE contaminant concentration for expected removal efficiency of 75%.

Sampling Train	Percent Error in Sampling Train by Sampling Frequency				
	1 day	2 day	3 day	5 day	7 day
Train 2	2.3(0.8)	4.5(1.6)	6.8(2.4)	11.4(4.0)	15.9(5.6)
Train 3	0.8(0.3)	1.6(0.6)	2.4(0.8)	4.0(1.4)	5.7(2.0)
Train 4	0.3(0.1)	0.6(0.2)	1.0(0.3)	1.6(0.6)	2.3(0.8)
Train 5	0.2(0.1)	0.3(0.1)	0.5(0.2)	0.8(0.3)	1.2(0.4)

(+/- for mass loading variability)

The error associated with a 5 day sampling regime was reported to be acceptable for identifying cost competitiveness per GET. In addition, a five-day regime would provide the necessary level of system monitoring to assure the operation is working. The columns would be monitored every 5 days thereafter until 100% breakthrough was determined. In order to assure that breakthrough does not result in a discharge, more frequent monitoring near the predicted breakthrough period was recommended. However, this could be limited to sampling and system checks, with the option to measure sampled material within the storage times allowed under the following section.

Sampling and Storage Methodology

The consulting engineers performed sampling and analysis. Sampling methods and storage were to follow those specified in Chapter 4 sections 1 and 2, including all subsections in EPA SW846 Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods. Sample size, container, preservation and holding time was to conform to Massachusetts BWSC protocol for VOCs in water as specified in `310 CMR 40.0000: Massachusetts Contingency`. ECS personnel familiar with the referenced methods for sampling transported samples. Chain of custody protocol conforming to Massachusetts BWSC protocol was required. The analytical laboratory contracted for the work was to provide the STEP P.I., DEP staff, and consulting engineers written SOPs (standard operating practices) for review. This request was to assure they meet the stated criteria in EPA SW846 (1996), but was never fulfilled by ECS or their contracting laboratory, Spectrum Analytical, Agawam MA.

Analytical Methodologies

Measurement of BTEX, MTBE, TPH, pH, and temperature were to be performed at each sampling event from each specified sampling port. Total suspended solids (TSS) were to be measured in samples only during the first week of operation as baseline data. Analytical methodologies for each contaminant were to follow protocols specified under EPA SW846 methodologies and Standard Methods for the Examination of Water and Wastewater (APHA, 1989). These analytical methods are listed in Table 6. for each analyte. Sample preparation for organic compounds was to follow EPA SW846 method 5030. Replicate samples were to be analyzed as part of QA/QC protocol. Upon change-out of PolyGuard, a single TCLP analysis was to be performed utilizing the leaching protocol described in Chapter 7 section 4 of EPA SW846 followed by appropriate analysis of leachate using 6000, 7000, or 8000 series methodologies. This analysis was not performed by the consulting engineer.

Table 6. Analyte and Methods to be Utilized in Pilot Study.

Analyte	CAS Number	Methodology
Benzene	71-43-2	EPA 8020A, 8021A, or 8240B
Toluene	108-88-3	EPA 8020A, 8021A, or 8240B
Ethyl benzene	100-41-4	EPA 8020A, 8021A, or 8240B
Total Xylenes	1330-20-7	EPA 8020A, 8021A, or 8240B
MTBE	1634-04-4	EPA 8020A, 8021A, or 8240B
TPH		EPA 8015 or 8020 Modified
pH		EPA 9040B
Temperature		APHA 2550.B
Specific Conductance		
Dissolved Oxygen		
Fe		EPA-600/4-82-055

Quality Assurance/ Quality Control

Due to the nature of the demonstration, QA/QC responsibility was left to the engineering firm managing the site. Where possible, deviations to the proposed protocol were reported to the PI. Necessary deviations from the protocol were to be based on compliance with the regulated discharge permit. All analytical services were to follow QA/QC required under MA BWSC. A Massachusetts state certified laboratory was used for all analytical services. All personnel involved in the project were supervised by the lead project manager at ECS.

Disposal Issues

At the time of this report writing there were no plans for dismantling the pilot system or disposing of the spent materials. Spent PolyGuard containing MTBE, BTEX, and TPH must be treated as a hazardous containerized waste due to the presence of Benzene. In all cases, the nature of the contaminants will determine whether spent material is hazardous or non-hazardous. PolyGuard alone, is non-hazardous. The lowest reported cost for disposal of spent media as hazardous waste was reported to be $295 per 55-gallon drum plus shipping, based on a proposal from A & A Environmental Services, Linthicum Heights, MD. Other bids from Safety Kleen, Salem, NH and Tri-S, Inc, Ellington, CT were somewhat higher. Lowest cost for disposal of PolyGuard as non hazardous material (flash point >140F) was $78 per 55-gallon drum plus shipping, based on a proposal from Safety Kleen, Salem, NH. Where longer distances are required for pickup and disposal, additional mileage rates would add cost. Typical disposal practices are likely to include incineration and or use in fuel blending.

Data Analysis

Data generated from influent and effluent concentrations of the PolyGuard bed were entered into a standard computer spread sheet and analyzed using standard statistical parameters, where possible.

RESULTS

Results from this pilot demonstration are reported for the period between August 25, 1997 and December 24, 1998. During this period treated groundwater volume and contaminant concentrations were monitored to assess the removal efficiency and mass removal capacity of PolyGuard for BTEX and MTBE. The data from this period of monitoring is segregated into three phases, which reflect three distinct operating conditions on the site. In reporting the results from these tests, deviations from the original system configuration provide somewhat less detailed information on the properties of PolyGuard. These data, however, indicate trends that may be useful for developing additional field models. In this analysis the data are better described as qualitative, since the planned replication of operating conditions did not occur controlled statistical comparisons were not possible.

Five primary objectives were established for this study. Based on data quality and quantity four of the objectives had sufficient data to be discussed in this report. The table below illustrates the objectives and completion status.

Table 7. Objectives and Completion Status.

	Objective	Completed
1	Demonstrate removal of organic compounds associated with gasoline contaminated ground water utilizing PolyGuard	Yes
2	Quantify the absorption potential of PolyGuard specifically for MTBE in conjunction with other organic contaminants	Yes
3	Quantify the absorption potential of PolyGuard for BTEX compounds,	Yes
4	Evaluate the stability of the spent PolyGuard material providing information on disposal alternatives, and	No
5	Monitor the hydraulic performance of PolyGuard under pump and treat remediation operation.	Yes

Detailed descriptions of system operating conditions and sampling data are included in Appendices C and D of this document. The following results are based on data reported in those Appendices. Additional data tables are presented in Appendix B, from which the following analysis is based. A summary of the operating concentrations and flow rates is presented in Table 8, below.

Table 8. Average operating conditions for each test Phase. (s = Standard Deviation)

Test	Average Influent Concentration and Standard Deviation (mg/L)		Average Flow Rate (GPM)
	MTBE	BTEX	
Phase 1	263 (s=147)	36 (s=25.3)	0.98
Phase 2	86 (s=24.8)	33 (s=10.8)	0.63
Phase 3	38 (s=14)	15 (s=7.1)	0.44

Phase 1

Phase 1 of the pilot demonstration operated between August 25, 1997 and September 6, 1997 using PolyGuard vessels GET 1 and GET 2. Initial operation began August 25, 1997 and five sampling events were carried out prior to system shutdown. Mass flow to the system was 22,203 gallons. The range of flow rates recorded at each of the 4 sampling dates after startup was 0.56 to 2.0 GPM with an average flow of 0.98 GPM over the duration of the test. Average flow was approximate one half the design flow. However, average flow during the test does not reflect the actual flow during pumping cycles.

Influent MTBE concentrations ranged from 133 to 438 mg/L. Average MTBE influent concentration over the sampling period was 263 mg/L (n=5). Effluent MTBE concentrations from the first and second 110-gallon PolyGuard tanks (GET 1 and GET 2) ranged from non-detect out of GET 2 on the second sampling date to 70 mg/L out of GET 1 on the last sampling date. Figure 9 illustrates the influent and effluent concentrations and removal efficiency over the course of the test.

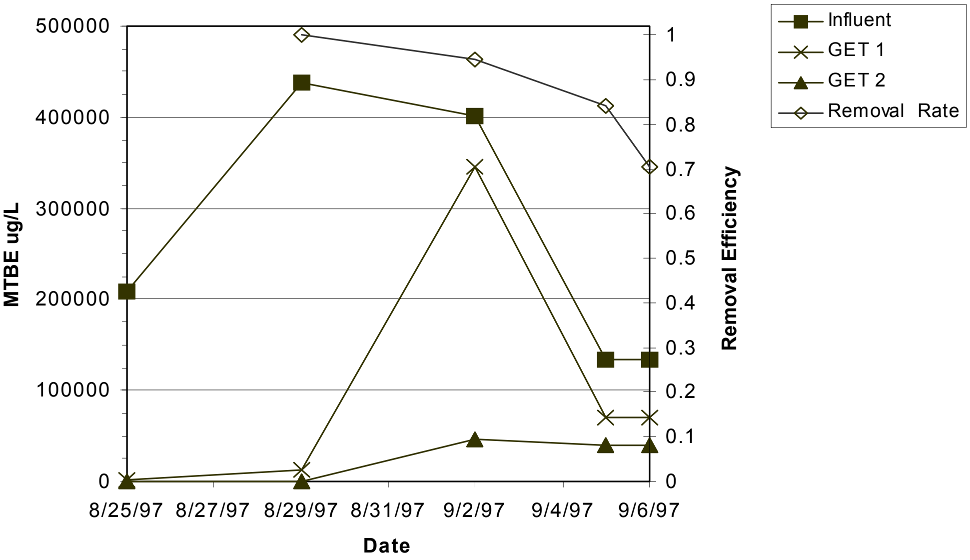

Figure 9: Phase 1 MTBE concentrations and removal efficiency.

PolyGuard system removal efficiency for MTBE decreased during the course of the test from 100% to 71% at the close. Average column mass removal efficiency during this test was 56% and 78% for GET 1 and GET 2, respectively. Mass removal was calculated by interpolating the mass loading between the target sampling period and the prior period, using an average of the concentrations multiplied by the volume loading. MTBE mass loading based on this method totaled 66.7 lbs. of which the PolyGuard removed 61.8 lbs. The mass loading to the PolyGuard material was approximately 15% on a weight per weight basis. Since the overall system removal efficiency for MTBE exceeded 71% at the close of the test it is possible that the system could achieve a higher capacity than that measured during the test. PolyGuard exhibited “initial breakthrough,” the point at which the PolyGuard beds showed a very low removal of MTBE. The termination point as specified in the test protocol, or the point at which the effluent and influent concentrations were within 10% or unchanged over 3 consecutive sampling events, was not observed. In addition, the treatment train for this demonstration, required the use of GAC as a polishing technology for MTBE prior to discharge in order to meet permit requirements. In Phase 1, the contractor did not install a GAC unit, as specified, which may have resulted in premature termination of the test.

Influent BTEX concentrations ranged from 6.2 to 61 mg/L. Average BTEX influent concentration over the sampling period was 36 mg/L (n=5). Effluent BTEX concentration from the system after the second 110-gallon PolyGuard tank (GET 2) was always at non-detect levels. Effluent BTEX concentration from GET 1 ranged from non-detect to 3 mg/L. Figure 10 illustrates the influent and effluent concentrations and removal efficiency over the course of the test. Overall PolyGuard system removal efficiency for BTEX decreased less than that observed for MTBE during the course of the test. Average mass removal efficiency during this test was 95% and 100% for GET 1 and GET 2, respectively. Mass removal was calculated as previously described. BTEX mass loading based on this method totaled 5.2 lbs. of which the PolyGuard columns removed 100%. The mass loading to the PolyGuard material was approximately 1% on a weight per weight basis. Due to low mass loading and cessation of the test prior to breakthrough, it is not possible to fully quantify the capacity of PolyGuard for BTEX. The capacity may be significantly higher than that observed in this test. Further testing is required to investigate this potential.

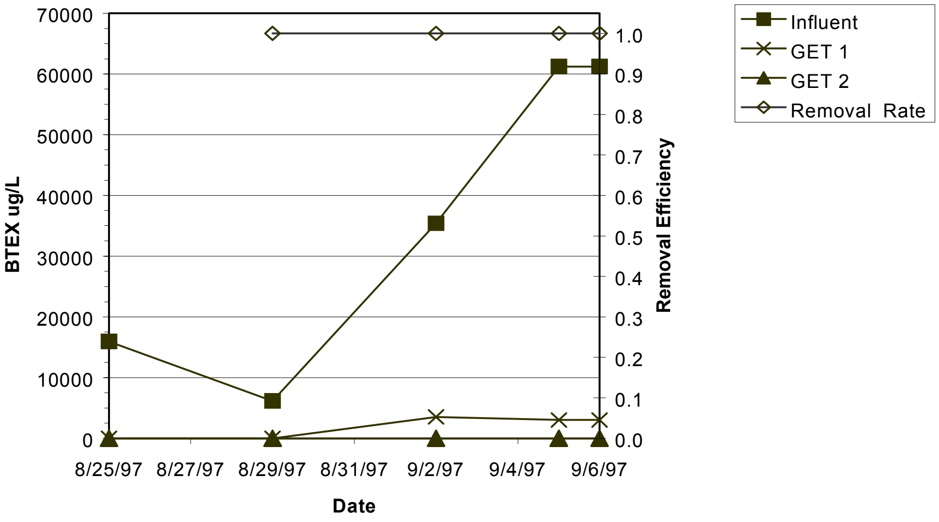

Figure 10: Phase 1 BTEX concentrations and removal efficiency.

Phase 2

Phase 2 of the pilot demonstration operated between October 27, 1997 and December 3, 1997 using PolyGuard vessels N1, N2 and N3. Initial operation began the on October 27, 1997 and nine sampling events were carried out prior to system shutdown. Mass flow to the system was 40,707 gallons. The range of flow rates recorded at each of the 8 sampling dates after startup was 0.31 to 1.57 GPM with an average flow of 0.63 GPM over the duration of the test. Average flow was approximately one third the design flow. However, average flow during the test does not reflect the actual flow during pumping cycles. During this test the N1 was rebedded on November 26. N2 was placed in the primary position and N3 was put on line in second position. N1 received a total flow of

35,040 gallons before being taken off line. N2 received the full mass flow of 40,707 gallons. While N3 only received a total flow of 5,667 gallons.

Influent MTBE concentrations ranged from 58.8 to 132.8 mg/L during the test period. Average MTBE influent concentration over the sampling period was 85.6 mg/L (n=9). Effluent MTBE concentrations ranged from non detect to 82.8 mg/L. Average MTBE effluent concentrations were 51.2, 30.3 and 29.6 mg/L for N1, N2, and N3, respectively. System effluent concentration after the GAC bed was non-detect up to November 18 and was approximately 40 mg/L during the last two sampling dates. Figure 11 illustrates the influent and effluent concentrations and removal efficiency over the course of the test.

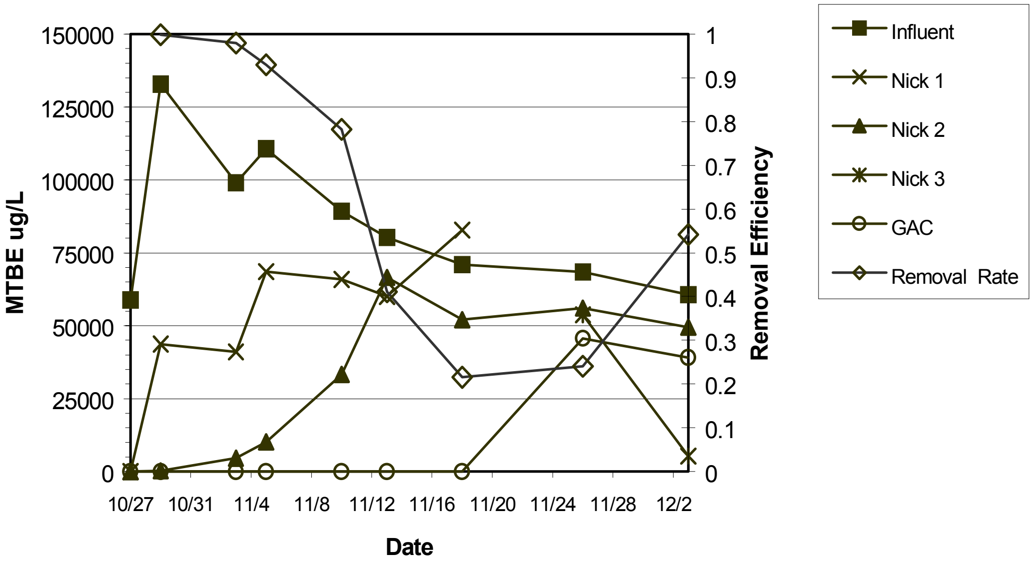

Figure 11: Phase 2 MTBE concentrations and removal efficiency.

PolyGuard system removal efficiency for MTBE decreased during the course of the test from 100% to 21% at the time when N1 was rebedded. System removal efficiency using N2 and N3 was 51% at the close of the test. Average PolyGuard bed mass removal efficiency during this test was 42% (n=6), 58% (n=7) and 44% (n=1) for N1, N2 and N3, respectively. Mass removal was calculated as describe above. Removal efficiency based on concentration may also be calculated for N 3 which indicates a removal rate of 89%. MTBE mass loading during this test period totaled 28.1 lbs. of which the PolyGuard beds removed 15.1 lbs. The mass loading to the PolyGuard material was approximately 4% on a weight per weight basis. In this test the removal efficiency was still positive at the close of the test, therefore a quantitative determination of the capacity can not be made at this time. Since the overall system removal efficiency for MTBE exceeded 40% at the close of the test it is possible that the system could achieve a higher capacity than that measured during the test. Influent MTBE concentrations were significantly lower during this phase as compared to Phase 1. And this may have impacted the capacity of PolyGuard for MTBE. Further testing is required to investigate this potential.

Influent BTEX concentrations ranged from 21.3 to 56.8 mg/L. Average BTEX influent concentration over the sampling period was 30.3 mg/L (n=9). Effluent BTEX concentration from the entire system including the GAC treatment was at non-detect levels throughout the test. BTEX concentration out of N1 was typically an order of magnitude lower than influent concentration. The N2 bed had BTEX concentrations at non-detect levels up to the 7th sampling period, when it increased to 0.13 mg/L.

After the N1 bed was repacked, N2 and N3 had BTEX concentrations between 0.1 and 1.4 mg/L. Figure 12 illustrates the influent and effluent concentrations and removal efficiency over the course of the test.

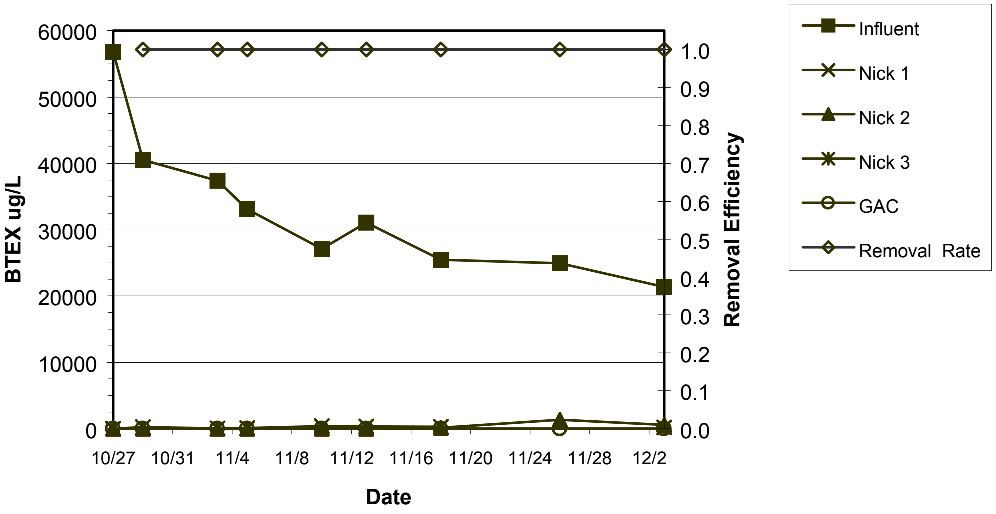

Figure 12: Phase 2 BTEX concentrations and removal efficiency.

PolyGuard system removal efficiency for BTEX decreased minimally and less than that observed for MTBE during the course of the test. Average removal efficiency during this test was 98 to 100% for all three N columns. On one instance, November 18th, removal efficiency dropped to 81% in N2. However, it is unclear whether an analytical error occurred on that data rendering a sample concentration bias. Mass removal was calculated as previously described. BTEX mass loading based on this method totaled 10.35 lbs. of which the PolyGuard beds removed 99.6%. The GAC unit removed BTEX, which passed through the N columns. The mass loading to the PolyGuard material was approximately 3% on a weight per weight basis. Due to low mass loading and cessation of the test prior to breakthrough, it is not possible to fully quantify the capacity of PolyGuard for BTEX. Based on this test and previous laboratory studies, the capacity may be significantly higher than that observed in this test. Further testing is required to investigate this potential.

Phase 3

Phase 3 of the pilot demonstration was implemented June 17, 1998 and data is reported up until August 31, 1998. The system was shut down due to fouling of a pretreatment unit between July 24, 1998 and August 11, 1998. The system was shut down again on September 8, 1998 due to detection of MTBE in effluent from the GAC columns. GAC columns were replaced and the system was operated for a period of 4 days starting September 24, 1998 due to fouling of pneumatic pumps. Repairs were made and the system was started up again December 18, 1998. The system was completely shut down December 23, 1998. The range of flow rates recorded at each of the sampling dates after startup was 0.26 to 0.94 GPM with an average flow of 0.44 GPM over the duration of the test. Average flow was approximate one quarter the design flow. However, average flow during the test does not reflect the actual flow during pumping cycles. Total mass flow pumped though the system during this test was 51,951 gallons between June 17, 1998 and August 31, 1998. While additional pumping occurred during 10 days in September and December, these data were not available at the time this report was being prepared. For this reason, no water quality data are reported for sampling dates after August 31, 1998. Operational problems after August 31 included freezing problems in the ECS units, due to low air temperatures and uninsulated columns. The N beds showed no sign of freezing. Additionally, low influent concentrations, significantly different from those measured in Phases 1 and 2 make comparisons difficult.

The system operated in Phase 3 included the Phase 2 N1 and N2 units and the eight ECS units. Eleven sampling events are reported including sampling at startup June 17, 1998. System sampling during this test was varied and not all sampling points were sampled at each event. Typical sampling occurred at 7 locations: Influent, N3, ECS 1, ECS 2, ECS 4, ECS 7 and ECS 8. Data from the GAC columns are not reported for Phase 3. For the purpose of this review, missing data was reported as NR and no estimation was used for calculating removal efficiency or capacity. This analysis will likely result in a negative bias on performance due to the fact that these missing data occur early on in this test when absorption would be highest.

Influent MTBE concentrations ranged from 10.6 to 69.2 mg/L. Average MTBE influent concentration over the sampling period was 38.3 mg/L (n=11). Effluent MTBE concentrations from the Phase 3 N2 and N3 (at the N3 effluent port) ranged from 5.6 to 71.7 mg/L. Average MTBE influent concentration to the ECS columns was 39.6 mg/L. Overall ECS PolyGuard column effluent concentrations ranged from non-detect to 55.7 mg/L. With average MTBE effluent concentrations for the test at 27.9, 34.4, 25.5, 11.2 and 8.8 mg/L for ECS 1, ECS 2, ECS 4, ECS 7 and ECS 8, respectively. Figure 13 illustrates the influent and effluent concentrations and removal efficiency over the course of the test.

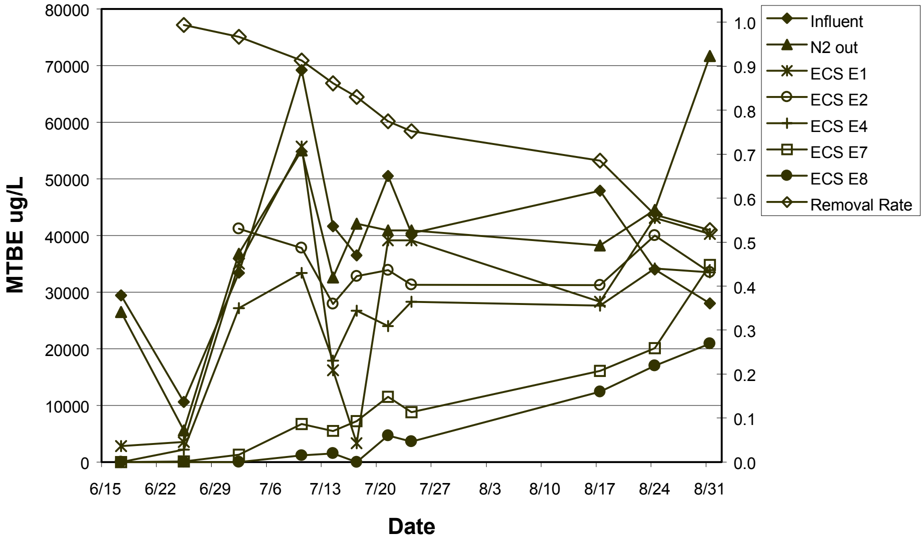

Figure 13: Phase 3 MTBE concentrations and removal efficiency.

PolyGuard system removal efficiency for MTBE decreased during the course of the test from 100% to 39% at the close. Average system mass removal efficiency during this test was 82%. Individual ECS column efficiency ranged from 95% to values indicating that MTBE was released from the column. While the data is not presumed to be equivocal, what appears to be MTBE contributed from the N2 and N3 units may be within error associated with sampling and analysis. The N2 and N3 units used in this test did not remove any MTBE on average. MTBE mass loading totaled 14.9 lbs. of which the ECS PolyGuard units removed 13.1 lbs. The mass loading to the PolyGuard material in the ECS units ranged from 1 to 7% on a weight per weight basis. The ECS units at the end of the test continued to demonstrate absorption removal rates from 8 to 31%. Since the overall system removal efficiency for MTBE was better than 35% at the close of the test, it is possible that the system could achieve a higher capacity than that measured during the test. Further testing is required to investigate this potential.

Influent BTEX concentrations ranged from 5.9 to 28.3 mg/L. Average BTEX influent concentration over the sampling period was 14.6 mg/L (n=11). Effluent BTEX concentrations from the N2 and N3 units (at the N3 effluent port) ranged from non-detect to 0.07 mg/L. Average BTEX influent concentration to the ECS units was less than 0.05 mg/L. ECS PolyGuard unit effluent concentrations ranged from non-detect to 0.05 mg/L. On all but 4 of the 10 sampling dates, past the initial start date, effluent out of ECS 1 was non detect. BTEX concentrations were at non-detect levels on all dates in ECS 2, ECS 4, ECS 7 and ECS 8. Overall, analytical testing suggests that most BTEX was removed in the N2 and N3 units and a small portion was removed in ECS 1. Non-detect values reported in the Appendix B indicate method detection limits (MDL) for the sum of benzene, toluene, ethylbenzene, m,p-xylenes, and o-xylene. In some cases the MDL value is large suggesting that comparisons of non-detects and zero values is not appropriate. However, for the purposes of this review a non-detect was considered zero, since it is conservative when estimating removal capacity. In this study non-detect was not considered ½ the MDL. Figure 14 illustrates the influent and effluent concentrations and removal efficiency over the course of the test.

PolyGuard system removal efficiency for BTEX remained at 100% during the course of the test. Average column mass removal efficiency during this test ranged from 3% to 100%. On more than one instance the effluent from ECS 1 exceeded the influent from the N2 and N3 units, possibly due to sampling or analytical error. Mass removal was calculated as previously described. BTEX mass loading based on this method totaled 6.82 lbs. of which the N2 and N3 units removed 6.81 lbs. Based on the useful data, apart from the non-detects, it is estimated that the ECS columns removed 0.01 lbs. of BTEX. The mass loading to the PolyGuard material in the system was approximately 1% on a weight per weight basis. The N columns had a slightly higher mass loading rate of 3% on a weight per weight basis. As was the case in Phase 2, the low mass loading to the system and cessation of the test prior to breakthrough, does not provide suitable information to quantify the capacity of PolyGuard for BTEX. Based on this test the capacity may be significantly higher than that observed in this test. Further testing is required to investigate this potential.

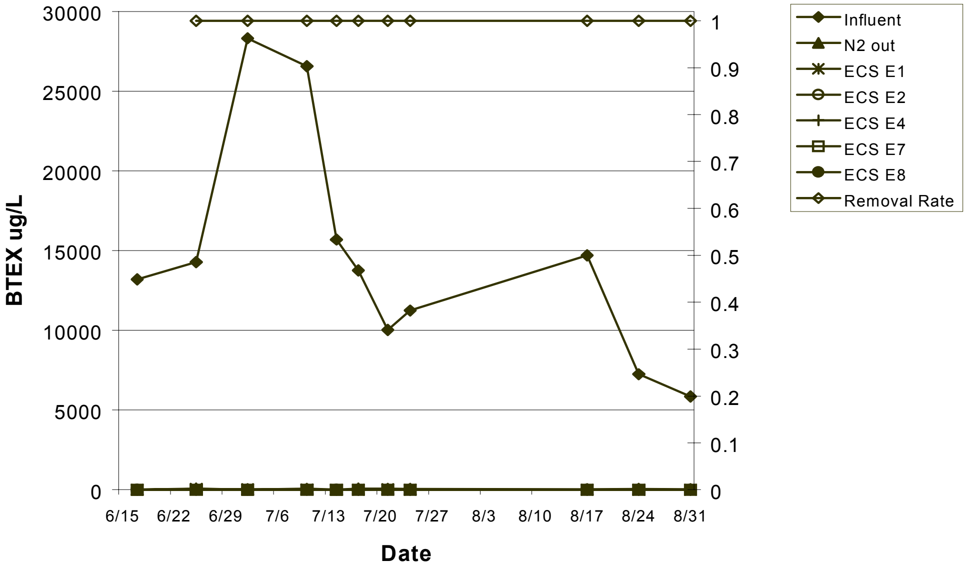

Figure 14: Phase 3 BTEX concentrations and removal efficiency

Test System Analysis

System performance demonstrated removal rates for BTEX up to 100% during the operation of each of the phases. The removal rates for MTBE were lower ranging from 3% to 100% for any individual column during each interval. While average system removal for MTBE was 91, 41 and 82% for Phases 1, 2, and 3, respectively. Quantitative comparison of the three tests for the purpose of identifying different operating parameters is not possible based on the fact that the test data was not replicated as outlined in the demonstration protocol.

It is desirable to define an overall performance characteristic based on the results of the three tests. To this end, an evaluation of rates of removal relative to flow volume per pound of PolyGuard is presented. One hypothesis is that PolyGuard performs uniformly under a range of flow and concentration conditions. If this were the case, a plot of the flow per pound and the removal rate for all the test columns would have a similar characteristic curve. This concept normalizes for flow rate effects (Q) whereby each column becomes a replicate of any PolyGuard system. The shape of the curve may linear or non-linear, the latter may be exponential or s-shaped as depicted in Figure 15 (After, USEPA, 1973). The s-shaped curve is representative of adsorption phenomena, similar to that observed with GAC. The exponential curve may suggest a rate limited transport process such as that expected in PolyGuard. In this case, the adsorption process is fast relative to the diffusion of contaminants into the molecular structure.

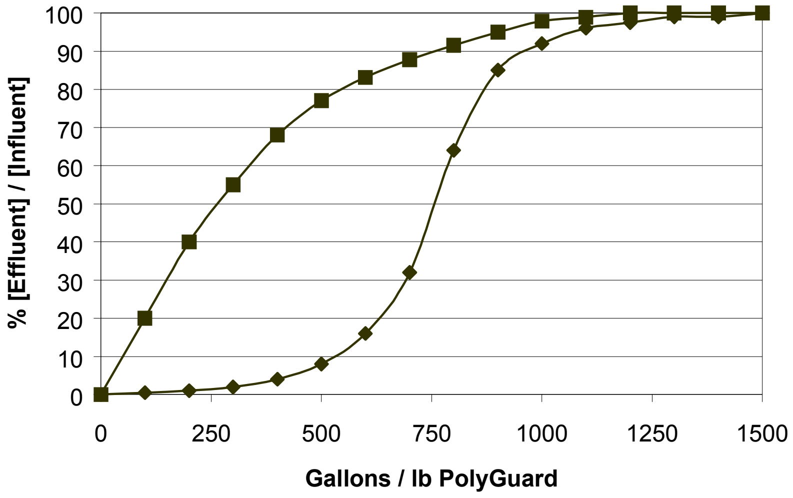

Figure 15: Theoretical removal efficiency curves corrected for time and system configuration.

The MTBE data for each test are plotted together in Figure 16. As evidenced by the plot, no significant patterns are discernable across all the tests. In Phase 1, the GET units loaded at relatively high concentrations exhibit removal efficiencies decreasing rapidly corresponding to high mass loading. In this case it is concluded that sufficient MTBE is present to saturate the surface sites on the PolyGuard and that diffusion into the molecular structure is limiting removal rates. In Phases 2 and 3 a combination of effects are present which make such a determination difficult. Even at the lower concentration of influent MTBE, it is likely that surface adsorption was not rate limiting. However, a gradient may have resulted in slower diffusion rates. In units described as ECS 5, 6, 7, and 8 in Phase 3, a noticeable S-shaped pattern is exhibited suggesting that adsorption is dominant at lower concentrations.

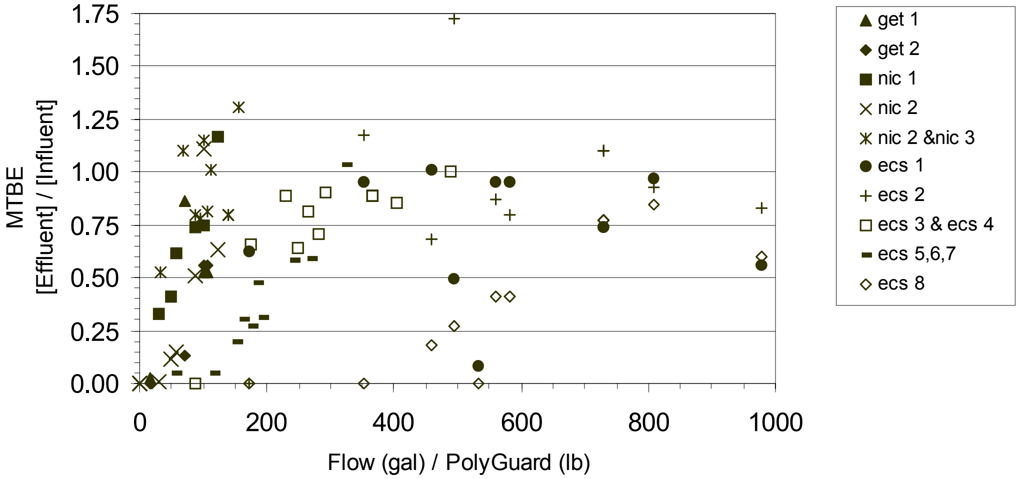

Figure 16: Plot of MTBE removal efficiency for each column correcting for flow per pound of PolyGuard illustrating.

An overall conclusion relative to performance at different loading rates and contact time is not apparent from these data. It is however, possible to assert that the PolyGuard may perform closer to those characteristics observed in laboratory studies when solute concentrations are greater than 100 mg/L. It is also possible to conclude that PolyGuard is not suitable for removing MTBE from aqueous systems to concentrations at or near drinking water standards except during initial loading. Again, this may be a function of competitive absorption but cannot be confirmed at this time.

Data plotted for BTEX in a similar manner provides little insight into the performance characteristics of PolyGuard under varying concentration and contact times (Figure 17). Under the majority of conditions observed in this test, PolyGuard removed all the BTEX introduced into the system.

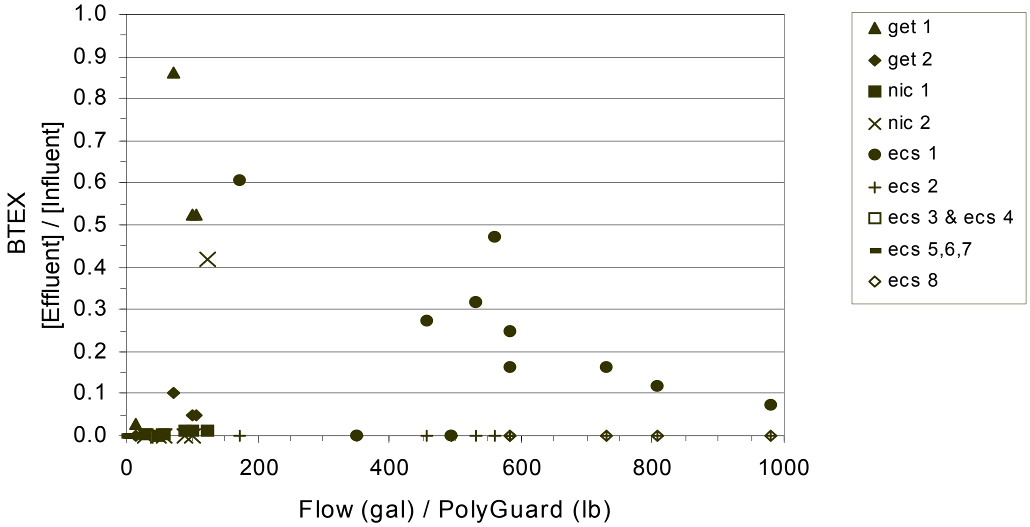

Figure 17: Plot of BTEX removal efficiency for each column correcting for flow per pound of PolyGuard illustrating.

Hydraulic Performance

A complete analysis of hydraulic performance data is not available for this report. Under the study operating conditions system hydraulic performance did not present any limitations to use. Only one instance was reported in which excessive back-pressure resulted in system shut down. This occurred in Phase 3 and was attributed to fouling in the Provectr iron removal system and was not related to fouling or physical changes in the PolyGuard Columns. The hydraulic performance is generally attributed to the material makeup of PolyGuard, which contains a fraction of GAC to maintain porosity. The hydraulic performance is secondarily attributed to minimizing exposure of PolyGuard material to free product hydrocarbons. The fractionation unit in the system apparently was capable of minimizing this exposure and or the low concentrations of contaminant assured solubilization of free product if present. A qualitative assessment of the hydraulic performance suggests that under the operating rates observed in this study, the system configuration and system construction, PolyGuard is capable of handling flows as high as 2 GPM or higher without significant effort to increase operating pressures. Over the course of the three tests, system configurations were changed resulting in changes to linear velocity. This in combination with changes to average flow rates makes it difficult to characterize the actual retention time and the effects on removal efficiency.

Product Stability and Disposal

No data was made available during or after the test with respect to product stability or disposal issues. At the close of the test, the N3 bed was opened and observed visually and tested for odor. While only a slight odor was observed, contaminant concentrations were not determined.

Cost Analysis

It is useful to identify costs associated with remediation technologies. The USEPA provides guidance for documenting and cost and performance information for remediation projects under a similar title (USEPA, 1998). However, under piloting conditions it is difficult to develop accurate cost analysis for full deployment of a commercial application. The protocol for this demonstration was not developed with these guidelines and therefore does not conform to those standards. Cost data was not made readily available for this report and tests conducted under this study were not carried out to completion. Therefore capacity data do not reflect the ultimate capacity of PolyGuard or the minimum cost associated with contaminant removal. Because the cost analysis data is incomplete and true operations and maintenance data could not be collected in this first demonstration of PolyGuard, STEP cannot confirm or disprove GET's competitive advantage claims when compared to GAC systems, the current industry standard.

The cost estimates for MTBE removal presented in Table 9 are based only on the data available from this demonstration. The figures do not include capital casts or operation and maintenance costs, since those data are not realistic under piloting conditions. Instead cost per pound of contaminant removal is based on the total cost of PolyGuard. The cost for MTBE removal calculated for Phases 2 and 3 are considered unrealistic since these tests appeared to have operational problems and low mass loading.

Table 9. Cost estimates data reflecting maximum cost for MTBE removal using PolyGuard, not including capital or operating costs.

Test Phase	**Volume (ft^3)**	**Cost**	**MTBE Removed (lbs)**	**Cost / lb MTBE**
Phase 1	22	$3630	61.76	$59
Phase 2	21	$3465	15.13	$227
Phase 3	22.4	$3696	14.11	$262

Economic analysis demonstrates a range of costs which reflect somewhat positively on the potential advantages for PolyGuard. For example, cost per pound of MTBE removed using PolyGuard during Phase 1 compares favorably to estimates for removal using GAC at $125/lb, based on 1% capacity (GAC cost estimate provided by GET). These data suggest that PolyGuard may be cost competitive under conditions of high MTBE mass loading. Again, since these tests were ended before PolyGuard removal efficiency reached zero, it is likely that PolyGuard can remove greater quantities of MTBE than evidenced here and therefore would have even lower costs per pound removal. Based on these data additional work is warranted to further investigate this possibility, using cost documentation guidelines recommended by the USEPA.

CONCLUSIONS

PolyGuard has been demonstrated to absorb large quantities of MTBE and BTEX relative to its own mass compared to GAC. These studies were previously performed under laboratory conditions at contaminant concentrations and flow rates that favor higher absorption rates and capacity. Initial studies suggest that PolyGuard may be capable of absorbing more than twice its weight in MTBE and four times its weight in BTEX. Typical adsorption rates for MTBE with GAC are estimated at less than 3%. Under the claimed performance characteristics, PolyGuard was proposed as a cost-effective absorbent for the removal of MTBE and BTEX from contaminated groundwater compared to GAC. Under this study, demonstration objectives were to define the operating removal efficiencies and absorption capacity for PolyGuard with MTBE and BTEX contaminated groundwater from a gas station spill site.

Changes in system configurations and average flow rates make it difficult to characterize the actual retention time and effects on removal efficiency. In addition, changes in influent concentrations added considerable uncontrolled test variation, which confounded results. For this reason and circumstances beyond the control of this reviewer, it is not possible to place quantitative weight to a performance characteristic, which may be applied to other sites with different operating conditions. However, certain conclusions may be drawn from the data and used in assessing potential application of PolyGuard under similar or related conditions.

The three tests conducted during this study reflect different operating conditions for the use of PolyGuard. The first test had the highest average flow rate, at 0.98 GPM and the highest average influent concentrations for MTBE, 263 mg/L. Under these conditions, PolyGuard demonstrated the highest absorption capacity of 15%. During this test removal efficiency was 93% on a mass basis. The second test had an average flow rate of 0.63 GPM and an average influent concentration of 86 mg/L MTBE. System absorption capacity for MTBE was 4% on a mass basis. The MTBE removal efficiency of this PolyGuard system was the lowest at 41%. Test three had the lowest average flow rate and influent MTBE concentration, at 0.48 GPM and 38 mg/L, respectively. In all test cases the PolyGuard system never reached capacity and continued to remove MTBE at 71%, 54% and 39% efficiency for tests 1, 2, and 3 respectively. Due to permit restraints on allowable discharge of MTBE, the failure to install the GAC units, and breakthrough characteristics of PolyGuard, all the tests were ended before the PolyGuard reached its maximum adsorption capacity.

With respect to BTEX removal, all three tests demonstrated excellent BTEX removal. Influent concentrations did not vary as much between tests with average influent concentrations of 36, 33, and 15 mg/L BTEX for tests 1, 2, and 3 respectively. Capacity for BTEX was never reached since system absorption of BTEX was 100% in each test. Due to the solubility characteristics of the BTEX constituents relative to MTBE, high absorption to PolyGuard was expected. Changes in system configuration, operating flow rates and influent concentrations add additional uncertainty to the results of these tests. Further, the applicability of the performance characteristics to operating conditions not defined by those in these studies is limited.

Data from this study suggests that PolyGuard has greater potential for MTBE removal when concentrations are greater than 100 mg/L. These data also indicate that, except with virgin PolyGuard, removal efficiencies are not suitable for treatment of MTBE in aqueous systems to concentrations at or near drinking water standards. This feature tends to suggest that PolyGuard is useful as a bulk contaminant remover and not a final polishing agent. One operational feature this demonstration was able to demonstrate was the need for a final polishing step such as GAC to achieve MTBE levels as required by the NPDES Permit exclusion. Further testing is recommended to determine to what extent competitive absorption may limit applications using PolyGuard.

Hydraulic performance of the PolyGuard system under the test conditions was not fully investigated. However, only one instance of system flow problems over the course of all three tests and was not attributed to the PolyGuard units.

No information regarding product stability or disposal costs were available from these studies. Disposal costs reported by GET indicate approximate costs of $295 per 55-gallon drum for hazardous material disposal and $78 per 55-gallon drum for non-hazardous material disposal. Final disposal may include fuel blending and or incineration.

A minimal cost analysis was performed, considering only removal cost of MTBE based on material cost of PolyGuard and did not include capital or operational costs. Operational and capital cost were excluded from this analysis because of costs associated with pilot system modifications are not expected under full deployment of the technology. Due to the nature of this pilot demonstrations, data was not of suitable quality to conform to reported methods recommended by the USEPA. Cost per pound of MTBE removed using PolyGuard during all phases ranged from $59 to $262 per pound of MTBE. Lowest costs were realized during Phase 1 with a cost of $59/lb and the highest mass loading rate. Phase 1 costs may compare favorably to estimates for MTBE removal using GAC at $125/lb, based on 1% capacity. Phase 2 and 3 costs were estimated at $229 and $262 per pound of MTBE removed These data suggest that PolyGuard may be cost competitive under conditions of high MTBE mass loading and that further cost analysis should be performed once the system can be optimized for performance. These studies should conform to USEPA guidance for documenting cost and performance.

Further studies are recommended based on qualitative results from this study. Foremost, isotherm analysis under a variety of operating conditions will assist in quantifying absorption rates, especially where concentration varies. Furthermore, investigations of complex solutions under controlled conditions may assist in understanding competitive absorption phenomena hypothesized herein. Additional investigation into system fouling and microbial activity is also recommended since they are problems in GAC systems. Field studies under alternative conditions to those reported in this study may assist in developing full scale operating parameters, but may be less useful for broader applicability to diverse sets of operating conditions.

The potential strengths and weaknesses of PolyGuard compared with GAC should also be further explored. Full life cycle costs, including capital costs, O&M, and disposal need to be more fully characterized for operational systems, following EPA methodologies.

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APPENDICES

Appendix A: Design Calculations for Test number 3.

Liquid Phase System Worksheet. (GET, 1998)

Column		**N1/N2**	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**	**E8**
Input	**Total Bed**	**BTEX**	**MTBE**	**MTBE**	**MTBE**	**MTBE**	**MTBE**	**MTBE**	**MTBE**	**MTBE**
Flow Rate (gpm)	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
ppm in (ug/L)		3.000	30.000	15.000	7.500	3.750	1.875	0.938	0.469	0.234
ppm out (ug/L)		0.0015	15.000	7.500	3.750	1.875	0.938	0.469	0.2344	0.1172
gallons/day	2,880	2,880	2,880	2,880	2,880	2,880	2,880	2,880	2,880	2,880
Daily Loading, (lbs)		0.0720	0.7200	0.3600	0.1800	0.0900	0.0450	0.0225	0.0113	0.0056
Desired Residence (min)	20.0									
Actual Residence (min)	*84.1*	57.8	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Media Calculation										
Actual bed size (ft^3)	38	15.4	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Actual Bed Size (gal)	284	231.31	20.98	20.98	20.98	20.98	20.98	20.98	20.98	20.98
Media Bed Size (lbs)	572	146.5	53.1	53.1	53.1	53.1	53.1	53.1	53.1	53.1
Removal Rate		99.95%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%	50.00%
BedCapacity, (lbs/lb)		1.25	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Bed Absorption Capacity, (lbs BTEX)	183.1	183.1								
Bed Absorption Capacity, (lbs MTBE)	85		10.6	10.6	10.6	10.6	10.6	10.6	10.6	10.6
System Calculation	E1-E8	118								
Column diameter (in)		14	8	8	8	8	8	8	8	8
Column height (in)		96	96	96	96	96	96	96	96	96
Capacity Column (ft^3)		7.71	2.80	2.80	2.80	2.80	2.80	2.80	2.80	2.80
Total Columns Required		2	1	1	1	1	1	1	1	1
Total Media Required (ft^3)	38	15.4	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Gallons	399	231	21	21	21	21	21	21	21	21
Pounds	572	146	53	53	53	53	53	53	53	53
Cost Calculation										
Media Cost/ft^3	$165	$165	$165	$165	$165	$165	$165	$165	$165	$165
Media Cost	*$6,237*	$2,544	$462	$462	$462	$462	$462	$462	$462	$462
Cost to treat 1 pound		$6.95	$43.42							
Cost to treat 1000 gallons		$3.30	($0.12)							
Cost to treat one pound with carbon		$12.50	$125.00							

Appendix B: Pilot Test Analytical Data

Pilot 1

DATE

	8/25/97	8/29/97	9/2/97	9/5/97	9/6/97	All Dates
Concentration (ug/L)						**Mean**
MTBE Influent	208200	438100	401200	133200	133200	262780
MTBE GET 1	800	12500	346100	69800	69800	99800
MTBE GET 2	0	0	45600	39100	39100	24760
BTEX Influent	15930	6150	35400	61200	61200	35976
BTEX GET 1	0	0	3529	3000	3000	1906
BTEX GET 2	0	0	0	0	0	0

Flow Rate (GPM)						**Mean/Total**
flow rate	0.00	0.56	2.02	1.38	0.95	0.98
gallons	0.00	3215.00	11660.00	5954.00	1374.00	22203

Mass Loading (lbs)						**Sum Mass Loading**
MTBE Influent		8.99	42.36	13.77	1.58	66.71
MTBE GET 1		0.19	18.10	10.72	0.83	29.83
MTBE GET 2		0.00	2.30	2.18	0.47	4.95
BTEX Influent		0.31	2.10	2.49	0.73	5.62
BTEX GET 1		0.00	0.18	0.17	0.04	0.38
BTEX GET 2		0.00	0.00	0.00	0.00	0.00

Interval Mass Removal (lbs)						**Sum Mass Removal**
MTBE Influent						
MTBE GET 1		8.81	24.26	3.05	0.75	36.88
MTBE GET 2		0.19	15.80	8.54	0.37	24.88
Sum removal		8.99	40.06	11.59	1.12	61.76
BTEX Influent						
BTEX GET 1		0.31	1.92	2.32	0.69	5.24
BTEX GET 2		0.00	0.18	0.17	0.04	0.38
Sum removal		0.31	2.10	2.49	0.73	5.62

Interval Mass Removal / Lb PolyGuard (lb/lb)						**Sum Mass Removal / lb PolyGuard**
MTBE Influent						
MTBE GET 1		0.04	0.12	0.01	0.00	0.18
MTBE GET 2		0.00	0.08	0.04	0.00	0.12
PG System Removal		0.02	0.10	0.03	0.00	0.15
BTEX Influent						
BTEX GET 1		0.00	0.01	0.01	0.00	0.03
BTEX GET 2		0.00	0.00	0.00	0.00	0.00
PG System Removal		0.00	0.01	0.01	0.00	0.01

Interval Removal Efficiency (Mass)						**Removal Efficiency (Mass)**
MTBE Influent						
MTBE GET 1		0.98	0.57	0.22	0.48	0.56
MTBE GET 2		1.00	0.87	0.80	0.44	0.78
PG System Removal		1.00	0.95	0.84	0.71	0.93
BTEX Influent						
BTEX GET 1		1.00	0.92	0.93	0.95	0.95
BTEX GET 2			1.00	1.00	1.00	1.00
PG System Removal		1.00	1.00	1.00	1.00	1.00

Pilot 2 **DATE**

	10/27/97	10/29/97	11/3/97	11/5/97	11/10/97	11/13/97	11/18/97	11/26/97	12/3/97	All Dates
Concentration (ug/L)										**Mean**
MTBE Influent	58800	132800	99000	110600	89200	80300	71000	68400	60600	85633
MTBE N 1	9.40	43700	41000	68500	65900	60000	82800			51701
MTBE N 2	0.00	300	4600	10200	33300	66600	52100	56100	49500	30300
MTBE N 3								53800	5300	29550
MTBE GAC	0.00	0	0	0	0	0	0	45600	39100	9411
BTEX Influent	56800.00	40510.00	37400.00	33100.00	27130.00	31100.00	25500.00	24950.00	21340.00	33092
BTEX N 1	20.80	240.00	64.00	78.00	370.00	360.00	310.00			206
BTEX N 2	0.00	0.00	0.00	0.00	0.00	0.00	130.00	1370.00	580.00	231
BTEX N 3								210.00	110.00	160
BTEX GAC	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Flow Rate (GPM)										**Mean/Total**
flow rate	0.00	1.44	0.38	0.31	0.61	0.44	0.40	1.57	0.56	0.63
gallons	0	4139	2708	903	4379	1897	2886	18128	5667	40707
Mass Loading (lbs)										**Sum Mass Loading**
MTBE Influent		3.43	2.72	0.82	3.79	1.39	1.89	10.94	3.16	28.14
MTBE N 1		0.78	0.99	0.43	2.55	1.03	1.78			7.57
MTBE N 2		0.01	0.06	0.06	0.82	0.82	1.48	10.90	2.59	16.74
MTBE N 3								8.31	1.45	9.76
MTBE GAC		0.00	0.00	0.00	0.00	0.00	0.00	3.58	2.08	5.66
BTEX Influent		1.74	0.91	0.28	1.14	0.48	0.71	3.96	1.14	10.35
BTEX N 1		0.00	0.00	0.00	0.01	0.01	0.01			0.03
BTEX N 2		0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.05	0.18
BTEX N 3								0.03	0.01	0.03
BTEX GAC		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interval Mass Removal (lbs)										**Sum Mass Removal**
MTBE Influent										
MTBE N 1		2.65	1.72	0.39	1.24	0.36	0.11			6.47
MTBE N 2		0.78	0.94	0.37	1.72	0.21	0.30	0.04	0.57	4.93
MTBE N 3								2.59	1.14	3.73
MTBE GAC		0.01	0.06	0.06	0.82	0.82	1.48	4.73	-0.63	7.35
Sum removal		3.43	2.72	0.82	3.79	1.39	1.89	7.36	1.09	22.49
BTEX Influent										
BTEX N 1		1.74	0.91	0.28	1.13	0.47	0.70			5.23
BTEX N 2		0.00	0.00	0.00	0.01	0.01	0.01	3.83	1.09	4.94
BTEX N 3								0.11	0.04	0.15
BTEX GAC		0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.04
Sum removal		1.74	0.91	0.28	1.14	0.48	0.71	3.96	1.14	10.35
Interval Mass Removal / Lb PolyGuard (lb/lb)										**Sum Mass Removal/lb PolyGuard**
MTBE Influent										
MTBE N 1		0.02	0.01	0.00	0.01	0.00	0.00			0.05
MTBE N 2		0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.04
MTBE N 3								0.02	0.01	0.03
MTBE GAC										
PG System Removal		0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	0.04
BTEX Influent										
BTEX N 1		0.02	0.01	0.00	0.01	0.00	0.01			0.05
BTEX N 2		0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.01	0.05
BTEX N 3								0.00	0.00	0.00
BTEX GAC										
PG System Removal		0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.03
Interval Removal Efficiency										**Removal Efficiency (Mass)**
MTBE Influent										
MTBE N 1		0.67	0.59	0.38	0.26	0.25	-0.17			0.33
MTBE N 2		0.99	0.89	0.85	0.49	-0.11	0.37		0.18	0.52
MTBE N 3									0.89	0.89
MTBE GAC		1.00	1.00	1.00	1.00	1.00	1.00	0.57	-0.43	0.77
PG System Removal		1.00	0.98	0.93	0.78	0.41	0.22	0.24	0.54	0.41
BTEX Influent										
BTEX N 1		1.00	1.00	1.00	0.99	0.99	0.99			1.00
BTEX N 2		1.00	1.00	1.00	1.00	1.00	0.81	0.97	0.96	0.98
BTEX N 3								0.80	0.84	1.00
BTEX GAC							1.00	1.00	1.00	1.00
PG System Removal		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

NOTES:

[1] Polyguard Unit 1 - Represents Virgin Polyguard Installed in First FRP Canister on October 27, 1997, and removed on November 18, 1997, after

[2] Polyguard Unit 2 - Virgin Polyguard Installed in Second FRP Canister on October 27, 1998 and transferred into First FRP Canister on November 18, 1997, after

[3] Polyguard Unit 3 - Represents Virgin Polyguard Installed in Second FRP Canister on November 18, 1997, after

[4] GAC Unit 1 - Represents Virgin 55-gallon GAC Unit Installed on October 27, 1997, and removed on November 18, 1997, after

[5] GAC Unit 2 - Represents Virgin GAC Unit Installed on November 18, 1997, to replace GAC Unit

Phase 3 MTBE

DATE

	6/17/98	6/25/98	7/2/98	7/10/98	7/14/98	7/17/98	7/21/98	7/24/98	8/17/98	8/24/98	8/31/98	All Dates
Concentration (ug/L)												**Mean**
Influent	29400	10600	33400	69200	41600	36500	50500	40400	47900	34000	28000	38318
N2 out	26500	5600	36800	55000	32600	42100	40900	40900	38200	44500	71700	39527
ECS E1	2800	3500	35000	55700	16200	3300	39100	39100	28300	43100	40300	27855
ECS E2			41200	37800	27900	32800	33900	31300	31200	40000	33500	34400
ECS E4	ND	2200	27200	33400	17900	26700	24000	28300	27600	34200	33500	25500
ECS E7	ND	100	1300	6700	5500	7200	11500	8800	16100	20100	34800	11210
ECS E8	NR	NR	NR	1200	1500	NR	4700	3600	12400	17000	20900	8757
Flow Rate (GPM)												**Mean/Total**
flow rate	0	0.79	0.94	0.49	0.34	0.46	0.26	0.27	0.9	0.41	0.45	0.48
gallons	167	9142	9481	5611	1949	1983	1488	1168	7798	4158	9006	51951
MTBE Mass Loading (lbs)												**Sum Mass Loading**
Influent		1.58	1.81	2.49	0.93	0.67	0.56	0.46	2.98	1.47	2.42	15.38
N2 out		1.27	1.74	2.23	0.74	0.64	0.53	0.41	2.67	1.49	4.53	16.26
ECS E1		0.25	1.58	2.20	0.61	0.17	0.27	0.40	2.28	1.29	3.25	12.29
ECS E2		0.00	1.69	1.92	0.55	0.52	0.43	0.33	2.11	1.28	2.87	11.70
ECS E4		0.17	1.21	1.47	0.43	0.38	0.33	0.26	1.89	1.11	2.64	9.90
ECS E7		0.01	0.06	0.19	0.10	0.11	0.12	0.10	0.84	0.65	2.14	4.33
ECS E8								0.04	0.54	0.53	1.48	2.59
Interval Mass Removal lbs)												**Sum Mass Removal**
Influent												
N2 out		0.31	0.07	0.26	0.20	0.03	0.03	0.05	0.31			1.25
ECS E1		1.02	0.16	0.03	0.13	0.47	0.26	0.02	0.39	0.20	1.28	3.97
ECS E2				0.28	0.05			0.07		0.00	0.39	0.79
ECS E4		0.08	0.48	0.45	0.12	0.14	0.10	0.07	0.22	0.17	0.23	2.05
ECS E7		0.17	1.15	1.28	0.33	0.27	0.21	0.16	1.05	0.46	0.50	5.57
ECS E8			0.06	0.19	0.10	0.11	0.12	0.06	0.30	0.12	0.66	1.73
Sum removal		1.58	1.92	2.49	0.93	1.02	0.72	0.42	2.28	0.96	3.05	15.36
Interval Mass Removal / Lb PolyGuard (lb/lb)												**Sum Mass Removal / lb PolyGuard**
Influent												
N2 out		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E1		0.02	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.02	0.08
ECS E2		0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
ECS E4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
ECS E7		0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04
ECS E8		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.03
System Removal		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Interval Removal Efficiency (Mass)												**Removal Efficiency (Mass)**
Influent												
N2 out		0.20	0.04	0.11	0.21	0.04	0.05	0.10	0.10	-0.01	-0.87	-0.06
ECS E1		0.80	0.09	0.01	0.18	0.74	0.49	0.04	0.15	0.14	0.28	0.24
ECS E2			-0.07	0.13	0.09	-2.11	-0.57	0.17	0.07	0.00	0.12	0.05
ECS E4		0.30	0.29	0.23	0.22	0.27	0.24	0.20	0.11	0.13	0.08	0.15
ECS E7		0.95	0.95	0.87	0.76	0.72	0.63	0.61	0.55	0.41	0.19	0.56
ECS E8								0.59	0.36	0.19	0.31	0.40
System Efficeincy		1.00	0.97	0.92	0.89	0.84	0.79	0.91	0.82	0.64	0.39	0.83

Phase 3 BTEX

	DATE											
	6/17/98	6/25/98	7/2/98	7/10/98	7/14/98	7/17/98	7/21/98	7/24/98	8/17/98	8/24/98	8/31/98	**All Dates**
Concentration (ug/L)												**Mean**
Influent	13200	14280	28320	26560	15690	13750	10020	11250	14700	7241	5852	14624
N2 out	N.D. h	71	0	62	N.D. k	79	55	40	31	42	34	46
ECS E1	N.D. g	43	26	17	N.D. k	N.D. j	26	N.D. f	N.D. e	N.D. e	N.D. b	28
ECS E2	NR	NR	N.D. L	N.D. f	N.D. l	N.D. h	N.D.	N.D. f	N.D. k	N.D. f	N.D. d	N.D.
ECS E4	N.D. a	N.D. e	N.D. a	N.D. a	N.D. l	N.D. l	N.D.	N.D. e	N.D. e	N.D. e	N.D. e	N.D.
ECS E7	N.D. a	N.D. c	NR	N.D. a	N.D. f	N.D. h	N.D.	N.D. e	N.D. f	N.D. e	N.D. f	N.D.
ECS E8	NR	NR	NR	NR	N.D. c	NR	N.D.	N.D. d	N.D. f	N.D. e	N.D. f	N.D.

Flow Rate (GPM)												**Mean/Total**
flow rate	0	0.79	0.94	0.49	0.34	0.46	0.26	0.27	0.9	0.41	0.45	0.48
gallons	167	9142	9481	5611	1949	1983	1488	1168	7798	4158	9006	51951

BTEX Mass Loading (lbs)												**Sum Mass Loading**
Influent		1.09	1.75	1.33	0.36	0.25	0.15	0.11	0.88	0.39	0.51	6.82
N2 out		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
ECS E1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E2		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E4			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E7			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E8								0.00	0.00	0.00	0.00	0.00

Interval Mass Removal lbs)												**Sum Mass Removal**
Influent												
N2 out		1.09	1.75	1.33	0.36	0.25	0.15	0.11	0.87	0.39	0.51	6.81
ECS E1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
ECS E2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E7		0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E8					0.00		0.00	0.00	0.00	0.00	0.00	0.00
Sum removal		1.09	1.75	1.33	0.36	0.25	0.15	0.11	0.88	0.39	0.51	6.82

Interval Mass Removal / Lb PolyGuard (lb/lb)												**Sum Mass Removal / lb PolyGuard**
Influent												
N2 out		0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03
ECS E1		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E2			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E7		0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E8					0.00		0.00	0.00	0.00	0.00	0.00	0.00
System Removal		0.002	0.003	0.002	0.001	0.000	0.000	0.000	0.001	0.001	0.001	0.01

Interval Removal Efficiency (Mass)												**Removal Efficiency (Mass)**
Influent												
N2 out		1.00	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	0.99	1.00
ECS E1		0.00	0.03	0.31	0.00	0.00	1.00	1.00	1.00	1.00	1.00	0.69
ECS E2		0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00
ECS E4		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E7			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS E8					0.00			0.00	0.00	0.00	0.00	0.00
System Efficeincy		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

M.D.L. : a=6, b=7, c=12, d=15,e=30, f=60, g=120, h=150, I=250, j=275, k=600, L=1500 ug/L

Appendix C: Remediation Action Plan Status Report, April 1998

RELEASE ABATEMENT MEASURE
STATUS REPORT
B & D PETROLEUM SALES FACILITY
220 SOUTH MAIN STREET
BELLINGHAM, MASSACHUSETTS
DEP SITE #2-10377

Prepared For:

Massachusetts Department of
Environmental Protection
Bureau of Waste Site Cleanup
627 Main Street
Worcester, Massachusetts 01605

Prepared By:

Environmental Compliance Services, Inc.
588 Silver Street
Agawam, Massachusetts 01001

File No. J12116.10
RAMStatus1.doc
April, 1998

April 28, 1998
File No. J12116.10
RAMStatus1.doc

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup
627 Main Street
Worcester, Massachusetts 01605

Attn: Mr. Radesha Thuraisingham

RE: Release Abatement Measure Status Report
B & D Petroleum Sales Facility
220 South Main Street
Bellingham, Massachusetts
DEP RTN #2-10377

Dear Mr. Thuraisingham:

On behalf of B & D Petroleum Sales, Inc. of Springfield, Massachusetts, Environmental Compliance Services, Inc. (ECS) has prepared this Release Abatement Measure (RAM) status report summarizing activities which took place at the B & D Petroleum Sales Facility located at 220 South Main Street in Bellingham, Massachusetts (here-in-after referred to as the Site, Figure 1). This report discusses remedial operations associated with the groundwater recovery and treatment system (GTS), GTS sampling and analysis results, and monitoring of the groundwater quality at the Site since the implementation of the RAM modification in August, 1997.

REMEDIAL OPERATIONS

Data and observations concerning GTS operations at the B & D Petroleum Sales Facility in Bellingham, Massachusetts are discussed in this section, covering the operation of recovery wells RW-1, RW-2, RW-3, and RW-4 located on the property of New England Food Service, and the operation and modifications of the GTS as part of each pilot test (Figure 2). Analytical results of influent, midpoint, and effluent water samples collected from the GTS are presented in Table 1a for the first pilot test conducted from August 25, 1997 to September 6, 1997 and in Table 1b for the second pilot test conducted from October 27, 1998 to December 3, 1998. Analytical results of groundwater samples collected at the Site in July, 1997 and April, 1998 are summarized in Tables 2 - 4. The laboratory reports for all of the analyses are included in Attachment I.

Groundwater Treatment System Operations

During the time period encompassed by this report, the GTS at the Site was operational from August 25, 1997 to September 6, 1997 and from October 27, 1997 to December 3, 1997. The GTS was shut down on September 6, 1997 and on December 3, 1997 due to the exceedance of the NPDES permitted discharge concentration of 70 parts per billion (ppb) for methyl tert-butyl ether (MTBE). Total discharges of MTBE were estimated to be 4.8 pounds between August 29, 1997 and September 6, 1997 and 5.4 pounds between November 18, 1997 and December 3, 1997. Exceedance of the permitted NPDES concentration and the associated shutdown of the GTS were reported to Mr. Scott Pellerin, On-Scene Coordinator with the United States Environmental Protection Agency (USEPA), within 24 hours of each occurrence.

Additionally, none of the other target contaminants, benzene, toluene, ethylbenzene, xylene (BTEX), or total petroleum hydrocarbons (TPH) were detected at any time in the GTS effluent during either pilot test.

The submission of the RAM modification in July, 1997 proposed a pilot test be conducted at the Site utilizing Polyguard™ as an absorbent to treat BTEX and MTBE contaminated groundwater at a flowrate of 5 gallons per minute (gpm) and the use of a compost biofilter to treat effluent gases at a flowrate of 10 standard cubic feet per minute (scfm) from a diffuser (See Figure 3). ECS proposed utilizing the compost biofilter for off-gas treatment based upon their demonstrated effectiveness at treating a variety of BTEX and TPH contaminated airstreams. However, upon initiating construction of the biofilter, ECS determined that the proposed seeding bacteria was incapable of degrading MTBE. Additionally, ECS was unable to locate a vender with a demonstrated MTBE degrading bacteria. As the diffuser, at an airflow rate of 10 scfm and groundwater flowrate of 5 gpm, was determined to only reduce the groundwater MTBE concentration by approximately 5%, removal of the diffuser from the proposed GTS was determined to have only a minor impact on the estimated utilization rate of Polyguard™.

ECS and Guardian Environmental Technologies (GET) of Kent, Connecticut designed the initial operation parameters of the GTS based upon the results of the bench scale tests of Polyguard™ presented in Appendix B of the July, 1997 RAM modification, "Pump and Treat Remediation of Groundwater Using a Polymer Absorbent: A Pilot Demonstration Protocol For Polyguard™." Bench scale tests presented in the Protocol indicated an 87.8% removal rate of MTBE for PolyGuard™ with a residence time of 10 minutes and an absorption capacity of 1.53 pounds MTBE per pound PolyGuard™ (153%) with a contact time of 24 hours. For design purposes an absorption capacity of 135%, an absorption rate of 87.8%, and a residence time of 15 minutes were assumed for the GTS as presented in the Protocol. Consequently, ECS initiated construction of the GTS at the Site utilizing two 110-gallon (14.4 ft^3) PolyGuard™ canisters (total of 634 pounds, 316 pounds per drum). As an added safety measure, ECS reduced the initial flowrate of the GTS to approximately 2 gpm, increasing the total residence time to approximately 55 minutes (assuming a porosity of 50%).

GTS PolyGuard™ Pilot Test One

All water samples were collected during the pumping cycle of the GTS. All samples were collected directly into 40-milliliter septum-sealed glass vials which were pre-preserved with hydrochloric acid to a pH value of less than 2. The samples were refrigerated on-site and during transport to the laboratory following chain-of-custody protocols. The samples were submitted to Spectrum Analytical, Inc. of Agawam, Massachusetts for analysis using EPA Method 602, with MTBE as an additional parameter, and using EPA Method 8100M for TPH. The results of these analyses are included in Attachment I. The operational details of the first PolyGuard™ Pilot Test are as follows:

August 20, 1997;	Installed two 110-gallon PolyGuard™ absorbent drums, water flow meter, Provectr 13P iron removal system, transfer sump and pump, oil/water separator, new water lines from four existing bottom loading pneumatic pumps (MH-1, MH-2, MH-3, and MH-4) to oil/water separator, and installation of explosion proof wiring for sump pump.
August 21, 1997;	Completed plumbing of water lines and test sump pump and compressor.

August 25, 1997;	Tied high level alarm in sump to compressor control panel. Commenced start-up of GTS, and collected first set of groundwater samples. Recorded flow meter reading.
August 29, 1997;	Collected water samples from before, between, and after PolyGuard™ absorbent drums. Noted that two of the pneumatic pumps were not pumping. Recorded flow meter reading.
September 2, 1997;	Disconnected air lines to down pumps. Installed oil and moisture filters with automatic blowdown on air discharge line from compressor. Blew all air lines out, cleaned pumps, reconnected and started pumps. Collected water samples from before, between, and after PolyGuard™ absorbent drums. Recorded flow meter reading.
September 5, 1997;	Collected water samples from before, between, and after PolyGuard™ absorbent drums. Recorded flow meter reading. Received groundwater analytical results indicating exceedance of NPDES permitted discharge concentration of 70 ppb for MTBE on September 2, 1997.
September 6, 1997;	Collected water samples from before, between, and after PolyGuard™ absorbent drums. Recorded flow meter reading and shut GTS down. Notified Mr. Scott Pellerin of EPA of discharge exceedance and GTS shutdown.

As presented in Table 1a, breakthrough of both BTEX and MTBE through the first drum of PolyGuard™ occurred within 8 days of start-up after treating only 14, 875 gallons of water and removing approximately 32 pounds of MTBE and 2.15 pounds of BTEX. Total volume of groundwater treated by the GTS between August 25, 1997 and September 6, 1997 was 22,203 gallons and the total mass of MTBE removed by the PolyGuard™ was approximately 60 pounds and the total mass of BTEX recovered was approximately 5.4 pounds. No BTEX and no TPH were discharged from the GTS.

The average MTBE concentration over the period of operation was 262,780 micrograms per liter (ug/l). GET reported that the sudden drop in efficiency of BTEX removal in drum 1 documented by the breakthrough of BTEX on September 2, 1997 was likely due to channeling, void collapse, or other mechanical failures and could not be attributed to “saturation” of the PolyGuard™. Recognizing that the bench scale tests as reported in the Protocol were conducted with packed vessels with a length to diameter ratio of 5:1, GET and ECS met with Steve Emmendorfer, P.E., Vice President of Construction of Nickerson Engineering of Torrington, Connecticut, regarding design of new pressure vessels to contain the PolyGuard™.

GTS Polyguard™ Pilot Test Two

The redesigned PolyGuard™ absorption units each contained approximately 8 ft^3 of PolyGuard™ and were designed for flowrates of 2 - 3 gpm. The units were constructed of 65 inch long 14 inch diameter fiberglass wrapped pipe (FRP) having a length to diameter ratio of 4.6 to 1. The treatment train was also redesigned to include a 55-gallon drum of granular activated carbon (GAC) after the two PolyGuard™ absorption units.

All water samples were collected during the pumping cycle of the GTS. All samples were collected directly into 40-milliliter septum-sealed glass vials which were pre-preserved with hydrochloric acid to a pH value of less than 2. The samples were refrigerated on-site and during transport to the laboratory following chain-of-custody protocols. The samples were submitted to Spectrum Analytical, Inc. of Agawam, Massachusetts for analysis using EPA Method 602, with MTBE as an additional parameter. Only effluent samples from the GAC unit were analyzed for TPH in order to meet the NPDES permit exclusion requirements. GTS Influent, PolyGuard™ midpoint, and PolyGuard™ discharge/GAC influent, samples were not analyzed for TPH given that laboratory analyses performed during the first pilot test indicated total BTEX concentrations exceeding TPH concentrations. The results of these analyses are included in Attachment I. The operational details of the second PolyGuard™ Pilot Test are as follows:

October 27, 1997;	Nickerson and ECS installed the new PolyGuard™ absorption contactor units and GAC drum at the Site. A 48 hour pump test was conducted from October 27, 1997 to monitor system operating flowrates and pressures. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.
October 29, 1997;	Approximately 4,140 gallons of contaminated water were pumped between October 27, 1997 at 5:10 pm and October 29, 1997 at 7 am. During the time period the sump pump was on the system had an average flowrate of 1.8 gpm and an initial pressure of 18 pounds per square inch (psi) between the Provectr water treatment system and the first PolyGuard™ unit. However, a pressure of 45 psi was observed on October 29, 1997 before the Provectr system was observed and the system was shutdown in order to avoid burning out the sump pump. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit, and the flow meter reading was recorded prior to shutting the GTS down.
October 31, 1997;	Due to excessive pressure drop across the venturi and Provectr system the venturi was removed, given that the water entering the Provectr is significantly aerated by both QED pneumatic pumps and the sump pump. The GTS was restarted and observed to cycle on for approximately 10 minutes and off for approximately 2 hours.
November 3, 1997;	The GTS was still observed to be cycling with a peak flowrate of 1.8 gpm during the time period the sump pump cycled on, and an average flowrate of less than 0.5 gpm. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.
November 5, 1997;	Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.
November 10, 1997;	Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.

November 13, 1997; Cleaned all four pneumatic pumps, low delivery air pressure noted at all of the pumps, two of the pumps would not restart. Transfer sump heating up but operating with significant back pressure from Provectr and PolyGuard™ absorption units. Maximum flowrate was 2 gpm. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.

November 18, 1997; ECS replaced GAC unit. Nickerson personnel replaced PolyGuard™ in first absorption unit with PolyGuard™ from second column and placed virgin PolyGuard™ in second absorption unit. Low pressure to pneumatic pumps was determined to be stuck solenoid valve on compressor. All four pneumatic pumps restarted. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.

November 26, 1997; Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded.

December 3, 1997; Sump pump containment observed to be periodically leaking due to exceedance of sump pump capacity by pneumatic pumps, and delay between shutdown of compressor and sufficient line pressure drop to shut off pneumatic pumps. PolyGuard™ flowrate increased to 3 gpm. Back pressure on pneumatic pumps increased and lid on oil/water separator resealed. Sump pump set to cycle at 45 minutes on and 10 minutes off. Water samples were collected from before the first PolyGuard™ unit, between the PolyGuard™ units, after the second PolyGuard™ unit (before the GAC unit), and after the GAC unit. The flow meter reading was recorded and the system was shutdown. Notified Mr. Scott Pellerin of EPA of discharge exceedance and GTS shutdown.

Between October 27, 1997 and November 18, 1997 approximately 10.4 pounds of MTBE and 5 pounds of BTEX were recovered by the two PolyGuard™ absorption units at an average flowrate of 0.5 gpm (Table 1b). Approximately, 16,912 gallons were treated during this time period. Removal rates of MTBE for the entire PolyGuard™ bed decreased from 100% to 27% over the same time period. Total capacity (assuming saturation of the first PolyGuard™ unit on November 13, 1997) was only 5.79 pounds of MTBE and 5.04 pounds of BTEX per 220 pounds of PolyGuard™.

On November 18, 1997, with all four pumps on-line, the GTS resumed pumping at an average continuous flowrate of approximately 2 gpm, approximately 4 times the flowrate of 0.5 gpm observed during the previous period. Approximately 23,800 gallons of contaminated groundwater were treated between November 18, 1997 and when the GTS was shutdown on December 3, 1997. Removal rates for the entire PolyGuard™ were approximately 21% over this time period. Although breakthrough of MTBE from the second PolyGuard™ unit into the GAC unit and breakthrough of MTBE through the GAC unit occurred between November 18, 1997 and November 26, 1997, the PolyGuard™ appeared to have additional absorption capacity as demonstrated by the laboratory analytical results for the water samples collected on December 3, 1997, which indicated a removal rate of 93.4%.

GTS PolyGuard™ Pilot Test Three

An analysis of the laboratory data from the GTS for both pilot tests indicates that the breakthrough characteristics of PolyGuard™ are not similar to GAC. PolyGuard™ appears to have significant absorption capacity even after breakthrough concentrations of MTBE reach 80% of the MTBE inlet concentration. Consequently, ECS and GET in conjunction with STEP have redesigned the Pilot Test Protocol and the PolyGuard™ absorption columns (Figure 4). The revised process flow diagram depicts the requirement for a long and narrow absorption bed, which was achieved by constructing eight 10 ft. tall, 8 inch diameter, PolyGuard™ packed columns. These columns will be operated in series after the existing 8 ft^3 Nickerson units. Each of the new columns will contain approximately 3.3 ft^3 or 73 pounds of PolyGuard™. Two 55-gallon GAC drums will be installed after the last 3.3 ft^3 PolyGuard™ column. The new columns will be installed at the Site and the Third Pilot Test will commence in May, 1998.

Estimated BTEX and MTBE Mass Removal

The concentration of each of the BTEX constituents for each sample collected from the GTS were added together to yield the “total BTEX” concentration. The mass of MTBE and BTEX treated by the GTS over each time period, MTBE In and Total BTEX In, were determined by average the concentrations obtained at the beginning and end of each sampling period and multiplying by the gallons pumped during the same period. The mass of MTBE and BTEX recovered by each drum or column during each period was equivalent to the mass in of MTBE and BTEX minus the mass out of the drum or column of MTBE and BTEX. Column or drum changes were noted by starting a new “unit” (e.g. PolyGuard™ Unit 3 and GAC Unit 2 installed on November 18, 1997, presented in Table 1b). The peak MTBE inlet concentration of 438,100 ppb from the combined pumping from MH-1, MH-2, MH-3, and MH-4 was observed during the first pilot test on August 29, 1997. The peak total BTEX concentration in of 56,800 ppb was observed from the combined pumping of MH-1, MH-2, MH-3, and MH-4 on October 27, 1997. The average inlet MTBE concentration during the second pilot test was only 85,633 ug/l versus an average inlet concentration of MTBE of 262,780 ug/l during the first pilot test.

. Approximately 59.5 pounds of MTBE and 5.4 pounds of total BTEX were recovered by the GTS during the first pilot test, and approximately 13.98 pounds of MTBE and 9.95 pounds of total BTEX were recovered by the GTS during the second pilot test. A total of 22,203 gallons of BTEX and MTBE contaminated groundwater were treated during the first pilot test and approximately 40,707 gallons of BTEX and MTBE contaminated groundwater were treated during the second pilot test. A total of 73.48 pounds of MTBE were recovered, equivalent to approximately 12 gallons of MTBE (assuming a density of 0.7405).

GROUNDWATER QUALITY MONITORING

ECS collected groundwater samples from the Site on July 30, 1997 and on April 17, 1998. The laboratory analytical results for the groundwater samples collected on July 30, 1997 are presented in Tables 2a, 2b, 3a, 3b, and 4. The laboratory analytical results for the groundwater samples collected on April 17, 1998 are presented in Tables 2c and 2d. On July 30, 1997 groundwater samples were collected from ECS-1, ECS-5, ECS-6, ECS-7, ECS-8, MH-1, MH-2, MH-3, and MH-4. On April 17, 1998 groundwater samples were collected from ECS-1 (identified in the laboratory report as ECS-10), ECS-2, ECS-3, ECS-4, ECS-5, ECS-6, ECS-7, and ECS-8.

Groundwater samples collected on July 30, 1997 were analyzed for VOCs by EPA Method 602, for TPH by EPA Method 8100 Modified, and samples from the recovery wells, MH-1, MH-2, MH-3, and MH-4 were also analyzed for total iron, total manganese, and hardness. Groundwater samples collected on April 17, 1998 were analyzed for VOCs by MADEP volatile petroleum hydrocarbon (VPH) method. All groundwater samples were obtained using dedicated disposable polyethylene bailers.

Upon collection of each sample, the sample containers were refrigerated on-site and during transport to Spectrum Analytical, Inc. of Agawam, Massachusetts, following chain-of-custody procedures.

Groundwater Monitoring Results

The laboratory reports of the analyses performed on these groundwater samples are included in Attachment I. Summary tables of the analytical results are presented in Tables 2a, 2b, 2c, 2d, 3a, 3b, and 4. Groundwater samples from ECS-5, ECS-7, and ECS-8 were observed to exceed the MCP Method 1 Risk Characterization GW-2 standard for benzene, toluene, total xylenes, and MTBE for both the July, 1997 and April, 1998 sampling rounds. The results of these analyses indicate that the highest MTBE concentrations in July, 1997 detected in ECS-1, ECS-7, and ECS-8, of 173,700 ug/l, 361,500 ug/l, and 529,200 ug/l (Table 2a), respectively, decreased to 5,000 ug/l, 64,000 ug/l, and 83,000 ug/l, (Tables 2c and 2d) respectively, in April, 1998. No aliphatic or aromatic petroleum hydrocarbons or MTBE or BTEX compounds were detected above the method detection limits in monitoring wells ECS-3 and ECS-4 in April, 1998. Additionally, aliphatic and aromatic petroleum hydrocarbon, MTBE, and BTEX compound concentrations were below applicable MCP Method 1 Risk Characterization GW-2 and GW-3 standards for ECS-2.

TPH concentrations in groundwater monitoring wells in July, 1997 were determined to be 112.3 milligrams per liter (mg/l), 138 mg/l, 120 mg/l, 94 mg/l, and 94 mg/l for ECS-1, ECS-5, ECS-6, ECS-7, and ECS-8, respectively (Table 3a). These TPH values exceeded the Method 1 Risk Characterization GW-2 standard of 1 mg/l and GW-3 standard of 20 mg/l. TPH concentrations in groundwater samples from MH-1, MH-2, MH-3, and MH-4 ranged from 0.8 mg/l to 9.4 mg/l, below the applicable GW-3 standard and above the GW-2 standard (Table 3b).

Total iron concentration from groundwater samples collect in July, 1997, ranged from 22.9 mg/l in MH-4 to 6,270 mg/l in MH-2. Hardness as calcium carbonate ranged from 97.7 mg/l in MH-3 to 228 mg/l in MH-2.

If you have any questions or require any additional information, please feel free to contact this office.

Sincerely,
ENVIRONMENTAL COMPLIANCE SERVICES, INC.

Frederick W. Hostrop
Senior Project Manager

FWH

cc: Mr. Michael McCarthy, B & D Petroleum Sales, Inc.
File

B & D Petroleum
220 South Main Street
Bellingham, Massachusetts
RTN 2-10377

Table 1a
Polyguard Pilot Test One
GTS - Two 14.4 ft3 Polyguard Drums and 1 55-gal. GAC Unit
BTEX & MTBE Analytes Detected in Treatment System Wastewater
(USEPA Method 8020)

Sampling Date	8/25/97	8/29/97	9/2/97	9/5/97	9/6/97
Laboratory Analytical Results					
MTBE In (ug/l)	208200.00	438100.00	401200.00	133200.00	133200.00
Total BTEX In (ug/l)	15930.00	6150.00	35400.00	61200.00	61200.00
MTBE Btwn Polyguard Units (ug/l)	800.00	12500.00	346100.00	69800.00	69800.00
Total BTEX Btwn Polyguard Units (ug/l)	0.00	0.00	3529.00	3000.00	3000.00
MTBE Out (ug/l)	0.00	0.00	45600.00	39100.00	39100.00
Total BTEX Out (ug/l)	0.00	0.00	0.00	0.00	0.00
Total Recorded Flow & Estimated Flowrate					
Total Flow Recorded (gallons)	270148.00	273363.00	285023.00	290977.00	292351.00
Gallons	0.00	3215.00	14875.00	20829.00	22203.00
Gallons Pumped Per Period	0.00	3215.00	11660.00	5954.00	1374.00
Estimated Flowrate (gallons / minute)	0.00	0.56	2.02	1.38	0.95
Polyguard Performance Data					
Total MTBE into system (lbs.)	0.00	8.67	49.51	62.78	64.31
Total BTEX into system (lbs.)	0.00	0.30	2.32	4.72	5.42
Polyguard Drum 1[1]					
MTBE Recovered by Unit 1/Period (lbs.)	0.00	8.49	23.39	2.94	0.73
BTEX Recovered by Unit 1/Period (lbs.)	0.00	0.30	1.85	2.24	0.67
Total MTBE Recovered by Unit 1 (lbs.)	0.00	8.49	31.88	34.82	35.55
Total BTEX Recovered by Unit 1 (lbs.)	0.00	0.30	2.15	4.38	5.05
Polyguard Drum 2[2]					
MTBE Recovered Unit 2/Period (lbs.)	0.00	0.18	15.23	8.23	0.35
BTEX Recovered Unit 2/Period (lbs.)	0.00	0.00	0.17	0.16	0.03
Total MTBE Recovered Unit 2 (lbs.)	0.00	0.18	15.41	23.64	23.99
Total BTEX Recovered Unit 2 (lbs.)	0.00	0.00	0.17	0.33	0.37
Contaminant Removal Totals					
MTBE Recovered by Polyguard / Period (lbs.)	0.00	8.67	38.62	11.17	1.08
BTEX Recovered by Polyguard / Period (lbs.)	0.00	0.30	2.02	2.40	0.70
Total MTBE Recovered by Polyguard (lbs.)	0.00	8.67	47.29	58.46	59.54
Total BTEX Recovered by Polyguard (lbs.)	0.00	0.30	2.32	4.72	5.42
MTBE Discharged/Period (lbs.)	0.0000	0.0000	2.2186	2.1043	0.4483
BTEX Discharged/Period (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000
Total MTBE Discharged (lbs.)	0.0000	0.0000	2.2186	4.3229	4.7713
Total BTEX Discharged (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000

NOTES:

[1] Polyguard Drum 1 - Represents Virgin Polyguard Installed in First Drum on August 27, 1997, and removed Sept. 6, 1997.

[2] Polyguard Drum 2 - Represents Virgin Polyguard Installed in Second Drum on August 27, 1997, and removed Sept. 6, 1997.

B & D Petroleum
220 South Main Street
Bellingham, Massachusetts
RTN 2-10377

Table 1b
Polyguard Pilot Test Two
Groundwater Treatment System - Two 8 ft^3 Polyguard Columns and 1 55-gal. GAC Unit
BTEX & MTBE Analytes Detected in Treatment System Wastewater
(USEPA Method 8020)

Sampling Date	10/27/97	10/29/97	11/3/97	11/5/97	11/10/97	11/13/97	11/18/97	11/26/97	12/3/97
Laboratory Analytical Results									
MTBE In (ug/l)	58800.00	132800.00	99000.00	110600.00	89200.00	80300.00	71000.00	68400.00	60600.00
Total BTEX In (ug/l)	56800.00	40510.00	37400.00	33100.00	27130.00	31100.00	25500.00	24950.00	21340.00
MTBE Btwn Polyguard Units (ug/l)	9.40	43700.00	41000.00	68500.00	65900.00	60000.00	82800.00	56100.00	49500.00
Total BTEX Btwn Polyguard Units (ug/l)	20.80	240.00	64.00	78.00	370.00	360.00	310.00	1370.00	580.00
MTBE Into GAC (ug/l)	0.00	300.00	4600.00	10200.00	33300.00	66600.00	52100.00	53800.00	5300.00
Total BTEX Into GAC (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	130.00	210.00	110.00
MTBE Out of GAC (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45600.00	39100.00
Total BTEX Out of GAC (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Recorded Flow & Estimated Flowrate									
Total Flow Recorded (gallons)	292351.00	296490.00	299198.00	300101.00	304480.00	306377.00	309263.00	327391.00	333058.00
Gallons	0.00	4139.00	6847.00	7750.00	12129.00	14026.00	16912.00	35040.00	40707.00
Gallons Pumped Per Period	0.00	4139.00	2708.00	903.00	4379.00	1897.00	2886.00	18128.00	5667.00
Estimated Flowrate (gallons / minute)	0.00	1.44	0.38	0.31	0.61	0.44	0.40	1.57	0.56
Polyguard Performance Data									
Total MTBE into system (lbs.)	0.00	3.31	5.93	6.72	10.37	11.71	13.53	24.08	27.13
Total BTEX into system (lbs.)	0.00	1.68	2.56	2.83	3.93	4.39	5.07	8.89	9.98
Polyguard Unit 1[1]									
MTBE Recovered by Unit 1/Period (lbs.)	0.00	2.55	1.66	0.38	1.20	0.00	0.00	0.00	0.00
BTEX Recovered by Unit 1/Period (lbs.)	0.00	1.68	0.88	0.27	1.09	0.46	0.67	0.00	0.00
Total MTBE Recovered by Unit 1 (lbs.)	0.00	2.55	4.22	4.59	5.79	5.79	5.79	0.00	0.00
Total BTEX Recovered by Unit 1 (lbs.)	0.00	1.68	2.55	2.82	3.91	4.37	5.04	0.00	0.00
Polyguard Unit 2[2]									
MTBE Recovered Unit 2/Period (lbs.)	0.00	0.75	0.90	0.36	1.66	0.21	0.29	0.04	0.55
BTEX Recovered Unit 2/Period (lbs.)	0.00	0.00	0.00	0.00	0.01	0.01	0.01	3.69	1.05
Total MTBE Recovered Unit 2 (lbs.)	0.00	0.75	1.65	2.01	3.67	3.88	4.17	4.20	4.76
Total BTEX Recovered Unit 2 (lbs.)	0.00	0.00	0.01	0.01	0.02	0.02	0.03	3.72	4.77
Polyguard Unit 3[3]									
MTBE Recovered Unit 3/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.49
BTEX Recovered Unit 3/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.04
Total MTBE Recovered Unit 3 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	2.99
Total BTEX Recovered Unit 3 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.14
GAC Carbon Unit 1[4]									
MTBE Recovered GAC Unit 1/Period (lbs.)	0.00	0.01	0.06	0.06	0.79	0.79	1.43	0.00	0.00
BTEX Recovered GAC Unit 1/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered GAC Unit 1 (lbs.)	0.00	0.01	0.06	0.12	0.91	1.70	3.13	0.00	0.00
Total BTEX Recovered GAC Unit 1 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GAC Carbon Unit 2[5]									
MTBE Recovered GAC Unit 3/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.56	0.00
BTEX Recovered Unit 3/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01
Total MTBE Recovered Unit 3 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.56	4.56
Total BTEX Recovered Unit 3 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
Contaminant Removal Totals									
MTBE Recovered by Polyguard / Period (lbs.)	0.00	3.30	2.56	0.73	2.86	0.55	0.39	2.53	1.05
BTEX Recovered by Polyguard / Period (lbs.)	0.00	1.68	0.88	0.27	1.10	0.46	0.68	3.79	1.09
Total MTBE Recovered by Polyguard (lbs.)	0.00	3.30	5.87	6.60	9.46	10.01	10.40	12.94	13.98
Total BTEX Recovered by Polyguard (lbs.)	0.00	1.68	2.56	2.83	3.93	4.39	5.07	8.86	9.95
MTBE Recovered by GAC / Period (lbs.)	0.00	0.01	0.06	0.06	0.79	0.79	1.43	4.56	0.00
BTEX Recovered by GAC / Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.01
Total MTBE Recovered by GAC (lbs.)	0.00	0.01	0.06	0.12	0.91	1.70	3.13	7.69	7.69
Total BTEX Recovered by GAC (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
MTBE Discharged from GAC/Period (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4493	2.0029
BTEX Discharged from GAC/Period (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Total MTBE Discharged from GAC (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.4493	5.4522
Total BTEX Discharged from GAC (lbs.)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

NOTES:

[1] Polyguard Unit 1 - Represents Virgin Polyguard Installed in First FRP Canister on October 27, 1997, and removed on November 18, 1997, after sampling.

[2] Polyguard Unit 2 - Virgin Polyguard Installed in Second FRP Canister on October 27, 1998 and transferred into First FRP Canister on November 18, 1997, after sampling.

[3] Polyguard Unit 3 - Represents Virgin Polyguard Installed in Second FRP Canister on November 18, 1997, after sampling.

Appendix D: Remediation Action Plan Status Report, May, 1999

RELEASE ABATEMENT MEASURE
STATUS REPORT
B & D PETROLEUM SALES FACILITY
220 SOUTH MAIN STREET
BELLINGHAM, MASSACHUSETTS
DEP SITE #2-10377

Prepared For:

Massachusetts Department of
Environmental Protection
627 Main Street
Worcester, Massachusetts 01605

Prepared By:

Environmental Compliance Services, Inc.
18 Shepard Street
Brighton, Massachusetts 02135

File No. J50053
RAMStatus2.doc
May, 1999

May 14, 1999
File No. J50053

Massachusetts Department of Environmental Protection
Bureau of Waste Site Cleanup
627 Main Street
Worcester, Massachusetts 01605

Attn: Mr. Radesha Thuraisingham

RE: Release Abatement Measure Status Report
B & D Petroleum Sales Facility
220 South Main Street
Bellingham, Massachusetts
DEP RTN #2-10377

Dear Mr. Thuraisingham:

On behalf of B & D Petroleum Sales, Inc. of Springfield, Massachusetts, Environmental Compliance Services, Inc. (ECS) has prepared this Release Abatement Measure (RAM) status report summarizing activities which took place between April, 1998 and April, 1999 at the B & D Petroleum Sales Facility located at 220 South Main Street in Bellingham, Massachusetts (here-in-after referred to as “the Site”) (See Figure 1 - Site Locus). This report presents the results of remedial operations associated with the groundwater recovery and treatment system (GTS), GTS sampling and analysis results, and monitoring of the groundwater quality at the Site.

REMEDIAL OPERATIONS

Data and observations concerning GTS operations at the B & D Petroleum Sales Facility in Bellingham, Massachusetts are discussed in this section, covering the operation of recovery wells RW-1, RW-2, RW-3, and RW-4 located on the property of New England Food Service, and the operation and modification of the GTS after the completion of the second pilot test. The process flow schematic for the third pilot test is presented in Figure 2. Owing to the configuration of the absorption columns for the third pilot test, water samples from the system were collected from various sampling points: before the first Nickerson Absorption Column, after the second Nickerson Absorption Column, after the first, second, fourth, seventh, and eighth ECS Absorption Columns, and after the first and second granular activated carbon (GAC) adsorption unit.

Analytical results of GTS water samples are summarized in Table 1 for the third pilot test commenced on June 17, 1998. The laboratory reports for all of the analyses are included in Attachment I.

Groundwater Treatment System Operations

During the time period encompassed by this report, the GTS at the Site was operational from June 17, 1998 to July 24, 1998, and from August 11, 1998 through September 8, 1998 and from September 24, 1998 to September 28, 1998, and from December 18, 1998 through December 23, 1998.

The GTS was shut down from July 24, 1998 to August 11, 1998 due to an extremely low pumping rate. The low pumping rate was attributed to fouling of the pneumatic pumps and excessive back pressure from the Provectr iron removal system. Repairs were completed on August 11, 1998 and the GTS was restarted.

On September 8, 1998, the GTS was shut down owing to the detection of MTBE in the effluent from the first of two 55-gallon granular activated carbon (GAC) adsorption units (depicted in Figure 2). No exceedance of the NPDES permitted discharge concentration of 70 parts per billion (ppb) for methyl tert-butyl ether (MTBE) from the GTS occurred. Additionally, none of the other target contaminants: benzene, toluene, ethylbenzene, xylene (BTEX), or total petroleum hydrocarbons (TPH) were detected at any time in the GTS effluent during the pilot test.

The GAC units were replaced and the GTS was restarted on September 24, 1998. On September 28, 1998, the GTS shut down owing to failure of the pneumatic pumps from iron fouling. Additional modifications were proposed and implemented at this time to the GTS, including heat taping and insulating of the lines associated with the ECS columns and installation and replacement of the automatic head for the Provectr iron removal system. Repairs to the system were conducted in October and November, 1998 and the system was restarted on December 18, 1999. Sustained subfreezing temperatures caused system failure on December 23, 1998, and the GTS was shut down pending redesign to increase the overall system flowrate. The design of the new GTS will be presented in the Phase III - Identification, Evaluation, and Selection of Comprehensive Remedial Action Alternatives Report (Phase III, 310 CMR 40.0851-0869).

ECS and Guardian Environmental Technologies (GET) of Kent, Connecticut modified the absorption column design to eliminate mechanical failure or bypass associated with the 110-gallon (14.4 ft^3) Polyguard™ canisters after Pilot Test One. This modified absorption column design was continued for Pilot Test Three with the construction of eight 10' long vertical absorption columns, each with a capacity of 3.2 ft^3. These columns were placed in series after the two 7 ft^3 columns constructed and utilized in Pilot Test Two (See Figure 2). Given Polyguard^{TM}'s density of approximately 18 lbs./ft^3, these additional columns contained approximately 57.6 lbs. of Polyguard^{TM} each for a total of 460 lbs. Consequently, Pilot Test Three utilized a total of 712 lbs. of Polyguard^{TM}, 252 lbs. of which were contained in the two 7 ft^3 "Nickerson" columns, and 460 lbs. of which were contained in the eight "ECS" columns. The total residence time for the Polyguard^{TM} treatment train at a flowrate of 2 gpm was estimated to be 148 minutes. Two 55-gallon, 200 lbs. GAC units were installed after the final Polyguard^{TM} absorption column given that the two prior Pilot Tests indicated rapid breakthrough of MTBE at low concentrations.

GTS PolyGuard™ Pilot Test Three

All water samples were collected during the pumping cycle of the GTS. All samples were collected directly into 40-milliliter septum-sealed glass vials which were pre-preserved with hydrochloric acid to a pH value of less than 2. The samples were refrigerated on-site and during transport to the laboratory following chain-of-custody protocols. The samples were submitted to Spectrum Analytical, Inc. of Agawam, Massachusetts for analysis using EPA Method 602, with MTBE as an additional parameter. Only effluent samples from the GAC unit were analyzed for TPH in order to meet the NPDES permit exclusion requirements. GTS Influent or Polyguard™ In (PIN), discharge from second Nickerson column (N2), discharge from first ECS column (E1), discharge from second ECS column (E2), discharge from fourth ECS column (E4), discharge from seventh ECS column (E7), discharge from eighth ECS column (E8), and discharge from GAC units one and two (C1) and (C2). The results of these analyses are included in Attachment I.

GTS PolyGuard™ Pilot Test Three

An analysis of the laboratory data from the GTS for all three pilot tests indicates that the breakthrough characteristics of Polyguard™ are not similar to GAC for MTBE. Polyguard™ still has significant absorption capacity even after breakthrough of MTBE occurs. During pilot test three MTBE concentrations exceeding NPDES allowable concentrations broke through the entire 712 lbs. of Polyguard™ into the GAC units after removing only 5.86 lbs. of MTBE, or breakthrough occurred after 0.8% mass ratio application of MTBE to Polyguard™ (This ratio was only 0.2% when MTBE broke through column E7).

The existing Nickerson columns, which were carried over in their configuration from pilot test two, absorbed an additional 1.24 lbs. of MTBE during pilot test three and 99+% of the total BTEX compounds. Total loadings on the Nickerson columns between pilot tests two and pilot test three were 8.99 lbs. of MTBE and 10.38 lbs. of total BTEX (approximately 99% of the total BTEX treated during pilot tests two and three). MTBE breakthrough of the Nickerson columns within 10% of the inlet MTBE concentration was observed on July 2 and July 17, 1998. This may indicate that the Nickerson columns were near capacity for MTBE absorption, in which case the capacity of Polyguard™ for MTBE would be approximately 4% (8.99 lbs. MTBE absorbed / 252 lbs. Polyguard™). No comparable value can be calculated for total BTEX; however, sampling of the GTS in December, 1998 documented that only benzene was breaking through the first of the two Nickerson columns; consequently, Polyguard's capacity for BTEX is greater than 8% (10.38 lbs. total BTEX / 126 lbs. Polyguard™).

Estimated BTEX and MTBE Mass Removal

The concentration of each of the BTEX constituents for each sample collected from the GTS were added together to yield the "total BTEX" concentration. The mass of MTBE and BTEX treated by the GTS over each time period, MTBE In and Total BTEX In, were determined by averaging the concentrations obtained at the beginning and end of each sampling period and multiplying by the gallons pumped during the same period. The mass of MTBE and BTEX recovered by each column or set of columns (e.g. ECS-4 represents the total absorbed by columns ECS-3 and ECS-4, and ECS-7 represents the total absorbed by columns ECS-5, ECS-6, and ECS-7) during each period was equivalent to the mass in of MTBE and BTEX minus the mass out of the column or train of columns of MTBE and BTEX. Only the GAC units were changed during the performance of pilot test three. The peak MTBE inlet concentration of 438,100 ug/l from the combined pumping from MH-1, MH-2, MH-3, and MH-4 was observed during the first pilot test on August 29, 1997. The peak total BTEX concentration in of 56,800 ug/l was observed from the combined pumping of MH-1, MH-2, MH-3, and MH-4 on October 27, 1997. The peak MTBE inlet concentration during the third pilot test was 69,200 ug/l on July 10,1998, and the peak total BTEX inlet concentration during the third pilot test was 26,560 ug/l on July 10, 1998. The average inlet MTBE concentration during the second pilot test was only 85,633 ug/l versus an average inlet concentration of MTBE of 262,780 ug/l during the first pilot test. The average inlet MTBE concentration during the third pilot test decreased to 43,451 ug/l from the first and second pilot tests. The average total BTEX concentration during the third pilot test decreased to

. Approximately 59.5 lbs. of MTBE and 5.4 lbs. of total BTEX were recovered by the GTS during the first pilot test, 13.98 lbs. of MTBE and 9.95 lbs. of total BTEX were recovered by the GTS during the second pilot test, and 12.07 lbs. of MTBE and 5.1 pounds of total BTEX were recovered by the GTS during the third pilot test. A total of 22,203 gallons of BTEX and MTBE contaminated groundwater were treated during the first pilot test, approximately 40,707 gallons were treated during the second pilot test, and approximately 47,626 gallons were treated during the third pilot test. A total of 85.55 pounds of MTBE was recovered during the performance of the three pilot tests, equivalent to approximately 13.8 gallons of MTBE (assuming a density of 0.7405).

GROUNDWATER QUALITY MONITORING

ECS collected groundwater samples from the Site on March 10, 1999 as part of the Phase II Scope of Work after completing the installation of five additional soil borings along South Main Street (See Figure 1). These laboratory analytical results will be presented in the Phase II - Comprehensive Site Assessment Report.

If you have any questions or require any additional information, please feel free to contact this office.

Sincerely,
ENVIRONMENTAL COMPLIANCE SERVICES, INC.

Frederick W. Hostrop
Senior Project Manager

FWH

cc: Mr. Michael McCarthy, B & D Petroleum Sales, Inc.
File

B & D Petroleum
220 South Main Street
Bellingham, Massachusetts
RTN 2-10377

Table 1
Polyguard Pilot Test Three
Groundwater Treatment System - Two 7 ft^3 and eight 3.2 ft^3 Polyguard Columns and two 55-gal. GAC Units
BTEX & MTBE Analytes Detected in Treatment System Wastewater
(USEPA Method 8020)

Sampling Date	6/17/98	6/25/98	7/2/98	7/10/98	7/14/98	7/17/98	7/21/98	7/24/98	8/11/98	8/17/98	8/24/98	8/31/98
Laboratory Analytical Results												
MTBE In (ug/l)	29400.00	10600.00	33400.00	69200.00	41600.00	36500.00	50500.00	40400.00	40400.00	47900.00	34000.00	28000.00
Total BTEX In (ug/l)	13220.00	14280.00	14610.00	26560.00	15690.00	13750.00	10020.00	11250.00	11250.00	14700.00	7241.00	5852.00
MTBE Btwn Nickerson Units (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total BTEX Btwn Nickerson Units (ug/l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE out Nickerson Units (ug/l)	26500.00	5600.00	36800.00	55000.00	32600.00	42100.00	38000.00	40900.00	40900.00	38200.00	44500.00	71700.00
Total BTEX Out Nickerson Units (ug/l)	0.00	71.00	60.30	62.00	0.00	72.00	55.00	40.00	40.00	31.00	42.00	34.00
MTBE out of ECS Unit 1 (ug/l)	2800.00	3500.00	35000.00	55700.00	16200.00	33000.00	35700.00	39100.00	39100.00	28300.00	43100.00	40300.00
Total BTEX out of ECS Unit 1 (ug/l)	0.00	43.00	26.10	17.00	0.00	0.00	26.00	0.00	0.00	0.00	0.00	0.00
MTBE out of ECS Unit 2 (ug/l)	0.00	**2850.00**	41200.00	37800.00	27900.00	32800.00	33900.00	31300.00	31300.00	31200.00	40000.00	33500.00
Total BTEX out of ECS Unit 2 (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE out of ECS Unit 4 (ug/l)	0.00	2200.00	27200.00	33400.00	17900.00	26700.00	24000.00	28300.00	28300.00	27600.00	34200.00	33500.00
Total BTEX out of ECS Unit 4 (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE out of ECS Unit 7 (ug/l)	0.00	100.00	1300.00	6700.00	5500.00	7200.00	11500.00	8800.00	8800.00	16100.00	20100.00	34800.00
Total BTEX out of ECS Unit 7 (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE out of ECS Unit 8 (ug/l)	0.00	0.00	0.00	1200.00	1500.00	**3100.00**	4700.00	3600.00	3600.00	12400.00	17000.00	20900.00
Total BTEX out of ECS Unit 8 (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE Out of GAC (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.70
Total BTEX Out of GAC (ug/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total Recorded Flow & Estimated Flowrate												
Total Flow Recorded (gallons)	333225.50	342368.00	351849.00	357459.90	359408.80	361392.23	362879.80	364047.50	364047.50	371845.50	376003.50	380851.50
Gallons	40874.50	50017.00	59498.00	65108.90	67057.80	69041.23	70528.80	71696.50	71696.50	79494.50	83652.50	88500.50
Gallons Pumped Per Period	167.50	9142.50	9481.00	5610.90	1948.90	1983.43	1487.57	1167.70	0.00	7798.00	4158.00	4848.00
Estimated Flowrate (gallons/minute)	0.00	0.79	0.94	0.49	0.34	0.46	0.26	0.27	0.00	0.90	0.41	0.24
Polyguard Performance Data												
Total MTBE into system (lbs.)	27.17	28.70	30.44	32.84	33.74	34.39	34.93	35.37	34.93	38.24	39.66	39.78
Total BTEX into system (lbs.)	10.00	11.05	12.19	13.15	13.50	13.74	13.89	13.99	13.89	14.84	15.22	15.25
Polyguard Unit 2[1]												
MTBE Recovered Unit 2/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTEX Recovered Unit 2/Period (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered Unit 2 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total BTEX Recovered Unit 2 (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Polyguard Unit 3[2]												
MTBE Recovered Unit 3/Period (lbs.)	0.00	0.30	0.06	0.25	0.19	0.03	0.04	0.06	0.00	0.30	**0.00**	**0.00**
BTEX Recovered Unit 3/Period (lbs.)	0.00	1.05	1.14	0.96	0.34	0.24	0.15	0.10	0.00	0.84	0.38	0.26
Total MTBE Recovered Unit 3 (lbs.)	7.75	8.05	8.11	8.37	8.56	8.58	8.63	8.69	8.69	8.99	8.99	8.99
Total BTEX Recovered Unit 3 (lbs.)	4.91	5.96	7.09	8.06	8.40	8.64	8.79	8.89	8.89	9.73	10.11	10.38

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Table 1 Continued
Polyguard Pilot Test Three
Groundwater Treatment System - Two 7 ft³ and eight 3.2 ft³ Polyguard Columns and two 55-gal. GAC Units
BTEX & MTBE Analytes Detected in Treatment System Wastewater
(USEPA Method 8020)

Sampling Date	6/17/98	6/25/98	7/2/98	7/10/98	7/14/98	7/17/98	7/21/98	7/24/98	8/11/98	8/17/98	8/24/98	8/31/98
Laboratory Analytical Results												
MTBE Recovered ECS Unit 2/Period (l	0.00	0.13	**0.00**	0.27	0.05	**0.00**	0.01	0.05	0.00	**0.00**	0.00	0.20
BTEX Recovered ECS Unit 2/Period (lb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered ECS Unit 2 (lbs	0.00	0.13	0.13	0.41	0.46	0.46	0.47	0.52	0.52	0.52	0.52	0.72
Total BTEX Recovered ECS Unit 2 (lbs	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ECS Unit 4[5]												
MTBE Recovered ECS Unit 4/Period (l	0.00	0.02	0.58	0.43	0.12	0.13	0.10	0.06	0.00	0.21	0.16	0.12
BTEX Recovered ECS Unit 4/Period (lb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered ECS Unit 4 (lbs	0.00	0.02	0.60	1.04	1.15	1.29	1.38	1.45	1.45	1.66	1.83	1.94
Total BTEX Recovered ECS Unit 4 (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS Unit 7[6]												
MTBE Recovered ECS Unit 7/Period (l	0.00	0.08	1.11	1.23	0.32	0.26	0.20	0.16	0.00	1.01	0.44	0.26
BTEX Recovered ECS Unit 7/Period (lb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered ECS Unit 7 (lbs	0.00	0.08	1.19	2.42	2.74	3.00	3.20	3.36	3.36	4.36	4.81	5.07
Total BTEX Recovered ECS Unit 7 (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ECS Unit 8[7]												
MTBE Recovered ECS Unit 8/Period (l	0.00	0.00	0.06	0.16	0.08	0.07	0.07	0.06	0.00	0.29	0.12	0.34
BTEX Recovered ECS Unit 8/Period (lb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered ECS Unit 8 (lbs	0.00	0.00	0.06	0.22	0.30	0.36	0.43	0.49	0.49	0.78	0.90	1.24
Total BTEX Recovered ECS Unit 8 (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GAC Carbon Unit 1[8]												
MTBE Recovered GAC Unit 1/Period (	0.00	0.00	0.00	0.03	0.02	0.04	0.05	0.04	0.00	0.52	0.51	0.77
BTEX Recovered GAC Unit 1/Period (l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered GAC Unit 1 (lbs	0.00	0.00	0.00	0.03	0.05	0.09	0.14	0.18	0.18	0.70	1.21	1.97
Total BTEX Recovered GAC Unit 1 (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Contaminant Removal Totals												
MTBE Recovered by Polyguard /Perio	0.00	0.54	1.81	2.35	0.75	0.49	0.42	0.38	0.00	1.81	0.73	0.92
BTEX Recovered by Polyguard /Period	0.00	1.05	1.14	0.96	0.34	0.24	0.15	0.10	0.00	0.84	0.38	0.26
Total MTBE Recovered by Polyguard (	13.98	14.52	16.33	18.68	19.43	19.92	20.34	20.73	20.34	22.54	23.27	23.46
Total BTEX Recovered by Polyguard (l	9.95	10.99	12.13	13.10	13.44	13.68	13.83	13.93	13.83	14.77	15.15	15.04
MTBE Recovered by GAC /Period (lbs	0.00	0.00	0.00	0.03	0.02	0.04	0.05	0.04	0.00	0.52	0.51	0.77
BTEX Recovered by GAC /Period (lbs.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Recovered by GAC (lbs.)	0.00	0.00	0.00	0.03	0.05	0.09	0.14	0.18	0.18	0.70	1.21	1.97
Total BTEX Recovered by GAC (lbs.)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MTBE Discharged from GAC/Period (l	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BTEX Discharged from GAC/Period (lb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total MTBE Discharged from GAC (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total BTEX Discharged from GAC (lbs	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

NOTES:

BOLD Values are estimated not observed.

[1] Polyguard Unit 2 - Virgin Polyguard Installed in Second FRP Canister on October 27, 1998 and transferred into First FRP Canister on November 18, 1997, after sampling.

[2] Polyguard Unit 3 - Represents Virgin Polyguard Installed in Second FRP Canister on November 18, 1997, after sampling.

[3] ECS Unit 1 - Represents the 3.2 cubic foot polyguard column installed in May, 1998. Samples collected from ECS Unit 1 represent the effluent from the column.

[4] ECS Unit 2 - Represents the 3.2 cubic foot polyguard column installed in May, 1998. Samples collected from ECS Unit 2 represent the effluent from the column.

[5] ECS Unit 4 - Represents the 3.2 cubic foot polyguard column installed in May, 1998. Samples collected from ECS Unit 4 represent the effluent from column 4, after absorption in columns 3 & 4.

[6] ECS Unit 7 - Represents the 3.2 cubic foot polyguard column installed in May, 1998. Samples collected from ECS Unit 7 represent the effluent from column 7, after absorption in columns 5, 6, and 7.

[7] ECS Unit 8 - Represents the 3.2 cubic foot polyguard column installed in May, 1998. Samples collected from ECS Unit 8 represent the effluent from column 8, after absorption in column 8.

[5] GAC Unit - Represents Virgin GAC Unit Installed in May, 1998. Samples were collected from C-1 and C-2; however, no MTBE or BTEX was ever detected in the effluent from C-2.