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This technical memorandum summarizes the five-year results of natural attenuation treatability studies at 42 Air Force sites contaminated with fuel hydrocarbons. The main emphasis of the work described in this report was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, ethylbenzene, toluene, and xylenes concentrations in groundwater to levels that are protective of human health and the environment.

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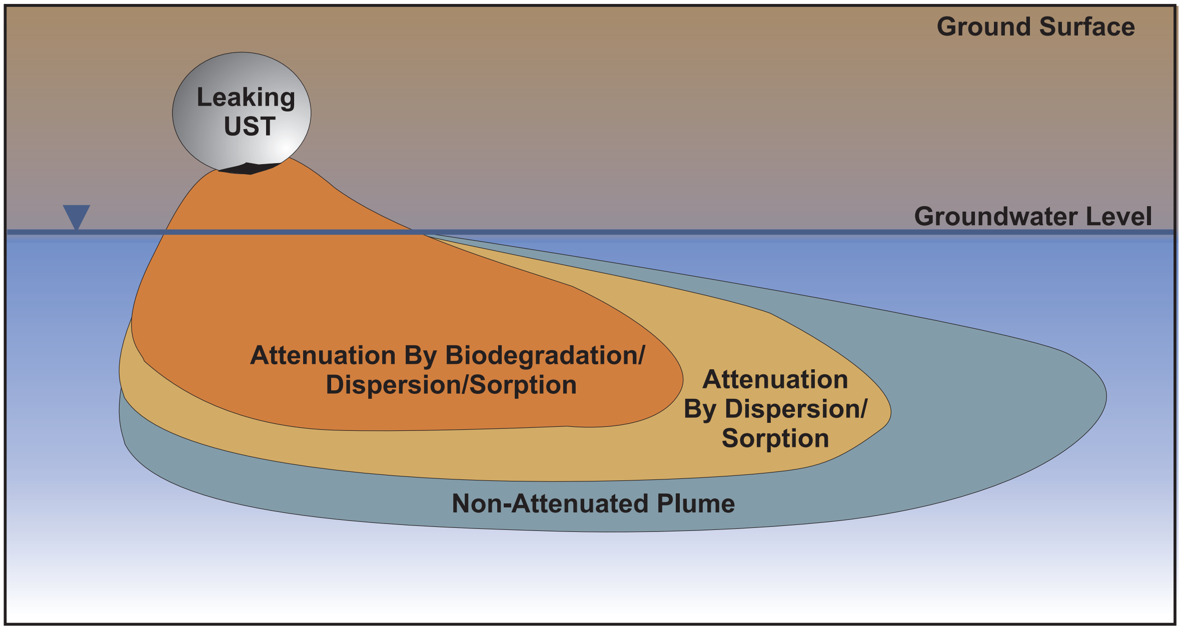
Natural Attenuation of Fuel Hydrocarbons Performance and Cost Results from Multiple Air Force Demonstration Sites

Technology Demonstration Technical Summary Report



Air Force Center
for Environmental Excellence

NATURAL ATTENUATION OF FUEL HYDROCARBONS
PERFORMANCE AND COST RESULTS FROM
MULTIPLE AIR FORCE DEMONSTRATION SITES

TECHNOLOGY DEMONSTRATION
TECHNICAL SUMMARY REPORT

October 1999

Prepared For

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TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

Appendix A - Summary Data Table for the Natural Attenuation of Fuel Hydrocarbons from Multiple Air Force Demonstration Sites

LIST OF TABLES

LIST OF FIGURES

TABLE OF CONTENTS (Continued)

LIST OF FIGURES (Continued)

EXECUTIVE SUMMARY

This technical memorandum summarizes the results of natural attenuation treatability studies (TSs) conducted at multiple United States (US) Air Force sites in the Continental US. In June 1993, the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT), in cooperation with the US Environmental Protection Agency National Risk Management Research Laboratory (USEPA/NRMRL), Subsurface Protection and Remediation Division and Parsons Engineering Science, Inc. (Parsons ES) began a major initiative to evaluate the effectiveness of monitored natural attenuation (MNA) for remediation of groundwater contaminated with fuel hydrocarbons. This 5-year study is nearing completion, and the results are summarized in this technical memorandum.

TEST OBJECTIVES

The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations in groundwater to levels that are protective of human health and the environment. The TSs were not intended to be contamination assessment reports or remedial action plans; rather, they were designed to provide scientific documentation of natural attenuation that could be used by individual Air Force bases and their prime environmental contractor(s) for future decision making regarding the subject sites. Specific objectives included:

- Developing site characterization techniques to more accurately document *in situ* geochemistry and to maximize the quantity and quality of collected field data while reducing overall expenditures of money and time;

- Providing a consistent framework for documenting historical contaminant reductions and geochemical patterns consistent with biodegradation, and determining rates of contaminant destruction;

- Identifying those biological processes most responsible for contaminant attenuation in varied subsurface environments;

- Using analytical or numerical groundwater flow and solute fate and transport models to predict the effects of natural attenuation, both alone and in combination with engineered remedial technologies, on the future migration and persistence of dissolved BTEX;

- Evaluating strategies for using MNA as the sole remedial approach or in combination with other remedial techniques; and

- Developing long-term monitoring (LTM) strategies to verify the progress of natural attenuation over time until appropriate action levels are attained.

RESULTS AND CONCLUSIONS

- Dissolved BTEX compounds are undergoing natural attenuation at all 42 Air Force test sites representing a broad range of environmental conditions.

- Most of the dissolved BTEX plumes investigated were evaluated to be either stable or receding.

- The average relative contribution of each primary biodegradation process to the total assimilative capacity of the groundwater system decreased in the following order: sulfate reduction, methanogenesis, iron reduction, denitrification, and aerobic oxidation. The total BTEX assimilative capacity of groundwater averaged 64 milligrams per liter.

- The field-scale first-order biodegradation rate constants ranged from 0.0002 to 0.08 per day (day^{-1}), with a geometric mean value of 0.0019 day^{-1}.

- There was some correlation between field biodegradation rates and groundwater velocity; correlations between biodegradation rates and groundwater temperature, assimilative capacity, and plume length were not apparent.

- The average predicted time frame for dissolved BTEX to naturally attenuate below state or federal groundwater cleanup standards is conservatively estimated at approximately 30 years. More aggressive, engineered source reduction typically is required to attain cleanup standards in less than 20 years.

- The average cost per site for completing Geoprobe® site characterization, laboratory analysis, data analysis, fate and transport modeling, and reporting was $125,000. Slightly higher costs were incurred at sites where conventional auger drilling was required due to groundwater depth.

- Recommended LTM programs for MNA included an average network of 11 wells, and had an average annual cost of $192,000.

RECOMMENDATION

Due to the ubiquitous occurrence of microbial degradation of dissolved BTEX, all remedial contractors working for the Department of Defense should consider MNA as a primary groundwater remedial option for fuel-contaminated sites. In many cases, source reduction technologies also should be evaluated to determine how they would limit plume migration and/or accelerate attainment of target cleanup levels.

In most cases, migration of dissolved BTEX plumes is sufficiently restricted by natural attenuation that downgradient receptors will not be adversely affected by the plume. In addition, institutional controls can be implemented at many site in commercial/industrial areas (particularly on military installations) to eliminate the potential for receptor exposure pathway completion prior to remediation by natural attenuation. Based on these findings, there should be strong justification of the use of engineered remediation systems for the remediation of BTEX plumes.

SECTION 1

INTRODUCTION

1.1 SCOPE

This technical memorandum summarizes the results of natural attenuation treatability studies (TSs) conducted at multiple United States (US) Air Force sites in the Continental US. In June 1993, the Air Force Center for Environmental Excellence, Technology Transfer Division (AFCEE/ERT), in cooperation with the US Environmental Protection Agency National Risk Management Research Laboratory (USEPA/NRMRL), Subsurface Protection and Remediation Division and Parsons Engineering Science, Inc. (Parsons ES), began a major initiative to evaluate the effectiveness of monitored natural attenuation (MNA) for remediation of groundwater contaminated with fuel hydrocarbons. The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX) concentrations in groundwater to levels that are protective of human health and the environment. This 5-year study is nearing completion, and the results are summarized in this cost and performance technical memorandum.

1.2 OVERVIEW OF NATURAL ATTENUATION

Natural attenuation refers to the decrease of groundwater contaminants by natural physical, chemical, and biological processes. More recently, the term monitored natural attenuation (MNA) has been used to refer to the use of naturally occurring attenuation processes to aid in overall site remediation. The United States Environmental Protection Agency (USEPA, 1999) Office of Solid Waste and Emergency Response (OSWER) defines MNA as:

> *the reliance on natural attenuation processes (within the context of a carefully controlled and monitored clean-up approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other, more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil and groundwater. These in-situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants.*

It should be noted that, when relying on natural attenuation processes, the USEPA prefers those processes that degrade or destroy contaminants. In addition, the USEPA generally expects that MNA will be appropriate for sites that have a low potential for contaminant migration.

As early as 1950, Zobell (1950) discovered that aliphatic hydrocarbons are susceptible to microbial degradation processes. Subsequent laboratory research by other scientists described biodegradation mechanisms for the more complex branched alkanes, cycloalkanes, and aromatics. However, it was not until the mid-1980s that scientists obtained evidence that petroleum hydrocarbons could be biodegraded under both aerobic and anaerobic subsurface conditions. This discovery sparked a rapidly growing interest in both understanding and documenting environmental mechanisms controlling natural hydrocarbon degradation.

By the early to mid-1990s, several empirical studies were available to show the beneficial effects of natural contaminant attenuation, primarily through the process of biodegradation. Of more than 1,000 fuel spill sites reviewed by Lawrence Livermore National Laboratory (LLNL), only 8 percent of the resulting groundwater plumes were expanding. The vast majority of these plumes were stable and were less than 250 feet long (Rice *et al.*, 1995). In 1997, the University of Texas (1997) published a detailed statistical analysis of 605 Texas sites with petroleum-hydrocarbon-contaminated groundwater. The results fully supported the findings of the LLNL study. Benzene plumes of less than 250 feet were observed at 75 percent of the sites, and only 3 percent of the plumes were determined to be increasing in length. Although 60 percent of the sites had public or domestic wells within a 0.5-mile radius, less than 5 percent were posing an immediate threat to public health. Natural attenuation and low aquifer permeability are effectively remediating the majority of petroleum generated groundwater plumes at the 605 Texas sites.

MNA provides nonintrusive groundwater remediation, and avoids the transfer of groundwater contaminants to another phase or location in the environment, as may occur with some conventional engineered treatment techniques. MNA generally is less costly than engineered remedial technologies and often is equally protective of human health and the environment on most sites. However, long-term monitoring (LTM) and land use control measures typically are required to ensure continuous protection of human health and potential ecological receptors.

The intent of the Air Force natural attenuation initiative is to comprehensively document the effectiveness of natural attenuation, and to promote the use of MNA to cost-effectively achieve cleanup and closure of fuel spill sites at Air Force facilities. The procedures for documenting natural attenuation of dissolved fuel constituents were formalized in the *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater* (AFCEE, 1995). Currently, at least 44 states and all 10 USEPA regions will consider the use of MNA as a viable remedy for fuel-contaminated groundwater. However, if free product is present, source control may be required before MNA is approved as a part of the final remedy.

1.3 DEMONSTRATION SITE LOCATIONS

Between July 1993 and December 1998, natural attenuation treatability studies (TSs) for fuel hydrocarbons were completed at 42 Air Force fuel-contaminated sites in 22 states within all 10 USEPA regions (Figure 1.1). Sites with a wide variety of environmental and contaminant conditions were investigated, including:

- Site locations ranging from Alaska to Florida;
- Depths to groundwater ranging from 0 to 48 feet below ground surface (bgs);
- Plume areas ranging from 0.3 to 60 acres;
- Average groundwater temperatures ranging from 5.5 to 26.9 degrees Celsius (°C); and
- Soil types ranging from silty clay to coarse sand and gravel.

All 42 sites were evaluated for natural attenuation trends according to the procedures outlined in the technical protocol document (AFCEE, 1995). Seven of the 42 sites were evaluated under the AFCEE risk-based remediation program that incorporates MNA into risk-based site closure strategies (Downey, 1998). Data from these seven sites are included in this summary report to broaden the available database. The seven sites evaluated under the AFCEE risk-based remediation program are identified in Table I of Appendix A with the acronym RBCA (Risk-Based Corrective Action). Groundwater contamination is directly discharging to streams, canals, and other surface water bodies to which receptors may be exposed at only 6 of the 42 sites. The remaining 36 sites have groundwater plumes that pose no current or future threat to receptors based on current and projected groundwater use. To date, formal regulatory acceptance of MNA, either alone or in combination with engineered remedial actions (primarily low-cost, *in situ* source reduction actions), has been obtained for approximately 17 of the 42 sites (Table 1.1).

FIGURE 1.1
AIR FORCE NATURAL ATTENUATION INITIATIVE LOCATIONS
As of September 1999

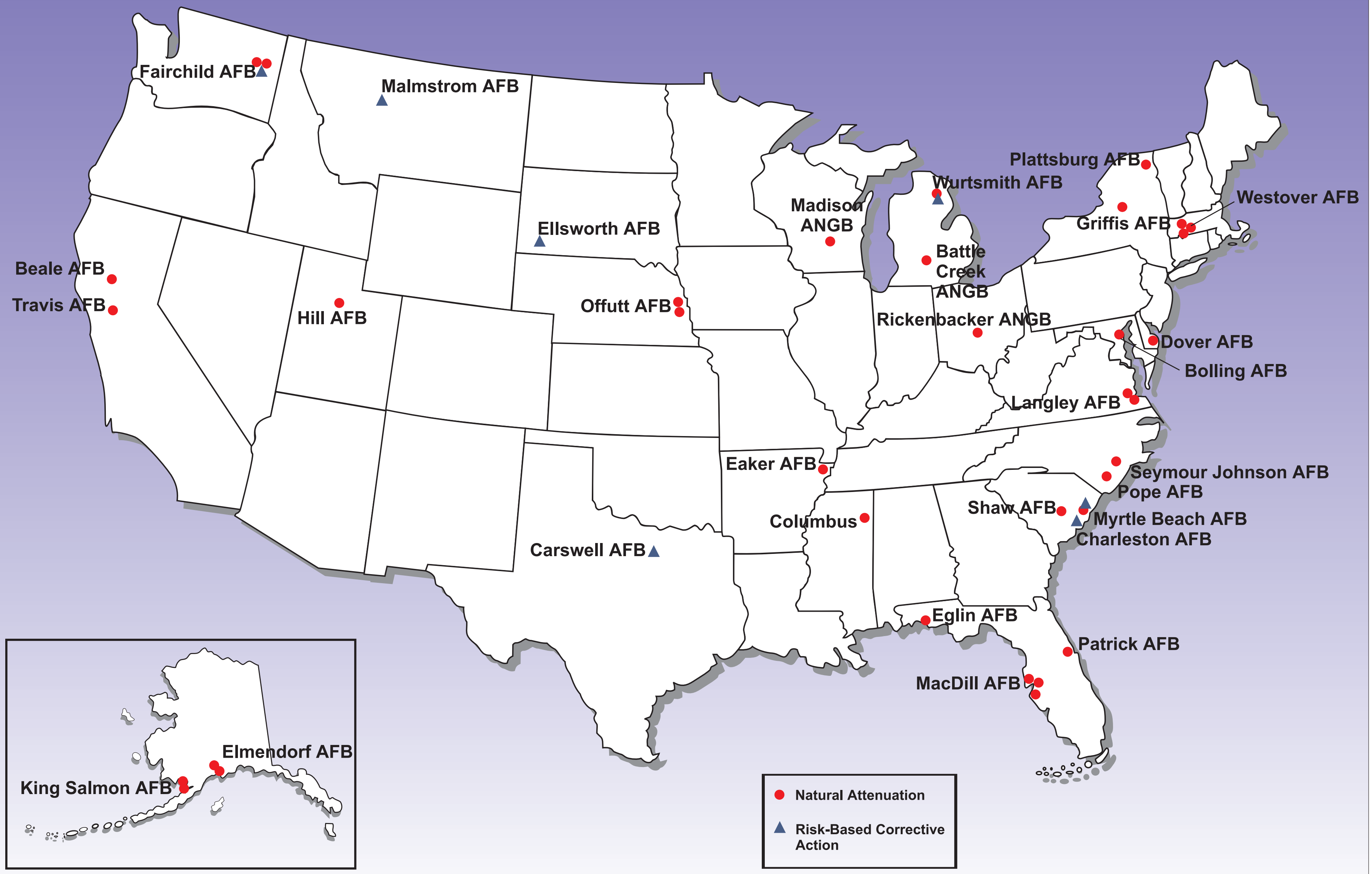

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TABLE 1.1
SITES WITH REGULATORY ACCEPTANCE OF MNA AS A COMPLETE OR PARTIAL REMEDIAL ACTION

Base and Site	City and State
Carswell AFB, ST-14	Fort Worth, Texas
Charleston AFB, ST-27	Charleston, South Carolina
Eaker AFB, BX Shoppette	Blytheville, Arkansas
Ellsworth AFB, Area D	Rapid City, South Dakota
Elmendorf AFB, Hangar 10	Anchorage, Alaska
Elmendorf AFB, Site ST-41	Anchorage, Alaska
Fairchild AFB, West Defuel	Spokane, Washington
Langley AFB, Site SS04	Hampton, Virginia
Langley AFB, Site SS16	Hampton, Virginia
Malmstrom AFB, Pumphouse #2	Great Falls, Montana
Myrtle Beach, MOGAS Site	Myrtle Beach, Florida
Plattsburgh AFB, FT-002	Plattsburg, New York
Rickenbacker ANGB, Building 560	Columbus, Ohio
Westover ARB, Zone 1	Chicopee, Massachusetts
Wurtsmith AFB, KC-135	Oscoda, Michigan
Wurtsmith AFB, OT-41	Oscoda, Michigan
Wurtsmith AFB, SS-42	Oscoda, Michigan

SECTION 2

TREATABILITY STUDY PROTOCOL

The six primary tasks described below were performed for each natural attenuation TS site. Parsons ES performed the majority of this work, with assistance from the USEPA/NRMRL (field data collection and laboratory analyses) and the US Army Corps of Engineers (USACE) (cone penetrometer support).

- Each TS began with a site meeting and an MNA briefing among Base officials and concerned regulatory agencies. At that time, pertinent site-related documents and data files were identified.
- A site-specific work plan was prepared describing the TS methods and goals.
- Site investigation activities were performed to fill data gaps related to the nature and extent of soil and groundwater contamination and groundwater geochemical conditions. Rapid, low-cost soil and groundwater sampling was performed using a Geoprobe® or cone penetrometer testing (CPT) to locate contaminant source areas and install small-diameter groundwater monitoring points. The cone penetrometer was equipped with laser-induced fluorescence (LIF) to aid in identifying high concentrations of fuel residuals.
- Groundwater monitoring wells and points were sampled for contaminant concentrations, and physical and geochemical biodegradation indicator parameters (pH, temperature, conductivity, oxidation/reduction potential [ORP], dissolved oxygen [DO], nitrate, nitrite, sulfate, sulfide, ferrous iron, total iron, methane, carbon dioxide [CO_2], and alkalinity). If necessary, surface water samples were collected to assess the impact of groundwater discharge on surface water quality. Slug tests were performed to estimate aquifer hydraulic conductivity.
- Soil samples were analyzed for total organic carbon in order to calculate the fraction of organic carbon (f_{oc}).
- Geochemical trends and biodegradation rates were evaluated to assess the impact of natural attenuation on contaminant fate and transport. Groundwater models such as Bioplume II (Rifai *et al.*, 1987) and Bioscreen (Newell *et al.*, 1997) were applied to predict future migration trends for contaminant plumes under the influence of natural attenuation processes, both alone and combined with engineered source reduction and/or hydraulic containment.
- The cost, effectiveness, and implementability of MNA, both alone and in combination with engineered remediation technologies, were assessed. In addition, an LTM plan was developed. At many sites, natural attenuation processes had stabilized the groundwater plume, but engineered source remediation was recommended to reduce the duration and cost of LTM.

SECTION 3

TREATABILITY STUDY RESULTS

The results of the TSs indicated that natural attenuation was decreasing the mass of dissolved contamination at all 42 demonstration sites. The susceptibility of dissolved BTEX to natural biodegradation is not surprising, because microbial degradation of gasoline, kerosene, diesel, and jet fuel has been documented in hundreds of laboratory and pilot scale studies. However, the consistency of hydrocarbon attenuation over such a broad range of sites, some with less-than-optimal environmental conditions, was unexpected. A summary of initial site conditions and their influence on natural attenuation is provided in this section.

3.1 PLUME BEHAVIOR

The most direct and convincing evidence for natural attenuation is historical groundwater data showing stabilization or decline of dissolved contaminant concentrations. At least two sets of groundwater quality data were available for 30 of the 42 MNA test sites. Historic plume analyses indicate that 87 percent of the 30 groundwater plumes were either stable or receding. Fate and transport model predictions for the 12 sites without historical data suggested that most of these plumes also were stabilized. In summary, 35 groundwater BTEX plumes appeared to be stable (e.g., the plume size remained the same) and 6 were receding. Of the stabilized plumes, 13 had decreasing dissolved BTEX concentrations in the interior of the plume, and 3 had increasing concentrations. Only one site exhibited an expanding groundwater plume. Sites with expanding plumes or increasing concentrations tend to have had relatively recent fuel releases, and dissolved contamination may not yet spread out over a large enough area to reach steady-state conditions.

3.2 GEOCHEMISTRY AND BTEX ASSIMILATIVE CAPACITY

Natural contaminant biodegradation causes geochemical changes in the groundwater system as a result of the fuel hydrocarbon being utilized as a primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors common to most groundwater systems include DO, nitrate, ferric iron, sulfate, and CO_2. These compounds can easily be detected in groundwater, and their depletion, coupled with the accumulation of reaction byproducts (ferrous iron and methane), provides evidence regarding the preferred microbial pathways for contaminant biodegradation. For instance, high background DO concentrations upgradient from a contaminant plume and low DO concentration in the plume interior indicate that aerobic biodegradation of fuel hydrocarbons has occurred at the site. The "assimilative capacity" of the groundwater system can be computed by converting the relative mass of individual electron acceptors available for utilization by bacteria at a site into the mass of BTEX that could be consumed during the biodegradation reaction. The assimilative capacity identifies the contaminant mass that can theoretically be oxidized as one pore-volume of groundwater travels through the plume core.

The assimilative capacity values presented in the TS reports and summarized in this document represent the apparent electron acceptor utilization at the site based on differences between background and plume core concentrations of electron acceptors and metabolic byproducts. For example, if the background and plume core sulfate concentrations were 100 mg/L and 50 mg/L, respectively, the apparent sulfate utilization was 50 mg/L, although the theoretical total assimilative capacity was 100 mg/L. Most (approximately 70 percent or greater) of the apparent electron acceptor utilization is believed to be related to BTEX oxidation, with the remainder resulting from the oxidation of non-BTEX organics (Newell et al., 1997).

Figure 3.1(a) shows the average relative contribution of each primary biodegradation process to the total assimilative capacity of site groundwater, based on data from the 42 TS sites. The data indicate that sulfate reduction was the most prominent biodegradation process. However, it should be noted that the high percentage of assimilative capacity attributed to sulfate reduction is largely due to very high sulfate concentrations (>200 milligrams per liter [mg/L]) measured at 5 of the TS sites. Sulfate reduction was the predominant biological attenuation mechanism at 17 of the 42 test sites. Methanogenesis also was an important dissolved BTEX attenuation process, and was the predominant biological attenuation mechanism at 19 of the 42 test sites (Figure 3.1[b]). The relative importance of the remaining biological attenuation processes decreased in the following order: iron reduction, denitrification, and aerobic oxidation. The data indicate that as much as 97 percent of the assimilative capacity of the groundwater systems may be attributed to the influence of anaerobic biodegradation processes.

The total BTEX assimilative capacity computed for the TS sites ranged from 23 mg/L to 892 mg/L and averaged 64 mg/L. Sixty-seven percent of all sites had assimilative capacities that exceeded the maximum observed dissolved BTEX concentration. Three of the four groundwater plumes that had increasing BTEX concentrations also had below average assimilative capacities, indicating the importance of electron acceptor availability in limiting plume advancement. However, it should be noted that the assimilative capacity is not a measure of the rate at which BTEX constituents are biodegraded. This is dependent on the kinetics of the biodegradation reactions.

3.3 FIELD BIODEGRADATION RATES

Estimation of field-scale biodegradation rate constants is necessary to predict the fate and transport of contaminants dissolved in groundwater. In many cases, field-scale biodegradation of fuel hydrocarbon contaminants can be approximated using first-order kinetics. In order to calculate first-order field biodegradation rate constants, the apparent degradation rate must be normalized for the effects of dilution, sorption, and volatilization. Several methods for estimating first-order biodegradation rates are available:

Figure 3.1(a)
Average Relative Contributions of BTEX Biodegradation Processes In Site Groundwater

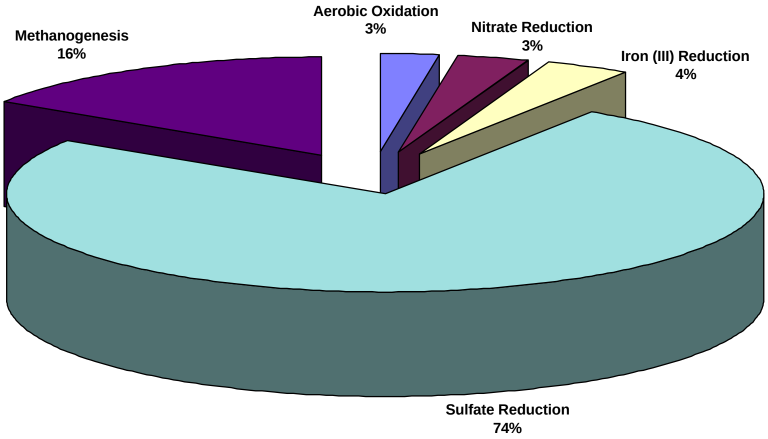
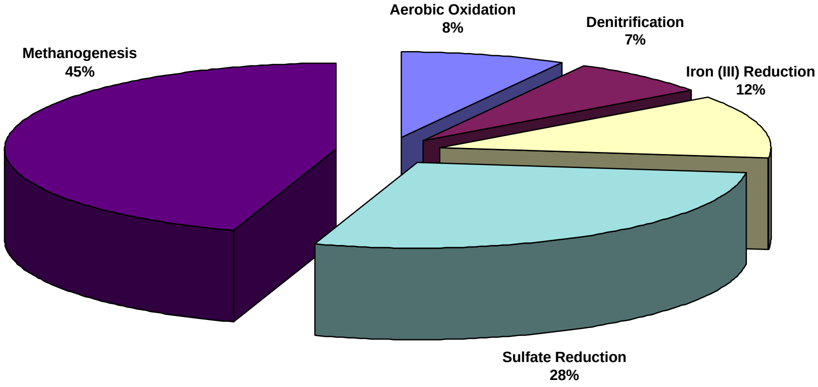


Figure 3.1(b)
Average Relative Contributions of BTEX Biodegradation Processes In Site Groundwater
(Excluding 5 Sites With > 200 mg/L Sulfate Reduction Capacity)



- Use of a biologically recalcitrant compound, which acts as a conservative tracer (AFCEE, 1995);
- Use of the one-dimensional, steady-state analytical solution to the advection-dispersion equation presented by Bear (1979) (Buscheck & Alcantar, 1995); and
- Use of analytical or numerical groundwater models, where the biodegradation rate is adjusted during model calibration to accurately simulate a measured plume.

Field biodegradation rates were estimated using a combination of these techniques, and results are summarized below:

- Field biodegradation rates for dissolved BTEX plumes ranged over three orders of magnitude, from 0.0002 to 0.08 day^{-1} (half-lives of 9.5 to 0.02 years, respectively). Figure 3.2 shows the frequency distribution of observed field biodegradation rates. The geometric mean of the field biodegradation rates was 0.0019 day^{-1} (half-life of 1 year).
- In laboratory experiments, rates of microbial production have been shown to increase by a factor of two for every 10°C increase in temperature (Atlas, 1988). This trend was not observed at the 42 test sites, where average groundwater temperatures ranged from 5.5°C to 26.9°C. Figure 3.3 indicates that temperature did not significantly influence biodegradation rates. The lack of correlation between field biodegradation rates and groundwater temperature supports the observation that each site appears to have a microbial community adapted to efficiently degrade fuels at the site-specific temperature range.

- Figure 3.4(a) represents the combined assimilative capacity attributable to aerobic biodegradation, denitrification, iron reduction, sulfate reduction, and methanogenesis versus biodegradation rates. Biodegradation rates do not correlate well with assimilative capacity, indicating that total assimilative capacity is not a reliable indicator of the biodegradation rate. Figures 3.4(b) to 3.4(f) represent separate comparisons of biodegradation rates to assimilative capacity for aerobic biodegradation, denitrification, iron reduction, sulfate reduction, and methanogenesis. Similar to Figure 3.4(a), no clear correlations are observed between specific biological assimilative capacity and biodegradation rate.
- Biodegradation rates equal to or greater than 0.003 day^{-1} were estimated for contaminated aquifers where groundwater velocities exceeded 300 feet per year (ft/yr), as shown on Figure 3.5. This suggests that remediation by natural attenuation (RNA) can be an effective remediation alternative at sites characterized by rapid groundwater velocities. At these sites, electron-acceptor-enriched groundwater sweeps through the source area at a relatively rapid rate, contributing to the reduction of the source. For example, natural attenuation processes were sufficient to stabilize the dissolved BTEX plume at Hill AFB

Figure 3.2 Estimated BTEX Biodegradation Rates

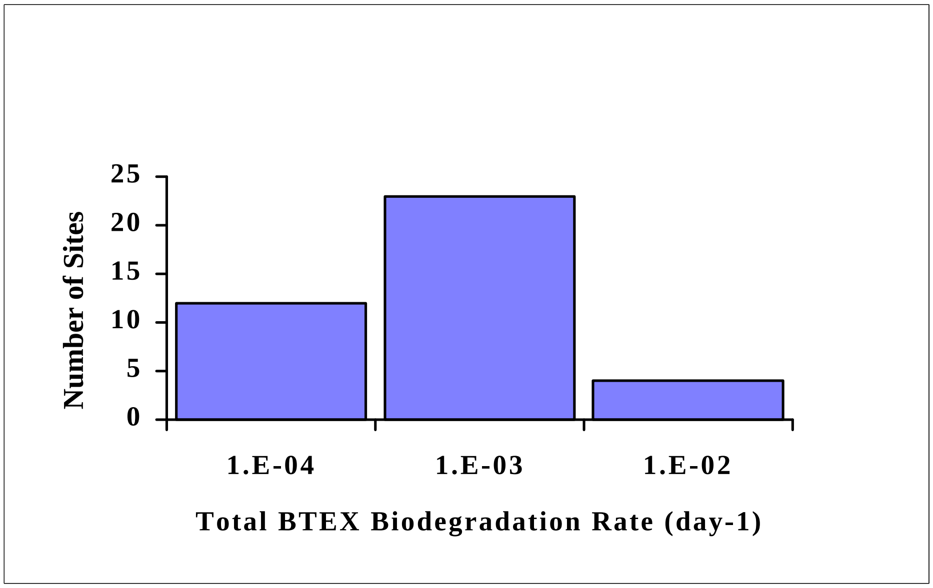


Figure 3.3 Average Biodegradation Rates versus Groundwater Temperature

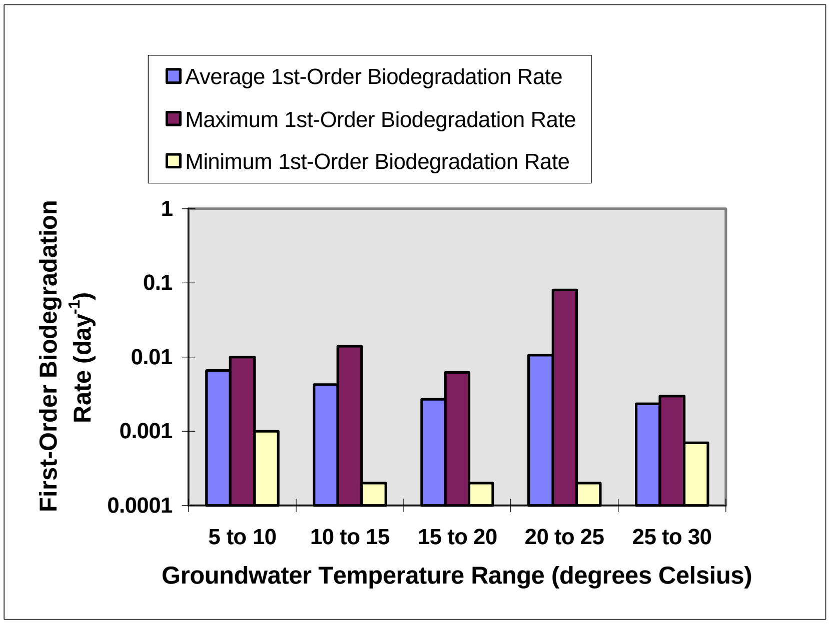


Figure 3.4(a) Biodegradation Rate versus Total Assimilative Capacity

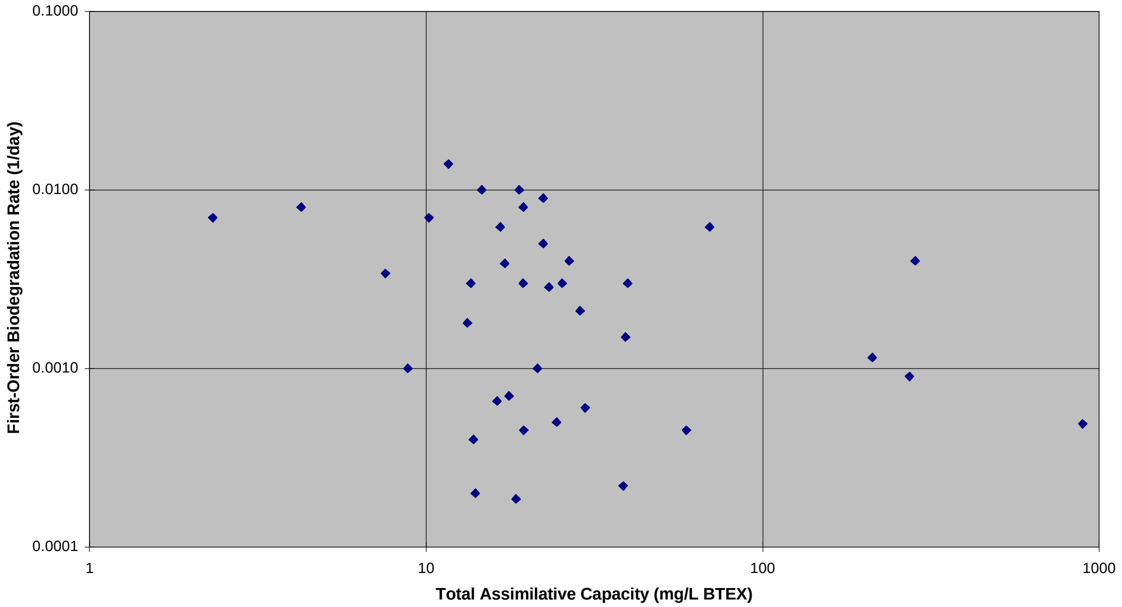


Figure 3.4(b) BTEX Biodegradation Rate vs. Aerobic BTEX Assimilative Capacity

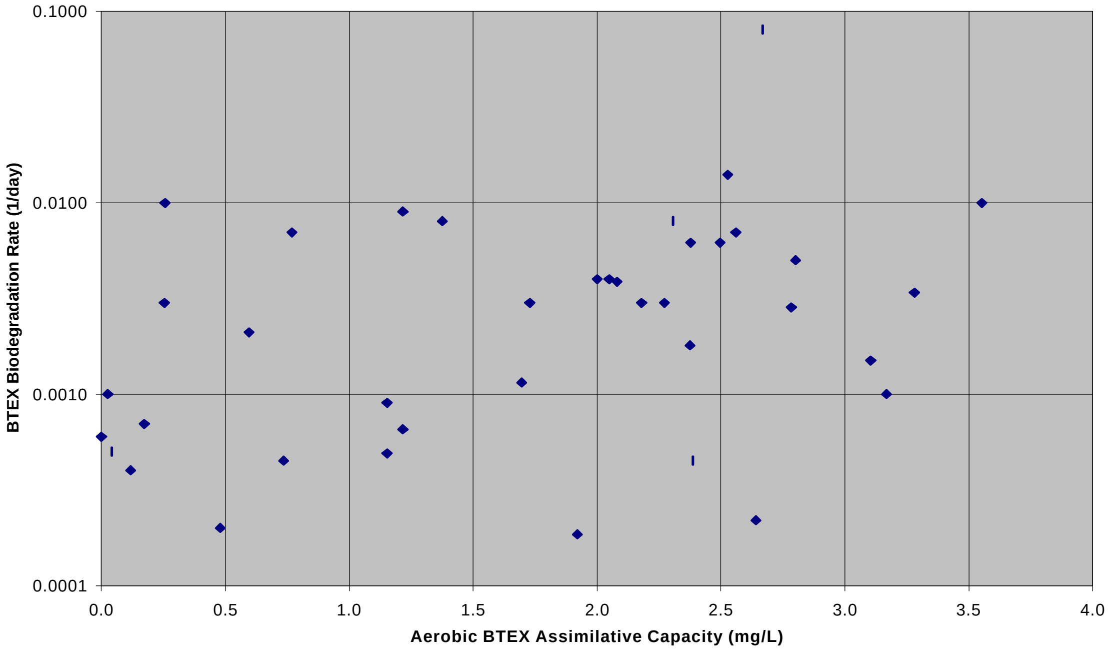


Figure 3.4(c) BTEX Biodegradation Rate vs. Denitrification Assimilative Capacity

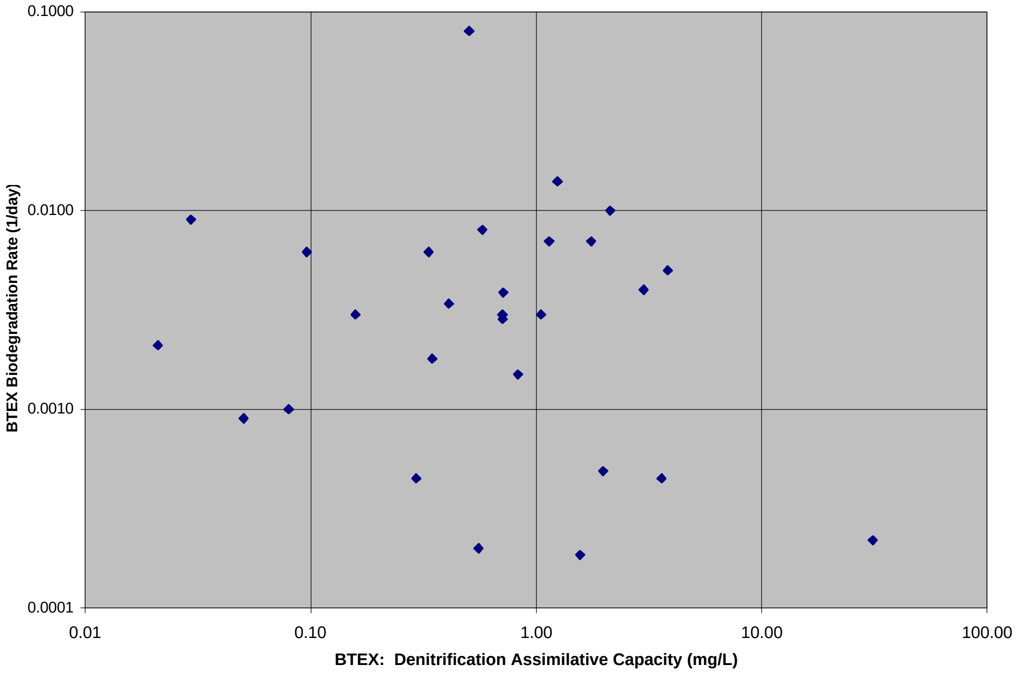


Figure 3.4(d) BTEX Biodegradation Rate vs. Iron III Assimilative Capacity

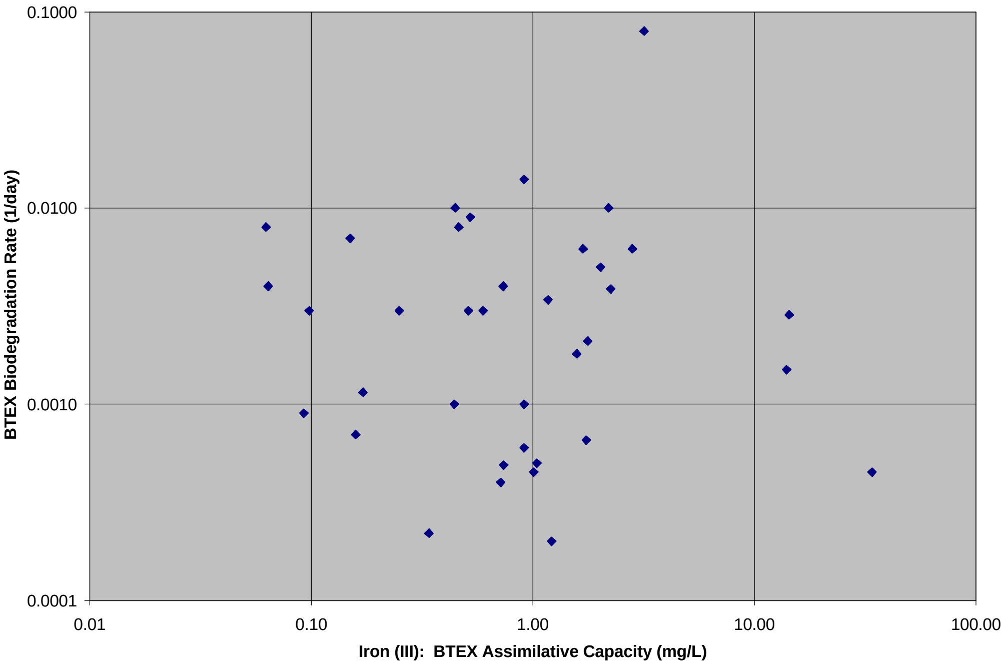


Figure 3.4(e) BTEX Biodegradation Rate vs. Sulfate Reduction Assimilative Capacity

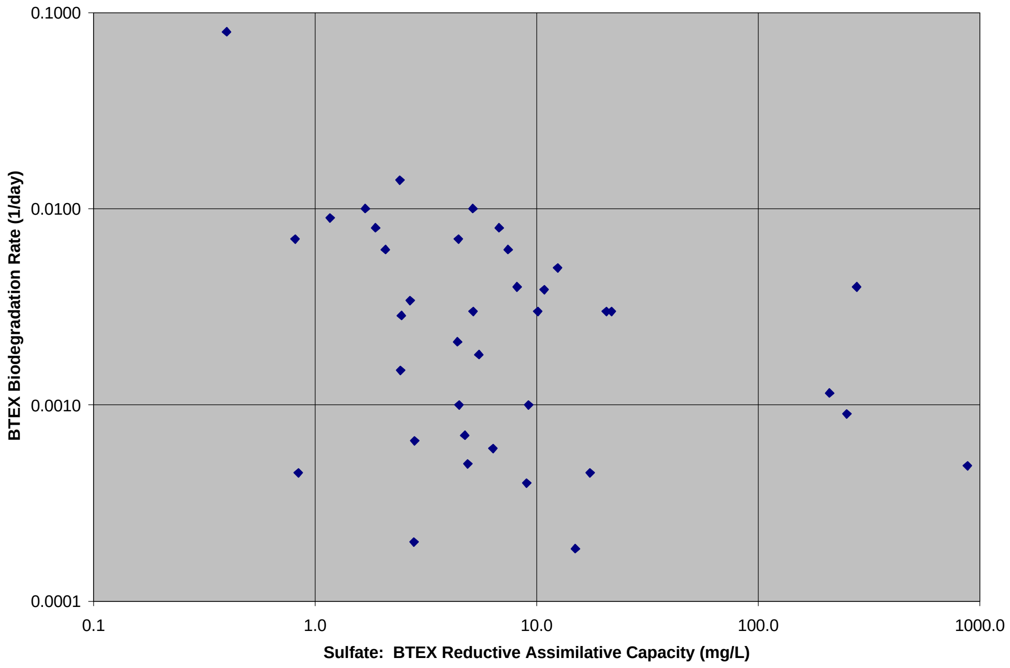


Figure 3.4(f) BTEX Biodegradation Rate vs. Methane Assimilative Capacity

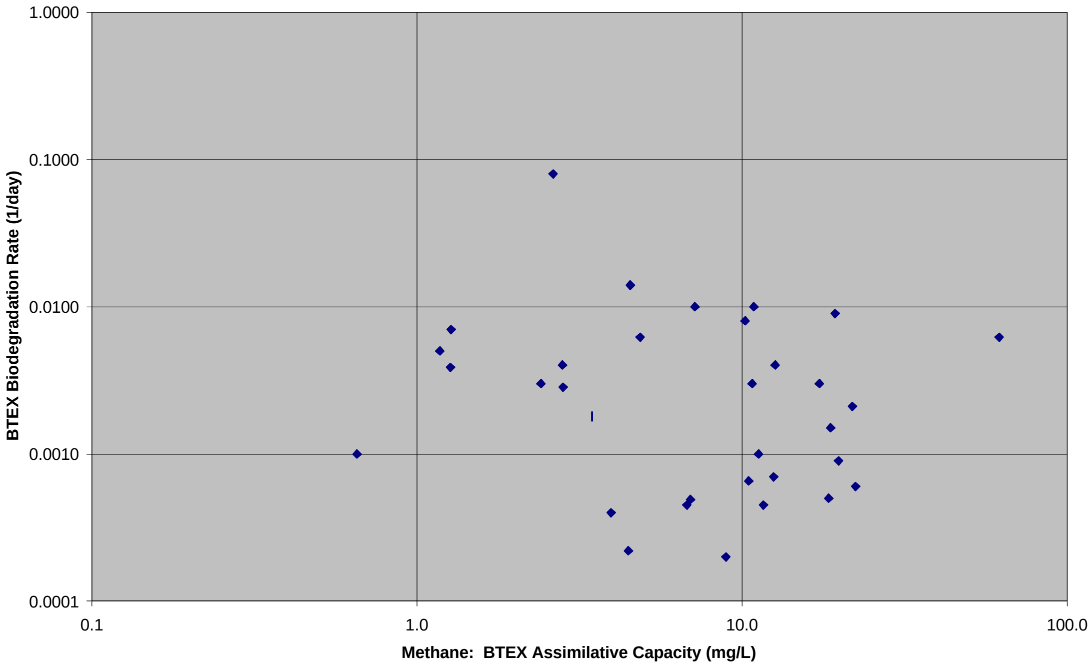
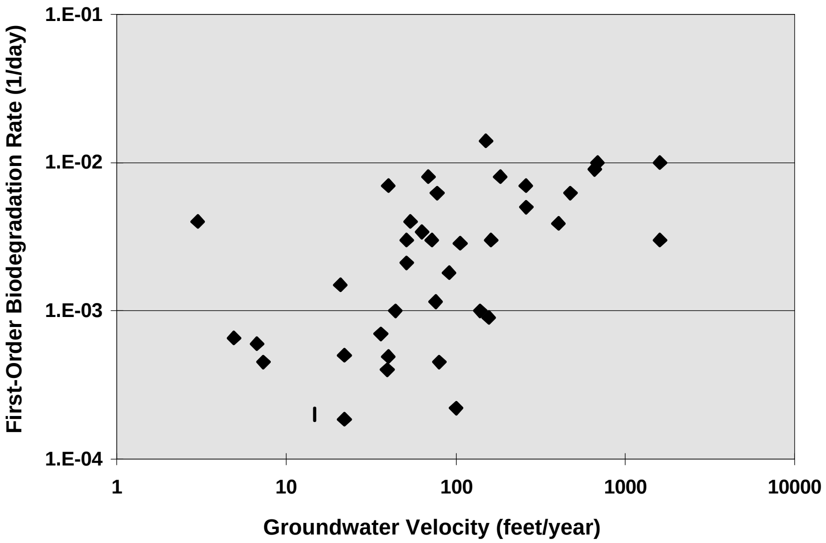


Figure 3.5 Biodegradation Rate versus Groundwater Velocity



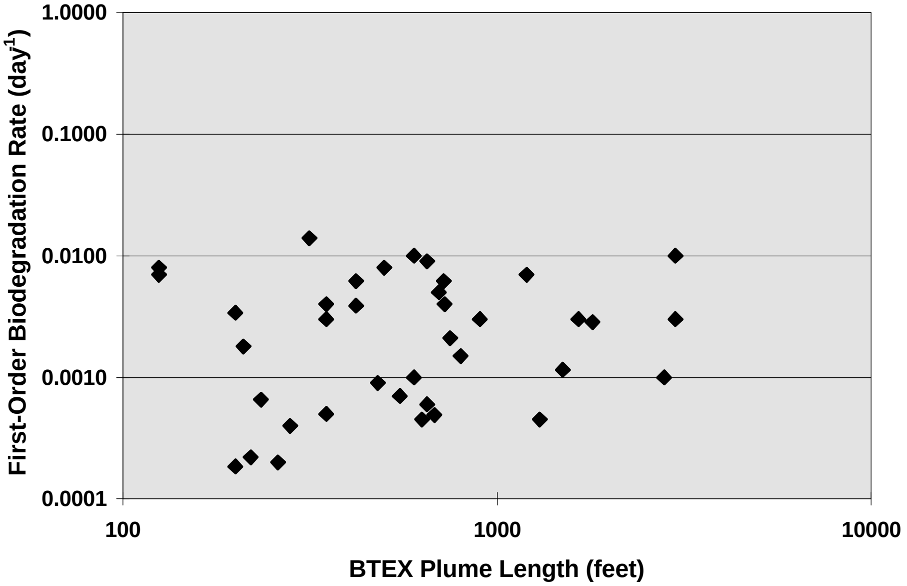
underground storage tank (UST) Site 870 prior to off-Base migration, despite a relatively high groundwater velocity (see Section 4.1).

- Biodegradation rates were compared to plume length with the assumption that higher rates would result in shorter plumes (Figure 3.6). However, this correlation is not evident, indicating that other factors, such as contaminant concentrations, soil type, and groundwater velocity, may influence plume length to a greater degree.

3.4 MODELING RESULTS

Groundwater modeling was performed for 39 of the 42 demonstration sites. The two-dimensional (2-D) groundwater flow and solute fate and transport model Bioplume II (Rifai *et al.*, 1987) was used for 32 study sites to predict natural attenuation trends and support development of LTM plans. One site had sufficiently complex hydrogeology to warrant the construction of a three-dimensional (3-D) numerical model using MODFLOW (McDonald & Harbough, 1988) and MT3D (S.S. Papadopulous & Associates, Inc., 1996). One-dimensional fate and transport models (Bioscreen [Newell *et al.*, 1997], ONED3 (Beljin, 1991), and analytical solutions by van Genuchten and Alves [1982]) were used for the remaining sites. Simulation results indicate that the models are most sensitive to field biodegradation rates and hydraulic conductivity. Given the widespread acceptance of the effectiveness of natural attenuation for fuel hydrocarbons dissolved in groundwater, simple analytical models generally are adequate to predict the future migration and persistence of BTEX contamination at a

Figure 3.6 First-Order Biodegradation Rate versus BTEX Plume Length



site. However, if significant aquifer heterogeneity exists, either laterally or vertically, use of a 2- or 3-D numerical model may be warranted. In addition, the nature of potential receptors may influence the selection of a model. For example, accurate simulation of an active water supply well and its accompanying cone of depression may require the use of a numerical model. Also, simulation of the source term and the effects of engineered remedial actions is often easier and more precise using numerical models.

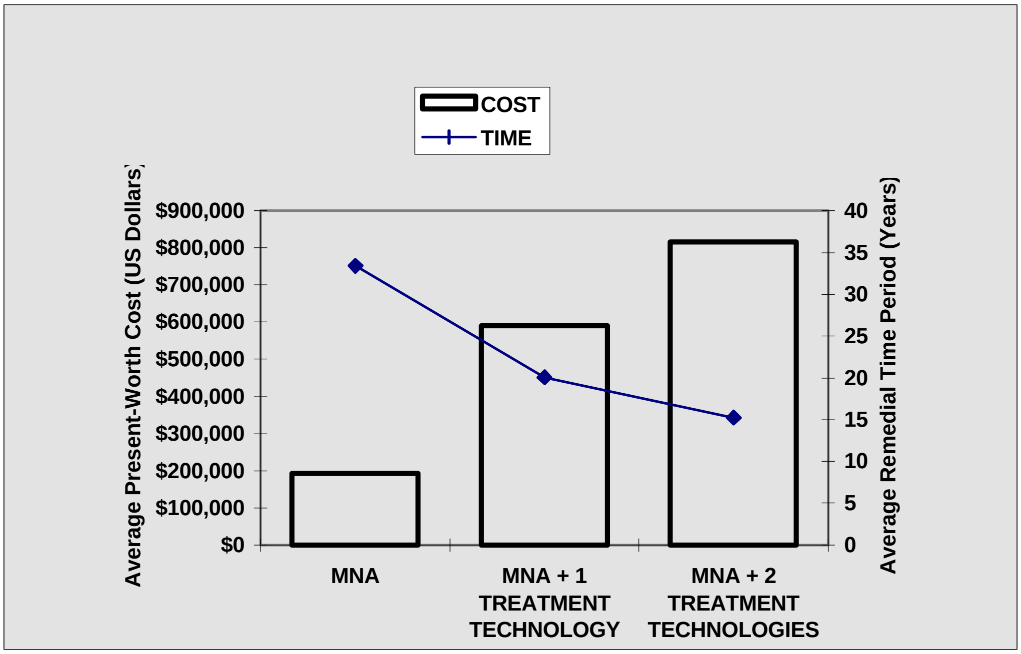
3.5 PROPOSED REMEDIAL ALTERNATIVES

Natural attenuation processes at 8 of the 42 sites were sufficient to achieve site remediation within a reasonable time frame. At these 8 sites, MNA in combination with institutional controls was proposed as the sole remedial alternative. The regulatory community has approved the partial or full use of MNA with institutional controls at 17 of the 42 study sites. Measurable free-phase product was present in monitoring wells at approximately 19 sites; the recommended remedial alternative for these sites generally consisted of MNA and institutional controls for plume remediation and low-cost source removal technologies such as free-product wicking, bioslurping, soil vapor extraction (SVE), and/or bioventing. A combination of MNA and engineered source reduction typically was recommended in cases where surface water bodies or groundwater receptors either were impacted or could be impacted in the future, or when the costs of MNA were expected to exceed the costs of short-term engineered source reduction followed by a shorter LTM period. The average estimated length of time required for natural attenuation to achieve state or federal groundwater quality standards for BTEX without engineered remediation was approximately 30 years, based on conservative modeling assumptions (Figure 3.7). The addition of engineered source reduction using free-product recovery and/or removal of residual soil contaminants reduced the average estimated LTM period to 20 years. More aggressive remediation (e.g., excavation of source area soils or combined source reduction and groundwater pumping) reduced the average estimated LTM period to 14 years, but increased the estimated remediation cost significantly.

3.6 LONG-TERM MONITORING

A network of LTM and point-of-compliance (POC) wells was recommended at each demonstration site to monitor natural attenuation trends and to protect downgradient receptors. The recommended number of LTM and POC wells ranged from 5 to 22 and averaged 11. Sampling frequencies recommended for these sites ranged from quarterly to biennial; however, annual sampling was recommended most frequently. The recommended duration of LTM for all test sites averaged 22 years.

Figure 3.7 Time and Cost Relationships for Remedial Alternatives



SECTION 4

NATURAL ATTENUATION CASE STUDIES

The following case studies summarize site investigation methods, data analysis procedures, modeling results, and proposed remedial alternatives at representative sites characterized by a variety of hydrogeologic and chemical conditions. Detailed results for each site are available in the site-specific TS reports.

4.1 HILL AIR FORCE BASE, UTAH, UST SITE 870

4.1.1 Site Description

Site 870 contained a leaking 1,000-gallon underground storage tank (UST) located at a Hill Air Force Base (AFB) fuel tank farm; the UST was used to store condensate and off-specification jet propulsion fuel - grade 4 (JP-4). The quantity of product released at UST Site 870 is not known. Site geology primarily consists of silty and clayey sand and sand, with dissolved contaminants migrating through a sandy, unconfined aquifer. The water-table elevation drops by at least 80 feet across the site, resulting in an average estimated groundwater velocity of 1,600 ft/yr. Groundwater depth ranges from 5 to 25 feet bgs. The nearest downgradient receptor is a storm sewer located approximately 1,600 feet downgradient from the source area; the sewer discharges to a stormwater holding pond.

4.1.2 Extent and Magnitude of Contamination

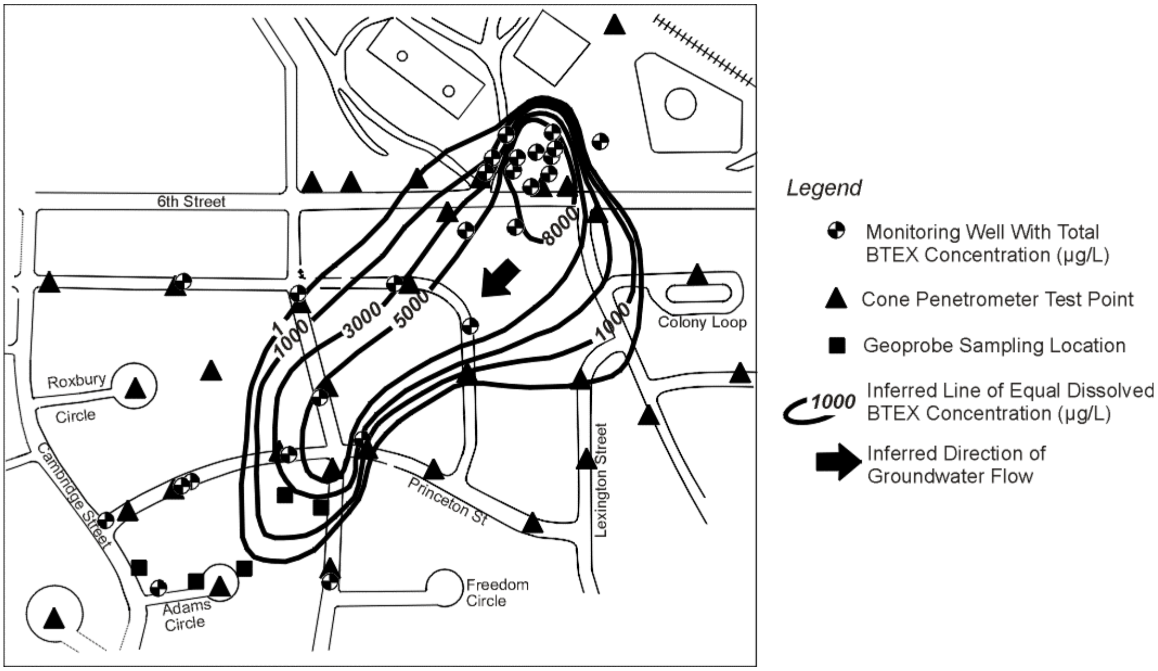
Apparent free product thicknesses of up to 4 feet were measured in monitoring wells, and the areal extent of the free product body was estimated to be approximately 5.2 acres. Residual product was spread across an estimated 11-acre area. Laboratory analysis of product samples indicated that weathering had diminished the BTEX content of the product by 50 to nearly 100 percent relative to fresh JP-4.

The area of the observed dissolved BTEX plume was approximately 16.7 acres. The maximum groundwater total BTEX concentration was 26,576 micrograms per liter (g/L) (Figure 4.1). The estimated distance from the source area to the downgradient toe of the plume (defined by the 10- g/L BTEX isopleth) was 1,650 feet.

4.1.3 Natural Attenuation Processes and Rates

Dissolved BTEX compounds were being biodegraded via aerobic oxidation, denitrification, iron reduction, sulfate reduction, and methanogenesis at an estimated rate of 0.003 day^{-1}. The most prominent degradation processes appeared to be sulfate

Figure 4.1 Total BTEX in Groundwater, 1993, Hill AFB, Utah



reduction and methanogenesis. The estimated total BTEX assimilative capacity of the groundwater was 25,300 µg/L.

4.1.4 Historical Trends and Modeling

Several years of groundwater quality data indicated that the leading edge of the contaminant plume had stabilized approximately 2,100 feet downgradient from the source area. Groundwater modeling supported this observation, and indicated that the plume would not migrate more than an additional 500 feet under worst-case conditions. Skimming of free product and bioventing of the source area were underway prior to the natural attenuation TS. An estimated geometric source removal rate that includes the effects of natural attenuation, product skimming, and bioventing (5 percent BTEX reduction per year) would result in an order-of-magnitude decrease in plume concentrations and shorten the plume length by half within 7 years (based on Bioplume II model predictions). Without source removal via product skimming and natural weathering (of a constant source), the model predicted that the plume would initially expand, then reach equilibrium in 4 years. If more active source removal, consisting of expanded free product pumping and bioventing, were implemented, the model predicted that the plume would attenuate entirely in 4 years.

4.1.5 Recommendation

Operation of the existing free product skimming and bioventing systems should continue for 5 years, and 11 LTM wells should be sampled annually for approximately 13 years. A temporary stormwater treatment system (sparge tank) should be installed at the outlet of the storm sewer to minimize discharge of contaminants to the stormwater pond in the unlikely event that future plume migration impacted the pond to an unacceptable degree. Performance of LTM for 13 years, combined with operation and maintenance of the existing treatment system for 5 years, would cost an estimated $455,000 (Table 4.1).

TABLE 4.1
ESTIMATED COSTS FOR PROPOSED TREATMENT TECHNOLOGIES AT HILL AFB UST SITE 870

Present Worth Cost Estimate	Proposed Remedial Alternatives
$372,000	• Continued skimming/wicking of free-product; • Continued Bioventing of <6,000 square feet of source area; • Monitored Natural Attenuation; • Institutional Controls; and • Long-term Monitoring.
$455,000	• Same as above; and • Provisional stormwater treatment system.
$782,000	• Expanded skimming of free-product; • Expand bioventing system to >120,000 square-feet; • Monitored Natural Attenuation; • Institutional Controls; and • Long-term Monitoring.

4.2 ELMENDORF AFB, ALASKA, SITE ST-41

4.2.1 Site Description

A weathered mixture of JP-4 fuel and aviation gasoline (AVGAS) was present as free-phase and residual product. The fuel was released from four 1,000,000-gallon USTs and associated piping. The USTs were installed in the 1940s, and have been documented to be leaking since the 1960s. Thousands of gallons of product had been released by 1984, and the tanks were decommissioned in 1991. The aquifer is semi-confined and consists of fine- to coarse-grained sand bounded above and below by clay layers. The average groundwater velocity is estimated to be 280 ft/yr, and depth to groundwater ranges from 1 to 35 feet bgs.

4.2.2 Extent and Magnitude of Contamination

Mobile LNAPL was detected in a 100- by 100-foot area, with a maximum observed thickness in a monitoring well of 0.67 foot. The volume of mobile LNAPL was estimated at 8,770 gallons. A free product recovery system began operation in 1993.

The area of the dissolved BTEX plume was approximately 4.9 acres (Figure 4.2). The maximum measured groundwater BTEX concentration was 43,280 g/L, and the plume extended 700 feet from the source area.

4.2.3 Natural Attenuation Processes and Rates

Dissolved BTEX was being biodegraded via aerobic oxidation, denitrification, iron reduction, sulfate reduction, and methanogenesis at an estimated rate of 0.005 day^{-1}. Lower groundwater temperatures (averaging 6.7°C) had little apparent negative impact on biodegradation rates. The most prominent degradation processes appeared to be denitrification and sulfate reduction. The estimated total BTEX assimilative capacity of site groundwater was 22,300 µg/L.

4.2.4 Historical Trends and Modeling

Insufficient groundwater data were available to determine historical trends in contaminant concentration or distribution. A conservative Bioplume II model that assumed a constant source over time (i.e., no source weathering) indicated that natural attenuation would contain the dissolved BTEX plume within 1,000 feet of the source area (Figures 4.2 and 4.3). Natural attenuation of dissolved BTEX and natural source weathering were predicted to result in reduction of dissolved BTEX concentrations to below USEPA (1996) maximum contaminant levels (MCLs) by approximately 2024. A third simulation assumed that continued operation of the existing free product recovery system would achieve a 70-percent source reduction in 5 years (Figure 4.4). This scenario was predicted to decrease remediation time by an estimated 8 years.

4.2.5 Recommendation

Source removal (product-skimming) was implemented prior to the natural attenuation TS in 1994. Because the product recovery system was installed and operational, continuation of source removal activities until 1999 and performance of LTM annually until 2009 were recommended. The necessity for continued LTM should be reevaluated in 2009. The total estimated cost for 5 years of engineered source removal and 15 years of LTM would be $1,142,000. The annual cost of operating the product recovery system was $224,000, based on information obtained from the Base's primary environmental contractor.

4.3 TRAVIS AFB, CALIFORNIA, SITE NSGS

4.3.1 Site Description

Leaking USTs and transfer piping released thousands of gallons of gasoline at two service stations located at a Base intersection. The largest single recorded release at the site was 3,800 gallons of gasoline. The USTs were installed by 1960, and were repaired or replaced between 1988 and 1994. The aquifer is comprised of fine- to coarse-grained sand and silt overlain by a 10- to 15-foot-thick layer of clay. The average groundwater velocity was estimated to be 40 ft/yr, and the groundwater depth ranged from 7 to 14 feet bgs.

Figure 4.2 Total BTEX in Groundwater, 1994, Elmendorf AFB, Alaska

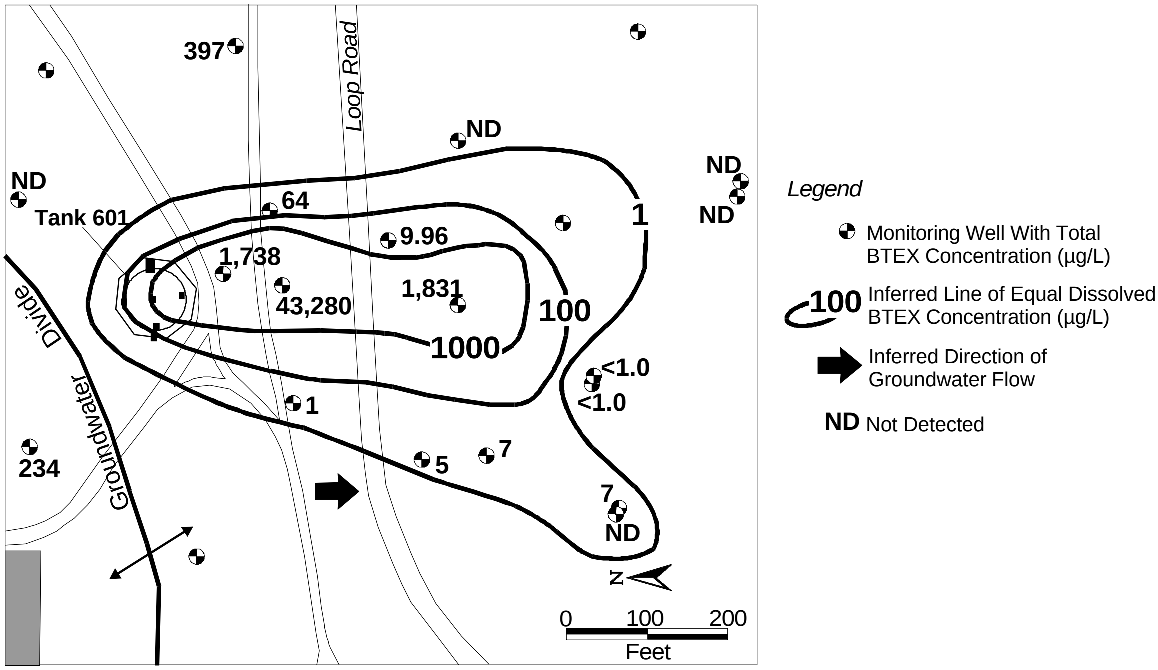


Figure 4.3 Predicted BTEX Plume after 20 years (No Source Reduction), Elmendorf AFB, Alaska

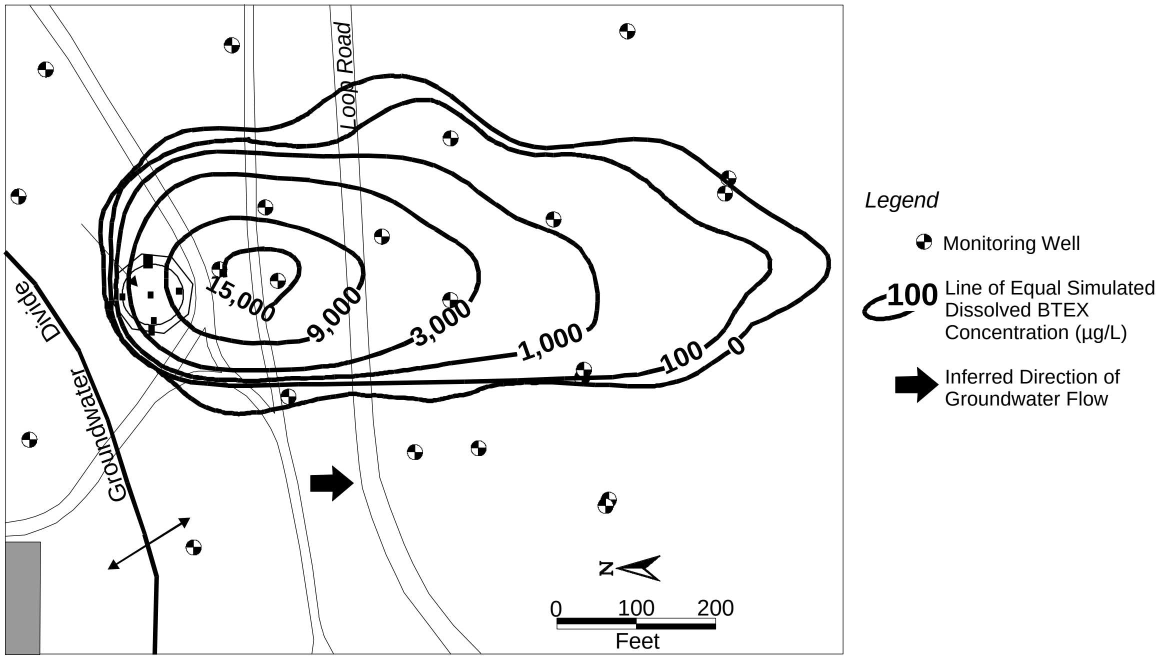
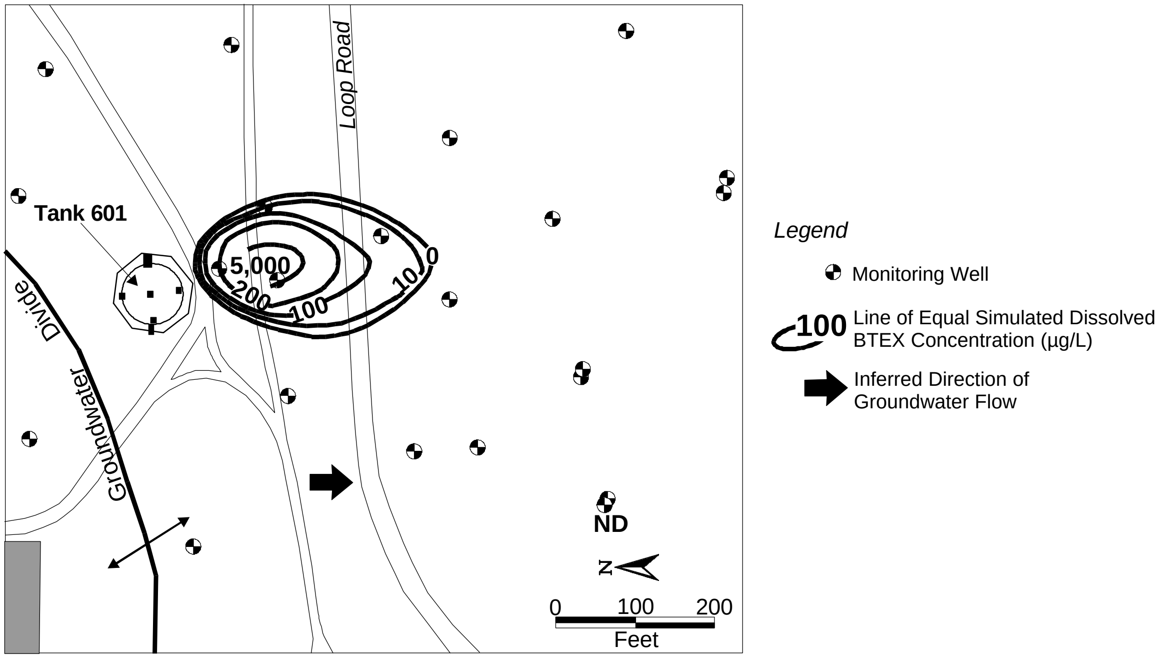


Figure 4.4 Predicted BTEX Plume after 21 Years (Continued Free Product Recovery), Elmendorf AFB, Alaska



4.3.2 Extent and Magnitude of Contamination

Isolated free product layers less than 2 inches thick were observed near the former UST and piping locations. Most of the residual product was removed during replacement of the USTs.

Dissolved BTEX migrating from the two service stations converged to form a single plume having an area of approximately 3.7 acres (Figure 4.5). The maximum dissolved BTEX concentration was 67,000 μg/L. The total length of the BTEX plume was 680 feet.

4.3.3 Natural Attenuation Processes and Rates

Dissolved BTEX was being biodegraded via aerobic oxidation, denitrification, iron reduction, sulfate reduction, and methanogenesis at an estimated rate of 0.0005 day^{-1}. The most prominent degradation processes appeared to be sulfate reduction and methanogenesis. Dissolved methane concentrations are mapped on Figure 4.6. The estimated total BTEX assimilative capacity of site groundwater was 892,000 μg/L.

4.3.4 Historical Trends and Modeling

Historical groundwater analytical data suggested that the BTEX plume was stabilized, with plume concentrations neither increasing nor decreasing. Conservative Bioplume II simulations suggested that the plume length could potentially expand in the future by up to 60 percent under worst-case conditions. However, downgradient

Figure 4.5 Total BTEX in Groundwater, 1995, Travis AFB, California

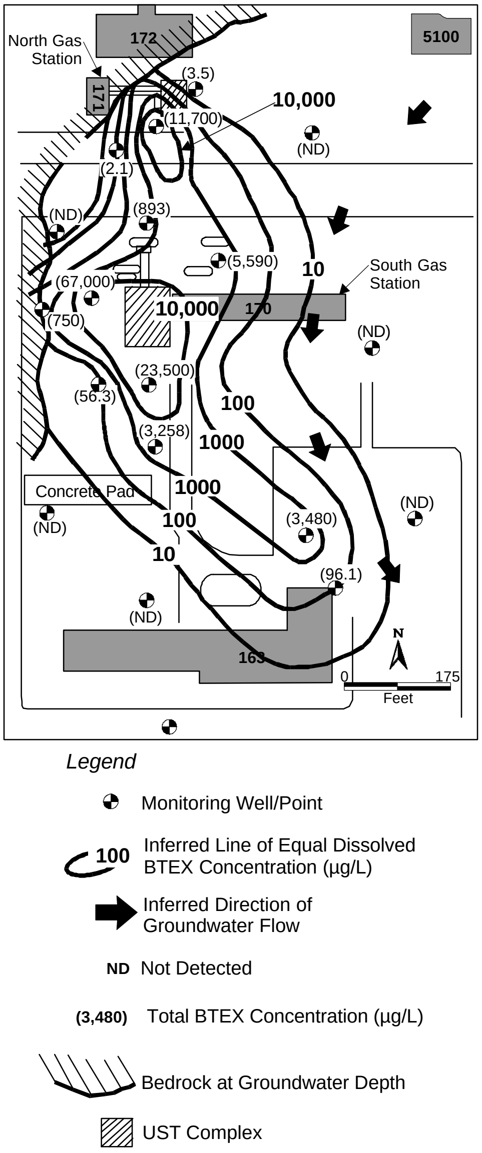
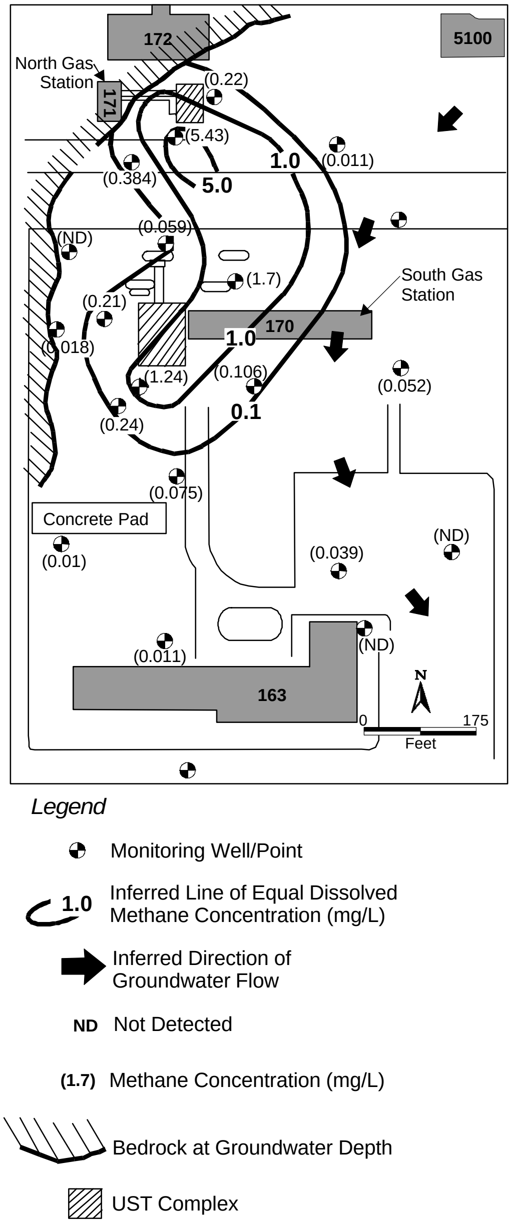


Figure 4.6 Methane in Groundwater, 1995, Travis AFB, California



receptors would not be threatened if this occurred. Modeling results indicate that, possibly due to the slow groundwater velocity, at least 30 years would be required for natural attenuation to remediate the groundwater plume, even if the source areas were removed through excavation.

4.3.5 Recommendation

In this case study, source reduction provided little reduction in plume remediation time. Therefore, MNA with LTM and institutional controls was recommended and accepted by the California regional water quality board. Annual groundwater sampling for 20 years, followed by biennial sampling for 30 additional years, was proposed at an estimated cost of $333,100. If free product removal via bioslurping is implemented, LTM would be required for an estimated 35 years, with an estimated total cost for this alternative of $586,400.

4.4 LANGLEY AFB, VIRGINIA, SITE SS-04

4.4.1 Site Description

Site SS-04 is the location of an abandoned UST farm formerly used to store JP-4. Unreported quantities of JP-4 were released at Site SS-04, which contained 24 25,000-gallon USTs with associated transfer piping. All tanks and transfer piping were abandoned between 1987 and 1990. The aquifer consists of sand, silt, and clay with contamination primarily migrating through sandy soils. The average groundwater velocity is 44 ft/yr, and the groundwater depth ranges from 3 to 7 feet bgs.

4.4.2 Extent and Magnitude of Contamination

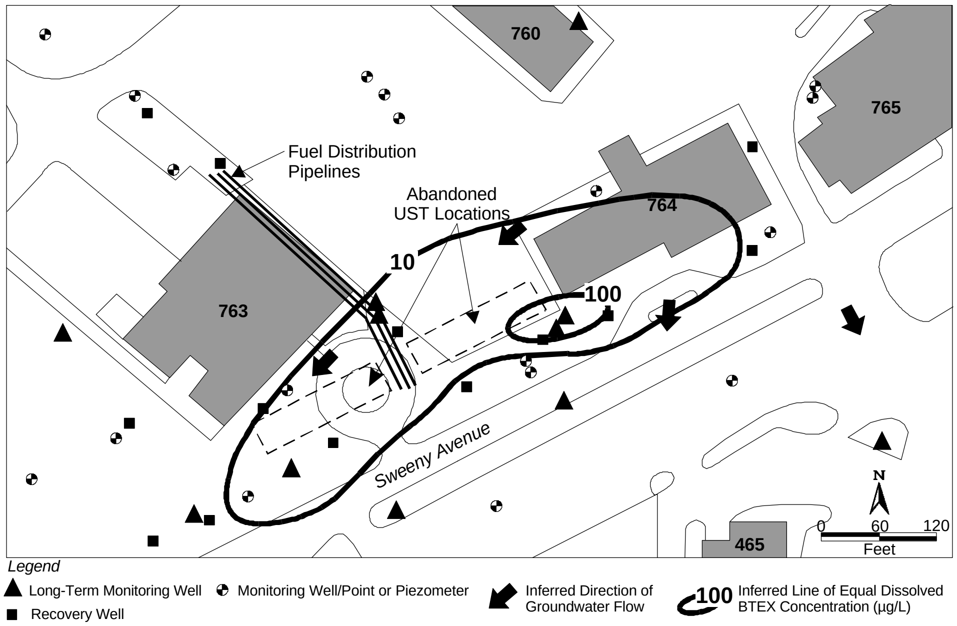
Free product was observed sporadically in three site monitoring wells at thicknesses of 0.01 to 0.61 foot. Analysis of a product sample indicated that the JP-4 was extremely weathered and contained less than 4 percent of the original BTEX content. Residual product exists above the water table in a 1- to 3-foot-thick smear zone; the maximum soil BTEX concentration was 425 mg/kg.

The maximum groundwater BTEX concentration detected was 1,810 µg/L. The approximate areal extent of the BTEX plume was 1.7 acres, and the distance from the source area to the downgradient toe of the plume (defined by the 10-µg/L BTEX isopleth) was 600 feet (Figure 4.7).

4.4.3 Natural Attenuation Processes and Rates

Biodegradation of dissolved BTEX was occurring via iron reduction, sulfate reduction, and methanogenesis at an estimated rate of 0.001 day^{-1}. The most prominent degradation processes appeared to be sulfate reduction and methanogenesis. The estimated total BTEX assimilative capacity of site groundwater was 21,400 µg/L.

Figure 4.7 Long-Term Monitoring Well Locations, Langley AFB, Virginia



4.4.4 Historical Trends and Modeling

Based on historical data, the groundwater BTEX plume is receding. A conservative analytical (Bioscreen) model supported the conclusion that the plume will not impact downgradient receptor exposure points. Dissolved benzene concentrations were predicted to decrease below the USEPA (1996) MCL of 5 g/L by 2010. The model indicated that source area biosparging would reduce plume remediation times by only 3 to 4 years at the most.

4.4.5 Recommendation

A 16-well vacuum-extraction recovery system was used to lower the water table and to recover free-phase fuel from July 1992 to April 1996. As a result of the MNA TS and low BTEX concentrations in air-stripper influent, the Virginia Department of Environmental Quality (VDEQ) accepted MNA with institutional controls as the cleanup method. Annual sampling of 13 wells (Figure 4.7; 11 wells shown) through calendar year 2010 was recommended to complete the LTM program. The total anticipated cost to implement this recommendation was $158,200. In contrast, the estimated cost to implement source area biosparging with LTM was $245,600.

SECTION 5

COST ANALYSIS

The cost of each natural attenuation TS includes the performance of an initial site visit and presentation, work plan development, field sampling/testing, data review, groundwater modeling, report preparation, and presenting the TS results to the Air Force and regulators at a final meeting. Groundwater samples were analyzed in the field for a suite of physical and geochemical biodegradation indicator parameters, and at a fixed-base laboratory for contaminants and geochemical parameters that could not be analyzed in the field. Hollow-stem auger (HSA) drilling, CPT, or Geoprobe® devices were used to delineate soil contamination and place new monitoring wells or points. The finite-difference model Bioplume II was generally used to calibrate the groundwater model, perform sensitivity analyses, and to predict the future fate and transport of the dissolved BTEX plume. These model predictions were used to assess the effectiveness of natural attenuation processes either alone or in conjunction with existing or potential future engineered remedial technologies. A conceptual engineering design of remedial alternatives was performed, and an LTM plan was developed.

Using data from the 35 natural attenuation TS sites (excluding the 7 risk-based corrective action sites), the average cost for a groundwater natural attenuation TS as described above when Geoprobe® characterization was used was $125,000 per site (Table 5.1). This estimate includes installation of an average of 18 new monitoring points to augment the existing well network and delineate the horizontal and vertical extent of the dissolved BTEX plume.

Table 5.1
Typical Natural Attenuation Treatability Study Costs

Task	**Hollow-Stem Auger**	**CPT**	**Geoprobe®**
Site Visit/Technical Support[a/]	$9,690	$9,690	$9,690
Work Plan/Regulatory Approval[b/]	$19,300	$19,300	$19,300
Field Work Labor	$13,900	$13,900	$13,900
Field Work ODCs			
- Survey/Supplies/Per Diem	$9,150	$9,150	$9,150
- Drilling	$12,800	$11,500	$2,300
- Data Analysis/Analytical	$15,300	$15,300	$15,300
Total Field Work ODCs	$37,300	$36,000	$26,800
Modeling	$15,000	$15,000	$15,000
Treatability Study Report	$40,500	$40,500	$40,500
Total Project:	$136,000	$134,000	$125,000

[a/] Includes kickoff meeting, post-reporting meeting, and regulatory support.
[b/] Includes draft and final versions, and gathering/analyzing existing data.
[c/] Includes draft and final versions, with formal written responses to review comments on the draft report.

At sites where either CPT/LIF or HSA was used, the average total cost was $135,000 per site. CPT generally was used where complex site conditions required extensive soil exploration to delineate a contaminant source. On average, the use of CPT/LIF allowed 270 percent more linear feet of soil to be characterized than did HSA techniques for approximately the same cost.

The average proposed LTM program was estimated to cost $192,000 over a monitoring period of 30 years with an LTM network of 11 wells. Engineered source removal efforts (e.g., bioventing or SVE of the source area or product removal through bioslurping) generally were predicted to cost an average of $591,000 and reduce the required LTM period to 20 years. More aggressive site remediation approaches employing a combination of natural attenuation and two or more source treatment technologies (e.g., excavation and/or bioslurping followed by bioventing) reduced the average time for site cleanup to 15 years at an average cost of $816,000. Some form of engineered source removal was recommended at 66 percent of the MNA demonstration sites.

SECTION 6

LESSONS LEARNED

Lessons learned regarding site characterization, fate and transport modeling, the effectiveness of natural attenuation, and the implementation of the MNA remedial alternative are summarized in this section.

6.1 SITE CHARACTERIZATION

- Successful documentation of natural attenuation of fuel hydrocarbons in the subsurface involves combining multiple lines of evidence, including geochemical evidence and documented loss of contaminant mass at the field scale. In addition, delineation of the magnitude and extent of the dissolved contaminant plume and the source area(s) is necessary. Therefore, rapid, low-cost collection of adequate field data is desirable. Use of CPT/LIF or Geoprobe® techniques to collect soil samples, investigate subsurface stratigraphy, and install small-diameter groundwater monitoring points proved advantageous except where the water table was relatively deep (greater than 20 feet bgs) or where subsurface obstructions (e.g., structural foundations or gravel/cobbles) were present.

- Time-sensitive geochemical indicators such as DO, ORP, pH, and temperature should be performed in the field during well purging. The use of a continuous-flow apparatus to protect extracted groundwater from interference by reoxygenation is recommended for best results. Analysis for other geochemical parameters, including alkalinity, ferrous iron, and sulfate, also can be performed quickly and inexpensively in the field. Nitrate tests performed in the field are susceptible to chemical interference and analysis error; therefore, they generally were performed at a fixed-base laboratory.

6.2 FATE AND TRANSPORT MODELING

- At sites with relatively simple hydrogeology, 1-D models (e.g., Bioscreen) are sufficient to determine the persistence and migration potential of the dissolved contaminant plume. However, the ability of these models to simulate spatial heterogeneities in the aquifer or the contaminant source and the effects of weathering and engineered source reduction is very limited. In addition, the effects of other types of remedial systems such as air sparging curtains or groundwater extraction systems cannot be simulated. Therefore, more sophisticated (2- or 3-D numerical) groundwater models are recommended for more complex sites or where more precise simulation of the effects of engineered treatment is desired.

- Reasonably conservative input parameters should be used for groundwater models so that the simulated persistence and migration potential of the dissolved plume are not likely to exceed that predicted by the model.

- Accurate prediction of contaminant fate and transport often is hindered by the inability to predict the natural source weathering rate. Fuel weathering studies currently being performed for AFCEE/ERT are intended to help quantify source weathering rates (Parsons ES, 1999a).

6.3 EFFECTIVENESS OF NATURAL ATTENUATION

- The nearly ubiquitous occurrence of natural BTEX biodegradation has been widely documented in the literature. Therefore, laboratory microcosm studies generally are not necessary to document the site-specific biodegradation potential, and the presence of a native fuel-hydrocarbon-degrading microbial population. Microcosm studies may be useful for determining site-specific biodegradation potential for less studied, non-BTEX fuel compounds. At most sites, two important questions must be answered regarding natural chemical attenuation:

    1. Are historical data available to show a stabilized or receding plume?

    2. Is there evidence in the form of altered geochemical trends at the site that supports the occurrence of biological attenuation?

- The geometric mean of the dissolved BTEX biodegradation rates was 0.0019 day^{-1}, equivalent to a contaminant half-life of approximately 1 year. Natural attenuation rates generally were rapid enough to stabilize hydrocarbon plume migration even when groundwater velocities were relatively high.

- Significant BTEX degradation rates occurred at sites with average groundwater temperatures as low as 5.5°C. Temperature did not appear to significantly influence biodegradation rates.

- Anaerobic biodegradation (particularly sulfate reduction and methanogenesis) dominated biological attenuation mechanisms.

6.4 GENERAL IMPLEMENTATION

- Most states are now receptive to the use of MNA for dissolved BTEX plumes, and some have published guidance or regulations regarding the conduct of natural attenuation studies. Early coordination with concerned regulatory agencies is important. The burden of proof is on the investigator to adequately document the effectiveness of natural attenuation at stabilizing groundwater contamination and protecting human health and the environment. Important factors to consider when using MNA are the required level of groundwater modeling and the potential value of source reduction technologies in reducing LTM time frames and obtaining regulatory acceptance of a site closure strategy.

- The average size of the groundwater plume in these treatability studies was 7 acres, and the average cost of a natural attenuation TS was $125,000 to $135,000. In the future, more streamlined and inexpensive studies to support remedy selection and site closure at fuel sites should be feasible. AFCEE/ERT is currently implementing a streamlined risk-based site closure program that incorporates the “lessons learned” from natural attenuation studies to complement a risk-based corrective action and site closure methodology. Under this program, fuel-contaminated sites are obtaining MNA site closure agreements at less than half the cost of the original natural attenuation TSs (Parsons ES, 1999b).

- This AFCEE initiative, combined with other state and USEPA natural attenuation studies, has laid the groundwork for increasing regulatory acceptance of natural attenuation for dissolved BTEX plumes.

SECTION 7

RECOMMENDATIONS

In cases where engineered remediation is required to lessen the remediation time frame or to protect potential receptors, low-cost, *in situ* source reduction (e.g., bioventing, SVE, and biosparging) should be considered to speed the remediation process. More costly remediation techniques (e.g., groundwater extraction and treatment) should be implemented only if the plume poses an imminent threat to human health or the environment (e.g., the plume is or will shortly impact a receptor exposure point such as a drinking water well or an ecologically sensitive area).

Implementation of MNA is aided by the fact that many sites already have an established monitoring well network, and the need for installation of additional LTM wells is typically minimal. LTM programs generally are simple to implement and involve only periodic groundwater sampling and project oversight with respect to reporting of groundwater trends, maintaining institutional controls until remedial standards are achieved, and public education (AFCEE, 1997). In summary, the results of this study support an Air Force requirement to evaluate natural attenuation as a preferred remedy for fuel-contaminated groundwater before considering other more costly alternatives.

SECTION 8

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Parsons ES, 1996, Intrinsic Remediation Engineering Evaluation/Cost Analysis for Site SS27/XYZ, Dover Air Force Base, Delaware. January.

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Parsons ES, 1996, Remedial Action Plan for the Risk-Based Remediation of Area D, Ellsworth Air Force Base, South Dakota. May.

Parsons ES, 1996, Remedial Action Plan for the Risk-Based Remediation of the KC-135 Crash Site, Wurtsmith Air Force Base, Michigan. December.

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Parsons ES, 1997, Corrective Action Study to Evaluate Intrinsic Remediation for the POL Bulk Fuel Storage Area, Myrtle Beach Air Force Base, Myrtle Beach, South Carolina. May.

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Parsons ES, 1997, Treatability Study in Support of Intrinsic Remediation for Pumphouse 75 (Site 57), MacDill Air Force Base, Tampa, Florida. January.

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Parsons ES, 1997, Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Site ST-24, Columbus Air Force Base, Columbus, Mississippi. July.

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Parsons ES, 1998, Risk-Based Site Assessment Report and Remedial Action Plan for The West Defuel Site, Fairchild Air Force Base, Washington. June.

Parsons ES, 1999, Remediation by Natural Attenuation Treatability Study for Site SS-04, Langley Air Force Base, Virginia. September.

Parsons ES, 1999, Treatability Study in Support of Remediation by Natural Attenuation for Groundwater at Building 1613, Shaw Air Force Base, Sumter, South Carolina. September.

SECTION 9

LIST OF ACRONYMS AND ABBREVIATIONS

1-D	1-dimensional
2-D	2-dimensional
3-D	3-dimensional
AFB	Air Force Base
AFCEE/ERT	Air Force Center for Environmental Excellence, Technology Transfer Division
AVGAS	Aviation gas
bgs	Below ground surface
BTEX	Benzene, toluene, ethylbenzene, xylene
CO_2	Carbon dioxide
CPT	Cone penetrometer test
°C	degrees Celsius
DO	Dissolved Oxygen
ft/yr	Feet per year
HSA	Hollow stem auger
JP-4	Jet propulsion fuel - grade 4
LIF	Laser-induced fluorescence
LLNL	Lawrence Livermore National Laboratory
LTM	Long-term monitoring
MCL	Maximum contaminant level
µg/L	Micrograms per liter
mg/L	Milligrams per liter
MNA	Monitored natural attenuation
ORP	Oxidation/reduction potential
OSWER	Office of Solid Waste and Emergency Response
Parsons ES	Parsons Engineering Science, Inc.
POC	Point of Compliance
RBCA	Risk-based corrective action study
RNA	Remediation by natural attenuation
SVE	Soil vapor extraction
TS	Treatability Study
US	United States
USACE	US Army Corps of Engineers
USEPA	US Environmental Protection Agency
USEPA/NRMRL	US Environmental Protection Agency National Risk Management Research Laboratory

UST	Underground storage tank
VDEQ	Virginia Department of Environmental Quality

APPENDIX A

SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATIONS SITES

TABLE A.1
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOGRAPHIC LOCATION	STATUS[A/]			CONTAMINANT[B/]			ASSISTANCE[C/]
Air Force Facility	Site	City/State	Draft Report Date	Final Report Date	RNA or RBCA Site?	BTEX	CAH	CB	EPA or ACOE Involvement?
Battle Creek ANGB, MI	Site 3	Battle Creek, Michigan	Mar-95	--	RNA	x	x	--	EPA/ACOE
Beale AFB, CA	UST Site	Yuba City, California	Oct-96	--	RNA	x	--	--	None
Bolling AFB, D.C.	Car Care Center	Washington D.C.	--	Jan-97	RNA	x	--	--	ACOE
Carswell AFB	ST-14	Fort Worth, Texas	--	Jul-97	RBCA	x	--	--	None
Charlston AFB, SC	Site ST-27	Charleston, South Carolina	--	Aug-97	RBCA	x	--	x	None
Columbus AFB, MS	ST-24	Columbus, Mississippi	Jul-97	--	RNA	x	--	--	None
Dover AFB, DL	Site SS27/XYZ	Dover, Delaware	--	Jan-96	RNA	x	--	--	ACOE
Eaker AFB, AR	BX Shppette	Blytheville, Arkansas	Jan-97	--	RNA	x	x	x	ACOE
Eglin AFB, FL	POL Facility	Fort Walton Beach, Florida	Jul-95	--	RNA	x	--	--	EPA/ACOE
Ellsworth, SD	Area D	Rapid City, South Dakota	--	May-96	RBCA	x	--	--	None
Elmendorf AFB, AK	Hangar 10	Anchorage, Alaska	--	Mar-95	RNA	x	--	--	EPA
Elmendorf AFB, AK	ST-41	Anchorage, Alaska	--	Oct-95	RNA	x	--	--	EPA
Fairchild AFB, WA	Building 1212	Spokane, Washington	Jan-97	--	RNA	x	--	--	EPA
Fairchild AFB, WA	West Defuel	Spokane, Washington	--	Jun-98	RBCA	x	--	x	None
Fairchild AFB, WA	FT-1	Spokane, Washington	--	Oct-97	RNA	x	x	--	EPA
Griffis AFB, NY	Pumphouse 5	Rome, New York	Feb-96	--	RNA	x	--	x	None
Hill AFB, UT	UST Site 870	Ogden, Utah	--	Jun-95	RNA	x	--	--	EPA/ACOE
King Salmon AFB, AK	Site SS-12	King Salmon, Alaska	Apr-95	--	RNA	x	--	--	EPA
King Salmon AFB, AK	Site FT-01	King Salmon, Alaska	May-96	--	RNA	x	--	--	EPA
Langley AFB, VA	Site SS04	Hampton, Virginia	Aug-98	--	RNA	x	--	--	ACOE
Langley AFB, VA	Site SS16	Hampton, Virginia	Aug-96	--	RNA	x	--	--	None
MacDill AFB, FL	OT24	Tampa Bay, Florida	Jan-97	--	RNA	x	x	--	None
MacDill AFB, FL	Pumphouse 75	Tampa Bay, Florida	--	Jan-97	RNA	x	--	--	None
MacDill AFB, FL	Site 56	Tampa Bay, Florida	--	Oct-96	RNA	x	--	--	None
Madison ANGB at Truax Field, WI	Building 412	Madison, Wisconson	--	Jan-97	RNA	x	--	--	ACOE
Malmstrom AFB	Pumphouse #2	Great Falls, Montana	--	Jan-97	RBCA	x	--	--	None

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOGRAPHIC LOCATION	STATUS[A/]			CONTAMINANT[B/]			ASSISTANCE[C/]
Air Force Facility	Site	City/State	Draft Report Date	Final Report Date	RNA or RBCA Site?	BTEX	CAH	CB	EPA or ACOE Involvement?
Myrtle Beach, SC	MOGAS Site	Myrtle Beach, South Carolina	--	Jul-97	RBCA	x	x	x	ACOE
Myrtle Beach, SC	POL Bulk Fuel Storage Area	Myrtle Beach, South Carolina	--	May-97	RNA	x	--	--	EPA/ACOE
Offutt AFB, NE	Site FPTA3	Omaha, Nebraska	May-95	--	RNA	x	--	--	EPA/ACOE
Offutt AFB, NE	Tank 349	Omaha, Nebraska	Nov-97	--	RNA	x	--	--	EPA/ACOE
Patrick AFB, FL	Site ST-29 (BX Station)	Satellite Beach, Florida	--	Aug-95	RNA	x	--	--	EPA/ACOE
Plattsburg AFB	FT-002	Plattsburg, New York	--	Apr-96	RNA	x	x	--	EPA/ACOE
Pope AFB, NC	Site FPTA #4	Fayetteville, North Carolina	Apr-96	--	RNA	x	--	--	EPA
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	Columbus, Ohio	Oct-96	--	RNA	x	x	--	EPA/ACOE
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	Goldsboro, NC	Apr-96	--	RNA	x	--	--	ACOE
Shaw AFB, SC	Building 1613 (ST-30)	Sumter, South Carolina	Jul-98	--	RNA	x	--	--	EPA/ACOE
Travis AFB, CA	NS Gas Station	Sacramento, California	--	Aug-96	RNA	x	--	--	None
Westover ARB, MA	Current FT Area (FT-08)	Chicopee, Massacheusetts	Mar-97	--	RNA	x	x	--	EPA
Westover ARB, MA	Christmas Tree Fire Training Area	Chicopee, Massacheusetts	--	Jan-97	RNA	x	--	--	EPA
Westover ARB, MA	Zone 1	Chicopee, Massacheusetts	May-97	--	RNA	x	x	--	None
Wurtsmith AFB	KC-135	Oscoda, Michigan	--	Dec-96	RBCA	x	--	--	None
Wurtsmith AFB	OT-41, SS42	Oscoda, Michigan	Jul-97	--	RNA/RAP	x	x	--	EPA/ACOE

Note: "--" indicates inapplicable or unavailable.

A/ STATUS: Indicates the published dates of treatability study (TS) reports. RNA=Remediation by Natural Attenuation Study. RBCA=Risk Based Corrective Action Study.

B/ CONTAMINANT: The matrix identifies if chlorinated solvents were detected at the site. BTEX=Benzene, toluene, ethylbenzene, and xylenes. CAH=Chlorinated Aliphatic Hydrocarbon. CB=Chlorobenzene.

C/ ASSISTANCE: Indicates if US Environmental Protection Agency (EPA) or US Army Corps of Engineers (ACOE) personnel were involved with site characterization efforts.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PLUME DIMENSIONS$^{D/}$				CHEMICAL DATA$^{E/}$						
Air Force Facility	Site	Plume Length (feet)	Plume Width (feet)	Plume Thickness (feet)	Plume Area (Acres)	Maximum Observed CAH (mg/L)	Maximum Observed Total BTEX (mg/L)	Maximum Observed Benzene (µg/L)	Maximum Observed Toluene (µg/L)	Maximum Observed Ethylbenzene (µg/L)	Maximum Observed Xylenes (µg/L)	Maximum Observed TPH (mg/L)
Battle Creek ANGB, MI	**Site 3**	**900**	**375**	**30**	**4.1**	**2.5**	**3,552**	**376**	**1,500**	**159**	**1,517**	**--**
Beale AFB, CA	**UST Site**	**220**	**180**	**10**	**0.8**	**0**	**71.9**	**9.1**	**30**	**22**	**39.9**	**5.9**
Bolling AFB, D.C.	**Car Care Center**	**630**	**300**	**30**	**3.45**	**0**	**110,000**	**44,000**	**57,000**	**3,000**	**68,000**	**--**
Carswell AFB	**ST-14**	**1300**	**400**	**14**	**10.2**	**0**	**1,504**	**110**	**69**	**409**	**1,089**	**--**
Charlston AFB, SC	**Site ST-27**	**234**	**156**	**28**	**0.99**	**--**	**25,400**	**6,900**	**10,000**	**2,400**	**6,100**	**--**
Columbus AFB, MS	**ST-24**	**350**	**200**	**15**	**15.5**	**--**	**20,950**	**920**	**11,000**	**1,500**	**8,100**	**55**
Dover AFB, DL	**Site SS27/XYZ**	**3000**	**750**	**25**	**59.7**	**--**	**22,900**	**6,500**	**13,000**	**820**	**2,600**	**19.9**
Eaker AFB, AR	**BX Shppette**	**420**	**330**	**15**	**2**	**0**	**84,900**	**23,000**	**44,000**	**2,900**	**15,000**	**200**
Eglin AFB, FL	**POL Facility**	**650**	**350**	**25**	**3.4**	**0**	**4,908.5**	**300**	**1,950**	**287**	**2,960**	**7.8**
Ellsworth, SD	**Area D**	**1500**	**350**	**7**	**5.25**	**0**	**5,375**	**3,400**	**29**	**640**	**2,700**	**--**
Elmendorf AFB, AK	**Hangar 10**	**3000**	**1500**	**20**	**37.07**	**--**	**477.64**	**203**	**60.8**	**65.8**	**200**	**--**
Elmendorf AFB, AK	**ST-41**	**700**	**400**	**20**	**4.89**	**--**	**43,280**	**16,500**	**17,300**	**1,920**	**7,560**	**--**
Fairchild AFB, WA	**Building 1212**	**125**	**175**	**20**	**0.26**	**0**	**13,118**	**291**	**673**	**892**	**11,262**	**--**
Fairchild AFB, WA	**West Defuel**	**188**	**100**	**7**	**0.28**	**--**	**3,570**	**100**	**5.5**	**870**	**2,600**	**--**
Fairchild AFB, WA	**FT-1**	**500**	**275**	**10**	**2.87**	**--**	**5,221**	**251**	**273**	**616**	**4,103**	**9762**
Griffis AFB, NY	**Pumphouse 5**	**260**	**360**	**18**	**1.53**	**--**	**12,840**	**4,600**	**540**	**1,100**	**6,600**	**39**
Hill AFB, UT	**UST Site 870**	**1650**	**750**	**25**	**16.7**	**0**	**26,575**	**5,600**	**5,870**	**955**	**9,050**	**--**
King Salmon AFB, AK	**Site SS-12**	**600**	**900**	**10**	**8.84**	**--**	**5,261**	**274**	**2,970**	**375**	**1,642**	**39**
King Salmon AFB, AK	**Site FT-01**	**1200**	**200**	**30**	**6.67**	**--**	**9,225**	**1,050**	**5,400**	**706**	**3,319**	**8980**
Langley AFB, VA	**Site SS04**	**600**	**120**	**21**	**1.68**	**--**	**1,806**	**1,300**	**18**	**140**	**410**	**9**
Langley AFB, VA	**Site SS16**	**125**	**100**	**10**	**0.27**	**--**	**123**	**43**	**68**	**16**	**75**	**19.6**
MacDill AFB, FL	**OT24**	**550**	**200**	**20**	**2.03**	**--**	**2,840**	**480**	**1,800**	**130**	**690**	**13**
MacDill AFB, FL	**Pumphouse 75**	**350**	**150**	**25**	**0.79**	**--**	**676.2**	**96**	**82**	**580**	**110**	**17.9**
MacDill AFB, FL	**Site 56**	**350**	**250**	**10**	**1.68**	**--**	**29,636**	**7,600**	**12,722**	**2,200**	**11,000**	**> 94**
Madison ANGB at Truax Field, WI	**Building 412**	**725**	**400**	**10**	**4.64**	**--**	**28,000**	**26,000**	**30**	**780**	**2,300**	**25.5**
Malmstrom AFB	**Pumphouse #2**	**350**	**275**	**2**	**0.65**	**0**	**5,478**	**430**	**28**	**920**	**4,100**	**--**

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PLUME DIMENSIONS[D/]				CHEMICAL DATA[E/]						
Air Force Facility	Site	Plume Length (feet)	Plume Width (feet)	Plume Thickness (feet)	Plume Area (Acres)	Maximum Observed CAH (mg/L)	Maximum Observed Total BTEX (mg/L)	Maximum Observed Benzene (µg/L)	Maximum Observed Toluene (µg/L)	Maximum Observed Ethylbenzene (µg/L)	Maximum Observed Xylenes (µg/L)	Maximum Observed TPH (mg/L)
Myrtle Beach, SC	MOGAS Site	280	360	10	2	29	48,650	5,960	26,000	2,690	14,000	--
Myrtle Beach, SC	POL Bulk Fuel Storage Area	750	1140	35	11.75	--	18,270	9,530	6,060	1,200	5,260	--
Offutt AFB, NE	Site FPTA3	650	425	30	4.05	--	3,233	775	206	991	1,463	--
Offutt AFB, NE	Tank 349	200	175	10	2	0	104,620	46,300	44,300	4,410	14,310	273
Patrick AFB, FL	Site ST-29 (BX Station)	480	120	15	2.25	0	14,096	1,496	1,526	2,253	8,821	--
Plattsburg AFB	FT-002	2800	500	50	47.3	--	6,010	448	1,560	808	3,300	120000
Pope AFB, NC	Site FPTA #4	720	360	25	3.83	--	8,180	1,620	1,600	830	4,130	12.6
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	100	80	8	0.6	10527	963.26	424.18	41.94	317.97	375.93	--
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	210	165	8	0.6	0	13,800	2,300	3,300	1,100	7,100	24.2
Shaw AFB, SC	Building 1613 (ST-30)	420	280	22	3	--	4,246	1,632	1,042	444	1,539	7.6
Travis AFB, CA	NS Gas Station	680	320	20	3.7	--	67,000	32,000	25,000	1,700	12,000	160
Westover ARB, MA	Current FT Area (FT-08)	800	350	55	4.7	13540	32,557	8,489	15,760	1,569	6,739	38350
Westover ARB, MA	Christmas Tree Fire Training Area	200	150	15	4.77	--	1,656.55	14.51	184.60	378.61	1,088.33	1.04
Westover ARB, MA	Zone 1	1800	1200	30	6	408.5	15,601	2,100	11,000	1,000	4,900	--
Wurtsmith AFB	KC-135	500	150	20	1.2	0	9,230	ND	6,300	330	3,300	--
Wurtsmith AFB	OT-41, SS42	315	105	12	0.43	0	3,126	122	528	437	1,855	4540

D/ PLUME DIMENSIONS: Indicates general size of the groundwater BTEX plume. Feet bgs=Feet below ground surface.
TPH=Total Petroleum Hydrocarbons.

E/ CHEMICAL DATA: Shows maximum contaminant concentrations detected at the site. mg/L=Micrograms per liter.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA$^{F/}$							
Air Force Facility	Site	Dissolved Oxygen Plume (mg/L)	Dissolved Oxygen Background (mg/L)	Dissolved Oxygen Delta (mg/L)	Aerobic BTEX Assimilative Capacity (mg/L)	Nitrate Plume (mg/L)	Nitrate Background (mg/L)	Nitrate Delta (mg/L)	BTEX Denitrification Capacity (mg/L)
Battle Creek ANGB, MI	Site 3	0.09	6.9	6.8	2.2	0.05	3.42	3.4	0.7
Beale AFB, CA	UST Site	0.15	8.4	8.3	2.6	0.083	148	147.9	31.1
Bolling AFB, D.C.	Car Care Center	0.05	7.5	7.5	2.4	0.056	17.2	17.1	3.6
Carswell AFB	ST-14	0.1	2.4	2.3	0.7	0.1	1.5	1.4	0.3
Charlston AFB, SC	Site ST-27	0.2	4	3.8	1.2	0.95	0.9	0.0	0.0
Columbus AFB, MS	ST-24	0.19	8.52	8.3	2.7	0.1	2.5	2.4	0.5
Dover AFB, DL	Site SS27/XYZ	0.3	7.4	7.1	2.3	0	5	5.0	1.1
Eaker AFB, AR	BX Shppette	0.4	8.2	7.8	2.5	0.003	0.46	0.5	0.1
Eglin AFB, FL	POL Facility	0	3.8	3.8	1.2	0.05	0.19	0.1	0.0
Ellsworth, SD	Area D	0.2	5.5	5.3	1.7	--	--	--	
Elmendorf AFB, AK	Hangar 10	0.0	0.8	0.8	0.3	0.5	10.64	10.1	2.1
Elmendorf AFB, AK	ST-41	0.1	8.85	8.8	2.8	0.5	18.77	18.3	3.8
Fairchild AFB, WA	Building 1212	0.7	8.7	8.0	2.6	0.05	8.4	8.4	1.8
Fairchild AFB, WA	West Defuel	--	--	0.0	0.0	--	--	--	
Fairchild AFB, WA	FT-1	0.5	5.7	5.2	1.7	0.05	10.6	10.6	2.2
Griffis AFB, NY	Pumphouse 5	0.2	1.7	1.5	0.5	0.06	2.7	2.6	0.6
Hill AFB, UT	UST Site 870	0.5	5.9	5.4	1.7	--	--	--	
King Salmon AFB, AK	Site SS-12	0.2	11.3	11.1	3.6	0.05	0.097	0.0	0.0
King Salmon AFB, AK	Site FT-01	0.4	2.8	2.4	0.8	0.05	5.48	5.4	1.1
Langley AFB, VA	Site SS04	0.13	0.21	0.1	0.0	ND	ND	ND	
Langley AFB, VA	Site SS16	0.22	4.52	4.3	1.4	0.056	2.8	2.7	0.6
MacDill AFB, FL	OT24	0.06	0.6	0.5	0.2	ND	ND	ND	
MacDill AFB, FL	Pumphouse 75	0.08	0.2	0.1	0.0	0.06	ND	ND	
MacDill AFB, FL	Site 56	0.02	0.81	0.8	0.3	0.05	0.8	0.8	0.2
Madison ANGB at Truax Field, WI	Building 412	0.83	7.08	6.3	2.0	0.14	14.4	14.3	3.0
Malmstrom AFB	Pumphouse #2	1	7.4	6.4	2.0	--	--	--	

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA[F/]							
Air Force Facility	Site	Dissolved Oxygen Plume (mg/L)	Dissolved Oxygen Background (mg/L)	Dissolved Oxygen Delta (mg/L)	Aerobic BTEX Assimilative Capacity (mg/L)	Nitrate Plume (mg/L)	Nitrate Background (mg/L)	Nitrate Delta (mg/L)	BTEX Denitrification Capacity (mg/L)
Myrtle Beach, SC	MOGAS Site	0.05	0.42	0.4	0.1	ND	ND	ND	
Myrtle Beach, SC	POL Bulk Fuel Storage Area	0.04	1.9	1.9	0.6	0.05	0.15	0.1	0.0
Offutt AFB, NE	Site FPTA3	0.1	0.1	0.0	0.0	0.05	0	-0.1	0.0
Offutt AFB, NE	Tank 349	0.8	6.8	6.0	1.9	0.22	7.67	7.5	1.6
Patrick AFB, FL	Site ST-29 (BX Station)	0.1	3.7	3.6	1.2	0.05	0.29	0.2	0.1
Plattsburg AFB	FT-002	0.1	10	9.9	3.2	0.06	0.44	0.4	0.1
Pope AFB, NC	Site FPTA #4	0	7.43	7.4	2.4	0.05	1.64	1.6	0.3
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	0	3.9	3.9	1.2	0.1	9.1	9.0	1.9
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	0.18	7.6	7.4	2.4	0.056	1.7	1.6	0.3
Shaw AFB, SC	Building 1613 (ST-30)	0	6.5	6.5	2.1	0.05	3.45	3.4	0.7
Travis AFB, CA	NS Gas Station	0.1	3.7	3.6	1.2	0.06	9.5	9.4	2.0
Westover ARB, MA	Current FT Area (FT-08)	0.12	9.82	9.7	3.1	0.05	4	4.0	0.8
Westover ARB, MA	Christmas Tree Fire Training Area	0.18	10.43	10.3	3.3	0.05	2	2.0	0.4
Westover ARB, MA	Zone 1	0.3	9	8.7	2.8	0.12	3.5	3.4	0.7
Wurtsmith AFB	KC-135	0.5	7.7	7.2	2.3	--	--	--	
Wurtsmith AFB	OT-41, SS42	0.1	8	7.9	2.5	0.09	6	5.9	1.2

F/ GEOCHEMICAL DATA: Describes the overall electron acceptor and metabolic byproduct trends observed at each site. mg/L=Milligrams per liter. "Delta" indicates the difference between the geochemical indicator concentration in the plume interior versus background concentrations. "Assimilative Capacity" is the theoretical mass of BTEX that can be transformed to carbon dioxide and water with the supply of the respective electron acceptor at the site.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA (CONTINUED)$^{G/}$								
Air Force Facility	Site	Iron (II) Plume (mg/L)	Iron (II) Background (mg/L)	Iron (II) Delta (mg/L)	Iron (III): BTEX Utilization Capacity (mg/L)	Sulfate Plume (mg/L)	Sulfate Background (mg/L)	Sulfate Delta (mg/L)	Sulfate: BTEX Assimilative Capacity (mg/L)	Methane Plume (mg/L)
Battle Creek ANGB, MI	Site 3	12	0.05	12.0	0.6	2.7	27.3	24.6	5.2	8.4
Beale AFB, CA	UST Site	6.84	0.02	6.8	0.3	467	1.1	0.0	0.0	3.5
Bolling AFB, D.C.	Car Care Center	20.3	0.1	20.2	1.0	83	0.88	4.0	0.8	9.1
Carswell AFB	ST-14	680	0.01	680.0	34.0	1.57	84.5	82.9	17.4	5.3
Charlston AFB, SC	Site ST-27	34.9	0.1	34.8	1.7	4.6	18	13.4	2.8	8.2
Columbus AFB, MS	ST-24	63.75	0.01	63.7	3.2	0.1	2	1.9	0.4	2.06
Dover AFB, DL	Site SS27/XYZ	2.05	0.09	2.0	0.1	1.7	50	48.3	10.1	--
Eaker AFB, AR	BX Shppette	33.8	0.01	33.8	1.7	0.32	35.8	35.5	7.5	3.8
Eglin AFB, FL	POL Facility	10.5	0.05	10.5	0.5	0.05	5.62	5.6	1.2	16.82
Ellsworth, SD	Area D	3.45	0.02	3.4	0.2	0.01	1000	1000.0	210.0	--
Elmendorf AFB, AK	Hangar 10	9.0	0.05	9.0	0.4	*2.12*	*26.7*	24.6	5.2	8.5
Elmendorf AFB, AK	ST-41	40.5	0.05	40.5	2.0	0.05	59.3	59.3	12.4	0.922
Fairchild AFB, WA	Building 1212	3.1	0.1	3.0	0.2	3.63	24.8	21.2	4.4	0.9975
Fairchild AFB, WA	West Defuel	35	0.18	34.8	1.7	0	3.7	3.7	0.8	4.8
Fairchild AFB, WA	FT-1	20.5	0.01	20.5	1.0	0.05	11.3	11.3	2.4	19.1
Griffis AFB, NY	Pumphouse 5	24.5	0.1	24.4	1.2	0.49	13.8	13.3	2.8	7
Hill AFB, UT	UST Site 870	10.3	0.05	10.3	0.5	0.5	99	98.5	20.7	1.886
King Salmon AFB, AK	Site SS-12	44	0.05	44.0	2.2	0.5	8.54	8.0	1.7	5.612
King Salmon AFB, AK	Site FT-01	0.01	3	-3.0	-0.1	2.5	6.38	3.9	0.8	0.001
Langley AFB, VA	Site SS04	18.3	0.01	18.3	0.9	0.25	44.1	43.9	9.2	8.8
Langley AFB, VA	Site SS16	9.3	0.01	9.3	0.5	0.25	32.5	32.3	6.8	8
MacDill AFB, FL	OT24	3.58	0.4	3.2	0.2	1.04	23.6	22.6	4.7	9.89
MacDill AFB, FL	Pumphouse 75	20.9	0.01	20.9	1.0	1.74	25	23.3	4.9	14.47
MacDill AFB, FL	Site 56	5.08	0.09	5.0	0.2	0.4	104	103.6	21.8	13.57
Madison ANGB at Truax Field, WI	Building 412	14.8	0.067	14.7	0.7	1.1	40	38.9	8.2	9.9
Malmstrom AFB	Pumphouse #2	1.29	0.01	1.3	0.1	3.2	1332	1328.8	279.0	2.2

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA (CONTINUED)[G/]								
Air Force Facility	Site	Iron (II) Plume (mg/L)	Iron (II) Background (mg/L)	Iron (II) Delta (mg/L)	Iron (III): BTEX Utilization Capacity (mg/L)	Sulfate Plume (mg/L)	Sulfate Background (mg/L)	Sulfate Delta (mg/L)	Sulfate: BTEX Assimilative Capacity (mg/L)	Methane Plume (mg/L)
Myrtle Beach, SC	MOGAS Site	17.7	3.34	14.4	0.7	0.86	43.83	43.0	9.0	3.17
Myrtle Beach, SC	POL Bulk Fuel Storage Area	37.5	2	35.5	1.8	0.5	21.4	20.9	4.4	17.13
Offutt AFB, NE	Site FPTA3	26.3	8	18.3	0.9	2.83	33.1	30.3	6.4	17.57
Offutt AFB, NE	Tank 349	0.05	0.05	0.0	0.0	4.13	75.5	71.4	15.0	0.008
Patrick AFB, FL	Site ST-29 (BX Station)	1.9	0.05	1.9	0.1	0.52	1200	1199.5	251.9	15.534
Plattsburg AFB	FT-002	8.9	0.05	8.9	0.4	0.08	21.35	21.3	4.5	0.512
Pope AFB, NC	Site FPTA #4	56.3	0.05	56.3	2.8	0.5	10.4	9.9	2.1	48.4
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	14.8	0.05	14.8	0.7	6.1	1443	1436.9	301.7	19.2
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	31.63	0.04	31.6	1.6	0.7	26.9	26.2	5.5	2.7
Shaw AFB, SC	Building 1613 (ST-30)	45	0.03	45.0	2.2	0.1	51.6	51.5	10.8	0.991
Travis AFB, CA	NS Gas Station	14.85	0.05	14.8	0.7	4.2	4200	4195.8	881.1	5.43
Westover ARB, MA	Current FT Area (FT-08)	280	0.05	280.0	14.0	0.5	12.1	11.6	2.4	14.63
Westover ARB, MA	Christmas Tree Fire Training Area	23.5	0.05	23.5	1.2	6.32	19.11	12.8	2.7	0.006
Westover ARB, MA	Zone 1	288	0.01	288.0	14.4	1.3	13	11.7	2.5	2.2
Wurtsmith AFB	KC-135	1.26	0.01	1.3	0.1	0.48	9.43	9.0	1.9	0.001
Wurtsmith AFB	OT-41, SS42	18.3	0.05	18.3	0.9	3	14.5	11.5	2.4	3.55

G/ GEOCHEMICAL DATA (CONTINUED): Describes the overall electron acceptor and metabolic byproduct trends observed at each site. mg/L=Milligrams per liter. "Delta" indicates the difference between the geochemical indicator concentration in the plume interior versus background concentrations. "Assimilative Capacity" is the theoretical mass of BTEX that can be transformed to carbon dioxide and water with the supply of the respective electron acceptor at the site.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA (CONCLUDED)[H/]										
Air Force Facility	Site	Methane Background (mg/L)	Methane Delta (mg/L)	Methane: BTEX Utilization Capacity (mg/L)	Sum of BTEX Assimilative and Utilization Capacities (mg/L)	Ratio of Max BTEX to Total BTEX Assimilative Capacity	ORP Min. (mV)	ORP Max. (mV)	Alk. Min (mg/L)	Alk. Max (mg/L)	pH Avg.	Temp. Avg (Celsius)
Battle Creek ANGB, MI	Site 3	0.001	8.4	10.8	19.4	0.18	-335	255	132	670	7.5	14.9
Beale AFB, CA	UST Site	0.002	3.5	4.5	38.5	0.00	56	426	53	1220	6.8	17.6
Bolling AFB, D.C.	Car Care Center	0.003	9.1	11.6	19.5	5.65	-154	176	20	1100	6	20.3
Carswell AFB	ST-14	0.004	5.3	6.8	59.2	0.03	-342	215	280	500	6.9	24.0
Charlston AFB, SC	Site ST-27	0.004	8.2	10.5	16.3	1.56	6	539	10	280	5.65	26.9
Columbus AFB, MS	ST-24	0.01	2.1	2.6	9.4	2.23	-234	338	1	168	5.5	20.6
Dover AFB, DL	Site SS27/XYZ	--	--		13.6	1.69	-431	380	5	198	6	14.0
Eaker AFB, AR	BX Shppette	0.001	3.8	4.9	16.6	5.12	-235	222	60	780	5.5	14.5
Eglin AFB, FL	POL Facility	1.71	15.1	19.3	22.3	0.22	-253	-30	4	96.7	6.1	24.1
Ellsworth, SD	Area D	--	--		211.9	0.03	26	242	55	760	7.5	12.1
Elmendorf AFB, AK	Hangar 10	0.004	8.5	10.9	18.9	0.03	-120	257	94	467	6.95	6.7
Elmendorf AFB, AK	ST-41	0.001	0.9	1.2	22.3	1.94	-53	258	47	1210	6.88	5.7
Fairchild AFB, WA	Building 1212	0.001	1.0	1.3	10.2	1.29	-121	149	340	1160	7.06	12.1
Fairchild AFB, WA	West Defuel	0.001	4.8	6.1	8.7	0.41	-114	150	140	1080	---	---
Fairchild AFB, WA	FT-1	0.001	19.1	24.4	31.7	0.16	-127	200	72	1260	7.3	10.1
Griffis AFB, NY	Pumphouse 5	0.02	7.0	8.9	14.0	0.92	-158	206	120	480	6.812	14.9
Hill AFB, UT	UST Site 870	0.001	1.9	2.4	25.3	1.05	-190	272	349	959	7.3	18.7
King Salmon AFB, AK	Site SS-12	0.001	5.6	7.2	14.6	0.36	-50	255	12	256	6.47	6.9
King Salmon AFB, AK	Site FT-01	0.195	-0.2	-0.2	2.3	3.97	-65	260	23	177	6.7	5.5
Langley AFB, VA	Site SS04	0.002	8.8	11.3	21.4	0.08	-260	30	161	460	7.47	25.4
Langley AFB, VA	Site SS16	0.004	8.0	10.2	19.4	0.01	-158	204	120	480	6.6	26.7
MacDill AFB, FL	OT24	0.1	9.8	12.5	17.6	0.16	-19	-238	200	620	6.75	23.7
MacDill AFB, FL	Pumphouse 75	0.04	14.4	18.5	24.4	0.03	-169	35	10	380	6.1	26.3
MacDill AFB, FL	Site 56	0.03	13.5	17.3	39.7	0.75	-246	-5	120	520	6.8	25.2
Madison ANGB at Truax Field, WI	Building 412	0.005	9.9	12.7	26.6	1.05	-87	180	200	540	6	10.8
Malmstrom AFB	Pumphouse #2	0.005	2.2	2.8	284.0	0.02	-253	-4	380	1600	7.2	14.6

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		GEOCHEMICAL DATA (CONCLUDED)[H/]										
Air Force Facility	Site	Methane Background (mg/L)	Methane Delta (mg/L)	Methane: BTEX Utilization Capacity (mg/L)	Sum of BTEX Assimilative and Utilization Capacities (mg/L)	Ratio of Max BTEX to Total BTEX Assimilative Capacity	ORP Min. (mV)	ORP Max. (mV)	Alk. Min (mg/L)	Alk. Max (mg/L)	pH Avg.	Temp. Avg (Celsius)
Myrtle Beach, SC	MOGAS Site	0.078	3.1	4.0	13.8	3.52	-183	67	42	280	5.95	25.0
Myrtle Beach, SC	POL Bulk Fuel Storage Area	0.05	17.1	21.9	28.6	0.64	-255	260	3	570	6.19	18.0
Offutt AFB, NE	Site FPTA3	0.066	17.5	22.4	29.7	0.11	-170	90	412	784	7.1	12.9
Offutt AFB, NE	Tank 349	0.001	0.0	0.0	18.5	5.66	153	283	80	536	7.5	22.2
Patrick AFB, FL	Site ST-29 (BX Station)	0.034	15.5	19.8	273.0	0.05	-293	54	148	520	7.1	26.1
Plattsburg AFB	FT-002	0.001	0.5	0.7	8.8	0.68	-188	149	--	--	7.71	9.1
Pope AFB, NC	Site FPTA #4	0.002	48.4	61.9	69.6	0.12	-160	393	5	251	5.8	16.8
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	0.001	19.2	24.6	330.2	0.00	-136	212	212	426	7.19	13.0
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	0.004	2.7	3.5	13.3	1.04	-93	312	10	130	5.9	17.4
Shaw AFB, SC	Building 1613 (ST-30)	0.001	1.0	1.3	17.1	0.25	-149	278	10	110	5.5	22.6
Travis AFB, CA	NS Gas Station	0.009	5.4	6.9	891.9	0.08	-32	325	180	1140	6.6	21.7
Westover ARB, MA	Current FT Area (FT-08)	0.001	14.6	18.7	39.1	0.83	-125	280	4	260	7.34	11.4
Westover ARB, MA	Christmas Tree Fire Training Area	0.001	0.0	0.0	7.6	0.22	-159	300	20	134	7	13.4
Westover ARB, MA	Zone 1	0.001	2.2	2.8	23.2	0.67	-207	313	10	145	5.85	15.4
Wurtsmith AFB	KC-135	0.001	0.0	0.0	4.2	2.17	-206	155	80	180	8.1	12.9
Wurtsmith AFB	OT-41, SS42	0.001	3.5	4.5	11.6	0.27	-161	310	140	345	7.16	14.2

H/ GEOCHEMICAL DATA (CONCLUDED): ORP=Oxidation Reduction Potential. mV=Millivolts. Celsius=degrees Celsius.

TABLE A.1 (Continued)

SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES

AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE

BROOKS AIR FORCE BASE, TEXAS

SITE		HYDROGEOLOGIC DATA[1/]							
		General Soil Type	Transport Soil Type	Depth to Groundwater		Number	Groundwater Flow Velocity		
		S=Sand, G=Gravel ST=Silt, C=Clay f=fine, c=coarse, m=medium	S=Sand, G=Gravel ST=Silt, C=Clay f=fine, c=coarse, m=medium						
Air Force Facility	Site			Minimum (Feet)	Maximum (Feet)	of Slug Tests	Max (ft/year)	Min (ft/year)	Average (ft/year)
Battle Creek ANGB, MI	Site 3	S,G	S,G	18	28	5	126	38	72
Beale AFB, CA	UST Site	S,G,C	S,G	3	7	2	120	80	100
Bolling AFB, D.C.	Car Care Center	S,ST,CL,G	S, ST	17	22	0	14.6	1.5	7.3
Carswell AFB	ST-14	ST-C, C, S-C, f&c-S, G	ST-C, C, S-C, f&c-S	6	16	6	149	10.2	79.5
Charlston AFB, SC	Site ST-27	ST-S,CL-S	ST-S	4	6	10	40.8	0.245	4.9
Columbus AFB, MS	ST-24	S, ST, CL, G	S-G, ST-G	11	16	6	978	422	700
Dover AFB, DL	Site SS27/XYZ	G-S, S-C	G-S	4.2	26.2	4	314	131	161
Eaker AFB, AR	BX Shppette	S, St-S, ST-C, C	ST-S, ST-C	3	14	9	285	18	77.4
Eglin AFB, FL	POL Facility	F-C/S, C, Peat	F-C/S	0	4	6	4380	263	657
Ellsworth, SD	Area D	G, ST-C	G	7.5	24	9	146	5	76
Elmendorf AFB, AK	Hangar 10	S, G	S, G	14	26	1	2400	800	1600
Elmendorf AFB, AK	ST-41	f&c-S, ST	f&c-S	1	35	5	538	4.5	260
Fairchild AFB, WA	Building 1212	G-S, C-ST	C-ST	8	12	6	94	17	40
Fairchild AFB, WA	West Defuel	S	S	6.7	8.7	0	--	--	40
Fairchild AFB, WA	FT-1	S, G	S, G	5	7	8	230	57.5	71.9
Griffis AFB, NY	Pumphouse 5	f&c-S, ST, C	f&c-S	0.6	17.5	4	63	1.6	14.6
Hill AFB, UT	UST Site 870	m&c-S, c&st-S	m&c-S	5	26	5	2113	945	1600
King Salmon AFB, AK	Site SS-12	S, G	S, G	0	16	4	1051	315	683
King Salmon AFB, AK	Site FT-01	S	S	0	20	2	447	69	258
Langley AFB, VA	Site SS04	S, ST, C	S	3	7	12	14.6	175.2	44
Langley AFB, VA	Site SS16	S, ST	S	1.5	6.6	3	275	92	183
MacDill AFB, FL	OT24	f&m-S, ST-S	f&m-S	0	5	2	105	26.3	36
MacDill AFB, FL	Pumphouse 75	S, C-S, G, C	S	3	5	1	128	7	22
MacDill AFB, FL	Site 56	f&m-S, C	f&m-S	3	5	1	183	33	51
Madison ANGB at Truax Field, WI	Building 412	S, G	S	3	10	3	90	45	54
Malmstrom AFB	Pumphouse #2	C-S, Glacial	C-S	2	5.8	4	22	2	3

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		HYDROGEOLOGIC DATA[I/]							
		General Soil Type	Transport Soil Type	Depth to Groundwater		Number	Groundwater Flow Velocity		
Air Force Facility	Site	S=Sand, G=Gravel ST=Silt, C=Clay f=fine, c=coarse, m=medium	S=Sand, G=Gravel ST=Silt, C=Clay f=fine, c=coarse, m=medium	Minimum (Feet)	Maximum (Feet)	of Slug Tests	Max (ft/year)	Min (ft/year)	Average (ft/year)
Myrtle Beach, SC	MOGAS Site	m&c-S, ST-S, ST, CL	m&c-S, ST-S	1	12	8	65.7	18.8	39.4
Myrtle Beach, SC	POL Bulk Fuel Storage Area	f&m-S, S-ST, C	f&m-S, S-ST	1.5	9	15	145	5	51
Offutt AFB, NE	Site FPTA3	f&c-S, ST	f&c-S	8	10	2	16.9	6.7	6.7
Offutt AFB, NE	Tank 349	f-S, ST, C	f-S, ST, C	39	48	3	73	0.4	22
Patrick AFB, FL	Site ST-29 (BX Station)	S, G-S, ST	S, G-S	4	5	4	220	110	156
Plattsburg AFB	FT-002	S, C	S	0	45	0	1102	0.73	139
Pope AFB, NC	Site FPTA #4	S, C-ST	S	3.6	14.7	3	840	105	473
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	f-S, G	f-S, G	2.9	13.8	4	33	3.6	25
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	S&ST-C, ST-S, C	ST-S	10	13	0	258	15	91
Shaw AFB, SC	Building 1613 (ST-30)	S, ST-S, C-S, C	S, ST-S	35.5	46.7	6	--	--	402
Travis AFB, CA	NS Gas Station	F-C/S, C, Shale	F-C/S, C	7	13.41	0	60	20	40
Westover ARB, MA	Current FT Area (FT-08)	F-S, M&C-S, G,	F-S, M&C-S, G,	5	7	6	35.7	18.92	20.8
Westover ARB, MA	Christmas Tree Fire Training Area	f&c-S, G, ST-S	f-S	40	45	2	219	62	63
Westover ARB, MA	Zone 1	f&c-S	f&c-S	10	20	4	109.5	65.7	106
Wurtsmith AFB	KC-135	g-S, S	g-S, S	8.79	13.44	0	68.7	68.7	68.7
Wurtsmith AFB	OT-41, SS42	m&c-S	m&c-S	18	22	2	150	150	150

I/ HYDROGEOLOGIC DATA: "General Soil Type" describes the variety of vadose and aquifer soil types observed during drilling operations. "Transport Soil Type" refers to the general aquifer soil type(s).

TABLE A.1 (Continued)

SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES

AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE

BROOKS AIR FORCE BASE, TEXAS

SITE		HYDR. DATA(CONCLUDED)$^{J/}$				BIODEGRADATION DATA$^{K/}$				
Air Force Facility	Site	Soil Fraction Organic Carbon	Estimated Effective Porosity	Average BTEX Migration Velocity (ft/year)	Approximate Retardation Coefficient	Average TMB (1/day)	Average Buscheck (1/day)	Average Other (1/day)	Average of all Biodeg. Rates (1/day)	Average Half Life (days)
Battle Creek ANGB, MI	**Site 3**	**0.00069**	**0.25**	**48**	**1.50**	**--**	**--**	**0.003**	**0.0030**	**231.0**
Beale AFB, CA	**UST Site**	**0.001145**	**0.25**	**31.8**	**3.14**	**--**	**--**	**0.00022**	**0.0002**	**3150.0**
Bolling AFB, D.C.	**Car Care Center**	**0.00105**	**0.25**	**5.8**	**1.25**	**0.0005**	**--**	**--**	**0.0005**	**1540.0**
Carswell AFB	**ST-14**	**0.0045**	**0.3**	**27.1**	**2.93**	**--**	**0.00045**	**--**	**0.0005**	**1540.0**
Charlston AFB, SC	**Site ST-27**	**0.005**	**0.3**	**2.5**	**1.94**	**--**	**--**	**0.000655**	**0.0007**	**1058.0**
Columbus AFB, MS	**ST-24**	**0.0006**	**0.3**	**548**	**1.28**	**--**	**0.08**	**--**	**0.0800**	**8.7**
Dover AFB, DL	**Site SS27/XYZ**	**0.0027**	**0.3**	**146**	**1.10**	**0.0030**	**--**	**--**	**0.0030**	**231.0**
Eaker AFB, AR	**BX Shppette**	**0.0007**	**0.25**	**56.9**	**1.36**	**--**	**0.0062**	**--**	**0.0062**	**111.8**
Eglin AFB, FL	**POL Facility**	**--**	**0.3**	**453**	**1.45**	**--**	**--**	**0.009**	**0.0090**	**77.0**
Ellsworth, SD	**Area D**	**0.0076**	**0.3**	**18**	**4.20**	**--**	**0.00115**	**--**	**0.0012**	**602.6**
Elmendorf AFB, AK	**Hangar 10**	**0.00252**	**0.35**	**842**	**1.90**	**0.0100**	**--**	**--**	**0.0100**	**69.3**
Elmendorf AFB, AK	**ST-41**	**0.00242**	**0.35**	**137**	**1.90**	**0.0050**	**--**	**--**	**0.0050**	**138.6**
Fairchild AFB, WA	**Building 1212**	**0.005**	**0.15**	**28.0**	**1.43**	**--**	**0.007**	**--**	**0.0070**	**99.0**
Fairchild AFB, WA	**West Defuel**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**	**--**
Fairchild AFB, WA	**FT-1**	**0.0042**	**0.25**	**22.68138801**	**3.17**	**--**	**--**	**--**	**--**	**--**
Griffis AFB, NY	**Pumphouse 5**	**0.00085**	**0.25**	**11.9**	**1.23**	**--**	**--**	**0.0002**	**0.0002**	**3465.0**
Hill AFB, UT	**UST Site 870**	**0.00069**	**0.25**	**1240**	**1.29**	**--**	**--**	**0.003**	**0.0030**	**231.0**
King Salmon AFB, AK	**Site SS-12**	**0.00859**	**0.25**	**452**	**1.51**	**--**	**--**	**0.01**	**0.0100**	**69.3**
King Salmon AFB, AK	**Site FT-01**	**0.00019**	**0.25**	**235**	**1.10**	**0.0060**	**0.008**	**--**	**0.0070**	**202.1**
Langley AFB, VA	**Site SS04**	**0.0001**	**0.2**	**40**	**1.10**	**--**	**--**	**0.001**	**0.0010**	**693.0**
Langley AFB, VA	**Site SS16**	**0.00085**	**0.2**	**120**	**1.53**	**--**	**--**	**0.008**	**0.0080**	**86.6**
MacDill AFB, FL	**OT24**	**--**	**0.25**	**14**	**2.62**	**--**	**--**	**0.0007**	**0.0007**	**990.0**
MacDill AFB, FL	**Pumphouse 75**	**0.0006**	**0.25**	**16.9**	**1.30**	**0.0005**	**--**	**--**	**0.0005**	**1386.0**
MacDill AFB, FL	**Site 56**	**0.0028**	**0.25**	**16.5**	**3.10**	**--**	**--**	**0.003**	**0.0030**	**231.0**
Madison ANGB at Truax Field, WI	**Building 412**	**0.0024**	**0.3**	**26.2**	**2.06**	**0.0040**	**--**	**--**	**0.0040**	**173.3**
Malmstrom AFB	**Pumphouse #2**	**0.0024**	**0.3**	**--**	**--**	**--**	**--**	**0.004**	**0.0040**	**173.3**

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		HYDR. DATA(CONCLUDED)J/				BIODEGRADATION DATAK/				
Air Force Facility	Site	Soil Fraction Organic Carbon	Estimated Effective Porosity	Average BTEX Migration Velocity (ft/year)	Approximate Retardation Coefficient	Average TMB (1/day)	Average Buscheck (1/day)	Average Other (1/day)	Average of all Biodeg. Rates (1/day)	Average Half Life (days)
Myrtle Beach, SC	MOGAS Site	0.0006	0.25	27.4	1.44	--	0.0004	--	0.0004	1732.5
Myrtle Beach, SC	POL Bulk Fuel Storage Area	0.00036	0.2	41.5	1.23	--	0.0021	--	0.0021	330.0
Offutt AFB, NE	Site FPTA3	0.0007	0.2	--	--	--	0.0006	--	0.0006	1155.0
Offutt AFB, NE	Tank 349	0.00037	0.12	15.82733813	1.39	0.0001	0.00028	--	0.0002	10175.0
Patrick AFB, FL	Site ST-29 (BX Station)	0.0143	0.35	102.6315789	1.52	--	--	0.0009	0.0009	770.0
Plattsburg AFB	FT-002	0.0055	0.3	41.86746988	3.32	0.0010	--	--	0.0010	693.0
Pope AFB, NC	Site FPTA #4	0.00045	0.3	394	1.20	--	0.0062	--	0.0062	111.8
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	--	--	--	--	--	--	--	--	--
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	0.0022	0.3	47.2	1.93	0.0018	0.0018	--	0.0018	770.0
Shaw AFB, SC	Building 1613 (ST-30)	--	0.25	--	--	0.0038	0.00395	--	0.0039	357.8
Travis AFB, CA	NS Gas Station	0.00124	0.2	22.1	1.81	0.0005	0.00044	--	0.0005	2858.3
Westover ARB, MA	Current FT Area (FT-08)	0.0019	0.25	10.3	2.02	--	0.0015	--	0.0015	462.0
Westover ARB, MA	Christmas Tree Fire Training Area	--	0.2	--	--	--	0.0034	--	0.0034	203.8
Westover ARB, MA	Zone 1	0.00025	0.25	93.80530973	1.13	0.0050	--	0.0007	0.0029	1128.6
Wurtsmith AFB	KC-135	0.0005	0.3	63.8	1.08	--	0.008	--	0.0080	86.6
Wurtsmith AFB	OT-41, SS42	0.0003	0.3	142.8571429	1.05	--	0.014	--	0.0140	49.5

J/ HYDROGEOLOGIC DATA (CONC): "Approx. Ret. Coeff." refers to the approximate retardation coefficient that expresses the approximate ratio between groundwater and BTEX migration velocity. ft/year=Feet per year.

K/ TMB=trimethylbenzene (refers to the first-order biodegradation rate estimation through the use of a biologically recalcitrant compound [e.g., TMB], which acts as a conservative tracer [Wiedemeier et al., 1995]). "Average Buscheck" refers to the average first-order biodegradation rate estimation through the use of the one-dimensional, steady-state analytical solution to the advection-dispersion equation presented by Bear [1979] [Buscheck &Alcantar, 1995]). "Average Other" refers to the average first-order biodegradation rate estimation through the use of analytical or numerical groundwater models, where the biodegradation rate is adjusted during model calibration to accurately simulate a measured plume.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		MONITORING WELL DATA						
Air Force Facility	Site	Total Number of New and Pre-Existing Ground Water Sampling Points	Monitoring Well or Monitoring Points Installation Method Used as Part of This Study	Total Number of Installed Wells/Points as Part of This Study	Total Linear Feet Drilled With a Hollow Stem Auger	Total Linear Feet Drilled With a Cone Penetrometer	Total Linear Feet Drilled With a Geoprobeâ	Combined Linear Feet Drilled with Hollow Stem Auger, Geoprobeâ, or Cone Penetrometer
Battle Creek ANGB, MI	Site 3	33	Cone Penetrometer	25	--	735	--	735
Beale AFB, CA	UST Site	24	Geoprobeâ	22	--	--	256	256
Bolling AFB, D.C.	Car Care Center	33	Cone Penetrometer	22	--	373	--	373
Carswell AFB	ST-14	66	Hollow Stem Auger	27	506	--	--	506
Charlston AFB, SC	Site ST-27	22	Hollow Stem Auger	9	139.9	--	--	139.9
Columbus AFB, MS	ST-24	27	Geoprobeâ	18	--	--	403.4	403.4
Dover AFB, DL	Site SS27/XYZ	50	Cone Penetrometer	40	--	691	--	691
Eaker AFB, AR	BX Shppette	33	Cone Penetrometer/Geoprobeâ	22	--	705	180	885
Eglin AFB, FL	POL Facility	33	Hollow Stem Auger/Geoprobeâ	7/28	111.00	--	309.00	420
Ellsworth, SD	Area D	34	Hollow Stem Auger	18	489	--	--	489
Elmendorf AFB, AK	Hangar 10	23	Hollow Stem Auger	13	373.25	--	--	373.25
Elmendorf AFB, AK	ST-41	26	Hollow Stem Auger	13	356.34	--	--	356.34
Fairchild AFB, WA	Building 1212	15	Geoprobeâ	13	--	--	265	265
Fairchild AFB, WA	West Defuel	10	Geoprobeâ	10	--	--	107	107
Fairchild AFB, WA	FT-1	25	Geoprobeâ	4	--	--	49.5	49.5
Griffis AFB, NY	Pumphouse 5	25	Geoprobeâ	22	--	--	328	328
Hill AFB, UT	UST Site 870	20	Hollow Stem Auger/Geoprobeâ	9/15	214	--	136	350
King Salmon AFB, AK	Site SS-12	36	Hollow Stem Auger	11	115.2	--	--	115.2
King Salmon AFB, AK	Site FT-01	26	Hollow Stem Auger/Geoprobeâ	10	330	--	121	451
Langley AFB, VA	Site SS04	46	Geoprobeâ	26	--	--	402.1	402.1
Langley AFB, VA	Site SS16	23	Geoprobeâ	22	--	--	231.5	231.5
MacDill AFB, FL	OT24	37	Geoprobeâ/Hand	18,2	--	--	232.2	232.2
MacDill AFB, FL	Pumphouse 75	29	Geoprobeâ	13	--	--	184.5	184.5
MacDill AFB, FL	Site 56	29	Geoprobeâ	14	--	--	123.5	123.5
Madison ANGB at Truax Field, WI	Building 412	17	Cone Penetrometer	8	--	125.9	--	125.9
Malmstrom AFB	Pumphouse #2	22	Hollow Stem Auger	20	222.5	--	--	222.5

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		MONITORING WELL DATA						
Air Force Facility	Site	Total Number of New and Pre-Existing Ground Water Sampling Points	Monitoring Well or Monitoring Points Installation Method Used as Part of This Study	Total Number of Installed Wells/Points as Part of This Study	Total Linear Feet Drilled With a Hollow Stem Auger	Total Linear Feet Drilled With a Cone Penetrometer	Total Linear Feet Drilled With a Geoprobeâ	Combined Linear Feet Drilled with Hollow Stem Auger, Geoprobeâ, or Cone Penetrometer
Myrtle Beach, SC	MOGAS Site	36	Cone Penetrometer	14/14	346	463	--	809
Myrtle Beach, SC	POL Bulk Fuel Storage Area	50	Cone Penetrometer	38	--	1124.8	--	1124.8
Offutt AFB, NE	Site FPTA3	33	Cone Penetrometer	25	--	476.5	--	476.5
Offutt AFB, NE	Tank 349	14	None	0	--	680.8	--	680.8
Patrick AFB, FL	Site ST-29 (BX Station)	48	Cone Penetrometer	43	--	536	--	536
Plattsburg AFB	FT-002	23	Cone Penetrometer/Geoprobeâ	6	--	3093	30	3123
Pope AFB, NC	Site FPTA #4	29	Geoprobeâ/Hand	17	--	--	210.8	210.8
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	44	Cone Penetrometer	34	--	635	--	635
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	24	Cone Penetrometer/Geoprobeâ	23	--	320	351	671
Shaw AFB, SC	Building 1613 (ST-30)	22	None	0	--	--	--	0
Travis AFB, CA	NS Gas Station	29	Geoprobeâ	5	--	--	102	102
Westover ARB, MA	Current FT Area (FT-08)	32	Geoprobeâ	21	--	--	357	357
Westover ARB, MA	Christmas Tree Fire Training Area	15	Hollow Stem Auger	5	235	--	--	235
Westover ARB, MA	Zone 1	49	Geoprobeâ	16	--	--	458.5	458.5
Wurtsmith AFB	KC-135	21	Hollow Stem Auger	12	263	--	--	263
Wurtsmith AFB	OT-41, SS42	56	Cone Penetrometer	32	--	749	--	749

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PROPOSED REMEDIAL ALTERNATIVE DATA[L/]							
Air Force Facility	Site	Recommended Number of Long-Term (LTM) Points	Long-Term Monitoring (LTM) Sampling Frequency (years)	Remedial Alternative Selected	Specific Remedial Technologies Proposed in Remedial Alternative	Completed Exposure Pathway	Numerical Model Used	Historic Natural Atten. Trends?	Receding (R) Steady-State (S) or Expanding (E) Plume
Battle Creek ANGB, MI	Site 3	7	1	Alt. 1	BV+MNA+LTM+IC	No	Bioplume II	No	S,R
Beale AFB, CA	UST Site	5	1	Alt. 1	MNA+LTM+IC	No	Bioplume II	No	R
Bolling AFB, D.C.	Car Care Center	7	0.5	Alt. 3	SR+SVE+BV+MNA+LTM+IC	No	Bioplume II	Yes	S,R
Carswell AFB	ST-14	22	0.25	Alt. 1	BV+DPE+SR+MNA+LTM+IC	Yes	Bioplume II	Yes	S,R
Charlston AFB, SC	Site ST-27	13	.5,1	Alt. 2	SVE+BV+MNA+LTM+IC	No	ONED3	Yes	S,R
Columbus AFB, MS	ST-24	10	1	Alt. 1	MNA+LTM	No	1-DIM, G&A	Yes	S
Dover AFB, DL	Site SS27/XYZ	11	1	Alt. 3	DPE+BV+MNA+LTM+IC	No	Bioplume II	Yes	E
Eaker AFB, AR	BX Shppette	11	1	Alt.3	SR+MNA+LTM	YES	Bioscreen	Yes	S
Eglin AFB, FL	POL Facility	9	1	Alt. 1	MNA+LTM+IC	No	MOD/MT3D	No	S
Ellsworth, SD	Area D	11	1	Alt. 2	BV+Wicking+MNA+LTM+IC	No	Bioplume II	Yes	S, E
Elmendorf AFB, AK	Hangar 10	7	0.5	Alt. 1	MNA+LTM	No	Bioplume II	Yes	S, R
Elmendorf AFB, AK	ST-41	7	1	Alt. 2	SR+IR+LTM	No	Bioplume II	No	S
Fairchild AFB, WA	Building 1212	11	2	Alt. 1	MNA+LTM	No	Bioplume II	No	S
Fairchild AFB, WA	West Defuel	16	1	Alt. 1	BV+MNA+LTM+IC	No	None	No	S
Fairchild AFB, WA	FT-1	10	1	Alt. 1	BV+AS+MNA+LTM+IC	No	Bioplume II	Yes	S, E
Griffis AFB, NY	Pumphouse 5	6	1	Alt. 1	IR+SR+LTM	Yes	Bioplume II	No	S
Hill AFB, UT	UST Site 870	11	0.5	Alt 2	SR+BV+IR+LTM+SW (optional)	No	Bioplume II	Yes	S
King Salmon AFB, AK	Site SS-12	8	1	Alt. 1	SI+RISK+IR+LTM	Yes	Bioplume II	Yes	S
King Salmon AFB, AK	Site FT-01	14	1	Alt. 3	DPE+SR+SI+MNA+LTM+IC	Yes	Bioplume II	YEs	S, R
Langley AFB, VA	Site SS04	13	1	Alt. 1	MNA+LTM+IC	--	Bioscreen	Yes	R
Langley AFB, VA	Site SS16	11	2	Alt. 1	IR+LTM	No	Bioplume II	No	S
MacDill AFB, FL	OT24	5	1	Alt. 1	BV+MNA+LTM+IC	No	Bioplume II	Yes	S, R
MacDill AFB, FL	Pumphouse 75	15	1	Alt. 1	IR+LTM	No	Bioplume II	Yes	R
MacDill AFB, FL	Site 56	8	1	Alt. 2	BV+IR+LTM	No	Bioplume II	Yes	S, R
Madison ANGB at Truax Field, WI	Building 412	7	1	Alt. 1	IR+LTM	No	Bioplume II	Yes	R
Malmstrom AFB	Pumphouse #2	10	1	Alt. 1	Sediment Excavation+MNA+LTM+IC	No	None	Yes	S

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PROPOSED REMEDIAL ALTERNATIVE DATA[L/]							
Air Force Facility	Site	Recommended Number of Long-Term (LTM) Points	Long-Term Monitoring (LTM) Sampling Frequency (years)	Remedial Alternative Selected	Specific Remedial Technologies Proposed in Remedial Alternative	Completed Exposure Pathway	Numerical Model Used	Historic Natural Atten. Trends?	Receding (R) Steady-State (S) or Expanding (E) Plume
Myrtle Beach, SC	MOGAS Site	14	0.5	Alt. 1	BV+MNA+LTM+IC	No	Bioplume II	Yes	S
Myrtle Beach, SC	POL Bulk Fuel Storage Area	18	1	Alt. 2	DPE+IR+LTM	Yes	Bioplume II	No	S
Offutt AFB, NE	Site FPTA3	8	2	Alt. 1	IR+IC+LTM	No	Bioplume II	Yes	S
Offutt AFB, NE	Tank 349	15	2	Pending	Pilot Test + MNA+LTM+IC	No	Bioplume II	no	S
Patrick AFB, FL	Site ST-29 (BX Station)	6	0.5	Alt. 1	BV+MNA+LTM	No	Bioplume II	Yes	S
Plattsburg AFB	FT-002	12	1	Alt. 3	MNA+IC+LTM+BV+SR+AS	No	Bioplume II	Yes	S
Pope AFB, NC	Site FPTA #4	10	1	Alt. 1	SR+IR+LTM	No	Bioplume II	No	S, R
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	12	0.25	--	Build Cover+SR+DPE+MNA+LTM+IC	No	--	Yes	S, R
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	10	1	Alt. 1	SR+MNA+LTM	No	Bioplume II	No	S, E
Shaw AFB, SC	Building 1613 (ST-30)	12	1	Alt. 2	SVE+BV+MNA+LTM+IC	No	Bioplume II	Yes	S
Travis AFB, CA	NS Gas Station	12	1	Alt. 1	MNA+LTM+IC	No	Bioplume II	Yes	S
Westover ARB, MA	Current FT Area (FT-08)	9	2	Alt. 2	BV+MNA+Vertical Circulation+LTM+IC	No	Bioplume II	Yes	S,R
Westover ARB, MA	Christmas Tree Fire Training Area	8	1	Alt. 1	BV+IR+LTM	No	1-DIM, G&A	Yes	R
Westover ARB, MA	Zone 1	21	1	Alt. 1	GE+MNA+IC+LTM	No	Bioplume II	Yes	S, R
Wurtsmith AFB	KC-135	8	1	Alt. 1	MNA+LTM+IC	No	Bioplume II	Yes	R
Wurtsmith AFB	OT-41, SS42	10	1	Alt. 1	RISK+MNA+LTM+IC	No	Bioplume II	Yes	S,R

L/ PROPOSED REMEDIAL ALTERNATIVE DATA: Refers to the proposed use of monitored natural attenuation (MNA) in combination with other treatment technologies. "Completed Exposure Pathway" indicates that the groundwater BTEX plume has impacted a surface water source. DPE=Duel-phase extraction (e.g., bioslurping). MNA=Monitored natural attenuation. LTM=Long-term monitoring. IC=Institutional controls. BV=Bioventing. SVE=Soil vapor extraction. AS=Air sparging. CO=Continued operation of current remediation system. GE=Groundwater extraction and treatment. ASC=Additional site characterization. CBV=Continued bioventing. IR=Intrinsic remediation. SR=Source/LNAPL/Product reduction,removal,recovery,or extraction. RISK=Risk assessment. SI=Source identification. SW=Stormwater treatment.

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PROPOSED REMEDIAL ALTERNATIVE DATA (CONCLUDED)								
Air Force Facility	Site	Estimated Alt. 1 Capital Costs	Estimated Alt. 1 O & M Costs	Years to Achieve MCLS with Alt. 1	Estimated Alt. 2 Capital Costs	Estimated Alt. 2 O & M Costs	Years to Achieve MCLS with Alt. 2	Estimated Alt. 3 Capital Costs	Estimated Alt. 3 O & M Costs	Years to Achieve MCLS with Alt. 3
Battle Creek ANGB, MI	Site 3	$22,800	$192,500	15	$22,800	$208,200	20	--	--	--
Beale AFB, CA	UST Site	$85,600	15	--	--	--	--	--	--	--
Bolling AFB, D.C.	Car Care Center	$16,535	$470,465	>30	$102,955	$426,045	13	$111,465	$373,335	>11
Carswell AFB	ST-14	$119,556	$693,219	10	$181,513	$97,387	10	$321,738	$518,442	5
Charlston AFB, SC	Site ST-27	$23,060	$310,451	20	$40,836	$262,513	11	$354,060	$308,676	3
Columbus AFB, MS	ST-24	$20,761	$85,390	5	$190,204	$99,263	5	$185,769	$280,659	5
Dover AFB, DL	Site SS27/XYZ	$17,055	$264,045	30	$126,216	$601,084	30	$231,320	$335,080	24
Eaker AFB, AR	BX Shppette	$13,500	$303,500	200	$87,500	$311,500	40	$44,900	$295,100	14
Eglin AFB, FL	POL Facility	$16,800	$138,200	32	$80,300	$176,700	10	--	--	--
Ellsworth, SD	Area D	$25,980	$203,150	22	$83,724	$220,576	22	$523,044	$593,256	25
Elmendorf AFB, AK	Hangar 10	$12,000	$131,000	10	$412,000	$172,000	10	--	--	--
Elmendorf AFB, AK	ST-41	$16,000	$156,000	15	$16,000	$1,126,000	15	--	--	--
Fairchild AFB, WA	Building 1212	$16,760	$150,290	34	$77,160	$127,060	9	$206,366	$42,634	6
Fairchild AFB, WA	West Defuel	$50,120	$80,830	10	$51,780	$92,790	10	$81,670	$63,210	10
Fairchild AFB, WA	FT-1	--	--	--	--	--	--	--	--	--
Griffis AFB, NY	Pumphouse 5	$17,000	$239,000	20	$84,000	$501,000	20	$156,000	$550,000	20
Hill AFB, UT	UST Site 870	$12,000	$360,000	>10	$36,000	$419,000	7	$473,000	$309,000	4
King Salmon AFB, AK	Site SS-12	$85,000	$413,000	15	$884,600	$676,400	10	--	--	--
King Salmon AFB, AK	Site FT-01	$20,500	$298,500	35	$89,500	$276,500	20	$197,300	$465,700	20
Langley AFB, VA	Site SS04	$6,000	$152,200	12	$117,800	$127,800	9	--	--	--
Langley AFB, VA	Site SS16	$22,200	$299,800	50	--	--	--	--	--	--
MacDill AFB, FL	OT24	$14,970	$235,800	25	$61,470	$297,081	21	$91,470	$325,755	$17
MacDill AFB, FL	Pumphouse 75	$17,435	$245,722	18	$82,435	$234,212	12	--	--	--
MacDill AFB, FL	Site 56	$9,833	$240,243	56	$79,833	$268,278	14	$141,196	$344,633	10
Madison ANGB at Truax Field, WI	Building 412	$13,500	$186,500	20	$273,500	$198,500	15	--	--	--
Malmstrom AFB	Pumphouse #2	$28,100	$148,080	5	$59,790	$158,940	5	--	--	--

TABLE A.1 (Continued)
SUMMARY DATA TABLE FOR THE NATURAL ATTENUATION OF FUEL HYDROCARBONS FROM MULTIPLE AIR FORCE DEMONSTRATION SITES
AIR FORCE CENTER FOR ENVIRONMENTAL EXXCELLENCE
BROOKS AIR FORCE BASE, TEXAS

SITE		PROPOSED REMEDIAL ALTERNATIVE DATA (CONCLUDED)								
Air Force Facility	Site	Estimated Alt. 1 Capital Costs	Estimated Alt. 1 O & M Costs	Years to Achieve MCLS with Alt. 1	Estimated Alt. 2 Capital Costs	Estimated Alt. 2 O & M Costs	Years to Achieve MCLS with Alt. 2	Estimated Alt. 3 Capital Costs	Estimated Alt. 3 O & M Costs	Years to Achieve MCLS with Alt. 3
Myrtle Beach, SC	MOGAS Site	$238,841	$246,088	6	$332,274	$377,980	6	$395,788	$307,527	5
Myrtle Beach, SC	POL Bulk Fuel Storage Area	$41,000	$635,500	50	$307,200	$1,008,800	20	$328,000	$1,120,000	20
Offutt AFB, NE	Site FPTA3	$31,100	$221,100	110	$125,700	$324,500	40	--	--	--
Offutt AFB, NE	Tank 349	$17,496	$162,113	100	$452,580	$720,547	100	--	--	--
Patrick AFB, FL	Site ST-29 (BX Station)	$94,000	$183,000	12	$14,000	$212,000	20	--	--	--
Plattsburg AFB	FT-002	$63,000	$322,770	30	$360,000	$2,526,740	30	$1,960,000	$3,602,640	30
Pope AFB, NC	Site FPTA #4	$20,395	$293,405	20	$114,704	$499,096	15	$313,626	$475,474	12
Rickenbacker ANGB, OH	Haz. Waste Storage Area (Building 560)	--	--	--	--	--	--	--	--	--
Seymour Johnson AFB, NC	Former AGE FFS (Volume I)	$68,200	$171,800	40	$188,700	$236,300	35	$184,800	$108,200	32
Shaw AFB, SC	Building 1613 (ST-30)	$7,298	$253,122	45	$139,654	$390,063	30	$259,830	$378,533	20
Travis AFB, CA	NS Gas Station	$18,020	$315,080	50	$128,500	$457,900	35	$143,900	$564,500	30
Westover ARB, MA	Current FT Area (FT-08)	$57,660	$246,540	60	$142,184	$254,616	30	$140,683	$253,717	30
Westover ARB, MA	Christmas Tree Fire Training Area	--	--	--	--	--	--	--	--	--
Westover ARB, MA	Zone 1	$35,280	$247,649	22	$55,280	$214,692	16	$148,265	$203,729	5
Wurtsmith AFB	KC-135	$0	$123,100	8	$51,370	$127,863	7	$147,480	$236,520	5
Wurtsmith AFB	OT-41, SS42	--	--	9	--	--	--	--	--	--