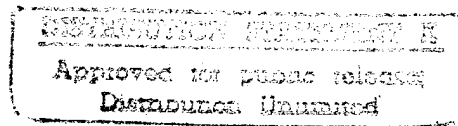




**U.S. Army
Environmental
Center**

**FORT DEVENS
FEASIBILITY STUDY
FOR GROUPS 2 & 7 SITES**

**FINAL
FEASIBILITY STUDY REPORT
AREA OF CONTAMINATION (AOC) 43G**



**CONTRACT DAAA15-91-D-0008
DELIVERY ORDER NUMBER 005**

**U.S. ARMY ENVIRONMENTAL CENTER
ABERDEEN PROVING GROUND, MARYLAND**

June 1996

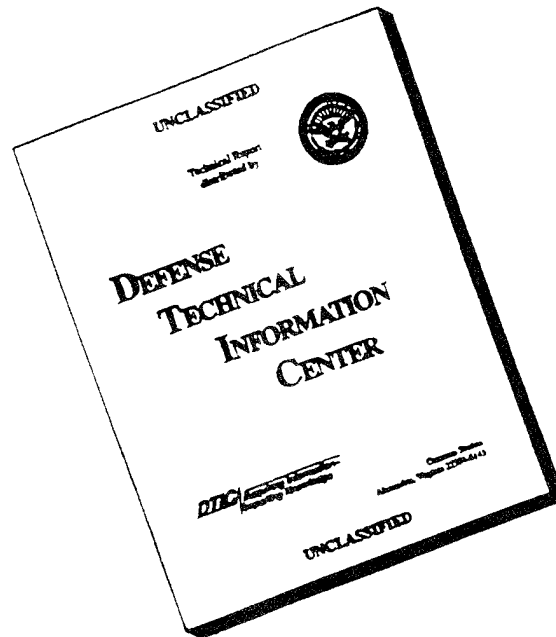
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**FORT DEVENS FEASIBILITY STUDY FOR GROUP 2 & 7
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**CONTRACT DAAA15-91-D-0008
DELIVERY ORDER NUMBER 005**

Prepared for:

**U.S. Army Environmental Center
Aberdeen Proving Ground, Maryland**

Prepared by:

**ABB Environmental Services, Inc.
Wakefield, Massachusetts
Project No. 07053-11**

JUNE 1996

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EXECUTIVE SUMMARY

The U.S. Army Environmental Center (USAEC) directed ABB Environmental Services, Inc. (ABB-ES), under Contract No. DAAA15-91-D-0008, to conduct a Remedial Investigation (RI) and Feasibility Study (FS) to address the contamination of soil and groundwater at Area of Contamination (AOC) 43G. This FS Report is prepared as part of the FS process in accordance with the 1988 U.S. Environmental Protection Agency (USEPA) guidance document entitled *Guidance for Conducting Remedial Investigations and Feasibility Studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)*. The purpose of the FS Report is to initially identify and screen potentially feasible alternatives to control human health and environmental risks at AOC 43G. Following the screening of alternatives, the FS Report presents a detailed analysis and comparison of the retained alternatives.

AOC 43G is located in the central portion of the Main Post at Fort Devens. The AOC consists of the inactive Army Air Force Exchange Service (AAFES) gas station and a historic gas station (Study Area 43G). For purposes of the field investigations and this report, AOC 43G was divided into three areas. Area 1 is the former location of historic gas station G which was used as a vehicle motor pool to support military operations during World War II. Based on the results of the Site Investigation (SI) and Supplemental SI (SSI), no further action was recommended in the SSI Data Package (ABB-ES, 1994) for Area 1. Therefore, all discussions and remedial considerations within the FS Report pertain to only Areas 2 and 3.

Areas 2 and 3 are the locations of the former and existing gasoline underground storage tanks (USTs), and the former waste oil UST, respectively. The latter two areas are both associated with the AAFES gas station. AAFES gas station consists of the service station (Building 2008) which houses three vehicle service bays and the AAFES store, three 10,000-gallon USTs, and associated pump islands. At the present time the gas station is not in operation and the AAFES management has been discontinued. The Fort Devens Reuse Plan (BRAC, 1991) has indicated that this gas station will stay within the Army Reserve Enclave and it will continue to be used for Army Reserve units operations. Because of the presence of soil and groundwater contamination, an RI and subsequent FS was recommended in the SSI Data Package (ABB-ES, 1994) for Areas 2 and 3.

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Area 2 is the location where three 9,000-gallon and two 10,000-gallon USTs were installed on the north side of the AAFES gas station. These five USTs were removed on October 15 through 19, 1990, and later replaced with the three existing 10,000-gallon USTs in 1991. Because of the elevated total petroleum hydrocarbon (TPHC) concentrations detected during the UST removals, approximately 1,400 tons of soil were removed from the former UST excavations in December 1990. The excavation could only be extended 20 feet below ground surface (bgs) because of the limited reach of the excavator. Confirmation soil samples collected from the walls of the excavation revealed that the lateral extent of contamination had been removed, but no samples were collected from the bottom of the excavation.

Area 3 is the location of a former waste oil UST and an existing sand and gas trap. On May 27, 1992, the 500-gallon waste oil UST was removed by ATEC Associates, Inc. (ATEC). The UST was located approximately 5 to 10 feet south of Building 2008. Soil removed from the side walls and bottom of the UST excavation was reported as "visibly contaminated" and produced a "strong septic odor". Excavation work was stopped because of the proximity of the building footing. Soil samples taken from the excavation walls and bottom revealed TPHC concentrations up to 35,100 micrograms per gram ($\mu\text{g/g}$) in soils remaining in the excavation. The existing sand and gas trap is located adjacent to the former waste oil UST. Field sampling in this area revealed elevated concentrations of TPHC, benzene, toluene, ethylbenzene, and xylenes (BTEX) in subsurface soils. Soil boring samples collected during the RI revealed TPHC concentrations at only 62.6 $\mu\text{g/g}$ and 40.8 $\mu\text{g/g}$ in deeper subsurface soils below the waste oil UST excavation (an 18- to 20-foot soil sample and 25- to 27-foot soil sample, respectively).

The RI Report evaluated potential baseline human health risks associated with exposure to site contaminants in subsurface soil and groundwater based on soil and groundwater sampling data collected during the RI (ABB-ES 1996). The risk assessment was conducted to evaluate potential human health risks to commercial/industrial receptors under current and future foreseeable site conditions. Commercial/industrial receptors were selected because the property at AOC 43G is to be retained by the Army. Future use of the site is to be similar to current use (commercial/industrial). According to the Devens Reuse Plan (Vanasse Hangen Brustlin, 1994), the area downgradient of the Army Reserve Enclave property will be used for Innovation and Technology Business and open

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space/recreation. Therefore, drinking water supplies for residential recipients would not be expected within these immediate downgradient areas.

Human health risks exceeded the USEPA points of departure (i.e., risk management guidelines corresponding to cancer risks exceeding 1×10^{-6} and noncancer hazard index values exceeding 1 only for the risk scenario of commercial/industrial worker exposure to groundwater under future land-use conditions. Human health risks associated with exposure to subsurface soils were found to be less than the USEPA points of departure (acceptable range).

The Army is proposing to remove the three existing 10,000-gallon gasoline USTs as part of the Fort Devens UST removal program (USACE, 1996). The areas and system components proposed to be removed with the existing gasoline USTs include the associated UST fuel lines/pump islands, and the sand and gas trap with adjacent sand and gas trap contaminated soils. These removals are scheduled for the summer of 1996 prior to signing the ROD. The removal of the sand and gas trap and adjacent soils will minimize the possibility of this area contributing to additional groundwater contamination.

Based on the risk assessment results, the following groundwater remedial action objectives were developed in the FS Report for AOC 43G:

- Protect potential commercial/industrial receptors located on Army Reserve Enclave property from exposure to groundwater having chemicals in excess of the following Preliminary Remediation Goals (PRGs): iron (9,100 micrograms per liter [$\mu\text{g/L}$]), manganese (291 $\mu\text{g/L}$), nickel (100 $\mu\text{g/L}$), benzene (5 $\mu\text{g/L}$), ethylbenzene (700 $\mu\text{g/L}$), and xylenes (10,000 $\mu\text{g/L}$).
- Protect potential commercial/industrial receptors located off Army Reserve Enclave property from exposure to groundwater having chemicals in excess of the above PRGs.

The FS Report identifies and screens response actions and potential remedial technologies that are capable of attaining the remedial action objectives. Remedial alternatives were assembled using these identified remedial technologies. The alternatives are then screened based on the criteria of

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effectiveness, implementability and cost. The five alternatives screened and retained in the FS Report for detailed analysis are:

Alternative 1: No Action

Alternative 2A: Intrinsic Bioremediation

- intrinsic biodegradation
- predesign data collection and modeling
- installing groundwater monitoring wells
- long-term groundwater monitoring
- five-year site reviews

Intrinsic bioremediation is the principal component in Alternative 2A that will prevent contaminants of potential concern (CPCs) that exceed PRGs from migrating off Army Reserve Enclave property. Calculations indicate that intrinsic bioremediation may also reduce on-site CPC concentrations to below PRGs within a time period of less than 30 years. Intrinsic bioremediation modeling would be performed to refine the remediation time period once the sand and gas trap adjacent soils have been removed. Installing four additional monitoring wells and implementing a long-term groundwater monitoring program will enable assessment of the biodegradation progress and permit detection of any migration of contaminants beyond the Army Reserve Enclave boundary. Five-year reviews will be implemented to assess whether the implemented remedy continues to be protective of human health and the environment. Criteria would be established to assess the progress and effectiveness of intrinsic bioremediation. The Army would implement a contingency alternative should Alternative 2A not meet the remedial objectives.

\$39,000	Capital
\$406,300	Operation and Maintenance (O&M) Present Worth (PW)
\$445,300	Total PW (30 years)

Alternative 2B: Intrinsic Bioremediation / Soil Venting of Gasoline UST Soils

- intrinsic biodegradation (Same as Alternative 2A)
- predesign data collection and modeling (Same as Alternative 2A)
- installing groundwater monitoring wells (Same as Alternative 2A)

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- soil venting soils below and adjacent the gasoline USTs
- long-term groundwater monitoring (Same as Alternative 2A)
- five-year site reviews (Same as Alternative 2A)

Alternative 2B involves the same actions as Alternative 2A except that the residual contaminated soils below and adjacent to the former (and now existing) gasoline USTs would also be remediated by soil venting. Soil venting would be achieved by installing a soil vapor extraction (SVE) system within and adjacent to the residual contaminated soil below the gasoline USTs. The objective of soil venting is to remediate the gasoline UST soils to prevent further contamination of the aquifer. The soils that contain VOCs may contribute to groundwater contamination during periods of high water table conditions. Intrinsic bioremediation is the principal component in Alternative 2B that will prevent CPCs that exceed PRGs from potentially migrating off Army Reserve Enclave property.

\$137,600	Capital
\$473,900	Operation and Maintenance (O&M) Present Worth (PW)
\$611,500	Total PW (30 years)

Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

- intrinsic biodegradation (Same as Alternative 2A)
- predesign data collection and design
- groundwater treatment facility construction
- groundwater treatment facility operation and maintenance
- installing groundwater monitoring wells (Same as Alternative 2A)
- long-term groundwater monitoring (Same as Alternative 2A)
- five-year site reviews (Same as Alternative 2A)

Alternative 3 is designed to reduce potential future human health risks by installing a groundwater extraction and treatment system to hydraulically intercept and the contaminant plume immediately downgradient of the source area. The system would be located at the base of the hill, between the AAFES gas station and the car wash. Pumping tests and hydrogeologic modeling would be required to assess the number and location of extraction wells, and flow rates required to intercept the plume. Intrinsic bioremediation of the downgradient plume area

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would prevent CPCs that exceed PRGs from migrating off the Army Reserve Enclave property. This alternative is similar to Alternative 2A except the plume near the source would be intercepted hydraulically rather than relying on intrinsic biodegradation to treat the plume near the source area.

\$257,600	Capital
\$1,444,900	O&M PW
\$1,702,500	Total PW (30 years)

Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

- intrinsic biodegradation (Same as Alternative 2A)
- installing passive bioremediation wells
- passive in-situ bioremediation system maintenance
- predesign data collection and design (Same as Alternative 3)
- groundwater treatment facility construction (Same as Alternative 3)
- groundwater treatment facility operation and maintenance (Same as Alternative 3)
- installing groundwater monitoring wells (Same as Alternative 2A)
- long-term groundwater monitoring (Same as Alternative 2A)
- five-year site reviews (Same as Alternative 2A)

Alternative 4 is designed to provide back-up protection to protect against potential future human health risks off the Army Reserve Enclave property. In addition to the components of Alternative 3, this alternative provides installation of passive in-situ bioremediation system to reduce potential future risk to downgradient receptors from CPCs that exceed PRGs in groundwater. The system would consist of installing approximately 20 2-inch diameter passive bioremediation wells and adding slow release peroxide to the groundwater through these wells. Monitoring for dissolved oxygen, nutrients and possible iron/manganese well fouling would be achieved by installing approximately 16 piezometers upgradient and downgradient of the bioremediation wells.

\$387,400	Capital
\$2,139,800	O&M PW
\$2,527,200	Total PW (30 years)

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The detailed analysis evaluates these five remedial alternatives with respect to seven evaluation criteria defined by CERCLA. The evaluation criteria are divided into three specific categories during remedy selection: Threshold Criteria, Primary Balancing Criteria, and Modifying Criteria. Threshold criteria include Overall Protection of Human Health and the Environment, and Compliance with applicable or relevant and appropriate requirements (ARARs). Alternatives must meet threshold criteria to be chosen as the selected remedy. Primary balancing criteria include: Long-term Effectiveness and Permanence; Reduction of Toxicity, Mobility, and Volume through Treatment; Short-term Effectiveness; Implementability; and Cost. Following the detailed analysis, a comparison of the five remedial alternatives that were the focus of the detailed evaluation is performed, highlighting the relative advantages and disadvantages of the alternatives with respect to the seven evaluation criteria. The evaluation is performed to assist decision-makers in selecting a remedy that cost-effectively meets the remedial action objectives. The summary of the detailed analysis and comparative analysis follows.

Alternative 1 is considered equal to Alternative 2A when comparison is made to threshold criteria except that Alternative 1 compliance would not be able to be monitored. Alternative 1 is similar to Alternative 2A when considering primary balancing criteria except that there would be no effects to site-workers during remedial implementation or cost associated with implementation of Alternative 1. (There is no active remedial action or monitoring implemented in Alternative 1.)

Alternative 2A is similar to Alternatives 2B, 3, and 4 considering threshold criteria in that they all are protective of human health and are expected to eventually meet ARARs. Alternative 2B uses SVE to minimize the potential for groundwater recontamination thereby improving the probability that intrinsic biodegradation can achieve PRGs. However, if gross contamination exists within the bedrock fractures, removal of the gasoline UST residual soil contamination with SVE may not improve groundwater remediation significantly. Alternatives 3 and 4 use backup components to achieve PRGs if intrinsic biodegradation does not perform as anticipated. Alternative 2A would rely on additional data collection, modeling, long-term groundwater monitoring, five-year site reviews and contingencies for additional action to ensure that intrinsic bioremediation is protective of human health and the environment. The added treatment technologies in Alternatives 2B, 3, and 4 can be interpreted as increasing the potential protection of downgradient receptors, although each could be added as

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contingency alternatives to Alternative 2A upon nonperformance of intrinsic biodegradation without jeopardizing overall protection of human health and the environment.

In general, Alternative 2A is also similar to (but in comparing cost, less expensive than) Alternatives 2B, 3, and 4 considering primary balancing criteria. Alternatives 2B, 3, and 4 more favorably offer supplemental or back-up treatment processes which contribute to the reduction of toxicity, mobility and volume of contaminants. However, intrinsic biodegradation is likely to be the controlling factor in determining the time required for remedial action. The back-up treatments in Alternatives 2B, 3, and 4 would generate concentrated waste streams (sludge, filtered material, and spent carbon) that would require disposal. Because of more intrusive activities, monitoring requirements and construction work, the potential for contaminant exposure and safety hazards to workers increases with Alternatives 2A, 2B, 3, and 4, in order presented. The engineering complexity also increases for Alternatives 2A, 2B, 3, and 4, in order presented. Alternatives 2A through 4 all require additional data collection, modeling, or pumping tests prior to design and implementation. Alternative 2A is the least expensive alternative followed by Alternatives 2B, 3, and 4.

Alternative 3 is considered equal to Alternative 4 in comparing with threshold criteria in that they both are protective of human health and will eventually meet ARARs. Alternatives 3 and 4 use active redundant or backup treatment components to stop CPCs that exceed PRGs from migrating off Army Reserve Enclave property. Alternative 3 utilizes groundwater collection and treatment to intercept the more highly contaminated portion of the plume, therefore protecting human health and the environment downgradient of the Army Reserve Enclave boundary. Alternative 4 utilizes both groundwater collection/treatment and passive aerobic bioremediation to ensure protection of human health downgradient of the Army Reserve Enclave boundary. The added active treatment technologies in Alternative 4 can be interpreted as increasing the potential protection for downgradient receptors, although passive bioremediation could be added as a contingency alternative to Alternative 3 upon nonperformance of groundwater extraction and intrinsic biodegradation without jeopardizing overall protection of human health and the environment. Alternative 3 might also be considered equal to Alternative 4 in comparing primary balancing criteria for similar reasons specified for Alternative 2A.

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1.0 INTRODUCTION

ABB Environmental Services, Inc. (ABB-ES), prepared this Feasibility Study (FS) Report for Area of Contamination (AOC) 43G at Fort Devens, Massachusetts in accordance with the U.S. Army Environmental Center (USAEC) Contract DAAA15-91-D-0008, Delivery Order 005.

On December 21, 1989, Fort Devens was placed on the National Priorities List (NPL) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA). In addition, under Public Law 101-510, the Defense Base Realignment and Closure (BRAC) Act of 1990, Fort Devens was selected for cessation of operations and closure. In accordance with these acts, numerous studies, including a Master Environmental Plan (Biang et al., 1992), Enhanced Preliminary Assessment, and Site Investigations (SIs) have been conducted which address potential areas of contamination referred to as Study Areas (SAs) at Fort Devens. A current total of 76 SAs have been identified and placed in 13 priority groups. These SAs are subject to a Federal Facility Agreement (FFA) (Interagency Agreement [IAG]) between the U.S. Department of the Army and the U.S. Environmental Protection Agency (USEPA) for environmental investigations and remedial actions (USEPA, 1991a).

Beginning in 1992, SIs and Supplemental Site Investigations (SSIs) were conducted in SA Group 2. SA 43G, one of 18 historic gas stations at Fort Devens, was an SA in Group 2 that was investigated and designated as an AOC because of the presence of petroleum contamination in the soil and groundwater. The IAG under Section 120 of CERCLA requires that an FS be undertaken at an AOC to develop and analyze potential remedial alternatives leading to a Record of Decision (ROD). The USAEC directed ABB-ES to conduct a Remedial Investigation (RI) and FS to address the contamination of soil and groundwater at AOC 43G. This FS Report is prepared as part of the FS process in accordance with USEPA *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988).

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1.1 PURPOSE AND ORGANIZATION OF REPORT

The purpose of this report is to initially identify and screen potentially feasible alternatives to reduce human health risks at AOC 43G. The initial steps of this process consist of:

- establishing remedial action objectives to reduce actual or potential risks to human health or the environment at AOC 43G.
- identifying the types of response actions for soil and groundwater necessary to achieve remedial action objectives;
- identifying and screening specific remedial technologies that may be capable of attaining remedial action objectives; and
- assembling the selected representative technologies into alternatives which represent a range of treatment and containment combinations as appropriate, and screening these alternatives with respect to the criteria of effectiveness, implementability, and cost.

Following assembly and screening of the remedial alternatives this report presents a detailed analysis and comparison of the retained alternatives. As part of the detailed analysis and comparison, the alternatives are evaluated against seven of nine CERCLA evaluation criteria (USEPA, 1988). The seven criteria are:

1. overall protection of human health and environment;
2. compliance with applicable or relevant and appropriate requirements (ARARs);
3. long-term effectiveness and permanence;
4. reductions in toxicity, mobility, and volume through treatment;
5. short-term effectiveness;
6. implementability; and
7. cost.

The eighth and ninth CERCLA evaluation criteria-- state acceptance and community acceptance-- are modifying criteria and will be addressed following the public information meeting, public hearing, and public comment period. Figure 1-1 is a schematic of the FS process.

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The FS Report is based on information and data presented in the Final RI Report (ABB-ES, 1996), and the Revised Final SI Report (ABB-ES, 1995). The FS Report consists of five sections. Section 1.0 provides a brief description and history of AOC 43G. It summarizes the nature and distribution of contamination and the human health baseline risk assessment presented in the Final RI Report. Because of the nature and location of the site-related contaminants, an ecological baseline risk assessment was not completed.

Section 2.0 identifies remedial action objectives, general response actions, and potentially applicable technologies and process options for AOC 43G. These technologies and process options are screened considering site-specific waste characteristics and applicability to the site. Section 3.0 assembles a number of potential remedial alternatives from the selected technologies and screens them based on effectiveness, implementability and cost.

Section 4.0 provides a detailed analysis of the retained alternatives and evaluates each alternative against the seven CERCLA criteria previously listed. Section 5.0 presents a comparison of the retained alternatives that are the focus of the detailed evaluation, highlighting the relative advantages and disadvantages of the alternatives with respect to the seven evaluation criteria.

1.2 BACKGROUND

1.2.1 Site Description and History

AOC 43G is located on Queenstown Road in the central portion of the Main Post (Figure 1-2). The AOC consists of the inactive Army Air Force Exchange Service (AAFES) gas station and historic gas station G (Figure 1-3). For purposes of field investigations and this FS Report, AOC 43G was divided into three areas. Area 1 is the former location of historic gas station G. Areas 2 and 3 are the locations of the former (and existing) gasoline underground storage tanks (USTs) and the former waste oil UST respectively. The latter two areas are both associated with the AAFES gas station (Figure 1-3).

The original Study Area [SA 43G (Area 1)] was the historic gas station G which was used as a motor vehicle pool to support military operations during World War II. Operations concerning the motor pool were halted during the late 1940s

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or early 1950s. The reported location of the historic gas station was to the southwest of the AAFES gasoline station (Building 2008) and to the southwest of Building 2009 (Figure 1-3). SI and SSI revealed that there was some residual total petroleum hydrocarbon (TPHC) contamination at the site but not at concentrations that present risk to human health and the environment. Details of the SI and SSI work performed at Area 1 are covered in the RI Report (ABB-ES, 1996). Based on the results of the SI and SSI and human health Preliminary Risk Evaluation (PRE), no further action was recommended for Area 1. Therefore, all further discussions within the FS will pertain only to Areas 2 and 3.

The location of the AAFES gasoline station (Areas 2 and 3) is approximately 120 feet northeast of the site of historic gas station G. It consists of the service station (Building 2008) which houses three vehicle service bays and the AAFES store, three existing 10,000-gallon USTs, and associated pump islands (Figure 1-3). At the present time the gas station is not in operation and the AAFES management has been discontinued. The Fort Devens Reuse Plan (BRAC, 1991) has indicated that this gas station will stay within the Army Reserve Enclave and it will continue to be used for Army Reserve operations. Because of the presence of soil and groundwater contamination, an RI and subsequent FS was recommended in the SSI Data Package (ABB-ES, 1994) for Areas 2 and 3.

Area 2

Prior to 1990, the AAFES station stored gasoline in three 9,000-gallon and two 10,000-gallon USTs located on the northeast side of that gas station. These five USTs were removed on October 15 through 19, 1990, and replaced with the three existing 10,000-gallon USTs. The three existing USTs are positioned in the same relative footprint as the three former 9,000-gallon USTs (Figure 1-3). According to the UST removal contractor (Nobis Engineering, Inc. [Nobis]), there was no visual indication of leaks or holes in any of the USTs, but there was some surficial rusting and minor pitting along the sides and the bottom of the three 9,000-gallon USTs. The two removed 10,000-gallon USTs were covered with a protective coating of asphalt and showed no evidence of rusting or pitting (Nobis, 1990).

Soil samples collected from the UST excavations by Nobis were screened in the field with a photoionization detector (PID). Up to 10 soil samples were collected from each UST excavation for screening. Nobis collected two soil samples from each of the UST excavations for off-site laboratory analysis for TPHC using

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USEPA Method 418.1. The results of the laboratory analysis indicated TPHC concentrations ranged from 100 to 3,713 micrograms per gram ($\mu\text{g/g}$). These TPHC concentrations exceeded the Massachusetts Department of Environmental Protection (MADEP) soil standards, at that time, for remediation of contaminated soil (policy #WSC-400-89) (Nobis, 1990).

Because of the elevated TPHC concentrations detected during the UST removals, a soil removal and subsurface soil and groundwater investigation were conducted by Nobis at the AAFES gas station from October 24, 1990 through April 24, 1991 (Nobis, 1991).

The soil sampling consisted of drilling 15 soil borings, sampling subsurface soil, and field screening for total volatile organic compounds (VOCs) using a PID. The soil borings were located in and around the five former gasoline USTs. Results of the field screening indicated total VOCs ranging from non-detect to 2,817 parts per million (ppm). The highest concentrations of total VOCs were detected in soil samples collected from soil borings located on the southeast side of the former gasoline USTs (Nobis, 1991). Details of this investigation and a figure depicting boring locations are located in the Final RI Report (ABB-ES, 1996).

The removal of the contaminated soil from the UST graves was the second activity completed. The soil excavation activity began by removing soil from the northwest portion of the former UST area. The soil was removed, screened for total VOCs using a PID, and stockpiled on polyethylene sheeting on a vacant area of land southeast of Building 2008. Approximately 1,400 tons of soil were excavated from the former UST excavation, including the areas around the initial excavation site. The excavation was extended only 20 feet downward, because of the limited reach of the excavator. Upon completing the excavation activities, Nobis personnel collected 22 soil samples from the walls of the excavation. No samples were collected from the base of the excavation. The soil samples were submitted for laboratory analysis for TPHC using USEPA Method 418.1. The results of the soil samples revealed that TPHC concentrations ranged from 39 to 569 mg/kg in the soil left in the excavation. After the samples were taken, the former UST excavation was backfilled with approximately 1,400 tons of "clean" soil on December 13, 1990.

The final activity completed by Nobis was the installation of seven groundwater

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monitoring wells (AAFES-1D through AAFES-7) (Figure 1-4). The monitoring wells were sampled by Nobis on December 12, 1990. The samples were analyzed at a non-USAEC performance demonstrated off-site laboratory for TPHC only, using USEPA Method 418.1. TPHC concentrations ranged from 1.7 to 5.1 milligrams per liter (mg/L). The results of the groundwater sampling did not exceed the MADEP action levels for remediation for low environmental impact areas (Nobis, 1991).

Based on the review of the design drawings, it is believed that the existing USTs at AAFES gas station were installed in the spring of 1991. Drawings show that three 10,000-gallon USTs were installed within the footprint of the three former 9,000-gallon USTs. The USTs are double wall fiberglass-constructed and placed on an approximate 32-by-32-by-1-foot thick concrete pad. A similarly sized pad was installed at the ground surface over the USTs. Reportedly, the USTs were each furnished with a tank leak detector system, overspill protection, double wall supply line piping, and vapor recovery piping (capped for future connection).

Area 3

On May 27, 1992, a 500-gallon waste oil UST was removed by ATEC Associates Inc. (ATEC). The UST was located behind Building 2008 (Figure 1-3). The UST was found in good condition by ATEC personnel (ATEC, 1992). Soil removed from the side walls and bottom of the UST excavation was reported as "visibly contaminated" and produced a "strong septic odor". Soil samples were taken from the excavation by ATEC personnel for field screening consisting of PID headspace and TPHC screening via non-dispersed infrared (NDIR) spectroscopy. The results of the PID field screening revealed total VOCs ranging from 0.0 to 48 ppm and TPHC concentrations ranging from 6.3 to 28,745 $\mu\text{g/g}$. The highest TPHC concentration was detected along the north wall, followed by the west wall at 28,215 $\mu\text{g/g}$ and the floor at 27,000 $\mu\text{g/g}$.

One soil sample (LSS-1) was collected from the north wall of the excavation and another soil sample (LSS-2) was collected from the bottom of the excavation for laboratory analysis (Figure 1-12). The samples were analyzed for VOCs, semivolatile organic compounds (SVOCs), Priority Pollutant metals, and TPHC. The results of the off-site laboratory analyses indicated that chlorinated solvents (tetrachloroethene [PCE], 1,1,1-trichloroethane, and methylene chloride) were present in samples at a maximum concentration of 0.152 $\mu\text{g/g}$ (PCE in LSS-1).

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Bis(2-ethylhexyl)phthalate (BEHP), pyrene and xylene were also detected (maximum concentrations of 4.17 $\mu\text{g/g}$ in LSS-2, 2.84 $\mu\text{g/g}$ in LSS-1, and 0.069 $\mu\text{g/g}$ in LSS-2, respectively.) TPHC was detected at concentrations of 35,100 $\mu\text{g/g}$ and 23,200 $\mu\text{g/g}$ (LSS-1 and LSS-2, respectively.) A complete discussion of ATEC's data is presented in Section 7.0 of the Final RI Report (ABB-ES, 1996).

Area 3 also contains an existing sand and gas trap. No detailed drawings of this trap have been found. However, this structure is believed to collect fluids from floor drains in Building 2008, trapping floating product for manual removal and discharging water below the ground surface.

1.2.2 Surficial Geology

Surficial soil at AOC 43G is classified as part of the Hinckley-Merrimac (Freetown)-Windsor Association. The soil is described as being deep, excessively drained, nearly level to very steep. Soils from this association were likely excavated and refilled to level ground surfaces at AOC 43G during construction of the AAFES gas station, car wash, and Auto Crafts Shop (Building 1212) (Figure 1-4).

Observations indicate that surficial soils consist of well-graded sand and fill. The fill was used to level the ground surface immediately southeast of the Auto Crafts Shop and in the vicinity of Building 3553 (Figure 1-4). Soil borings were not installed through the fill, but it is presumed that the fill is 6- to 8-feet thick.

1.2.3 Bedrock Geology

Bedrock in the vicinity of AOC 43G is classified as the Oakdale Formation (Zen, 1983). The formation is described as fine-grained metasiltstone and phyllite, consisting of quartz and minor feldspar and ankerite. The metasiltstone and phyllite are commonly deformed by kink banding. Measured depths to bedrock from soil borings indicate that the bedrock surface slopes to the southeast mimicking surficial topography. Figure 1-5 shows the orientation of the geologic cross-sections presented in Figures 1-6 through 1-8. Bedrock beneath the AAFES gas station and the area to the northwest appears to be relatively flat with a localized high beneath the western side of the former and existing gasoline USTs (Area 2) (Table 1-1, Figure 1-9). The maximum observed bedrock elevation at AOC 43G, 289.3 feet mean sea level (MSL), was at the soil boring XGB-93-07X

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located along the western side of the former and existing gasoline USTs (Figure 1-9). The lowest measured bedrock elevation, 254.7 feet MSL, was encountered in monitoring well XGM-94-06X and piezometer XGP-94-02X, both of which are located 65 feet northwest of Building 3553 (Figure 1-9). The bedrock surface in the vicinity of AOC 43G is highly weathered, resulting in a gradational change from overburden till to bedrock. For purposes of this report, the bedrock surface was defined as the point at which hollow-stem augers (HSAs) and split-spoons met refusal.

Bedrock coring was performed at 10 monitoring well borings at AOC 43G: AAFES-1D, AAFES-2, XGM-94-03X, XGM-94-04X, XGM-94-05X, XGM-94-07X, XGM-94-08X, XGP-94-05X, XGP-94-06X, and XGP-94-07X (Figures 1-5 through 1-8 and Table 1-2). The rock core samples collected are light gray to rust brown phyllite. The bedding is comprised of thin laminae that are severely deformed via banding and folding. Existing fractures occur primarily along bedding planes, although both natural and mechanical fractures were noted perpendicular to bedding. As all samples were collected via rock core, it was not possible to orient the fractures directionally. Fracture dips ranged between 0 and 50 degrees with the majority dipping at approximately 45 degrees. Secondary quartzite and calcite replacement was noted along fractures. Secondary mineralization has resulted in numerous healed fractures. Iron staining was observed in some of the fractures along with secondary sulfides (pyrite) and less prevalent greenish staining possibly indicating secondary chlorides (monitoring well XGM-94-05X only). Evidence of mud seams and heavily fractured (rubble) zones were noted in monitoring wells XGM-94-04X, XGM-94-07X, and XGM-94-08X, and in piezometers XGP-94-05X, XGP-94-06X, and XGP-94-07X. Small, iron stained solution cavities, 0.05 to 0.1 foot in diameter were also observed in piezometer XGP-94-06X.

1.2.4 Site Hydrology

Surface water drainage at AOC 43G is controlled predominantly by pavement, topography and a storm water collection system. The unpaved areas of AOC 43G are well-drained with no indication of seasonal ponding or wetlands environment. Precipitation runoff apparently follows topography which slopes away to the southeast (Figure 1-5). The storm water collection system outfall is located 600 feet northeast of the AAFES gas station along the southern side of Queenstown Road. A drainage ditch runs southeast away from the outfall. Seasonal ponding has been observed in the outfall's drainage ditch southeast of

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AOC 43G in the vicinity of monitoring well AAFES-7. A small northeasterly flowing stream exists 1,000 feet southeast of the AAFES gas station. The stream drains the Ammunition Storage Area and flows into Robbins Pond 1,500 feet east of the AAFES gas station.

1.2.5 Site Hydrogeology

Groundwater at AOC 43G occurs in overburden till and the metasiltstone and phyllite bedrock. Depth to groundwater at the site ranges between approximately 15 and 29 feet below ground surface (bgs) (Figures 1-7 and 1-8). The predominant groundwater flow direction at the site is to the east-southeast with the horizontal gradient varying seasonally between 0.036 and 0.052 feet/foot across the site. Interpretive water table elevation contours for January 1995 are depicted in Figure 1-10. Water level data indicate that the area around monitoring well XGM-94-06X is particularly sensitive to recharge. In-situ hydraulic conductivity estimates yield a mean value of 5.5×10^{-4} cm/sec for monitoring wells screened entirely in the overburden, and 1.7×10^{-5} cm/sec for monitoring wells screened entirely in the bedrock. Results of water level surveys and aquifer pumping tests indicate that there is little differentiation between the overburden and bedrock aquifers.

The overburden aquifer pumping tests conducted at monitoring well XGM-94-06X yielded transmissivity values ranging between 27 and 134 square feet/day. These values are consistent with the in-situ hydraulic conductivity estimates. Storativity values ranged between 0.16 and 0.001. Transmissivity and storativity values are consistent with observed geology and unconfined situations. A zone of influence of 80 feet was calculated by distance drawdown analysis for XGM-94-06X at 0.4 gallons per minute (gpm).

The bedrock aquifer pumping test conducted at monitoring well XGM-94-04X yielded transmissivity values ranging between 27 and 340 square feet/day. These values are commensurate with the transmissivity calculated for the monitoring well XGM-94-06X test. Storativity values calculated from the monitoring well XGM-94-04X test data ranged between 0.001 and 0.07, which is slightly lower than the storativities estimated from the monitoring well XGM-94-06X test. Evidence of linear flow was noted during the XGM-94-04X pumping test at locations XGM-94-04X, XGP-94-05X, XGP-94-06X, and XGP-94-07X. According to Jenkins and Prentice (1982) the presence of linear flow characteristics indicates

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that flow between monitored wells is controlled by one or more major fractures. The permeability of these fractures is many orders of magnitude higher than the permeability of the surrounding aquifer thereby causing the fractures to behave as an extension of the pumped well. In linear systems flow lines are parallel, and drawdown is dependent on the perpendicular distance from the extended well (fractures) and not dependent on the radius from the pumped well. Flow characteristics within the bedrock aquifer in the vicinity of monitoring well XGM-94-04X were shown to be dependent on water level.

Results of the overburden aquifer pumping test conducted at monitoring well XGM-94-06X indicate that it would be possible to institute a groundwater extraction system within the overburden till. Drawdown was observed in all of the observation piezometers and a zone of influence of 80 feet was calculated by distance drawdown analysis at a pumping rate of 0.4 gpm.

Analysis of the bedrock aquifer pumping test conducted at monitoring well XGM-94-04X indicates that an extraction system would be viable within the shallow bedrock and weathered bedrock/overburden interface. The observed linear flow characteristics near monitoring well XGM-94-04X would allow an extraction system to benefit from the fractures behaving as an extended well. Drawdown observed during the pumping test in piezometers/monitoring wells XGP-94-01X, XGM-94-10X, XGM-94-03X, XGM-93-02X, AAFES-6, and AAFES-1D suggests that it would be possible to institute a groundwater extraction system. However, in-situ hydraulic conductivity testing at monitoring wells AAFES-1D, AAFES-2, XGM-93-02X, and XGM-94-03X indicates that these locations probably lack sufficient hydraulic characteristics to support an extraction system.

1.3 NATURE AND DISTRIBUTION OF CONTAMINATION AT AREAS 2 AND 3

An SSI and an RI were conducted by ABB-ES at Areas 2 and 3 of AOC 43G.

August 1993 Supplemental Site Investigation: The SSI was conducted at the historic gas station as well as at the potential source areas at the AAFES gas station (Figure 1-11). The activities conducted at the potential source areas (Areas 2 and 3) at the AAFES gas station are summarized below. Analyses of soil and groundwater samples were for parameters shown in Table 1-3.

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- A total of 34 TerraProbe™ points around the existing gasoline USTs and the former waste oil UST were completed (TS-01 through TS-34). Up to two soil samples were collected from each point and analyzed in the field for benzene, toluene, ethylbenzene, and xylenes (BTEX) and TPHC.
- Five soil borings were completed at apparent "hot spots" identified by the TerraProbe™ survey at the AAFES gas station (XGB-93-03X through -07X).
- Two groundwater monitoring wells were installed at the AAFES gas station (one upgradient and one downgradient of the existing gasoline USTs) to supplement the existing monitoring well network (XGM-93-01X and -02X.) Table 1-2 summarizes the construction of these monitoring wells.
- Two rounds of groundwater samples were collected from the newly installed monitoring wells and existing monitoring wells.

August 1994 Remedial Investigation: The RI was conducted at the potential source areas at the AAFES gas station and downgradient areas (Figure 1-4). Major field activities performed are detailed below. Analyses of soil and groundwater samples were for parameters shown in Table 1-3.

- Soil samples from soil borings were field analyzed using a gas chromatograph (GC) and infrared spectrophotometer (IR), and groundwater using a GC.
- Six soil borings were completed adjacent to the existing USTs in Area 2 (XGB-94-10X through -15X).
- Eight water table monitoring wells were installed downgradient and crossgradient of Areas 2 and 3 to supplement the existing monitoring well network (XGM-94-03X through -10X). Table 1-2 summarizes the construction of these monitoring wells.
- Seven piezometers were installed to support aquifer pumping tests at two monitoring wells. (XGP-94-01X through XGP-94-07X).

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- Two rounds of groundwater samples were collected from the newly installed and existing monitoring wells.
- A soil vapor extraction (SVE) / bioventing pilot study was conducted in the vicinity of the former gasoline USTs. (See Appendix O of the Final RI Report [ABB-ES, 1996]).

1.3.1 Field Analytical Soil Results

1.3.1.1 Area 2.

TerraProbe™ Sample Results. No field analytical soil samples were collected from Area 2 during the SI field investigation. However, during the SSI field investigation, a total of 23 TerraProbe™ points (TS-12 through TS-34) were completed around the existing gasoline USTs. Up to two soil samples were collected from each point and analyzed in the field for BTEX and TPHC. Soil samples were not collected from TerraProbe™ points TS-12, TS-15 to TS-17, and TS-27 because of underground utilities. The sample depth ranged between 9 and 13 feet bgs.

TPHC was detected in 14 of the 22 samples collected. TPHC concentrations ranged from below the detection limit ($<52 \mu\text{g/g}$) to $5,800 \mu\text{g/g}$ in the 9-foot sample from TS-31. TPHC contamination was found in the deepest sample collected at 13 feet ($160 \mu\text{g/g}$ at TS-22). The concentrations were highest in the soil samples collected from the points located south and east of the existing gasoline USTs. Toluene was detected at a concentration of $0.0013 \mu\text{g/g}$ in the 9-foot sample from TS-31. Xylene was detected also in this sample at $0.0009 \mu\text{g/g}$ (meta/para [m/p]) and $0.001 \mu\text{g/g}$ (ortho). The only other VOC detected was o-xylene at $0.0063 \mu\text{g/g}$ in the 10-foot sample from TS-13.

No TerraProbe™ samples were collected from Area 2 during the 1994 RI field investigation.

Soil Boring Field Analytical Sample Results. Field analytical sampling showed that soil contamination from toluene, ethylbenzene, and xylenes (TEX) was present beginning at approximately 16 feet bgs and continuing to the top of bedrock between 27 and 30 bgs in XGB-94-10X, XGB-94-11X, and XGB-94-12X. Benzene was detected as well in the 27-foot sample from XGB-94-11X at a

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concentration of $0.018 \mu\text{g/g}$. Benzene was likely present in the other samples containing TEX, but because of the dilutions necessary to perform the analysis the detection limits for benzene ranged between 0.55 and $2.8 \mu\text{g/g}$. BTEX was not detected in any of the four samples (10, 15, 20, and 30 feet bgs) collected from XGB-94-13X. Individual minimum and maximum TEX detections ranged between $0.02 \mu\text{g/g}$ of toluene (XGB-94-11X, 27 feet) and $210 \mu\text{g/g}$ of m/p xylene (XGB-94-12X, 25 feet). TPHC concentrations ranged from $340 \mu\text{g/g}$ (XGB-94-12X, 15 feet) to $3,800 \mu\text{g/g}$ (XGB-94-12X, 20 feet). No targeted chlorinated VOCs were detected within Area 2 field screening samples. But because of the dilutions necessary to perform the analysis, the detection limits for the selected chlorinated VOCs ranged between $0.002 \mu\text{g/g}$ and $5.7 \mu\text{g/g}$. Despite the elevated detection limits in some of field analyses, laboratory analytical results (Subsection 1.3.2.1) indicate that no significant chlorinated solvent soil contamination exists in this area. Field screening indicated that fuel-related (BTEX) volatile contaminants were present in XGB-94-10X through XGB-94-12X but not in XGB-94-13X.

1.3.1.2 Area 3.

TerraProbe™ Sample Results. No field analytical soil samples were collected from Area 3 during the SI or RI field investigations. During the SSI field investigation a total of 11 TerraProbe™ points (TS-01 through TS-11) were completed in and around the former waste oil USTs and the existing sand and gas trap located behind the AAFES gas station (Figure 1-11). Up to two soil samples were collected from each point and analyzed in the field for BTEX and TPHC. No samples were collected from TS-06, TS-09 and TS-11 because of subsurface obstructions.

TEX contamination was detected in six of the 11 soil samples. Benzene was detected at $0.14 \mu\text{g/g}$ in only one sample, TS-08 at 10 feet. Total BTEX ranged from below the detection limit to $32.9 \mu\text{g/g}$ in the 10- to 11-foot sample from TS-08. Individual minimum and maximum detected concentrations ranged from $0.0003 \mu\text{g/g}$ of m/p xylene (TS-02, 10 feet) to $14.0 \mu\text{g/g}$ of ethylbenzene (TS-08, 10 feet). Area 3 VOC contamination appears to be confined to the area of the former waste oil UST excavation and existing sand and gas trap. TPHC concentrations ranged from below the detection limit ($<54 \mu\text{g/g}$) to $8,500 \mu\text{g/g}$ in the 9-foot sample from TP-02.

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1.3.2 Laboratory Analytical Soil Results

1.3.2.1 Area 2.

Soil Boring Results. No subsurface soil samples were collected from Area 2 during the SI. The off-site laboratory results for the six soil samples collected from the three soil borings drilled in Area 2 (XGB-93-05X, XGB-93-06X, and XGB-93-07X) during the SSI showed low concentrations (below $1.0 \mu\text{g/g}$) of VOCs (acetone and/or trichlorofluoromethane [freon] which are common laboratory contaminants), and SVOCs consisting predominantly of polynuclear aromatic hydrocarbons (PAHs). TPHC was detected in the 6- to 8-foot sample at $185 \mu\text{g/g}$ in XGB-93-05X and in the 10- to 12-foot sample at $158 \mu\text{g/g}$ in XGB-93-06X. Each of these soil borings was advanced to refusal on apparent bedrock.

Several inorganic analytes were detected above their Fort Devens background concentrations in the subsurface soil sample collected from the SSI borings. These analytes are listed and evaluated in Section 1.4 Summary of Human Health Risk Assessment, and in Table 1-4.

The off-site results for the soil samples collected from Area 2 during the RI field program, indicated that BTEX was present in soil directly adjacent to the then-active gasoline USTs. Total BTEX concentrations (which are primarily total xylenes) ranged from $372 \mu\text{g/g}$ in the 25- to 27-foot sample from XGB-94-10X to $0.0037 \mu\text{g/g}$ of xylenes in the 25- to 27-foot sample from XGB-94-13X. Low concentrations of benzene ($0.0027 \mu\text{g/g}$) and total xylenes ($0.0051 \mu\text{g/g}$) were detected in the 15- to 17-foot samples from XGB-94-14X.

SVOCs were detected also in soil samples collected from the soil boring completed directly adjacent to the then-active gasoline USTs (XGB-94-10X through XGB-94-13X). A majority of the SVOCs detected were PAHs, although BEHP (common laboratory contaminant) was also detected in several subsurface soil samples. A majority of the PAHs were detected in the soil sample collected from XGB-94-10X and XGB-94-11X. Additional PAHs were also detected in the 27 to 29-foot sample from XGB-94-12X.

TPHC was detected in 11 of 12 soil samples collected from Area 2 during the RI. Concentrations in soil borings XGB-94-10X through XGB-94-13X ranged from

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40.5 $\mu\text{g/g}$ in the 25- to 27-foot sample from XGB-94-13X, to 1,730 $\mu\text{g/g}$ in the 27- to 29-foot sample from XGB-94-12X. Concentrations of TPHC ranged from below the detection limit ($<28 \mu\text{g/g}$) to 41.5 $\mu\text{g/g}$ in the soil samples collected from XGB-94-14X and XGB-94-15X.

Several inorganic analytes were detected above their Fort Devens background concentrations in each of the soil samples collected during the RI. These analytes are listed and evaluated in Section 1.4 Summary of Human Health Risk Assessment and in Table 1-4.

1.3.2.2 Area 3. Off-site laboratory results for Area 3 indicated some low concentrations of VOCs from samples collected from soil borings XGB-93-03X and XGB-93-04X. These two borings were drilled in or adjacent to the former waste oil UST and the existing sand and gas trap. BEHP and di-n-butyl phthalate (common laboratory contaminants) were the only SVOCs detected in Area 3. TPHC concentrations ranged from 40.8 $\mu\text{g/g}$ (25- to 27-foot soil sample) to 1,020 $\mu\text{g/g}$ (6- to 8-foot soil sample) at XGB-93-04X. TPHC concentrations were only 62.6 $\mu\text{g/g}$ (18- to 20-foot soil sample), 59.2 $\mu\text{g/g}$ (10- to 12-foot soil sample), and 359 $\mu\text{g/g}$ (6- to 8 foot soil sample) at XGB-93-03X.

Several inorganic analytes were detected above their Fort Devens background concentrations in the subsurface soil samples collected from the SSI borings. These analytes are listed and evaluated in Section 1.4 Summary of Human Health Risk Assessment and in Table 1-4.

1.3.3 Groundwater

Previous Investigation Groundwater Results. As part of the 1991 gasoline UST removal program, a total of seven groundwater monitoring wells (AAFES-1D through AAFES-7) were installed by Nobis (Figure 1-11). The monitoring wells were analyzed only for TPHC at a non-USAEC performance demonstrated laboratory. TPHC concentrations ranged from 1.7 to 5.1 mg/L.

SSI Groundwater Results. During the 1993 SSI two groundwater monitoring wells (XGM-93-01X and XGM-93-02X) were installed around Areas 2 and 3 to enhance the existing groundwater monitoring network. They were installed to monitor upgradient (XGM-93-01X) and downgradient (XGM-93-02X) groundwater quality (Figure 1-11).

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SECTION 1

Two rounds (Round Three and Four) of groundwater samples were collected from the new and existing monitoring wells. These samples were submitted to an off-site laboratory for analysis of project analyte list (PAL) VOCs, SVOCs, inorganics (both filtered and unfiltered), TPHC, and total suspended solids (TSS) (Table 1-3).

The results of the Round Three and Four laboratory analysis showed the presence of several VOCs and SVOCs (including acetone which is a common laboratory contaminant, BTEX, PCE, naphthalene, and 1,2-dichloroethane [1,2-DCA]) in the groundwater samples collected from the downgradient and crossgradient monitoring wells. Benzene, ethylbenzene, and naphthalene were the only compounds detected above maximum drinking water standards/guidelines in monitoring wells directly downgradient of Areas 2 and 3 (XGM-93-02X, AAFES-1D, AAFES-2, and AAFES-6). Concentrations of benzene ranged from 13 micrograms per liter ($\mu\text{g/L}$) in AAFES-6 to 2,000 $\mu\text{g/L}$ in XGM-93-02X. Ethylbenzene concentrations ranged from 200 $\mu\text{g/L}$ in AAFES-1D to 2,000 $\mu\text{g/L}$ in AAFES-2. Concentrations of naphthalene ranged from 2.5 $\mu\text{g/L}$ in AAFES-6 to 4,000 $\mu\text{g/L}$ in AAFES-2.

TPHC was detected in Round Three and Four groundwater samples collected from the existing upgradient monitoring well, AAFES-3 (5,170 and 190 $\mu\text{g/L}$, respectively). No VOCs or SVOCs were detected in either SSI round collected from AAFES-3. No VOCs, SVOCs or TPHC were detected in the samples collected from the upgradient monitoring well XGM-93-01X. The monitoring wells directly downgradient of Areas 2 and 3 (XGM-93-02X, AAFES-1D, AAFES-2 and AAFES-6), had TPHC concentrations that ranged from 274 $\mu\text{g/L}$ at AAFES-6 to 120,000 $\mu\text{g/L}$ at AAFES-2.

Both filtered and unfiltered inorganic groundwater samples were collected during the SSI. Several inorganic analytes were detected above their respective Fort Devens groundwater background concentrations in the unfiltered groundwater samples. Calcium, magnesium, manganese, potassium, and sodium were the only inorganic analytes detected above respective Fort Devens background concentrations in the filtered groundwater samples collected during Rounds Three and Four.

RI Groundwater Results. As part of the RI field investigation, ABB-ES installed eight additional groundwater monitoring wells (XGM-94-03X through

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XGM-94-10X) downgradient and crossgradient of Areas 2 and 3 to supplement the existing monitoring well network (Figure 1-4). Two rounds of groundwater sampling (Rounds Five and Six) were collected from each of the new and existing monitoring wells.

The results of the Rounds Five and Six laboratory analysis showed the presence of several VOCs and SVOCs (including acetone, BTEX, PCE, 2,4-dimethylphenol, 4-methylphenol, 2-methylnaphthalene, acenaphthene, anthracene, BEHP, fluorene, naphthalene, phenanthrene, carbon disulfide, methylene chloride, methyl isobutyl ketone, and trichlorofluoromethane [freon]) in monitoring wells located downgradient and crossgradient of Areas 2 and 3. The highest concentrations of site-related contaminants (BTEX, naphthalene, and 2-methylnaphthalene) were detected in the monitoring wells directly downgradient of Areas 2 and 3 (AAFES-1D, AAFES-2, AAFES-6, XGM-93-02X, XGM-93-03X, and XGM-94-04X). Analysis of samples from monitoring wells XGM-94-06X, XGM-94-07X, XGM-94-08X, and XGM-94-10X (located further downgradient) showed lower concentrations of these site-related contaminants. PCE was detected in XGM-94-07X (3.8 $\mu\text{g/L}$ in Round Five and 3.3 $\mu\text{g/L}$ in Round Six), AAFES-5 (2.1 $\mu\text{g/L}$ in Round Five) and XGM-94-05X (2.4 $\mu\text{g/L}$ in Round 6). These monitoring wells are located downgradient and crossgradient of Areas 2 and 3. BEHP, acetone, and trichlorofluoromethane (common laboratory contaminants) were detected in a number of samples.

Concentrations of benzene ranged from 0.56 $\mu\text{g/L}$ at monitoring well XGM-94-10X (Round Six) to 2,000 $\mu\text{g/L}$ at monitoring wells AAFES-2 and XGM-93-02X (Round Five). Toluene was detected at concentrations ranging from 0.51 $\mu\text{g/L}$ in monitoring well XGM-94-06X (Round Five) to a maximum of 300 $\mu\text{g/L}$ at AAFES-2 (Round Five). Ethylbenzene concentrations ranged from 0.95 $\mu\text{g/L}$ in monitoring well XGM-94-09X (Round Six) to 2,000 $\mu\text{g/L}$ in AAFES-2 (Round Five). Xylenes were detected at concentrations ranging from 1.3 $\mu\text{g/L}$ in AAFES-6 (Round Five) to 20,000 $\mu\text{g/L}$ in AAFES-2 (Round Five). Based on these results, the highest concentration of contamination is apparently in the groundwater in the vicinity of AAFES-2.

Several inorganic analytes were detected above the Fort Devens groundwater background concentrations in the unfiltered samples. Antimony, arsenic, barium, calcium, copper, iron, magnesium, manganese, nickel, potassium, and sodium were the inorganic analytes detected above background in the filtered groundwater

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samples collected during Rounds Five and Six.

1.3.4 Summary of Soil and Groundwater Analytical Results

Soil. Analytes detected in soil samples collected from tank areas at AOC 43G are consistent with the historical use of this area as a gas station. The BTEX and TPHC concentrations detected in Areas 2 and 3 indicated that residual soil contamination is still present in the tank areas from previous spills and leaks associated with the former waste oil and gasoline USTs. Soil borings (XGB-94-14X and XGB-94-15X) drilled in areas near the existing fuel distribution lines confirm that no additional soil contamination is present in the fuel line areas. These borings were located at the portions of the fuel distribution lines that exhibited fuel contamination during the UST removal program completed by Nobis in 1990.

Groundwater. The distribution of the groundwater contamination appears to confirm that the groundwater contaminant source is the apparent residual soil contamination adjacent to and potentially below the existing gasoline USTs in Area 2, and potentially the residual soil contamination in Area 3.

The highest concentrations of BTEX and PAHs were detected in the monitoring wells at the base of the slope directly downgradient of Areas 2 and 3 (AAFES-1D, AAFES-2, AAFES-6, XGM-93-02X, XGM-94-03X, and XGM-94-04X). The highest concentrations from these monitoring wells was in AAFES-2.

BTEX was detected in several downgradient (XGM-94-06X, XGM-94-07X, XGM-94-08X and XGM-94-10X) and a crossgradient (XGM-94-09X) monitoring wells. Concentrations were in exceedance of drinking water standards in XGM-94-10X, XGM-94-08X, and XGM-94-07X.

Based on historical use, a potential source of chlorinated VOCs would be the former waste oil storage tank area. However, the detections/distribution of chlorinated VOCs in groundwater were noted to be somewhat sporadic and not necessarily from this potential source area. (i.e., PCE was detected in monitoring well AAFES-5 (Rounds Three, Four and Five) which is not as directly downgradient of the waste oil storage tank as monitoring well AAFES-6. Yet AAFES-6, which exhibits petroleum contamination, did not reveal the presence of PCE above detection limits [1.6 µg/L]). Therefore, the PCE either has a different

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migratory path through the bedrock if the former waste oil storage tank is the source area, or there is potential off-site, upgradient or cross-gradient source unrelated to AAFES gas station activities.

The source of detected chlorinated VOCs is not fully known. The detections/distribution of chlorinated VOCs in groundwater were noted to be somewhat sporadic and not necessarily related to Area 2 and 3. PCE was detected in monitoring well AAFES-5 (Rounds Three, Four and Five) which is not as directly downgradient of the apparent BTEX source areas as monitoring well AAFES-6. However, AAFES-6 has shown no concentrations of chlorinated solvents. Based on this data, and the lack of chlorinated VOCs in soil samples collected from Areas 2 and 3, it appears that the source area for the chlorinated solvents may not be the same as the sources of the BTEX contamination. Concentrations of chlorinated solvents did not exceed drinking water standards in any source area or downgradient monitoring wells.

1.4 SUMMARY OF HUMAN HEALTH RISK ASSESSMENT

A baseline human health risk assessment was conducted to evaluate potential health risks to individuals under current or foreseeable future site conditions at AOC 43G. This risk assessment is presented in the Final RI Report (ABB-ES, 1996). Based on the results of the SI, the SSI, and the Human Health Preliminary Risk Evaluation conducted in the SSI Data Package (ABB-ES, 1994), no further action was recommended for Area 1 (historic gas station G). The focus of the risk assessment for AOC 43G was on the subsurface soil and groundwater associated with Area 2, the existing gasoline USTs, and Area 3, the former waste oil UST and sand and gas trap.

1.4.1 Risk Assessment Considerations

Risk assessments were prepared to evaluate the following data:

- Subsurface soil data collected from the source area
- Groundwater data collected from the source area
- Groundwater data collected from downgradient areas

Rounds Five and Six groundwater analytical data were used in the evaluation.

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These rounds were selected because groundwater data from all monitoring wells (including wells installed as part of the RI) was collected during these rounds. Also considered were all available subsurface soil data taken above 15 feet bgs from Areas 2 and 3. This includes analytical data collected during the SSI and the RI. Data from the 1992 ATEC waste oil UST removal action were used only qualitatively in the risk assessment.

An exposure assessment was conducted to identify the potential pathways by which human populations may be exposed to chemicals at AOC 43G. Exposures under both current and potential future site use and surrounding land use conditions were evaluated. The future use of AOC 43G is expected to be similar to its current use; it is being retained to support Army Reserve operations. No construction (other than the removal of the USTs and pump islands, sand and gas trap, and associated contaminated soil [Subsection 1.6]) is anticipated at AOC 43G in the foreseeable future. Also, according to the Devens Reuse Plan (Vanasse Hangen Brustlin, 1994), the area downgradient of the Army Reserve Enclave property will be used for Innovation and Technology Business and open space/recreation. Therefore, drinking water supplies for residential recipients would not be expected within these immediate downgradient areas. (Figures depicting the Army Reserve Enclave property in relation to the position of the site and potential remedial alternative components are presented in Section 4.0 [Figures 4-1 and 4-3]).

For subsurface soil, the exposure scenario evaluated was a utility/maintenance worker involved in excavation activities (i.e., UST or utility line repair). The two principal routes by which workers could be exposed to chemicals in soil are ingestion and dermal contact. For groundwater, the receptor evaluated was a future commercial/industrial worker using groundwater at the site as a drinking water source. Ingestion of groundwater as a drinking water source was the exposure route evaluated.

Chemicals of Potential Concern (CPCs) for each scenario are presented in Table 1-4.

1.4.2 Subsurface Soil Data - Source Area

Potential health risks associated with current and future exposure to subsurface soil at Areas 2 and 3 of AOC 43G were evaluated. Estimated carcinogenic risks

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associated with exposures to subsurface soil did not exceed the USEPA target risk range of 1×10^4 to 1×10^6 or the Massachusetts Contingency Plan (MCP) target cancer risk level of 1×10^5 . Similarly, estimated noncarcinogenic exposures did not exceed the USEPA or MCP target level of 1. Total carcinogenic and noncarcinogenic risks assuming exposure to mean and to maximum concentrations are included in Table 1-5.

1.4.3 Groundwater - Source Area

Risks associated with the potential future use of site groundwater as a potable water source were evaluated using unfiltered and filtered data sets from source area monitoring wells. In each case, the receptor evaluated was a future commercial/industrial worker.

Estimated carcinogenic risks are at the upper limit of or exceed the USEPA target risk range and the MCP target cancer risk level (Table 1-5). The estimated cancer risk associated with unfiltered source area groundwater assuming exposures to mean concentrations is 1×10^4 . Contribution to the risk is shared equally by arsenic (49 percent) and benzene (51 percent). The individual cancer risk for each compound is 6×10^5 . The estimated risk assuming exposure to maximum concentrations is 6×10^4 . Arsenic (64 percent) and benzene (36 percent) are again the major risk contributors; their respective individual risks are 4×10^4 and 2×10^4 .

The estimated carcinogenic risk associated with filtered source area groundwater assuming exposure to mean concentrations is 1×10^4 . Contribution to the risk is shared by arsenic (53 percent) and benzene (47 percent). The individual cancer risks are 7×10^5 for arsenic and 6×10^5 for benzene. The estimated risk assuming exposure to maximum concentrations is 4×10^4 . Arsenic (42 percent) and benzene (58 percent) are the major risk contributors; their respective individual risks are 1.5×10^4 and 2×10^4 .

Estimated noncarcinogenic risk, expressed as a hazard index (HI) value, also exceed the USEPA and MCP target level. The noncarcinogenic HI value for unfiltered source area groundwater is estimated at 37 assuming exposures to mean concentrations, and at 99 for exposures to maximum concentrations. Based on mean concentrations, the primary contributors to the noncarcinogenic risk are manganese at 41 percent, benzene at 55 percent and iron at 2 percent. Respective hazard indices are 15, 20 and 0.84. For maximum concentrations, the

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contributors to noncarcinogenic risk are arsenic at 2 percent, iron at 3 percent, manganese at 28 percent, and benzene at 66 percent. Respective hazard indices are 1.9, 2.8, 28, and 65.

The noncarcinogenic HI value for filtered source area groundwater is estimated at 36 assuming exposures to mean concentrations, and at 98 for exposures to maximum concentrations. The primary contributors to the noncarcinogenic risk based on mean concentrations are manganese at 41 percent and benzene at 56 percent. Respective hazard indices are 15 and 20. For maximum concentrations, the contributors to noncarcinogenic risk are iron at 2 percent, manganese at 30 percent, and benzene at 67 percent. Respective hazard indices are 1.8, 30 and 65.

1.4.4 Groundwater - Downgradient

Risks associated with the potential future use of site groundwater as a potable water source were evaluated using unfiltered and filtered data sets from downgradient monitoring wells. In each case, the receptor evaluated was a future commercial/industrial worker.

Estimated carcinogenic risks for both filtered and unfiltered downgradient groundwater exceed the USEPA risk range in one case and exceed the MCP target level in all cases. The estimated cancer risk associated with unfiltered downgradient groundwater assuming exposure to mean concentrations is 6×10^5 . The major risk contributors are arsenic (97 percent) and benzene (3 percent); their respective individual risks are 6.1×10^5 and 2×10^6 . For exposure to maximum CPC concentrations in downgradient groundwater, the total cancer risk is 2×10^4 . Arsenic (94 percent) and benzene (5 percent) are the major contributors to the risk. Respective individual risks are 1.4×10^4 and 8×10^6 .

For filtered downgradient groundwater, estimated cancer risk is 5×10^5 for exposure to mean concentrations of CPCs. Arsenic and benzene contribute 95 percent and 5 percent respectively to the risk in this scenario. Respective individual risks are 4.3×10^5 and 2.0×10^6 . For exposure to maximum CPC concentrations in filtered downgradient groundwater, the total cancer risk is 9×10^5 . Arsenic and benzene contribute 91 percent and 8 percent to the risk, respectively. Respective individual risks are 8.6×10^5 and 8×10^6 .

Estimated noncarcinogenic exposures exceeded the USEPA and MCP target level

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for both filtered and unfiltered downgradient groundwater. The noncarcinogenic HI value for unfiltered downgradient groundwater is estimated at 11 assuming exposures to mean concentrations, and at 21 for exposures to maximum concentrations. Based on mean concentrations, manganese, benzene and arsenic are the primary noncarcinogenic risk contributors at 90 percent, 5 percent and 3 percent respectively. Respective individual hazard indices are 10, 0.5 and 0.3, respectively. For exposures to maximum concentrations, manganese contributes 82 percent of the risk and benzene and arsenic add 12 percent and 4 percent, respectively. Individual hazard indices are 17, 2.6 and 0.8 respectively.

The noncarcinogenic HI value for filtered downgradient groundwater is estimated at 11 assuming exposures to mean concentrations, and at 21 for exposures to maximum concentrations. The primary risk contributor based on mean concentrations are manganese, benzene, and arsenic which contribute 92 percent, 5 percent and 2 percent of the risk, respectively. Individual hazard indices are 10, 0.52, and 0.23, respectively. For exposures to maximum concentrations, manganese contributes 84 percent of the risk and benzene and arsenic contribute 12 percent and 2 percent respectively. Individual hazard indices are 17, 2.6 and 0.8, respectively.

1.5 ECOLOGICAL RISK

A baseline ecological risk assessment was not completed for AOC 43G because no significant habitat for resident or migratory ecological receptors is present at AOC 43G and contamination is limited predominantly to subsurface soil and groundwater. The site is mostly paved and has been used historically as a gas station.

1.6 SCHEDULED REMOVAL ACTIONS

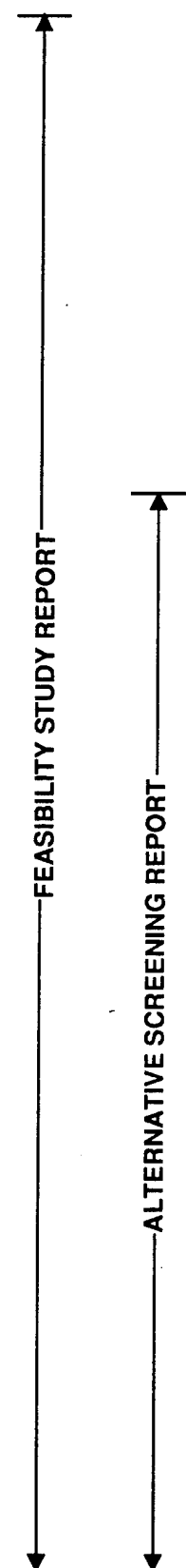
The Army is proposing to remove the three existing 10,000-gallon gasoline USTs as part of the Fort Devens UST removal program (USACE, 1996). The areas and system components proposed to be removed with the existing gasoline USTs include the associated UST fuel lines/pump islands, and the sand and gas trap with adjacent sand and gas trap contaminated soils. These removals are scheduled for the summer of 1996 prior to signing the ROD.

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The Army does not propose to remove the soils which contain residual fuel contamination below the existing gasoline USTs, or adjacent to the former waste oil UST as part of this tank removal action. Further discussion regarding these soils is provided in Subsection 2.2.2.

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Remedial Investigation

- Define Physical Characteristics
- Assess Contamination
- Evaluate Risk

Remedial Objectives

- Develop Remedial Action Objectives
- Develop General Response Actions

Alternatives Development

- Identify Potential Technologies
- Screen Technologies
- Assemble Alternatives
- Screen Alternatives

Detailed Analysis of Alternatives

- Evaluate Alternatives according to:
 - Overall Protection of Human Health and the Environment
 - Compliance with ARARs
 - Long-term Effectiveness and Permanence
 - Reduction of Toxicity, Mobility, or Volume
 - Short-term Effectiveness
 - Implementability
 - Cost
 - State Acceptance
 - Community Acceptance
- Compare Alternatives

FIGURE 1-1
FEASIBILITY STUDY PROCESS
AOC 43G
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

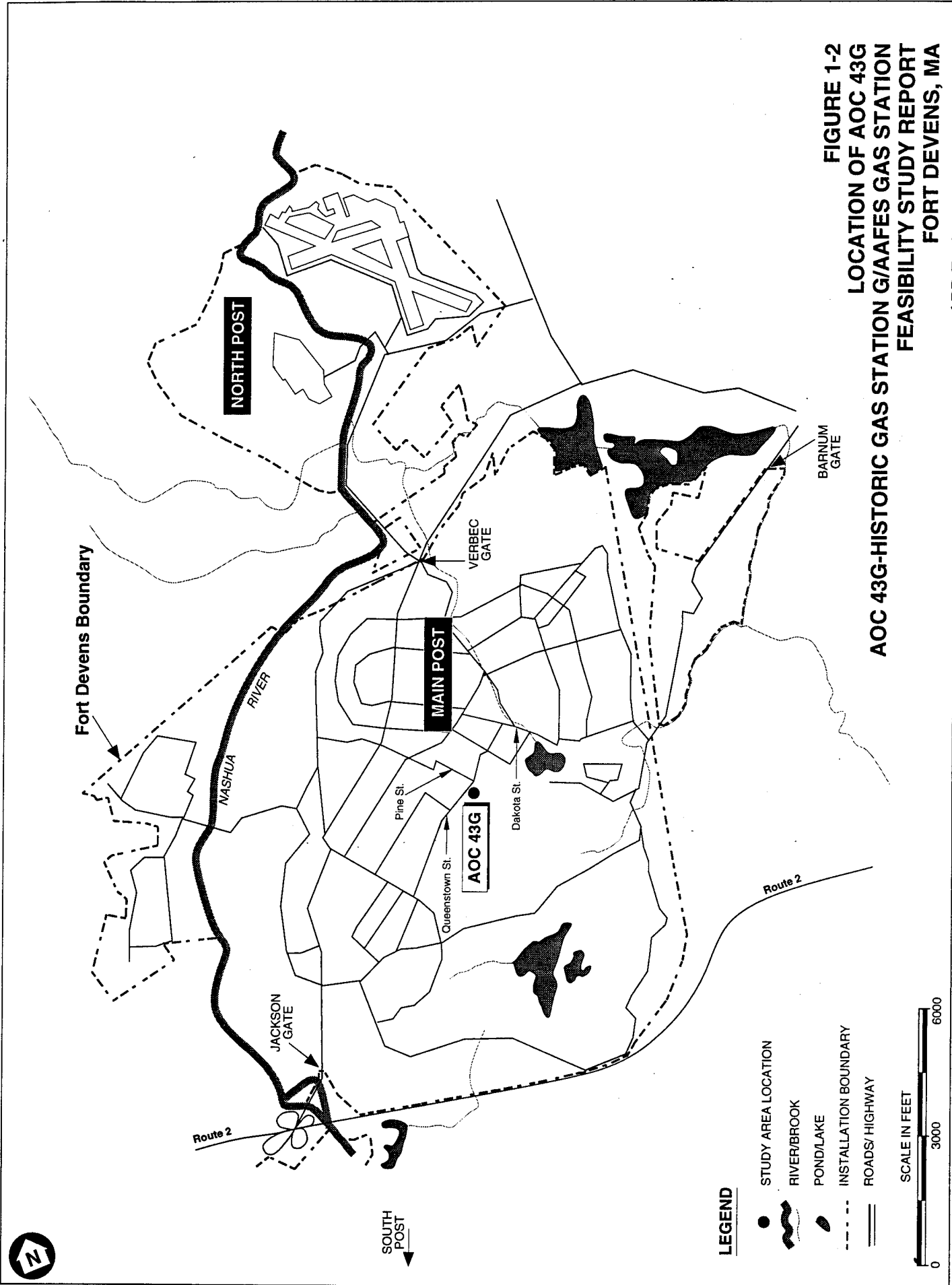


FIGURE 1-2
LOCATION OF AOC 43G
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

QU

COVER

LO
OF
WA

- CONCRETE RETAINING WALL

WOODEN PLATFORM

2009

ABOVE GROUND
WASTE OIL
STORAGE TANK-

~~AREA 1
HISTORIC
GAS STATION G~~

0 15 30 60 FEET

SCALE: 1"=30'

(2)

LOCATION
OF EXISTING
GASOLINE
USTS
(SHADED AREA)

LOCATION
OF FORMER
GASOLINE
USTS

QUEENSTOWN

ROAD

COVERED GASOLINE PUMP ISLANDS

AREA 2

LOCATION
OF FORMER
WASTE OIL
UST

AAFES GAS
STATION
2008

ABOVE GROUND
WASTE OIL
STORAGE TANK

EXISTING
SAND AND
GAS TRAP

AREA 3

FEINBERG

ROAD

WOODED AREA

NOTE:
GROUND SURFACE ELEVATION CONTOUR
INTERVAL IS 5 FEET.

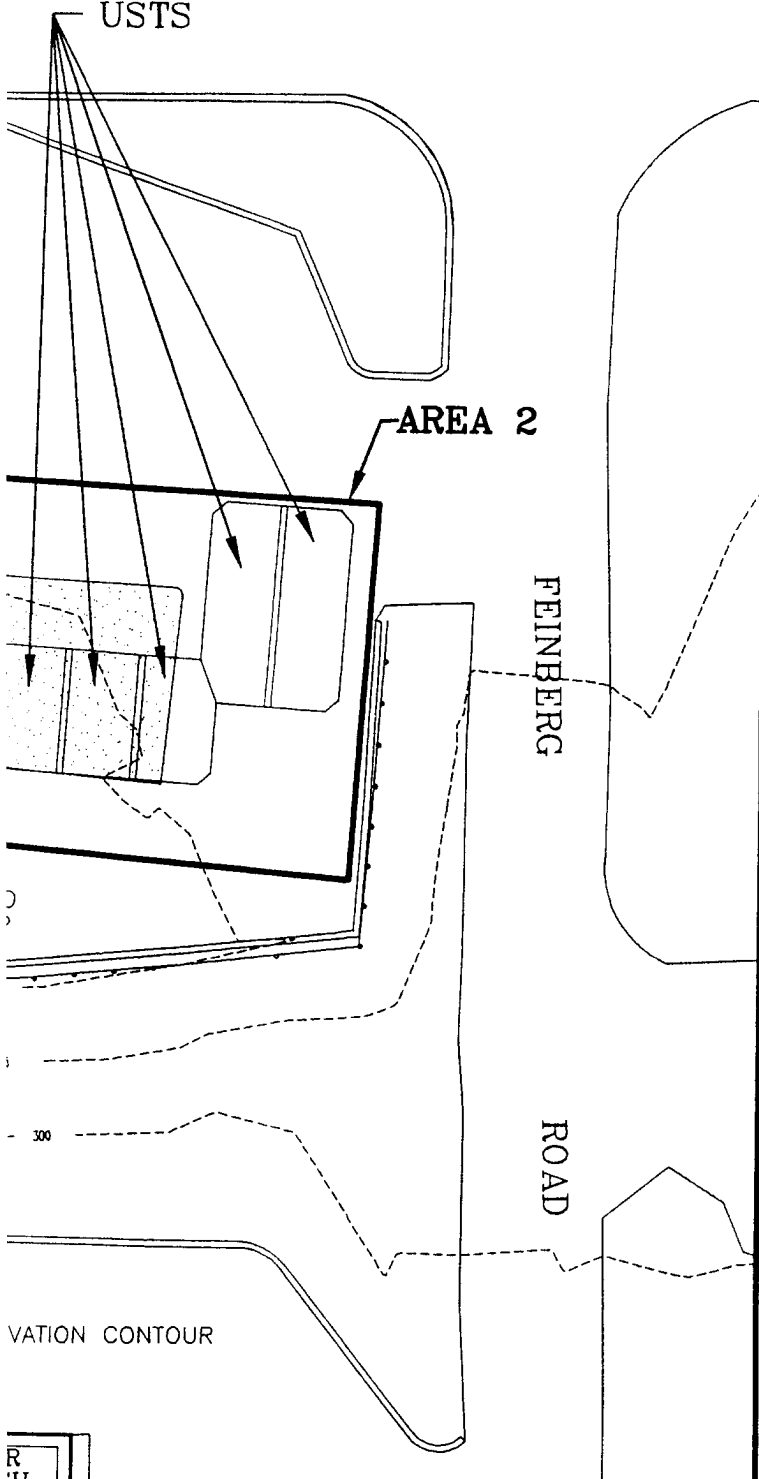
CAR
WASH
2017

FIGURE
SITE MAP OF AOC
AOC 43G-HISTORIC GAS STATION G/AAFES GAS ST,
FEASIBILITY STUDY RE
FORT DEVEN



3

LOCATION
OF FORMER
GASOLINE
USTS



ELEVATION CONTOUR

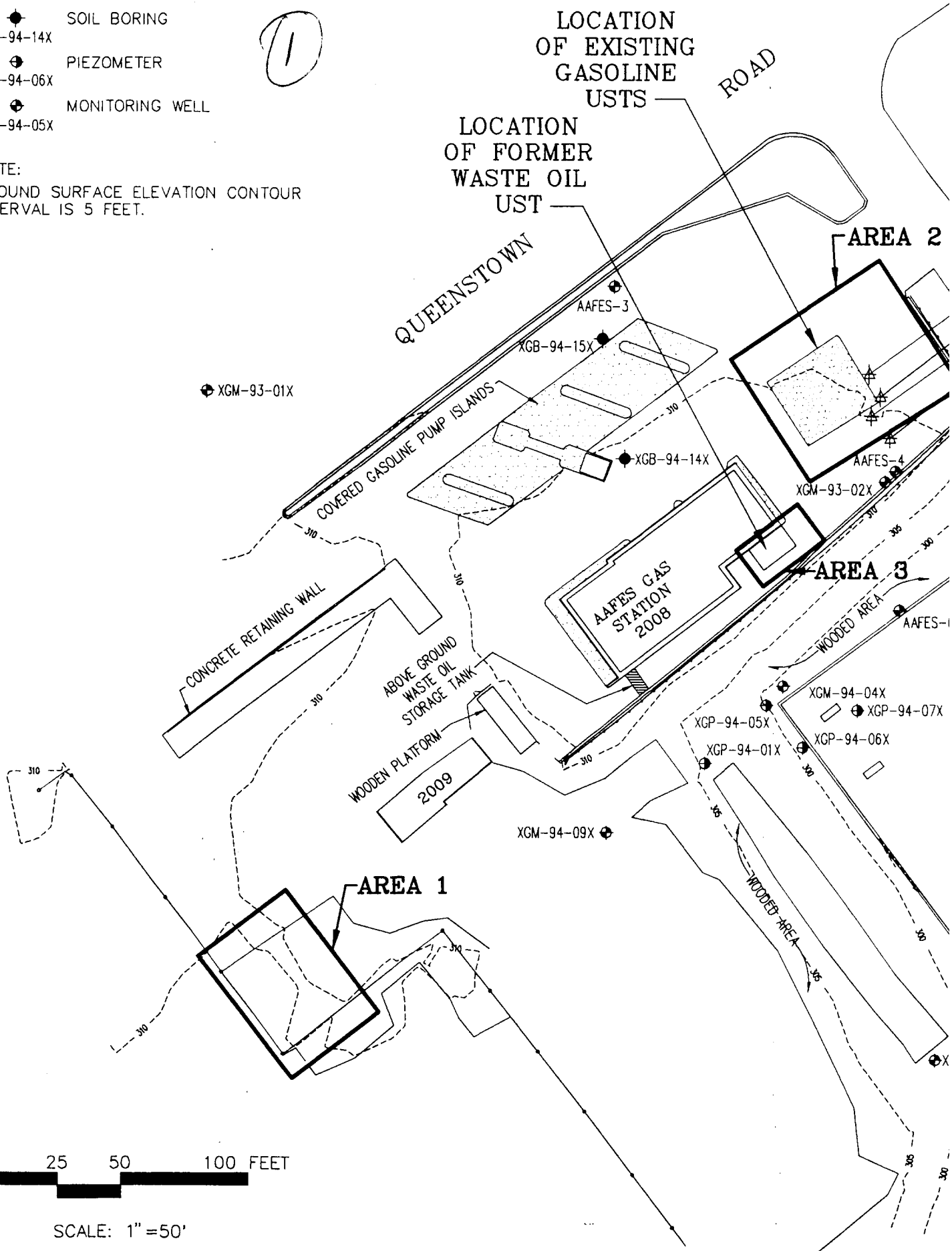
R
SH
7

FIGURE 1-3
SITE MAP OF AOC 43G
FORMER GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

LEGEND

-  SOIL BORING/VAPOR EXTRACTION WELL
 -  SOIL BORING
 -  PIEZOMETER
 -  MONITORING WELL
- XGB-94-10X
XGB-94-14X
XGP-94-06X
XGM-94-05X

NOTE:
GROUND SURFACE ELEVATION CONTOUR
INTERVAL IS 5 FEET.



0 25 50 100 FEET

SCALE: 1" = 50'

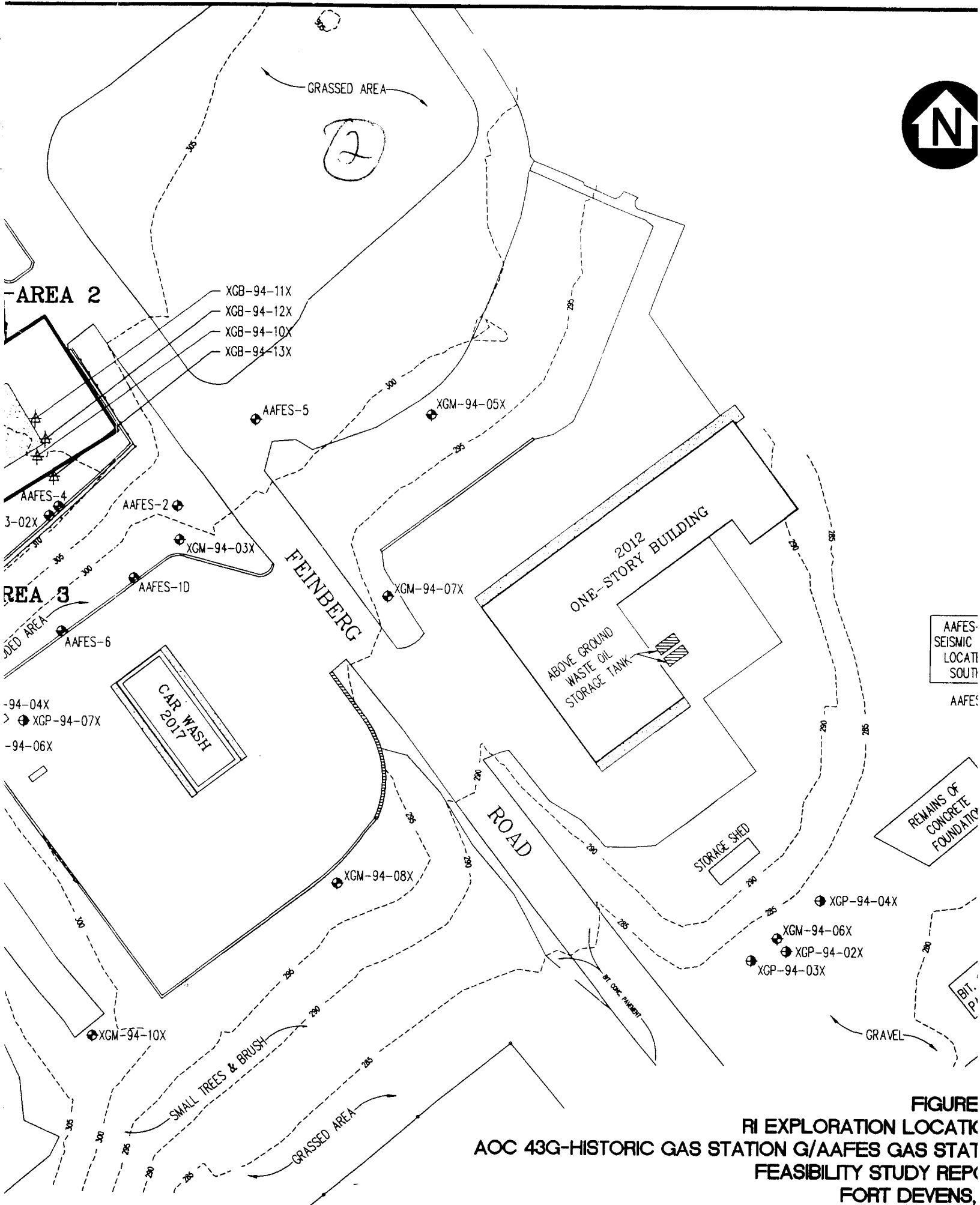


FIGURE
RI EXPLORATION LOCATIONS
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS,
ABB Environmental Services

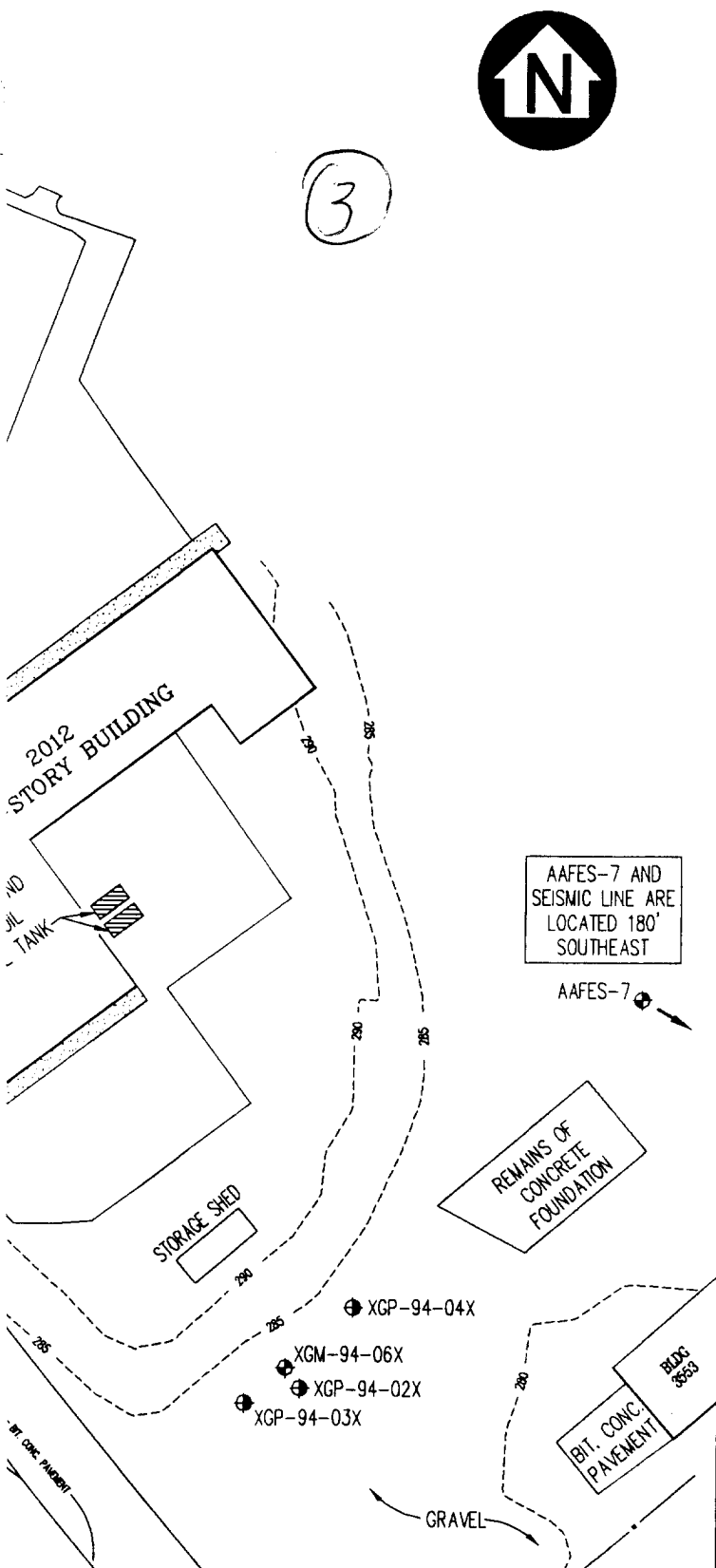
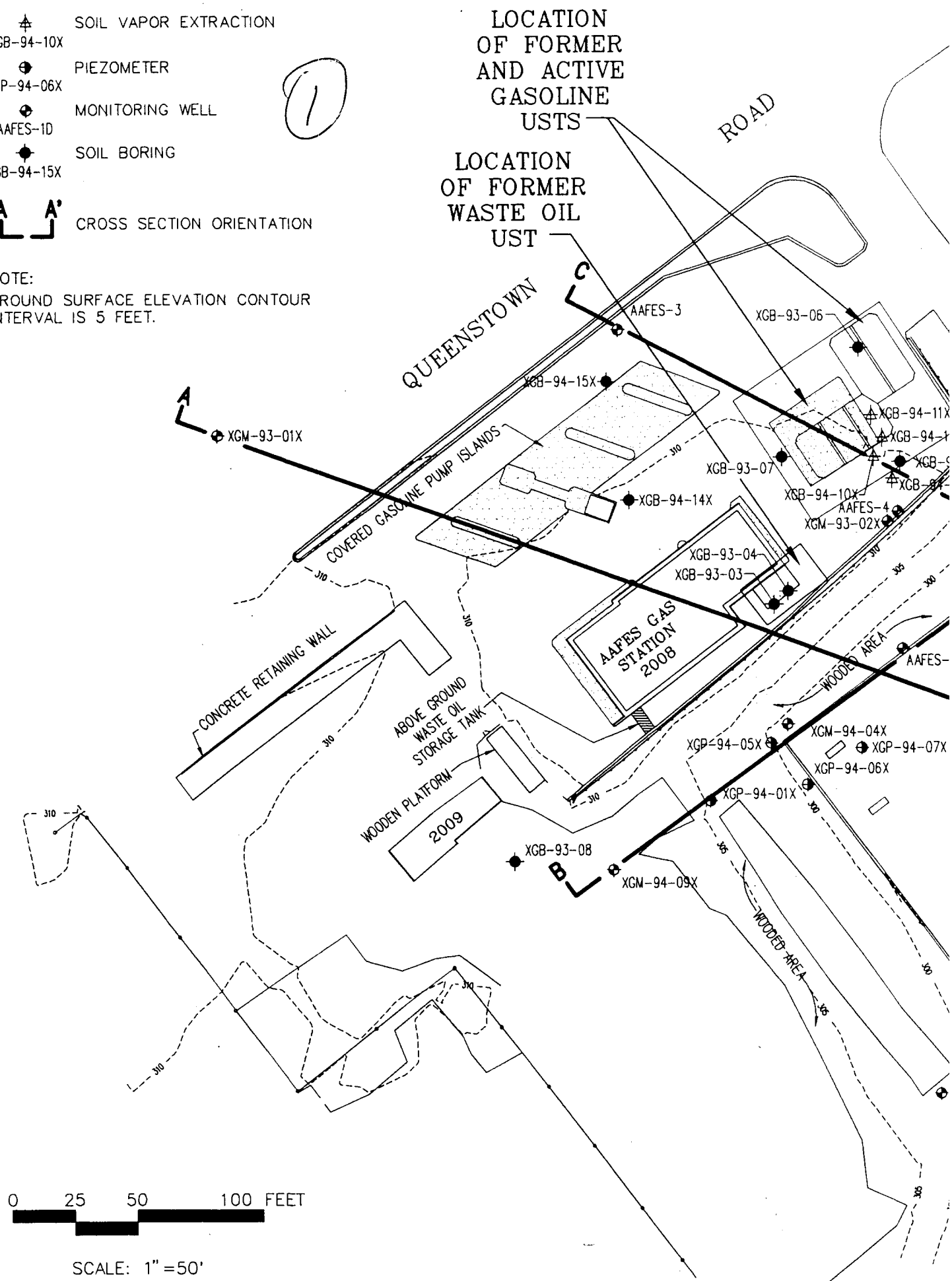


FIGURE 1-4
RI EXPLORATION LOCATIONS
TORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA
ABB Environmental Services, Inc.

 SOIL VAPOR EXTRACTION
 XGB-94-10X
 PIEZOMETER
 XGP-94-06X
 MONITORING WELL
 AAFES-1D
 SOIL BORING
 XGB-94-15X

 CROSS SECTION ORIENTATION

NOTE:
GROUND SURFACE ELEVATION CONTOUR
INTERVAL IS 5 FEET.



3

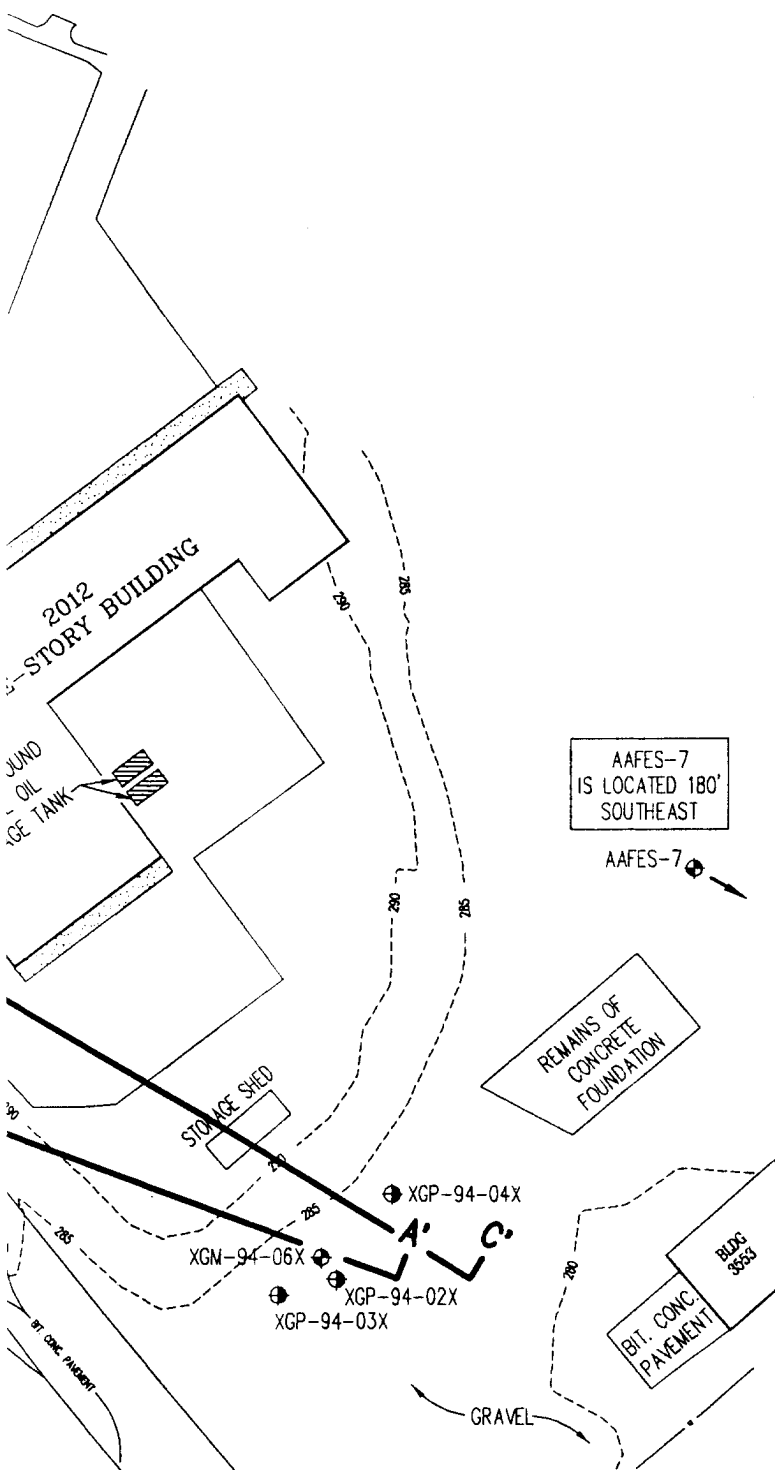


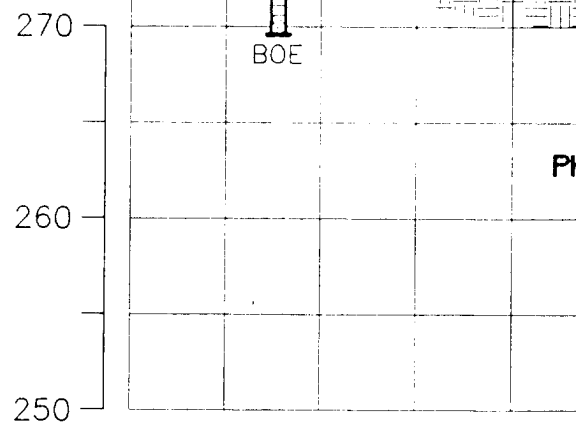
FIGURE 1-5

ORIENTATION OF GEOLOGIC CROSS
SECTIONS A-A', B-B', AND C-C'

STORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT

FORT DEVENS, MA

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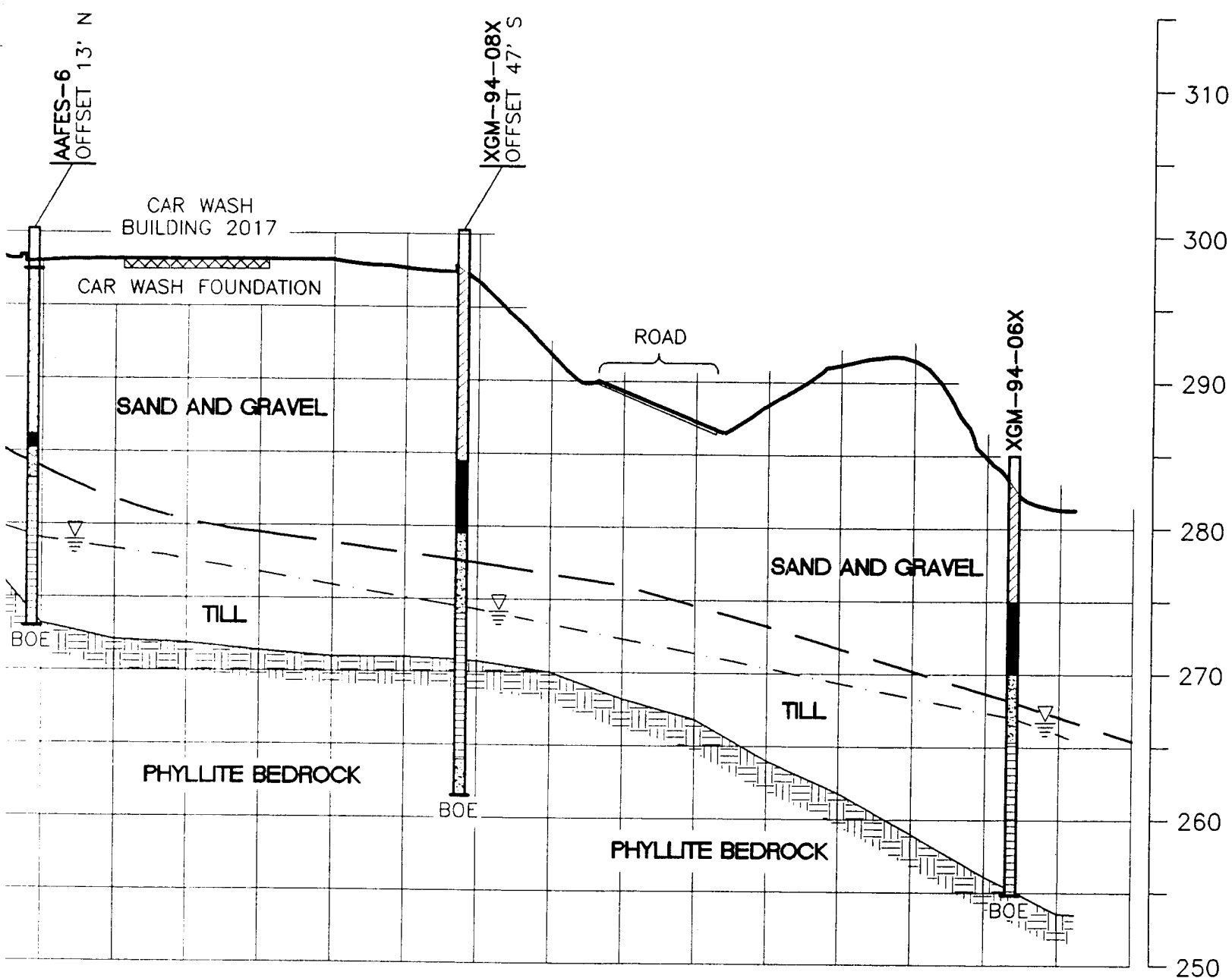
LEGEND



1. FOR ORIENTATION OF CROSS SECTION
2. DUE TO ITS HIGHLY WEATHERED NATURE, THE CONTACT
WAS DEFINED BY SPLIT-SPOON/AUGER
3. GEOLOGIC CONDITIONS BETWEEN WELL AND
AVAILABLE DATA. ACTUAL CONDITIONS

(2)

SOUTHEAST
A'



CROSS SECTION A - A'

0 25 50 100 FEET

HORIZONTAL SCALE: 1"=50'
VERTICAL SCALE: 1"=10'
VERTICAL EXAGGERATION: 5:1

OF CROSS SECTION, SEE FIGURE 1-5.

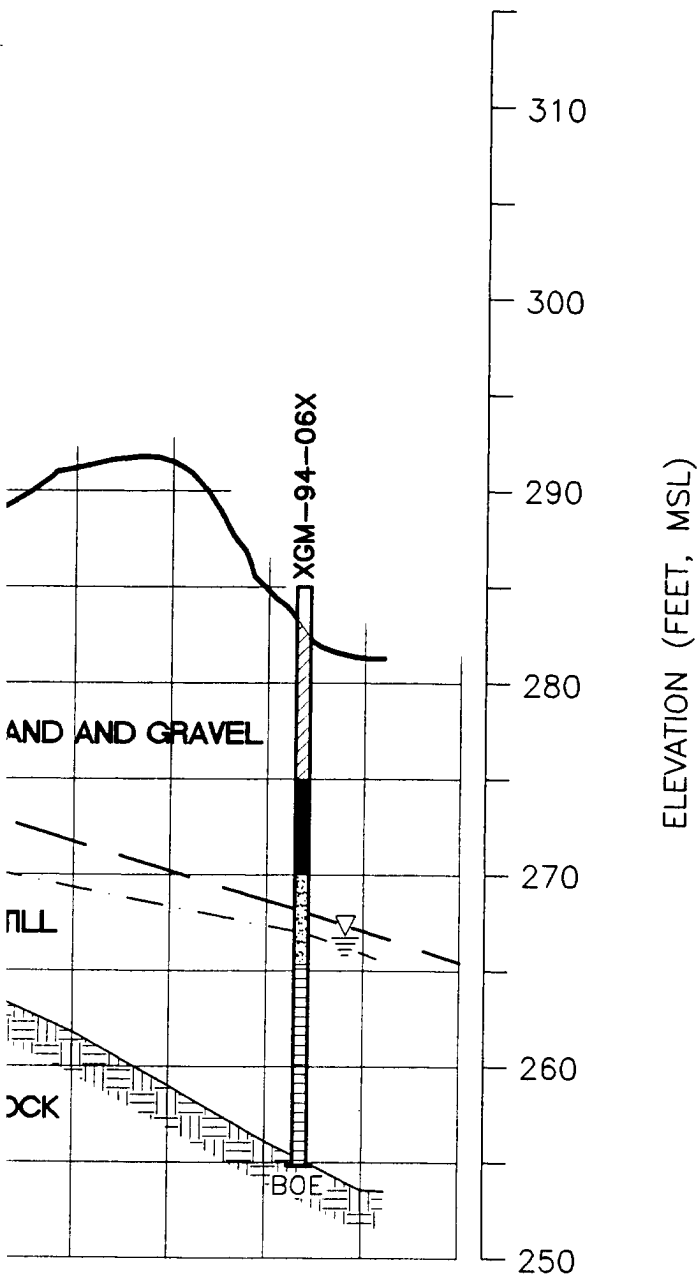
WEATHERED NATURE, THE BEDROCK SURFACE
SPIT-SPOON/AUGER REFUSAL.

IS BETWEEN WELLS ARE AN INTERPRETATION-OF
TUAL CONDITIONS MAY VARY.

FIGURE
INTERPRETIVE GEOLOGIC CROSS SECTION
AOC 43G-HISTORIC GAS STATION G/AAFES GAS ST.
FEASIBILITY STUDY RE
FORT DEVEN

3

SOUTHEAST
A'



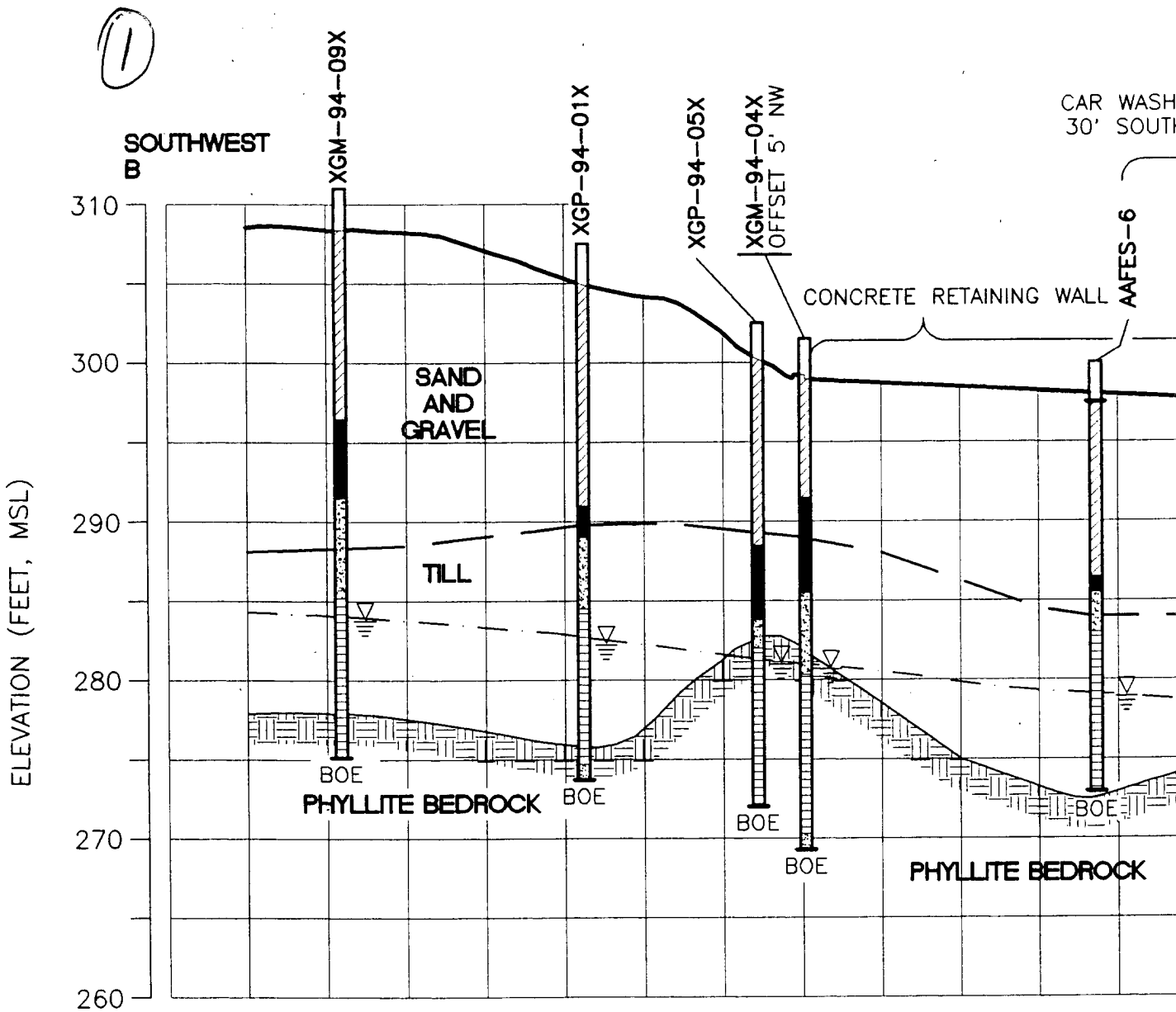
0 25 50 100 FEET

HORIZONTAL SCALE: 1"=50'

VERTICAL SCALE: 1"=10'

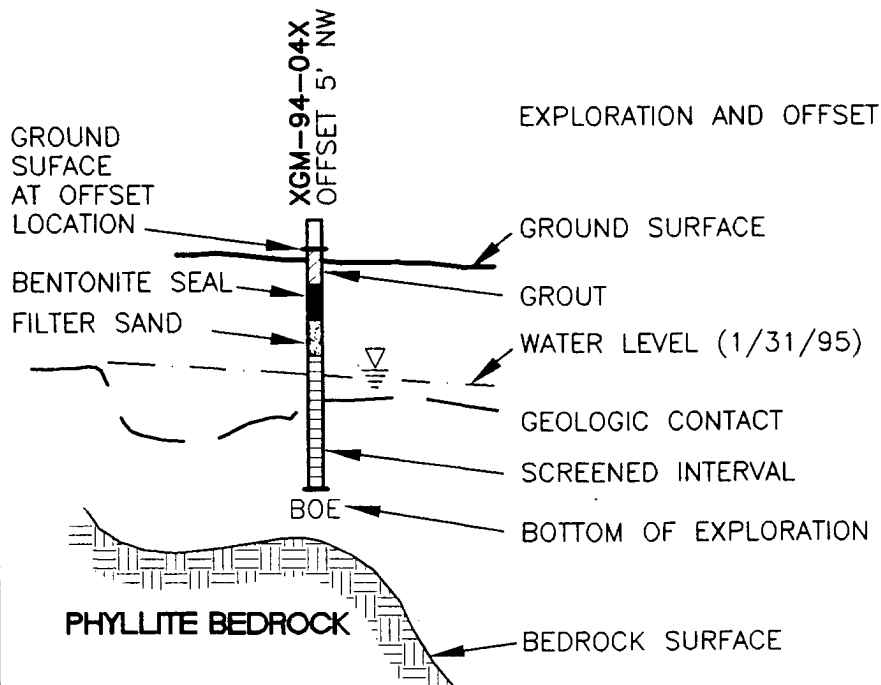
VERTICAL EXAGGERATION: 5:1

FIGURE 1-6
INTERPRETIVE GEOLOGIC CROSS SECTION A-A'
AFRICAN GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA



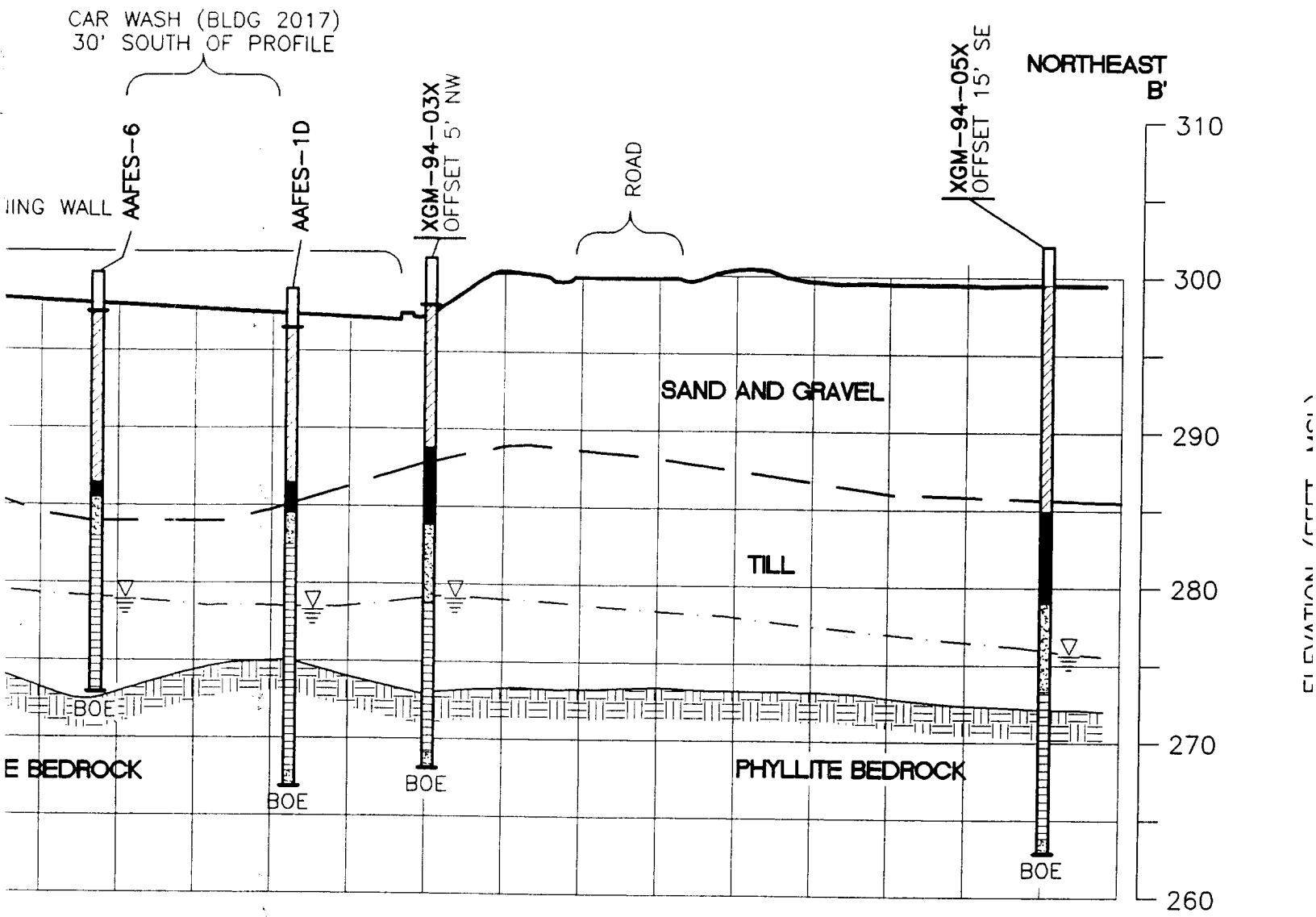
LEGEND

CROSS SECTION



NOTES:

1. FOR ORIENTATION OF CROSS SECTION
2. DUE TO ITS HIGHLY WEATHERED NATURE, THE BEDROCK SURFACE WAS DEFINED BY SPLIT-SPOON/AL
3. GEOLOGIC CONDITIONS BETWEEN WALL AND AVAILABLE DATA. ACTUAL CONDITIONS



CROSS SECTION B - B'

0 15 30 60 FEET

HORIZONTAL SCALE: 1"=30'

VERTICAL SCALE: 1"=10'

VERTICAL EXAGGERATION: 3:1

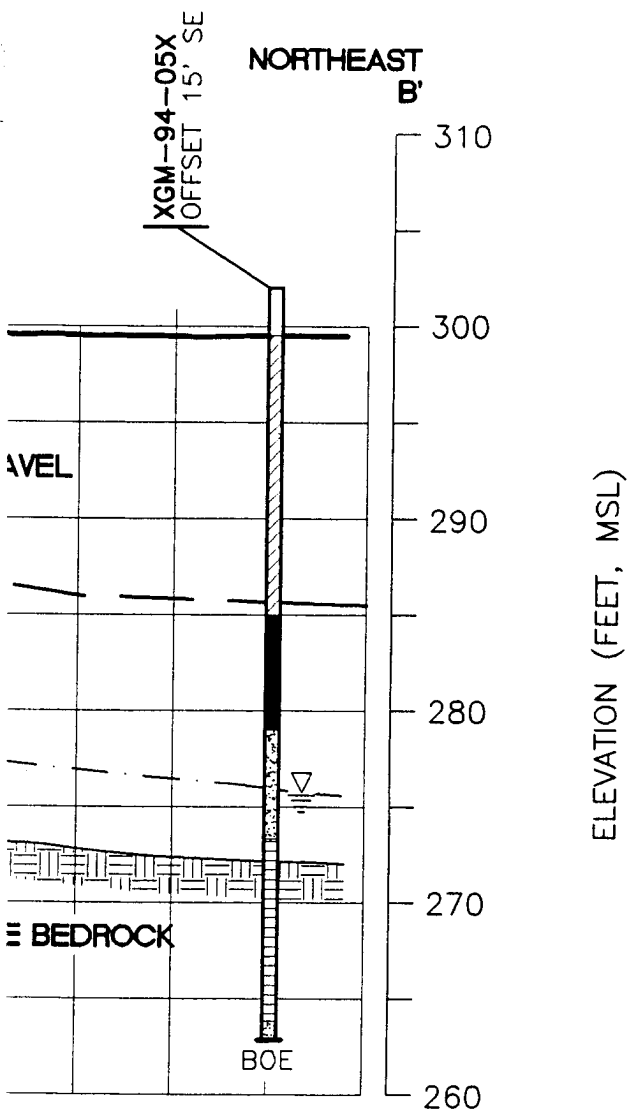
CROSS SECTION, SEE FIGURE 1-5.

WEATHERED NATURE, THE BEDROCK SURFACE
LIT-SPOON/AUGER REFUSAL.

S BETWEEN WELLS ARE AN INTERPRETATION-OF
UAL CONDITIONS MAY VARY.

FIGURE
INTERPRETIVE GEOLOGIC CROSS SECTION
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STA
FEASIBILITY STUDY RE
FORT DEVENS

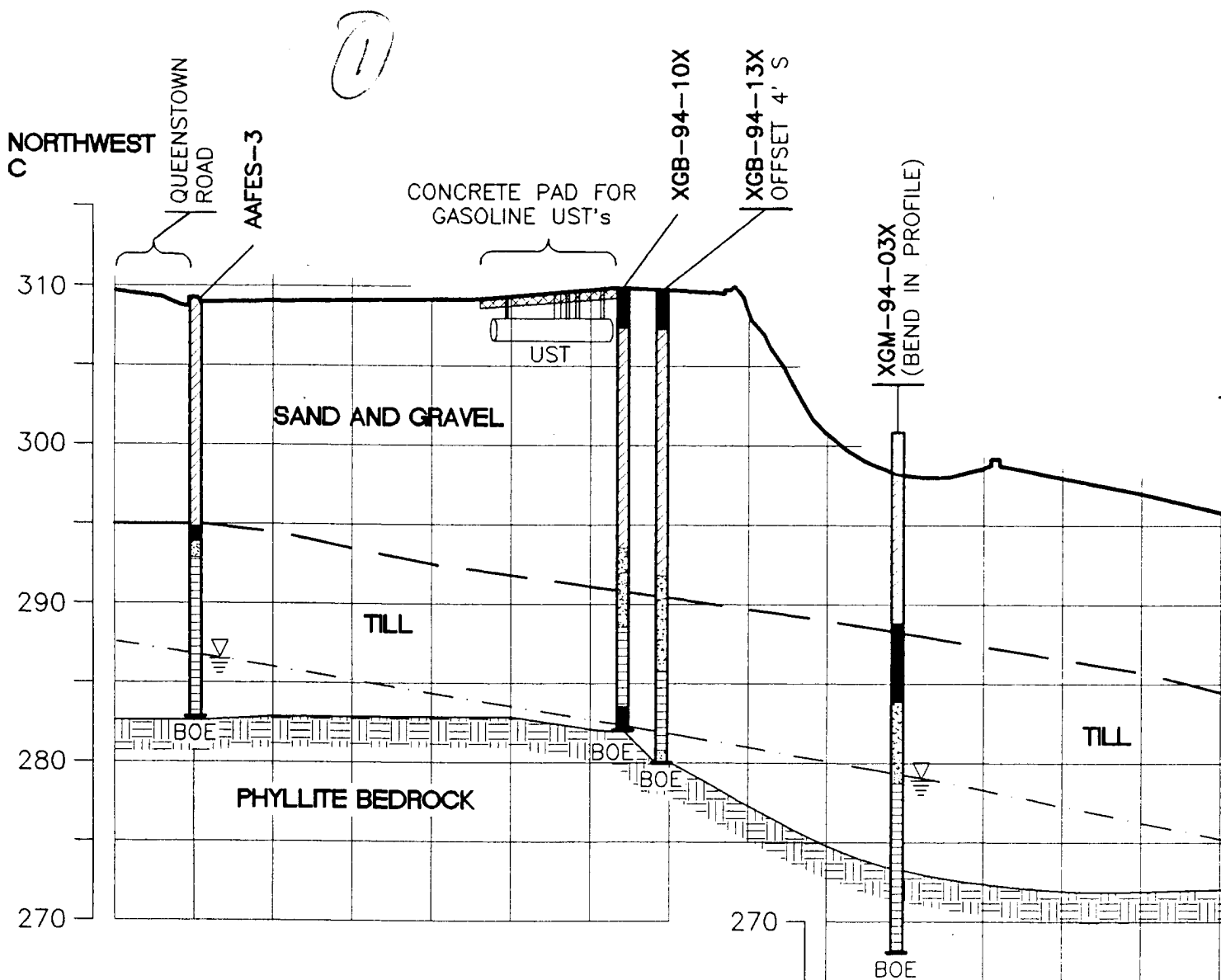
3



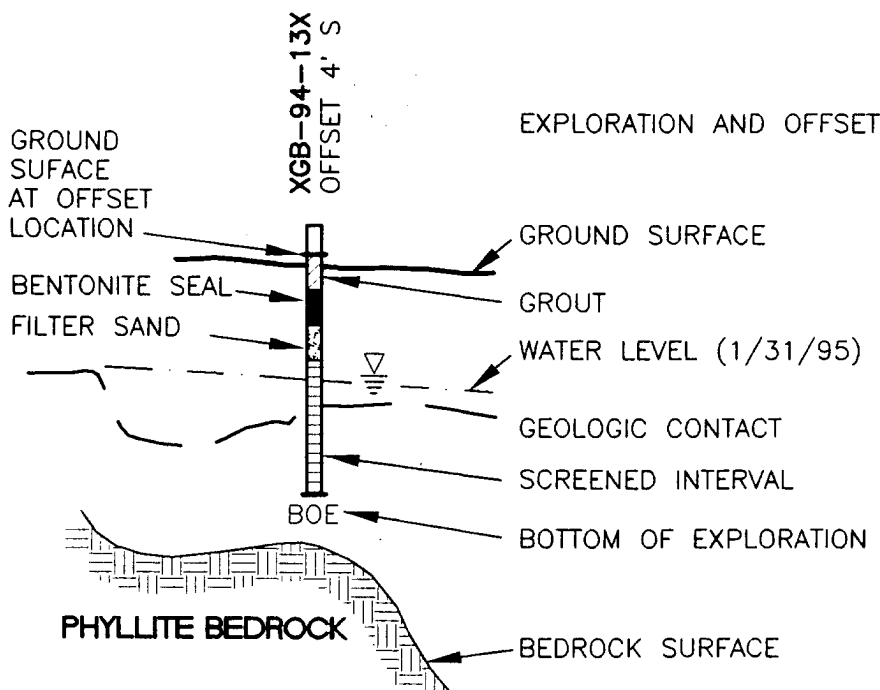
0 15 30 60 FEET

HORIZONTAL SCALE: 1"=30'
VERTICAL SCALE: 1"=10'
VERTICAL EXAGGERATION: 3:1

FIGURE 1-7
INTERPRETIVE GEOLOGIC CROSS SECTION B-B'
AFRICAN GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA



LEGEND



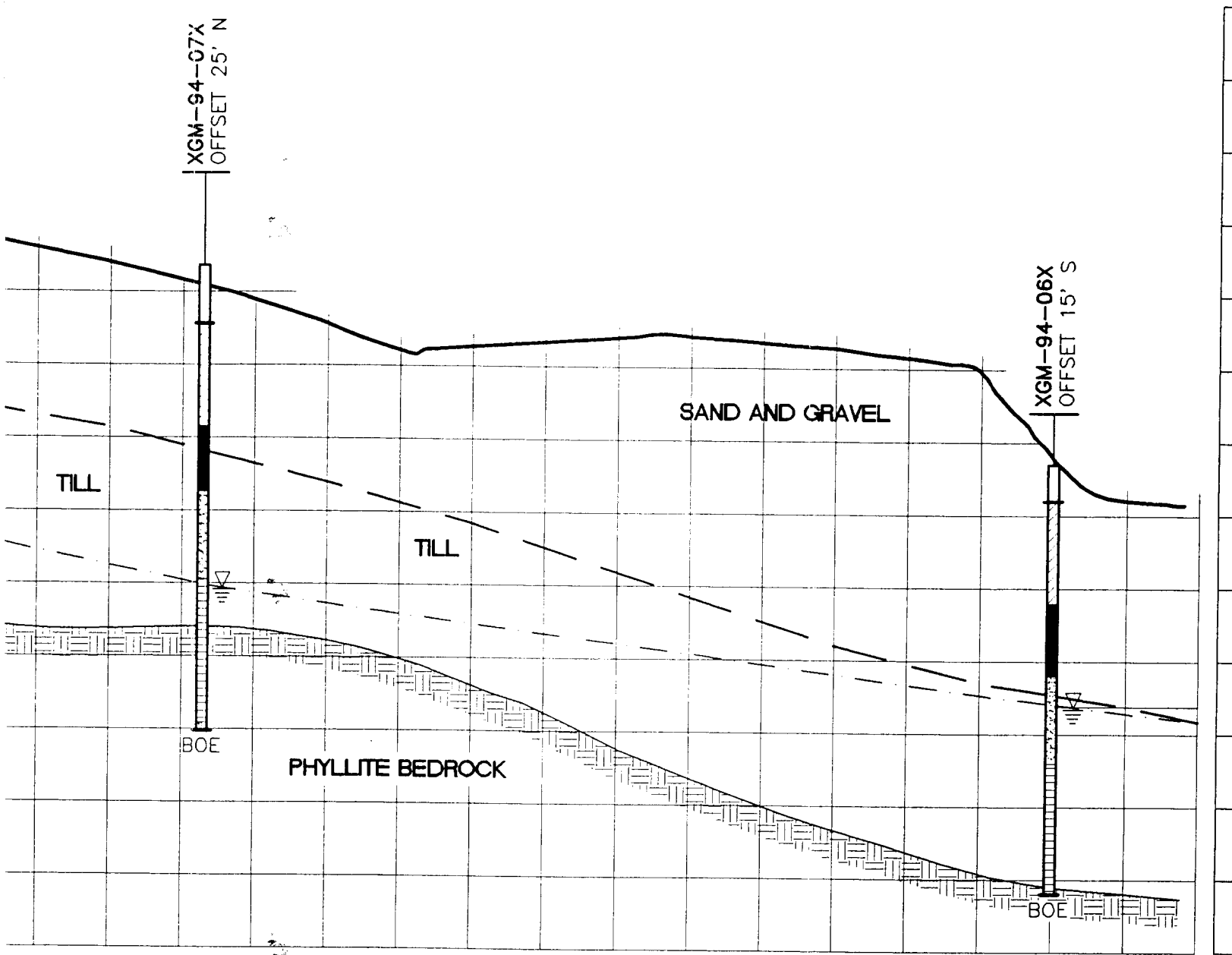
CROSS SECTION

NOTES:

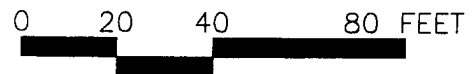
1. FOR ORIENTATION OF CROSS SECTION
2. DUE TO ITS HIGHLY WEATHERED NATURE, THE BEDROCK SURFACE WAS DEFINED BY SPLIT-SPOON/AUGER DATA.
3. GEOLOGIC CONDITIONS BETWEEN WELLS ARE BASED ON AVAILABLE DATA. ACTUAL CONDITIONS MAY VARY.

2

SOUTHEAST
C



SECTION C - C'



HORIZONTAL SCALE: 1"=40'
 VERTICAL SCALE: 1"=10'
 VERTICAL EXAGGERATION: 4:1

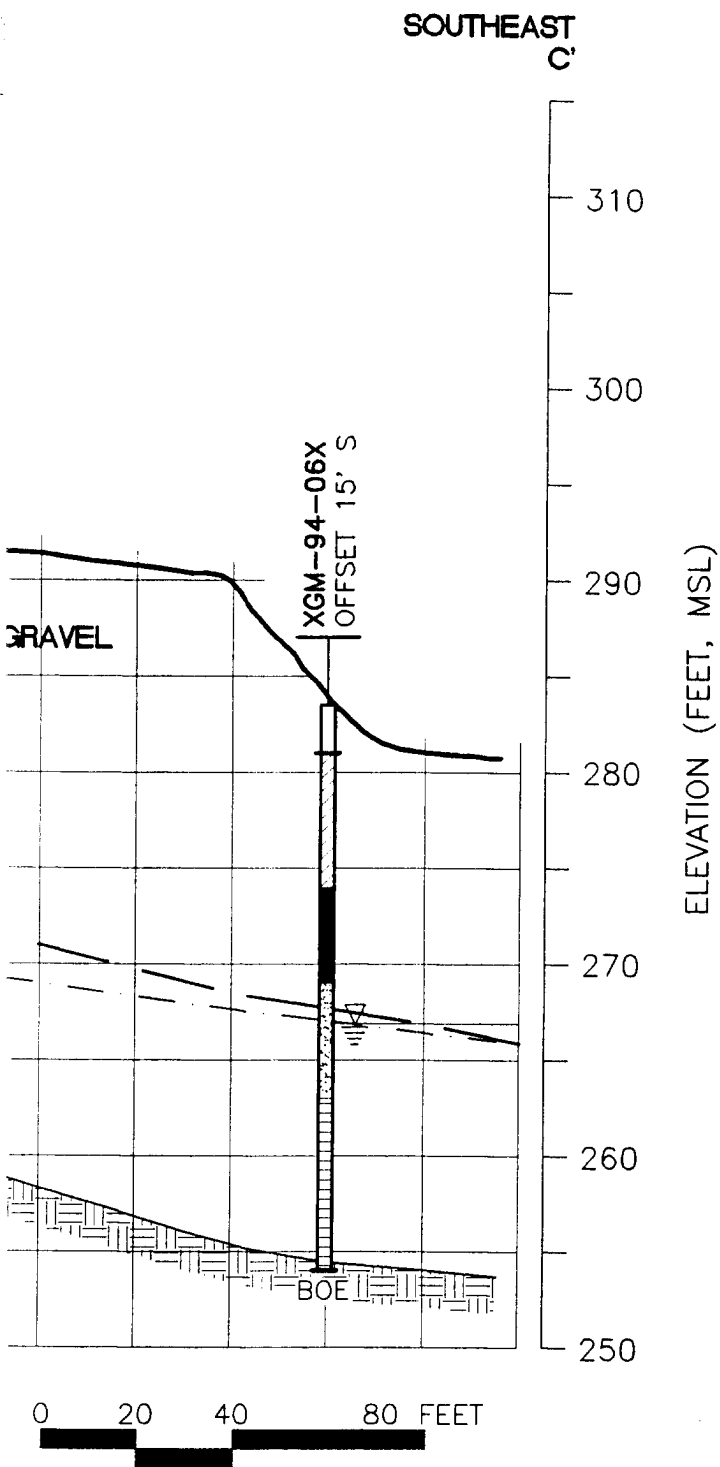
OF CROSS SECTION, SEE FIGURE 1-5.

Y WEATHERED NATURE, THE BEDROCK SURFACE
 SPLIT-SPOON/AUGER REFUSAL.

ONS BETWEEN WELLS ARE AN INTERPRETATION OF
 CTUAL CONDITIONS MAY VARY.

FIG
INTERPRETIVE GEOLOGIC CROSS SECTIC
AOC 43G-HISTORIC GAS STATION G/AAFES GAS S
FEASIBILITY STUDY F
FORT DEVE

3



HORIZONTAL SCALE: 1"=40'

VERTICAL SCALE: 1"=10'

VERTICAL EXAGGERATION: 4:1

FIGURE 1-8
APPRECIATIVE GEOLOGIC CROSS SECTION C-C'
FORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA
ABB Environmental Services, Inc.

SOIL BORING/VAPOR EXTRACTION WELL

PIEZOMETER

MONITORING WELL

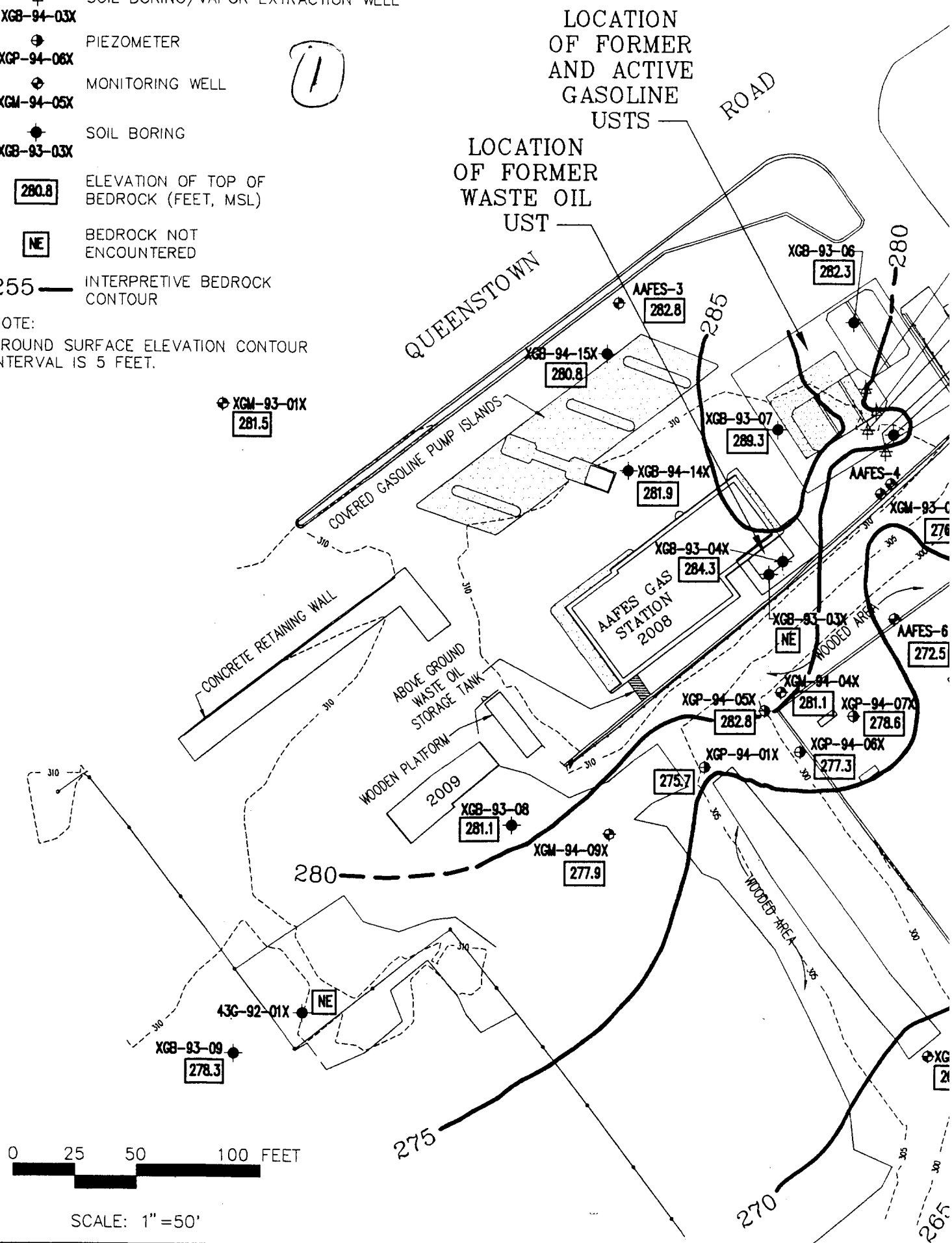
SOIL BORING

ELEVATION OF TOP OF
BEDROCK (FEET, MSL)

BEDROCK NOT
ENCOUNTERED

255 — INTERPRETIVE BEDROCK
CONTOUR

NOTE:
GROUND SURFACE ELEVATION CONTOUR
INTERVAL IS 5 FEET.



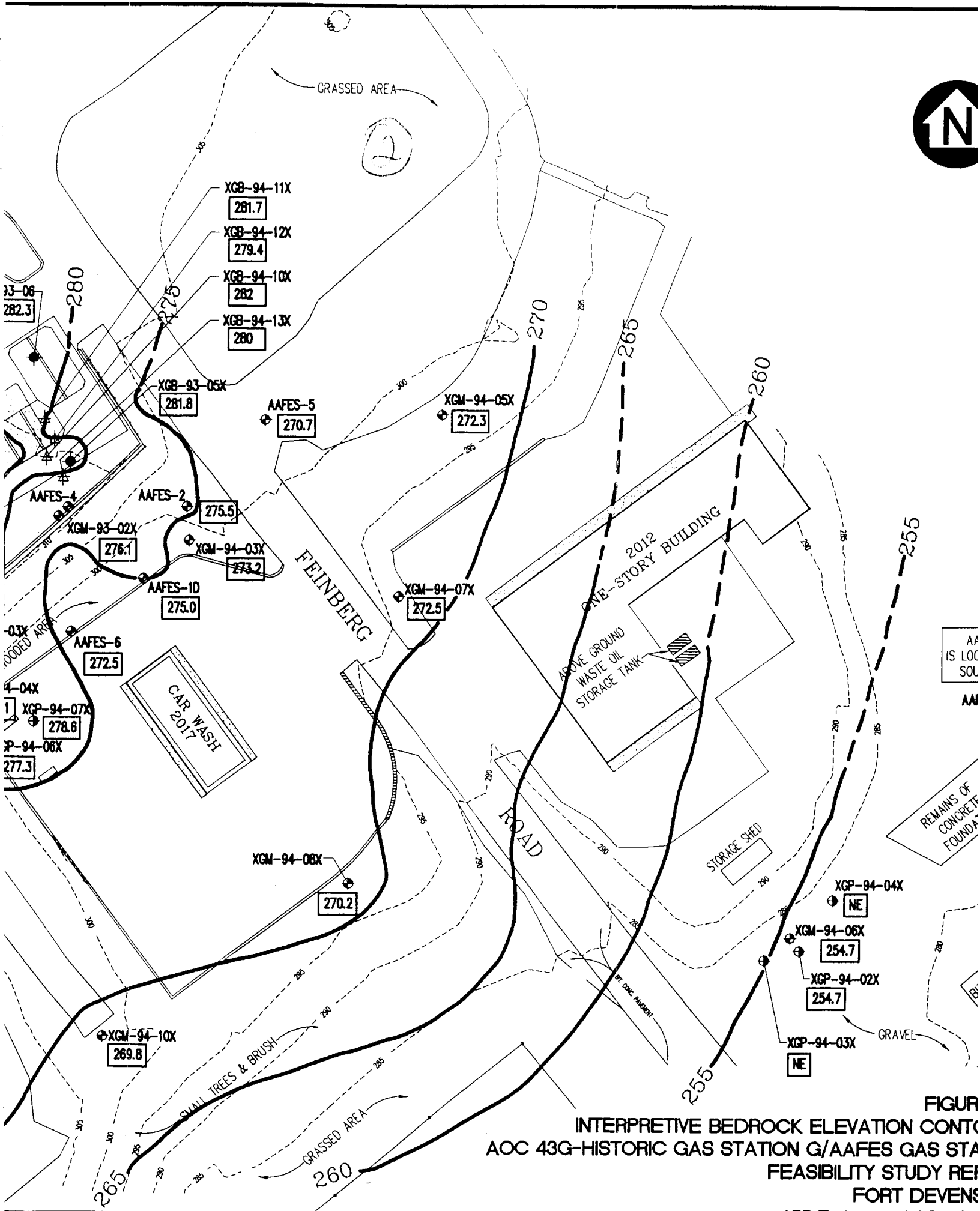


FIGURE 1
 INTERPRETIVE BEDROCK ELEVATION CONTOUR MAP
 AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
 FEASIBILITY STUDY REVISION 1
 FORT DEVENS

3

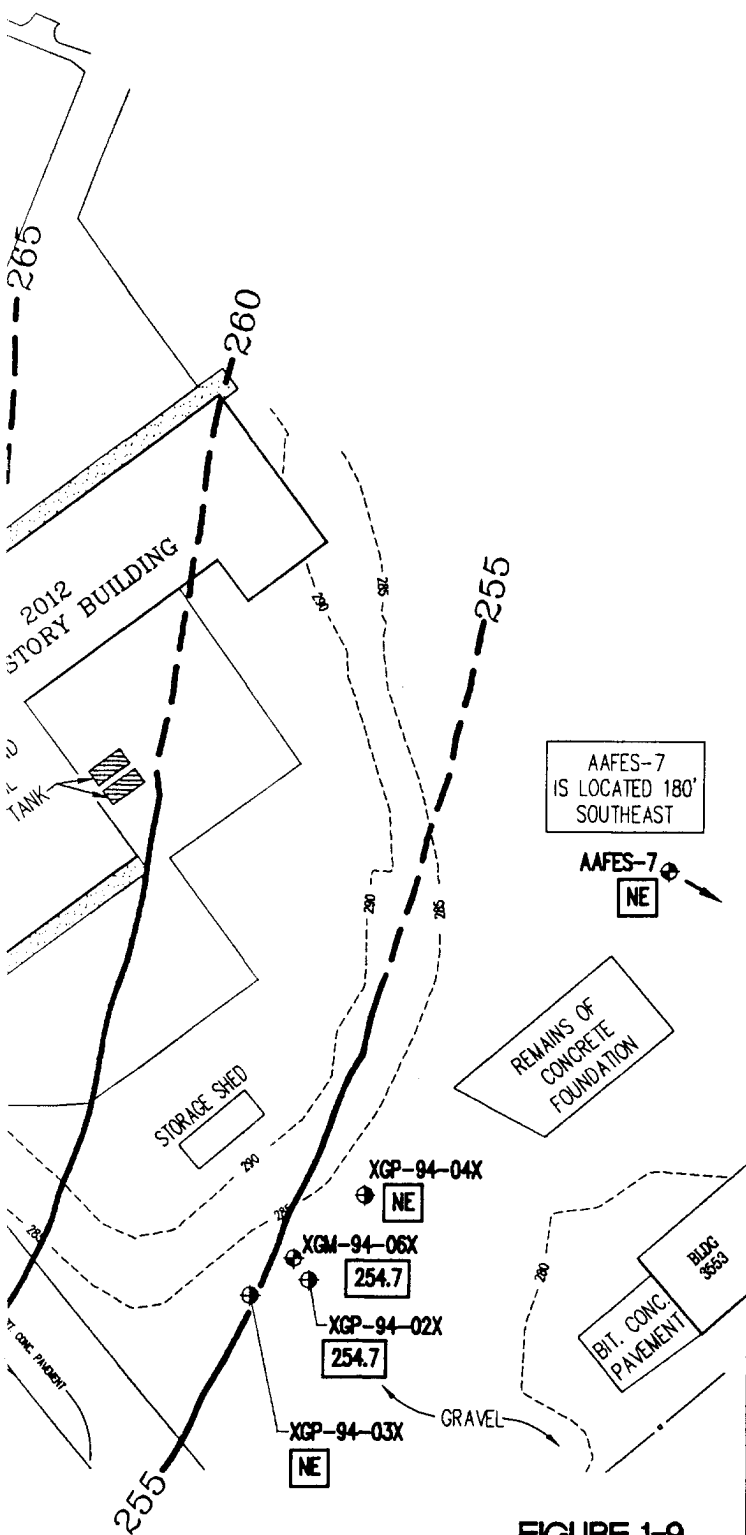


FIGURE 1-9
INTERPRETIVE BEDROCK ELEVATION CONTOURS
HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

LEGEND

⊕
XGP-94-06X

PIEZOMETER

⊕
XGM-94-05X

MONITORING WELL

275.68

ELEVATION OF GROUNDWATER
(FEET, MSL) JAN 31, 1995

280

INTERPRETIVE WATER
TABLE ELEVATION
CONTOUR

NOTE:

GROUND SURFACE ELEVATION CONTOUR
INTERVAL IS 5 FEET.

LOCATION
OF FORMER
AND ACTIVE
GASOLINE
USTS

LOCATION
OF FORMER
WASTE OIL
UST

ROAD

QUEENSTOWN

⊕ XGM-93-01X
287.62

AAFS-3
286.71

COVERED GASOLINE PUMP ISLANDS

CONCRETE RETAINING WALL

ABOVE GROUND
WASTE OIL
STORAGE TANK

WOODEN PLATFORM
2008

AAFS GAS
STATION
2008

XGM-93-02X
279.90

AAFS-4
DRY

AAFS-6
279.00

XGM-94-04X
280.89

XGP-94-07X

XGP-94-06X
279.73

XGP-94-05X
281.06

XGP-94-01X
282.30

XGM-94-09X
283.93

XG
27

0 25 50 100 FEET

SCALE: 1" = 50'

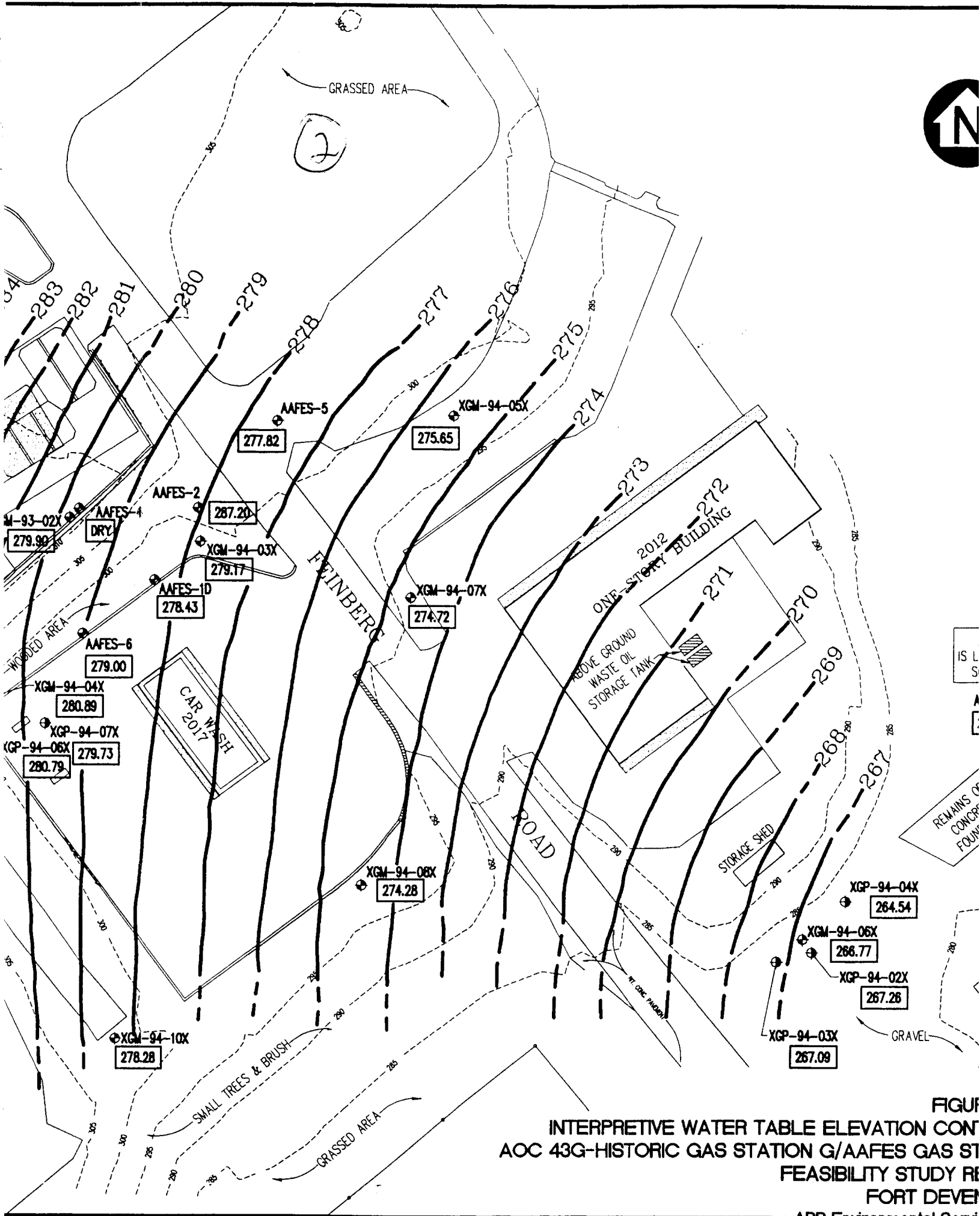


FIGURE 1
INTERPRETIVE WATER TABLE ELEVATION CONTOUR MAP
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVEL

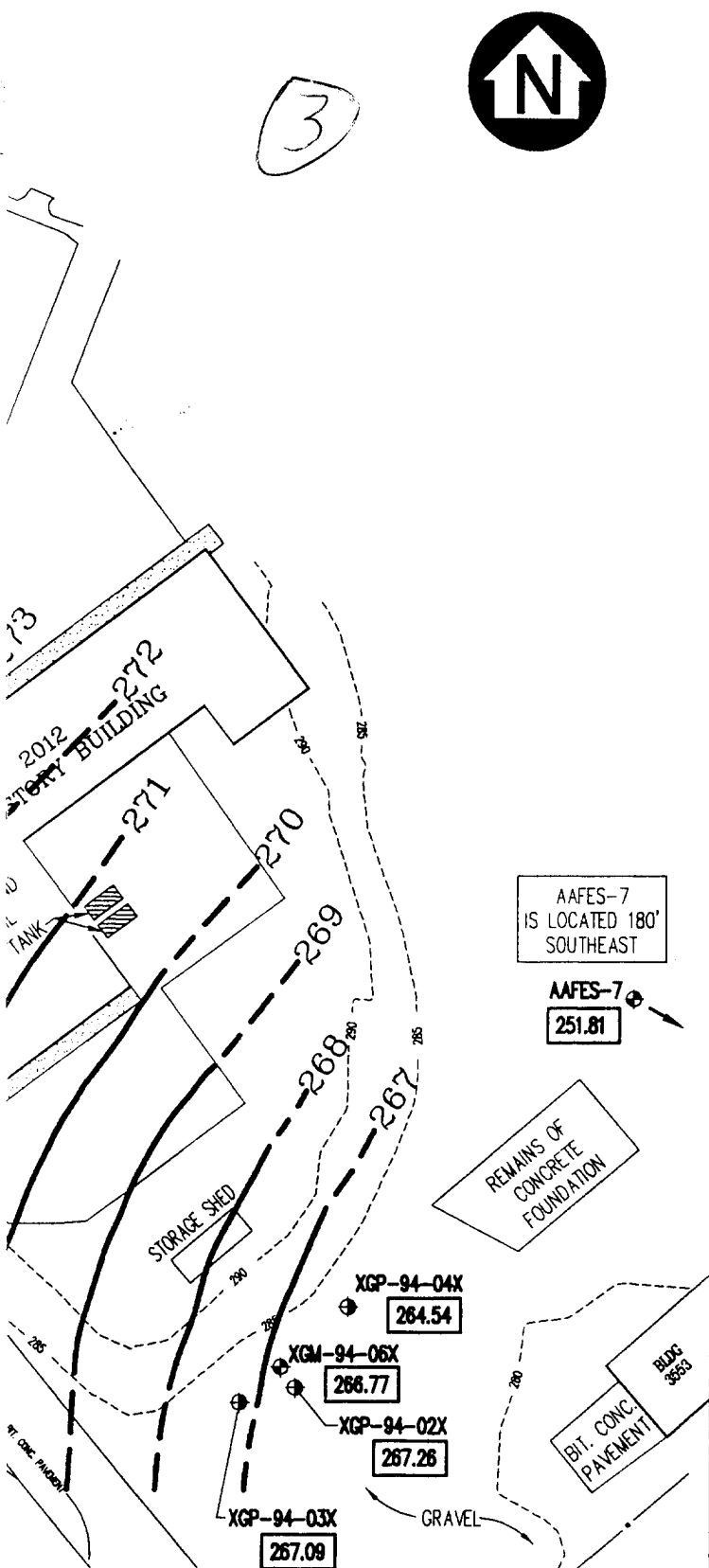


FIGURE 1-10
 EFFECTIVE WATER TABLE ELEVATION CONTOURS
 FOR HISTORIC GAS STATION G/AAFES GAS STATION
 FEASIBILITY STUDY REPORT
 FORT DEVENS, MA
 ABB Environmental Services, Inc.

• XGM-93-01X

0

- CONCRETE RETAINING WALL

COVERED

LO
OF
WAS

WOODEN PLATFORM.

2009

-AREA 1
HISTORIC
GAS STATION G

ABOVE GROUND
WASTE OIL
STORAGE TANK—

HEATI

XGB-93-09X

TS-39

TS-38 •

TS-37

• TS-36

TS-35

● XGB-93-08X

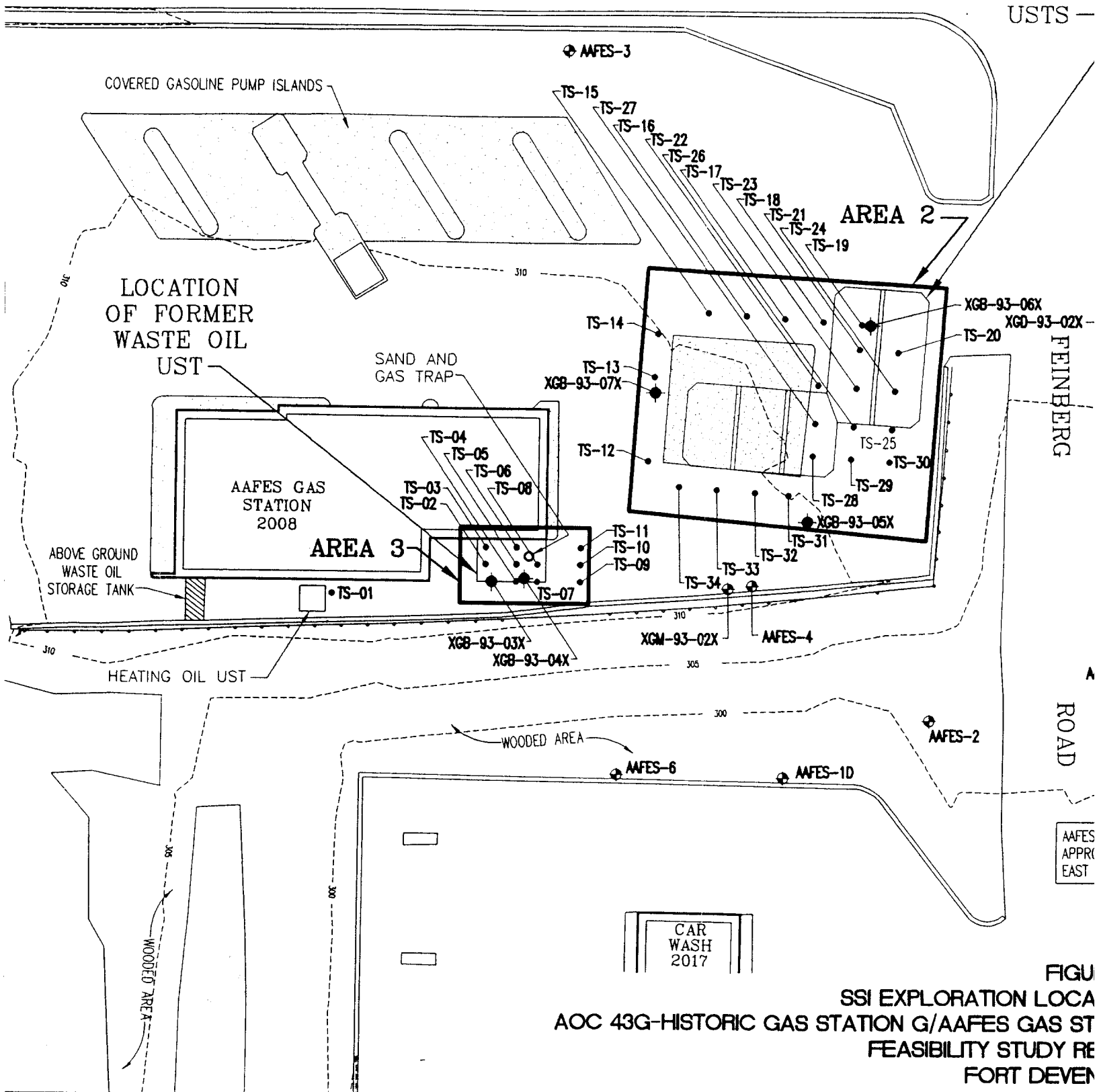
0 15 30 60 FEET

SCALE: 1"=30'

(2)

QUEENSTOWN

ROAD

LOCATION
OF FORMER
AND ACTIVE
GASOLINE
USTS —

FIGU
SSI EXPLORATION LOCA
AOC 43G-HISTORIC GAS STATION G/AAFES GAS ST
FEASIBILITY STUDY RE
FORT DEVEN



3

LOCATION
OF FORMER
AND ACTIVE
GASOLINE
USTS

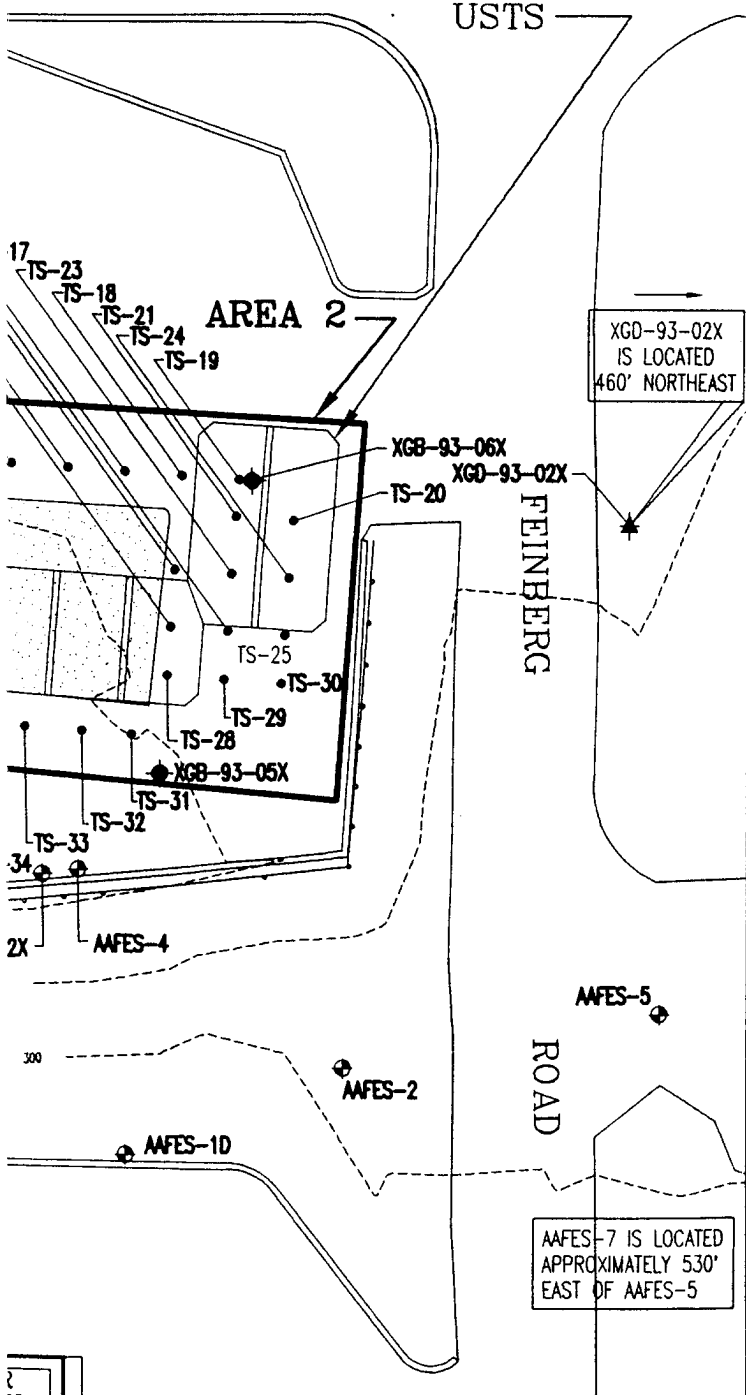


FIGURE 1-11

SSI EXPLORATION LOCATIONS

FORMER GAS STATION G/AAFES GAS STATION

FEASIBILITY STUDY REPORT

FORT DEVENS, MA

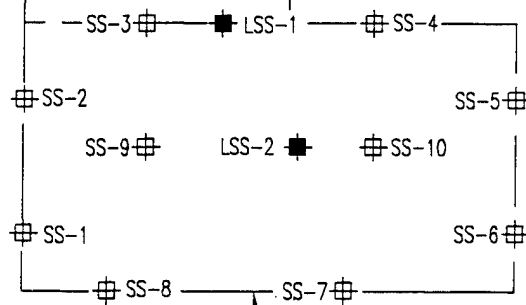
ABB Environmental Services, Inc.

LEGEND

- ⊕ ATEC OFF-SITE SCREENING SAMPLE LOCATION
SS-1
- ATEC OFF-SITE LABORATORY SAMPLE LOCATION
LSS-1



AAFES GAS
STATION 2008



WASTE OIL UST
EXCAVATION

0 2.5 5 10 FEET

SCALE: 1"=5'

FIGURE 1-12
PREVIOUS CONTRACTOR (ATEC) SAMPLE LOCATIONS
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

TABLE 1-1
SUMMARY OF BEDROCK ELEVATION DATA
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

EXPLORATION TYPE	EXPLORATION ID	GROUND ELEVATION (FEET MSL)	DEPTH TO BEDROCK (FEET bgs)	BEDROCK ELEV. (FEET MSL)
SOIL BORINGS	43G-92-01X	309.8	NE	
	XGB-93-03X	310.4	NE	
	XGB-93-04X	310.3	26	284.3
	XGB-93-05X	309.8	28	281.8
	XGB-93-06X	308.7	25.5	283.2
	XGB-93-07X	309.8	20.5	289.3
	XGB-93-08X	308.6	27.5	281.1
	XGB-93-09X	308	29.7	278.3
	XGB-94-10X	310	28	282
	XGB-94-11X	309.7	28	281.7
	XGB-94-12X	309.9	30.5	279.4
	XGB-94-13X	310.3	30.3	280
	XGB-94-14X	310.4	28.5	281.9
	XGB-94-15X	309.5	28.7	280.8
MONITORING WELLS	XGM-93-01X	311.5	30	281.5
	XGM-93-02X	310.6	34.5	276.1
	XGM-94-03X	298.2	25	273.2
	XGM-94-04X	299.1	18	281.1
	XGM-94-05X	299.3	27	272.3
	XGM-94-06X	282.2	27.5	254.7
	XGM-94-07X	293	20.5	272.5
	XGM-94-08X	297.2	27	270.2
	XGM-94-09X	308.4	30.5	277.9
	XGM-94-10X	300.4	30.6	269.8
	AAFES-1D	296.5	21.5	275
	AAFES-2	300.7	25	275.7
	AAFES-3	309	26.25	282.75
	AAFES-5	301.2	30.5	270.7
	AAFES-6	297.5	25	272.5
	AAFES-7	256.9	NE	
PIEZOMETER	XGP-94-01X	304.7	29	275.7
	XGP-94-02X	281.7	27	254.7
	XGP-94-03X	282.2	NE	
	XGP-94-04X	282	NE	
	XGP-94-05X	299.8	17	282.8
	XGP-94-06X	299.3	22	277.3
	XGP-94-07X	298.6	20	278.6

NOTES:

Top of bedrock defined by split-spoon and auger refusal

bgs = below ground surface

MSL = Mean Sea Level

NE = not encountered

TABLE 1-2
SUMMARY OF MONITORING WELL COMPLETION DETAILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

WELL IDENTIFICATION	SOIL DRILLING METHOD	BEDROCK DRILLING METHOD	MEDIA SCREENED	WELL SCREEN DEPTH (Feet bgs)	WELL SCREEN ELEVATION (Feet MSL)	COMPLETION DEPTH (Feet bgs)	WELL CONSTRUCTION MATERIAL
PREVIOUS INVESTIGATIONS							
AAFES-1D	HSA	ROCK CORE	BEDROCK/SOIL	13.9-28.9	282.6 - 267.6	29.7	2" ID PVC
AAFES-2	HSA	ROCK CORE	BEDROCK/SOIL	16.2-31.2	284.5 - 269.5	34.6	2" ID PVC
AAFES-3	HSA	NA	SOIL	16.0-26.0	293.0 - 283.0	26.3	2" ID PVC
AAFES-4	HSA	NA	SOIL	12.8-27.8	297.8 - 282.8	27.8	2" ID PVC
AAFES-5	HSA	NA	SOIL	15.5-30.5	287.7 - 270.7	30.8	2" ID PVC
AAFES-6	HSA	NA	SOIL	14.5-24.5	283.0 - 273.0	24.5	2" ID PVC
AAFES-7	HSA	NA	SOIL	4.5-14.5	252.4 - 242.4	14.5	2" ID PVC
SUPPLEMENTAL SITE INVESTIGATION							
XGM-93-01X	HSA/D&W	ROLLER CONE	BEDROCK/SOIL	23.0-33.0	288.5 - 278.5	34.0	4" ID PVC
XGM-93-02X	HSA/D&W	NA	BEDROCK/SOIL	28.0-38.0	282.6 - 272.6	38.2	4" ID PVC
REMEDIATION INVESTIGATION							
XGM-94-03X	HSA	ROCK CORE/ OVER REAM	BEDROCK/SOIL	19.0-29.0	279.2 - 269.2	30.1	4" ID PVC
XGM-94-04X	HSA	ROCK CORE/ OVER REAM	BEDROCK	18.2-28.2	280.9 - 270.9	29.8	4" ID PVC
XGM-94-05X	HSA	ROCK CORE/ OVER REAM	BEDROCK/SOIL	26.0-36.0	273.3 - 263.3	36.5	4" ID PVC
XGM-94-06X	HSA	NA	SOIL	17.0-27.0	265.2 - 255.2	27.5	4" ID PVC
XGM-94-07X	HSA	ROCK CORE/ OVER REAM	BEDROCK/SOIL	17.0-27.0	276.0 - 266.0	28.2	4" ID PVC
XGM-94-08X	HSA	ROCK CORE/ OVER REAM	BEDROCK/SOIL	23.5-33.5	273.7 - 263.7	36.2	4" ID PVC
XGM-94-09X	HSA	ROLLER CORE	SOIL	23.0-33.0	285.4 - 275.4	33.2	4" ID PVC
XGM-94-10X	HSA	NA	SOIL	21.5-31.5	278.9 - 268.9	32.5	4" ID PVC
XGP-94-01X	HSA/D&W	NA	BEDROCK/SOIL	20.5-30.5	284.2 - 274.2	31.4	4" ID PVC
XGP-94-02X	HSA	NA	SOIL	16.5-26.5	265.2 - 255.2	27.0	1.5" ID PVC
XGP-94-03X	HSA	NA	SOIL	17.0-27.0	265.2 - 255.2	27.0	1.5" ID PVC
XGP-94-04X	HSA	NA	SOIL	17.0-27.0	265.2 - 255.2	27.0	1.5" ID PVC
XGP-94-05X	HSA/D&W	ROCK CORE	BEDROCK	19.6-27.6	280.2 - 272.2	27.8	1.5" ID PVC
XGP-94-06X	HSA/D&W	ROCK CORE	BEDROCK	21.4-31.4	279.9 - 267.9	31.5	1.5" ID PVC
XGP-94-07X	HSA/D&W	ROCK CORE	BEDROCK	19.0-29.0	279.9 - 269.6	30.0	1.5" ID PVC

NOTES:
 bgs = below ground surface
 HSA = Hollow Stem Auger
 NA = Not Applicable
 ID = Inside Diameter
 MSL = Mean Sea Level
 PVC = Polyvinyl Chloride
 HSA/D&W = Boring advanced to refusal with hollow stem auger. 6-inch casing is then driven to or beyond refusal depth. Boring is cleaned out with 5/8-inch roller cone and advanced into bedrock if so noted.
 Rock Core/Oven Ream = Boring was advanced through bedrock by first coring with HQ 14-inch OD core barrel and then reaming out bedrock borehole with 5/8-inch OD roller cone to desired depth for installation of 4-inch monitoring well.

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH ROUND	PARAMETERS										FIELD ANALYTICAL	
					OFF-SITE LABORATORY - PAL ANALYSES					FIELD ANALYSES					BTEX	TPHC/IR
					VOA	SVOA	INOR	INOR - tot	INOR - diss	TPHC	TSS	TOC	H2O QUAL			
SI	Soil	Boring	43G-92-01X	10-12	X											
				20-22	X											
SI	Gas	T-Probe	TS-01	8-9						X					X	
SI			TS-02	8-9						X					X	
SI			TS-03	8-9											X	
SI			TS-04	8-9											X	
SI			TS-05	8-9											X	
SI			TS-06	8-9											X	
SI			TS-07	8-9											X	
SI			TS-08	8-9											X	
SI			TS-09	8-9											X	
SI			TS-10	8-9											X	
SI	Soil		TS-04	9-10											X	
SI			TS-04	12-13											X	
SI			TS-09	9-10											X	
SI			TS-09	12-13											X	
SI			TS-10	11-12											X	
SI			TS-11	9-10											X	
SI			TS-11	12-13											X	
SSI	Soil	T-Probe	TS-01	10-12											X	
SSI			TS-02	9-10											X	
SSI			TS-02	10-11											X	
SSI			TS-02	11-12											X	
SSI			TS-03	9-10											X	
SSI			TS-03	10-11											X	
SSI			TS-04	9-10											X	
SSI			TS-04	10-11											X	
SSI			TS-04	12-13											X	
SSI			TS-05	9-10											X	
SSI			TS-05	10-11											X	
SSI			TS-07	10-11											X	
SSI			TS-08	10-11											X	
SSI			TS-09	9-10											X	
SSI			TS-09	12-13											X	
SSI			TS-10	10-11											X	
SSI			TS-10	11-12											X	
SSI			TS-11	9-10											X	

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH ROUND	PARAMETERS										FIELD ANALYTICAL		
					OFF-SITE LABORATORY - PAL ANALYSES					H2O QUAL					BTEX	CHLOR	TPHC/IR
					VOA	SVOA	INOR - tot	INOR - diss	TPHC	TSS	TOC	H2O QUAL	BTEX	CHLOR	TPHC/IR		
SSI	Soil	T - Probe	TS - 11	12 - 13									X		X		
SSI			TS - 13	10 - 11										X		X	
SSI			TS - 14	10 - 11										X		X	
SSI			TS - 18	9 - 10											X		X
SSI			TS - 19	9 - 10											X		X
SSI			TS - 19	10 - 11											X		X
SSI			TS - 20	9 - 10											X		X
SSI			TS - 20	11 - 12											X		X
SSI			TS - 21	9 - 10											X		X
SSI			TS - 22	13 - 14											X		X
SSI			TS - 23	9 - 10											X		X
SSI			TS - 24	9 - 10											X		X
SSI			TS - 25	9 - 10											X		X
SSI			TS - 26	9 - 10											X		X
SSI			TS - 26	11 - 12											X		X
SSI			TS - 28	11 - 12											X		X
SSI			TS - 29	9 - 10											X		X
SSI			TS - 30	9 - 10											X		X
SSI			TS - 30	10 - 11											X		X
SSI			TS - 31	9 - 10											X		X
SSI			TS - 32	9 - 10											X		X
SSI			TS - 33	9 - 10											X		X
SSI			TS - 34	9 - 10											X		X
SSI			TS - 35	10 - 11											X		X
SSI			TS - 35	11 - 12											X		X
SSI			TS - 36	10 - 11											X		X
SSI			TS - 36	11 - 12											X		X
SSI			TS - 37	10 - 11											X		X
SSI			TS - 37	11 - 12											X		X
SSI			TS - 38	10 - 11											X		X
SSI	TS - 38	11 - 12											X		X		
SSI	TS - 39	10 - 11											X		X		
SSI	TS - 39	11 - 12											X		X		

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH	ROUND	PARAMETERS										
						OFF-SITE LABORATORY - PAL ANALYSES					FIELD ANALYTICAL					
						VOA	SVOA	INOR - 1st	INOR - 2nd	TPIC	TSS	TOC	H2O QUAL	BTEX	CHLOR	TPHC/IR
SSI	Soil	Boring	XGB-93-03X	1-3										X		X
SSI			XGB-93-03X	5-7										X		X
SSI			XGB-93-03X	8-10												
SSI			XGB-93-03X	12-14												
SSI			XGB-93-03X	15-17												
SSI			XGB-93-03X	20-22												
SSI			XGB-93-03X	20-22												
SSI			XGB-93-03X	25-27												
SSI			XGB-93-04X	1-3												
SSI			XGB-93-04X	5-7												
SSI			XGB-93-04X	8-10												
SSI			XGB-93-04X	12-14												
SSI			XGB-93-04X	15-17												
SSI			XGB-93-04X	25-27												
SSI			XGB-93-05X	0-2												
SSI			XGB-93-05X	5-7												
SSI			XGB-93-05X	8-10												
SSI			XGB-93-05X	12-14												
SSI			XGB-93-05X	15-17												
SSI			XGB-93-05X	20-22												
SSI			XGB-93-05X	25-27												
SSI			XGB-93-06X	8-10												
SSI			XGB-93-06X	12-14												
SSI			XGB-93-07X	1-3												
SSI			XGB-93-07X	5-7												
SSI			XGB-93-07X	8-10												
SSI			XGB-93-07X	10-12												
SSI			XGB-93-07X	15-17												
SSI			XGB-93-07X	20-22												
SSI			XGB-93-08X	1-3												
SSI			XGB-93-08X	5-7												
SSI			XGB-93-08X	8-10												
SSI			XGB-93-08X	10-12												
SSI			XGB-93-08X	12-14												
SSI			XGB-93-08X	15-17												

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH	ROUND	PARAMETERS												
						OFF-SITE LABORATORY - PAL ANALYSES					FIELD ANALYTICAL							
						VOA	SVOA	INOR	lot	INOR	--diss	TPHC	TSS	TOC	H2O QUAL	BTEX	CHLOR	TPHC/IR
SSI			XGB-93-04X	17-19		X		X				X					X	X
SSI			XGB-93-04X	19-21													X	X
SSI			XGB-93-04X	25-27													X	X
SSI			XGB-93-09X	1-3													X	X
SSI		Boring	XGB-93-09X	5-7													X	X
SSI			XGB-93-09X	8-10		X		X				X		X			X	X
SSI			XGB-93-09X	12-14		X		X				X		X				
SSI			XGB-93-09X	15-17														
SSI			XGB-93-09X	20-22		X		X				X		X			X	X
SSI			XGB-93-09X	25-27													X	X
SSI		Groundwater	AAFES-1D		3	X		X				X						
SSI			AAFES-1D		4	X		X				X						
SSI			AAFES-2		3	X		X				X						
SSI			AAFES-2		4	X		X				X						
SSI			AAFES-3		3	X		X				X						
SSI			AAFES-3		4	X		X				X						
SSI			AAFES-5		3	X		X				X						
SSI			AAFES-5		4	X		X				X						
SSI			AAFES-6		3	X		X				X						
SSI			AAFES-6		4	X		X				X						
SSI			AAFES-7		3	X		X				X						
SSI			AAFES-7		4	X		X				X						
SSI		Groundwater	XGM-93-01X		3	X		X				X						
SSI			XGM-93-01X		4	X		X				X						
SSI			XGM-93-02X		3	X		X				X						
SSI			XGM-93-02X		4	X		X				X						
SSI			XGD-93-02X			X		X				X		X				
RI		Screened Auger	XGM-94-01X	17-22										X			X	
RI			XGM-94-02X	20-25													X	
RI			XGM-94-04X	22-27													X	
RI			XGM-94-06X	20-25													X	
RI			XGM-94-06X	27-32													X	
RI			XGM-94-09X	29-34													X	
RI			XGM-94-09X	30-35													X	
RI			XGM-94-10X	30-35													X	
RI		Boring	XGM-94-06X	5-7													X	
RI			XGM-94-06X	10-12													X	

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH ROUND	PARAMETERS												
					OFF-SITE LABORATORY - PAL ANALYSES					FIELD ANALYTICAL							
					VOA	SVOA	INOR	tot	INOR	diss	TPHC	TSS	TOC	H20 QUAL	BTEX	CHLOR	TPHC/IR
RI			XGM-94-06X	11-13											X	X	X
RI			XGM-94-06X	15-17											X	X*	X
RI			XGM-94-06X	20-22											X	X*	X
RI			XGM-94-06X	25-27											X	X	X
RI			XGM-94-09X	5-7											X	X	X
RI	Soil	Boring	XGM-94-09X	10-12											X	X	X
RI			XGM-94-09X	15-17											X	X	X
RI			XGM-94-09X	20-22											X	X	X
RI			XGM-94-09X	25-27											X	X	X
RI			XGB-94-09X	30-32											X	X	X
RI			XGB-94-10X	20-22											X	X	X
RI			XGB-94-10X	20-22		X		X							X	X	X
RI			XGB-94-10X	25-27		X		X					X		X	X	X
RI			XGB-94-11X	15-17		X		X					X		X	X	X
RI			XGB-94-11X	25-27		X		X					X		X	X	X
RI			XGB-94-11X	27-29				X							X	X	X
RI			XGB-94-12X	15-17		X							X		X	X	X
RI			XGB-94-12X	20-22											X	X	X
RI			XGB-94-12X	25-27											X	X	X
RI			XGB-94-12X	27-29		X									X	X	X
RI			XGB-94-13X	10-12		X		X					X		X	X	X
RI			XGB-94-13X	15-17		X		X					X		X	X	X
RI			XGB-94-13X	20-22		X									X	X	X
RI			XGB-94-13X	25-27		X		X					X		X	X	X
RI			XGB-94-13X	30-32													
RI			XGB-94-14X	15-17		X							X		X	X	X
RI			XGB-94-14X	20-22		X									X	X	X
RI			XGB-94-14X	25-27		X							X		X	X	X
RI			XGB-94-15X	15-17		X							X		X	X	X
RI			XGB-94-15X	20-22		X		X					X		X	X	X
RI			XGB-94-15X	25-27											X	X	X
RI			XGB-94-15X	27-29		X		X							X	X	X
RI	Water	Groundwater	AAFES-ID		5	X		X									
RI			AAFES-ID		6	X		X					X		X		
RI			AAFES-2		5	X		X									

TABLE 1-3
SUMMARY OF FIELD AND LABORATORY ANALYTICAL PROGRAM
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

FIELD EVENT	MATRIX	SAMPLE TYPE	EXPLORATION	DEPTH ROUND	PARAMETERS											
					OFF-SITE LABORATORY - PAL ANALYSES				FIELD ANALYTICAL							
					VOA	SVOA	INOR - tot	INOR - diss	TPHC	TSS	TOC	H2O QUAL	BTX	CHLOR	TPHC/IR	
RI			AAFES-2	6	X	X	X			X		X				
RI			AAFES-3	5	X	X	X			X		X				
RI			AAFES-3	6	X	X	X			X		X				
RI			AAFES-5	5	X	X	X			X		X				
RI			AAFES-5	6	X	X	X			X		X				
RI			AAFES-6	5	X	X	X			X		X				
RI			AAFES-6	6	X	X	X			X		X				
RI			AAFES-7	5	X	X	X			X		X				
RI			AAFES-7	6	X	X	X			X		X				
RI			XGM-93-01X	5	X	X	X			X		X				
RI			XGM-93-01X	6	X	X	X			X		X				
RI			XGM-93-02X	5	X	X	X			X		X				
RI			XGM-93-02X	6	X	X	X			X		X				
RI			XGM-94-03X	5	X	X	X			X		X				
RI			XGM-94-03X	6	X	X	X			X		X				
RI			XGM-94-04X	5	X	X	X			X		X				
RI			XGM-94-04X	6	X	X	X			X		X				
RI			XGM-94-05X	5	X	X	X			X		X				
RI			XGM-94-05X	6	X	X	X			X		X				
RI			XGM-94-06X	5	X	X	X			X		X				
RI			XGM-94-06X	6	X	X	X			X		X				
RI			XGM-94-07X	5	X	X	X			X		X				
			XGM-94-07X	6	X	X	X			X		X				
RI			XGM-94-08X	5	X	X	X			X		X				
RI			XGM-94-08X	6	X	X	X			X		X				
RI			XGM-94-09X	5	X	X	X			X		X				
RI			XGM-94-09X	6	X	X	X			X		X				
RI			XGM-94-10X	5	X	X	X			X		X				
RI			XGM-94-10X	6	X	X	X			X		X				

Notes:

VOA = Volatile Organic Analysis

SVOA = Semi-volatile Organic Analysis

Inorg. = Inorganics

TOC = Total Organic Carbon

TSS = Total Suspended Solids

PAL = Project Analyte List (See Appendix K of the RI Report for a list of these analytes.)

CHLOR = Chlorinated VOCs (Select list developed for a concurrent sampling program at AOC 41 consisting of vinyl chloride, t- and c-1,2-dichloroethene, trichloroethene, tetrachloroethene, 1,1,2,2-tetrachloroethane)

TPHC = Total Petroleum Hydrocarbons

H2O QUAL = Sulfate, Alkalinity, Phosphate, Nitrite as Nitrogen, Total Kjeldahl Nitrogen, Lead

BTX = Benzene, Toluene, ethylbenzene, M/P/O-Xylenes

TPHC/IR = Total Petroleum Hydrocarbons by Infrared Spectrophotometry

**TABLE 1-4
CHEMICALS OF POTENTIAL CONCERN
AOC 43G**

**FEASIBILITY STUDY REPORT
FORT DEVENS, MA**

	Range of SOLs	Frequency of Detection	Detected Concentrations		Mean of all Samples	Back- Ground	CPC?	Notes
			Minimum	Maximum				
AREA 2 SUBSURFACE SOIL (1 - 15 feet bgs) (mg/kg)								
PAL METALS								
Aluminum	N/A	5/5	3770	12200	6788	18000	No	Background ¹
Arsenic	N/A	5/5	7.15	21	12.1	19	Yes	
Barium	N/A	5/5	21.5	66.5	38.0	54	Yes	
Beryllium	0.5 - 0.5	4/5	0.964	1.38	0.9	0.81	Yes	
Calcium	N/A	5/5	651	2000	1073.6	810	No	Essential Nutrient
Chromium	N/A	5/5	8.89	37.4	23.8	33	Yes	
Cobalt	1.42 - 1.42	4/5	1.67	9.94	4.9	4.7	Yes	
Copper	N/A	5/5	6.54	14.4	10.2	13.5	Yes	
Iron	N/A	5/5	9460	15300	12292	18000	No	Background ¹
Lead	N/A	5/5	3.58	50	14.1	48	Yes	Toxicity Values
Magnesium	N/A	5/5	1590	5670	3488	5500	No	Essential Nutrient
Manganese	N/A	5/5	81.7	324	177.8	380	No	Background ¹
Nickel	N/A	5/5	6.08	33.4	17.4	14.6	Yes	
Potassium	N/A	5/5	702	4290	2086.4	2400	No	Essential Nutrient
Sodium	N/A	5/5	267	330	295.6	234	No	Essential Nutrient
Vanadium	N/A	5/5	11.6	26.3	18.1	32.3	No	Background ¹
Zinc	N/A	5/5	18.2	208	63.5	43.9	Yes	
PAL SEMIVOLATILE ORGANICS								
Acenaphthylene	0.033 - 0.2	1/5	5	5	1.0	NDB	Yes	
Anthracene	0.033 - 0.2	1/5	4	4	0.8	NDB	Yes	
Benzo [a] Anthracene	0.17 - 0.8	1/5	7	7	1.5	NDB	Yes	
Benzo [a] Pyrene	0.25 - 1	1/5	10	10	2.2	NDB	Yes	
Benzo [b] Fluoranthene	0.21 - 1	1/5	30	30	6.2	NDB	Yes	
Benzo [g,h,i] Perylene	0.25 - 1	1/5	3	3	0.8	NDB	Yes	
Benzo [k] Fluoranthene	0.066 - 0.3	1/5	6	6	1.2	NDB	Yes	
Chrysene	0.12 - 0.6	1/5	10	10	2.1	NDB	Yes	
Di-n-butyl Phthalate	0.061 - 0.6	3/5	0.43	0.6	0.4	NDB	No	Blank ⁴
Fluoranthene	0.068 - 0.3	1/5	20	20	4.1	NDB	Yes	
Fluorene	0.033 - 0.2	1/5	1	1	0.2	NDB	Yes	
Indeno [1,2,3-c,d] Pyrene	0.29 - 1	1/5	4	4	1.0	NDB	Yes	
Naphthalene	0.037 - 0.2	1/5	0.5	0.5	0.1	NDB	Yes	
Phenanthrene	0.033 - 0.2	1/5	10	10	2.0	NDB	Yes	
Pyrene	0.033 - 0.2	1/5	10	10	2.0	NDB	Yes	
PAL VOLATILE ORGANICS								
Acetone	0.017 - 0.017	1/5	0.047	0.047	0.02	NDB	No	Blank ⁴
Trichlorofluoromethane	0.006 - 0.006	3/5	0.0057	0.01	0.01	NDB	No	Blank ⁴
OTHER								
Total Petroleum Hydrocarbons	28.5 - 28.8	2/5	158	185	77.2	NDB	Yes	Toxicity Values

TABLE 1-4
CHEMICALS OF POTENTIAL CONCERN
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

	Range of SOLs	Frequency of Detection	Detected Concentrations		Mean of all Samples	Back- Ground	CPC?	Notes
			Minimum	Maximum				
AREA 3 SUBSURFACE SOIL (1 - 15 feet bgs): (mg/kg)								
PAL METALS								
Aluminum	N/A	4/4	5100	11200	8835	18000	No	Background ¹
Arsenic	N/A	4/4	17	51	31.8	19	Yes	
Barium	N/A	4/4	14.6	53.3	30.2	54	No	Background ¹
Cadmium	0.7 - 0.7	1/4	2.61	2.61	0.9	1.28	Yes	
Calcium	N/A	4/4	405	1570	1026.3	810	No	Essential Nutrient
Chromium	N/A	4/4	17.4	46	30.4	33	Yes	
Cobalt	1.42 - 1.42	1/4	3.56	9.93	6.4	4.7	Yes	
Copper	N/A	4/4	9.09	29.2	16.4	13.5	Yes	
Iron	N/A	4/4	9660	19300	12665	18000	Yes	
Lead	N/A	4/4	5.12	57	21.8	48	Yes	
Magnesium	N/A	4/4	2250	6100	3915.0	5500	No	Essential Nutrient
Manganese	N/A	4/4	86.6	267	205.4	380	No	Background ¹
Nickel	N/A	4/4	19.5	38.3	25.2	14.6	Yes	
Potassium	N/A	4/4	568	1340	965.5	2400	No	Essential Nutrient
Sodium	N/A	4/4	287	419	336	234	No	Essential Nutrient
Vanadium	N/A	4/4	8.24	19.9	15.4	32.3	No	Background ¹
Zinc	N/A	4/4	21.3	87.6	42.4	43.9	Yes	
PAL SEMIVOLATILE ORGANICS								
2-Methylnaphthalene	0.049 - 0.5	1/4	0.72	0.72	0.3	NDB	Yes	
Naphthalene	0.037 - 0.4	1/4	0.46	0.46	0.2	NDB	Yes	
PAL VOLATILE ORGANICS								
Toluene	0.001 - 0.001	1/4	0.02	0.02	0.005	NDB	Yes	
Ethylbenzene	0.002 - 0.002	1/4	0.03	0.03	0.008	NDB	Yes	
Xylenes	0.002 - 0.002	1/4	0.6	0.6	0.2	NDB	Yes	
Trichlorofluoromethane	0.006 - 0.006	1/4	0.03	0.03	0.01	NDB	No	Blank ⁴
OTHER								
Total Petroleum Hydrocarbons	N/A	4/4	59.2	1020	412.8	NDB	Yes	Toxicity Values

**TABLE 1-4
CHEMICALS OF POTENTIAL CONCERN
AOC 43G**

**FEASIBILITY STUDY REPORT
FORT DEVENS, MA**

	Range of SQLs	Frequency of Detection	Detected Concentrations		Mean of all Samples	Back- Ground	CPC?	Notes
			Minimum	Maximum				
SOURCE AREA GROUNDWATER c (mg/L) - UNFILTERED								
PAL METALS								
Aluminum	0.141 - 0.141	8/12	0.147	10.7	2.20	6.87	Yes	
Arsenic	0.003 - 0.003	11/12	0.0033	0.0577	0.01	0.0105	Yes	
Barium	NA	12/12	0.0078	0.0816	0.03	0.0396	Yes	
Calcium	NA	12/12	51.2	112	74.53	14.7	No	Essential Nutrient
Chromium	0.006 - 0.006	3/12	0.0069	0.0292	0.007	0.0147	Yes	
Cobalt	0.025 - 0.025	2/12	0.034	0.046	0.02	0.025	Yes	
Copper	0.008 - 0.008	2/12	0.0199	0.0402	0.008	0.0081	Yes	
Iron	NA	12/12	1.46	87.2	25.89	9.1	Yes	
Lead	0.001 - 0.001	8/12	0.0017	0.0491	0.009	0.0043	Yes	
Magnesium	NA	12/12	8.84	29.6	18.9	3.48	No	Essential Nutrient
Manganese	NA	12/12	2.88	14.3	7.6	0.291	Yes	
Nickel	0.034 - 0.034	4/12	0.0812	0.209	0.05	0.0343	Yes	
Potassium	NA	12/12	1.36	7.82	3.2	2.37	No	Essential Nutrient
Sodium	NA	12/12	40.5	98.6	70.6	10.8	No	Essential Nutrient
Vanadium	0.011 - 0.011	2/12	0.0122	0.0122	0.006	0.011	Yes	
Zinc	0.021 - 0.021	5/12	0.0276	0.101	0.03	0.0211	Yes	
PAL SEMIVOLATILE ORGANICS								
2,4-Dimethylphenol	0.006 - 0.06	2/12	0.016	0.021	0.01	NDB	Yes	
2-Methylnaphthalene	0.002 - 0.002	10/12	0.0021	2	0.3	NDB	Yes	
4-Methylphenol / 4-Cresol	0.001 - 0.005	1/12	0.0033	0.0033	0.0007	NDB	Yes	
Acenaphthene	0.002 - 0.02	1/12	0.0032	0.0032	0.002	NDB	Yes	
Anthracene	0.001 - 0.005	1/12	0.0014	0.0014	0.0005	NDB	Yes	
Bis (2-ethylhexyl) Phthalate	NA	12/12	0.0045	0.2	0.05	NDB	No	Blank ⁴
Fluorene	0.004 - 0.004	2/12	0.02	0.04	0.007	NDB	Yes	
Naphthalene	0.001 - 0.001	11/12	0.0009	1	0.2	NDB	Yes	
Phenanthrene	0.001 - 0.001	3/12	0.0006	0.02	0.003	NDB	Yes	
PAL VOLATILE ORGANICS								
Xylenes	NA	12/12	0.0013	20	3.36	NDB	Yes	
Benzene	NA	12/12	0.0021	2	0.62	NDB	Yes	
Carbon Disulfide	0.001 - 0.1	1/12	0.0009	0.0009	0.01	NDB	Yes	
Ethylbenzene	NA	12/12	0.019	2	0.43	NDB	Yes	
Methylene Chloride	0.002 - 0.6	3/12	0.0027	0.02	0.04	NDB	No	Blank ⁴
Methyl isobutyl ketone	0.003 - 0.8	1/12	0.019	0.019	0.06	NDB	No	Blank ⁴
Toluene	0.001 - 0.001	11/12	0.0015	0.3	0.09	NDB	Yes	
SOURCE AREA GROUNDWATER c (mg/L) - FILTERED								
PAL METALS								
Aluminum	0.141 - 0.141	1/12	0.3	0.3	0.09	6.87	No	Background ¹
Antimony	0.003 - 0.003	2/12	0.0028	0.004	0.002	0.003	Yes	
Arsenic	NA	12/12	0.0047	0.0241	0.01	0.0105	Yes	
Barium	NA	12/12	0.0081	0.0485	0.02	0.0396	Yes	
Calcium	NA	12/12	53.1	101	72.4	14.7	No	Essential Nutrient
Iron	NA	12/12	2.19	54.1	18.50	9.1	Yes	
Lead	0.001 - 0.001	4/12	0.0014	0.003	0.001	0.0043	No	Background ¹
Magnesium	NA	12/12	9.06	27.3	17.6	3.48	No	Essential Nutrient
Manganese	NA	12/12	3.12	15.2	7.5	0.291	Yes	
Nickel	0.034 - 0.034	2/12	0.0651	0.18	0.03	0.0343	Yes	
Potassium	NA	12/12	1.41	6.66	2.7	2.37	No	Essential Nutrient
Sodium	NA	12/12	42	105	70.9	10.8	No	Essential Nutrient

**TABLE 1-4
CHEMICALS OF POTENTIAL CONCERN
AOC 43G**

**FEASIBILITY STUDY REPORT
FORT DEVENS, MA**

	Range of SQLs	Frequency of Detection	Detected Concentrations		Mean of all Samples	Back- Ground	CPC?	Notes
			Minimum	Maximum				
DOWNGRAIDENT GROUNDWATER _a (mg/L) - UNFILTERED								
PAL METALS								
Aluminum	0.141 - 0.141	5/8	0.459	1.86	0.7	6.87	No	Background ¹
Arsenic	0.003 - 0.003	5/8	0.0107	0.0236	0.01	0.0105	Yes	
Barium	NA	8/8	0.0131	0.0276	0.02	0.0396	No	Background ¹
Calcium	NA	8/8	45.5	64.7	55.2	14.7	No	Essential Nutrient ²
Iron	NA	8/8	0.19	12.4	5.6	9.1	Yes	
Lead	0.001 - 0.001	4/8	0.0018	0.0035	0.002	0.0043	No	Background ¹
Magnesium	NA	8/8	8.37	13.6	10.5	3.48	No	Essential Nutrient ²
Manganese	NA	8/8	1.71	8.63	5.2	0.291	Yes	
Potassium	NA	8/8	1.48	3.79	2.6	2.37	No	Essential Nutrient ²
Sodium	NA	8/8	40.1	104	60.6	10.8	No	Essential Nutrient ²
Zinc	0.021 - 0.021	1/8	0.0249	0.0249	0.01	0.0211	Yes	
PAL SEMIVOLATILE ORGANICS								
2-Methylnaphthalene	0.002 - 0.002	1/8	0.0022	0.0022	0.001	NDB	Yes	
Bis (2-ethylhexyl) Phthalate	0.005 - 0.005	4/8	0.0046	0.064	0.02	NDB	No	Blank ⁴
Naphthalene	0.001 - 0.001	3/8	0.003	0.0062	0.002	NDB	Yes	
PAL VOLATILE ORGANICS								
Xylenes	0.001 - 0.001	4/8	0.0018	0.047	0.01	NDB	Yes	
Benzene	0.001 - 0.001	6/8	0.0015	0.079	0.02	NDB	Yes	
Ethylbenzene	0.001 - 0.001	3/8	0.015	0.029	0.008	NDB	Yes	
Methylene Chloride	0.002 - 0.002	1/8	0.0022	0.0022	0.001	NDB	No	Blank ⁴
Tetrachloroethylene	0.002 - 0.002	2/8	0.0033	0.0038	0.001	NDB	Yes	
Toluene	0.001 - 0.001	5/8	0.0005	0.0044	0.002	NDB	Yes	
DOWNGRAIDENT GROUNDWATER _a (mg/L) - FILTERED								
PAL METALS								
Arsenic	0.003 - 0.003	5/8	0.0078	0.0141	0.007	0.0105	Yes	
Barium	NA	8/8	0.0117	0.0237	0.02	0.0396	No	Background ¹
Calcium	NA	8/8	44.2	66	55.6	14.7	No	Essential Nutrient ²
Iron	NA	8/8	0.0602	9.84	2.9	9.1	Yes	
Magnesium	NA	8/8	8.09	12.8	10.2	3.48	No	Essential Nutrient ²
Manganese	NA	8/8	1.86	8.82	5.3	0.291	Yes	
Potassium	NA	8/8	1.44	2.91	2.3	2.37	No	Essential Nutrient ²
Sodium	NA	8/8	39.3	110	61.6	10.8	No	Essential Nutrient ²
Zinc	0.021 - 0.021	1/8	0.0689	0.0689	0.02	0.0211	Yes	

NOTES:

^a Based on samples XGB-93-05X, XGB-93-06X, and XGB-93-07X

^b Based on samples XGB-93-03X and XGB-94-04X

^c Based on samples XGM-94-03X to -04X, XGM-93-02X, AAFES-1D, -2, -6

^d Based on samples XGM-94-06X to -08X, -10X

Background¹ - Sample concentrations detected are below background concentrations.

Essential Nutrient² - Analyte is an essential human nutrient (magnesium, calcium, potassium, sodium) and is not considered a CPC.

Toxicity Values³ - Compound cannot be evaluated quantitatively because toxicity values are not available.

Blank⁴ - Compound was detected in field and/or laboratory blanks.

SQL - Sample Quantitation Limit

NDB - not detected in background

N/A - not applicable

mg - milligram

L - liter

kg - kilogram

bgs - below ground surface

CPC - chemical of potential concern

TABLE 1-5
QUANTITATIVE RISK SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
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	Total Cancer Risk	MEAN EPC Total Hazard Index	Total Cancer Risk	MAXIMUM EPC Total Hazard Index
CURRENT AND FUTURE LAND USE				
SUBSURFACE SOIL (1 - 15 feet bgs) at AREA 2				
Incidental Ingestion of Subsurface Soil: Utility/Maintenance Worker	6E-07	0.008	2E-06	0.01
Inhalation of Volatiles from Soil: Utility/Maintenance Worker	ND	ND	ND	ND
TOTAL: UTILITY/MAINTENANCE WORKER	6E-07	0.008	2E-06	0.01
SUBSURFACE SOIL (1 - 15 feet bgs) at AREA 3				
Incidental Ingestion of Subsurface Soil: Utility Worker	7E-07	0.03	1E-06	0.05
Inhalation of Volatiles from Soil: Utility Worker	NC	4E-08	NC	2E-07
TOTAL: UTILITY/MAINTENANCE WORKER	7E-07	0.03	1E-06	0.05
FUTURE LAND USE				
SOURCE AREA GROUNDWATER - UNFILTERED				
Ingestion of Groundwater: Future Commercial/Industrial Worker	1E-04	37	6E-04	99
TOTAL: FUTURE COMMERCIAL/ INDUSTRIAL WORKER	1E-04	37	6E-04	99
SOURCE AREA GROUNDWATER - FILTERED				
Ingestion of Groundwater: Future Commercial/Industrial Worker	1E-04	36	4E-04	98
TOTAL: FUTURE COMMERCIAL/ INDUSTRIAL WORKER	1E-04	36	4E-04	98
DOWNGRADIANT GROUNDWATER - UNFILTERED				
Ingestion of Groundwater: Future Commercial/Industrial Worker	6E-05	11	2E-04	21
TOTAL: FUTURE COMMERCIAL/ INDUSTRIAL WORKER	6E-05	11	2E-04	21
DOWNGRADIANT GROUNDWATER - FILTERED				
Ingestion of Groundwater: Future Commercial/Industrial Worker	5E-05	11	9E-05	21
TOTAL: FUTURE COMMERCIAL/ INDUSTRIAL WORKER	5E-05	11	9E-05	21

Notes:

EPC - exposure point concentration

ND - No volatiles detected

NC - No carcinogenic volatiles detected

2.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

Remedial action objectives and general response actions form the basis for identifying remedial technologies and developing remedial alternatives. This section identifies remedial response and action objectives and the general response actions to meet those objectives. Remedial technologies considered implementable, and which also address the remedial action objectives and general response actions, are identified. Candidate remedial technologies are then screened based on their applicability to site and waste characteristics. The purpose of the screening is to produce an inventory of suitable technologies that can be assembled into remedial alternatives capable of mitigating actual or potential risks at AOC 43G.

2.1 IDENTIFICATION OF REMEDIAL RESPONSE OBJECTIVES

Remedial response objectives are site-specific qualitative cleanup objectives established on the basis of the nature and distribution of contamination, the resources currently or potentially threatened, and the potential for human and environmental exposure. For AOC 43G, remedial response objectives were formulated based on environmental concerns defined in the environmental contamination assessment, risk assessment, and ARARs analysis. Response objectives are used for defining remedial action objectives and for developing appropriate remedial alternatives.

Based on the environmental contamination assessment in the RI Report and considering the planned future soil removal actions, the following remedial response objectives were identified for AOC 43G:

- Protect potential commercial/industrial receptors located on Army Reserve Enclave property from exposure to groundwater having chemicals in excess of ARARs.
- Protect potential commercial/industrial receptors located off Army Reserve Enclave property from exposure to groundwater having chemicals in excess of ARARs.

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2.2 PRELIMINARY REMEDIATION GOALS

Preliminary Remediation Goals (PRGs) are numerical goals for site cleanup that are intended to be protective and to comply with ARARs. PRGs are based both on risk assessment and on ARARs. PRGs for AOC 43G were developed following the USEPA guidance document entitled *Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part B, Development of Risk Based Preliminary Remediation Goals)*, Interim, December 1991 (RAGS Part E) (USEPA, 1991c) and OSWER Directive 9355.0-30, *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (USEPA, 1991b).

The first step in developing human health PRGs is to identify those environmental media that, in the baseline human health risk assessment, present either a cumulative current or future cancer risk greater than 1×10^{-4} or a cumulative noncarcinogenic HI greater than 1, based on reasonable maximum exposure (RME) assumptions. The RME is defined as the maximum exposure that is reasonably expected to occur at a site. It is derived for a given exposure pathway by combining the maximum exposure point concentration (EPC) of each chemical with reasonable maximum values describing the extent, frequency, and duration of exposure. The specific assumptions used in deriving the RME for each exposure scenario are discussed in detail in the Final RI Report (ABB-ES, 1996). The next step is to identify CPCs within the media that present cancer risks greater than 1×10^{-6} or a hazard quotient (HQ) greater than 1. Following identification of media of concern and CPCs, PRGs are developed and refined by considering ARARs, exposures, uncertainties and other technical factors.

Under assumptions of current land use, the baseline human health risk assessment did not identify media of concern or CPCs presenting cancer risks or HIs greater than USEPA criteria. Under assumptions of future land use, commercial/industrial use of groundwater at AOC 43G does present potential human health risks above the criteria for both source area groundwater and downgradient groundwater (Table 1-5).

2.2.1 Groundwater

Risk Evaluation: The consumption of groundwater with maximum EPCs from evaluated groundwater samples from source and downgradient areas (unfiltered source/downgradient areas and filtered source area) presents cancer risks above

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1×10^4 . Following USEPA guidance, for those media with cancer risks above 1×10^4 , the next step is to identify those CPCs within the media that present cancer risks above 1×10^6 . Arsenic and benzene are the only two CPCs that meet this criterion for source area and downgradient groundwater.

Similarly, for noncancer risks under future use assumptions, only the risks from commercial/industrial groundwater use exceed the criterion. As seen in Table 1-5, the HIs for both the unfiltered and filtered groundwater exceed 1 for source area and downgradient groundwater. As with carcinogens, USEPA guidance states that within those media with noncancer risks above 1, the next step is to identify those CPCs within the medium whose HQ exceeds 1. Benzene, manganese, iron and arsenic are the only CPCs meeting this criterion from exposure to maximum concentrations detected at AOC 43G at the source area. Only manganese and benzene meet this criteria in downgradient groundwater.

Comparison with ARARs: The baseline human health risk assessment also identified source area and downgradient groundwater analytes that exceeded federal or Massachusetts drinking water standards. These analytes are xylene, benzene, ethylbenzene, aluminum, arsenic, iron, lead, manganese, and nickel in source area groundwater and benzene, iron, aluminum and manganese in downgradient area groundwater. Aluminum, iron, and manganese only have secondary maximum contaminant level (SMCL) drinking water standards which are not ARARs. Therefore, only arsenic, lead, nickel, benzene, ethylbenzene and xylene exceed ARARs in source or downgradient areas.

Tables 2-1 and 2-2 (for source area groundwater and downgradient groundwater, respectively) list CPCs from the baseline human health risk assessment that either exceed ARARs or present cancer risks above 10^6 or HQs greater than 1. The tables provide the average and maximum EPCs for each CPC and compare these values with:

- ARARs (federal and Massachusetts drinking water standard concentrations) identified in Section 4.0 of the Final RI Report (ABB-ES, 1996).
- The Fort Devens background concentrations of inorganics in unfiltered groundwater samples as discussed in Section 4.0 and Appendix L of the Final RI Report (ABB-ES, 1996).

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- The average and maximum analyte concentrations detected in groundwater upgradient of the source area as detailed in Section 7.0 of the Final RI Report (ABB-ES, 1996).

Table 2-1 and 2-2 also include all CPCs identified in the baseline human health risk assessment that present cancer risks above 1×10^{-6} or an HQ greater than 1.0. PRGs are based on the maximum contaminant levels (MCLs) when available and default to risk-based values only if an MCL is not available. MCL-based PRGs are proposed in Tables 2-1 and 2-2 as either the lowest drinking water standard (ARAR) or as the Fort Devens inorganic background concentration, whichever is highest. As seen in Table 2-1 for source area groundwater, ARARs-based PRGs are proposed for benzene, ethylbenzene, xylene and nickel. PRGs are proposed at Fort Devens inorganic background concentrations for iron and manganese because background concentrations exceed the risk-based concentration derived from the available reference dose values. These reference dose values are 3.0×10^{-1} and 5.0×10^{-3} for iron and manganese, respectively.

Similarly, PRGs are determined in Table 2-2 (for manganese and benzene) in downgradient area groundwater. Risk-based PRGs were not developed for AOC 43G. Figures 2-1 and 2-2 show the estimated MCL concentration contours for benzene, ethylbenzene, and xylenes for Rounds 5 and 6, respectively. Xylenes did not exceed its MCL in the latter round.

Lead and arsenic exceedances in source area groundwater are directly attributable to the high level of suspended solids in the samples and as a result, respective PRGs were not developed (Table 2-1). Lead concentrations exceeded MCLs in only two samples within the source area in Rounds 5 and 6 of groundwater sampling ($21.4 \mu\text{g/L}$ in XGM-93-02X and $49.1 \mu\text{g/L}$ in AAFES-2). The TSS concentrations for these samples were 2,950,000 and 1,060,000 $\mu\text{g/L}$, respectively, which are more than 5 times the average TSS concentration of the other 10 samples. Lead concentrations in filtered source area groundwater samples from Rounds 5 and 6 were all below federal and Commonwealth standards, and Fort Devens background.

Arsenic unfiltered sample concentrations exceeded its MCL ($50 \mu\text{g/L}$) in upgradient ($82.5 \mu\text{g/L}$) as well as source area groundwater ($57.7 \mu\text{g/L}$). All filtered samples were below its MCL.

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Inorganic Solubility: Tables 2-1 and 2-2 also show that although EPCs for iron, manganese and nickel in the source area exceed an MCL (nickel) and/or Fort Devens background (nickel, iron, and manganese) the concentrations of these analytes in upgradient wells (XGM-93-01X and AAFES-3) also exceed the MCL or Fort Devens background concentrations. This implies that these inorganics are not specific to AOC 43G activities. However, PRGs for these inorganics have been established. It appears that AOC 43G activities may be impacting the solubility of these analytes. Because ARAR or risk exceedances are largely due to the increase in solubility, measurements for compliance with the inorganic PRGs will be performed by filtered sampling. Otherwise, as presented by upgradient monitoring well results, PRGs based upon unfiltered samples would never be achievable due to the presence of elevated unfiltered inorganic concentrations upgradient of the source area.

It is noted that filtered source area samples contain higher concentrations of arsenic, iron, manganese and nickel than respective upgradient samples. The higher dissolved concentrations of these inorganics are likely due to ongoing biological degradation of the site-related organic contaminants. Studies show that hydrocarbon biodegradation is essentially an oxidation-reduction reaction where the hydrocarbon is oxidized (donates electrons) and an electron acceptor, such as oxygen, is reduced (accepts electrons) (Borden, 1995; McAllister, 1994).

Under aerobic conditions the electron acceptor is oxygen. When oxygen is depleted, and nitrate (and other oxidized forms of nitrogen) are present, anaerobic microorganisms will use nitrate instead of oxygen as a terminal electron acceptor. At this time in the orderly succession of oxidation-reduction reactions, manganese oxides (Mn[IV]) are also reduced to Mn(II), increasing manganese concentration in solution. Once oxygen, nitrate and manganese acceptors are depleted, subsurface microorganisms use oxidized ferric iron (Fe[III]) as an electron acceptor. The reduction of Fe(III) results in elevated concentrations of the more soluble ferrous (Fe[II]) ion in solution.

Sulfate-reducing and methanogenic (methane-generating) degradation generally follow ferric iron reduction in the sequence of microbial induced redox processes. The farther the progression in this redox sequence, the lower the redox potential. Nickel and arsenic are not directly identified as electron acceptors in microbial induced processes. However, their increased solubility is likely due to the changed chemical environment. For instance, arsenic is more soluble at low redox

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potentials (As[III] is more soluble than As[V]).

Table 2-3 presents the average measurements of nitrite/nitrate, sulfate, oxidation-reduction potential (ORP) from groundwater monitoring wells upgradient of the source, at the source area, at the perimeter of the plume, downgradient within the plume (where benzene concentrations exceed $5 \mu\text{g/L}$), and downgradient (where benzene concentrations were less than $5 \mu\text{g/L}$). Reduced average nitrate/nitrite, phosphate, sulfate, and ORP measurements in the source area are indicative that these microbial-induced redox processes are occurring at AOC 43G and causing some inorganics to become more soluble.

Sulfate and chloride concentrations in the downgradient ($<5 \mu\text{g/L}$ benzene) zone appear to be contrary to the expected trend. Under ideal model conditions, it would be expected that sulfate downgradient concentrations would increase back up to upgradient concentrations. However, the apparent decrease in sulfate between downgradient plume and downgradient ($<5 \mu\text{g/L}$ benzene) zone could be contributed to the smaller data set collected for the downgradient wells (4 sampling points/events each zone) than for the source area and the perimeter area (15 and 8 sampling points/events, respectively). Due to the general variability in the data within many wells between sampling rounds (i.e., AAFES 6 sulfate concentrations jumped from $11,000 \mu\text{g/L}$ in Round 5 to $25,000 \mu\text{g/L}$ in Round 6) a smaller data set is not as likely to be as representative of the true average. Also, Lovely, Chapelle, and Woodward (Lovely, 1994) note that when shallow aquifers are heavily contaminated with organic compounds, it is generally difficult to delineate the distribution of the anoxic redox processes. They further state that reduced products that are actively produced near the source of organic contamination may persist in the groundwater as it moves downgradient into areas where there is little or no ongoing production of these compounds. This persistence could also partially explain the lower than expected sulfate concentrations observed in far downgradient wells.

Under ideal model conditions, it would be expected that chloride concentrations would remain constant from upgradient to downgradient wells. Road salt most likely contributes to the variability of the chloride concentrations in Table 2-3 as can be noted by observing the generally higher concentrations and seasonal fluctuations in wells that are close and downgradient of roadside or parking areas (AAFES-3, AAFES-5, XGM-94-05X, -07X) as compared with more remote wells such as (XGM-94-09X, -10X and AAFES-7).

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2.2.2 Subsurface Soil

Under assumptions of current and future land use, the baseline human health risk assessment did not identify CPCs within subsurface soil that present cancer risks or HIs greater than USEPA criteria (Table 1-5). Additionally, there are currently no chemical-specific ARARs which govern the extent of site remediation for subsurface soil at AOC 43G.

The Army also has, or will be, removing the three known source soil areas at AOC 43G. The former gasoline USTs with adjacent contaminated soils down to a depth of 20 feet bgs and the former waste oil UST with immediately adjacent contaminated soils have been previously removed as discussed in Subsection 1.2.1. The sand and gas trap with associated contaminated soils are to be removed as discussed in Subsection 1.6. Details of this removal action are specified in the Construction Solicitation and Specifications Design package prepared by the U.S. Army Corps of Engineers (USACE, 1996). This removal is scheduled for the summer of 1996 prior to signing the ROD.)

However, because groundwater at AOC 43G does present potential health risks above the target risk range, consideration was given to minimizing the possibility of soils with residual contamination from contributing to groundwater contamination in excess of ARARs. Two locations of residual soil contamination identified in the RI and evaluated in the following paragraphs as possibly influencing groundwater are (a) soils below and around the former waste oil UST (Area 3) and (b) soils associated with the former gasoline USTs (Area 2).

Laboratory analyses of SSI samples collected in the former waste oil UST excavation location have shown minimal contamination at a lower depth near groundwater (Subsection 1.3.2.2). For this reason, the residual contaminated soil associated with the former waste oil UST is not believed to be a continuing source of groundwater contamination. Further FS evaluation regarding subsurface soils will pertain to only the gasoline UST soils.

On May 2, 1996 the Army held a meeting with the regulators at Fort Devens to discuss the draft FS report for AOC 43G. Discussions pertained primarily to the residual soil contamination that remains below the existing gasoline USTs and the possible repercussions on groundwater remediation. The Army does not propose to remove this soil as part of the UST removal action. The residual soil

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contamination, which is approximately 20 to 28 feet bgs, is impractical to remove due to soil depth and the proximity to adjacent structures and roadways. Additionally, groundwater remediation benefit from removing the soil is not readily definable at this time.

Conclusions from the meeting were that soil removal below the gasoline USTs and the former waste oil tank location are not practical considering the questionable benefits that soil removal would have on groundwater remediation. However, as part of this FS, a soil treatment (in-situ) component will be evaluated for treatment of residual contamination below the gasoline USTs. Additionally, a contingency action will be included in the ROD and would be implemented should the remedial alternative fail to meet remedial objectives. This contingency will consider the residual soil contamination at the site and/or aggressive groundwater remedial approaches.

2.3 REMEDIAL ACTION OBJECTIVES

Remedial action objectives are medium- or operable unit-specific, quantitative goals defining the extent of cleanup required to achieve response objectives. They specify contaminants of concern, exposure routes and receptors, and PRGs. Remedial action objectives are used as the framework for developing remedial alternatives. The remedial action objectives are formulated to achieve the overall goal of USEPA of protecting human health and the environment. Table 2-4 lists remedial action objectives for AOC 43G.

2.4 GENERAL RESPONSE ACTIONS

General response actions describe categories of remedial actions that may be employed to satisfy remedial action objectives. General response actions provide the basis for identifying specific remedial technologies.

Applicable general response actions to meet remedial action objectives are listed in Table 2-5 in conjunction with potential remedial technologies. The general response actions for groundwater focus on preventing possible future commercial/industrial use of groundwater near the source of contamination on Army Reserve Enclave property; and on preventing possible future

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commercial/industrial use of groundwater downgradient off Army Reserve Enclave property. These general response actions are in accordance with recommendations made in USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (USEPA, 1988).

Similarly, because the residual soil contamination below the gasoline USTs has limited potential to recontaminate groundwater at the site, general response actions for soil were developed and are presented in Table 2-8. The general response actions presented for soils focus on minimizing the possibility of the residual soil contamination contributing to groundwater contamination in excess of the groundwater PRGs. For this FS, soils that are removed to implement groundwater remedial actions are minimal in volume and will be evaluated as an incidental capital expense for the groundwater treatment alternative.

2.5 TECHNOLOGY IDENTIFICATION

Categories of remedial technologies and specific process options were identified based on a review of literature, vendor information, performance data, and experience in developing other FSs under CERCLA. Of these process options, 18 were selected as being potentially applicable to petroleum-contaminated media and attaining the preliminary remedial response objectives. Selected groundwater technologies focus on organic contamination. This is based on the premise that the naturally occurring inorganic chemicals within the groundwater have become more soluble as a result of microbial induced redox processes (Subsection 2.2.1). Removal of the organics will return the groundwater quality (oxygen content, ORP, pH) to upgradient conditions resulting in a return of the more insoluble inorganic fractions. For ex-situ groundwater treatment process options, inorganic pretreatment that is required for effective treatment of organics and to meet discharge requirements is included as part of the organic treatment process option.

Technologies selected for the gasoline UST soils at AOC 43G are the USEPA presumptive remedies for CERCLA sites with VOCs in soil (USEPA, 1993) with inclusion of the asphalt batching technology, also for treatment of petroleum contaminated soils. Disposal response actions are also included for instances where soil volumes are minimal. Tables 2-6 and 2-9 provide descriptions for groundwater and soil process options, respectively.

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2.6 TECHNOLOGY SCREENING

The technology screening process reduces the number of potentially applicable technologies and process options by evaluating factors that may influence process option effectiveness and implementability. This overall screening is consistent with the guidance for conducting FSs under CERCLA (USEPA, 1988).

The screening process assesses each technology or process option for its probable effectiveness and implementability with regard to site-specific conditions, known and suspected contaminants, and affected environmental media. The effectiveness evaluation focuses on: (1) whether the technology is capable of handling the estimated areas or volumes of media and meeting the contaminant reduction goals identified in the remedial action objectives; (2) the effectiveness of the technology in protecting human health during the construction and implementation phase; and (3) how proven and reliable the technology is with respect to the contaminants and conditions at the site. Implementability encompasses both the technical and institutional feasibility of implementing a technology. Effectiveness and implementability are incorporated into two screening criteria: waste- and site-limiting characteristics.

Waste-limiting characteristics largely establish the effectiveness and performance of a technology; site-limiting characteristics affect implementability of a technology. Waste-limiting characteristics consider the suitability of a technology based on contaminant types, individual compound properties (e.g., volatility, solubility, specific gravity, adsorption potential, and biodegradability), and interactions that may occur between mixtures of compounds (e.g., reactions and increased solubility). Site-limiting characteristics consider the effect of site-specific physical features, including topography, buildings, underground utilities, available space, and proximity to sensitive operations on the implementability of a technology. Technology screening based on waste- and site-limiting characteristics serves a two-fold purpose of screening out technologies whose applicability is limited by site-specific waste or site considerations, while retaining as many potentially applicable technologies as possible.

Tables 2-7 and 2-10 summarize the groundwater and soil technology screening phase for AOC 43G. Technologies and process options judged ineffective or not implementable were eliminated from further consideration. All soil technologies requiring removal (ex-situ treatment) were eliminated for reasons discussed in

Subparagraph 2.2.2.

Table 2-11 summarizes the groundwater and soil technologies retained for further consideration. The technologies retained following screening represent an inventory of technologies considered most suitable for AOC 43G. Technologies retained in this section may be used to develop remedial alternatives.

2.7 PROCESS OPTION EVALUATION (CARBON ADSORPTION AND UV OXIDATION)

For some general response actions more than one process option is retained. For groundwater, limited action, zoning restrictions, deed restrictions, and groundwater monitoring were all retained. Each will be carried forward for incorporation into alternatives. For collection, interceptor trenches and extraction wells were both retained and will be evaluated in the alternative screening based on groundwater modeling and/or geologic constraints. In these instances, more than one process option was retained because the processes were sufficiently different in their performance that one would not adequately represent the other. Similarly, all retained soil process options will be incorporated into alternatives. However, for groundwater treatment there were two ex-situ groundwater process options retained, ultraviolet (UV) oxidation and granular activated carbon (GAC) adsorption. These process options are evaluated in more detail within this section and a single process option is retained.

CERCLA guidance recommends that these process options be evaluated based on their effectiveness, implementability and relative cost. These criteria are described in detail in Section 3. The process option retained from this evaluation will be used to develop remedial alternatives for the groundwater at AOC 43G. This intermediate evaluation step is performed to select a representative process option for the remedial technologies and streamline the FS process by reducing the number of alternatives developed and evaluated (USEPA, 1988).

The process options of GAC adsorption and UV oxidation would be used as an ex-situ treatment technology for all alternatives that entail extraction (collection) of groundwater. GAC adsorption is a physical separation process in which contaminated groundwater is passed through a bed (drum) of GAC which selectively adsorbs the organic contaminants (adsorbate) onto the carbon (adsorbent). When the GAC has been utilized to its maximum adsorptive

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capacity ("spent"), it is then removed for disposal, destruction, or regeneration.

UV oxidation involves pumping contaminated groundwater through a stainless steel oxidation chamber containing UV lamps. The UV radiation and simultaneous application of a chemical oxidant (hydrogen peroxide) promote a rapid breakdown (destruction) of the dissolved organic contaminants. When the reaction is carried to completion, hydrocarbon contaminants are converted to carbon dioxide and water. Any halogens present in the organic molecule are converted to halides.

2.7.1 Effectiveness

Both GAC adsorption and UV oxidation would be effective at mitigating the risks associated with groundwater contamination at AOC 43G. GAC will adsorb the organic contaminants of concern from the groundwater onto the carbon thereby reducing the toxicity and volume of contaminants through treatment. UV oxidation achieves the same results through destruction of the contaminants within the groundwater. Both processes are likely to be affected by the elevated inorganic and suspended solids concentrations at AOC 43G and pretreatment for inorganic and suspended solid removal/reduction will be required. UV oxidation is more susceptible to loss in efficiency under these conditions because the suspended solids and oxidized inorganics can impede the passage of ultraviolet radiation. Some UV units come equipped with automated lamp cleaners to minimize the need to clean the lamps manually.

The GAC adsorption process option may create a slightly greater exposure to human health and the environment during implementation due to the handling and transportation of the spent carbon to an off-site regeneration or treatment, storage and disposal (TSD) facility. The time taken to treat the groundwater would be the same for either process option because the low effective pumping rate from the aquifer is the controlling factor.

2.7.2 Implementability

Both process options are technically feasible for mitigating the risk associated with groundwater contamination. UV oxidation is a more complex process requiring pilot testing to optimize UV light intensity, residence time, and oxidant dose rates to achieve effluent limitations. Due to the low flow conditions, the UV unit

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would probably come equipped with a holding tank and would be programmed to run when the water level in the tank rises above a control point. The UV system would also have greater power requirements than the GAC adsorption process option. Power needs at the site would need to be assessed.

Neither process option would prevent further remedial action should it be required in the future.

2.7.3 Cost

For comparison purposes, costs were based upon treatment of groundwater at a 1 gpm flow rate over a period of 30 years at a discount rate of 10%. Operation and maintenance costs for the UV system includes a weekly site visit to record meter readings of light intensity, oxidant dose, and flow rates; periodic cleaning of UV lights; UV bulb replacement; power costs; and pretreatment expenditures.

Operation and maintenance costs for the GAC system includes a weekly site visit to check flow rates and system conditions; power costs; GAC purchase and disposal costs; and pretreatment expenditures. Approximate costs for both process options are shown below:

UV Oxidation	Capital:	\$ 430,375
	O&M Present Worth:	\$ 811,395
	Total Present Worth:	\$ 1,241,770
GAC Adsorption	Capital:	\$ 220,690
	O&M Present Worth:	\$ 496,904
	Total Present Worth:	\$ 717,594

2.7.4 Process Option Selection

Due to higher costs and more stringent pretreatment requirements, UV oxidation will be eliminated from further evaluation.

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LEGEND

①

-  SOIL BORING/VAPOR EXTRACTION WELL
-  SOIL BORING
-  PIEZOMETER
-  MONITORING WELL
-  ESTIMATED MCL CONTOURS
-  B — BENZENE — 5 ug/L
-  E — ETHYLBENZENE — 700 ug/L
-  — — — INDICATES ASSUMPTION DUE TO LACK OF DATA POINTS

NOTES:

1. GROUND SURFACE ELEVATION CONTOUR INTERVAL IS 5 FEET.
2. ALL CONCENTRATIONS IN ug/L.
3. NA — NOT ANALYZED.

0 25 50 100 FEET

SCALE: 1" = 50'

LOCATION
OF EXISTING
GASOLINE
USTS

ROAD

LOCATION
OF FORMER
WASTE OIL
UST

QUEENSTOWN

AREA 2

AREA 3

AREA 1

XGM-93-01X
B - <0.5
E - <0.5

B - <0.5
E - <0.5

XGB-94-15X

XGB-94-14X

XGM-93-02X
B - 900
E - 800

AAFE8-6
B - 37
E - 19

XGM-94-04X
XGP-94-07X

XGP-94-05X

XGP-94-01X

XGP-94-06X

XGM-94-09X
B - <0.5
E - 0.95

XGB-94-10X
B -
E -

CONCRETE RETAINING WALL

ABOVE GROUND
WASTE OIL
STORAGE TANK

WOODEN PLATFORM
2009

AAFE8 GAS
STATION
2008

WOODED AREA

WOODED AREA

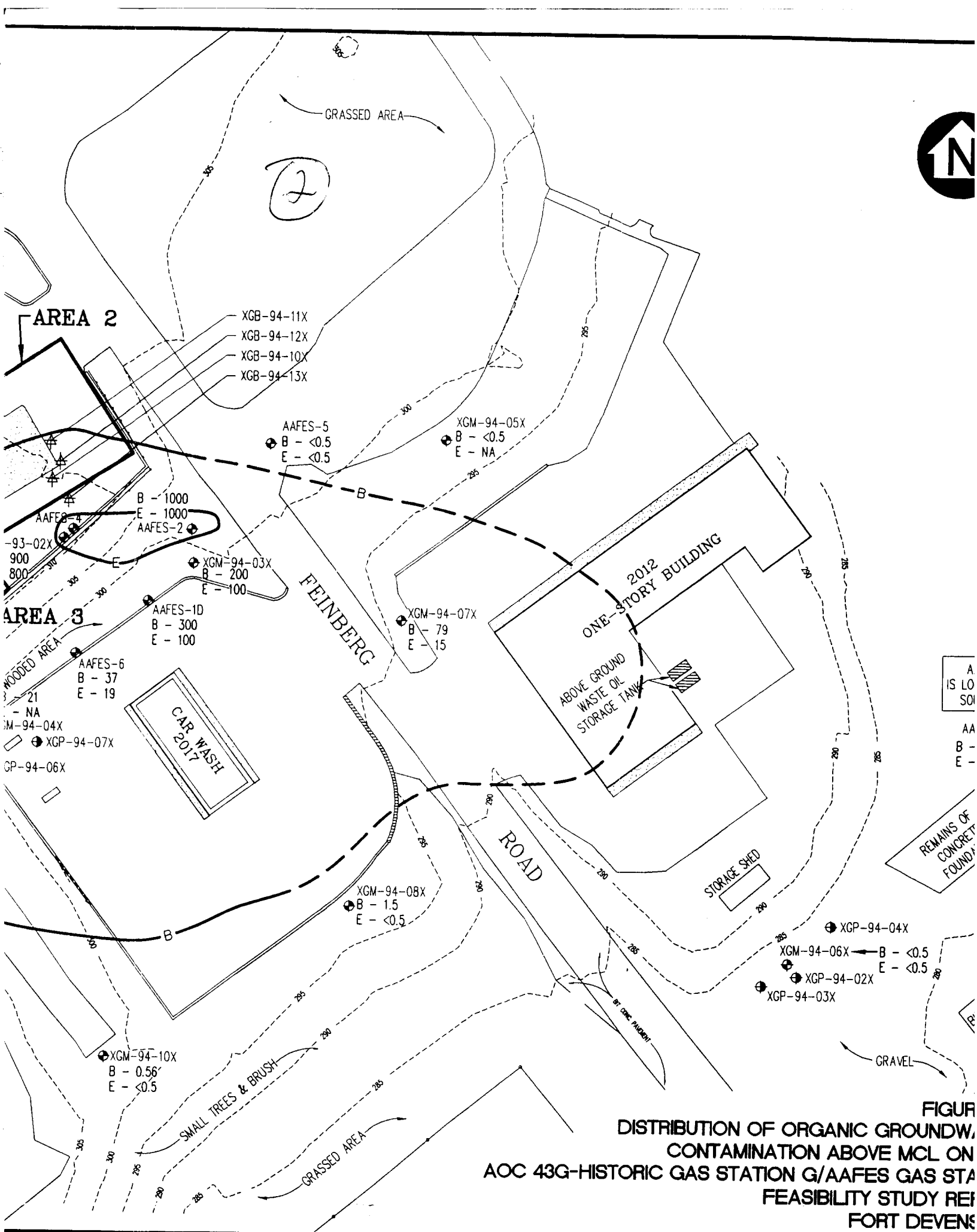


FIGURE 1
DISTRIBUTION OF ORGANIC GROUNDWATER CONTAMINATION ABOVE MCL ON AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS

3

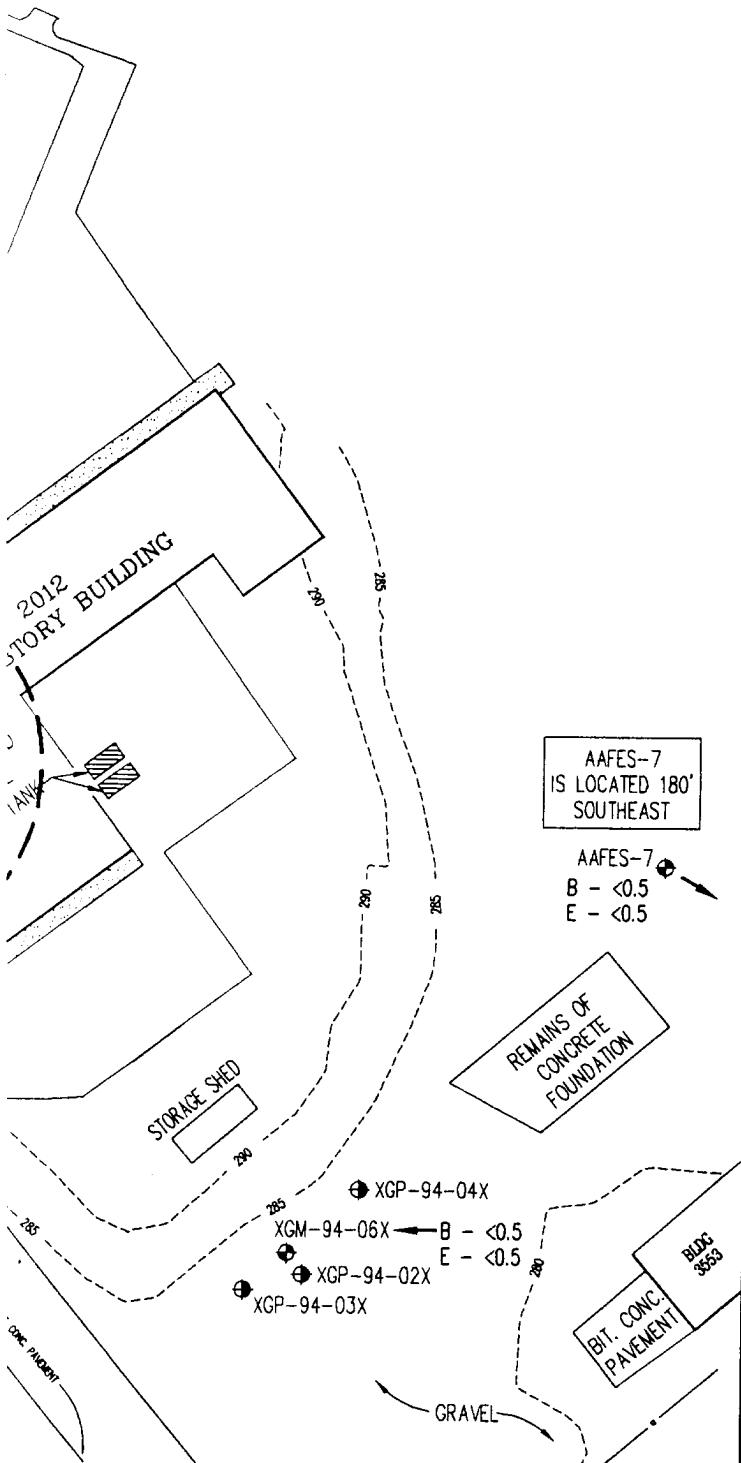
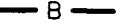
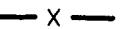
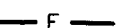


FIGURE 2-1
DISTRIBUTION OF ORGANIC GROUNDWATER
CONTAMINATION ABOVE MCL ON 3/95
ORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

LEGEND

-  SOIL BORING/VAPOR EXTRACTION WELL
-  SOIL BORING
-  PIEZOMETER
-  MONITORING WELL

-  ESTIMATED MCL CONTOURS
-  BENZENE - 5 ug/L
-  XYLENES - 10,000 ug/L
-  ETHYLBENZENE - 700 ug/L
-  INDICATES ASSUMPTION DUE TO LACK OF DATA POINTS

XGM-93-01X
B - <0.5
E - <0.5
X - <0.84

NOTES:

1. GROUND SURFACE ELEVATION CONTOUR INTERVAL IS 5 FEET.
2. ALL CONCENTRATIONS IN ug/L.
3. NA - NOT ANALYZED.

0 25 50 100 FEET

SCALE: 1" = 50'



LOCATION OF EXISTING GASOLINE USTS

LOCATION OF FORMER WASTE OIL UST

ROAD

QUEENSTOWN

COVERED GASOLINE PUMP ISLANDS

CONCRETE RETAINING WALL

ABOVE GROUND WASTE OIL STORAGE TANK

WOODEN PLATFORM

2009

AREA 1

AAFES GAS STATION 2008

AREA 3

AREA 2

WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

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WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

WOODEN AREA

B - <0.5
E - <0.5
X - <0.84

B - 2000
E - 600
X - 5000

B - 100
E - 200
X - 900

B - 2
E - 1
X - 3

XGM-94-09X
B - <0.5
E - 3.7
X - 21

XGM-94-04X

XGP-94-05X

XGP-94-01X

XGP-94-06X

XGP-94-07X

XGP-94-08X

XGP-94-09X

XGP-94-10X

XGP-94-11X

XGP-94-12X

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XGP-94-15X

XGP-94-16X

XGP-94-17X

XGP-94-18X

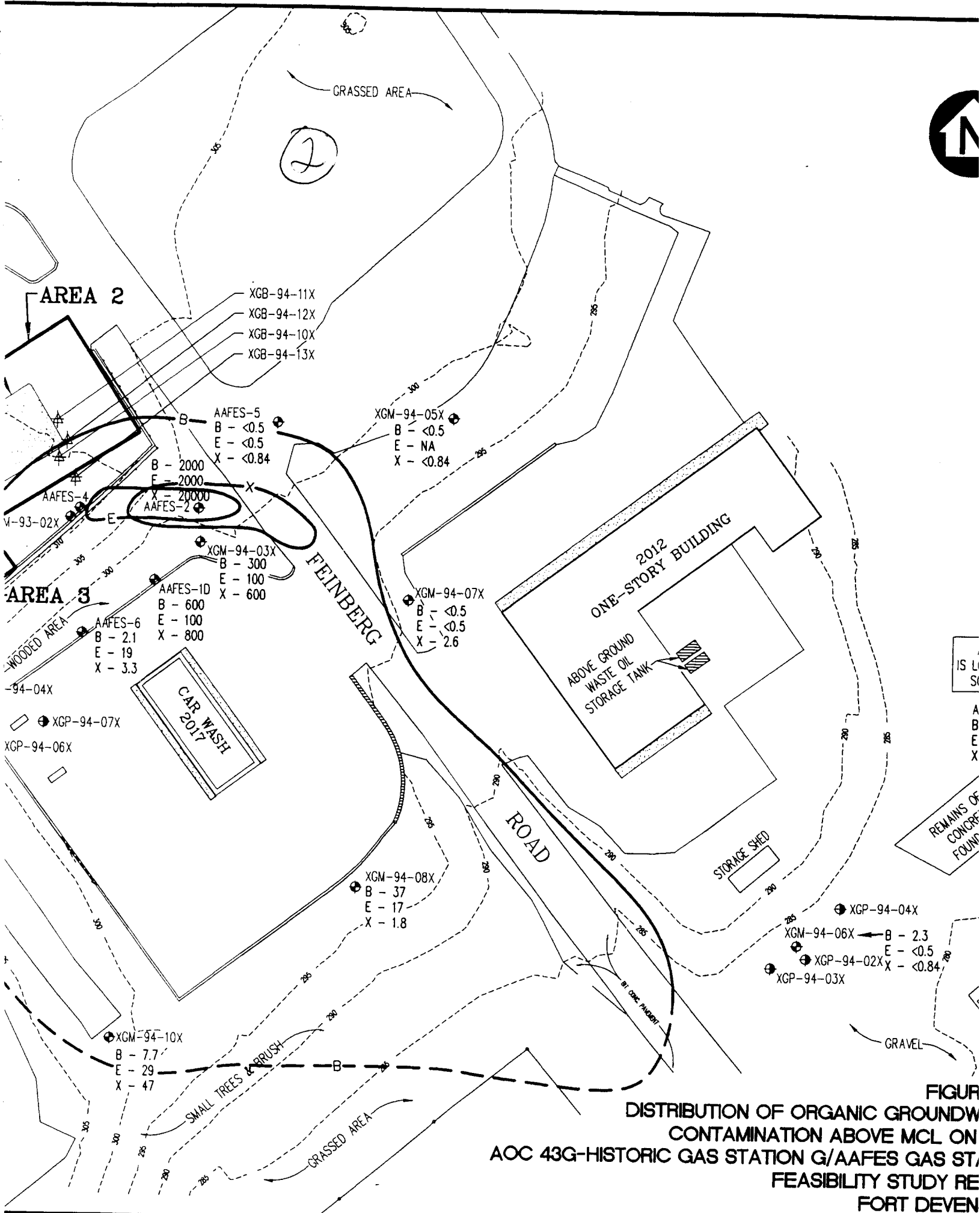


FIGURE 1
DISTRIBUTION OF ORGANIC GROUNDWATER
CONTAMINATION ABOVE MCL ON
AOC 43G-HISTORIC GAS STATION G/AAFES GAS ST,
FEASIBILITY STUDY REPORT
FORT DEVEN

3

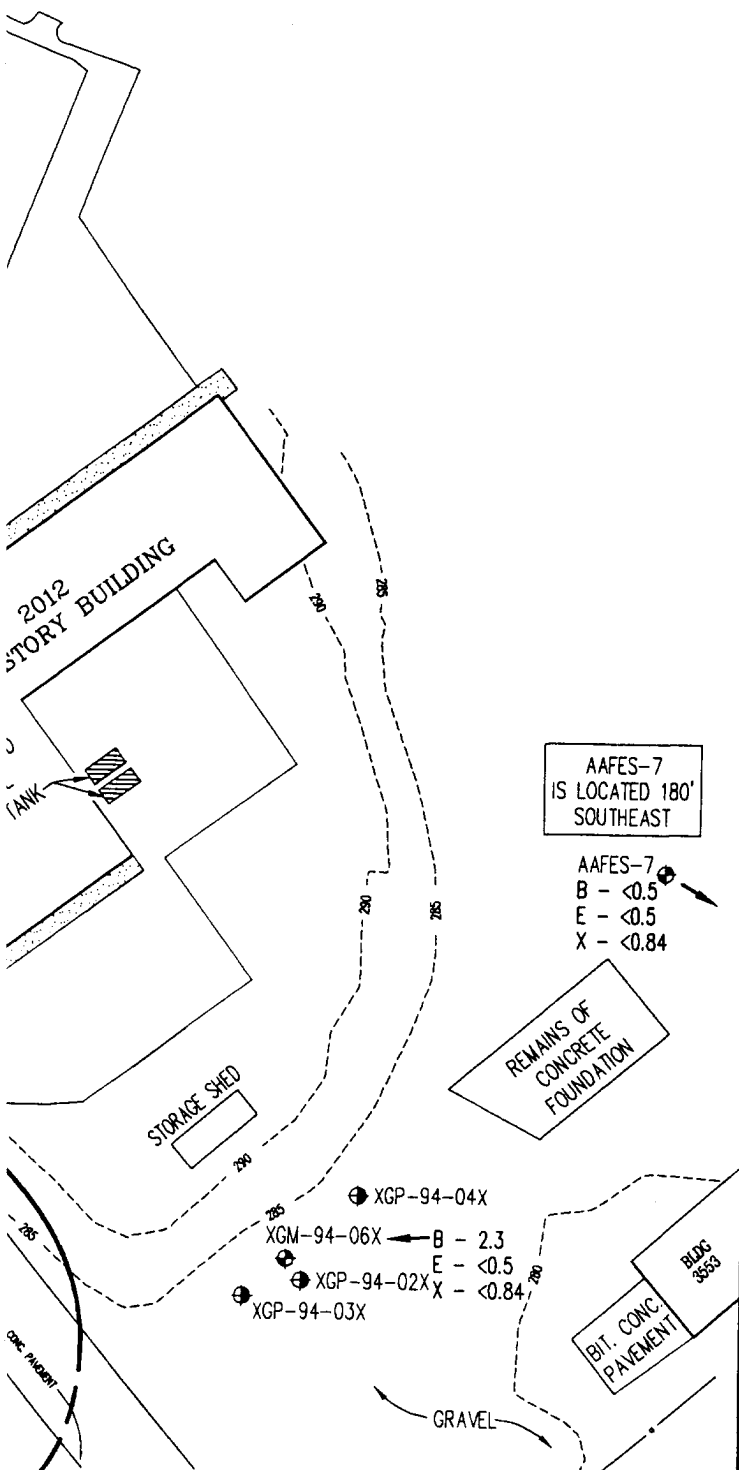


FIGURE 2-2
DISTRIBUTION OF ORGANIC GROUNDWATER
CONTAMINATION ABOVE MCL ON 12/94
ORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA
ABB Environmental Services, Inc.

TABLE 2-1
PROPOSED PRELIMINARY REMEDIATION GOALS
FOR SOURCE AREA GROUNDWATER
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

CHEMICAL OF POTENTIAL CONCERN ⁽¹⁾	SOURCE AREA GROUNDWATER ⁽²⁾				UPGRADIENT GROUNDWATER ⁽³⁾				BKGND ⁽⁴⁾		ABAR ⁽⁵⁾		PROPOSED PRG ($\mu\text{g/L}$)
	AVERAGE EPC ($\mu\text{g/L}$)		MAXIMUM EPC ($\mu\text{g/L}$)		AVERAGE EPC ($\mu\text{g/L}$)		MAXIMUM EPC ($\mu\text{g/L}$)		BKGND ⁽⁴⁾ ($\mu\text{g/L}$)	SMCL ($\mu\text{g/L}$)	MMCL ($\mu\text{g/L}$)		
	UNFILTERED	FILTERED	UNFILTERED	FILTERED	UNFILTERED	FILTERED	UNFILTERED	FILTERED			MCL ($\mu\text{g/L}$)	MMCL ($\mu\text{g/L}$)	
INORGANICS													
Arsenic	10	10	57.7	24.1	26.9	1.7	82.5	2.98	10.5	-	50	50	-6
Iron	25,890	18,030	87,200	54,100	16,615	ND	31,800	ND	9,100	300	-	-	9,100
Lead	9	1	49.1	3.04	21.5	ND	51.2	ND	4.25	-	15(3)	15	-6
Manganese	7,600	7,500	14,300	15,200	795	24	1,870	44.9	291	50	-	-	291
Nickel	50	30	209	180	63.2	ND	152	ND	34.3	-	100	100	100
VOCs													
Benzene	620	NA	2,000	NA	ND	NA	ND	NA	ND	-	5	5	5
Ethylbenzene	430	NA	2,000	NA	ND	NA	ND	NA	ND	-	700	700	700
Xylenes	3,360	NA	20,000	NA	ND	NA	ND	NA	ND	-	10,000	10,000	10,000

Notes:
 (1) Drinking Water Regulations and Health Advisories, May 1993, USEPA Office of Water
 (2) Drinking Water Standards & Guidelines for Chemicals in Massachusetts Drinking Waters, Autumn 1994, Massachusetts Department of Environmental Protection
 (3) Action level
 (4) Based on samples XGM-94-07X and -04X, XGM-93-07X, and AAFES-1D, -2, -6.
 (5) Based on samples XGM-93-01X and AAFES-3.
 (6) MCL exceedance due to high total suspended solids content or MCL exceeded in upgradient samples.
 (7) Analyses that exceed primary federal or Massachusetts drinking water standards or CPCs that present cancer risks above 10⁻⁶ or HQs above 1.0 as indicated by the baseline risk assessment in the RI report.
 (8) Proposed PRGs for inorganic analyses to be measured using filtered samples.
 (9) Background concentrations determined from unfiltered samples from 10 wells at select locations on base. (Samples analyzed for Total Suspended Solids ranged from <4,000 to 53,000 $\mu\text{g/L}$)
 EPC = Exposure Point Concentration
 ND = Not detected
 NA = Not analyzed
 MCL = Maximum Contaminant Level(1)
 MMCL = Massachusetts Maximum Contaminant Level(2)
 SMCL = Secondary MCL(1) based on aesthetics.
 HQ = Hazard Quotient.

TABLE 2-3
WATER QUALITY PARAMETERS⁽¹⁾
FOR GROUNDWATER
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GROUNDWATER AREA	UPGRADIENT	SOURCE	PERIMETER	DOWNGRADIENT PLUME (>5ug/L BENZENE)	DOWNGRADIENT (<5ug/L BENZENE)
PARAMETER⁽²⁾					
Alkalinity	111,250	187,805	113,500	131,000	85,933
Nitrate ⁽³⁾	4,675	24	2,401	169	892
Nitrogen ⁽⁴⁾	770	540	558	512	398
TDS	270,000	399,916	330,000	-	-
Hardness	206,000	269,944	211,625	189,000	123,600
Chloride	148,000	146,611	196,250	89,000	78,625
Phosphate	541	168	482	288	339
Sulfate	28,750	15,166	21,875	25,500	15,500
pH	6.5	6.7	6.65	-	6.87
ORP (mV)	110	-13.88	70.5	-	10.33

Notes:

⁽¹⁾Averaged values from:

Upgradient Area (XGM-93-01X and AAFES-3)

Source Area (AAFES-1D, -2, -6, XGM-93-02X, XGM-94-03X and -04X)

Perimeter (AAFES-5, XGM-94-05X, -07X, and -09X)

Downgradient > 5 ug/L benzene (XGM-94-08X and XGM-94-10X)

Downgradient < 5 ug/L benzene (XGM-94-06X and AAFES-7)

⁽²⁾Units for all parameters (except pH and ORP) are in micrograms/Liter

⁽³⁾Nitrite, nitrate-nonspecific

⁽⁴⁾By Kjeldahl Method

**TABLE 2-4
REMEDIAL ACTION OBJECTIVES
AOC 43G**

**FEASIBILITY STUDY REPORT
FORT DEVENS, MA**

AOC 43G GROUNDWATER	
	• Protect potential commercial/industrial receptors located on Army Reserve Enclave property from exposure to groundwater having chemicals in excess of the following PRGs: iron (9,100 µg/L), manganese (291 µg/L), nickel (100 µg/L), benzene (5 µg/L), ethylbenzene (700 µg/L), and xylenes (10,000 µg/L).
	• Protect potential commercial/industrial receptors located off Army Reserve Enclave property from exposure to groundwater having chemicals in excess of the above PRGs.

TABLE 2-5
POTENTIAL REMEDIAL TECHNOLOGIES
AND PROCESS OPTIONS FOR GROUNDWATER
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION
No Action	None	Not Applicable
Limited Action	Institutional Controls	Zoning Restrictions Deed Restrictions
	Environmental Monitoring	Groundwater Monitoring
Containment	Hydraulic Barriers	Slurry Wall
		Sheet Piling
Collection	Extraction	Interceptor Trenches
		Extraction Wells
Treatment	Physical/Chemical	Air Stripping
		UV Oxidation
		Activated Carbon
		Air Sparging (In situ)
		Bioremediation (Ex situ)
		Bioremediation (In situ)
		Fort Devens WWTP
		Ayer POTW
Discharge	On Site	Fort Devens WWTP
	Off Site	To Groundwater
		To Surface Water Ayer POTW

Notes:

WWTP = wastewater treatment plant
POTW = publicly owned treatment works
USEPA = U.S. Environmental Protection Agency

TABLE 2-6
DESCRIPTION OF GROUNDWATER PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/TECHNOLOGY	DESCRIPTION OF PROCESS OPTIONS
<u>No Action</u> None	No action taken to reduce risk.
<u>Limited Action</u> Institutional Controls Environmental Monitoring	<u>Zoning Restrictions.</u> Through administrative controls, zone downgradient land off Army Reserve Enclave property to prohibit residential development. <u>Deed Restrictions.</u> Place deed restrictions on downgradient land off Army Reserve Enclave property to prohibit future installation of drinking water wells. <u>Groundwater Monitoring.</u> Perform water quality analyses to monitor contaminant concentrations and assess future environmental impacts.
<u>Containment</u> Hydraulic Barriers	<u>Slurry Wall.</u> Excavate a trench in overburden and fill with impervious backfill to provide a low-permeability cutoff wall. <u>Sheet Piling.</u> Drive steel sheet piles into the overburden to provide a low-permeability cutoff wall.
<u>Collection</u> Extraction	<u>Interceptor Trenches.</u> Trenches, drains, and piping used to passively collect (by gravity flow) groundwater. Trench installation is typically not used below the bedrock surface. <u>Extraction Wells.</u> Install extraction wells to collect groundwater. Wells are typically installed using augers in unconsolidated soils, and coring for bedrock wells. Wells are usually completed by placing a well screen to the desired depth and placing sandpack between well screen and aquifer materials. Well screens are chosen based on the characteristics of the aquifer material in which the well is placed.

TABLE 2-6
DESCRIPTION OF GROUNDWATER PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/TECHNOLOGY	DESCRIPTION OF PROCESS OPTIONS
<u>Treatment</u> Physical/Chemical	<u>Air Stripping.</u> Air stripping removes VOCs from extracted groundwater by contacting contaminated water with large volumes of air. Contaminants are transferred from the liquid phase to the gas phase, and carried off with effluent air. <u>UV Oxidation.</u> UV oxidation involves the simultaneous application of UV radiation and chemical oxidants to degrade low concentrations of aqueous organics. Ozone and hydrogen peroxide have been documented as chemical oxidants. <u>Activated Carbon.</u> Activated carbon adsorption is a physical separation process in which contaminants are removed from groundwater by sorption (i.e., the attraction and accumulation of one substance on another). Contaminants are removed by sorption onto available granular-activated carbon sites. <u>Air Sparging (In situ).</u> In situ air sparging removes VOCs from groundwater by forcing air into the saturated zone. Contaminants dissolved in the groundwater volatilize into the air stream, and are transported to the vadose zone where they can be collected by a soil vapor extraction system. <u>Bioremediation (Ex-situ).</u> BTEX is biologically degraded by fixed film microorganisms as groundwater passes through a bioreactor. Fixed film bioreactors include rotating biological contactors (RBC) and fluidized bed reactors. Destroys organics through biodegradation, acclimation, degradation, or chemical conversion of organic wastes.

TABLE 2-6
DESCRIPTION OF GROUNDWATER PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/TECHNOLOGY	DESCRIPTION OF PROCESS OPTIONS
Biological	<u>Bioremediation (In situ)</u> . Process which utilizes microorganisms to destroy organics through biodegradation, acclimation, degradation, or chemical conversion. Microorganisms and nutrients may be indigenous (intrinsic bioremediation) or one or both may be added into the groundwater using a matrix of injection wells and recirculation techniques. BTEX degrades more readily under aerobic conditions. However there is increasing evidence that degradation of these compounds also occurs under anaerobic conditions.
Biological (cont.)	<u>Fort Devens WWTP</u> . Transport untreated groundwater to Fort Devens WWTP for treatment. This plant is a primary wastewater treatment facility located on North Post. <u>Ayer POTW</u> . Transport untreated groundwater to Ayer POTW for Treatment. This plant is an activated sludge facility.
<u>Discharge</u> On Site Off Site Off Site	<u>Fort Devens WWTP</u> . Transport treated groundwater to Fort Devens WWTP. <u>To Groundwater</u> . Reinject treated groundwater meeting Massachusetts discharge limits outside limits of contamination. <u>Surface Water</u> . Discharge treated groundwater meeting NPDES permit limits into a surface water such as Robbins Pond. <u>Ayer POTW</u> . Transport treated groundwater to Ayer POTW.

Notes:

VOCs = volatile organic compounds
 UV = ultraviolet
 WWTP = waste water treatment plant
 POTW = publicly-owned treatment works

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
<u>No Action</u> None	None Easily implementable	None.	Retained.	Required for consideration by NCP. Does not achieve remedial action objectives.
<u>Limited Action</u> Zoning Restrictions	Would prohibit residential development within groundwater plume area if off the Army Enclave property. Would require negotiations with property owners downgradient.	Contamination has not migrated downgradient of the Army Reserve Enclave property boundary therefore no institutional control is needed.	Eliminated.	
Deed Restrictions	Would prohibit installation of groundwater wells within groundwater plume area if off the Army Enclave property. Would require negotiations with property owners downgradient.	Contamination has not migrated downgradient of the Army Reserve Enclave property boundary therefore no institutional control is needed.	Eliminated.	

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
Groundwater Monitoring	None. Easily implementable. Groundwater monitoring wells currently exist on site and may be used in a groundwater monitoring program.	None. Would enable assessment of changes in contaminant concentrations over time.	Retained.	May be considered in conjunction with other technologies.
<u>Containment</u> Slurry Wall	Hydraulic barrier could have unpredictable impacts on site groundwater flow out from the bedrock and within vertical gradients. Generally used in conjunction with capping.	Barrier design would require consideration of groundwater contaminants that may degrade barrier over time. May reduce mobility of chemicals in groundwater.	Eliminated.	Hydraulic barrier may contain groundwater contaminants but may also have unpredictable impacts on site groundwater flow out from the bedrock and within vertical gradients.
Sheet Piling	Implementable. Compared to slurry wall, less controlled installation, less likely to achieve low permeability seal due to poor connections between the steel sheets. Similar unpredictable hydraulic impacts as the slurry wall.	Similar effectiveness as slurry wall.	Eliminated.	Similar unpredictable hydraulic impacts as the slurry wall.

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
<u>Collection</u> Interceptor Trenches	Implementable. May improve collection capabilities within low-permeable soils at AOC 43G. Difficult to install in areas where groundwater is within bedrock.	Effective technology to passively collect contaminated groundwater. Can prevent migration of contaminated groundwater.	Retained.	A trench could be strategically located across the area of highest contamination to stop further migration.
Extraction Wells	None. Implementable. Commonly used technology. Produces very little contaminated soil requiring disposal. Can be installed where groundwater is within bedrock.	None. Effective mechanism to collect contaminated groundwater. Can prevent migration of contaminated groundwater.	Retained.	Several wells would have to be strategically located so that the cones of depression intersect and capture groundwater flow. Could be used in conjunction with interceptor trenches in areas of high bedrock.
<u>Treatment</u> Air Stripping	None. Easily implementable commonly used technology.	None. Provides effective treatment for VOCs. Special disposal or destruction required for off-gas collection.	Eliminated.	Can not effectively treat some toxic SVOCs to "health advisory" levels (ie; naphthalene) which is required for discharge to the Fort Devens WWTP.

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
UV Oxidation Activated Carbon	None. Commonly used technology. Self-contained and mobile units available.	Provides effective treatment for most organics. Contaminants are destroyed.	Retained.	
	None, Implementable. Commonly used technology. Self-contained and mobile units available.	Provides effective treatment for VOCs and other organics. Contaminants are adsorbed. Waste carbon considerably more toxic than influent water, special disposal, regeneration or destruction is required.	Retained.	
Air Sparging (In situ)	Does not require groundwater extraction. An emerging technology. The low-permeable soil at AOC 43G will potentially impact effectiveness of bubbling air in the water column.	Effective for treatment of VOCs but difficulties can arise in controlling and collecting off gases.	Eliminated.	

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
Bio-remediation (Ex situ)	None. An emerging groundwater treatment technology.	Volatiles must be contained. Oxygen may be required. Polishing with carbon is likely. A pilot scale test is recommended.	Eliminated.	
Bio-remediation (In situ)	Biodegradation of organic contaminants at AOC 43G may be naturally occurring under anaerobic conditions. Oxygenating groundwater plume for aerobic conditions is impractical due to potential mounding, impacts on groundwater flow, and fouling of injection points from high concentration of iron and manganese. Would require piping groundwater to existing Fort Devens sewer system.	None. Biological treatment will remove BTEX.	Retained.	
Fort Devens WWTP		Fort Devens has a <u>primary</u> wastewater treatment facility, not designed to treat toxic contaminants.	Eliminated.	

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
Ayer POTW	Would require piping or trucking groundwater to Ayer sewer system.	Untreated groundwater would not meet pre-treatment standards for total toxic organics (1 mg/l).	Eliminated.	
<u>Discharge</u> Fort Devens WWTP	Would require piping groundwater to existing Fort Devens sewer system. Facility currently has a notice of non-compliance. However, a Wastewater Discharge Management Plan and O&M Manual are being prepared in anticipation of future industrial discharges to the facility.	Fort Devens has a primary wastewater treatment facility which is not designed to treat inorganics and BTEX. Groundwater would need to be treated to meet proposed industrial pretreatment requirements.	Retained.	Does not permit discharge of any toxic pollutants (SVOCs) that exceed health advisories. This excludes air stripping as a possible treatment option.

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
To Groundwater	Limited by recharge/ permeability rates of soils and availability of suitable nearby discharge site. Reinjection wells or trench would likely foul due to high concentrations of Fe and Mn. On-site discharge would reduce administrative burden of obtaining discharge permit.	None, as long as water has been treated to acceptable discharge standards.	Eliminated.	No major advantage over discharge to Fort Devens WWTP.
Ayer POTW	Would require piping or trucking groundwater to Ayer sewer system.	Groundwater would also need to be treated to acceptable discharge standards (total toxic organics).	Eliminated.	Discharge to the Ayer POTW offers no significant advantage over discharge to the Fort Devens WWTP. Both alternatives require pre-treatment. The Ayer POTW option requires greater capital investment for piping or O&M for trucking.

TABLE 2-7
SCREENING OF GROUNDWATER TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
Surface Water	NPDES permit required for off-site discharge. Requires considerable piping to a major surface water body (Cold Spring Brook, Robbins Pond, Nashua River). Negative public perception.	None. If contaminants are treated to acceptable limits.	Eliminated.	

Notes:

- NCP
- MCLs
- WWTP
- POTW
- NPDES
- UV
- National Contingency Plan
- maximum contaminant levels
- waste water treatment plant
- publicly owned treatment works
- National Pollutant Discharge Elimination System
- ultraviolet

TABLE 2-8
POTENTIAL REMEDIAL TECHNOLOGIES
AND PROCESS OPTIONS FOR SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION	REMEDIAL TECHNOLOGY	PROCESS OPTION
No Action	None	Not Applicable
Removal	Excavation	Soil Excavation
Treatment	Physical/Chemical	Incineration Thermal Desorption Soil Vapor Extraction Asphalt Batching
Disposal	On Site Off Site	Landfilling TSD Facility

Notes:

TSD = treatment, storage, and disposal

TABLE 2-9
DESCRIPTION OF SOIL PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/TECHNOLOGY	DESCRIPTION OF PROCESS OPTIONS
<u>No Action</u> None	No action taken to reduce groundwater exposure to site soils.
<u>Removal</u> Excavation	<u>Soil Excavation.</u> Excavate grossly contaminated soils from below the existing gasoline USTs. Contaminated soils would be removed by using large excavation equipment and sheeting.
<u>Treatment</u> Physical/Chemical	<u>Incineration.</u> Transport excavated soils to an off-site facility for thermal destruction of organic contaminants. <u>Thermal Desorption.</u> Process excavated soils through an on-site or off-site thermal desorption unit. Thermal desorption uses indirect or direct heat exchange to vaporize organic contaminants including VOCs and some SVOCs from soil. <u>Soil Vapor Extraction (SVE)/Bioventing.</u> Remediate BTEX contaminated soils adjacent to or below the existing gasoline USTs in-situ by extracting gases from the soil using SVE wells and vacuum pumps and passing the gases through GAC or thermal/catalytic oxidizers for treatment. Flow of atmospheric air through the soil also enhances biological degradation of hydrocarbon contaminants (bioventing). <u>Asphalt Batching.</u> Mix excavated soils with an asphalt emulsion and other additives to make a pavement road base material. Asphalt batching immobilizes the petroleum contaminants within the soil-asphalt mix.
<u>Disposal</u> On Site Off Site	<u>Landfilling.</u> Dispose of petroleum contaminated soils that meet allowable contaminant levels in the Fort Devens consolidation landfill. <u>TSD Facility.</u> Transport contaminated soils to an off-site facility permitted to treat petroleum (including waste oil) contaminated soil.

Notes:

BTEX = benzene, toluene, ethylbenzene, xylene
 VOCs = volatile organic compounds
 SVOCs = semivolatile organic compounds
 GAC = Granulated Activated Carbon
 TSD = treatment, storage and disposal
 UST = underground storage tank

TABLE 2-10
SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
<u>No Action</u> None	None	Does not reduce toxicity, mobility, or volume of contaminants in soil.	Retained.	No risk associated with exposure to site soils. Groundwater effects from leaving untreated soil are not readily definable.
<u>Removal</u> Excavation	Access to residual contaminated soils is difficult due to depth of excavation and proximity of physical features.	Removes potential residual source of groundwater contamination.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.

TABLE 2-10
SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
<u>Treatment</u> Incineration Thermal Desorption	Off-site facilities on-line. Requires soil excavation.	Effective treatment for organics. More specifically applicable to hazardous wastes. Not competitive with vendors that treat only petroleum contaminated soils.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.
	Permit requirements must be considered. Do not have enough soil requiring treatment to competitively warrant on- site units. Many Desorption vendors available to do off-site treatment. Requires soil excavation.	Proven effective for petroleum contaminated soils. Less effective for high moisture content material which will be present at depths close to the water table.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.

TABLE 2-10
SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
Soil Vapor Extraction/ Bioventing (In situ)	Easily implementable for the small area around the gas USTs. Existing extraction well and monitoring probes available for use.	Proven effective for BTEX removal. Bioventing may further remove less volatile fractions.	Retained.	EPA Presumptive Remedy for VOC contaminated soil. Does not require soil excavation.
	System design will need to consider effects of low- permeable site soils.	May be less effective than ex-situ treatment due to potential short-circuiting of air that can leave some untreated areas.		
Asphalt Batching	Soil excavation is required. Reuse of batched material on-base may be more difficult due to base closure.	Effectively immobilizes petroleum contaminants within pavement mix.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.
	Quantity of contaminated material is marginal in order for the on-site treatment to be cost effective.	Must be permitted to accept used waste oil. High percent of silt will likely require the addition of aggregate to make an acceptable road-base material.		

TABLE 2-10
SCREENING OF SOIL TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/ PROCESS OPTION	APPLICABILITY TO		SCREENING STATUS	COMMENTS
	SITE-LIMITING CHARACTERISTICS	WASTE-LIMITING CHARACTERISTICS		
<u>Disposal</u>				
Fort Devens Consolidation Landfill	Soil excavation required. Space requirements on site must be evaluated. Facility must comply with Massachusetts landfill regulations.	Concentrations of VOCs or TPHC in extreme hot spot areas may exceed allowable contaminant levels for soil reuse at lined landfills.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.
TSD Facility	Implementable. Many off- site vendors available who treat (asphalt batch, thermal desorb).	Facilities provide treatment/disposal/reuse. Must comply with Land Disposal Restrictions.	Eliminated.	Soil depth and physical constraints make excavation impractical and groundwater benefits from soil removal are not definable.

Notes:

TSD = treatment, storage, and disposal
VOCs = volatile organic compound
TPHC = total petroleum hydrocarbon

TABLE 2-11
SCREENING SUMMARY OF TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/PROCESS OPTION	RETAINED	ELIMINATED
GROUNDWATER		
<u>No Action</u>		
None	X	
<u>Limited Action</u>		
Zoning Restrictions		X
Deed Restrictions		X
Groundwater Monitoring	X	
<u>Containment</u>		
Slurry Wall		X
Sheet Piling		X
<u>Collection</u>		
Interceptor Trenches	X	
Extraction Wells	X	
<u>Treatment</u>		
Air Stripping		X
UV Oxidation		X ⁽¹⁾
Activated Carbon	X	
Air Sparging (In situ)		X
Bioremediation (Ex situ)		X
Bioremediation (In situ)	X	
Fort Devens WWTP		X
Ayer POTW		X
<u>Discharge</u>		
Fort Devens WWTP	X	
To Groundwater		X
Surface Water		X
Ayer POTW		X

TABLE 2-11
SCREENING SUMMARY OF TECHNOLOGIES AND PROCESS OPTIONS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

GENERAL RESPONSE ACTION/PROCESS OPTION	RETAINED	ELIMINATED
SOILS		
<u>No Action</u>		
None	X	
<u>Removal</u>		
Excavation		X
<u>Treatment</u>		
Incineration		X
Soil Vapor Extraction/Bioventing	X	
Asphalt Batching		X
Thermal Desorption		X
<u>Disposal</u>		
TSD Facility		X
Fort Devens Consolidation Landfill		X

Notes:

TSD = treatment, storage and disposal
 UV = ultraviolet
 WWTP = wastewater treatment plant
 POTW = publicly owned treatment works
 (1) = Although UV/oxidation is effective and implementable, it was eliminated based on higher cost relative to activated carbon (See subsection 2.7)

3.0 DEVELOPMENT AND SCREENING OF ALTERNATIVES

In this section, technically feasible process options retained following the screening described in Section 2.0 are combined to form remedial action alternatives. Alternatives are developed to attain the remedial action objectives discussed in Section 2.0, using the following General Response Actions either singly or in combination: (1) No Action; (2) Limited Action; (3) Containment; (4) Collection; (5) Treatment; (5) Discharge.

The developed remedial alternatives are then screened with respect to the criteria of effectiveness, implementability, and cost to meet the requirements of CERCLA and the National Contingency Plan (NCP). The objective of this screening step is to eliminate impractical alternatives or higher cost alternatives (i.e., order of magnitude cost differences) that provide little or no improvement in effectiveness or implementability over their lower cost counterparts.

3.1 DEVELOPMENT OF ALTERNATIVES

Five remedial alternatives were developed for AOC 43G to address remedial action objectives presented in Section 2.0. In assembling these alternatives, general response actions and process options, chosen to represent the various technology types for the medium of concern, were combined to form alternatives for the site as a whole. Alternatives were developed to provide a range of options consistent with USEPA RI/FS guidance (USEPA, 1988).

These alternatives include:

- Alternative 1: No Action
- Alternative 2A: Intrinsic Bioremediation
- Alternative 2B: Intrinsic Bioremediation / Soil Venting of Gasoline UST Soils
- Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

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- Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

3.1.1 Alternative 1: No Action

The No Action alternative does not include any remedial action components to reduce or control potential risks at AOC 43G. In addition, existing monitoring would be discontinued. The No Action alternative will not be evaluated according to screening criteria; it will pass through screening to be evaluated during the detailed analysis as a baseline for the other retained alternatives (USEPA, 1988).

3.1.2 Alternative 2A: Intrinsic Bioremediation

Key components of Alternative 2A include:

- Intrinsic Bioremediation
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 2A would involve intrinsic bioremediation for treatment of the groundwater.

Intrinsic Bioremediation. Based upon organic and inorganic speciation in the aquifer, it appears that biological degradation of the petroleum hydrocarbons is naturally occurring at AOC 43G. Alternative 2A would allow the natural biological degradation (intrinsic bioremediation) of the CPCs to continue to occur at the site without interruption. To assess the effectiveness of biological degradation at the site, groundwater monitoring would be performed on a scheduled basis. Additional monitoring wells would need to be installed.

The biological degradation of hydrocarbons is essentially an oxidation-reduction reaction in which the hydrocarbon compound is oxidized (donates electrons) and an electron acceptor, such as oxygen, is reduced (accepts electrons). Under aerobic conditions, oxygen is the electron acceptor for biological degradation activity. When oxygen is absent or depleted from a system, anaerobic conditions exist and other compounds are used as electron acceptors. Other compounds that

are used as electron acceptors during anaerobic degradation of petroleum hydrocarbons include nitrate, manganese oxides, sulfate, iron, and hydrogen.

The electron acceptor that is ultimately used in the anaerobic biodegradation of hydrocarbons depends upon compound concentrations, availability, and the redox conditions of the aquifer. The order in which electron acceptors are used in anaerobic biodegradation (according to free energy laws) is as follows: oxygen (aerobic conditions), nitrate, manganese oxides, ferric iron (FeIII), sulfate, and hydrogen (methanogenic conditions). As the progression of electron acceptor use occurs through this sequence, the ORP of the aquifer decreases.

As defined by name, compounds that act as electron acceptors in anaerobic biodegradation gain electrons and are reduced. Typical examples of reduced forms of compounds that are produced during anaerobic biodegradation of hydrocarbons include nitrite from nitrate, manganese as Mn[II] from Mn[IV], ferrous (Fe[II]) iron from ferric ([Fe(III)]) iron, sulfide compounds from sulfate reduction, and methane from hydrogen reduction. The presence of these reduced forms of compounds in an aquifer is an indicator that biological activity is occurring. Inorganic speciation can be used to model anaerobic biological degradation.

Table 2-3 presents the groundwater inorganic speciation data for groundwater upgradient of the source, at the source area, at the perimeter, downgradient within the plume (where benzene concentrations are greater than 5 µg/L) and downgradient (where benzene concentrations are less than 5 µg/L). Data included in this table include nitrite/nitrate concentrations, sulfate concentrations, phosphate concentrations, and ORP. Based on several speciation trends presented in this table, it appears that anaerobic activity is occurring in the zone of contamination. These trends include a) decreased average nitrate/nitrite concentrations in the contaminated region, b) decreased sulfate concentrations in the aquifer, c) decreased ORP measurements in the source area, and d) decreased total nitrogen and phosphate concentrations in the aquifer.

Decreased nitrate and sulfate concentrations in the plume area (compared to up- and down-gradient concentrations), indicate that microbial-induced redox processes are occurring at AOC 43G. This assumption is confirmed with ORP data which indicates that the ORP is negative in the contaminated zone and is less than the ORP found in surrounding groundwater. Decreasing nutrient

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concentrations (total nitrogen and phosphate concentrations) also affirm the premise that active microbiological degradation of the contaminants of concern is occurring in the zone of contamination, as these compounds are consumed (uptake) within the contaminated groundwater.

Intrinsic bioremediation would continue at AOC 43G until the remedial action objectives are achieved. Calculations based upon degradation rates from literature indicate that contaminants would not migrate off Army Reserve Enclave property. Details of these calculations are discussed in Section 4.0. Additional data collection would be required as part of the design to confirm degradation rates and refine long-term groundwater monitoring needs.

Long-Term Groundwater Monitoring / Five-Year Site Reviews. Long-term groundwater monitoring would also be instituted to monitor organic and soluble inorganic contaminants of concern. Five-year site reviews would be conducted to evaluate whether the alternative continues to protect human health and the environment. Details of the monitoring and site reviews will be discussed in Section 4.0.

3.1.3 Alternative 2B: Intrinsic Bioremediation / Soil Venting Gasoline UST Soils

Key components of Alternative 2B include:

- Intrinsic Bioremediation
- Soil Venting Soils Below and Adjacent the Gasoline USTs
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 2B involves the same actions as Alternative 2A except that the residual contaminated soils below and adjacent to the former (and now existing) gasoline USTs would be remediated. Soil remediation would entail installing an SVE system to minimize the potential of groundwater re-contamination. Specifics regarding this system are detailed below. See Alternative 2A for description of the intrinsic bioremediation, long-term groundwater monitoring, and 5-year site review components.

Soil Venting. Soil venting of the soils adjacent to and below the gasoline USTs will require installation of vertical soil vent wells for soil venting and installation of aboveground soil vapor treatment equipment. The objective of soil venting is to remediate the vadose zone below and adjacent to the existing gasoline USTs to prevent further contamination of the aquifer. The soils that contain VOCs may contribute to groundwater contamination during periods of high water table conditions.

To determine the applicability for soil venting at the site and to gather full-scale vent design information, an on-site soil vapor extraction/bioventing pilot test was conducted. Details of the pilot test are included as Appendix O of the RI Report (ABB-ES, 1996). Permeability data gathered from AOC 43G indicates that the soils have a permeability (k) of $6.7E-8$ centimeters squared (cm^2). Flow conditions observed at AOC 43G include an effective radius of influence of 23 feet [defined by 0.1" water column (w.c.) vacuum]] and a soil venting flow rate of 1.8 standard cubic feet per minute (scfm) per foot of screened interval at a vacuum of 30" w.c.. Based on this soil venting data, vertical vent wells can be used to treat the soil under and adjacent to the existing gasoline USTs at AOC 43G.

This soil venting system would consist of a total of approximately five vertical vent extraction wells (one well is already installed at the site) located within the former UST area. A total extraction flow rate of approximately 90 scfm is estimated to be required to vent this site. Details of the system are provided in Section 4.0.

Because oxygen would move through the contaminated vadose zone as a result of soil vapor movement, aerobic biological degradation is expected to occur in the vadose zone soils adjacent to and below the gasoline USTs area due the soil venting activity. Contaminants at AOC 43G that would be susceptible to aerobic biological degradation would include volatile and non-volatile petroleum hydrocarbons. The additional removal of volatile contaminants through biological degradation would decrease the amount of vadose zone treatment time.

Extracted soil vapor would require treatment before discharge to the atmosphere. Based on soil vapor flow and make-up, vapor phase activated carbon is recommended for treatment of soil vapor extracted from AOC 43G. Operation and maintenance of the SVE system would consist of monitoring soil vapors for

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VOC concentrations, monitoring off-gases from the soil vapor treatment system and maintaining soil venting and treatment system equipment.

3.1.4 Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

Key components of Alternative 3 include:

- Groundwater Collection and Treatment
- Discharge of Treated Effluent to the Fort Devens Waste Water Treatment Facility (WWTF)
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 3 would entail installing a groundwater pump-and-treat system located at the base of the hill between the AAFES gas station, and the car wash (Building 2017) (Figure 2-1). This system would pump at a flow rate capable of capturing the groundwater plume emanating from Area 2 and 3. The downgradient groundwater contamination would be remediated by intrinsic bioremediation as described in Alternative 2A. Groundwater Collection and Treatment is described below.

Groundwater Collection and Treatment. Groundwater collection would be achieved using vertical extraction wells. The type of groundwater extraction well used at a site ultimately depends upon geologic characteristics such as soil and bedrock permeability, aquifer characteristics such as hydraulic gradient and depth to groundwater, and feasibility/cost. To determine more accurately which groundwater extraction system would be more appropriate at AOC 43G, a groundwater capture modeling program was used. This model utilizes soil and aquifer characteristics and other information (e.g., number and location of groundwater extraction wells) to predict what the resulting effects upon the aquifer would be.

Based upon results from the groundwater capture modeling program (presented in detail in Appendix A), a five vertical well groundwater extraction system is recommended for AOC 43G. This groundwater extraction system would consist of five 6-inch diameter polyvinyl chloride (PVC) groundwater extraction wells arranged within the central plume area. A groundwater extraction rate of

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approximately 1 to 3 gpm would be required to capture the contaminated plume emanating from Area 2 and 3.

Groundwater extracted from the aquifer would be treated in a liquid phase GAC treatment system and the treated effluent would be discharged to the Fort Devens WWTF. Operation and maintenance of the groundwater pump and treat system would consist of monitoring groundwater for CPC concentrations and maintaining groundwater extraction and treatment system equipment.

3.1.5 Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

Key components of Alternative 4 include:

- Groundwater Collection and Treatment
- Discharge of Treated Effluent to the Fort Devens WWTF
- Passive Bioremediation Downgradient by Slow Release Peroxide
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 4 is the same as Alternative 3 except that a passive bioremediation system would be installed downgradient to contain the contaminant plume. Passive Bioremediation is described below. Groundwater Collection is described in Alternative 3. The remaining actions are described in Alternative 2A.

Passive Bioremediation. Data presented in Table 2-3 infers that anaerobic biological degradation of the fuel is occurring on site. Detail on the anaerobic biological degradation of the contaminants of concern (intrinsic bioremediation) is presented in Alternative 2A.

In general, biological degradation of the volatile aromatic compounds associated with gasoline is achieved more readily under aerobic conditions than under anaerobic conditions, especially for benzene. Anaerobic biological degradation is occurring currently at AOC 43G. Aerobic biological treatment by aerating the entire groundwater plume would be impractical to achieve due to the difficulties in efficiently locating injection points upgradient or in the source area considering bedrock/overburden/groundwater complexity at the site. Other issues include the potential for groundwater mounding, the possible impacts on existing vertical and

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horizontal groundwater gradients at the site, and likely fouling of injection points/trenches from high concentrations of iron and manganese in the groundwater. However, oxygen can be passively introduced to the aquifer to promote aerobic conditions to enhance biological degradation at a faster rate near the plume edge thereby minimizing the potential of plume migration off-site. A Biotreatability Study performed on groundwater extracted from AOC 43G aquifer shows that gasoline biodegradation can be readily enhanced (Appendix B).

The passive introduction of oxygen to the aquifer would be accomplished using metal peroxides. Solid metal (magnesium) peroxides, in the form of briquettes or "pencils" would be inserted into 2-inch diameter passive bioremediation wells screened in the contaminated region of the aquifer. As groundwater passes through the well screen, the metal peroxides will dissolve slowly into the water and release oxygen. This oxygen will subsequently be available for aerobic biological degradation. Water and other inert byproducts (e.g., magnesium hydroxide) would also be formed from the metal peroxide dissolution. Nutrients to enhance biodegradation would also be added as needed.

To accomplish passive aerobic biological degradation at AOC 43G, it is estimated that up to 20 passive bioremediation wells would be needed at the site. These wells would be constructed of 2-inch diameter PVC risers, spaced on 10-foot centers, screened from 11 to 21 feet below ground surface (10 - 20 slot screens). Removable wire screens or fabric "socks" would be used to hold the solid metal peroxides.

Operation and maintenance of the passive in-situ bioremediation system would consist of a) monitoring groundwater for dissolved oxygen, and mineral nutrient in addition to the parameters required for long-term groundwater monitoring, b) replacing oxygen release and mineral nutrient material in the passive bioremediation wells, and c) providing well cleaning services (e.g., acid treatment and surge block pumping of the wells to relieve potential clogging of the well screens caused by microorganism growth and/or precipitate formation. Passive bioremediation would continue at AOC 43G as long as there is a contaminant plume upgradient with concentrations exceeding PRGs.

3.2 SCREENING OF ALTERNATIVES

In this subsection, the alternatives are screened with respect to the criteria of effectiveness, implementability, and cost to meet the requirements of CERCLA and the NCP. The three criteria used for screening the alternatives are as follows:

Effectiveness: Each alternative was judged for its ability to effectively protect human health by reducing the toxicity, mobility, or volume of contaminants; both short- and long-term effectiveness were evaluated. Short-term effectiveness involves reducing existing risks to the community and workers during the construction and implementation period, identifying expected impacts to the environment and potential mitigative measures during construction and implementation, the alternative's ability to meet remedial action objectives, and the time frame required to achieve remedial action objectives. Long-term effectiveness, which applies after remedial action objectives have been attained, considers the magnitude of the remaining residual risk due to untreated wastes and waste residuals, and the adequacy and reliability of specific technical components and control measures.

Implementability. Each alternative was evaluated in terms of technical and administrative feasibility. In the assessment of short-term technical feasibility, availability of a technology for construction or mobilization and operation, the availability of required services and trained specialists or operators, in addition to compliance with action-specific ARARs during the remedial action were considered. Long-term technical feasibility considered the ease of operation and maintenance (O&M), technical reliability, ease of undertaking additional remedial actions, and monitoring of technical controls of residuals and untreated wastes. Administrative feasibility for implementing a given technology addressed coordination with other agencies.

Cost. The final criterion for initial screening of alternatives is the cost associated with the given remedy. Absolute accuracy in cost estimates during screening is not essential. The focus should be to make comparative estimates for alternatives with relative accuracy so that cost decisions among alternatives will be sustained as the accuracy of cost estimates improves beyond screening (USEPA, 1988). Relative capital and O&M costs are discussed at this stage, in addition to factors influencing cost sensitivity. Potential liability associated with untreated waste and

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treatment residuals is also discussed. Cost estimates for alternatives screening are based on generic unit costs, vendor information, cost-estimating guides, and prior estimates. Cost estimates for items common to all alternatives or indirect costs do not normally warrant substantial effort during the alternative screening phase.

Alternative Evaluation. For each alternative, a matrix was developed highlighting the alternative's advantages and disadvantages with respect to effectiveness, implementability, and cost. The alternative evaluation matrix presents a clear, concise procedure for screening potential remedial action alternatives. Based on this matrix, a decision was made to either retain the alternative for detailed analysis or eliminate it from further consideration. Screening matrices for each alternative are presented in Tables 3-1 through 3-4. Table 3-5 provides a summary of the alternatives screening process.

3.2.1 Alternative 2A: Intrinsic Bioremediation

Alternative 2A would involve intrinsic bioremediation for treatment of the groundwater and long-term groundwater monitoring to monitor the effectiveness of the natural bioremediation process and to monitor for contaminant migration. Five-year site reviews would be conducted to evaluate whether the alternative continues to protect human health.

Effectiveness. In the anaerobic microbial degradation process of intrinsic bioremediation, the organic compounds of concern are ultimately converted to inert compounds such as carbon dioxide, methane, and water. Because of this process, intrinsic bioremediation will effectively reduce the toxicity and volume of the VOCs of concern in the site groundwater. As a result, downgradient or off-site migration of site contaminants will be eliminated or minimized to concentrations below PRGs. Additionally, removal of the organics will return the groundwater quality to upgradient conditions resulting in a return of the more insoluble forms of nickel, iron and manganese.

The time required to remediate the groundwater at AOC 43G using intrinsic bioremediation can be estimated using the first order degradation rate equation:

$$C = C_0 e^{-kt}, \text{ where}$$

C is the final concentration to be achieved ($\mu\text{g/L}$),

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C_0 is the starting concentration ($\mu\text{g/L}$),
 k is the first order decay coefficient (1/day), and
 t is the amount of time required to achieve concentration C (days).

Solute transport calculations were performed for the organic contaminants of concern, benzene, ethylbenzene, and xylene (Appendix C). The calculations considered the first order degradation rates (half-lives) for these compounds obtained from a literature search. Calculation details are further discussed in Section 4.0. Based on these calculations, the organic CPCs will not migrate beyond the Army Reserve Enclave boundary. Because there is potential of continuing groundwater contamination from contamination within the bedrock fractures, cleanup will likely take over 30 years. Therefore, for costing purposes, a default value of 30 years is assumed for a remedial time period. (Thirty years is the maximum period to be used for costing purposes based on USEPA guidance [USEPA, 1988]).

The potential for short-term worker exposure to contaminated groundwater is considered minimal during intrinsic groundwater monitoring well installation. Further exposure of site workers to site contamination would also be minimal for intrinsic bioremediation during groundwater sampling.

Intrinsic bioremediation in conjunction with groundwater monitoring will meet remedial objectives. The Army has no intention of installing drinking water wells on site in the future. Intrinsic bioremediation will minimize the potential migration of contaminants off the Army Reserve Enclave property. Long-term groundwater monitoring will be used to assess the effectiveness of the biodegradation and to evaluate migration potential.

Implementability. Because biological degradation is already occurring naturally under existing site conditions, no further implementation is necessary for the intrinsic bioremediation process itself. Additional groundwater monitoring wells are recommended as part of intrinsic bioremediation monitoring to provide additional biodegradation information. Local contractors and "off-the-shelf" materials would be available to install the monitoring wells. A long-term monitoring plan would be prepared and submitted for regulatory review and approval. Groundwater monitoring would use USAEC-approved groundwater sampling techniques.

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The ease of undertaking additional remedial action once this alternative is instituted would not be jeopardized.

Cost. The cost of implementing Alternative 2A would consist primarily of groundwater monitoring well installation and long-term groundwater monitoring costs.

Conclusion. This alternative will be retained for detailed analysis. Intrinsic bioremediation provides a low-cost approach that will protect human health.

3.2.2 Alternative 2B: Intrinsic Bioremediation / Soil Venting Gasoline UST Soils

Alternative 2B involves the same actions as Alternative 2A except that the residual contaminated soils below the former gasoline USTs (now adjacent and below the existing gasoline USTs) would also be remediated. Remediation would entail installing an SVE system to vent these residual contaminated soils. The same discussions regarding effectiveness and implementability in Alternative 2A apply to Alternative 2B. Additional discussion regarding effectiveness and implementability of the SVE venting system are described below.

Effectiveness. Soil venting is a physical transfer process in which VOCs are removed from the vadose zone soil and brought above ground where they can be treated. Contaminants would be transferred to activated carbon which would require disposal or regeneration. Soil venting effectively reduces the mass of organic contaminants in the vadose zone thus minimizing potential re-exposure of groundwater to contaminants.

The soil volume to be vented is estimated for costing purposes to be within the foot print of all five former USTs plus 3 feet on all sides by an average 8 to 10 foot depth to bedrock (575 to 720 cubic yards). Based on an assumed average soil BTEX concentration of 377 mg/kg and removal rates observed during the AOC 43G soil permeability test (ABB-ES, 1996), the estimated time required to remove this soil contamination at an approximate flow rate of 18 scfm/well would be 1.5 years. Details of these assumptions and calculations are provided in Section 4.0.

Because the extraction of soil air resulting from the soil venting process also would move oxygen through the vadose zone soil, soil venting would likely

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promote biological degradation of petroleum hydrocarbons further reducing the mass of the contaminants of concern. However, short circuiting of air can also sometimes occur with soil venting leaving some possible areas of untreated soil.

The potential for short-term worker exposure to contaminated soil is minimal for vent well installation. Further exposure of site workers to site contamination would only exist in the event of vapor extraction conveyance line failure.

The potential groundwater remediation benefit from removing the residual soil contamination is not readily definable at this time. Because bedrock may be a continuing source for groundwater contamination at the site, removal of the soil contamination will not likely improve groundwater remediation significantly and cleanup could still take over 30 years as estimated for Alternative 2A. If re-contamination of groundwater is halted as a result of soil venting the gasoline UST soils, cleanup could be quicker as detailed in the solute transport modeling described for Alternative 2A in Section 4.0. For costing purposes, a default value of 30 years is assumed for a remedial time period as described for Alternative 2A.

Implementability. Soil venting systems would be relatively easy to implement. Existing soil vent well and monitoring probes may be used as part of the final treatment system. Services, materials and contractors are readily available to construct and operate the SVE system.

Cost. The cost of implementing Alternative 2B would consist primarily of the costs discussed in Alternative 2A (intrinsic bioremediation groundwater sampling and modeling, groundwater monitoring well installations, and long-term groundwater monitoring). Additional costs associated with Alternative 2B entail installing the SVE system (design, vent well installations, piping, and system operation and maintenance including soil vapor sampling and vapor phase carbon disposal/regeneration).

Conclusion. This alternative will be retained for detailed analysis. Alternative 2B provides a greater degree of protection against potential migration of VOCs to groundwater from the gasoline UST area. As a result, intrinsic bioremediation will be potentially more effective at reducing CPCs below PRGs in groundwater.

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3.2.3 Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

Alternative 3 entails installing a groundwater pump-and-treat system located at the base of the hill between the AAFES gas station and the car wash (Building 2017) (Figure 2-1). Alternative 3 involves essentially the same actions as Alternative 2A except that groundwater within the source area will be collected and treated instead of using only intrinsic bioremediation in this area. The downgradient groundwater contamination will be treated by intrinsic bioremediation. The same discussions regarding effectiveness and implementability of intrinsic bioremediation and long-term groundwater monitoring in Alternative 2A apply to Alternative 3. Additional discussion regarding effectiveness and implementability of groundwater collection and treatment and discharge are described below.

Effectiveness. Groundwater pump and treat would reduce the mobility and volume of contamination in site groundwater in two ways. First, due to groundwater extraction activity, groundwater pump and treat would effectively contain the migration of contaminated groundwater. Second, groundwater extraction would reduce the overall mass of contamination in the groundwater by removing groundwater containing dissolved contamination. As a result, downgradient or off-site migration of site contaminants will be minimized in combination with intrinsic bioremediation. However, because there is potential of a continued source of groundwater contamination within the bedrock, remediation is expected to take over 30 years as described under Alternative 2A. Treatment of groundwater would be achieved by liquid phase GAC. Contaminants would be transferred to carbon which would require disposal or regeneration.

There would be minimal short-term worker exposure to contaminated groundwater during extraction well and associated piping installation. Further exposure of site workers to site contamination would only exist in the event of groundwater extraction/remediation pipe line failure.

Implementability. Upon completion of field testing and full-scale design, the groundwater pump and treat would be relatively easy to implement. Local contractors and common materials would be available to construct the groundwater extraction and treatment system. Discharge to the Fort Devens WWTF would have to meet the WWTF Industrial Pretreatment Standards

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(Rasco, 1995). These standards apply to all existing or potential industrial operations (including groundwater remediation systems) discharging to the Fort Devens WWTF. The standards prohibit discharge of any toxic pollutant which may interfere with the Fort Devens WWTF process and which may then pass through the WWTF thereby constituting a hazard, pollute receiving waters, or restrict sludge disposal options selected by Fort Devens. The Commonwealth of Massachusetts Class I groundwater quality parameters are referenced in the Pretreatment Standards. Details regarding compliance requirements are covered in Section 4.0.

Cost. The cost of implementing Alternative 3 would consist primarily of the costs discussed in Alternative 2A (groundwater monitoring well installations and long-term groundwater monitoring). Additional costs associated with Alternative 3 entail installing the groundwater extraction and treatment system. Included are costs for the groundwater extraction system, piping, treatment system, system operation and maintenance, and WWTF user fee.

Conclusion. This alternative will be retained for detailed analysis. Alternative 3 provides a greater degree of protection against potential migration of VOCs and inorganics from the Army Reserve Enclave.

3.2.4 Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

Alternative 4 is the same as Alternative 3 except that a passive bioremediation system would be installed to contain the contaminant plume that is downgradient of the groundwater collection and treatment system. The same discussions regarding effectiveness and implementability of intrinsic bioremediation, long-term groundwater monitoring, and groundwater collection and treatment/discharge in Alternatives 2A and 3 apply to Alternative 4. Additional discussion regarding effectiveness and implementability of passive bioremediation with slow release oxygen release compounds are described below.

Effectiveness. In the microbial degradation process brought about by in-situ bioremediation, the organic compounds of concern are ultimately converted to inert compounds such as carbon dioxide and water (aerobic conditions). Because of the actual degradation/destruction of the organic contaminants that occurs in this technology, passive in-situ bioremediation will effectively reduce the toxicity

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and volume of organic contaminants in the site groundwater. As a result, downgradient or off-site migration of site contaminants will be minimized.

There is minimal potential for short-term worker exposure to contaminated groundwater during passive bioremediation well installation. Exposure of site workers to site contamination also would not be extensive during passive bioremediation well maintenance.

Implementability. Prior to full-scale implementation of passive bioremediation, bench-scale and possibly field-scale testing would be required. Passive bioremediation design tests would include a) identification of the most suitable oxygen release compound for the site, b) determination of the effects of iron and manganese precipitation on oxygen diffusion in the aquifer, c) determination of the role of nutrient addition in passive bioremediation, and d) well design information (e.g., well layout requirements). Upon completion of design testing and full-scale design, a passive bioremediation system would be relatively easy to implement. Local contractors and "off-the-shelf" materials would be available to construct the passive bioremediation wells.

Cost. The cost of implementing Alternative 4 would consist primarily of design testing, passive bioremediation well installation, and passive bioremediation system operation and maintenance in addition to all costs associated with Alternative 3 (groundwater monitoring well installations and long-term groundwater monitoring; and groundwater extraction/treatment system installation and operation.)

Conclusion. This alternative will be retained for detailed analysis because it will aggressively prevent off-site migration and treat contaminants on-site.

TABLE 3-1
ALTERNATIVE 2A: INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
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Alternative 2A uses intrinsic bioremediation to minimize the potential migration of CPCs that exceed PRGs and groundwater monitoring to observe for any threat to receptors downgradient of the Enclave.

EFFECTIVENESS	IMPLEMENTABILITY	COST
<u>Advantages</u> • Intrinsic bioremediation will reduce toxicity/volume of contaminants and also reduce potential migration of contaminants off the Enclave. • Groundwater treatment is achieved with little implementation. <u>Disadvantages</u> • Groundwater contaminant reduction may take over 30 years to reach PRGs on-site due to potential presence of contamination within bedrock. • Careful monitoring of the groundwater plume is required to observe for any migration of contaminants downgradient. • Effectiveness is based on literature-based degradation rates.	<u>Advantages</u> • Intrinsic bioremediation and groundwater monitoring are readily implementable technologies. • Can use already existing groundwater monitoring system supplemented with only a few additional wells. • Natural biodegradation of contaminants is currently occurring on-site. <u>Disadvantages</u> • Regulatory approval of intrinsic biodegradation may be more difficult to obtain than for other more conventional processes. • CPC degradation rates and migration rates are determined as part of the predesign.	<u>Advantages</u> • Minimal costs associated with intrinsic bioremediation which will meet remedial objectives. <u>Disadvantages</u> • Long-term monitoring costs.

ESTIMATED CAPITAL COST: \$ 39,000
ESTIMATED PRESENT WORTH OF O&M COSTS: \$ 406,300
ESTIMATED TOTAL PRESENT WORTH: \$ 445,300

CONCLUSION: Alternative will be **retained** for detailed analysis. Intrinsic bioremediation provides a low-cost approach that is protective of human health.

Notes: O&M = operations and maintenance

TABLE 3-2
ALTERNATIVE 2B: INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

Alternative 2B uses intrinsic bioremediation to minimize the potential migration of CPCs that exceed PRGs and groundwater monitoring to observe for any threat to receptors downgradient of the Enclave. Soil venting, using the soil vapor extraction (SVE) technology, is used to treat soils below the gasoline USTs to reduce the possibility that these soils will re-contaminate the groundwater.

EFFECTIVENESS	IMPLEMENTABILITY	COST
<u>Advantages</u> • Intrinsic bioremediation and SVE will reduce toxicity/volume of contaminants and also reduce potential migration of contaminants off the Enclave. • Groundwater treatment is achieved with little implementation. • SVE will minimize the possibility of groundwater becoming re-contaminated. <u>Disadvantages</u> • Despite implementation of SVE, groundwater contaminant reduction may take over 30 years to reach PRGs on-site due to potential presence of contamination within bedrock. • Groundwater monitoring is required to observe for any migration of contaminants downgradient. • Effectiveness is based on literature-based degradation rates.	<u>Advantages</u> • Intrinsic bioremediation, SVE, and groundwater monitoring are readily implementable technologies. • Can use already existing groundwater monitoring system and SVE well supplemented with only a few additional wells. • Natural biodegradation of contaminants is currently occurring on-site. <u>Disadvantages</u> • Regulatory approval of intrinsic biodegradation may be more difficult to obtain than for other more conventional processes. • CPC degradation rates and migration rates are determined as part of the predesign. • SVE capability of minimizing groundwater re-contamination is not readily measurable.	<u>Advantages</u> • Minimal capital costs associated with intrinsic bioremediation and SVE which will meet remedial objectives. • Minimal O&M costs associated with SVE. <u>Disadvantages</u> • Long-term groundwater monitoring costs.

ESTIMATED CAPITAL COST: \$ 137,600
ESTIMATED PRESENT WORTH OF O&M COSTS: \$ 473,900
ESTIMATED TOTAL PRESENT WORTH: \$ 611,500

CONCLUSION: Alternative will be **retained** for detailed analysis. Intrinsic bioremediation provides a low-cost approach that is protective of human health. SVE may reduce groundwater recontamination potential.

Notes: O&M = operations and maintenance

TABLE 3-3
ALTERNATIVE 3: GROUNDWATER COLLECTION & TREATMENT/INTRINSIC
BIOREMEDIATION DOWNGRADIENT
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

Alternative 3 uses groundwater extraction and treatment to intercept the plume in the area of highest concentration and lower the contaminant concentrations within the source area. Intrinsic bioremediation is used to treat the downgradient plume. Groundwater monitoring is performed to observe for any threat to receptors downgradient of the Enclave.

EFFECTIVENESS	IMPLEMENTABILITY	COST
<u>Advantages</u> - GAC groundwater treatment will reduce toxicity/volume of VOCs and more aggressively reduce contaminant migration off the Enclave. - Pumping will hydraulically contain groundwater flow thereby stopping migration of contaminants from the source areas at the extraction system. <u>Disadvantages</u> - Groundwater contaminant reduction may take over 30 years to reach PRGs on-site due to potential presence of contamination within bedrock. - Monitoring of plume is required to observe for any migration of contaminants downgradient.	<u>Advantages</u> - Intrinsic bioremediation and groundwater monitoring are readily implementable technologies. - Can use existing groundwater monitoring system supplemented with a few additional monitoring wells. - Natural biodegradation of contaminants is currently occurring on-site. - Technology is well proven and does not require contingencies to be in place. <u>Disadvantages</u> - Need on-site construction for groundwater technology. - Must meet pretreatment requirements for discharge. - The alternative entails active technologies which are more complex to operate than passive technologies.	<u>Advantages</u> - None. <u>Disadvantages</u> - Long-term monitoring costs. - Groundwater treatment O&M costs will be greater than less aggressive alternatives.

ESTIMATED CAPITAL COST: \$ 257,600

ESTIMATED PRESENT WORTH OF O&M COSTS: \$ 1,444,900

ESTIMATED TOTAL PRESENT WORTH: \$ 1,702,500

CONCLUSION: Alternative will be retained for detailed analysis. Groundwater pumping within the plume area with GAC treatment to contain the upgradient portion of the plume and intrinsic bioremediation of the downgradient plume provides an effective approach that is protective of human health.

Notes: O&M = operations and maintenance

TABLE 3-4
ALTERNATIVE 4: GROUNDWATER COLLECTION & TREATMENT/PASSIVE BIOREMEDIATION
DOWNGRADIENT
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

Alternative 4 uses groundwater extraction and treatment to intercept the plume in the area of highest contaminant concentrations and to lower contaminant concentrations within the source area. Passive slow release peroxide application is used to contain the downgradient plume. Groundwater monitoring is performed to observe for any threat to receptors downgradient of the Enclave.

EFFECTIVENESS	IMPLEMENTABILITY	COST
<u>Advantages</u> • GAC groundwater treatment will reduce toxicity/volume of VOCs and more aggressively reduce contaminant migration off the Enclave. • Pumping will hydraulically contain groundwater flow thereby stopping migration of contaminants from the source areas at the extraction system. <u>Disadvantages</u> • Groundwater contaminant reduction may take over 30 years to reach PRGs on-site due to potential presence of source areas within bedrock. • Monitoring of plume is required to observe for any migration of contaminants downgradient.	<u>Advantages</u> • Passive biodegradation and groundwater monitoring and soil venting are readily implementable technologies. • Can use existing groundwater monitoring and soil vent wells/probes supplemented with some additional monitoring and vent wells. <u>Disadvantages</u> • Groundwater pumping tests, ORP lab treatability tests and perhaps ORP pilot tests may be required prior to design. • Requires active technologies which are more complex to operate than passive technologies. • Need on-site construction for groundwater technology. • Must meet pretreatment requirements for discharge.	<u>Advantages</u> • None <u>Disadvantages</u> • Long-term monitoring costs. • Groundwater treatment O&M costs and bioremediation well maintenance costs are greater than intrinsic bioremediation annual costs.

ESTIMATED CAPITAL COST: \$387,400
ESTIMATED PRESENT WORTH OF O&M COSTS: \$2,139,800
ESTIMATED TOTAL PRESENT WORTH: \$2,527,200

CONCLUSION: Alternative will be retained for detailed analysis. Groundwater extraction and treatment, and passive biodegradation provide an effective means of plume containment that is protective of human health.

Notes: O&M = operations and maintenance

TABLE 3-5
SCREENING SUMMARY OF ALTERNATIVES
AOC 43G

FEASIBILITY STUDY REPORT
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REMEDIAL ALTERNATIVES	RETAINED	ELIMINATED
Alternative 1: No Action	X	
Alternative 2A: Intrinsic Bioremediation	X	
Alternative 2B: Intrinsic Bioremediation/Soil Venting of Gasoline UST Soils	X	
Alternative 3: Groundwater Collection and Treatment/Intrinsic Bioremediation Downgradient	X	
Alternative 4: Groundwater Collection and Treatment/Passive Bioremediation Downgradient	X	

3.0 DEVELOPMENT AND SCREENING OF ALTERNATIVES

In this section, technically feasible process options retained following the screening described in Section 2.0 are combined to form remedial action alternatives. Alternatives are developed to attain the remedial action objectives discussed in Section 2.0, using the following General Response Actions either singly or in combination: (1) No Action; (2) Limited Action; (3) Containment; (4) Collection; (5) Treatment; (5) Discharge.

The developed remedial alternatives are then screened with respect to the criteria of effectiveness, implementability, and cost to meet the requirements of CERCLA and the National Contingency Plan (NCP). The objective of this screening step is to eliminate impractical alternatives or higher cost alternatives (i.e., order of magnitude cost differences) that provide little or no improvement in effectiveness or implementability over their lower cost counterparts.

3.1 DEVELOPMENT OF ALTERNATIVES

Five remedial alternatives were developed for AOC 43G to address remedial action objectives presented in Section 2.0. In assembling these alternatives, general response actions and process options, chosen to represent the various technology types for the medium of concern, were combined to form alternatives for the site as a whole. Alternatives were developed to provide a range of options consistent with USEPA RI/FS guidance (USEPA, 1988).

These alternatives include:

- Alternative 1: No Action
- Alternative 2A: Intrinsic Bioremediation
- Alternative 2B: Intrinsic Bioremediation / Soil Venting of Gasoline UST Soils
- Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

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- Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

3.1.1 Alternative 1: No Action

The No Action alternative does not include any remedial action components to reduce or control potential risks at AOC 43G. In addition, existing monitoring would be discontinued. The No Action alternative will not be evaluated according to screening criteria; it will pass through screening to be evaluated during the detailed analysis as a baseline for the other retained alternatives (USEPA, 1988).

3.1.2 Alternative 2A: Intrinsic Bioremediation

Key components of Alternative 2A include:

- Intrinsic Bioremediation
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 2A would involve intrinsic bioremediation for treatment of the groundwater.

Intrinsic Bioremediation. Based upon organic and inorganic speciation in the aquifer, it appears that biological degradation of the petroleum hydrocarbons is naturally occurring at AOC 43G. Alternative 2A would allow the natural biological degradation (intrinsic bioremediation) of the CPCs to continue to occur at the site without interruption. To assess the effectiveness of biological degradation at the site, groundwater monitoring would be performed on a scheduled basis. Additional monitoring wells would need to be installed.

The biological degradation of hydrocarbons is essentially an oxidation-reduction reaction in which the hydrocarbon compound is oxidized (donates electrons) and an electron acceptor, such as oxygen, is reduced (accepts electrons). Under aerobic conditions, oxygen is the electron acceptor for biological degradation activity. When oxygen is absent or depleted from a system, anaerobic conditions exist and other compounds are used as electron acceptors. Other compounds that

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are used as electron acceptors during anaerobic degradation of petroleum hydrocarbons include nitrate, manganese oxides, sulfate, iron, and hydrogen.

The electron acceptor that is ultimately used in the anaerobic biodegradation of hydrocarbons depends upon compound concentrations, availability, and the redox conditions of the aquifer. The order in which electron acceptors are used in anaerobic biodegradation (according to free energy laws) is as follows: oxygen (aerobic conditions), nitrate, manganese oxides, ferric iron (FeIII), sulfate, and hydrogen (methanogenic conditions). As the progression of electron acceptor use occurs through this sequence, the ORP of the aquifer decreases.

As defined by name, compounds that act as electron acceptors in anaerobic biodegradation gain electrons and are reduced. Typical examples of reduced forms of compounds that are produced during anaerobic biodegradation of hydrocarbons include nitrite from nitrate, manganese as Mn[II] from Mn[IV], ferrous (Fe[II]) iron from ferric ([Fe(III)]) iron, sulfide compounds from sulfate reduction, and methane from hydrogen reduction. The presence of these reduced forms of compounds in an aquifer is an indicator that biological activity is occurring. Inorganic speciation can be used to model anaerobic biological degradation.

Table 2-3 presents the groundwater inorganic speciation data for groundwater upgradient of the source, at the source area, at the perimeter, downgradient within the plume (where benzene concentrations are greater than 5 $\mu\text{g/L}$) and downgradient (where benzene concentrations are less than 5 $\mu\text{g/L}$). Data included in this table include nitrite/nitrate concentrations, sulfate concentrations, phosphate concentrations, and ORP. Based on several speciation trends presented in this table, it appears that anaerobic activity is occurring in the zone of contamination. These trends include a) decreased average nitrate/nitrite concentrations in the contaminated region, b) decreased sulfate concentrations in the aquifer, c) decreased ORP measurements in the source area, and d) decreased total nitrogen and phosphate concentrations in the aquifer.

Decreased nitrate and sulfate concentrations in the plume area (compared to up- and down-gradient concentrations), indicate that microbial-induced redox processes are occurring at AOC 43G. This assumption is confirmed with ORP data which indicates that the ORP is negative in the contaminated zone and is less than the ORP found in surrounding groundwater. Decreasing nutrient

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concentrations (total nitrogen and phosphate concentrations) also affirm the premise that active microbiological degradation of the contaminants of concern is occurring in the zone of contamination, as these compounds are consumed (uptake) within the contaminated groundwater.

Intrinsic bioremediation would continue at AOC 43G until the remedial action objectives are achieved. Calculations based upon degradation rates from literature indicate that contaminants would not migrate off Army Reserve Enclave property. Details of these calculations are discussed in Section 4.0. Additional data collection would be required as part of the design to confirm degradation rates and refine long-term groundwater monitoring needs.

Long-Term Groundwater Monitoring / Five-Year Site Reviews. Long-term groundwater monitoring would also be instituted to monitor organic and soluble inorganic contaminants of concern. Five-year site reviews would be conducted to evaluate whether the alternative continues to protect human health and the environment. Details of the monitoring and site reviews will be discussed in Section 4.0.

3.1.3 Alternative 2B: Intrinsic Bioremediation / Soil Venting Gasoline UST Soils

Key components of Alternative 2B include:

- Intrinsic Bioremediation
- Soil Venting Soils Below and Adjacent the Gasoline USTs
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 2B involves the same actions as Alternative 2A except that the residual contaminated soils below and adjacent to the former (and now existing) gasoline USTs would be remediated. Soil remediation would entail installing an SVE system to minimize the potential of groundwater re-contamination. Specifics regarding this system are detailed below. See Alternative 2A for description of the intrinsic bioremediation, long-term groundwater monitoring, and 5-year site review components.

Soil Venting. Soil venting of the soils adjacent to and below the gasoline USTs will require installation of vertical soil vent wells for soil venting and installation of aboveground soil vapor treatment equipment. The objective of soil venting is to remediate the vadose zone below and adjacent to the existing gasoline USTs to prevent further contamination of the aquifer. The soils that contain VOCs may contribute to groundwater contamination during periods of high water table conditions.

To determine the applicability for soil venting at the site and to gather full-scale vent design information, an on-site soil vapor extraction/bioventing pilot test was conducted. Details of the pilot test are included as Appendix O of the RI Report (ABB-ES, 1996). Permeability data gathered from AOC 43G indicates that the soils have a permeability (k) of $6.7E-8$ centimeters squared (cm^2). Flow conditions observed at AOC 43G include an effective radius of influence of 23 feet [defined by 0.1" water column (w.c.) vacuum] and a soil venting flow rate of 1.8 standard cubic feet per minute (scfm) per foot of screened interval at a vacuum of 30" w.c.. Based on this soil venting data, vertical vent wells can be used to treat the soil under and adjacent to the existing gasoline USTs at AOC 43G.

This soil venting system would consist of a total of approximately five vertical vent extraction wells (one well is already installed at the site) located within the former UST area. A total extraction flow rate of approximately 90 scfm is estimated to be required to vent this site. Details of the system are provided in Section 4.0.

Because oxygen would move through the contaminated vadose zone as a result of soil vapor movement, aerobic biological degradation is expected to occur in the vadose zone soils adjacent to and below the gasoline USTs area due the soil venting activity. Contaminants at AOC 43G that would be susceptible to aerobic biological degradation would include volatile and non-volatile petroleum hydrocarbons. The additional removal of volatile contaminants through biological degradation would decrease the amount of vadose zone treatment time.

Extracted soil vapor would require treatment before discharge to the atmosphere. Based on soil vapor flow and make-up, vapor phase activated carbon is recommended for treatment of soil vapor extracted from AOC 43G. Operation and maintenance of the SVE system would consist of monitoring soil vapors for

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VOC concentrations, monitoring off-gases from the soil vapor treatment system and maintaining soil venting and treatment system equipment.

3.1.4 Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

Key components of Alternative 3 include:

- Groundwater Collection and Treatment
- Discharge of Treated Effluent to the Fort Devens Waste Water Treatment Facility (WWTF)
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 3 would entail installing a groundwater pump-and-treat system located at the base of the hill between the AAFES gas station, and the car wash (Building 2017) (Figure 2-1). This system would pump at a flow rate capable of capturing the groundwater plume emanating from Area 2 and 3. The downgradient groundwater contamination would be remediated by intrinsic bioremediation as described in Alternative 2A. Groundwater Collection and Treatment is described below.

Groundwater Collection and Treatment. Groundwater collection would be achieved using vertical extraction wells. The type of groundwater extraction well used at a site ultimately depends upon geologic characteristics such as soil and bedrock permeability, aquifer characteristics such as hydraulic gradient and depth to groundwater, and feasibility/cost. To determine more accurately which groundwater extraction system would be more appropriate at AOC 43G, a groundwater capture modeling program was used. This model utilizes soil and aquifer characteristics and other information (e.g., number and location of groundwater extraction wells) to predict what the resulting effects upon the aquifer would be.

Based upon results from the groundwater capture modeling program (presented in detail in Appendix A), a five vertical well groundwater extraction system is recommended for AOC 43G. This groundwater extraction system would consist of five 6-inch diameter polyvinyl chloride (PVC) groundwater extraction wells arranged within the central plume area. A groundwater extraction rate of

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approximately 1 to 3 gpm would be required to capture the contaminated plume emanating from Area 2 and 3.

Groundwater extracted from the aquifer would be treated in a liquid phase GAC treatment system and the treated effluent would be discharged to the Fort Devens WWTF. Operation and maintenance of the groundwater pump and treat system would consist of monitoring groundwater for CPC concentrations and maintaining groundwater extraction and treatment system equipment.

3.1.5 Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

Key components of Alternative 4 include:

- Groundwater Collection and Treatment
- Discharge of Treated Effluent to the Fort Devens WWTF
- Passive Bioremediation Downgradient by Slow Release Peroxide
- Long-Term Groundwater Monitoring
- 5-Year Site Reviews

Alternative 4 is the same as Alternative 3 except that a passive bioremediation system would be installed downgradient to contain the contaminant plume. Passive Bioremediation is described below. Groundwater Collection is described in Alternative 3. The remaining actions are described in Alternative 2A.

Passive Bioremediation. Data presented in Table 2-3 infers that anaerobic biological degradation of the fuel is occurring on site. Detail on the anaerobic biological degradation of the contaminants of concern (intrinsic bioremediation) is presented in Alternative 2A.

In general, biological degradation of the volatile aromatic compounds associated with gasoline is achieved more readily under aerobic conditions than under anaerobic conditions, especially for benzene. Anaerobic biological degradation is occurring currently at AOC 43G. Aerobic biological treatment by aerating the entire groundwater plume would be impractical to achieve due to the difficulties in efficiently locating injection points upgradient or in the source area considering bedrock/overburden/groundwater complexity at the site. Other issues include the potential for groundwater mounding, the possible impacts on existing vertical and

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horizontal groundwater gradients at the site, and likely fouling of injection points/trenches from high concentrations of iron and manganese in the groundwater. However, oxygen can be passively introduced to the aquifer to promote aerobic conditions to enhance biological degradation at a faster rate near the plume edge thereby minimizing the potential of plume migration off-site. A Biotreatability Study performed on groundwater extracted from AOC 43G aquifer shows that gasoline biodegradation can be readily enhanced (Appendix B).

The passive introduction of oxygen to the aquifer would be accomplished using metal peroxides. Solid metal (magnesium) peroxides, in the form of briquettes or "pencils" would be inserted into 2-inch diameter passive bioremediation wells screened in the contaminated region of the aquifer. As groundwater passes through the well screen, the metal peroxides will dissolve slowly into the water and release oxygen. This oxygen will subsequently be available for aerobic biological degradation. Water and other inert byproducts (e.g., magnesium hydroxide) would also be formed from the metal peroxide dissolution. Nutrients to enhance biodegradation would also be added as needed.

To accomplish passive aerobic biological degradation at AOC 43G, it is estimated that up to 20 passive bioremediation wells would be needed at the site. These wells would be constructed of 2-inch diameter PVC risers, spaced on 10-foot centers, screened from 11 to 21 feet below ground surface (10 - 20 slot screens). Removable wire screens or fabric "socks" would be used to hold the solid metal peroxides.

Operation and maintenance of the passive in-situ bioremediation system would consist of a) monitoring groundwater for dissolved oxygen, and mineral nutrient in addition to the parameters required for long-term groundwater monitoring, b) replacing oxygen release and mineral nutrient material in the passive bioremediation wells, and c) providing well cleaning services (e.g., acid treatment and surge block pumping of the wells to relieve potential clogging of the well screens caused by microorganism growth and/or precipitate formation. Passive bioremediation would continue at AOC 43G as long as there is a contaminant plume upgradient with concentrations exceeding PRGs.

3.2 SCREENING OF ALTERNATIVES

In this subsection, the alternatives are screened with respect to the criteria of effectiveness, implementability, and cost to meet the requirements of CERCLA and the NCP. The three criteria used for screening the alternatives are as follows:

Effectiveness: Each alternative was judged for its ability to effectively protect human health by reducing the toxicity, mobility, or volume of contaminants; both short- and long-term effectiveness were evaluated. Short-term effectiveness involves reducing existing risks to the community and workers during the construction and implementation period, identifying expected impacts to the environment and potential mitigative measures during construction and implementation, the alternative's ability to meet remedial action objectives, and the time frame required to achieve remedial action objectives. Long-term effectiveness, which applies after remedial action objectives have been attained, considers the magnitude of the remaining residual risk due to untreated wastes and waste residuals, and the adequacy and reliability of specific technical components and control measures.

Implementability. Each alternative was evaluated in terms of technical and administrative feasibility. In the assessment of short-term technical feasibility, availability of a technology for construction or mobilization and operation, the availability of required services and trained specialists or operators, in addition to compliance with action-specific ARARs during the remedial action were considered. Long-term technical feasibility considered the ease of operation and maintenance (O&M), technical reliability, ease of undertaking additional remedial actions, and monitoring of technical controls of residuals and untreated wastes. Administrative feasibility for implementing a given technology addressed coordination with other agencies.

Cost. The final criterion for initial screening of alternatives is the cost associated with the given remedy. Absolute accuracy in cost estimates during screening is not essential. The focus should be to make comparative estimates for alternatives with relative accuracy so that cost decisions among alternatives will be sustained as the accuracy of cost estimates improves beyond screening (USEPA, 1988). Relative capital and O&M costs are discussed at this stage, in addition to factors influencing cost sensitivity. Potential liability associated with untreated waste and

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treatment residuals is also discussed. Cost estimates for alternatives screening are based on generic unit costs, vendor information, cost-estimating guides, and prior estimates. Cost estimates for items common to all alternatives or indirect costs do not normally warrant substantial effort during the alternative screening phase.

Alternative Evaluation. For each alternative, a matrix was developed highlighting the alternative's advantages and disadvantages with respect to effectiveness, implementability, and cost. The alternative evaluation matrix presents a clear, concise procedure for screening potential remedial action alternatives. Based on this matrix, a decision was made to either retain the alternative for detailed analysis or eliminate it from further consideration. Screening matrices for each alternative are presented in Tables 3-1 through 3-4. Table 3-5 provides a summary of the alternatives screening process.

3.2.1 Alternative 2A: Intrinsic Bioremediation

Alternative 2A would involve intrinsic bioremediation for treatment of the groundwater and long-term groundwater monitoring to monitor the effectiveness of the natural bioremediation process and to monitor for contaminant migration. Five-year site reviews would be conducted to evaluate whether the alternative continues to protect human health.

Effectiveness. In the anaerobic microbial degradation process of intrinsic bioremediation, the organic compounds of concern are ultimately converted to inert compounds such as carbon dioxide, methane, and water. Because of this process, intrinsic bioremediation will effectively reduce the toxicity and volume of the VOCs of concern in the site groundwater. As a result, downgradient or off-site migration of site contaminants will be eliminated or minimized to concentrations below PRGs. Additionally, removal of the organics will return the groundwater quality to upgradient conditions resulting in a return of the more insoluble forms of nickel, iron and manganese.

The time required to remediate the groundwater at AOC 43G using intrinsic bioremediation can be estimated using the first order degradation rate equation:

$$C = C_0 e^{-kt}, \text{ where}$$

C is the final concentration to be achieved ($\mu\text{g/L}$),

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C_0 is the starting concentration ($\mu\text{g/L}$),
 k is the first order decay coefficient (1/day), and
 t is the amount of time required to achieve concentration C (days).

Solute transport calculations were performed for the organic contaminants of concern, benzene, ethylbenzene, and xylene (Appendix C). The calculations considered the first order degradation rates (half-lives) for these compounds obtained from a literature search. Calculation details are further discussed in Section 4.0. Based on these calculations, the organic CPCs will not migrate beyond the Army Reserve Enclave boundary. Because there is potential of continuing groundwater contamination from contamination within the bedrock fractures, cleanup will likely take over 30 years. Therefore, for costing purposes, a default value of 30 years is assumed for a remedial time period. (Thirty years is the maximum period to be used for costing purposes based on USEPA guidance [USEPA, 1988]).

The potential for short-term worker exposure to contaminated groundwater is considered minimal during intrinsic groundwater monitoring well installation. Further exposure of site workers to site contamination would also be minimal for intrinsic bioremediation during groundwater sampling.

Intrinsic bioremediation in conjunction with groundwater monitoring will meet remedial objectives. The Army has no intention of installing drinking water wells on site in the future. Intrinsic bioremediation will minimize the potential migration of contaminants off the Army Reserve Enclave property. Long-term groundwater monitoring will be used to assess the effectiveness of the biodegradation and to evaluate migration potential.

Implementability. Because biological degradation is already occurring naturally under existing site conditions, no further implementation is necessary for the intrinsic bioremediation process itself. Additional groundwater monitoring wells are recommended as part of intrinsic bioremediation monitoring to provide additional biodegradation information. Local contractors and "off-the-shelf" materials would be available to install the monitoring wells. A long-term monitoring plan would be prepared and submitted for regulatory review and approval. Groundwater monitoring would use USAEC-approved groundwater sampling techniques.

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The ease of undertaking additional remedial action once this alternative is instituted would not be jeopardized.

Cost. The cost of implementing Alternative 2A would consist primarily of groundwater monitoring well installation and long-term groundwater monitoring costs.

Conclusion. This alternative will be retained for detailed analysis. Intrinsic bioremediation provides a low-cost approach that will protect human health.

3.2.2 Alternative 2B: Intrinsic Bioremediation / Soil Venting Gasoline UST Soils

Alternative 2B involves the same actions as Alternative 2A except that the residual contaminated soils below the former gasoline USTs (now adjacent and below the existing gasoline USTs) would also be remediated. Remediation would entail installing an SVE system to vent these residual contaminated soils. The same discussions regarding effectiveness and implementability in Alternative 2A apply to Alternative 2B. Additional discussion regarding effectiveness and implementability of the SVE venting system are described below.

Effectiveness. Soil venting is a physical transfer process in which VOCs are removed from the vadose zone soil and brought above ground where they can be treated. Contaminants would be transferred to activated carbon which would require disposal or regeneration. Soil venting effectively reduces the mass of organic contaminants in the vadose zone thus minimizing potential re-exposure of groundwater to contaminants.

The soil volume to be vented is estimated for costing purposes to be within the foot print of all five former USTs plus 3 feet on all sides by an average 8 to 10 foot depth to bedrock (575 to 720 cubic yards). Based on an assumed average soil BTEX concentration of 377 mg/kg and removal rates observed during the AOC 43G soil permeability test (ABB-ES, 1996), the estimated time required to remove this soil contamination at an approximate flow rate of 18 scfm/well would be 1.5 years. Details of these assumptions and calculations are provided in Section 4.0.

Because the extraction of soil air resulting from the soil venting process also would move oxygen through the vadose zone soil, soil venting would likely

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promote biological degradation of petroleum hydrocarbons further reducing the mass of the contaminants of concern. However, short circuiting of air can also sometimes occur with soil venting leaving some possible areas of untreated soil.

The potential for short-term worker exposure to contaminated soil is minimal for vent well installation. Further exposure of site workers to site contamination would only exist in the event of vapor extraction conveyance line failure.

The potential groundwater remediation benefit from removing the residual soil contamination is not readily definable at this time. Because bedrock may be a continuing source for groundwater contamination at the site, removal of the soil contamination will not likely improve groundwater remediation significantly and cleanup could still take over 30 years as estimated for Alternative 2A. If re-contamination of groundwater is halted as a result of soil venting the gasoline UST soils, cleanup could be quicker as detailed in the solute transport modeling described for Alternative 2A in Section 4.0. For costing purposes, a default value of 30 years is assumed for a remedial time period as described for Alternative 2A.

Implementability. Soil venting systems would be relatively easy to implement. Existing soil vent well and monitoring probes may be used as part of the final treatment system. Services, materials and contractors are readily available to construct and operate the SVE system.

Cost. The cost of implementing Alternative 2B would consist primarily of the costs discussed in Alternative 2A (intrinsic bioremediation groundwater sampling and modeling, groundwater monitoring well installations, and long-term groundwater monitoring). Additional costs associated with Alternative 2B entail installing the SVE system (design, vent well installations, piping, and system operation and maintenance including soil vapor sampling and vapor phase carbon disposal/regeneration).

Conclusion. This alternative will be retained for detailed analysis. Alternative 2B provides a greater degree of protection against potential migration of VOCs to groundwater from the gasoline UST area. As a result, intrinsic bioremediation will be potentially more effective at reducing CPCs below PRGs in groundwater.

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3.2.3 Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient

Alternative 3 entails installing a groundwater pump-and-treat system located at the base of the hill between the AAFES gas station and the car wash (Building 2017) (Figure 2-1). Alternative 3 involves essentially the same actions as Alternative 2A except that groundwater within the source area will be collected and treated instead of using only intrinsic bioremediation in this area. The downgradient groundwater contamination will be treated by intrinsic bioremediation. The same discussions regarding effectiveness and implementability of intrinsic bioremediation and long-term groundwater monitoring in Alternative 2A apply to Alternative 3. Additional discussion regarding effectiveness and implementability of groundwater collection and treatment and discharge are described below.

Effectiveness. Groundwater pump and treat would reduce the mobility and volume of contamination in site groundwater in two ways. First, due to groundwater extraction activity, groundwater pump and treat would effectively contain the migration of contaminated groundwater. Second, groundwater extraction would reduce the overall mass of contamination in the groundwater by removing groundwater containing dissolved contamination. As a result, downgradient or off-site migration of site contaminants will be minimized in combination with intrinsic bioremediation. However, because there is potential of a continued source of groundwater contamination within the bedrock, remediation is expected to take over 30 years as described under Alternative 2A. Treatment of groundwater would be achieved by liquid phase GAC. Contaminants would be transferred to carbon which would require disposal or regeneration.

There would be minimal short-term worker exposure to contaminated groundwater during extraction well and associated piping installation. Further exposure of site workers to site contamination would only exist in the event of groundwater extraction/remediation pipe line failure.

Implementability. Upon completion of field testing and full-scale design, the groundwater pump and treat would be relatively easy to implement. Local contractors and common materials would be available to construct the groundwater extraction and treatment system. Discharge to the Fort Devens WWTF would have to meet the WWTF Industrial Pretreatment Standards

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(Rasco, 1995). These standards apply to all existing or potential industrial operations (including groundwater remediation systems) discharging to the Fort Devens WWTF. The standards prohibit discharge of any toxic pollutant which may interfere with the Fort Devens WWTF process and which may then pass through the WWTF thereby constituting a hazard, pollute receiving waters, or restrict sludge disposal options selected by Fort Devens. The Commonwealth of Massachusetts Class I groundwater quality parameters are referenced in the Pretreatment Standards. Details regarding compliance requirements are covered in Section 4.0.

Cost. The cost of implementing Alternative 3 would consist primarily of the costs discussed in Alternative 2A (groundwater monitoring well installations and long-term groundwater monitoring). Additional costs associated with Alternative 3 entail installing the groundwater extraction and treatment system. Included are costs for the groundwater extraction system, piping, treatment system, system operation and maintenance, and WWTF user fee.

Conclusion. This alternative will be retained for detailed analysis. Alternative 3 provides a greater degree of protection against potential migration of VOCs and inorganics from the Army Reserve Enclave.

3.2.4 Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

Alternative 4 is the same as Alternative 3 except that a passive bioremediation system would be installed to contain the contaminant plume that is downgradient of the groundwater collection and treatment system. The same discussions regarding effectiveness and implementability of intrinsic bioremediation, long-term groundwater monitoring, and groundwater collection and treatment/discharge in Alternatives 2A and 3 apply to Alternative 4. Additional discussion regarding effectiveness and implementability of passive bioremediation with slow release oxygen release compounds are described below.

Effectiveness. In the microbial degradation process brought about by in-situ bioremediation, the organic compounds of concern are ultimately converted to inert compounds such as carbon dioxide and water (aerobic conditions). Because of the actual degradation/destruction of the organic contaminants that occurs in this technology, passive in-situ bioremediation will effectively reduce the toxicity

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and volume of organic contaminants in the site groundwater. As a result, downgradient or off-site migration of site contaminants will be minimized.

There is minimal potential for short-term worker exposure to contaminated groundwater during passive bioremediation well installation. Exposure of site workers to site contamination also would not be extensive during passive bioremediation well maintenance.

Implementability. Prior to full-scale implementation of passive bioremediation, bench-scale and possibly field-scale testing would be required. Passive bioremediation design tests would include a) identification of the most suitable oxygen release compound for the site, b) determination of the effects of iron and manganese precipitation on oxygen diffusion in the aquifer, c) determination of the role of nutrient addition in passive bioremediation, and d) well design information (e.g., well layout requirements). Upon completion of design testing and full-scale design, a passive bioremediation system would be relatively easy to implement. Local contractors and "off-the-shelf" materials would be available to construct the passive bioremediation wells.

Cost. The cost of implementing Alternative 4 would consist primarily of design testing, passive bioremediation well installation, and passive bioremediation system operation and maintenance in addition to all costs associated with Alternative 3 (groundwater monitoring well installations and long-term groundwater monitoring; and groundwater extraction/treatment system installation and operation.)

Conclusion. This alternative will be retained for detailed analysis because it will aggressively prevent off-site migration and treat contaminants on-site.

4.0 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

The detailed analysis of alternatives provides a detailed description of each of the AOC 43G remedial alternatives and evaluates them using the evaluation criteria recommended in USEPA RI/FS guidance (USEPA, 1988b). These criteria are described in Table 4-1. The first seven of the evaluation criteria serve as a basis for conducting the detailed analysis, and are addressed in this FS. The remaining two criteria, state and community acceptance, will be addressed after the public comment period on the Proposed Plan. The alternatives that are evaluated in this section are those retained after initial screening in Section 3.0 and listed in Table 3-5. A detailed cost estimate is also included in this detailed analysis for each alternative except the No Action alternative. Costs are broken down by direct and indirect capital costs and O&M costs. The cost estimate includes a present worth analysis to evaluate expenditures that occur over different time periods. This analysis discounts all future costs to a present worth and allows the cost of remedial alternatives to be compared on an equal basis. Present worth represents the amount of money that, if invested now and disbursed as needed, would be sufficient to cover all costs associated with the remedial action over its planned life (USEPA, 1988b). A discount rate of 7 percent before taxes and after inflation was used as recommended in OWSER Directive 9355.3-20.

Five alternatives are evaluated in the detailed analysis:

- Alternative 1: No Action
- Alternative 2A: Intrinsic Bioremediation
- Alternative 2B: Intrinsic Bioremediation / Soil Venting of Gasoline UST Soils
- Alternative 3: Groundwater Collection and Treatment / Intrinsic Bioremediation Downgradient
- Alternative 4: Groundwater Collection and Treatment / Passive Bioremediation Downgradient

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The No Action alternative was retained as a baseline with which to compare other alternatives. Alternatives 2A, 2B, 3, and 4 were retained because they provide a range in remedial aggressiveness towards addressing groundwater contamination on-site and in minimizing potential migration of contaminants exceeding PRGs off the Army Reserve Enclave property.

4.1 ALTERNATIVE 1: NO ACTION

This subsection describes the No Action alternative and evaluates the alternative using the seven evaluation criteria except that no cost estimate is provided.

4.1.1 Description

The No Action alternative serves as a baseline alternative with which to compare other remedial alternatives for AOC 43G. The No Action alternative does not contain any additional remedial action components to reduce or control potential risks. Existing activities to maintain existing systems and monitor for potential contaminant migration would be discontinued.

4.1.2 Remedial Alternative Evaluation

The assessment of this alternative using the evaluation criteria is presented in the following subsections.

4.1.2.1 Overall Protection of Human Health and the Environment. The No Action alternative has potential for achieving an acceptable level of risk for human receptors. There is no commercial/industrial exposure to contaminated groundwater under current conditions as assessed in the baseline risk assessment. Consequently, there are no current human health risks above USEPA criteria. Furthermore, the site and property directly downgradient for approximately 600 feet (and approximately 500 feet cross-gradient) is to remain within the Army Reserve Enclave and will continue to be used to support the reserve training activities (Figure 4-1). Because there will be no future installation of drinking water wells for commercial/industrial use at or downgradient of the site on Army Reserve Enclave property, the potential for commercial/industrial exposure to CPCs presenting risks above USEPA criteria is minimal. As discussed in Section 2.0, anaerobic biodegradation of the petroleum hydrocarbons is occurring

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on site. Groundwater sampling has also shown that contaminant plume remains over 500 feet from the Army Reserve Enclave boundary and therefore does not presently create an unacceptable risk to downgradient receptors. However, without groundwater monitoring activities, there will be no way to assess the effectiveness of biodegradation or the potential for contaminant migration off Army Reserve Enclave property.

4.1.2.2 Compliance with ARARs. Section 4.0 of the Final RI Report provides a preliminary list of potential ARARs for AOC 43G (ABB-ES, 1996). Table 4-2 provides a summary of the ARARs analysis specific for Alternative 1. This alternative has potential for complying with chemical-specific ARARs through naturally occurring biodegradation of the petroleum contamination. However, no monitoring activities will occur with the No Action alternative to evaluate compliance with these ARARs. Federal and Massachusetts drinking water standards are currently met for all CPCs except nickel, benzene, ethylbenzene, and xylene. Only the MCL and Massachusetts Maximum Contaminant Level (MMCL) for benzene are exceeded under average conditions. MCLs and MMCLs for nickel, ethylbenzene, and xylene are met under average conditions in source and downgradient area groundwater, but are exceeded for maximum conditions within source area groundwater. No MCLs and MMCLs are exceeded under maximum or average conditions at monitoring wells farthest downgradient (AAFES-7, XGM-94-06X).

Iron (at 18,030 $\mu\text{g/L}$ average and 54,100 $\mu\text{g/L}$ maximum filtered concentrations), exceeds the federal and state aesthetically-based secondary drinking water standards (SMCL and SMMCL) and the Massachusetts Groundwater Quality criterion of 300 $\mu\text{g/L}$. Of these standards, only the Massachusetts Groundwater Quality criterion is considered an ARAR. The Ground Water Quality Standard (314 CMR 6.00) establishes the analyte concentrations and water quality parameters for which groundwater discharge permits are based. Although discharge to site groundwater is not occurring, aquifer quality must be maintained to sustain designated Class 1 use. This alternative will meet the ARAR despite the numerical standard (300 $\mu\text{g/L}$) exceedance because 310 CMR 6.07 states that natural background conditions must be considered in establishing effluent limitations. Fort Devens background iron concentration (9,100 $\mu\text{g/L}$) also exceeds the numerical standard. This alternative will revert the soluble forms of iron back to more insoluble forms upon reduction of the organic contaminants thereby

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reflecting natural background conditions and meeting the Fort Devens background iron concentration.

Similarly, manganese (at 7,500 $\mu\text{g/L}$ average and 15,200 $\mu\text{g/L}$ maximum filtered concentrations) also exceeds the aesthetically based secondary federal and state drinking water standards (SMCL and SMMCL) and the Massachusetts Groundwater Quality criterion of 50 $\mu\text{g/L}$. However, the Fort Devens manganese background concentration of 291 $\mu\text{g/L}$ also exceeds these criteria. The Fort Devens background concentration for manganese will be achieved by this alternative to meet ARARs.

The No Action alternative does not trigger any location-specific or action-specific ARARs.

4.1.2.3 Long-Term Effectiveness and Permanence. The No Action alternative does not provide means to monitor for contaminant reduction or to monitor for migration of contaminants toward the Army Reserve Enclave boundary. It also does not provide a means to verify biodegradation rates to refine the estimated time for restoration completion. However, it does potentially control future commercial/industrial exposure to groundwater downgradient of the Army Reserve Enclave property. The Army is retaining ownership of the property and does not propose to install drinking water wells on site. Furthermore, intrinsic bioremediation will minimize the potential for contaminants that exceed PRGs from migrating off Army Reserve Enclave property.

4.1.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment. The No Action alternative utilizes the intrinsic bioremediation process to potentially reduce the toxicity, mobility and volume of contamination. Benzene, ethylbenzene, and xylene are destroyed in the degradation process. Destruction of these organic compounds will return the groundwater quality (i.e., oxygen content, ORP, and pH) to upgradient conditions resulting in a return of the more insoluble fractions of nickel, iron and manganese. The No Action alternative does not provide a method of monitoring for contaminant concentration reductions or for verifying that contaminants are not migrating downgradient.

4.1.2.5 Short-Term Effectiveness. This alternative does not provide any active remedial actions at the site that would cause short-term risks to the community or environment as a result of implementation.

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4.1.2.6 Implementability. The No Action alternative would be easy to implement and would not interfere with possible future remedial actions. Intrinsic bioremediation is believed to be currently occurring on site.

4.1.2.7 Cost. The No Action alternative does not require any capital or O&M expenditures.

4.2 ALTERNATIVE 2A: INTRINSIC BIOREMEDIATION

This subsection describes Alternative 2A and evaluates the alternative using the seven evaluation criteria.

4.2.1 Description

Intrinsic bioremediation is the principal component in Alternative 2A that is proposed to prevent CPCs that exceed PRGs from potentially migrating off the Army Reserve Enclave property and to reduce contaminants on Army Reserve Enclave property to below PRGs. The installation of additional monitoring wells and implementation of a long-term groundwater monitoring program will enable assessment of the biodegradation progress and permit detection of any potential migration of contaminants beyond the Army Reserve Enclave boundary. Key components of this alternative include:

- intrinsic bioremediation
- predesign data collection and groundwater modeling
- installing additional groundwater monitoring wells
- long-term groundwater monitoring
- five-year site reviews

Each of these components is described in the following paragraphs.

Intrinsic Bioremediation. A discussion of the intrinsic bioremediation process is covered in Subsection 3.1.2, Alternative 2A: Intrinsic Bioremediation. Based upon organic and inorganic speciation in the aquifer and other water quality parameters, it appears that degradation of the organic CPCs is occurring naturally at AOC 43G. Solute transport calculations were conducted for the site to provide further basis for evaluating intrinsic bioremediation (Appendix C).

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An ONED3 analytical model for solute transport from the International Groundwater Modeling Center Solute Program Package (Beljin, 1990) was used for the evaluation. The objective of this evaluation was to simulate existing and future concentrations of benzene, ethylbenzene and xylene. A groundwater velocity of 0.07 m/day was used in the calculations. This velocity was calculated using the geometric mean of hydraulic conductivity values from all overburden monitoring wells which is higher than the mean of the bedrock monitoring wells. Therefore, the velocity is likely to be conservatively high with regard to contaminant dispersion/transport. Groundwater flow and regional gradient used in the calculations were assumed to be along the centerline of the groundwater contaminant plume. The regional gradient and flow direction are derived from water level data collected on January 31, 1995 (Figure 1-10). Degradation rates (half-lives) for the CPCs were obtained from a literature search and are compiled in Appendix C. The decay rates used in the evaluation were typically conservative in allowing approximately equal or less decay than the average values obtained from the literature. (Half-lives used in the calculations for benzene, ethylbenzene and xylene were 220 days, 1050 days, and 350 days, respectively.)

In all simulations, the source was assumed to be located between the former waste oil UST and the existing gasoline USTs. In the first simulation, the source was "turned on" (continuous) for the duration of the simulation. This simulates the possibility that there could be gross contamination within the bedrock fractures below the former gasoline USTs. In the second simulation, the source was "turned on" from the years 1960 to 1996 to simulate leaking USTs and the proposed plans to remove the fuel-contaminated soils associated with the existing sand and gas trap area. Current plans are to remove this potential source in the summer of 1996. Decay rates and source concentration were varied until calculated concentrations were equal to or greater than observed concentrations for groundwater samples collected in 1995. Details of the evaluation assumptions are discussed in Appendix C.

The transport calculations for both simulations predict that none of the organic CPCs will reach the Army Reserve Enclave boundary at concentrations exceeding PRGs. The "on/off" source simulation reveals that the CPCs may reduce below PRGs on site within four years. The continuous source simulation shows the plume in a steady-state condition, neither migrating or receding in future years. The actual degradation of the plume may be somewhere between these two simulations. However, for FS purposes, the more conservative continual source

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simulation (contamination may be within bedrock fractures) will be considered for costing purposes. Thirty years is the maximum period to be used for costing purposes based on USEPA guidance (USEPA, 1988).

Although not yet statistically significant, it is interesting to note that average concentrations of benzene, ethylbenzene and xylene decreased 50%, 29%, and 52% between Rounds Five and Six (2.5 months). Organic CPC concentrations within monitoring well AAFES-1D decrease noticeably for the four rounds between Round Three in September 1993 and Round Six in March 1995. Concentrations were noted to be 2.0, 0.9, 0.8, and 0.4 mg/L respectively, for xylene; 1.0, 0.6, 0.6, and 0.3 mg/L for benzene; and 0.2, 0.2, 0.1, and 0.1 mg/L for ethylbenzene, respectively. These trends are not as noticeable for the other source area monitoring wells (AAFES-2, AAFES-6 and XGM-93-02X). Installation of additional monitoring wells and implementation of a long-term groundwater monitoring program is required to assess the progress of intrinsic bioremediation following removal of the sand and gas trap and associated soils.

Pre-design Data Collection and Groundwater Modeling. Prior to installation of additional groundwater monitoring wells and refinement of a long-term groundwater monitoring plan, additional data collection and modeling is required. Pre-design/design work plans would be prepared detailing the proposed activities and submitted to the environmental regulators for review prior to implementation. For cost estimating purposes for this FS, data collection would likely consist of an additional round of groundwater sampling and analysis to refine estimates of intrinsic bioremediation effectiveness in protecting downgradient receptors. Collected data would include groundwater elevation, intrinsic bioremediation indicators, and CPC concentrations. Groundwater elevation data would supplement the existing Fort Devens water level data base for this site and would be used to refine groundwater flow direction. Intrinsic bioremediation indicator data (e.g., electron acceptor concentrations, nutrient concentrations, and ORP) will be used to verify occurring intrinsic bioremediation and determine future intrinsic bioremediation potential. CPC concentration data will assist directly in estimating site-specific degradation rates and the effectiveness of intrinsic bioremediation in achieving PRGs.

Data collected from the pre-design groundwater sampling will be incorporated into fate and transport modeling. This modeling will assess the degradation and migration of the organic CPCs and refine current estimates of intrinsic

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bioremediation effectiveness. Initial intrinsic bioremediation modeling will be conducted as part of the alternative predesign phase. The existing and the new groundwater information will be examined to determine the best location for additional groundwater monitoring wells and to finalize site-specific indicator data as required for the design. As additional monitoring data are collected during long-term monitoring (see Long-Term Groundwater Monitoring in this subsection), the fate and transport modeling will be updated to allow the most accurate depiction of current and future groundwater conditions. The fate and transport model used for monitoring intrinsic bioremediation (such as Bioplume II or III) will be selected based upon the type of groundwater monitoring information gathered and market availability. Details of the model will be proposed as part of the predesign/design work plan.

Groundwater Monitoring Well Installation. Additional groundwater monitoring wells will be required to improve data collection coverage in the overburden and bedrock within and downgradient of the site. The ultimate number and location of additional groundwater monitoring wells for monitoring intrinsic bioremediation at the site will depend upon predesign data results. However, for cost estimation purposes, it is assumed that four additional monitoring wells would be installed for long-term groundwater monitoring purposes. These monitoring wells would be used to monitor contaminant plume location and concentration in relation to the Army Reserve Enclave boundary in the overburden and bedrock and to collect intrinsic biodegradation indicators. A preliminary estimate of monitoring well locations is presented on Figure 4-1. Four 4-inch diameter PVC monitoring wells approximately 30 feet deep are proposed. Final monitoring well locations and details will be submitted for regulatory review and concurrence in the predesign/design work plan.

Long-term Groundwater Monitoring. Long-term groundwater monitoring is proposed to enable assessment of the intrinsic bioremediation progress and permit detection of any potential migration of contaminants that exceed PRGs beyond the Army Reserve Enclave boundary. Analytical parameters likely to be included in the monitoring program are presented in Table 4-3. Dependent upon the results of the predesign fate and transport modeling, groundwater monitoring would be conducted on an annual basis until three consecutive sampling rounds indicate that cleanup objectives have been met. The last two years of monitoring (confirmation) would be for only the CPCs. For costing purposes, it is assumed that groundwater monitoring would be performed for 30 years. Annual reports

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would be submitted to MADEP and the USEPA which would include a description of site activities and summary of results of the long-term groundwater monitoring program and modeling updates. Assumptions made for this monitoring plan are for cost estimating purposes only. The final detailed long-term monitoring plan would be developed in conjunction with regulatory agency review and comment.

Five-year Site Reviews. Under CERCLA 121c, any remedial action that results in contaminants remaining on site must be reviewed at least every five years. During five-year reviews, an assessment is made of whether the implemented remedy continues to be protective of human health and the environment or whether the implementation of additional remedial action is appropriate.

The five-year site review for Alternative 2A will evaluate the alternative's effectiveness at reducing potential future human health risk from exposure to groundwater on site and downgradient considering current and potential future receptors. This evaluation will be based on how successful the alternative is at attaining PRGs at the long-term monitoring wells.

Specific criteria for evaluating the alternative's progress and effectiveness will be established upon completion of the predesign data collection and groundwater modeling to permit refinement of contaminant transport and biodegradation estimates. However, for FS purposes, a criterion would be to maintain groundwater quality below PRGs at monitoring wells that historically have revealed concentrations below PRGs (XGM-94-09X, XGM-94-06X, AAFES-7, XGM-94-05X and AAFES-5.) Meeting this criterion would demonstrate that the contaminants will not likely migrate downgradient past the Army Reserve Enclave boundary. A second criterion might be established to also demonstrate that the contaminants within the plume will degrade to concentrations below PRGs, if modeling shows this to be the case following removal of the sand and gas trap and associated soils. Reductions might be expected in monitoring wells which have historically revealed concentrations exceeding PRGs (XGM-93-02X, AAFES-2, AAFES-1D, XGM-94-03X, AAFES-6, XGM-94-04X, XGM-94-10X, XGM-94-08X, XGM-94-07X). Specific assessment criteria which are probable (depending upon predesign modeling results) are stated below. These criteria would be used to assess the progress of intrinsic bioremediation and to assess if additional remedial action is appropriate.

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Contaminant Migration Assessment: For monitoring wells where analyte concentrations have historically attained PRGs, Alternative 2A will be considered effective if concentrations of individual chemicals within individual monitoring wells do not show statistically significant PRG exceedances. Statistical significance will be assessed using regulatory reviewed and approved methods similar to regulations at 40 CFR 264.97, 40 CFR 258.53 and 310 CMR 306.63.

On-Site Contaminant Assessment: On-site assessment criteria would be based upon modeling results. Should modeling confirm the FS continual source simulation, then it will be assumed that intrinsic bioremediation will not reduce CPCs below PRGs within the 30-year period. Future protection of human health will still be achieved on site because the Army has no intention of installing drinking water wells within this plume. Should modeling confirm the "on/off" simulation, Alternative 2A will be considered effective if contaminants are reduced to PRGs commensurate with the estimates projected by the predesign fate and transport model.

A major consideration in assessing the protectiveness of Alternative 2A and whether additional remedial actions may be appropriate will be the basis on which individual PRGs were set. The Army will consider the implementation of additional remedial actions if the above criteria (as refined based on the predesign fate and transport model) are not met for any chemicals for which PRGs are based on MCLs. The Army will not consider additional remedial actions under CERCLA if PRGs are not attained for iron and manganese. These two analytes are not directly attributable to past activities at AOC 43G, but may have increased solubility as a result of the biodegradation of the organic compounds (See Subsection 2.2.1). The soluble concentrations of iron and manganese will likely revert to insoluble fractions once organic concentrations have been reduced. Background concentration variability for iron and manganese within groundwater at Fort Devens adds further evaluation uncertainty. These analytes are identified as noncarcinogenic contributors at AOC 43G, and have only SMCLs (aesthetically based drinking water standards). Iron and manganese are naturally occurring, but problematic analytes which need to be pretreated at most drinking water supply wells in the Fort Devens/Town of Ayer area. Analysis for iron and manganese will be performed during long-term groundwater monitoring in Alternative 2A.

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4.2.2 Remedial Alternative Evaluation

The assessment of this alternative using the seven evaluation criteria is presented in the following subsections.

4.2.2.1 Overall Protection of Human Health and the Environment. Alternative 2A will be protective of human health and the environment under current land use conditions. There is no commercial/industrial or residential exposure to contaminated groundwater under current conditions. Because the site is to remain Army property, there also will be no future exposure (no drinking water source) on site. Alternative 2A will not control the potential future installation of drinking water wells for commercial/industrial use downgradient of the Army Reserve Enclave boundary. However, solute transport calculations indicate that the PRGs for the organic contaminants will not be exceeded downgradient of the Army Reserve Enclave boundary. The installation of additional monitoring wells and implementation of a long-term groundwater monitoring program will further reduce the probability that there could be exposure to contaminants that exceed PRGs beyond the Army Reserve Enclave boundary.

No exposure to ecological receptors currently exists.

4.2.2.2 Compliance with ARARs. Table 4-4 provides a summary of the ARARs analysis specific for Alternative 2A. This alternative has potential for complying with chemical-specific ARARs through naturally occurring biodegradation of the petroleum contamination. Monitoring activities would occur with Alternative 2A to evaluate compliance with these ARARs. Discussion regarding current exceedances and compliance are discussed in Subsection 4.1.2.2, Compliance with ARARs for Alternative 1.

Alternative 2A does not trigger any location-specific ARARs. Groundwater monitoring would be in general compliance with the Massachusetts Hazardous Waste Management Rules 310 CMR 30.660 - 30.670 (action-specific ARAR). Although this regulation applies to regulated units which treat, store or dispose of hazardous waste, substantive portions relating to development of a groundwater monitoring plan, monitoring well integrity, determination of groundwater flow rate and direction, and other technical criteria are relevant and appropriate.

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4.2.2.3 Long-Term Effectiveness and Permanence. In the microbial degradation process of intrinsic bioremediation, the organic CPCs are ultimately converted to inert compounds such as carbon dioxide, methane, and water. Inorganic CPCs are reverted back to more insoluble forms following completion of organic degradation. Because of the degradation/destruction of organic contaminants that occurs in this process, intrinsic bioremediation provides permanent treatment effectiveness without secondary waste disposal. Long-term groundwater monitoring will continue until three consecutive sampling rounds report contaminant concentrations below PRGs.

4.2.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment. Because of the degradation/destruction of organic contaminants that occurs in biological degradation (petroleum hydrocarbons serve as microbiological electron donor/carbon source), intrinsic bioremediation will effectively reduce the toxicity and volume of the CPCs in the groundwater at AOC 43G. The extent of remaining contamination within bedrock will dictate the length of time required to reduce toxicity and volume of contaminants on site. Based on solute transport calculations, downgradient or off-site migration of site contaminants will be minimized as a result of the intrinsic bioremediation process.

4.2.2.5 Short-Term Effectiveness. Based upon the solute transport calculations, degradation of the organic CPCs to below PRGs could take from four ("on/off" source simulation) to over 30 years (continuous source simulation) (Appendix C). However, because intrinsic bioremediation is an in-situ process, there would be minimal risk to the community. Long-term groundwater monitoring would be utilized to evaluate migration potential of contaminants off Army Reserve Enclave property. The potential for short-term worker exposure to contaminated groundwater is considered minimal during monitoring well installation and sampling. Personnel who install the additional monitoring wells and perform groundwater monitoring will be required to follow a site-specific Health and Safety Plan and utilize personnel monitoring and personal protective equipment to prevent potential exposure to hazardous chemicals. No other remedial activities are associated with Alternative 2A that would endanger the community or environment.

4.2.2.6 Implementability. Based on water quality parameters, biological degradation is already occurring naturally under existing site conditions. Therefore, no additional services or materials are necessary for the intrinsic

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bioremediation process itself. The installation of additional groundwater monitoring wells are recommended as part of monitoring to provide additional groundwater characteristic information and to assess contaminant migration. Services, materials and contractors are readily available to install new groundwater monitoring wells. Long-term monitoring would be also be easily implemented and would utilize basic groundwater sampling and analytical techniques.

The alternative is believed to be reliable. However, predesign data collection and modeling are necessary prior to installing additional monitoring wells and implementing the long-term monitoring plan. The effectiveness of the alternative will be monitored easily through groundwater sampling.

Alternative 2A would not limit or interfere with the ability to perform future remedial actions. The evaluation criteria for successful progressiveness of the alternative is such that, if the alternative is judged unsuccessful, additional remedial action could be readily implemented (i.e., the plume will have migrated very little from the current position).

No off-site activities requiring permits would be undertaken as part of Alternative 2A. The five-year review process would require coordination among regulatory agencies.

4.2.2.7 Cost. A cost estimate was prepared for Alternative 2A to assist in selecting a remedial alternative.

Direct capital costs for Alternative 2A include the cost to collect the predesign data, perform the modeling, mobilize a drill rig and install new groundwater monitoring wells. O&M costs include maintenance of the groundwater monitoring wells, long-term groundwater monitoring, and five-year site reviews. Table 4-8 summarizes the cost estimate for Alternative 2A.

Total Direct and Indirect Costs: \$39,000
Present Worth of O&M costs: \$406,300
Total Present Worth: \$445,300 (30 years)

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4.3 ALTERNATIVE 2B: INTRINSIC BIOREMEDIATION / SOIL VENTING OF GASOLINE UST SOILS

This subsection describes Alternative 2B and evaluates the alternative using the seven evaluation criteria.

4.3.1 Description

Like Alternative 2A, intrinsic bioremediation is the principal component in Alternative 2B that is proposed to prevent CPCs that exceed PRGs from potentially migrating off the Army Reserve Enclave property and to reduce on-site contaminants to below PRGs. However, Alternative 2B also includes installation of an SVE system to reduce residual contaminant concentrations in soils below the former gasoline USTs (now adjacent and below the existing gasoline USTs). The objective of the SVE system is to remediate the gasoline UST vadose zone soils to prevent further potential contamination of the aquifer. The soils that contain VOCs may contribute to groundwater contamination during periods of high water table conditions. Minimizing the potential re-contamination of groundwater will improve the effectiveness of intrinsic bioremediation. The following specific actions are included in Alternative 2B:

- intrinsic bioremediation (Subsection 4.2.1)
- predesign data collection / groundwater modeling (Subsection 4.2.1)
- installing additional groundwater monitoring wells (Subsection 4.2.1)
- SVE treatment system installation and operation
- Soil vapor monitoring
- long-term groundwater monitoring (Subsection 4.2.1)
- five-year site reviews (Subsection 4.2.1)

Many of these components are discussed in detail in Subsections 4.2.1. In general, only the addition of the soil vapor extraction component is discussed below.

SVE Treatment System Installation and Operation. To determine the applicability for soil venting at the site and to gather full-scale vent design information, an on-site soil vapor extraction/bioventing pilot test was conducted in 1994 in the vicinity of the existing gasoline USTs at AOC 43G. Details of the pilot test are included as Appendix O of the RI Report (ABB-ES, 1996). The pilot test system consisted of a vent well, four monitoring probes, a vacuum

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exhauster, vapor-phase carbon (off gas treatment), piping, and monitoring equipment.

Relative positions of the vent well (XGB-94-12X) and monitoring points (XGB-94-10X, -11X and -13X and AAFES-4) used during the pilot test are shown in Figure 1-4. The well system consisted of one 2-inch diameter soil vapor extraction well (29 feet deep, 10 foot screen) and three 1-inch diameter monitoring probes (26 to 29 feet deep, 5 foot screens). AAFES-4, an existing 2-inch diameter, dry, groundwater monitoring well (28 feet deep, 15 foot screen), was used as a background monitoring probe, representing a location with minimal contamination. The screen of the vent well was located in the soil zone extending from below the original tank excavation down to bedrock (approximately 20 feet down to 30 feet below ground surface). The distances from the vapor extraction well to the monitoring probe locations range from approximately 8 feet to 30 feet. The vapor extraction well was located as near to the USTs as possible and in an area where contaminant concentrations were likely to be highest, based on the Supplemental Site Investigation (SSI) (ABB-ES, 1994) data.

Permeability data gathered from the pilot test indicates that the soils have a permeability (k) of $6.7E-8$ centimeters squared (cm^2). Flow conditions observed at AOC 43G include an effective radius of influence of 23 feet [defined by 0.1" water column (w.c.) vacuum] and a soil venting flow rate of 1.8 standard cubic feet per minute (scfm) per foot of screened interval at a vacuum of 30 inches of water column (30" w.c.). Based on this soil venting data, vertical vent wells can be used to treat the soil under and adjacent to the existing gasoline USTs at AOC 43G.

The soil venting system installed for remediation would consist of a total of approximately five 2-inch PVC vertical vent extraction wells (including the one vent well already installed at the site for the pilot test) screened from approximately 20 to 28 feet bgs and arranged within the former UST areas. Vent wells would be installed through the existing concrete pad on which the existing USTs rest. (Concrete pads will not be removed during the UST removal program.) The pad will act as a barrier to minimize short circuiting potential. At 1.8 scfm per foot of SVE screen, a total extraction flow rate of approximately 90 scfm could be expected to vent this site (18 scfm per vent well). Soil venting piping, which would connect soil vapor wells to the system blower, would be installed below ground to avoid disturbance of aboveground activities. Extracted

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soil vapor would require treatment before discharge to the atmosphere. Vapor phase activated carbon (two canisters connected in series) would be used for treatment of soil vapor extracted from AOC 43G. All the aboveground system components including the blower, controls, and soil vapor treatment equipment, would be housed in a heated shelter for weather protection.

Operation and maintenance of the soil vent system would consist of monitoring soil gas for VOC concentrations, replacing spent carbon and maintaining soil venting and treatment system equipment.

It is estimated that approximately 1.5 years will be required to remove the residual soil contamination. This estimation is based on the assumption that the average BTEX concentrations of soil below the existing tanks is equal to the maximum laboratory detected concentration of BTEX (377 mg/kg in the 25 feet XGB-94-10X sample). The total mass of residual BTEX contaminants in the soil within influence (20 foot radius, 10 foot deep) of a single SVE well would therefore be estimated at approximately 223 kilograms (kg) BTEX.

Based on these estimates of residual soil contamination and a removal rate of 1.5 kg/day (observed during the pilot test), the estimated time required to remove this soil contamination (assuming zero order removal) at an approximate flow rate of 18 scfm/well would be 5 months. However, to account for a first order removal response and less than ideal conditions across the site, it is anticipated that three times this duration or 1.5 years could be expected before BTEX contaminants are reduced below concentrations that would recontaminate groundwater.

The potential groundwater remediation benefit from removing the residual soil contamination is not readily definable at this time. Because bedrock may be a continuing source for groundwater contamination at the site, removal of the soil contamination may not improve groundwater remediation significantly and cleanup could still take over 30 years as estimated for Alternative 2A. If re-contamination of groundwater is halted as a result of soil venting the gasoline UST soils, cleanup could be quicker as detailed in the solute transport modeling ("on/off" source simulation) described for Alternative 2A in Section 4.0. For costing purposes, a default value of 30 years is assumed for a remedial time period as described for Alternative 2A.

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Soil Vapor Monitoring. Soil vapor monitoring will be performed to determine the efficiency of soil venting in cleaning the vadose zone (which prevents further groundwater contamination) and to determine the effectiveness of the soil vapor treatment equipment in treating the extracted soil vapors. Data that will be collected as part of vadose zone monitoring include VOC concentrations in the extracted soil vapor stream (treated and untreated), oxygen, carbon dioxide, and VOC concentrations in the soil vapor monitoring wells. VOC measurements would be used to assess the progress of soil venting and the efficiency of the soil gas treatment system.

The VOC concentrations will be measured in the extracted and treated soil vapor streams using a PID once every other week and by gas chromatograph (GC) analysis for the organic CPCs once per month. It is anticipated that the soil vapor treatment equipment will be monitored every other week during operation.

Monitoring will also involve measuring changes in oxygen and carbon dioxide concentrations in the soil vapor monitoring wells to assess biological degradation as a result of soil venting on a monthly basis. In addition, VOC concentrations in the vapor monitoring wells will also be measured to indicate the progress of the venting treatment.

4.3.2 Remedial Alternative Evaluation

The assessment of this alternative using the seven evaluation criteria is presented in the following subsections. Discussions in Subsections 4.2.2.1 through 4.2.2.7 (Alternative 2A) regarding intrinsic bioremediation also apply to the following evaluations.

4.3.2.1 Overall Protection of Human Health and the Environment. Alternative 2B will be protective of human health and the environment under current land use conditions. There is no commercial/industrial or residential exposure to contaminated groundwater under current conditions. Because the site is to remain Army property, there also will be no future drinking water source on site. Alternative 2B will not control the future installation of drinking water wells for commercial/industrial use downgradient of the Army Reserve Enclave boundary. However, solute transport calculations indicate that the PRGs for the organic contaminants will not be exceeded downgradient of the Army Reserve Enclave boundary (Appendix C). SVE will also remove these contaminants from the

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residual contaminated soils beneath the gasoline USTs as biodegradation progresses. The installation of additional monitoring wells and implementation of a long-term groundwater will further reduce the probability that there could be exposure to contaminants that exceed PRGs beyond the Army Reserve Enclave boundary.

4.3.2.2 Compliance with ARARs. Table 4-5 provides a summary of the ARARs analysis specific for Alternative 2B. Compliance with ARARs for Alternative 2B will be as described for Alternative 2A (Subsection 4.2.2.2.). Additionally, the soil venting treatment system will comply with the Massachusetts Air Pollution Control regulations (310 CMR 7.03). These regulations require a minimum 95% reduction (by weight) reduction in VOCs in the air effluent stream. Spent activated carbon would need to be tested and characterized for proper disposal/reactivation in accordance with RCRA, Land Disposal Restrictions (40 CFR 268).

4.3.2.3 Long-Term Effectiveness and Permanence. Discussions regarding long-term effectiveness in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.3) also apply to Alternative 2B. The SVE process also permanently removes the CPCs from the soil preventing re-contamination of the groundwater. However, the potential for groundwater recontamination exists if the groundwater table rises and the contamination in the vadose zone soil is still not reduced. Soil monitoring from soil vapor monitoring wells would be performed to evaluate the progressiveness of SVE/biodegradation in the vadose zone. Long-term groundwater monitoring will continue until three consecutive sampling rounds report contaminant concentrations below PRGs.

4.3.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment. Discussions regarding reduction of toxicity, mobility and volume of CPCs in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.4) also apply to Alternative 2B. SVE will reduce the toxicity, mobility and volume of the organic CPCs at the site by removing these compounds. However, the vapor phase carbon used in treatment of SVE system effluent will require final disposal or regeneration.

4.3.2.5 Short-Term Effectiveness. Discussions regarding short-term effectiveness in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.5) also apply to Alternative 2B. As discussed in Subsection 4.3.1, it is estimated that

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approximately 1.5 years will be required to remove the residual soil contamination beneath the gasoline USTs. The potential groundwater remediation benefit from removing the residual soil contamination is not definable at this time. Because bedrock may be a continuing source for groundwater contamination at the site, removal of the soil contamination may not improve groundwater remediation significantly and cleanup could still take over 30 years as estimated for Alternative 2A. For costing purposes, a default value of 30 years is assumed for a remedial time period as described for Alternative 2A.

Because wastes are generated from the SVE system there would be some added exposure (minimal) to the community and environment. Long-term groundwater monitoring would be utilized to evaluate migration potential of contaminants off Army Reserve Enclave property. The potential for short-term worker exposure to contamination is increased from the SVE processes during equipment maintenance (i.e., carbon replacement) but is considered minimal for monitoring well installation and sampling. Personnel who install and operate the treatment facility, install the additional groundwater monitoring wells, and perform groundwater monitoring will be required to follow a site-specific Health and Safety Plan and utilize personnel monitoring and personal protective equipment to prevent potential exposure to hazardous chemicals.

4.3.2.6 Implementability. Discussions regarding implementability in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.6) also apply to Alternative 2B. The SVE system could be installed and operated with minimal effort but would require regular maintenance and monitoring. Services, materials and contractors are readily available to construct an SVE system of this size. Long-term groundwater monitoring would be easily implemented and would utilize basic groundwater sampling and analytical techniques.

The alternative is believed to be reliable. However, the possibility of groundwater recontamination upon aquifer rebound may be difficult to assess with soil monitoring and sampling because of the heterogenous soil medium and short circuiting. Alternative 2B would not limit or interfere with the ability to perform future remedial actions. The five-year review process would require coordination among regulatory agencies.

4.3.2.7 Cost. A cost estimate was prepared for Alternative 2B to assist in selecting a remedial alternative.

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Direct capital costs for Alternative 2B include all the costs discussed for Alternative 2A (Subsection 4.2.2.7) plus expenses incurred for design and construction of the SVE system.

O&M costs for the SVE system include biweekly site visits by a technician, carbon use and disposal, monthly GC analysis of the air streams and measurements from the soil vapor monitoring wells. Table 4-9 summarizes the cost estimate for Alternative 2B.

Total Direct and Indirect Costs: \$137,600

Present Worth of O&M costs: \$473,900

Total Present Worth: \$611,500 (30 years)

4.4 ALTERNATIVE 3: GROUNDWATER COLLECTION AND TREATMENT / INTRINSIC BIOREMEDIATION DOWNGRAIENT

This subsection describes Alternative 3 and evaluates the alternative using the seven evaluation criteria.

4.4.1 Description

Alternative 3 for AOC 43G is designed to reduce potential future human health risks by using groundwater extraction to hydraulically intercept and to treat the contaminant plume immediately downgradient of the source areas. Intrinsic bioremediation would be used to degrade CPCs below PRGs farther downgradient or to minimize the potential for further migration of the plume. This alternative is similar to Alternative 2A except the plume near the source would be intercepted hydraulically rather than relying on intrinsic bioremediation to treat the plume near the source area. Based on the continual source simulation of the solute transport model, more than 30 years is expected to be required to remove all the contamination in the aquifer using pumping remediation and intrinsic bioremediation (Appendix C). The CERCLA default value of 30 years will be used for cost estimating purposes (See Subsection 4.2.1). Extraction wells would be positioned within the higher contaminated portion of the plume and spaced to intercept the plume from the source area. The following specific actions are included in Alternative 3:

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- intrinsic bioremediation (Subsection 4.2.1)
- predesign data collection and design
- groundwater treatment facility construction
- groundwater treatment facility operation and maintenance
- installing additional groundwater monitoring wells (Subsection 4.2.1)
- long-term groundwater monitoring (Subsection 4.2.1)
- five-year site reviews (Subsection 4.2.1)

Many of these components are discussed in detail in Subsection 4.2.1 for Alternative 2. To avoid redundancy, only the addition of the groundwater treatment facility extraction, treatment and discharge components is discussed below. Details pertaining to the treatment facility design are conceptual and are presented only for FS cost estimating purposes.

Intrinsic Bioremediation. Intrinsic bioremediation would be one of the components used to achieve risk reduction for Alternative 3 (See Subsection 4.2.1 for further details on intrinsic bioremediation in groundwater). As previously discussed in Subsection 4.2.1, intrinsic biodegradation of CPCs below PRG in the groundwater may range from four years to over 30 years depending upon whether continuous or noncontinuous sources are considered in the evaluation. Following the removal of the sand and gas trap and associated soils in the summer of 1996, intrinsic bioremediation modeling would be performed for Alternative 3 to refine degradation rates and the long-term monitoring plan.

Predesign Data Collection and Design. A design would be performed for Alternative 3 which would detail the layout, equipment and materials required for installing the groundwater extraction, treatment, and discharge system. Additional site-specific geologic and hydrogeological data would need to be collected prior to commencing with the design. This data would be used to model more accurately the number and location of extraction wells, and flow rates required to capture the groundwater plume. Emphasis would be placed on modeling the hydrogeologic conditions at the site in Alternative 3, in addition to the intrinsic biodegradation/solute transport modeling as would be performed in Alternative 2A. Intrinsic bioremediation is anticipated to minimize the potential for migration of the downgradient plume, while groundwater extraction will intercept the plume farther towards the source. Existing site survey data and utility drawings would also be collected to assist in site layout. Treatability studies are not believed to be warranted as the organic CPCs are readily treatable using

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liquid phase GAC. As part of the design process, system design criteria would be assembled and would be the basis for appropriate and cost-effective system. The design of the groundwater extraction, treatment and discharge system and modeling would be submitted to the environmental regulators for review prior to implementation.

Groundwater Treatment Facility Construction. For FS cost estimating purposes, preliminary modeling was performed to estimate the pumping rate that would be required for this remedial alternative using five groundwater extraction wells to capture the groundwater plume at the base of the hill (near the area between XGM-94-04X and XGM-94-03X) (Figure 2-1). Details of the modeling are contained in Appendix A. The estimated groundwater flow rate from the five extraction wells is 3 gpm. The objective of groundwater extraction is to intercept and contain the portion of the overburden plume at the highest concentrations of CPCs thereby minimizing the potential for migration of CPCs which exceed PRGs. The extraction wells would be located within the higher contaminated portion of the plume to maximize contaminant extraction efficiency and arranged to optimize hydraulic containment. The extraction wells would be constructed of 6-inch diameter, schedule 40, PVC. Grain size of the sandpack material in the annular space around the screen would be compatible with the slot size of the well screen and the surrounding formation. A manhole with cover would be installed over each extraction well riser to allow access to the well and pump.

An conceptual process flow diagram is shown in Figure 4-2. Extracted groundwater would be pumped to the treatment building through buried influent piping. The single-walled influent piping would be connected through the side of the manholes below the frost line. The pumps would be a low flow type such as a pneumatically operated pump using compressed air. The compressed air lines would also be buried in the trench with the influent piping.

A permanent treatment building would be built in the vicinity of the groundwater extraction wells to minimize the extent of trenching and piping run lengths. The building would be a simple wood frame structure constructed on a concrete foundation and slab. The building would be insulated and heated for year-round use. Electric power would be brought to the building by an overhead service connection. The treatment process would consist of an equalization tank with level controls that activate a discharge pump that forces the collected groundwater through a bag filter and then through two GAC canisters placed in series mode.

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The groundwater extraction pumps would be powered from a compressor located inside the building. A control panel for the extraction pumps would be inside the building and would be used to control the flow rate and water level in the extraction wells. A high/low level control switch would operate the discharge pump from the equalization tank. A high/high level switch in the equalization tank would shut down the groundwater extraction pumps to prevent the tank from over-filling. The equalization tank would be approximately 250 gallons in capacity and constructed of polyethylene. The filter bag system would consist of a bag housing for a filter bag, which would remove suspended solids from the groundwater stream prior to being pumped through the GAC canisters. The canisters would contain 200 lbs of GAC each and would be suitable for use in removing VOC contaminants from the groundwater.

Final effluent would meet pretreatment regulations and would be discharged to the Fort Devens WWTF via a nearby sewer manhole. The Fort Devens WWTF is a primary treatment facility (bar screen, two comminutors, Imhoff Tank, 22 rapid infiltration beds, and four sludge drying beds). The facility was initially designed (1941) to receive a flow of three million gallons of wastewater per day (mgd). Recorded flows have gradually decreased from 1.9 in 1986 to 0.5 mgd in 1994.

Groundwater Treatment System Operation and Maintenance. Operation of the treatment system would consist of pumping approximately 3 gpm of groundwater to the equalization tank. The discharge pump for the equalization tank would pump at a rate slightly higher than the anticipated groundwater flow rate and would therefore cycle on and off based on the water elevation in the tank. The bag filter would be replaced on an approximately weekly basis or as needed based on back pressure build-up in the bag filter system. The carbon canisters would be changed as needed based on VOC analytical results from sampling before, between, and after the carbon canisters. The carbon would be replaced such that when the primary carbon canister was exhausted it would be removed from the system and shipped off-site for disposal or regeneration. The secondary carbon canister would be piped into the primary position and a new canister would be put into the secondary position. For purposes of estimating carbon consumption, an average VOC concentration was estimated from nearby monitoring wells.

Discharge to the Fort Devens WWTF will meet the WWTF Industrial Pretreatment Standards (Rasco, 1995). The standards prohibit discharge of any

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toxic pollutant which may interfere with the Fort Devens primary wastewater treatment facility process. The Commonwealth of Massachusetts Class I groundwater quality parameters are referenced in the Pretreatment Standards. Organic CPCs are to be treated to MCLs and will meet discharge requirements. It is assumed for purposes of the treatment system conceptual design that effluent limits for the inorganic CPCs (iron, manganese and nickel) will be equal to their respective background concentrations because background concentrations for these inorganics exceed the Fort Devens WWTF pretreatment limits. In accordance with the Massachusetts Groundwater Quality Standards 310 CMR 6.07 background concentrations must be considered when establishing effluent limits.

Iron and manganese, once brought to the surface and exposed to oxygen within the equalization tank, are expected to become more insoluble and be filtered to concentrations that approximate Fort Devens background concentrations (9,100 $\mu\text{g/L}$ and 291 $\mu\text{g/L}$, respectively). Fort Devens background concentrations for iron and manganese exceed the Commonwealth of Massachusetts secondary effluent limitations for Class 1 groundwater specified in the Pretreatment Standards.

At some locations at the site, nickel concentrations are above the target daily maximum limit of 21 $\mu\text{g/L}$ for discharge to the Fort Devens WWTF, the MCL of 100 $\mu\text{g/L}$ for nickel and the Fort Devens background nickel concentration of 34.3 $\mu\text{g/L}$. Nickel concentrations in filtered samples exceeded background concentrations in only two samples from the last two rounds of sampling (130 $\mu\text{g/L}$ from XGM-93-02X and 65.1 $\mu\text{g/L}$ from XGM-94-03X). During operation of the groundwater extraction system, the concentration of nickel in the extracted groundwater is not expected to exceed background concentrations because of the relative infrequent detection of this analyte. In addition, some nickel precipitation and removal is likely to occur on the bag filters and in the carbon canisters, further lowering the discharge concentration of nickel. During the course of remediation, the nickel concentration at the site would also be expected to drop to background concentrations because of the remediation of the VOC contaminants, which have caused select naturally occurring inorganic analytes in the soils to go into solution.

Upon satisfactory treatment system start-up, system discharge would be sampled monthly to ensure compliance with discharge limits.

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Groundwater Monitoring Well Installation. Additional groundwater monitoring wells will be required to improve monitoring coverage within and downgradient of the site. The ultimate number and location of additional groundwater monitoring wells for monitoring hydraulic containment and potential reduction in concentrations of CPCs will depend upon predesign data and modeling results. For cost estimating purposes, it is assumed that four additional monitoring wells as detailed in Alternative 2A (Subsection 4.2.1 and Figure 4-1) would be installed for long-term groundwater monitoring purposes. Final monitoring well locations and details will be submitted for regulatory review and concurrence.

4.4.2 Remedial Alternative Evaluation

The assessment of this alternative using the seven evaluation criteria is presented in the following subsections. Discussions in Subsections 4.2.2.1 through 4.2.2.7 (Alternative 2A) regarding intrinsic bioremediation also apply to the following evaluations.

4.4.2.1 Overall Protection of Human Health and the Environment. Alternative 3 will be protective of human health and the environment under current land use conditions. There is no commercial/industrial exposure to contaminated groundwater under current conditions. Because the site is to remain Army property, there also will be no future exposure (no drinking water source) on site. Solute transport calculations suggest that if the source area is removed the organic contaminants which pose human health risk could be reduced below PRGs on site through intrinsic bioremediation (Appendix C). Groundwater extraction and treatment also will be removing CPCs where concentrations are the highest as biodegradation progresses. Groundwater extraction provides hydraulic interception of the CPCs to minimize potential exposure to possible future receptors downgradient of the Army Reserve Enclave boundary. The installation of additional monitoring wells and implementation of a long-term groundwater monitoring program will further reduce the probability that there could be exposure to contaminants that exceed PRGs beyond the Army Reserve Enclave boundary.

No exposure to ecological receptors currently exists.

4.4.2.2 Compliance with ARARs. Table 4-6 provides a summary of the ARARs analysis specific for Alternative 3. This alternative has potential for complying

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with chemical-specific ARARs through naturally occurring biodegradation of the petroleum contamination and through groundwater extraction and treatment. Monitoring activities would occur with Alternative 3 to evaluate compliance with these ARARs. Discussion regarding current exceedances and compliance are discussed in Subsection 4.1.2.2, Compliance with ARARs for Alternative 1.

Alternative 3 does not trigger any location-specific ARARs. Action-specific ARARs discussed in Alternative 2A (Subsection 4.2.2.2) also apply to Alternative 3. Additionally, the discharge of non-domestic wastewater to a WWTF must comply with the Clean Water Act, General Pretreatment Program (40 CFR Part 403). Treatment wastes (i.e., activated carbon, filtered material, and sludge) would be tested to evaluate if they are classified as a characteristic hazardous waste in accordance with Resource Conservation and Recovery Act (RCRA) Land Disposal Restrictions (40 CFR 268). Engineering controls (dust suppression) would be used to comply with Massachusetts Air Pollution Control Regulations (310 CMR 6.00 - 7.00) which would regulate particulate emissions during site construction activities.

4.4.2.3 Long-Term Effectiveness and Permanence. Discussions regarding long-term effectiveness in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.3) also apply to Alternative 3. The groundwater extraction and treatment process also permanently removes the CPCs from the groundwater. Long-term groundwater monitoring will continue until three consecutive sampling rounds report contaminant concentrations below PRGs.

4.4.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment. Discussions regarding reduction of toxicity, mobility and volume of CPCs in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.4) also apply to Alternative 3. Groundwater extraction and treatment will reduce the toxicity, mobility and volume of the CPCs at the site by removing these compounds. However, pretreatment wastes (i.e., tank sludge and filters) will require final disposal. Spent activated carbon will also require disposal and may be regenerated by the supplier.

4.4.2.5 Short-Term Effectiveness. Discussions regarding short-term effectiveness in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.5) also apply to Alternative 3. As detailed previously in Subsection 4.2.1, intrinsic bioremediation may take from four to over 30 years for CPC concentrations to degrade below

PRGs. Modeling will be required following sand and gas trap removal to better refine remediation time. Because wastes are generated from the groundwater treatment system, there would be some but minimal added potential exposure to the community and environment. Long-term groundwater monitoring would be utilized to evaluate migration potential of contaminants off Army Reserve Enclave property. The potential for short-term worker exposure to contaminated groundwater is increased because of ex-situ treatment processes during equipment maintenance (i.e., tank cleaning, filter changes, and carbon replacement), but is considered minimal for monitoring well installation and sampling. Personnel who operate the treatment facility, install the additional monitoring wells, and perform groundwater monitoring will be required to follow a site-specific Health and Safety Plan and utilize personnel monitoring and personal protective equipment to prevent potential exposure to hazardous chemicals. No other remedial activities are associated with Alternative 3 that would endanger the community or environment.

4.4.2.6 Implementability. Discussions regarding implementability in Alternative 2A for intrinsic bioremediation (Subsection 4.2.2.6) also apply to Alternative 3. The installation of groundwater extraction wells for the treatment system will require further modeling to refine the number, placement and pumping rates to hydraulically intercept the plume. Upon completion of field testing and full-scale design, the treatment system would be easy to operate, but would require regular maintenance and monitoring. Discharge to the Fort Devens WWTF would require monitoring for compliance with existing pretreatment standards (Rasco, 1995). Services, materials and contractors are readily available to construct a groundwater extraction, treatment and discharge system of this size. Long-term monitoring would also be implemented easily and would utilize basic sampling and analytical techniques for soil and groundwater.

The alternative is believed to be reliable. However, predesign data collection and modeling are necessary to properly locate the extraction wells and implement the long-term monitoring plan. The effectiveness of the alternative will be monitored easily through groundwater sampling.

Alternative 3 would not limit or interfere with the ability to perform future remedial actions. The five-year review process would require coordination among regulatory agencies.

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4.4.2.7 Cost. Direct capital costs for Alternative 3 include the costs to collect the predesign data, perform hydrogeologic and intrinsic biodegradation modeling, and to design and construct the groundwater extraction/treatment system described above. Components include the building, equipment, extraction wells, trenching, and connection to the sanitary sewer. Also included are expenses for mobilizing a drill rig to install new groundwater monitoring wells.

O&M costs for the groundwater extraction and treatment facility include weekly site visits by a technician, carbon use of approximately 21 change-outs per year (based on a VOC concentration equivalent to 4.4 mg/L of benzene), disposal of the bag filters as a special waste, monthly VOC sampling and analysis, reporting, and WWTF user fee. Other O&M costs include long-term groundwater monitoring, and five-year site reviews. Table 4-10 summarizes the cost estimate for Alternative 3.

Total Direct and Indirect Costs: \$257,600

Present Worth of O&M costs: \$1,444,900

Total Present Worth: \$1,702,500

4.5 ALTERNATIVE 4: GROUNDWATER COLLECTION AND TREATMENT / PASSIVE IN-SITU BIOREMEDIATION CONTAINMENT DOWNGRAIENT

This subsection describes Alternative 4, evaluates the alternative using the seven evaluation criteria.

4.5.1 Description

Alternative 4 for AOC 43G is designed to reduce potential future human health risks. In addition to the components of Alternative 3, this alternative provides installation of passive in-situ bioremediation wells to reduce potential future risk to downgradient receptors from potentially contaminated groundwater. The following specific actions are included in Alternative 4:

- intrinsic bioremediation (Subsection 4.2.1)
- installing passive in-situ bioremediation wells
- passive in-situ bioremediation system maintenance
- predesign data collection and design (Subsection 4.4.1)

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- groundwater treatment facility construction (Subsection 4.4.1)
- groundwater treatment facility operation and maintenance (Subsection 4.4.1)
- installing additional groundwater monitoring wells (Subsection 4.2.1)
- long-term groundwater monitoring (Subsection 4.2.1)
- five-year site reviews (Subsection 4.2.1)

Most of these components are discussed in detail in Subsection 4.2.1 and 4.4.1 for Alternatives 2A and 3, respectively. The following discussion is generally limited to the addition of the passive in-situ bioremediation wells component.

Intrinsic Bioremediation. Intrinsic bioremediation would continue to be a component used to potentially achieve risk reduction or to minimize potential migration of CPCs that exceed PRGs off the Army Reserve Enclave property. Refer to Subsection 4.2.1 for further details.

Installing In-Situ Bioremediation Wells. The objective of the in-situ bioremediation wells is to promote more aggressive aerobic biological treatment of the downgradient plume edge. This component would help minimize the probability of plume migration off the Army Reserve Enclave boundary. As detailed in Subsection 3.1.5, in general, biological degradation of volatile compounds associated with gasoline (BTEX) is achieved more readily under aerobic conditions than under anaerobic conditions. Passive bioremediation will be performed by introducing oxygen and perhaps mineral nutrients to the aquifer to promote biological remediation of organic CPCs under aerobic conditions. The delivery of oxygen at AOC 43G would be accomplished by placing solid, slow-release metal peroxides in a series of passive bioremediation wells (without withdrawing or reinjecting groundwater). Added nutrients (if required) would be slow-release formulations of ammonia nitrogen and phosphate phosphorus. Possible amendments could include slow-release ammonium chloride, sodium phosphate, potassium phosphate, or tripolyphosphate, depending on design laboratory treatability testing results.

The passive bioremediation wells would be 2-inch diameter PVC, screened throughout the zone of contamination and fitted with an amendment receptacle. As groundwater passes through the passive bioremediation wells, oxygen and mineral nutrients will dissolve in the groundwater, diffuse into the aquifer, and promote biological degradation of contaminants under aerobic conditions.

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Although the actual location and number of passive bioremediation wells will depend upon predesign data collection and modeling results, it is estimated for FS purposes that 20 2-inch passive bioremediation wells and 16 piezometers for monitoring purposes would be required. Preliminary passive bioremediation well locations are presented on Figure 4-3. It is estimated that these wells would be placed approximately 10 to 15 feet apart to provide adequate aerobic conditions in the downgradient portion of the aquifer.

Passive In-situ Bioremediation System Maintenance. Bioremediation well maintenance will be required to ensure that adequate aerobic conditions are maintained in the downgradient portion of the aquifer at AOC 43G. Maintenance will consist of adding solid oxygen-releasing compound and mineral nutrients to the passive bioremediation wells on a regular basis (approximately every three months) and possibly conducting occasional well cleaning. Addition of solid oxygen-releasing compound and mineral nutrients would consist of removing the down-well amendment addition receptacle (e.g., cage or sack), placing additional solid oxygen-releasing compound and nutrient material (e.g., chips or bricks) in the amendment receptacle, and re-inserting the receptacle into the passive bioremediation well. Well cleaning, which may be required if excessive biological growth or inorganic precipitation occurs in the vicinity of the wells, would consist of administering standard well cleaning techniques (e.g., surging and acid treatment).

Predesign Data Collection and Design. As discussed previously for Alternative 3, predesign groundwater data and hydrogeologic/intrinsic bioremediation modeling are required prior to installing groundwater extraction wells, additional groundwater monitoring wells and refining the long-term groundwater monitoring plan. This would also be required for Alternative 4. The predesign data would also be used for the positioning of the passive bioremediation wells. Data collection would be as described in Subsection 4.2.1, but would also include design treatability testing to refine oxygen and nutrient release formulations which would be compatible with the water chemistry at AOC 43G. Predesign/design work plans would be prepared detailing the proposed activities and submitted to the environmental regulators for review prior to implementation.

Long-term Groundwater Monitoring. Long-term groundwater monitoring would be performed as detailed in Alternative 2A. Select piezometers installed as a

component of Alternative 4 would also be sampled to monitor for nutrients and oxygen production, and groundwater level differentials to assess fouling.

4.5.2 Remedial Alternative Evaluation

The assessment of this alternative using the seven evaluation criteria is presented in the following subsections. Discussion is limited generally to analysis of the passive bioremediation wells component. Alternative 2A discusses the intrinsic bioremediation component in Subsections 4.2.2.1 through 4.2.2.7. Alternative 3 discusses the groundwater extraction/treatment component in Subsections 4.4.2.1 through 4.4.2.7.

4.5.2.1 Overall Protection of Human Health and the Environment. Alternative 4 will be protective of human health and the environment for the same reasons as Alternative 3 (Subsections 4.4.2.1). Alternative 4 provides a more aggressive approach at minimizing the potential risk to downgradient receptors by promoting aerobic biological treatment at the downgradient plume edge. The installation of additional groundwater monitoring wells and implementation of a long-term groundwater monitoring program will further reduce the probability that there could be exposure beyond the Army Reserve Enclave boundary.

4.5.2.2 Compliance with ARARs. Table 4-7 provides a summary of the ARARs analysis specific for Alternative 4. Compliance with chemical specific and action specific ARARs will be as detailed in Alternative 2A (Subsection 4.2.2.2) and as detailed in Alternative 3 (Subsection 4.4.2.1). Introduction of oxygen and nutrients to the groundwater by passive means would be in general compliance with the Underground Injection Control Program at 40 CFR Parts 144 & 146 and the Underground Water Source Protection Standards at 310 CMR 27.00 through engineering controls.

4.5.2.3 Long-Term Effectiveness and Permanence. Long-term effectiveness and permanence of Alternative 4 will be similar to that of Alternative 3 (Subsection 4.4.2.3). In the anaerobic microbial degradation process, the organic CPCs are ultimately converted to inert compounds such as carbon dioxide, methane, and water. Alternative 4 also promotes an aerobic degradation process at the plume edge where organic CPCs are converted to carbon dioxide and water. As with Alternative 2A, inorganic CPCs are expected to revert back to more insoluble forms following completion of organic degradation. Because organic contaminants

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SECTION 4

are degraded/destroyed in this process, passive bioremediation provides permanent treatment effectiveness without secondary waste disposal. Long-term groundwater monitoring will continue until three consecutive sampling rounds report contaminant concentrations below PRGs.

4.5.2.4 Reduction of Toxicity, Mobility, or Volume through Treatment.

Alternative 4 will provide a similar potential level of toxicity and volume reduction as Alternative 3 (Subsection 4.4.2.4). Alternative 4 has additional protection against contaminant migration because of application of aerobic treatment (passive bioremediation wells) at the plume edge. The interception of the plume near the source, combined with the intrinsic bioremediation process and passive biological treatment will minimize downgradient or off-site migration of CPCs.

4.5.2.5 Short-term Effectiveness. Based upon the solute transport calculations, degradation of the organic CPCs to below PRGs could take from four to over 30 years for Alternative 4 (Appendix C). This is the same time for Alternatives 2A, 2B, and 3 because the passive in-situ biological treatment method is designed for bioremediation containment and only addresses downgradient contamination. The same discussion in Subsection 4.4.2.5 for Alternative 3 applies to Alternative 4. Because there are more wells to install for Alternative 3, there may be a marginally greater short-term worker exposure during installation and maintenance.

4.5.2.6 Implementability. Similar implementability issues regarding installation of the groundwater extraction and treatment system detailed in Alternative 3 would also apply to Alternative 4. The installation of passive bioremediation wells will be required as part of Alternative 4. Services, materials and contractors are readily available to install new wells. Currently there is only one manufacturer of magnesium peroxide oxygen-releasing compound and several manufacturers of calcium peroxide. Long-term monitoring of the passive bioremediation wells would be implemented easily and would utilize basic groundwater sampling and analytical techniques. Maintenance requirements for the passive bioremediation wells will be further assessed upon performing predesign treatability studies. Iron and manganese could present fouling problems, requiring that the wells be frequently cleaned by surging and acid treatment.

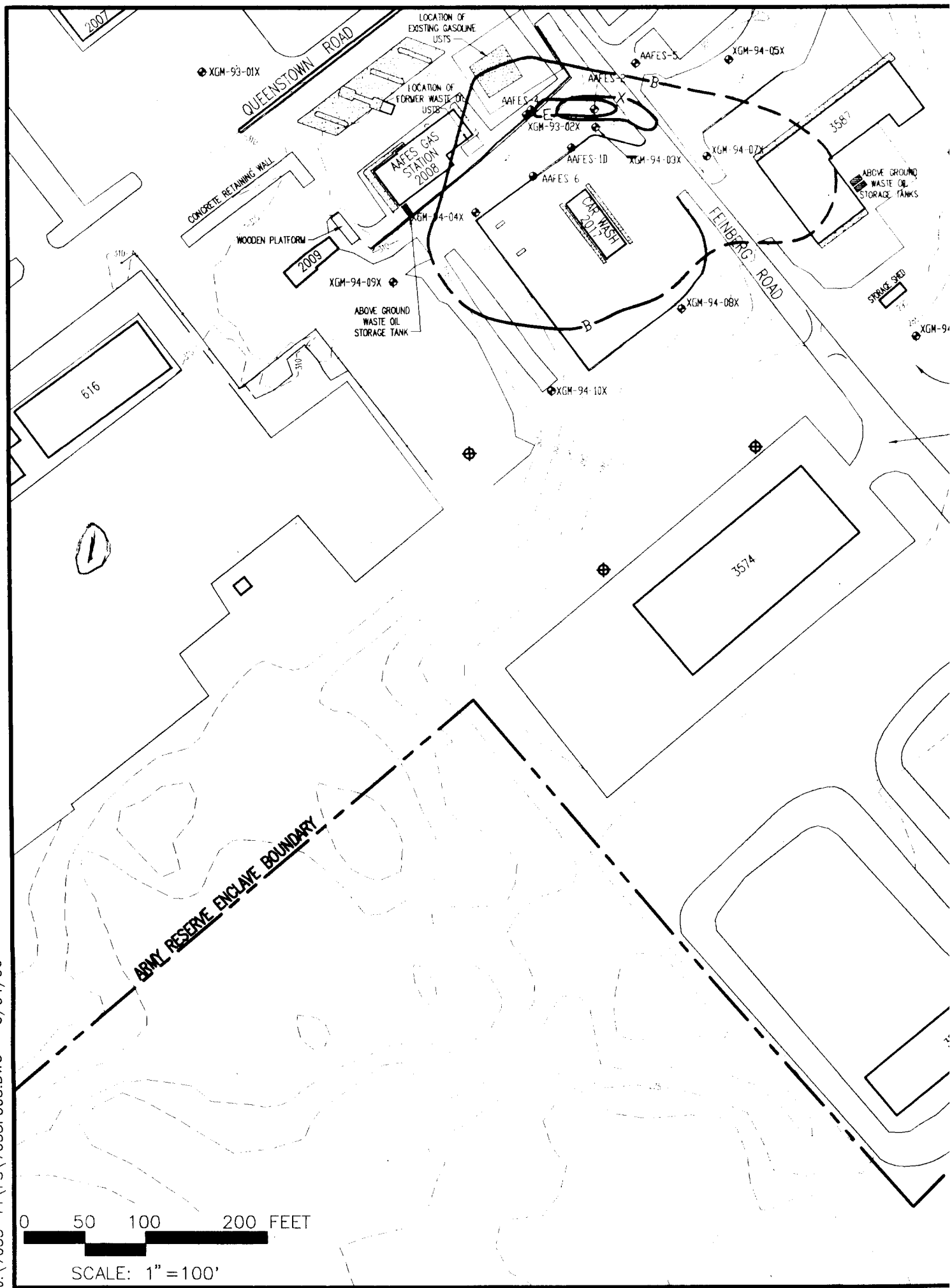
The alternative is believed to be reliable. However, predesign data collection and modeling are necessary prior to installing additional monitoring wells and implementing the long-term monitoring plan.

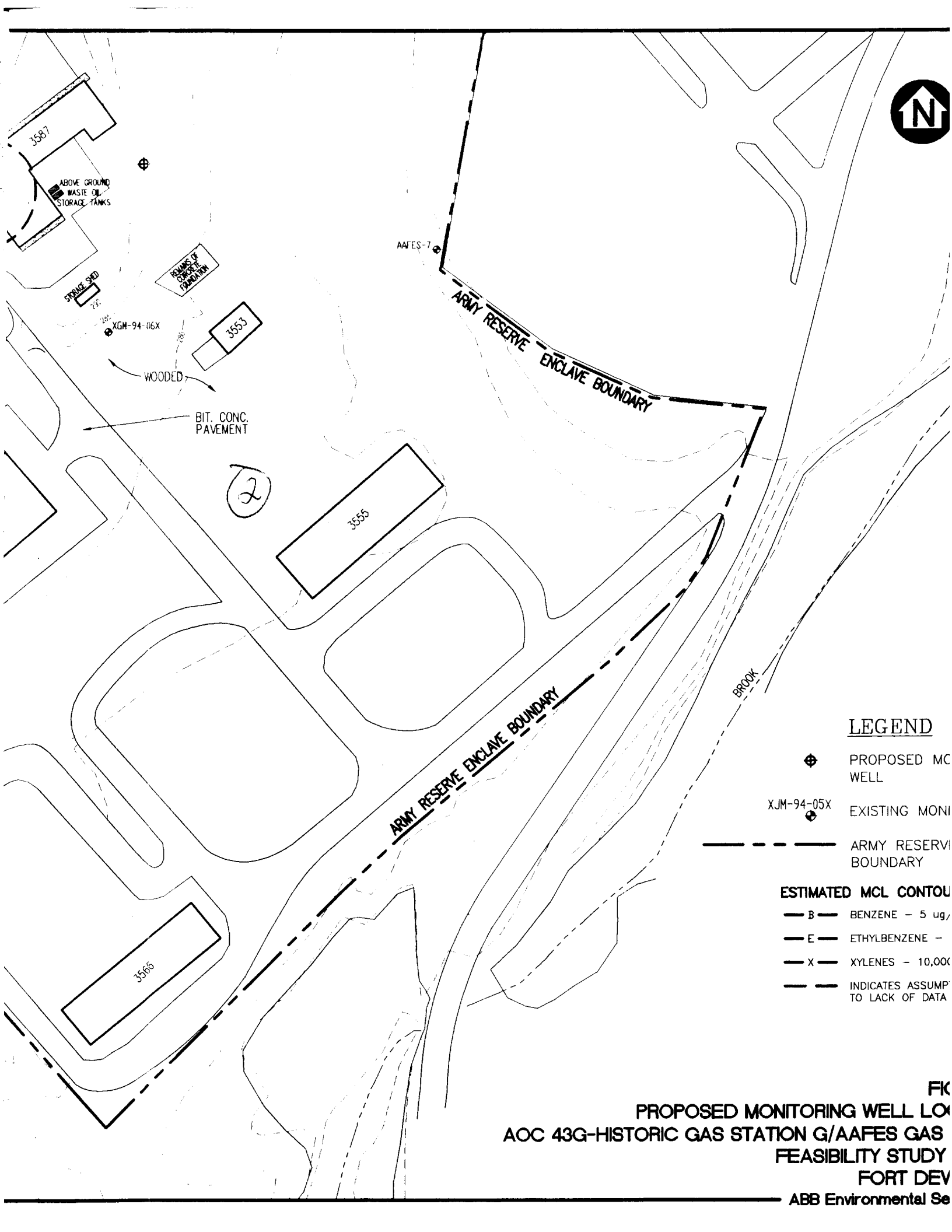
Alternative 4 would not limit or interfere with the ability to perform future remedial actions. The five-year review process would require coordination among regulatory agencies.

4.5.2.7 Cost. In addition to cost items listed for Alternative 3 (Subsection 4.4.2.7), Alternative 4 direct capital costs include expenses for predesign treatability testing and installation of 20 passive bioremediation wells and 16 piezometers. Additional O&M costs include purchase of the oxygen-releasing compound and nutrients, and maintenance of these wells. Maintenance expense assumes five oxygen-releasing compound/nutrient exchanges and one surge/acid treatment per year. Table 4-11 summarizes the cost estimate for Alternative 4.

Total Direct and Indirect Costs: \$387,400
Present Worth of O&M costs: \$2,139,800
Total Present Worth: \$2,527,200 (30 years)

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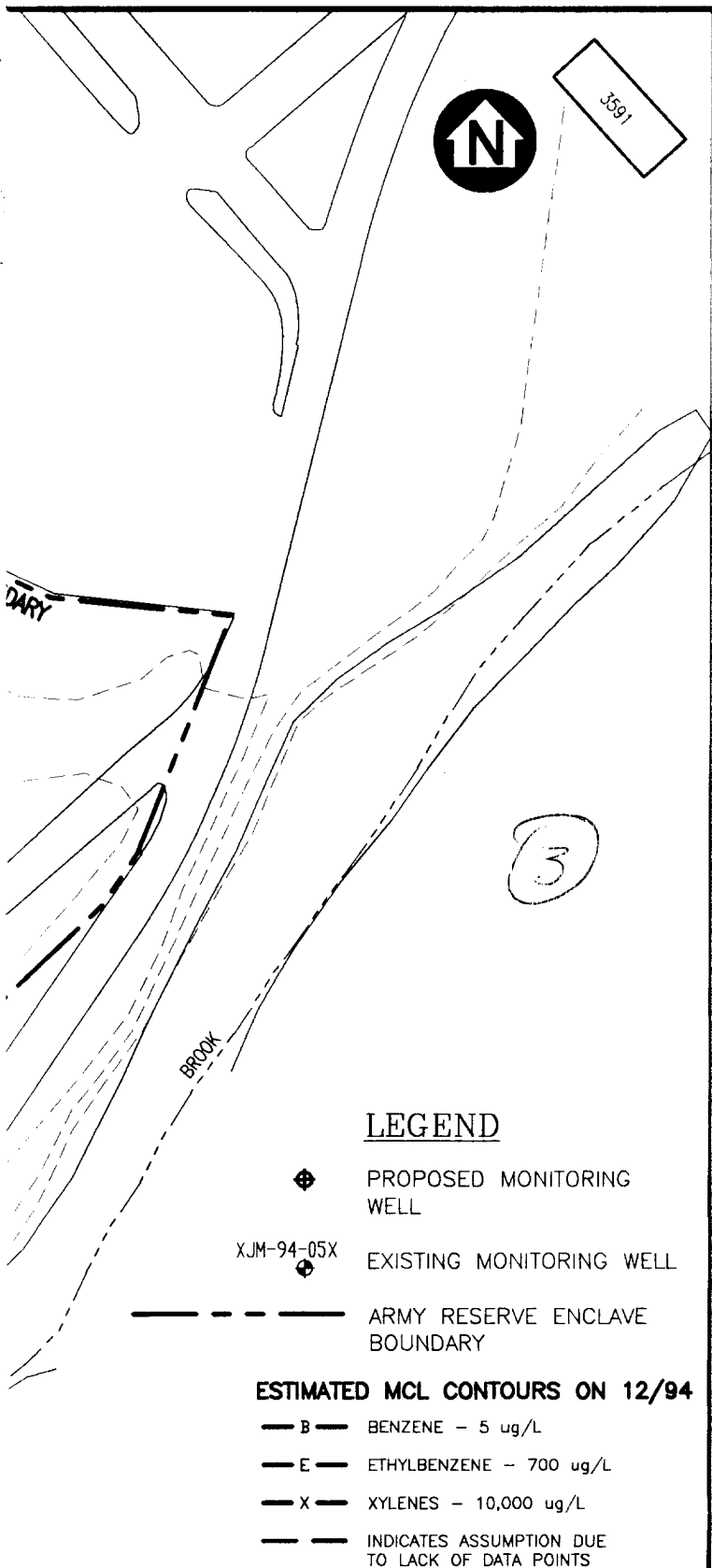


FIGURE 4-1
PROPOSED MONITORING WELL LOCATIONS
TORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA
ABB Environmental Services, Inc.

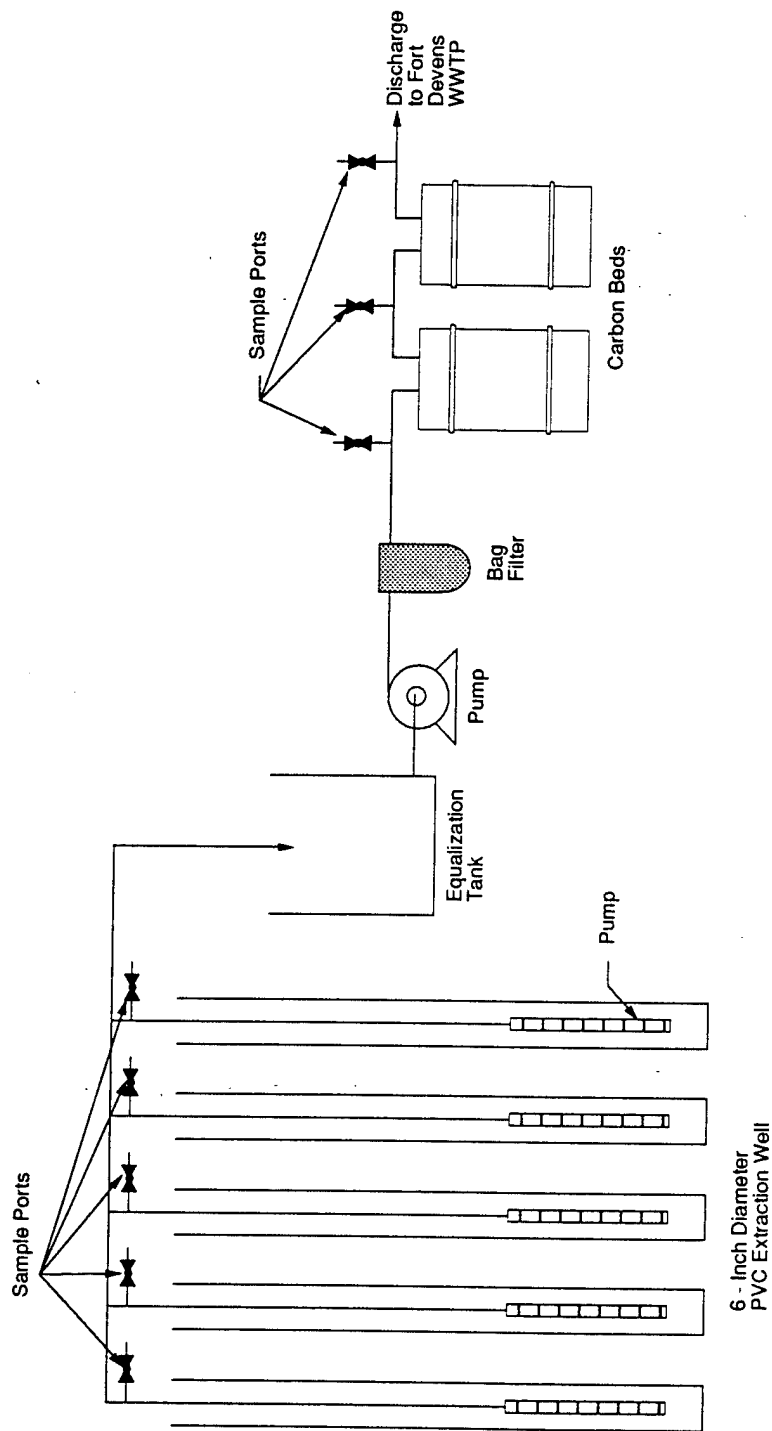
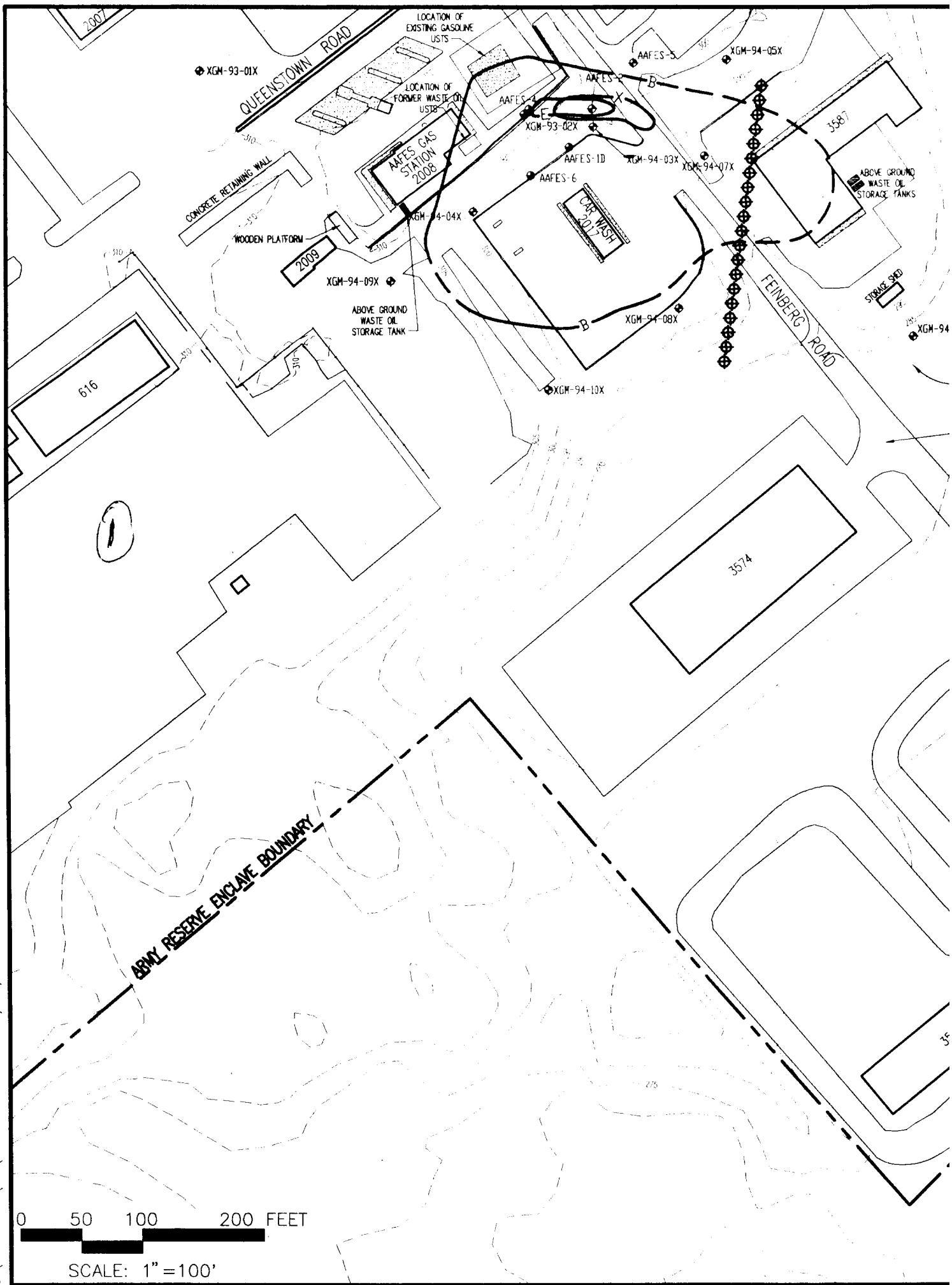


FIGURE 4-2
 PROCESS FLOW DIAGRAM - GROUNDWATER TREATMENT
 AOC 43G - HISTORIC GAS STATION G/AAFES GAS STATION
 FEASIBILITY STUDY REPORT
 FORT DEVENS, MA
 ABB Environmental Services, Inc.



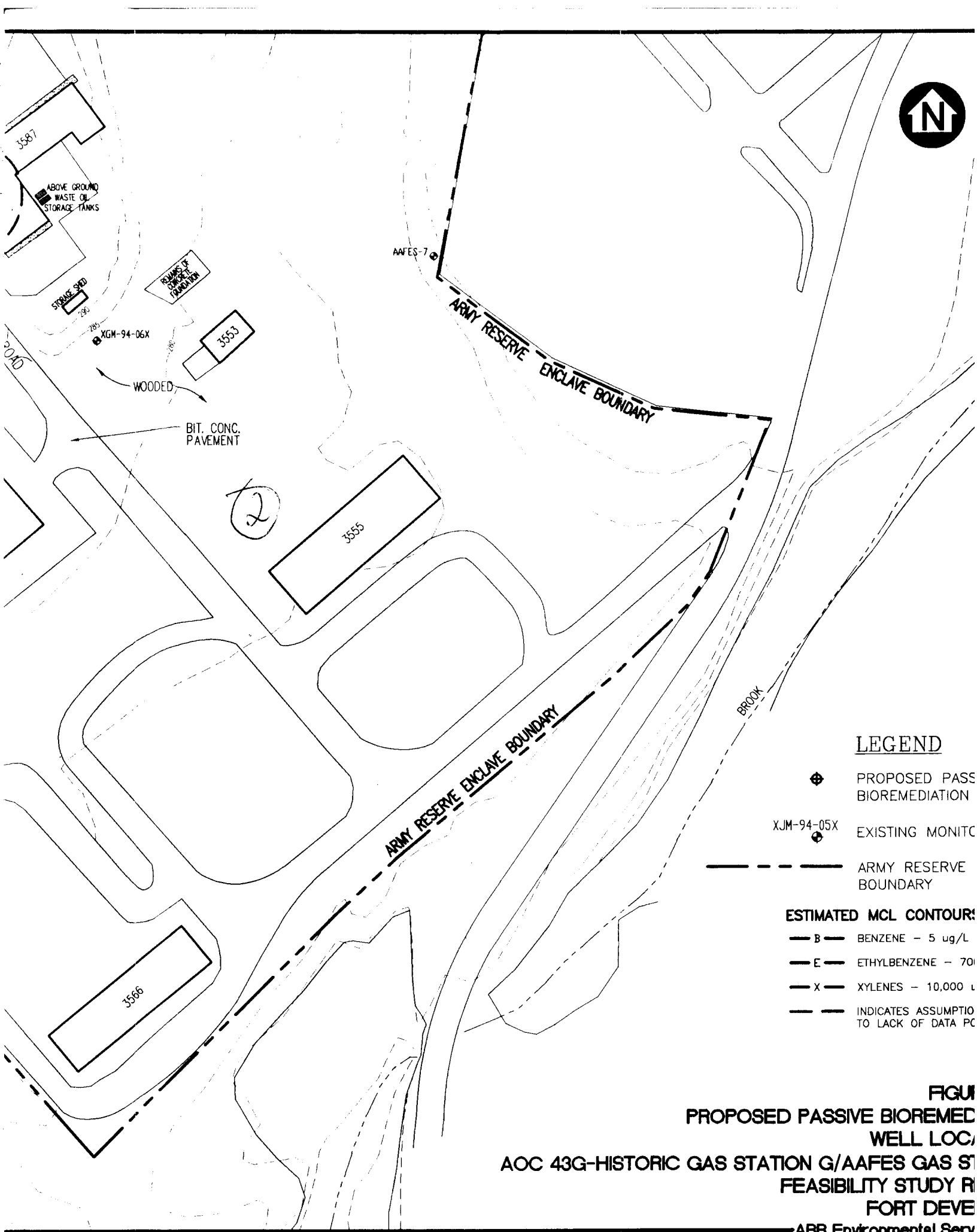


FIGURE 1
PROPOSED PASSIVE BIOREMEDIATION WELL LOCATION
AOC 43G-HISTORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVEL
 ABB Environmental Services

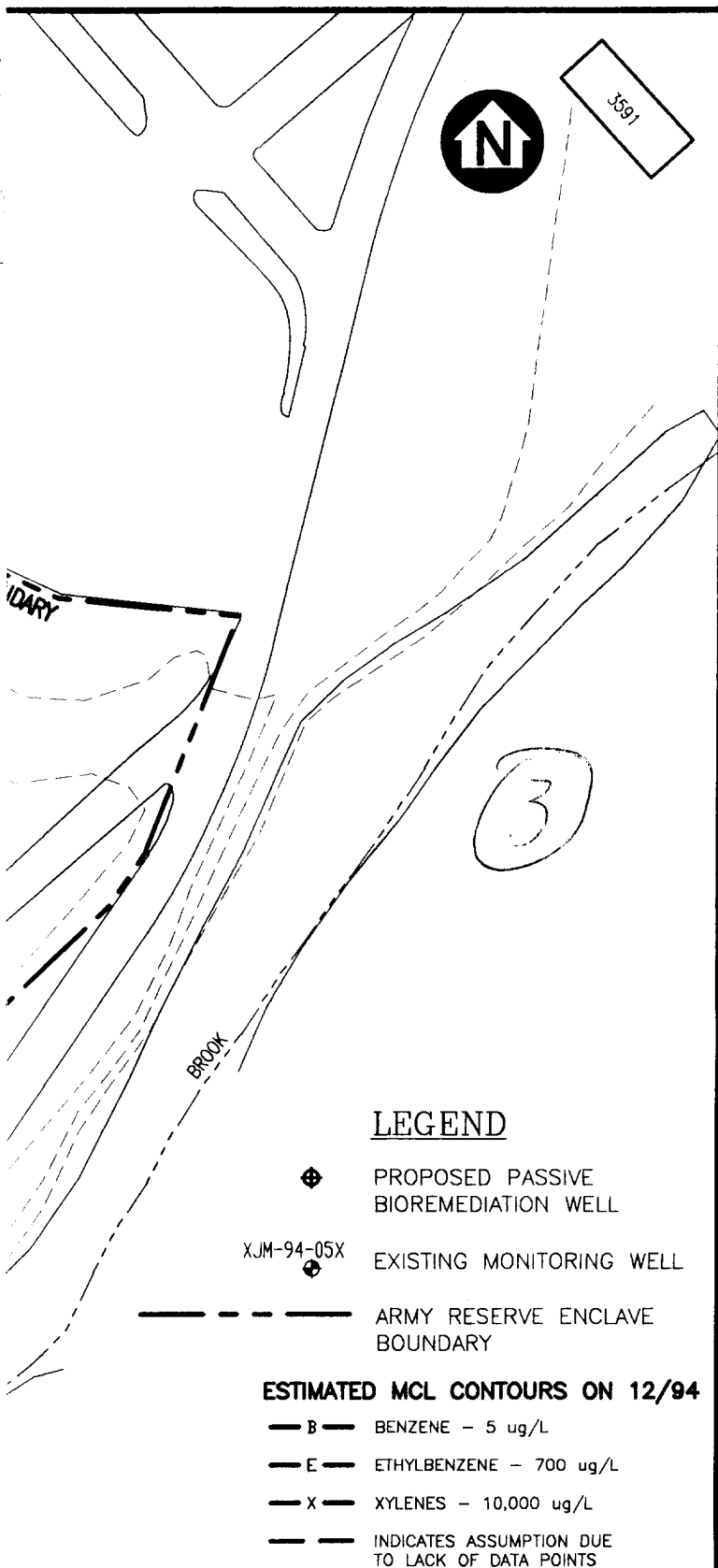


FIGURE 4-3
PROPOSED PASSIVE BIOREMEDIATION
WELL LOCATIONS

STORIC GAS STATION G/AAFES GAS STATION
FEASIBILITY STUDY REPORT
FORT DEVENS, MA

TABLE 4-1
ALTERNATIVE EVALUATION CRITERIA
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

THRESHOLD CRITERIA (must be met by each alternative)

- OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT - Assesses how well an alternative, as a whole, achieves and maintains protection of human health and the environment.
- COMPLIANCE WITH ARARs - Assesses how the alternative complies with location-, chemical-, and action-specific ARARs, and whether a waiver is required or justified.

PRIMARY CRITERIA (basis of alternative evaluation)

- LONG-TERM EFFECTIVENESS AND PERMANENCE - Evaluates the effectiveness of the alternative in protecting human health and the environment after response objectives have been met. Includes consideration of the magnitude of residual risks and the adequacy and reliability of controls.
- REDUCTION OF TOXICITY, MOBILITY, AND VOLUME THROUGH TREATMENT - Evaluates the effectiveness of treatment processes used to reduce toxicity, mobility, and volume of hazardous substances. This criterion considers the degree to which treatment is irreversible, and the type and quantity of residuals remaining after treatment.
- SHORT-TERM EFFECTIVENESS - Examines the effectiveness of the alternative in protecting human health and the environment during the construction and implementation of a remedy until response objectives have been met. Considers the protection of the community, workers, and the environment during implementation of remedial actions.
- IMPLEMENTABILITY - Assesses the technical and administrative feasibility of an alternative and availability of required goods and services. Technical feasibility considers the ability to construct and operate a technology and its reliability, the ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of a remedy. Administrative feasibility considers the ability to obtain approvals from other parties or agencies and extent of required coordination with other parties or agencies.
- COST - Evaluates the capital and operation and maintenance cost of each alternative.

BALANCING CRITERIA

- STATE ACCEPTANCE - This criterion considers the state's preferences among or concerns about alternatives.
- COMMUNITY ACCEPTANCE - This criterion considers the communities preferences among or concerns about alternatives.

TABLE 4-2
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 1: NO ACTION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	LOCATION CHARACTERISTIC	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No location-specific ARARs will be triggered.			
State Regulatory Authority		No location-specific ARARs will be triggered.			

TABLE 4-2
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 1: NO ACTION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Groundwater	SDWA, National Primary Drinking Water Standards, MCLs [40 CFR Parts 141.11 - 141.16 and 141.50 - 141.53]	Relevant and Appropriate	The NPDWR establishes MCLs for several common organic and inorganic contaminants. MCLs specify the maximum permissible concentrations of contaminants in public drinking water supplies. MCLs are federally enforceable standards based in part on the availability and cost of treatment techniques.	Biodegradation of organic contaminants exceeding MCLs is believed to be occurring under existing conditions. However, no monitoring activities will occur to evaluate compliance with these requirements.

TABLE 4-2
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 1: NO ACTION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Groundwater Quality Standards [314 CMR 6.00]	Applicable	Massachusetts Groundwater Quality Standards designate and assign uses for which groundwater of the Commonwealth shall be maintained and protected and set forth water quality criteria necessary to maintain the designated uses. Groundwater at Fort Devens is classified as Class 1. Groundwater assigned to this class are fresh groundwater designated as a source of potable water supply.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. However, no monitoring activities will occur to evaluate compliance with these requirements.
	Groundwater	Massachusetts Drinking Water Standards and Guidelines [310 CMR 22.0].	Relevant and Appropriate	The Massachusetts Drinking Water Standards and Guidelines list MMCLs which apply to water delivered to any user of a public water supply system as defined in 310 CMR 22.00. Private residential wells are not subject to the requirements of 310 CMR 22.00; however, the standards are often used to evaluate private residential contamination especially in CERCLA activities.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. However, no monitoring activities will occur to evaluate compliance with these requirements.

(continued)

TABLE 4-2
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 1: NO ACTION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No action-specific ARARs will be triggered.			
State Regulatory Authority		No action-specific ARARs will be triggered.			

Notes:

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
MCLs = Maximum Contaminant Level
MMCLs = Massachusetts Maximum Contaminant Levels

NPDR = National Primary Drinking Water Standards
SDWA = Safe Drinking Water Act

TABLE 4-3
INTRINSIC BIOREMEDIATION SAMPLING PARAMETERS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

PARAMETER	PURPOSE
DISSOLVED OXYGEN	defines zone of potential aerobic activity (greater than 0.5 mg/l)
REDOX (Eh)	define/confirm type of microbiological respiration process occurring
NITRATE	electron acceptor for anaerobic microbial respiration, microbial nutrient
NITRITE	electron acceptor for anaerobic microbial respiration, microbial nutrient
PHOSPHATE	microbial nutrient
SULFATE	electron acceptor for anaerobic microbial respiration
SULFIDE	product of sulfate-based microbial respiration
TOTAL IRON	provides indication of anaerobic microbial respiration potential (compared to filtered iron)
SOLUBLE IRON [FE(II)]	product of anaerobic biodegradation (compared to unfiltered iron)
METHANE	product of carbonate-based (CO ₂) microbial respiration (anaerobic degradation of carbon at redox less than -200 mV)
BENZENE, XYLENE AND ETHYLBENZENE	Compare to PRGs
NICKEL, IRON AND MANGANESE (filtered)	Compare to PRGs
TEMPERATURE	well development/purge parameter
pH	aquifer environment condition indicator
CONDUCTIVITY	well development/purge parameter
ALKALINITY	well development/purge parameter
AMMONIA-NITROGEN	microbial nutrient, preliminary form of nitrite/nitrate under aerobic conditions

TABLE 4-4
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2A:
INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	LOCATION CHARACTERISTIC	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No location-specific ARARs will be triggered.			
State Regulatory Authority		No location-specific ARARs will be triggered.			

TABLE 4-4
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2A:
INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Groundwater	SDWA, National Primary Drinking Water Standards, MCLs [40 CFR Parts 141.11 - 141.16 and 141.50 - 141.53]	Relevant and Appropriate	The NPDWR establishes MCLs for several common organic and inorganic contaminants. MCLs specify the maximum permissible concentrations of contaminants in public drinking water supplies. MCLs are federally enforceable standards based in part on the availability and cost of treatment techniques.	Biodegradation of organic contaminants exceeding MCLs is believed to be occurring under existing conditions. MCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-4
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2A:
INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Groundwater Quality Standards [314 CMR 6.00]	Applicable	Massachusetts Groundwater Quality Standards designate and assign uses for which groundwater of the Commonwealth shall be maintained and protected and set forth water quality criteria necessary to maintain the designated uses. Groundwater at Fort Devens is classified as Class 1. Groundwater assigned to this class are fresh groundwater designated as a source of potable water supply.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-4
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2A:
INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
	Groundwater	Massachusetts Drinking Water Standards and Guidelines [310 CMR 22.0].	Relevant and Appropriate	The Massachusetts Drinking Water Standards and Guidelines list MMCLs which apply to water delivered to any user of a public water supply system as defined in 310 CMR 22.00. Private residential wells are not subject to the requirements of 310 CMR 22.00; however, the standards are often used to evaluate private residential contamination especially in CERCLA activities.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

(continued)

TABLE 4-4
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2A:
INTRINSIC BIOREMEDIATION
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No action-specific ARARs will be triggered.			
State Regulatory Authority	Groundwater Monitoring	Massachusetts Hazardous Waste Management Rules (MHWMR) Groundwater Protection; [310 CMR 30.660- 30.679]	Relevant and Appropriate	Groundwater monitoring is required during and following remedial actions.	A long-term groundwater monitoring program is to be implemented to monitor the progress of remediation.

Notes:

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
MCLs = Maximum Contaminant Levels
MHWMR = Massachusetts Hazardous Waste Management Rules

MMCLs = Massachusetts Maximum Contaminant Levels
NPDWR = National Primary Drinking Water Standards
SDWA = Safe Drinking Water Act

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	LOCATION CHARACTERISTIC	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No location-specific ARARs will be triggered.			
State Regulatory Authority		No location-specific ARARs will be triggered.			

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Groundwater	SDWA, National Primary Drinking Water Standards, MCLs [40 CFR Parts 141.11 - 141.16 and 141.50 - 141.53]	Relevant and Appropriate	The NPDWR establishes MCLs for several common organic and inorganic contaminants. MCLs specify the maximum permissible concentrations of contaminants in public drinking water supplies. MCLs are federally enforceable standards based in part on the availability and cost of treatment techniques.	Biodegradation of organic contaminants exceeding MCLs is believed to be occurring under existing conditions. MCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Groundwater Quality Standards [314 CMR 6.00]	Applicable	Massachusetts Groundwater Quality Standards designate and assign uses for which groundwater of the Commonwealth shall be maintained and protected and set forth water quality criteria necessary to maintain the designated uses. Groundwater at Fort Devens is classified as Class 1. Groundwater assigned to this class are fresh groundwater designated as a source of potable water supply.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Continued	Groundwater	Massachusetts Drinking Water Standards and Guidelines [310 CMR 22.0].	Relevant and Appropriate	The Massachusetts Drinking Water Standards and Guidelines list MMCLs which apply to water delivered to any user of a public water supply system as defined in 310 CMR 22.00. Private residential wells are not subject to the requirements of 310 CMR 22.00; however, the standards are often used to evaluate private residential contamination especially in CERCLA activities.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

(continued)

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Disposal of Treatment residues	RCRA, Land Disposal Restrictions [40 CFR 268]	Applicable	Land disposal of RCRA hazardous wastes without specified treatment is restricted. LDRs require that wastes must be treated either by a treatment technology or to a specific concentration prior to disposal in a RCRA Subtitle C permitted facility.	SVE carbon would be tested to evaluate characteristics for proper disposal/reactivation.
State Regulatory Authority	Groundwater Monitoring	Massachusetts Hazardous Waste Management Rules (MHWMR) Groundwater Protection; [310 CMR 30.660-30.679]	Relevant and Appropriate	Groundwater monitoring is required during and following remedial actions.	A long-term groundwater monitoring program is to be implemented to monitor the progress of remediation.

(continued)

TABLE 4-5
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 2B:
INTRINSIC BIOREMEDIATION/SOIL VENTING OF GASOLINE UST SOILS
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Continued	SVE Treatment	Massachusetts Air Pollution Control Regulations [310 CMR 6.00 - 7.00]	Applicable	SVE system must reduce VOCs in air effluent stream by at least 95% by weight	Emissions will be managed through engineering controls.

Notes:

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
MCLs = Maximum Contaminant Levels
MHWMR = Massachusetts Hazardous Waste Management Rules

MMCLs = Massachusetts Maximum Contaminant Levels
NPDWR = National Primary Drinking Water Standards
SDWA = Safe Drinking Water Act

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADEMENT
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	LOCATION CHARACTERISTIC	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No location-specific ARARs will be triggered.			
State Regulatory Authority		No location-specific ARARs will be triggered.			

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Groundwater	SDWA, National Primary Drinking Water Standards, MCLs [40 CFR Parts 141.11 - 141.16 and 141.50 - 141.53]	Relevant and Appropriate	The NPDWR establishes MCLs for several common organic and inorganic contaminants. MCLs specify the maximum permissible concentrations of contaminants in public drinking water supplies. MCLs are federally enforceable standards based in part on the availability and cost of treatment techniques.	Biodegradation of organic contaminants exceeding MCLs is believed to be occurring under existing conditions. MCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Groundwater Quality Standards [314 CMR 6.00]	Applicable	Massachusetts Groundwater Quality Standards designate and assign uses for which groundwater of the Commonwealth shall be maintained and protected and set forth water quality criteria necessary to maintain the designated uses. Groundwater at Fort Devens is classified as Class 1. Groundwater assigned to this class are fresh groundwater designated as a source of potable water supply.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Drinking Water Standards and Guidelines [310 CMR 22.0].	Relevant and Appropriate	The Massachusetts Drinking Water Standards and Guidelines list MMCLs which apply to water delivered to any user of a public water supply system as defined in 310 CMR 22.00. Private residential wells are not subject to the requirements of 310 CMR 22.00; however, the standards are often used to evaluate private residential contamination especially in CERCLA activities.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Discharge to POTW.	CWA, General Pretreatment Program [40 CFR Part 403]	Applicable	Discharges of nonhazardous wastewater to POTWs must comply with the general prohibitions of this regulation, as well as categorical standards, and local pretreatment standards.	Discharge to POTW would be sampled to evaluate compliance with pre-treatment standards.
	Disposal of treatment residues	RCRA, Land Disposal Restrictions [40 CFR 268]	Applicable	Land disposal of RCRA hazardous wastes without specified treatment is restricted. LDRs require that wastes must be treated either by a treatment technology or to a specific concentration prior to disposal in a RCRA Subtitle C permitted facility.	Sludge and filtered material from inorganic pretreatment would be tested to evaluate if they are classified as a characteristic hazardous waste for proper disposal.

TABLE 4-6
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 3:
GROUNDWATER COLLECTION AND TREATMENT/INTRINSIC BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater Monitoring	Massachusetts Hazardous Waste Management Rules (MHWMR) Groundwater Protection; [310 CMR 30.660-30.679]	Relevant and Appropriate	Groundwater monitoring is required during and following remedial actions.	A long-term groundwater monitoring program is to be implemented to monitor the progress of remediation.
	Excavation/construction	Massachusetts Air Pollution Control Regulations [310 CMR 6.00 - 7.00]	Applicable	Particulate emissions from site activities must not exceed an annual geometric mean of 50 g/m ³ and a maximum 24-hour concentration of 150 mg/m ³ (primary standard). Carbon monoxide, nitrogen dioxide, and lead are also regulated.	Emissions will be managed through engineering controls.

Notes:

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
 CWA = Clean Water Act
 LDRs = Land Disposal Restrictions
 MCLs = Maximum Contaminant Levels
 MHWMR = Massachusetts Hazardous Waste Management Rules
 MMCLs = Massachusetts Maximum Contaminant Levels

NPDES = National Pollutant Discharge Elimination System
 NPDWR = National Primary Drinking Water Standards
 POTW = Publicly Owned Treatment Works
 RCRA = Resource Conservation and Recovery Act
 SDWA = Safe Drinking Water Act

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADEMENT
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	LOCATION CHARACTERISTIC	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority		No location-specific ARARs will be triggered.			
State Regulatory Authority		No location-specific ARARs will be triggered.			

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADIENT
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Groundwater	SDWA, National Primary Drinking Water Standards, MCLs [40 CFR Parts 141.11 - 141.16 and 141.50 - 141.53]	Relevant and Appropriate	The NPDWR establishes MCLs for several common organic and inorganic contaminants. MCLs specify the maximum permissible concentrations of contaminants in public drinking water supplies. MCLs are federally enforceable standards based in part on the availability and cost of treatment techniques.	Biodegradation of organic contaminants exceeding MCLs is believed to be occurring under existing conditions. In addition, pump and treat near the source area and passive application of oxygen and perhaps mineral nutrients near the plume edge will minimize the possibility that contaminants exceeding MCLs will migrate to receptors off Army Reserve Enclave property. MCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater	Massachusetts Groundwater Quality Standards [314 CMR 6.00]	Applicable	Massachusetts Groundwater Quality Standards designate and assign uses for which groundwater of the Commonwealth shall be maintained and protected and set forth water quality criteria necessary to maintain the designated uses. Groundwater at Fort Devens is classified as Class 1. Groundwater assigned to this class are fresh groundwater designated as a source of potable water supply.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. In addition, pump and treat near the source area and passive application of oxygen and perhaps mineral nutrients near the plume edge will minimize the possibility that contaminants exceeding MMCLs will migrate to receptors off Army Reserve Enclave property. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	CHEMICAL MEDIUM	REQUIREMENT	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
	Groundwater	Massachusetts Drinking Water Standards and Guidelines [310 CMR 22.0].	Relevant and Appropriate	The Massachusetts Drinking Water Standards and Guidelines list MMCLs which apply to water delivered to any user of a public water supply system as defined in 310 CMR 22.00. Private residential wells are not subject to the requirements of 310 CMR 22.00; however, the standards are often used to evaluate private residential contamination especially in CERCLA activities.	Biodegradation of organic contaminants exceeding MMCLs is believed to be occurring under existing conditions. In addition, pump and treat near the source area and passive application of oxygen and perhaps mineral nutrients near the plume edge will minimize the possibility that contaminants exceeding MMCLs will migrate to receptors off Army Reserve Enclave property. MMCLs will be used to evaluate the performance of this alternative through implementation of a long-term groundwater monitoring program.

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADE
AOC 43G

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FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
Federal Regulatory Authority	Discharge to POTW.	CWA, General Pretreatment Program [40 CFR Part 403]	Applicable	Discharges of nondomestic wastewater to POTWs must comply with the general prohibitions of this regulation, as well as categorical standards, and local pretreatment standards.	Discharge to POTW would be sampled to evaluate compliance with pre-treatment standards.
	Disposal of treatment residues	RCRA, Land Disposal Restrictions [40 CFR 268]	Applicable	Land disposal of RCRA hazardous wastes without specified treatment is restricted. LDRs require that wastes must be treated either by a treatment technology or to a specific concentration prior to disposal in a RCRA Subtitle C permitted facility.	Sludge and filtered material from inorganic pretreatment would be tested to evaluate if they are classified as a characteristic hazardous waste for proper disposal.
	Passive Oxygenation of Groundwater	Underground Injection Control Program [40 CFR Parts 144 & 146]	Relevant and Appropriate	Provides for protection of underground sources of drinking water and technical requirements for compliance. Applicable to underground injection of wastes and contaminated water.	Relevant portions of the regulation will be met through engineering controls.

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
State Regulatory Authority	Groundwater Monitoring	Massachusetts Hazardous Waste Management Rules (MHWMR) Groundwater Protection; [310 CMR 30.660-30.679]	Relevant and Appropriate	Groundwater monitoring is required during and following remedial actions.	A long-term groundwater monitoring program is to be implemented to monitor the progress of remediation.
	Excavation/construction	Massachusetts Air Pollution Control Regulations [310 CMR 6.00 - 7.00]	Applicable	Particulate emissions from site activities must not exceed an annual geometric mean of 50 g/m ³ and a maximum 24-hour concentration of 150 mg/m ³ (primary standard). Carbon monoxide, nitrogen dioxide, and lead are also regulated.	Emissions will be managed through engineering controls.

TABLE 4-7
SYNOPSIS OF FEDERAL AND STATE ARARS FOR ALTERNATIVE 4:
GROUNDWATER COLLECTION AND TREATMENT/PASSIVE BIOREMEDIATION DOWNGRADIENT
AOC 43G

FEASIBILITY STUDY REPORT
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AUTHORITY	ACTION	REQUIREMENTS	STATUS	REQUIREMENT SYNOPSIS	ACTION TO BE TAKEN TO ATTAIN REQUIREMENT
	Passive Oxygenation of Groundwater	Underground Water Source Protection [310 CMR 27.00]	Relevant and Appropriate	Regulates any underground injection of hazardous wastes and other fluids with potential to contaminate groundwater. Provides for protection of underground sources of drinking water and technical requirements for compliance.	Relevant portions of the regulations will be met by through engineering controls.

Notes:

CERCLA = Comprehensive Environmental Response, Compensation and Liability Act
 CWA = Clean Water Act
 LDRs = Land Disposal Restrictions
 MCLs = Maximum Contaminant Levels
 MHWMR = Massachusetts Hazardous Waste Management Rules
 MMCLs = Massachusetts Maximum Contaminant Levels
 NPDES = National Pollutant Discharge Elimination System
 NPDWR = National Primary Drinking Water Standards
 POTW = Publicly Owned Treatment Works
 RCRA = Resource Conservation and Recovery Act
 SDWA = Safe Drinking Water Act

TABLE 4-8
ALTERNATIVE 2A: INTRINSIC BIOREMEDIATION
COST SUMMARY TABLE
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FORT DEVENS, MA

ITEM	COST
DIRECT COSTS	
Well Construction and Development	\$11,000
INDIRECT COSTS	
Design/Engineering	\$15,000
Construction Oversight/Health and Safety	\$5,200
CAPITAL COST (DIRECT + INDIRECT) SUBTOTAL	\$31,200
UNDEVELOPED DESIGN DETAILS (25%)	\$7,800
TOTAL CAPITAL COSTS	\$39,000
OPERATION AND MAINTENANCE COSTS	
Analytical	\$9,900
ODCs (sampling equipment, shipping)	\$1,300
Sampling Labor	\$9,400
Engineering/Consulting	\$4,000
YEARLY O&M SUBTOTAL	\$24,600
UNDEVELOPED DESIGN DETAILS (25%)	\$6,100
TOTAL O&M PRESENT WORTH (P/A, 7%, 30 years)	\$381,000
5-YEAR SITE REVIEWS (Total Present Worth)	\$21,500
CLOSEOUT GROUNDWATER MONITORING (Total Present Worth)	\$3,800
TOTAL PRESENT WORTH OF ALTERNATIVE 2A	\$445,300

TABLE 4-9
ALTERNATIVE 2B: INTRINSIC BIOREMEDIATION/
SOIL VENTING OF GASOLINE UST SOILS
COST SUMMARY TABLE
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

ITEM	COST
DIRECT COSTS	
Groundwater Monitoring Well Construction and Development	\$11,000
Vent Well/System Construction	\$40,100
Treatment System Housing	\$20,000
INDIRECT COSTS	
Design/Engineering	\$27,000
Construction Oversight/Health and Safety/System Test	\$12,000
CAPITAL COST (DIRECT + INDIRECT) SUBTOTAL	\$110,100
UNDEVELOPED DESIGN DETAILS (25%)	\$27,500
TOTAL CAPITAL COSTS	\$137,600
OPERATION AND MAINTENANCE COSTS	
GW Analytical	\$9,900
ODCs (sampling equipment, shipping)	\$1,300
Sampling Labor	\$9,400
Engineering/Consulting	\$4,000
YEARLY O&M SUBTOTAL	\$24,600
UNDEVELOPED DESIGN DETAILS (25%)	\$6,100
Vent Analytical	\$14,200
ODCs (sampling equipment, shipping)	\$500
O&M and Sampling Labor	\$12,300
Engineering/Consulting	\$6,000
Carbon replacement/disposal	\$3,070
YEARLY O&M SUBTOTAL	\$36,070
UNDEVELOPED DESIGN DETAILS (25%)	\$8,968
TOTAL O&M PRESENT WORTH (P/A, 7%, 30 years)	\$448,600
5-YEAR SITE REVIEWS (Total Present Worth)	\$21,500
CLOSEOUT GROUNDWATER MONITORING (Total Present Worth)	\$3,800
TOTAL PRESENT WORTH OF ALTERNATIVE 2B	\$611,500

TABLE 4-10
ALTERNATIVE 3: GROUNDWATER COLLECTION & TREATMENT
INTRINSIC BIOREMEDIATION DOWNGRAIENT COST SUMMARY TABLE
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FEASIBILITY STUDY REPORT
FORT DEVENS, MA

ITEM	COST
DIRECT COSTS	
Groundwater Recovery System Construction	\$27,500
Groundwater Treatment System Construction	\$52,000
Treatment System Housing	\$26,800
Startup Analytical	\$1,800
INDIRECT COSTS	
Bedrock Pumping Test	\$32,000
Design/Engineering	\$50,000
Construction Oversight/System Startup/Health and Safety	\$16,000
CAPITAL COST (DIRECT + INDIRECT) SUBTOTAL	\$206,100
UNSPECIFIED DESIGN DETAILS (25%)	\$51,500
TOTAL CAPITAL COSTS	\$257,600
OPERATION AND MAINTENANCE COSTS	
Field Technician (GW extraction and treatment)	\$18,700
Analytical (GW treatment system)	\$7,200
ODCs	\$1,200
Power	\$2,400
Carbon System Exchange (GW)	\$26,300
Bag Filter System	\$1,000
Engineering/Consulting	\$14,100
GW Sampling (Labor + Analytical)	\$20,600
YEARLY GW O&M SUBTOTAL	\$91,500
UNSPECIFIED DESIGN DETAILS (25%)	\$22,900
TOTAL O&M PRESENT WORTH (P/A, 7%, 30 years)	\$1,419,600
5-YEAR SITE REVIEWS (Total Present Worth)	\$21,500
CLOSEOUT GROUNDWATER MONITORING (Total Present Worth)	\$3,800
TOTAL PRESENT WORTH OF ALTERNATIVE 3	\$1,702,500

TABLE 4-11
ALTERNATIVE 4: GROUNDWATER COLLECTION & TREATMENT
PASSIVE BIOREMEDIATION DOWNGRADE COST SUMMARY TABLE
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FEASIBILITY STUDY REPORT
FORT DEVENS, MA

ITEM	COST
DIRECT COSTS	
Well Construction and Development (Bioremediation/Monitoring)	\$68,300
Groundwater Recovery System Construction	\$27,500
Groundwater Treatment System Construction	\$52,000
Treatment System Housing	\$26,800
Startup Analytical	\$1,800
INDIRECT COSTS	
Design/Engineering	\$71,000
Construction Oversight/Health and Safety/System Startup	\$30,500
Bedrock Pumping Test	\$32,000
CAPITAL COST (DIRECT + INDIRECT) SUBTOTAL	\$309,900
UNDEVELOPED DESIGN DETAILS (25%)	\$77,500
TOTAL CAPITAL COSTS	\$387,400
OPERATION AND MAINTENANCE COSTS (Passive Bioremediation)	
Field Technician	\$13,000
Oxygen Release Compound/Nutrient Material	\$10,000
Well Maintenance	\$14,000
Engineering/Consulting	\$7,800
YEARLY O&M SUBTOTAL	\$44,800
UNDEVELOPED DESIGN DETAILS (25%)	\$11,200
OPERATION AND MAINTENANCE COSTS (Groundwater Extraction and Treatment)	
Field Technician	\$18,700
Analytical	\$7,200
ODCs	\$1,200
Power	\$2,400
Carbon System Exchange	\$26,300
Bag Filter System	\$1,000
Engineering/Consulting	\$14,100
GW Sampling (Labor + Analytical)	\$20,600
YEARLY GW O&M SUBTOTAL	\$91,500
UNSPECIFIED DESIGN DETAILS (25%)	\$22,900
TOTAL O&M PRESENT WORTH (P/A, 7%, 30 years)	\$2,114,500
5-YEAR SITE REVIEWS (Total Present Worth)	\$21,500
CLOSEOUT GROUNDWATER MONITORING (Total Present Worth)	\$3,800
TOTAL PRESENT WORTH OF ALTERNATIVE 4	\$2,527,200

5.0 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents a comparison of the five remedial alternatives that were the focus of the detailed evaluation, highlighting the relative advantages and disadvantages of the alternatives with respect to the seven evaluation criterion. The evaluation is performed to assist decision-makers in selecting a remedy that cost-effectively meets the remedial action objectives. The evaluation criteria are divided into three specific categories during remedy selection: Threshold Criteria, Primary Balancing Criteria, and Modifying Criteria. Threshold criteria include Overall Protection of Human Health and the Environment, and Compliance with ARARs. Alternatives must meet threshold criteria to be chosen as the selected remedy. Primary balancing criteria include: Long-term Effectiveness and Permanence; Reduction of Toxicity, Mobility, and Volume through Treatment; Short-term Effectiveness; Implementability; and Cost. These seven criteria are used in this section to compare the alternatives. Modifying criteria include state and community acceptance, and will be addressed in the ROD.

The five remedial alternatives that are the focus of the detailed analysis are:

- Alternative 1: No Action
- Alternative 2A: Intrinsic Bioremediation
- Alternative 2B: Intrinsic Bioremediation / Soil Venting of Gasoline UST Soils
- Alternative 3: Groundwater Collection and Treatment/Intrinsic Bioremediation Downgradient
- Alternative 4: Groundwater Collection and Treatment/Passive Bioremediation Downgradient

Results of the evaluation are summarized in Table 5-1.

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5.1 OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

This criteria, according to CERCLA, must be met for a remedial alternative to be chosen as a final site remedy. At AOC 43G groundwater sampling has shown that contaminants exceed PRGs on Army Reserve Enclave property; however, no current commercial/industrial exposure to groundwater exists because there are no drinking water wells installed on site. Also, no future exposure to groundwater on site is anticipated. The site is to remain Army property and will continue to be used to support Army Reserve activities. There are no future plans to install water supply wells on site to support these activities. Groundwater analysis results indicate that intrinsic biodegradation is occurring naturally at AOC 43G.

Calculations reveal that concentrations exceeding PRGs will not likely migrate beyond the Army Reserve Enclave boundary, thereby protecting downgradient receptors from future exposure to CPCs. Calculations also indicate that organic CPCs may potentially be reduced below PRGs over time on site as a result of the intrinsic biodegradation process. Because intrinsic biodegradation is a naturally occurring process, all alternatives consider it as a remedial component. However, the degree to which each alternative relies on intrinsic bioremediation varies. Some of the alternatives rely on backup components to achieve PRGs if intrinsic biodegradation does not perform as anticipated. Therefore, all alternatives are considered protective of human health and the environment.

Although Alternative 1 proposes no action, intrinsic bioremediation would likely prevent future potential exposure to contaminated groundwater. However, there would be no method to assess the protectiveness of this alternative because there would be no groundwater monitoring performed. Alternative 2A would use additional data collection, modeling, long-term groundwater monitoring, five-year site reviews and contingencies for additional action to ensure that intrinsic bioremediation is protective of human health and the environment. Alternatives 2B, 3, and 4 add supplemental or backup treatment components in addition to their reliance on intrinsic bioremediation. Alternative 2B adds soil venting of the gasoline UST soils to minimize the potential of groundwater recontamination. Alternative 3 adds groundwater collection and treatment as a means of intercepting the most contaminated portion of the plume to minimize the potential for migration of CPCs that exceed PRGs. Alternative 4 uses passive bioremediation (aerobic treatment) at the plume edge to minimize migration potential. The added technologies in Alternatives 2B, 3, and 4 increase the

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potential protection of downgradient receptors, although each could also be added as contingency alternatives upon nonperformance of intrinsic biodegradation without jeopardizing overall protection of human health and the environment.

5.2 COMPLIANCE WITH ARARS

CERCLA requires that the selected alternative also meet a second threshold criterion of compliance with ARARs, or obtain a waiver if the criterion cannot be met. No location-specific ARARs are triggered for remedial activities at AOC 43G. Organic CPC concentrations could be reduced to below MCLs and MMCLs by biological degradation depending upon modeling results and if the source area has been successfully removed. Inorganic CPCs in groundwater may also revert to more insoluble forms upon reduction of organic concentrations and meet MCLs/MMCLs and the Massachusetts Groundwater Quality Criteria (314 CMR 6.00).

Alternatives 2A through 4 would use groundwater monitoring to evaluate long-term effectiveness and the potential for CPC migration off Army Reserve Enclave property. Monitoring would be in compliance with substantive portions of the Massachusetts Hazardous Waste Management Rules 310 CMR 30.660 - 30.670 relating to the development of a groundwater monitoring plan. Alternatives 2B, 3, and 4 would need to meet additional action-specific ARARs because of the additional technologies used. Alternative 2B would use a soil venting treatment system (vapor phase activated carbon) to comply with the Massachusetts Air Pollution Control Regulations (310 CMR 6.00 - 7.00). These regulations require a minimum 95 percent reduction (by weight) in VOCs in the air effluent air stream. Additionally, spent activated carbon would be tested to meet disposal requirements in accordance with RCRA Land Disposal Restrictions (40 CFR 268). Alternative 3 groundwater treatment discharge would meet the requirements of the Clean Water Act, General Pretreatment Program (40 CFR Part 403). Similar to Alternative 2B, Alternative 3 treatment wastes (spent activated carbon, filtered material, sludge) would be tested for proper disposal (40 CFR 268). Engineering controls (dust suppression) would be used to comply with Massachusetts Air Pollution Control Regulations (310 CMR 6.00 - 7.00) which would regulate particulate emissions during site construction activities. Alternative 4 would be in general compliance with the Underground Injection Control Program (40 CFR Parts 144 & 146), the Underground Water Source

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Protection Standards (310 CMR 27.00) plus those regulations specified for Alternative 3.

5.3 LONG-TERM EFFECTIVENESS AND PERMANENCE

This criterion evaluates the magnitude of residual risk and the reliability of controls after response objectives have been met. In the microbial degradation process of intrinsic bioremediation, the organic CPCs are converted ultimately to inert compounds such as carbon dioxide, methane, and water. Inorganic CPCs will revert to more insoluble forms following completion of organic degradation. Because of the actual degradation/destruction of organic contaminants that occurs in this process, intrinsic bioremediation provides permanent treatment effectiveness without secondary waste disposal. Alternatives 2B, 3, and 4 which use supplemental technologies (SVE or groundwater extraction and treatment) have secondary waste (i.e., spent activated carbon and sludge) that will require disposal. All alternatives use long-term groundwater monitoring to ensure that compliance with PRGs is reached for three consecutive annual sampling rounds.

5.4 REDUCTION OF TOXICITY, MOBILITY, OR VOLUME THROUGH TREATMENT

This criterion evaluates whether the alternatives meet the statutory preference for treatment under CERCLA. The criterion evaluates the reduction of toxicity, mobility, or volume of contaminants, and the type and quantity of treatment residuals. All alternatives, including Alternative 1 (No Action), meet the statutory preference for treatment under CERCLA because intrinsic bioremediation is a naturally occurring process for all alternatives evaluated. Alternatives 2B, 3, and 4 offer supplemental or back-up treatment processes which also contribute to the reduction of toxicity, mobility and volume of contaminants.

Alternatives 2B, 3, and 4 would generate concentrated waste streams (i.e., sludge, filtered material, and/or spent carbon) that would require disposal.

5.5 SHORT-TERM EFFECTIVENESS

CERCLA requires that potential adverse short-term effects to workers, the surrounding community, and the environment be considered during selection of a remedial action. Major adverse short-term effects to site workers are not expected for any of the alternatives because all activities can be monitored readily and engineering control implemented in accordance with a Health and Safety Plan. However, because of more intrusive activities, monitoring requirements and construction work, the potential for contaminant exposure and safety hazards to workers increases with Alternatives 2A, 2B, 3, and 4, respectively. Alternatives 2B and 3 require installation of twice the number of wells required by Alternative 2A. Alternatives 2B, 3, and 4 also utilize active treatment processes that require more frequent contact with contaminated medium during O&M and monitoring activities.

For costing purposes, Alternatives 2A, 2B, 3, and 4 are all assumed to require greater than 30 years to meet remedial objectives.

5.6 IMPLEMENTABILITY

This criterion evaluates each alternative's ease of construction and operation and availability of services, equipment, and materials to construct and operate the alternative. Also evaluated is the ease of undertaking additional remedial actions and administrative feasibility.

Although the engineering complexity increases for each alternative (i.e., Alternative 4 > Alternative 3 > Alternative 2B > Alternative 2A > Alternative 1), engineering and construction services, equipment, and materials should be readily available to implement any of the alternatives. Alternatives 2A through 4 all require additional data collection, modeling or pilot testing prior to design and implementation. Alternatives 2A through 4 would require additional data collection and intrinsic bioremediation modeling to refine biodegradation rates following removal of the sand and gas trap with associated soils. Alternatives 3 and 4 both require additional groundwater pumping tests and hydrogeological modeling to verify flow rates and quantity and placement of extraction wells to hydraulically contain the contaminant plume. Alternative 4 would also require, as a minimum, laboratory treatability testing to assess oxygen-releasing compounds

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and nutrient needs. Limited pilot testing may be required to verify field application of oxygen-releasing compounds and nutrients.

Groundwater monitoring to assess the success of remedial action is performed easily for all alternatives. None of the alternatives would limit or interfere with the ability to perform future remedial actions. All alternatives would require coordination among regulatory agencies to institute the five-year review process.

5.7 COST

There are no costs associated with Alternative 1. Capital, O&M, and present worth costs were estimated for Alternatives 2A through 4. Cost estimates for these alternatives included similar expense for long-term groundwater monitoring. As would be expected, Alternatives 2A and 4 are the least and most expensive alternatives, respectively. The alternative with the lowest capital cost is Alternative 2A because it does not include extensive construction activities. Alternative 4 has the highest capital cost because it includes the design and construction of a groundwater extraction/treatment system and passive bioremediation system. Alternatives 3 and 4 both have high O&M costs because of long-term maintenance of the groundwater treatment and passive bioremediation systems.

After calculating the present worth for each alternative, the sensitivity of the costs to the estimating assumptions was evaluated. The total cost associated with all alternatives consist primarily of long-term O&M and/or groundwater monitoring costs. These long-term costs contribute between approximately 75 percent and 90 percent to the overall total cost. A high degree of uncertainty is associated with the length of time required to reduce contaminants to below PRGs. The effects from possible residual contamination within the bedrock fractures cannot yet be recognized. A 30-year remediation time was conservatively used for costing purposes. The estimate of four years for intrinsic bioremediation ("on/off" source simulation) is believed to be also based on conservative assumptions as detailed in Appendix C but assumes that there is no continuous source. This shorter treatment period would significantly reduce O&M costs and total present worth costs proportionally for all alternatives. The relative comparison between alternatives would remain similar. Therefore, further sensitivity analysis to assess

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effects from "across the board" remedial action time reduction was not performed for these alternatives.

It is also noted that expenses incurred for Alternative 4 assume that oxygen-releasing compounds and nutrient application would be required for the entire 30-year remedial action time period (assumes that intrinsic biodegradation is not capable of containing the plume for the entire 30 years). Numerous other scenarios are equally likely and could include 1) biodegradation within the plume area could occur to the extent that the contaminant plume would shrink in size within five years, 2) and that maintenance of the bioremediation wells would not be required for the remaining duration of 25 years that it would take to reduce CPCs below PRGs. Reducing need for aerobic treatment time would significantly reduce O&M costs for Alternative 4. The total present worth could be reduced to approximately 30 percent of the full 30-year total present worth.

5.8 COMPARATIVE ANALYSIS SUMMARY

Alternative 1 is considered equal to Alternative 2A when comparison is made to threshold criteria except that Alternative 1 compliance would not be able to be monitored. Alternative 1 is similar to Alternative 2A when considering primary balancing criteria except that there would be no effects to site-workers during remedial implementation or cost associated with implementation of Alternative 1. (There is no active remedial action or monitoring implemented in Alternative 1.)

Alternative 2A is similar to Alternatives 2B, 3, and 4 considering threshold criteria in that they all are protective of human health and are expected to eventually meet ARARs. Alternative 2B uses SVE to minimize the potential for groundwater recontamination thereby improving the probability that intrinsic biodegradation can achieve PRGs. However, if gross contamination exists within the bedrock fractures, removal of the gasoline UST residual soil contamination with SVE may not improve groundwater remediation significantly. Alternatives 3 and 4 use backup components to achieve PRGs if intrinsic biodegradation does not perform as anticipated. Alternative 2A would rely on additional data collection, modeling, long-term groundwater monitoring, five-year site reviews and contingencies for additional action to ensure that intrinsic bioremediation is protective of human health and the environment. The added treatment technologies in Alternatives 2B, 3, and 4 can be interpreted as increasing the

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potential protection of downgradient receptors, although each could be added as contingency alternatives to Alternative 2A upon nonperformance of intrinsic biodegradation without jeopardizing overall protection of human health and the environment.

In general, Alternative 2A is also similar to (but in comparing cost, less expensive than) Alternatives 2B, 3, and 4 considering primary balancing criteria. Alternatives 2B, 3, and 4 more favorably offer supplemental or back-up treatment processes which contribute to the reduction of toxicity, mobility and volume of contaminants. However, intrinsic biodegradation is likely to be the controlling factor in determining the time required for remedial action. The back-up treatments in Alternatives 2B, 3, and 4 would generate concentrated waste streams (sludge, filtered material, and spent carbon) that would require disposal. Because of more intrusive activities, monitoring requirements and construction work, the potential for contaminant exposure and safety hazards to workers increases with Alternatives 2A, 2B, 3, and 4, in order presented. The engineering complexity also increases for Alternatives 2A, 2B, 3, and 4, in order presented. Alternatives 2A through 4 all require additional data collection, modeling, or pumping tests prior to design and implementation. Alternative 2A is the least expensive alternative followed by Alternatives 2B, 3, and 4.

Alternative 3 is considered equal to Alternative 4 in comparing with threshold criteria in that they both are protective of human health and will eventually meet ARARs. Alternatives 3 and 4 use active redundant or backup treatment components to stop CPCs that exceed PRGs from migrating off Army Reserve Enclave property. Alternative 3 utilizes groundwater collection and treatment to intercept the more highly contaminated portion of the plume, therefore protecting human health and the environment downgradient of the Army Reserve Enclave boundary. Alternative 4 utilizes both groundwater collection/treatment and passive aerobic bioremediation to ensure protection of human health downgradient of the Army Reserve Enclave boundary. The added active treatment technologies in Alternative 4 can be interpreted as increasing the potential protection for downgradient receptors, although passive bioremediation could be added as a contingency alternative to Alternative 3 upon nonperformance of groundwater extraction and intrinsic biodegradation without jeopardizing overall protection of human health and the environment. Alternative 3 might also be considered equal to Alternative 4 in comparing primary balancing criteria for similar reasons specified for Alternative 2A.

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TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
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ASSESSMENT FACTORS	ALTERNATIVE 1: NO ACTION	ALTERNATIVE 2A: INTRINSIC BIOREMEDIATION	ALTERNATIVE 2B: INTRINSIC BIOREMEDIATION/ SOIL VENTING OF GASOLINE UST SOILS	ALTERNATIVE 3: GROUNDWATER COLLECTION AND TREATMENT / INTRINSIC BIOREMEDIATION DOWNGRADIENT	ALTERNATIVE 4: GROUNDWATER COLLECTION AND TREATMENT / PASSIVE BIOREMEDIATION DOWNGRADIENT
<u>OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT</u>					
<u>Human Health</u>	Can potentially reduce future exposure or potential risks by intrinsic bioremediation. No monitoring activities would occur to evaluate human health protection.	Protection of human health provided by intrinsic bioremediation and by implementing a long-term groundwater monitoring program.	Protection of human health provided by intrinsic bioremediation to reduce groundwater contaminant concentrations, SVE to minimize the potential for groundwater recontamination and by implementing a long-term groundwater monitoring program.	Protection of human health provided by groundwater extraction/treatment of source area groundwater and intrinsic bioremediation to minimize migration of downgradient groundwater CPCs. A long-term groundwater monitoring program would be implemented to evaluate human health protection.	Protection of human health provided by groundwater extraction & treatment to intercept the plume in the source area, installing passive bioremediation wells to promote aerobic biodegradation at the plume edge, and a long-term groundwater monitoring program.
<u>Environment</u>	No ecological exposures at the site.	No ecological exposures at the site.	No ecological exposures at the site.	No ecological exposures at the site.	No ecological exposures at the site.
<u>Compliance with ARARs</u>					
<u>Location-Specific</u>	No location-specific ARARs would be triggered.	No location-specific ARARs would be triggered.	No location-specific ARARs would be triggered.	No location-specific ARARs would be triggered.	No location-specific ARARs would be triggered.
<u>Chemical-Specific</u>	MCLs/MMCLs for CPCs could potentially be met. No monitoring activities would occur to evaluate compliance.	MCLs/MMCLs for CPCs could potentially be met. Long-term groundwater monitoring would be used to evaluate compliance.	MCLs/MMCLs for CPCs could potentially be met. Long-term groundwater monitoring would be used to evaluate compliance.	MCLs/MMCLs for CPCs could potentially be met. Long-term groundwater monitoring would be used to evaluate compliance.	MCLs/MMCLs for CPCs could potentially be met. Long-term groundwater monitoring would be used to evaluate compliance.

(continued)

TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

ASSESSMENT FACTORS	ALTERNATIVE 1: NO ACTION	ALTERNATIVE 2A: INTRINSIC BIOREMEDIATION	ALTERNATIVE 2B: INTRINSIC BIOREMEDIATION/ SOIL VENTING OF GASOLINE UST SOILS	ALTERNATIVE 3: GROUNDWATER COLLECTION AND TREATMENT / INTRINSIC BIOREMEDIATION DOWNGRADIENT	ALTERNATIVE 4: GROUNDWATER COLLECTION AND TREATMENT / PASSIVE BIOREMEDIATION DOWNGRADIENT
<u>Action-Specific</u>	• No action or monitoring performed.	• Long-term groundwater monitoring will meet the intent of 310 CMR 30.660-30.679.	• Same as Alternative 2A. Also disposal of carbon would meet 40 CFR 268 and SVE vapor treatment would meet 310 CMR 7.00 by reducing VOCs by a minimum of 95%.	• Same as Alternative 2. Also groundwater discharge would meet Pretreatment Program 40 CFR Part 403 requirements; disposal of treatment residues would meet 40 CFR 268; and air emissions would meet 310 CMR 6.00-7.00.	• Same as Alternative 3. Also Oxygen Releasing Compound application would be in compliance with 40 CFR Parts 144 & 146 Underground Injection Control Program and 310 CMR 27.00 Underground Water Source Protection
<u>Long-Term Effectiveness and Permanence</u>					
<u>Adequacy and Reliability of Controls</u>	• Not applicable	• No untreated groundwater that creates human health risk will migrate off site. Potential degradation to PRGs could occur on site but would need to be confirmed with additional sampling and modeling. Five-year site reviews will be performed until PRGs are achieved. Long-term monitoring will continue until 3 consecutive sampling rounds report concentrations below PRGs.		• Same as Alternative 2.	• Same as Alternative 2.

(continued)

TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

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FORT DEVENS, MA

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<u>Magnitude of Residual Risk</u>	Can potentially reduce risk by reducing CPCs to PRGs by intrinsic bioremediation. No monitoring activities would occur to evaluate magnitude of residual risk.	CPCs in groundwater could potentially be reduced to PRGs by intrinsic bioremediation. Sampling and modeling required to refine remediation time.	Same as Alternative 2A. SVE will permanently remove organic CPCs from the UST soils directly above the groundwater table to minimize the possibility of groundwater recontamination.	Same as Alternative 2. Also groundwater extraction also permanently removes CPCs from groundwater.	Same as Alternative 3. Passive bioremediation would minimize the probability of residual risk off Army Enclave property.
<u>Reduction of Toxicity, Mobility, or Volume through Treatment</u>	Can potentially reduce toxicity, mobility and volume of CPCs by intrinsic bioremediation. No monitoring activities would occur to evaluate effectiveness.	Intrinsic bioremediation destroys the organic CPCs, reducing toxicity, volume and the possibility that CPCs exceeding PRGs migrate off Army Reserve Enclave property.	Same as Alternative 2A. SVE also is implemented to extract and treat organic CPCs in the soil that might otherwise recontaminate the groundwater.	Same as Alternative 2. extraction & treatment also reduces toxicity and volume and hydraulically contains the plume within the source area.	Same as Alternative 3. Also, passive bioremediation wells will promote aerobic biodegradation which can further reduce organic CPC migration potential.
<u>Irreversible Treatment</u>	Potentially provides intrinsic bioremediation as detailed in Alternative 2. No monitoring activities would occur to evaluate the treatment.	Organic CPCs permanently destroyed to CO₂, methane and water and reduced to PRGs. Inorganic CPCs are reverted back to more insoluble inorganic forms.	Same as Alternative 2A. Also effluent gases from the SVE system adsorbed by activated carbon.	Same as Alternative 2. Groundwater treatment also removes organic CPCs from the site by adsorption on activated carbon.	Same as Alternative 3. Passive bioremediation wells will also promote aerobic biodegradation that will permanently degrade contaminants to CO₂ and water.
<u>Type and Quantity of Residuals Remaining after Treatment</u>	Potentially none.	Potentially none.	Spent vapor phase activated carbon from the SVE system.	Pretreatment wastes (sludge, filtered residue) and spent activated carbon.	Pretreatment wastes (sludge, filtered residue) and spent activated carbon.

(continued)

TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

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<u>Statutory Preference for Treatment</u>	Potentially satisfied but treatment can not be verified.	Satisfied.	Satisfied	Satisfied.	Satisfied.
<u>Short-Term Effectiveness</u>					
<u>Community Protection</u>	No short-term effects.	No short-term effects to the community. Long-term groundwater monitoring will assess the potential of CPCs migrating off Army Reserve Enclave property.	Risk to community minimized through air regulations applicable to SVE effluent air stream, and by transportation and disposal regulations of spent activated carbon.	- Same as Alternative 2. Risk to community minimized through transportation and disposal regulations of groundwater treatment wastes. - Dust controls utilized during construction activities.	Same as Alternative 3.
<u>Worker Protection</u>	No work performed.	All site activities would require following a HASP.	All site activities would require following a HASP.	- All site activities would require following a HASP. - Increased physical hazards are associated with additional general construction.	Same as Alternative 3.
<u>Environmental Impacts</u>	No work performed.	No impacts from groundwater monitoring well installation.	Minimal additional impacts from SVE system installation. Dust control & surface runoff restrictions would be imposed.	Dust controls would be utilized during construction activities. Surface water runoff restrictions would be imposed. No impacts from groundwater monitoring well installations.	Same as Alternative 3. No impacts from bioremediation well installations.

(continued)

TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

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<u>Time Until Action is Complete</u>	No action performed.	Assumed to be over 30 years for CPCs to be reduced below PRGs. Modeling following source removal may show remediation to be complete within 4 years.	Potentially the same as Alternative 2A. Groundwater remediation benefits from soil treatment not readily definable.	Same as Alternative 2.	Same as Alternative 3. Passive bioremedial containment minimizes migration potential but does not shorten the time for remedial action.
<u>Implementability</u>					
<u>Ability to Construct and Operate</u>	No action performed.	Long-term groundwater monitoring program easy to implement. Predesign data and modeling are required to refine degradation rates prior to installing additional wells and implementing long-term monitoring plan.	Required engineering and construction services readily available for installing and SVE system.	Same as Alternative 2. In addition, engineering and construction services readily available for installing a groundwater treatment facility and monitoring wells. Pumping tests and hydrogeologic modeling are required to refine well numbers, position and pumping rates to contain the plume.	Same as Alternative 3. In addition, application of Oxygen Releasing Compound will require laboratory treatability tests and if required, minimal field pilot testing to obtain needed design parameters. Required engineering and construction services readily available for installation of bioremediation wells.
<u>Ease of Undertaking Additional Action</u>	Would not interfere with future actions.	Would not interfere with future actions.	Would not interfere with future actions.	Would not interfere with future actions.	Would not interfere with future actions.

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TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

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<u>Ability to Monitor Effectiveness</u>	No monitoring performed.	Effectiveness would be evaluated by long-term groundwater monitoring.	Same as Alternative 2A. the potential of soil re-contaminating the groundwater may be difficult to assess with soil sampling because of possible effects from short-circuiting.	Effectiveness would be evaluated by long-term groundwater monitoring.	Effectiveness would be evaluated by long-term groundwater monitoring.
<u>Ability to Obtain Approvals and Coordinate with Other Agencies</u>	No additional approvals required.	Implementation of five-year site reviews would require coordination with the environmental regulators.	Same as Alternative 2A.	Same as Alternative 2.	Same as Alternative 2.
<u>Availability of Services and Capacity</u>	No action performed.	Sampling and analytical services readily available.	Same as Alternative 2A. Also engineering and construction services readily available.	- Same as Alternative 2. - Engineering and construction services readily available.	Same as Alternative 3.
<u>Availability of Equipment Specialists and Materials</u>	No action performed.	Groundwater sampling, intrinsic bioremediation modeling and groundwater monitoring well installation experience is available locally.	Same as Alternative 2A. Also SVE systems can also be installed by local contractors.	Same as Alternative 2. Groundwater extraction and treatment suppliers are available locally.	Same as Alternative 3. Also, currently there is only one manufacturer of magnesium peroxide Oxygen Releasing Compound and several manufacturers of calcium peroxide Oxygen Releasing Compound.

(continued)

TABLE 5-1
COMPARATIVE ANALYSIS SUMMARY
AOC 43G

FEASIBILITY STUDY REPORT
FORT DEVENS, MA

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Availability of Technologies	• No action performed.	• Groundwater monitoring and well installation are common technologies.	• Same as Alternative 2A. Also, SVE is commonly applied remedial technology.	• Same as Alternative 2. Groundwater extraction/carbon adsorption is a common remedial technology.	• Same as Alternative 3. The Oxygen Releasing Compound technology is also a very basic action but requires laboratory treatability testing.
<u>Cost</u>					
Capital Cost		\$0	\$137,600	\$257,600	\$387,404
Present Worth O&M Cost		\$0	\$473,900	\$1,444,900	\$2,139,800
Present Worth Cost		\$0	\$611,500	\$1,702,500	\$2,527,200

Notes:

CO₂ = Carbon dioxide
CPC = Chemical of Potential Concern
HASP = Health and Safety Plan
MADEP = Massachusetts Department of Environmental Protection
MCL = Maximum Contaminant Level
MMCL = Massachusetts Maximum Contaminant Level

LIST OF ACRONYMS AND ABBREVIATIONS

AAFES	Army Air Force Exchange Service
ABB-ES	ABB Environmental Services Inc.
AOC	Area of Contamination
ARAR	applicable or relevant and appropriate requirements
ATEC	ATEC Associates, Inc.
BEHP	bis(2-ethylhexyl)phthalate
bgs	below ground surface
BRAC	Base Realignment and Closure Act of 1990
BTEX	benzene, toluene, ethylbenzene, and xylenes
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm ²	centimeters squared
CMR	Code of Massachusetts Regulations
CPC	Chemical of Potential Concern
1,2-DCA	1,2-dichloroethane
EPC	Exposure Point Concentration
FFA	Federal Facility Agreement
FS	Feasibility Study
GAC	granular activated carbon
GC	gas chromatograph
gpm	gallons per minute
HSA	hollow-stem augers
HI	hazard index
HQ	Hazard Quotient
IAG	Interagency Agreement
IR	infrared spectrophotometer
MADEP	Massachusetts Department of Environmental Protection
MCL	Maximum Contaminant Level
MCP	Massachusetts Contingency Plan
MEP	Master Environmental Plan

ABB Environmental Services, Inc.

LIST OF ACRONYMS AND ABBREVIATIONS

mgd	million gallons per day
mg/L	milligrams per liter
MMCL	Massachusetts Maximum Contaminant Level
MSL	mean sea level
NCP	National Contingency Plan
NDIR	non-dispersed Infrared
NPL	National Priorities List
O&M	operation and maintenance
ORP	oxidation reduction potential
PAL	Project Analyte List
PAH	Poly Aromatic Hydrocarbons
PCE	tetrachloroethene
PID	photoionization detector
ppm	parts per million
PRE	preliminary risk evaluation
PRG	Preliminary Remediation Goals
PVC	polyvinyl chloride
RAGS	Risk Assessment Guidance for Superfund
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
SA	Study Area
SARA	Superfund Amendments and Reauthorization Act
scfm	standard cubic feet per minute
SCS	Soil Conservation Service
SI	Site Investigation
SMCL	Secondary Maximum Contaminant Level
SMMCL	Secondary Massachusetts Maximum Contaminant Level
SSI	Supplemental Site Investigation
SVE	soil vapor extraction
SVOC	semivolatile organic compound

ABB Environmental Services, Inc.

LIST OF ACRONYMS AND ABBREVIATIONS

TEX	toluene, ethylbenzene and xylenes
TPHC	Total Petroleum Hydrocarbons
TSD	treatment, storage and disposal
TSS	total suspended solids
$\mu\text{g/g}$	micrograms per gram
$\mu\text{g/kg}$	micrograms per kilogram
$\mu\text{g/L}$	micrograms per Liter
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
USEPA	U.S. Environmental Protection Agency
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound
WWTF	waste water treatment facility

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MEMORANDUM

To: Jake Jacobson/File
From : Rod Pendleton / Rod Rustad
Date: February 5, 1996
Subject: Fort Devens/AOC 43G Groundwater Modeling

This memorandum discusses the approach to groundwater modeling and simulation of groundwater extraction for AOC 43G at Fort Devens, MA, and summarizes the findings. Results from the modeling effort are to be used in the screening of potential remedial alternatives. The objectives of the groundwater modeling are to simulate a groundwater extraction system that halts the further migration of contaminants. The QuickFlow model by Geraghty and Miller (v. 1.0, © 1991) was used to simulate the groundwater extraction systems.

ASSUMPTIONS

The following assumptions are inherent in the QuickFlow model:

- 1) QuickFlow is designed to solve two-dimensional groundwater flow problems in a horizontal plane.
- 2) Groundwater flow is horizontal and occurs in an infinite aquifer.
- 3) The aquifer hydraulic conductivity is assumed to be isotropic and homogeneous.
- 4) The reference head in the steady-state model is constant throughout all calculations.
- 5) All pumping rates are constant throughout time.
- 6) All trenches/wells are assumed to fully penetrate the aquifer.

All model runs for this task were performed using the steady-state mode.

Based on these assumptions, it is obvious that the model cannot take into account all site-specific conditions. For example, the model cannot account for the heterogeneities of the fill/till aquifer, or the bedrock aquifer. In addition, simplifying assumptions had to be made regarding groundwater flow direction, gradient, and aquifer thickness since these are not uniform across the site. Therefore, results of this model should not be used for detailed remedial design purposes, but are sufficient to use for the screening of remedial alternatives. For actual remedial design, a more detailed modeling effort is recommended.

MODEL INPUTS

The following inputs were used in the QuickFlow model to simulate conditions at AOC 43G:

Hydraulic Conductivity:	6 ft/day
Porosity:	0.25
Elevation of Top of Aquifer:	286 ft, MSL
Elevation of Bottom of Aquifer:	250 ft, MSL
Uniform Regional Gradient:	0.04 ft/foot

The hydraulic conductivity used is derived from the geometric mean of transmissivities calculated from the aquifer pumping tests conducted at monitoring wells XGM-94-04X and XGM-94-06X (Table 1). The approximate average thickness of the overburden aquifer, accounting for seasonal variability and the eroded bedrock surface, is 8 feet. In order to simulate unconfined conditions and account for the sloping bedrock surface at AOC 43G, it was necessary to input an aquifer thickness of 36 feet (286-250 ft, MSL). Resultant saturated thickness in the vicinity of the proposed extraction wells, as simulated by the model, range between 30 and 26 feet. The equation for the volumetric flow rate, $Q=KiA$, shows that for constant hydraulic conductivity (K) and horizontal hydraulic gradient (i) the volumetric flow rate (Q) is directly proportional to the cross sectional area of saturated aquifer (A). Therefore, because the saturated thickness simulated by the model is approximately three and a half times greater than actual, extraction rates simulated by this model are approximately three and a half times greater than would be necessary for the actual 8 foot saturated thickness. The uniform regional gradient and groundwater flow direction used in the model are based on water level data from the site collected on May 9, 1995. This data set appears to provide the best approximation of average site conditions (as compared to the water level data collected on December 4, 1994 and January 31, 1995). A water level contour plan for the January 31, 1995 data is presented in the Final RI Report for AOC 43G (February 1996).

Figure 1 presents the simulated static water level at AOC 43G. The reference head (denoted by ® in the upper left corner of Figure 1) remains constant throughout the steady-state simulation, providing water to the model. As a result, recharge was not input into the model (see Section 6, Model Verification, in the QuickFlow Version 1.0 manual, September 1991 for a comparison of QuickFlow vs. MODFLOW).

MODEL RESULTS AND CONCLUSIONS

Based on the results of the model simulation runs, it appears that hydraulic containment of the groundwater plume can be obtained with five vertical 6-inch extraction wells, each pumping at a rate of approximately 0.66 gallons per minute (gpm) (3.3 gpm cumulative). As discussed above, this estimate is approximately a third of that calculated by the model due to the differing saturated thickness. Figure 2 presents the results of the steady-state simulation.

As a check of the models viability, the amount of water flowing through the area of saturated aquifer bounded by the outermost extraction wells over a given time (volumetric flow rate) was calculated under static conditions (no pumping):

$$\begin{aligned}Q &= KiA \\K &= 6 \text{ ft/day} \\i &= 0.04 \text{ ft/ft} \\ \text{length of trench} &= 140 \text{ ft} \\ \text{saturated thickness} &= 28 \text{ ft (model), 8 ft (actual conditions)}\end{aligned}$$

$$Q_{\text{model}} = 4.9 \text{ gpm}$$

$$Q_{\text{actual}} = 1.4 \text{ gpm}$$

These calculated volumetric flow rates indicate that the modeled estimates are viable.

To repeat, results of the QuickFlow model runs are not recommended for detailed remedial design purposes, but are sufficient to use for the screening of remedial alternatives. For actual remedial design, a more detailed modeling effort is recommended.

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AQUIFER PUMPING TEST TRANSMISSIVITY AND STORAGE RESULTS
AOC 43G - HISTORIC GAS STATION G / AAFES GAS STATION

MONITORING WELL ID	JENKINS AND PRENTICE	JACOB METHOD ¹		SEN DIMENSIONLESS ANALYSIS	COOPER LEAKY AQUIFER ²		RESIDUAL DRAWDOWN ANALYSIS ³
		T (FT ² /DAY)	S		T (FT ² /DAY)	S	
XGM-94-06X CONSTANT-RATE DISCHARGE TEST							
XGM-94-06X	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	77
XGP-94-02X	NON-LIN	36	0.16	2.3	39	0.08	30
XGP-94-03X	NON-LIN	134	0.001	2.35	41	0.016	27
XGP-94-04X	NON-LIN	74	0.016	2.16	65	0.012	61
DISTANCE-DRAWDOWN ANALYSIS AT t = 1 DAY, Q = 0.38 GPM: T = 69 FT ² /DAY, S = 0.02							
XGM-94-04X CONSTANT-RATE DISCHARGE TEST							
XGM-94-04X	LIN	NA	NA	NA	NO MATCH	NO MATCH	55
XGP-94-01X	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	340
XGP-94-05X	LIN	27	0.07	2.5	34	0.004	48
XGP-94-06X	LIN	36	0.006	2.1	28	0.001	43
XGP-94-07X	LIN	37	0.006	2.2	34	0.002	36
XGM-93-02X	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	71
XGM-94-10X	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	94
AAFES-6	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	59
AAFES-1D	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	74
XGM-94-03X	NON-LIN	NA	NA	NA	NO MATCH	NO MATCH	71

GEOMETRIC MEAN OF TRANSMISSIVITIES COMPUTED FROM PUMPING TEST DATA ¹ :	46 FT ² /DAY
HYDRAULIC CONDUCTIVITY (ASSUMING AN 8-FOOT AQUIFER THICKNESS):	6 FT/DAY

SOURCE: FINAL AOC43G RI REPORT (FEBRUARY 1996).

NOTES

- 1 - NA INDICATES THAT THE DIMENSIONLESS TIME FACTOR EXCEEDS 0.05, THIS CONDITION NOT SATISFIED
- 2 - "NO MATCH" INDICATES THAT THE LOG-LOG CURVE DID NOT SUFFICIENTLY MATCH THE THEIS TYPE CURVE
- 3 - GEOMETRIC MEAN DOES NOT INCLUDE TRANSMISSIVITIES FROM XGP-94-01X AND XGP-94-03X.

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AOC 43G SIMULATED STATIC WATER LEVEL

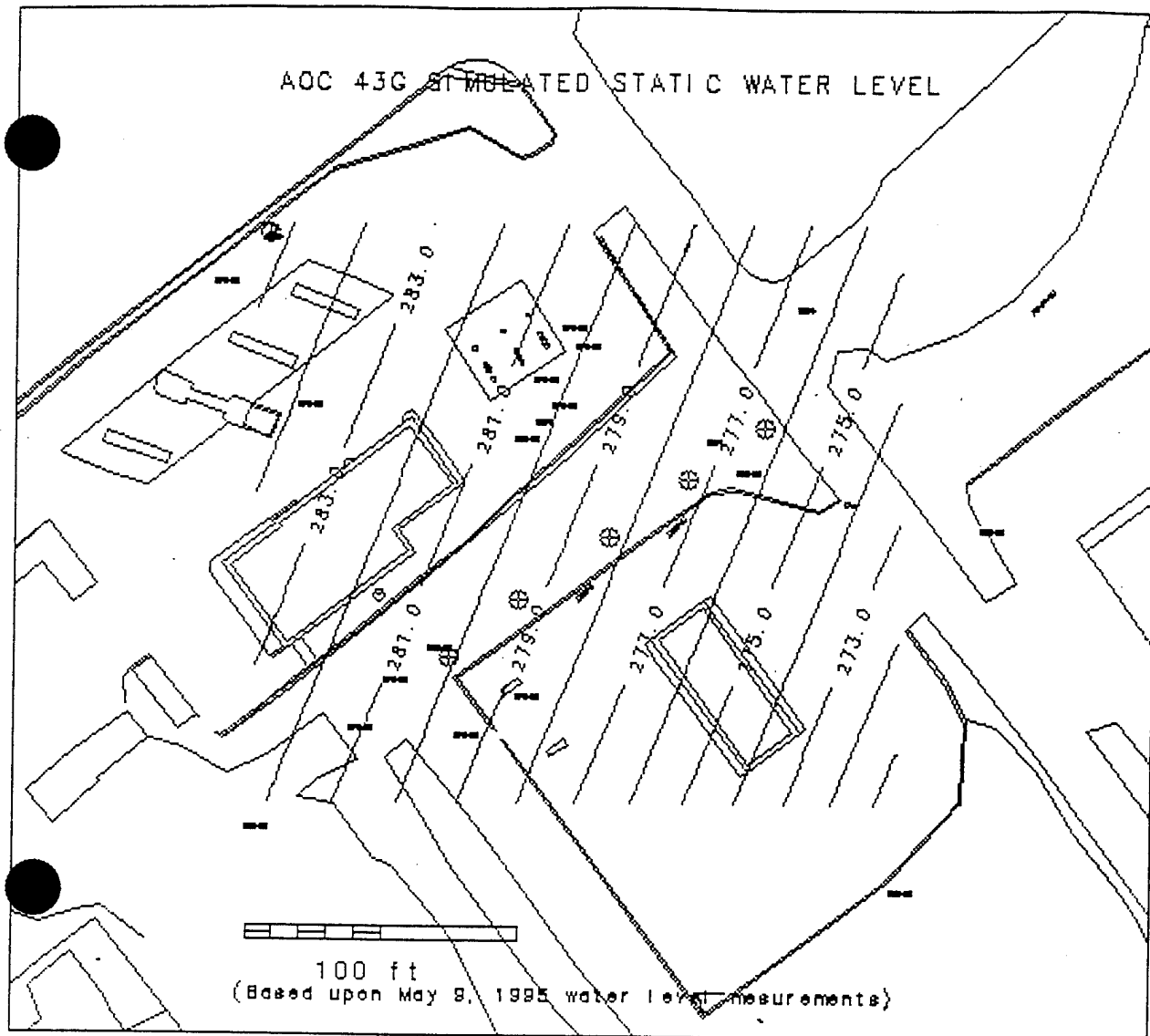


FIGURE 1

AOC 43G SIMULATED STATIC WATER LEVEL

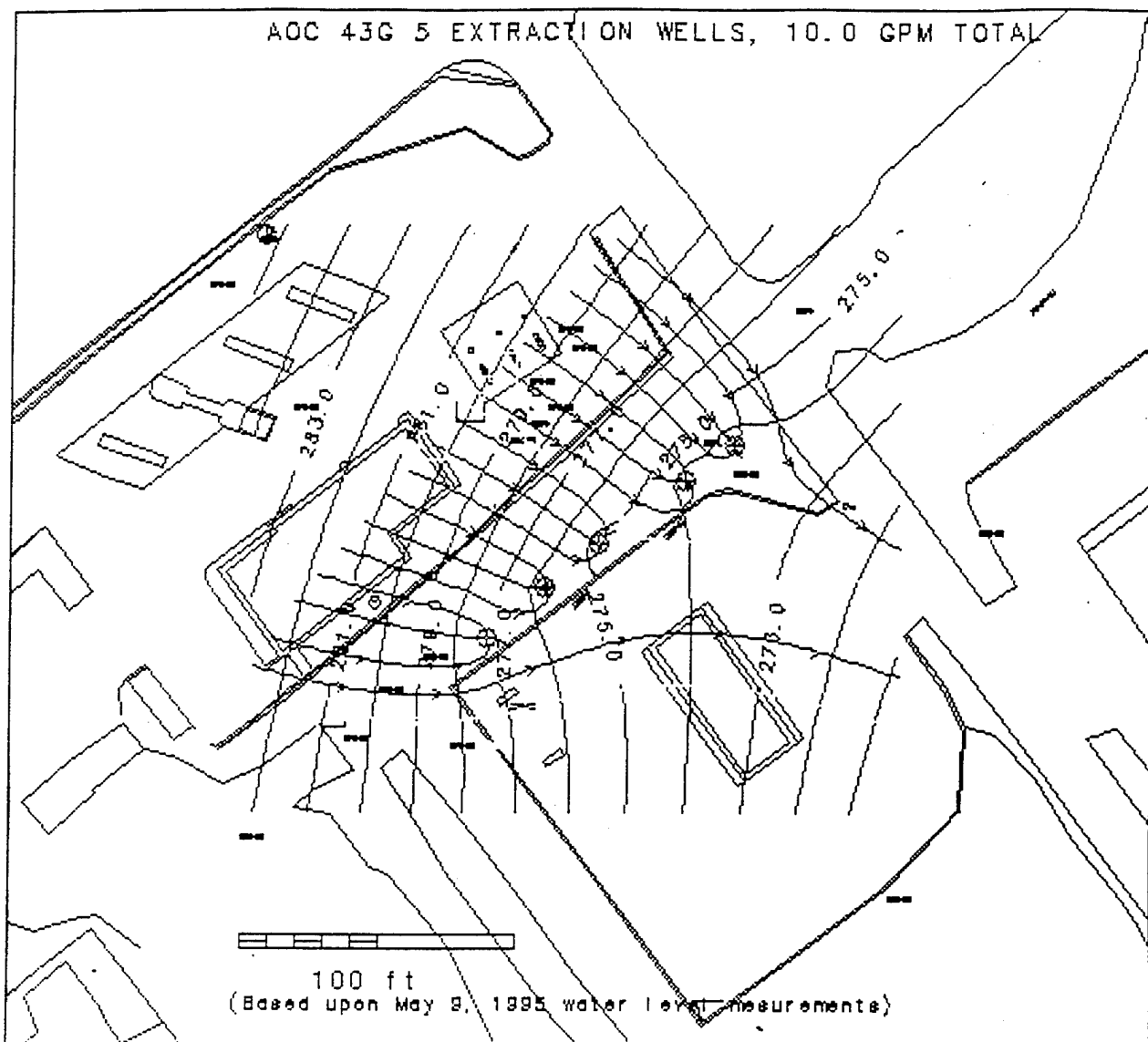


FIGURE 2 AOC 43G EXTRACTION WELL SCENARIO

TOTAL Q = 10 GPM (3.33 GPM FOR ACTUAL AQUIFER THICKNESS)

=====

QuickFlow
Analytical Model of 2D Ground-Water Flow

Developed by
James O. Rumbaugh, III

(c) 1991 Geraghty & Miller, Inc.

=====

Date: 2/2/1996
Time: 15:24:30. 2

Input File: 43g206.gfl
Map File : rod.map

=====

Model Entities

Number of Linesinks Defined by Infiltration Rate = 0

Number of Linesinks Defined by Head = 0

Number of Ponds = 0

Number of Wells = 5

Well #1

Center of Well -- x: 569854.875000 y: 560275.812500

Radius = 0.200000
 Pumping Rate = 384.000000
 Head at Well Radius = 272.619231
 Well #2
 Center of Well -- x: 569872.375000 y: 560289.000000
 Radius = 0.200000
 Pumping Rate = 384.000000
 Head at Well Radius = 272.361506
 Well #3
 Center of Well -- x: 569824.187500 y: 560253.625000
 Radius = 0.200000
 Pumping Rate = 384.000000
 Head at Well Radius = 273.643662
 Well #4
 Center of Well -- x: 569804.812500 y: 560238.375000
 Radius = 0.200000
 Pumping Rate = 384.000000
 Head at Well Radius = 274.449347
 Well #5
 Center of Well -- x: 569782.875000 y: 560220.625000
 Radius = 0.200000
 Pumping Rate = 384.000000
 Head at Well Radius = 275.790981

Reference Head = 285.279999 Defined at -- x: 569701.000000 y:
 560364.125000

=====
 =====

Aquifer Properties

.... Steady-State Flow Model

Permeability.....= 6.000000 [L/T]
 Porosity.....= 0.250000
 Elevation of Aquifer Top....= 286.000000
 Elevation of Aquifer Bottom.= 250.000000
 Uniform Regional Gradient...= 0.040000
 Angle of Uniform Gradient...= 338.000000
 Recharge.....= 0.000000

=====
 =====

Contour Matrix

Number of nodes in the X-direction = 35
 Number of nodes in the Y-direction = 35

Minimum X Coordinate = 569697.312500
 Minimum Y Coordinate = 560157.625000

Maximum X Coordinate = 569932.312500
 Maximum Y Coordinate = 560366.875000

Minimum Head = 270.158813
 Maximum Head = 285.494049

CONTOUR GRID -----

Row 1

1.000000	281.713562	281.366882	281.015717	280.560156
280.300537	279.937225	279.570831	279.202179	273.832184
278.462036	278.092926	277.726044	277.362427	277.002808
276.647583	276.296875	275.950500	275.608063	275.269043
274.932861	274.598846	274.266327	273.934662	273.603210
273.271271	272.938202	272.603394	272.266205	271.926056
271.582275	271.234253	270.881439	270.523163	270.158813

Row 2

282.119141	281.774506	281.424896	281.070312	280.710846
280.346771	279.978485	279.606659	279.232117	278.856110
278.480011	278.105408	277.733887	277.366730	277.004913
276.648865	276.298584	275.953735	275.613770	275.277985
274.945648	274.615997	274.288239	273.961639	273.635468
273.309021	272.981598	272.652527	272.321136	271.986847
271.648956	271.306885	270.959991	270.607666	270.249268

Row 3

282.183533	281.836304	281.483612	281.125427	280.761749
280.392822	280.018951	279.640839	279.259460	278.876190
278.492859	278.111511	277.734283	277.362915	276.998627
276.641815	276.292297	275.949493	275.612610	275.280701

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QuickFlow
Analytical Model of 2D Ground-Water Flow

Developed by
James O. Rumbaugh, III

(c) 1991 Geraghty & Miller, Inc.

=====

Date: 2/2/1996
Time: 11:28:11.77

Input File: 43gstat3.qfl
Map File : rod.map

=====

Model Entities

Number of Linesinks Defined by Infiltration Rate = 0

Number of Linesinks Defined by Head = 0

Number of Ponds = 0

Number of Wells = 5

Well #1

Center of Well -- x: 569768.125000 y: 560210.812500

```

Radius = 0.200000
Pumping Rate = 0.000000
Head at Well Radius      = 280.110055
Well #2
Center of Well -- x: 569793.687500   y: 560232.125000
Radius = 0.200000
Pumping Rate = 0.000000
Head at Well Radius      = 279.364176
Well #3
Center of Well -- x: 569826.000000   y: 560254.875000
Radius = 0.200000
Pumping Rate = 0.000000
Head at Well Radius      = 278.315193
Well #4
Center of Well -- x: 569854.875000   y: 560275.812500
Radius = 0.201000
Pumping Rate = 0.000000
Head at Well Radius      = 277.355494
Well #5
Center of Well -- x: 569882.875000   y: 560294.812500
Radius = 0.200000
Pumping Rate = 0.000000
Head at Well Radius      = 276.365515

```

```

Reference Head = 285.279999   Defined at -- x: 569701.000000   y:
560364.125000

```

```

=====
=====

```

Aquifer Properties

.... Steady-State Flow Model

```

Permeability.....= 6.000000 [L/T]
Porosity.....= 0.250000
Elevation of Aquifer Top....= 286.000000
Elevation of Aquifer Bottom.= 250.000000
Uniform Regional Gradient...= 0.040000
Angle of Uniform Gradient...= 338.000000
Recharge.....= 0.000000

```

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=====
=====

```

Contour Matrix

Number of nodes in the X-direction = 35
 Number of nodes in the Y-direction = 35

Minimum X Coordinate = 569697.312500
 Minimum Y Coordinate = 560157.625000

Maximum X Coordinate = 569932.312500
 Maximum Y Coordinate = 560366.875000

Minimum Head = 270.519104
 Maximum Head = 285.457550

CONTOUR GRID -----

Row 1

282.186981	281.904755	281.620026	281.332703	281.042725
280.750031	280.454498	280.156097	279.854706	279.550201
279.242584	278.931641	278.617371	278.299591	277.978180
277.653046	277.324066	276.991058	276.653900	276.312408
275.966431	275.615784	275.260254	274.899658	274.533783
274.162354	273.785095	273.401794	273.012115	272.615692
272.212219	271.801270	271.382416	270.955200	270.519104

Row 2

282.287903	282.006561	281.722748	281.436371	281.147369
280.855652	280.561157	280.263794	279.963470	279.660126
279.353607	279.043884	278.730835	278.414307	278.094238
277.770477	277.442871	277.111328	276.775665	276.435760
276.091431	275.742462	275.388733	275.029999	274.666016
274.296631	273.921509	273.540405	273.153046	272.759094
272.358215	271.949982	271.534027	271.109894	270.677032

Row 3

282.388489	282.108063	281.825165	281.539703	281.251648
280.960907	280.667419	280.371094	280.071869	279.769592
279.464264	279.155701	278.843842	278.528595	278.209808
277.887360	277.561188	277.231079	276.896912	276.558533

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FINAL REPORT
BIOTREATABILITY STUDY
FORT DEVENS, MASSACHUSETTS

Prepared for:

US ARMY ENVIRONMENTAL CENTER

Prepared by:

ABB Environmental Services, Inc.
Wakefield, MA 01880

PN: 07053.11

AUGUST 1995
(Rev. 2/96)

**FINAL REPORT
BIOTREATABILITY STUDY
FORT DEVENS, MASSACHUSETTS**

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**FINAL REPORT
BIOTREATABILITY STUDY
FORT DEVENS, MASSACHUSETTS**

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1.0 INTRODUCTION

A screening level biodegradation test was conducted to evaluate the feasibility of biodegrading petroleum found in groundwater located at Area of Contamination (AOC) 43G, Fort Devens, Massachusetts.

The specific objectives of the study were to:

- measure chemical parameters that influence biodegradation,
- determine if indigenous hydrocarbon bacteria are present,
- characterize petroleum,
- evaluate nutrient formulations, and
- demonstrate petroleum biodegradation.

Initial characterization analyses and biodegradation testing were performed as part of this screening process. Data obtained from these tests will be used to make an initial assessment on process feasibility and may also be used in conjunction with hydrogeological and other chemical data to prepare a remedial design.

The results from testing are summarized and recommendations for biological treatment are presented in this report.

2.0 CHEMICAL AND MICROBIOLOGICAL CHARACTERIZATION RESULTS

Groundwater was collected from monitoring well AAFES-2. Soil samples were not collected because a majority of the aquifer is in bedrock.

2.1 CHEMICAL ANALYSIS

Results from total petroleum hydrocarbon (TPHC) analysis, using USEPA Method 418.1, indicated that petroleum was measured in sample AAFES-2. Orange colored floc was present in the groundwater samples and TPHC analyses were conducted on samples both with and without the solids. The results, presented in Table 2-1, show that the TPHC levels were influenced by the presence of the solids and the TPHC was higher in the sample that contained the solids. Subsequent tests were conducted using groundwater that contained the solids.

The petroleum in the groundwater contained a high concentration of volatile compounds based on results from GC fingerprint analysis (Modified EPA Method 3550/8100). The petroleum present in the samples exhibited a chromatographic pattern similar to gasoline (Figure 2-1).

There were low levels of ammonia nitrogen detected in groundwater and the pH was neutral (Table 2-2).

2.2 MICROBIAL ANALYSIS

Results from bacteria analysis of groundwater indicated that there is a healthy population of bacteria present and also contained bacteria able to use gasoline as a sole source of carbon (Table 2-3).

2.3 NUTRIENT PRECIPITATION TEST

Phosphate is a nutrient that is provided to enhance microbial activity and in groundwater that contains calcium or magnesium, precipitate may be formed when these chemicals come in contact. Large quantities of precipitate has the potential to create clogging in soils with low permeability and could potentially

ABB Environmental Services, Inc.

affect groundwater flow. Therefore, nutrient formulations that form precipitate should be avoided. Magnesium or calcium phosphate precipitate formation can be avoided by using tripolyphosphate rather than ortho-phosphate as the source of phosphate.

Groundwater was amended with different concentrations of ACT, which is ABB-ES' nutrient formulation (1:1 ratio, by weight, of ammonia chloride and potassium tripolyphosphate). The groundwater was allowed to stand for three hours. Visual observations were made to look for evidence of precipitate formation.

The results showed that precipitate was observed in groundwater with ACT at all levels except 150 mg/L (Table 2-4) therefore, ABB-ES recommends delivering ACT at 150 mg/L during full-scale treatment to avoid precipitate formation.

TABLE 2-1
TOTAL PETROLEUM HYDROCARBON ANALYSIS
EPA 418.1

SAMPLE ID	AAFES-2, NO SOLIDS	AAFES-2, + SOLIDS
Matrix	Water	Water
Date Sampled	12/9/94	12/9/94
TPH (MG/L)	11	272

TABLE 2-2 NITROGEN, PHOSPHATE AND PH ANALYSIS						
SAMPLE ID	DATE SAMPLED	MATRIX	NH4-N ppm	NO3-N ppm	O-PO4 ppm	pH
AAFES-2	12/9/94	Water	0.5E	<0.25	<1	7

E = Estimated value, below detection Limit

**TABLE 2-3
BACTERIA ANALYSIS**

SAMPLE ID	DATE SAMPLED	MATRIX	TOTAL BACTERIA (CFU/ml)	HYDROCARBON BACTERIA (CFU/ml)
AAFES-2	12/9/94	Water	2.4×10^5	4.7×10^3

**TABLE 2-4
PRECIPITATION TEST**

ACT CONCENTRATION ¹	RESULTS
0 mg/L	-
25 mg/L	+
50 mg/L	+
100 mg/L	+/-
150 mg/L	-
175 mg/L	+/-
200 mg/L	+
250 mg/L	+
300 mg/L	+
500 mg/L	++
1000 mg/L	+++
- = no precipitate formed + = precipitate formed +/- = very slight increase in turbidity was observed ¹ 50 ml of Groundwater (AAFES-2) was amended with ACT at the levels specified in this column.	

PETROLEUM FINGERPRINT

MODIFIED 3550/8100

Project: FT DEVENS

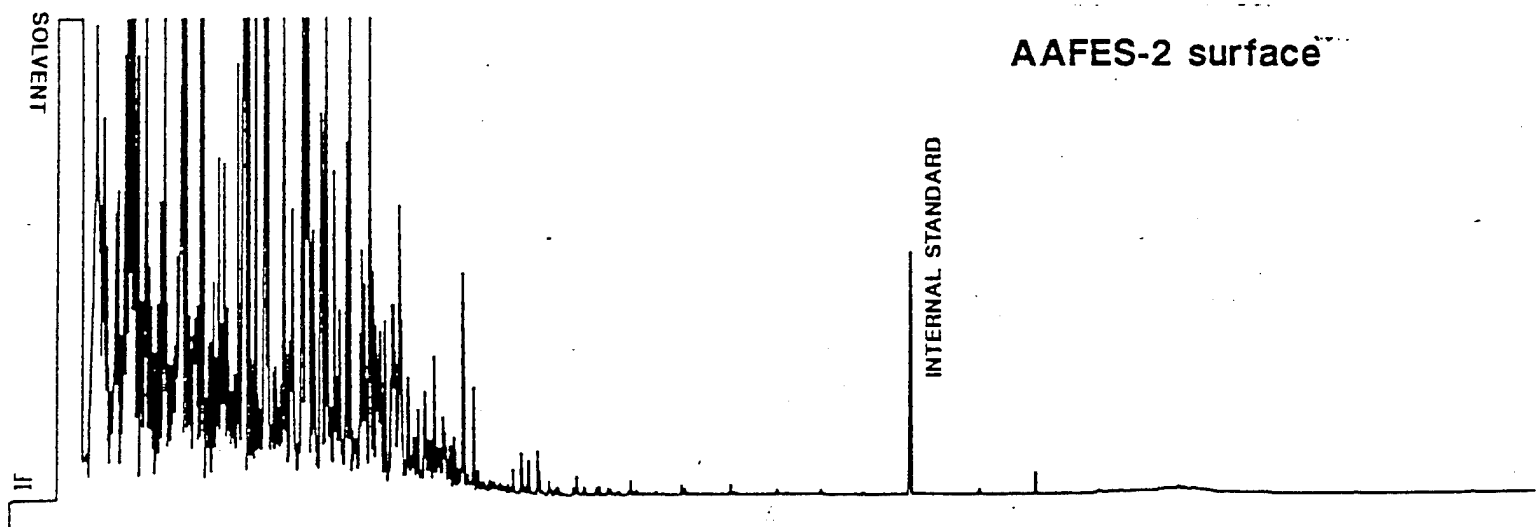
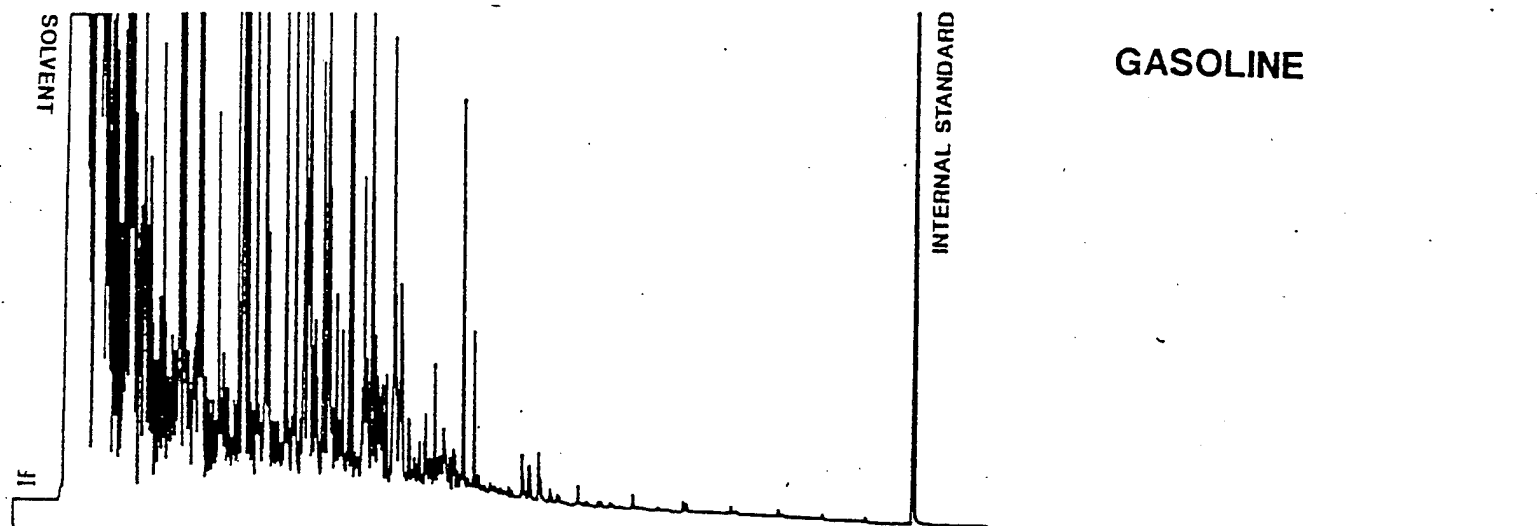


FIGURE 2-1

3.0 BIODEGRADATION TESTING

Biodegradation testing was conducted to demonstrate that TPHC in the groundwater can be biodegraded by indigenous microorganisms and the results are presented in this section.

3.1 TEST PROCEDURES

Test microcosms were prepared using groundwater from monitoring well AAFES-2 from the site. Test vessels were sealed and mineral nutrients, pH adjustment and oxygen were provided. A parallel set of control microcosms were prepared but were amended with the biocide mercuric chloride. The control vessels were used to measure abiotic losses such as volatilization.

TPHC was measured when the microcosms were prepared and after 15 days by IR (EPA 418.1) and GC/FID (Modified EPA Method 3550/8100). The entire contents of duplicate microcosms were extracted and analyzed for TPHC at each time point. Biological activity was monitored over the test period by measuring the concentration of volatile organics in the headspace (direct headspace injection/GC/FID detection), oxygen and carbon dioxide (direct headspace injection/GC/TCD detection).

3.2 RESULTS

An 80% reduction in the concentration of TPHC as measured by IR and 98% by GC/FID was observed in live microcosms after 15 days (Tables 3-1 and 3-2). Some losses in TPHC were also observed in the killed control and were likely due to volatilization.

Organic vapors in the headspace were measured several times during the testing period to monitor biodegradation (Tables 3-3 through 3-6). Results showed that BTEX levels were reduced to below the detection limit in the live microcosm. A reduction was also observed in the killed control, but that occurred primarily between Days 9 and 15. In contrast, BTEX was almost completely degraded in the live microcosm by Day 9, thus losses in the live microcosms would be attributed primarily to biodegradation and not volatilization.

ABB Environmental Services, Inc.

TABLE 3-1
TOTAL PETROLEUM HYDROCARBON ANALYSIS-IR
BIODEGRADATION TEST

TIME (Day)	LIVE (mg/L)		KILLED CONTROL (mg/L)	
0	168	170	168	182
15	43	26	132	152

TABLE 3-2
TOTAL PETROLEUM HYDROCARBON ANALYSIS-GC/FID
BIODEGRADATION TEST

TIME (day)	LIVE (ug/ml)		KILLED (ug/ml)	
0	201.3	204.5	196.1	206.3
15	4.0	1.0	79.6	94.1

TABLE 3-3
VOLATILE ANALYSIS-HEADSPACE GC/FID
BIODEGRADATION TEST

Live Microcosm (ug/L)					
TIME (days)	BENZENE	TOLUENE	ETHYL BENZENE	M/P- XYLENE	O- XYLENE
0	2785	2338	2075	2748	1084
3	1330	1043	733	824	442
5	518	507	ND	404	254
9	ND	ND	ND	61	58
15	ND	ND	ND	ND	ND

ND= Not Detected above 10 ug/L

TABLE 3-4 VOLATILE ANALYSIS-HEADSPACE GC/FID BIODEGRADATION TEST					
Killed Control Microcosm (ug/L)					
TIME (days)	BENZENE	TOLUENE	ETHYL BENZENE	M/P- XYLENE	O- XYLENE
0	2702	2196	1777	2224	874
3	3135	2886	2107	2607	508
5	4115	3088	2354	2885	565
9	3061	2232	1784	2222	461
15	ND	ND	448	609	149

ND= Not Detected above 10 ug/L

TABLE 3-5
CARBON DIOXIDE ANALYSIS-GC/TCD
BIODEGRADATION TEST

TIME (days)	LIVE (mg/L)	KILLED (mg/L)
0	22.8	48
3	185	N/A
5	228	50
9	268	43
15	282	67

TABLE 3-6
RESULTS FROM MINERAL NUTRIENT AND PH ANALYSIS
BIODEGRADATION TEST

Sample ID	Date Sampled	(NO ₃)N (mg/l)	(NH ₃)N (mg/l)	PO ₄ (mg/l)	pH
LIVE T=0	1/25/95	<.25	140	500	7
LIVE T=15	2/9/95	N/A	125	450	6.3

SECTION 3

Carbon dioxide measurements were taken to confirm that reductions in the TPHC were due to biological activity. Results from testing showed that significant quantities of carbon dioxide were formed in the live microcosm and very little in the killed control.

Review of GC chromatograms (Figures 3-1 and 3-2) also show a significant reduction in the chromatographable hydrocarbon in the live microcosm after 15 days.

MODIFIED 3550/8100

Biodegradation Test

Fort Devens

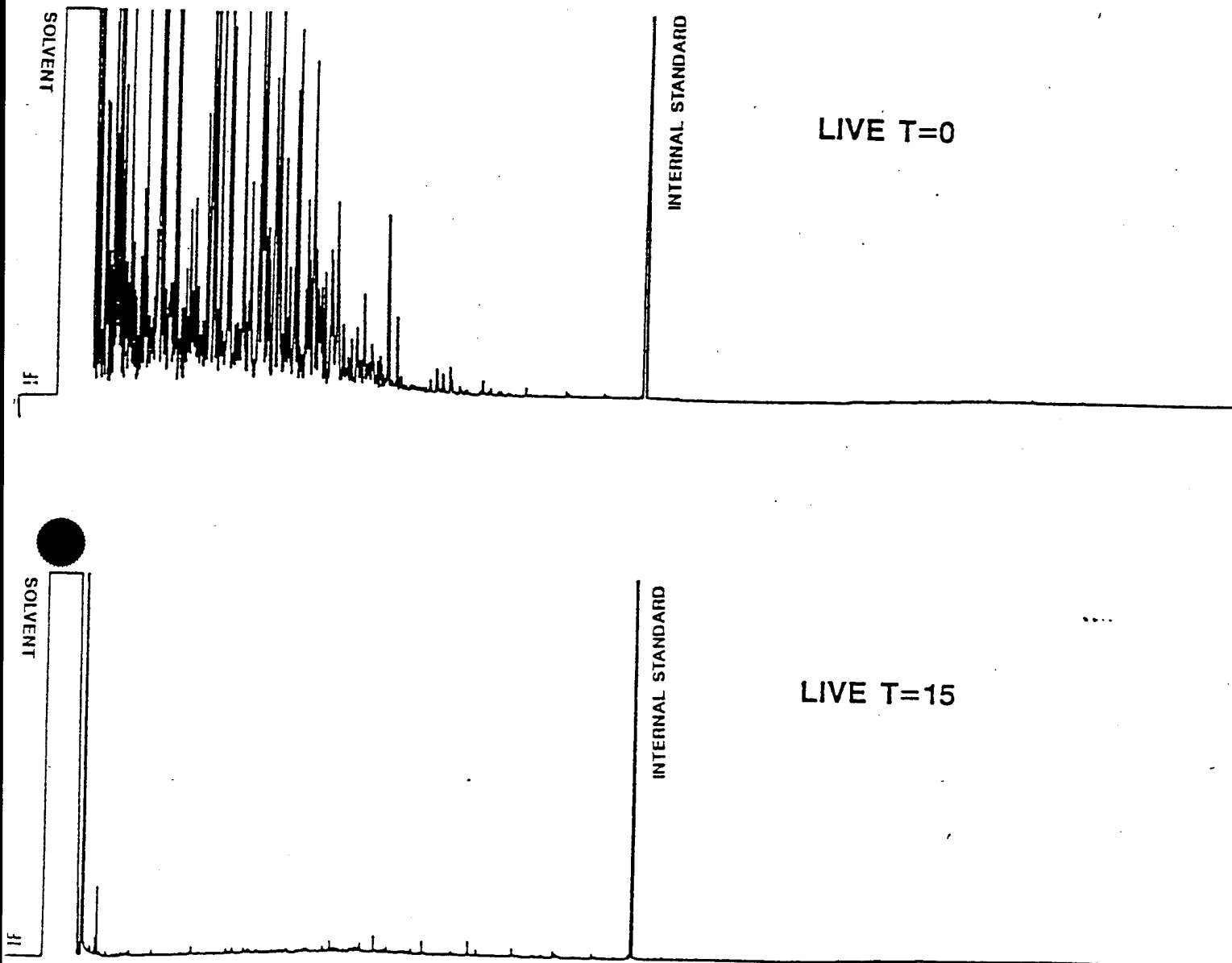


FIGURE 3-1

MODIFIED 3550/8100

Biodegradation Test

Fort Devens

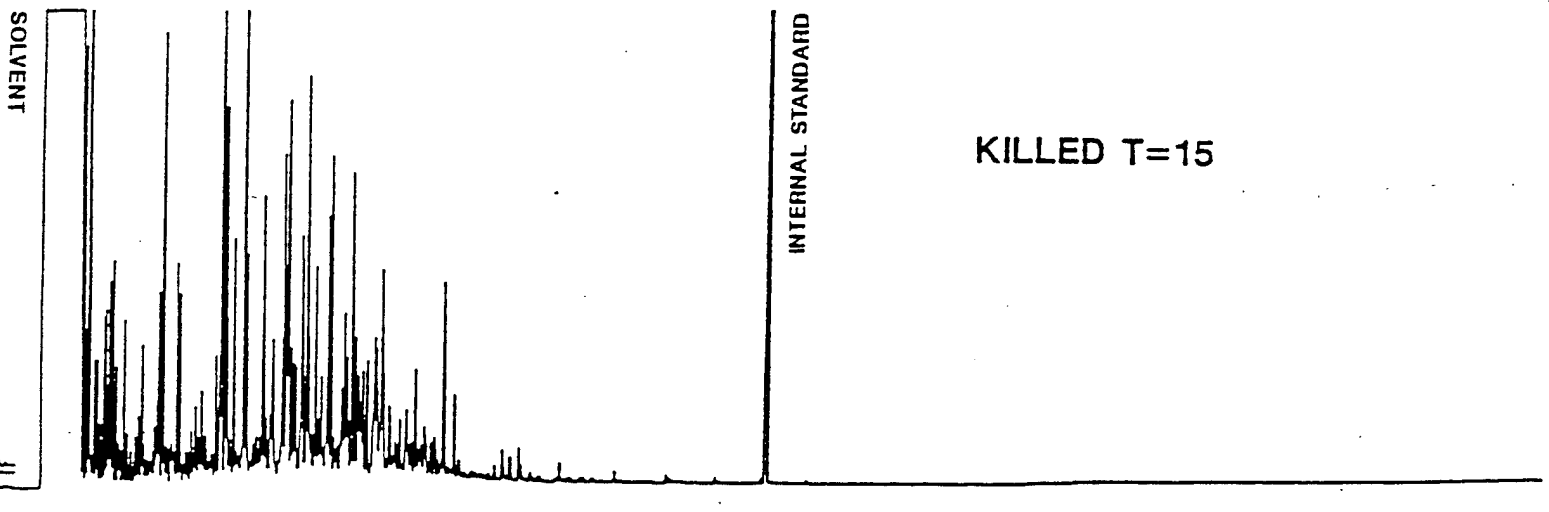
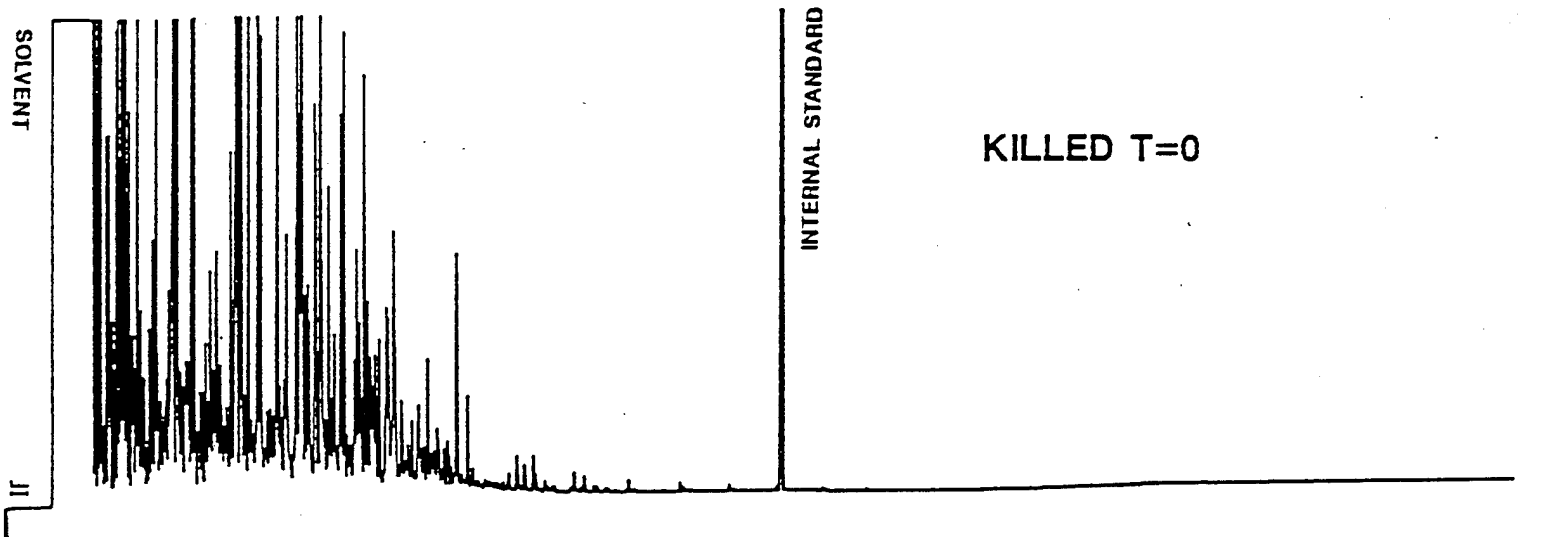


FIGURE 3-1

MODIFIED 3550/8100
Biodegradation Test
Fort Devens, Site
Headspace Finger Print

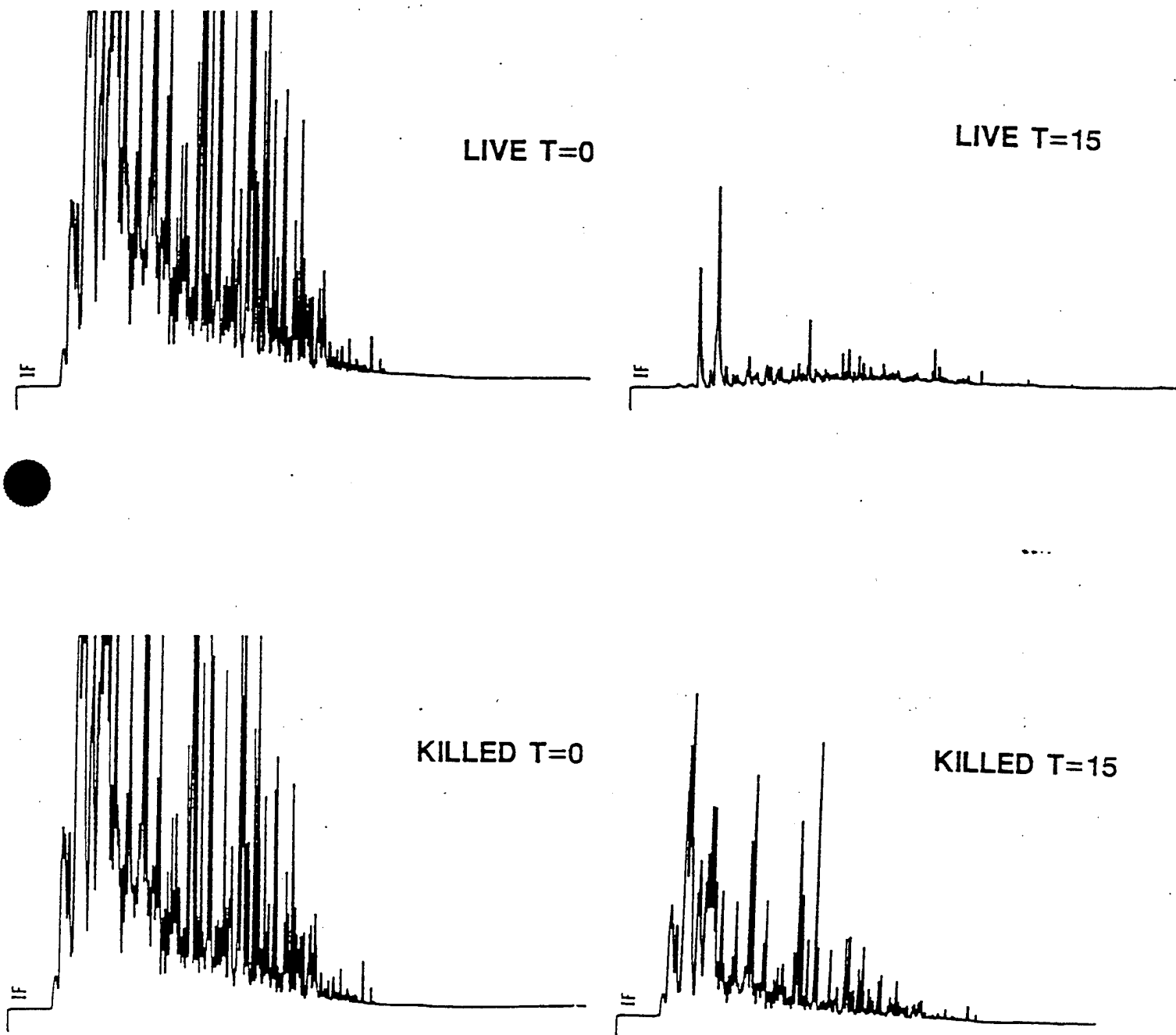


FIGURE 3-2

4.0 CONCLUSIONS

Results from testing have demonstrated that gasoline biodegradation can be enhanced in groundwater at AOC 43G and therefore bioremediation can be considered as a remedial option. The original objectives of the test were met such that:

- gasoline degrading bacteria were detected in groundwater,
- extensive petroleum\BTEX biodegradation was observed in groundwater microcosms that were amended with nitrogen, phosphate and oxygen, and
- if nutrient formulations are used during remediation they should include tripolyphosphate and ABB-ES' ACT formulation at concentrations of approximately 150 mg/L.

Based on these data, technologies such as in-situ bioremediation and intrinsic biodegradation should continue to be considered as remedial alternatives at this site.



MEMORANDUM

To: Jake Jacobson/File
From : Rod Pendleton
Date: February 6, 1996
Subject: Fort Devens/AOC 43G Solute Transport Modeling

This memorandum discusses the approach to solute transport modeling for AOC 43G at Fort Devens, MA, and summarizes the findings. Data from the modeling effort is to be used in the assessment of potential remedial alternatives for AOC 43G. The objective of the solute transport modeling is to simulate existing and future concentrations of contaminants of concern detected in groundwater at the site. In particular, the model assists in estimating contaminant concentrations over time along a flowpath from the source area at the site to the enclave boundary, 275 meters downgradient.

The ONED3 analytical model for solute transport from the International Groundwater Modeling Center Solute Program Package (Beljin, 1990) was used to simulate solute transport of the following contaminants of concern: benzene, ethylbenzene, and xylene.

MODEL ASSUMPTIONS

The following assumptions are inherent in the ONED3 model:

- 1) the aquifer is assumed to be uniformly porous and confined;
- 2) the aquifer is homogeneous, isotropic, semi-infinite in the areal extent, and of constant thickness;
- 3) a (contaminant) source/stream fully penetrates the aquifer;
- 4) there is one-dimensional steady-state uniform regional groundwater flow from the source/stream;
- 5) the density and viscosity of the solute in the source area and aquifer are the same; and
- 6) no solute advection or dispersion occurs through the aquicludes into or out of the aquifer.

This model was selected to provide a conservative estimate of solute transport at AOC 43J (i.e., to provide solute transport estimates that are likely to exceed actual concentrations and transport distances). The model conservatively does not account for dilution due to lateral and vertical dispersion.

Based on these assumptions, it is obvious that the model cannot take into account all site-specific conditions. For example, the model cannot account for the heterogeneities of the aquifer. In addition, simplifying assumptions had to be made regarding groundwater flow direction and gradient, since these are not uniform across the site.

MODEL INPUTS

The following inputs were used in the ONED3 model to simulate conditions at AOC 43G:

Groundwater Velocity:	0.07 m/day
Longitudinal Dispersivity:	12 m

Supporting calculations for these parameters are attached. The groundwater velocity is calculated using the geometric mean of hydraulic conductivity values from all overburden wells, which is higher than the mean of the bedrock wells. Therefore, the velocity is conservatively high with regard to contaminant dispersion. Groundwater flow direction at the site is assumed to be to the southeast (see Figure 1), generally along the centerline of the groundwater contaminant plume.

The regional gradient and flow direction are derived from water level data collected on January 31, 1995. Interpretive water table elevation contours presented in Figure 6-6 of the AOC 43G Final RI Report (February 1996). Calculations of retardation factors for individual contaminants of concern are also attached.

A literature search on decay rates/half-lives of the contaminants of concern was performed, and is summarized in an attachment. Initial decay rates used for modeling contaminants of concern were within the range determined from the literature search, for each compound, and were typically conservative in allowing for less decay than the average values.

For modeling purposes, the source area was assumed to be located between the former waste oil and existing gasoline USTs (see Figure 1). Two simulations of the source area were run for each contaminant of concern:

- 1) In the first simulation, the source was turned "on" (continuous) for the duration of the simulation.
- 2) In the second simulation, the source was turned "on" from the years 1960 to 1996 (13,140 days total), to simulate the leaking USTs. Current plans involve excavation and removal of the sand and gas trap and associated soils to be conducted in August 1996.

Model simulations were made for the following contaminants of concern: benzene, ethylbenzene, and xylene.

MODEL CALIBRATION

The model simulations for each contaminant of concern were performed using the same values for groundwater velocity (0.07 m/day) and longitudinal dispersivity (12 m). Contaminant-specific retardation factors were applied to each simulation. Target concentrations for model calibration were estimated from Figure 1, which presents the estimated distribution of organic groundwater contamination above MCLs in December, 1994. Target concentrations relative to distance from the source area are presented with the output files of the model simulations (attached).

The input parameter for which there is no data available is the concentration at the source. A trial and error approach was taken to estimate the source concentration. Decay rates/half-lives of the contaminants of concern were adjusted in conjunction with the source concentration to obtain a "best-fit" with the 1995 calibration targets. The objective with respect to calibration was to match the center and downgradient edges of the plume as closely as possible with the 1995 calibration targets. Calibration was considered satisfactory when model simulation concentrations (1995) were approximately equal to (or greater than) the 1995 calibration target concentrations. The simplified representation of the source/leak, which is likely to have been variable over the years, defies exact model calibration.

MODEL SIMULATION RESULTS

The outputs of the final model simulations for each of the contaminants of concern are attached. Results of the two different source simulations indicate that plume concentrations achieve steady-state prior to 1995. Discussions of the contaminant-specific simulation results for the continuous source scenario are presented below.

Benzene

The simulated 1995 concentration of 0.0116 mg/L at the leading edge of the benzene plume (100 meters) is slightly above the calibration target of 0.006 mg/L (see attachment). In addition, the simulated concentration in the center of the plume (0.8364 mg/L at 20 meters) reasonably approximates the calibration target of 0.6 mg/L. The simulation indicates that concentrations of benzene would not exceed the MCL of 0.005 mg/L at the enclave boundary (275 meters from the source area) in the future.

Ethylbenzene

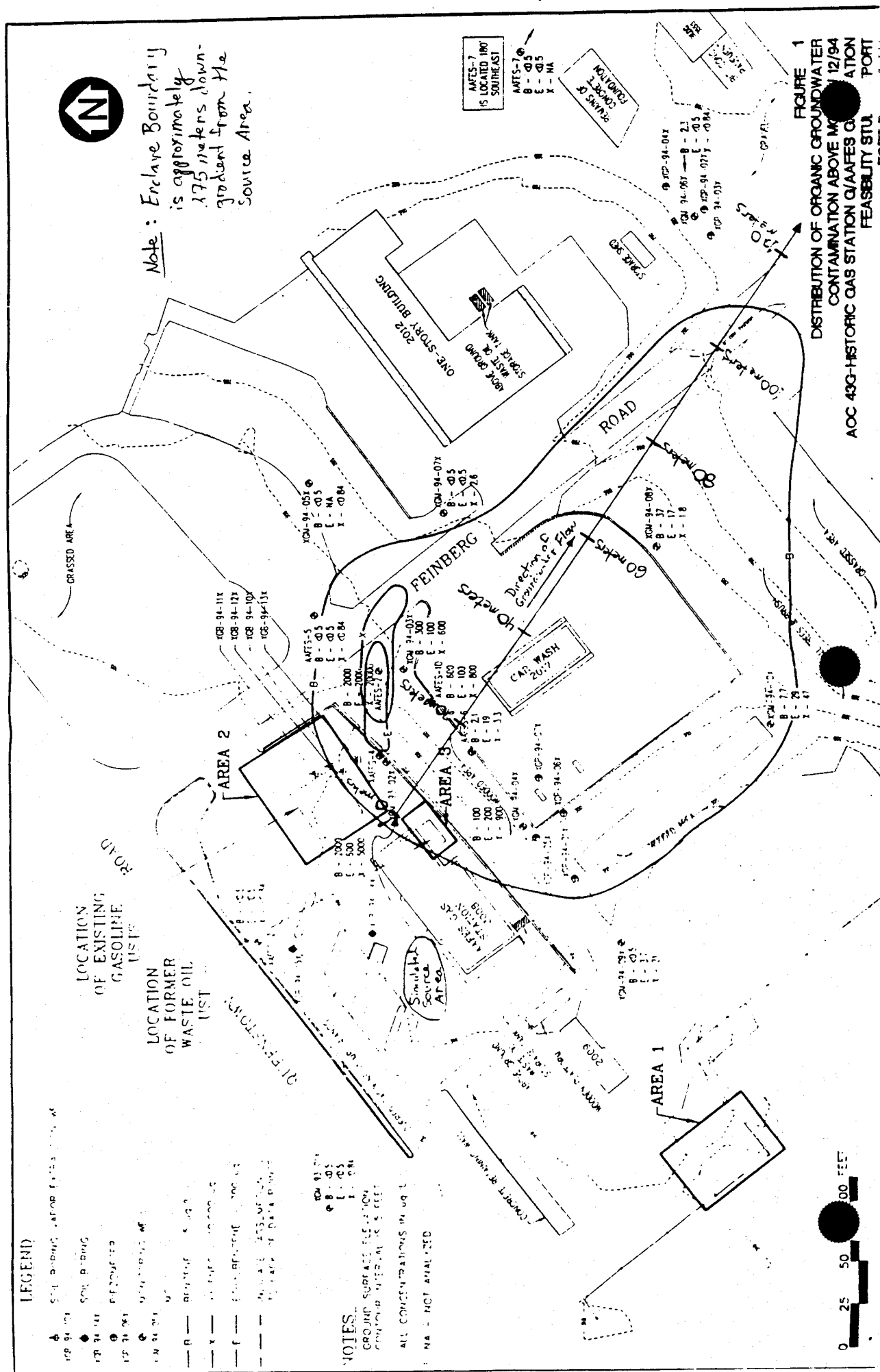
The simulated 1995 concentration of 0.0005 mg/L at 120 meters is conservatively above the calibration target of <0.0005 mg/L (see attachment). In addition, the simulated concentration of 0.0333 mg/L near the center of the plume (60 meters) conservatively approximates the calibration target of 0.02 mg/L. The simulation indicates that concentrations of ethylbenzene would not exceed the MCL of 0.7 mg/L at the enclave boundary (275 meters from the source area) in the future.

Xylene

The simulated 1995 concentration of 0.0144 mg/L at 60 meters is conservatively above the calibration target of 0.002 mg/L (see attachment). In addition, the simulated concentration of 1.8155 mg/L near the source area (20 meters) conservatively approximates the calibration target of 0.8 mg/L. The simulation indicates that concentrations of xylenes would not exceed the MCL of 10.0 mg/L at the enclave boundary (275 meters from the source area) in the future.

SUMMARY AND CONCLUSIONS

Model simulation results indicate that concentrations of contaminants of concern will not exceed MCLs at the enclave boundary. Inputs used for the model simulations are generally conservative, resulting in potential overestimation of contaminant transport. Review of the model outputs indicates that the retardation factor used in the model simulations allows the time for degradation of the contaminants, as downgradient migration is inhibited. Note that the model cannot account for changes in variables such as aquifer heterogeneities, or spatial and temporal changes in biodegradation rates as a result of contaminant concentration distribution, temperature variations, or bacterial count and type.



Benzene

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 1.95
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 4 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS. = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 220 [d]
DECAY CONSTANT (lambda)..... = .315D-02 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 18250 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	2.4367	2.4367	2.4367	2.4367	2.4367	>2.0000
20	0.8364	0.8364	0.8364	0.8364	0.8364	0.6000
40	0.2871	0.2871	0.2871	0.2871	0.2871	
60	0.0985	0.0985	0.0985	0.0985	0.0985	0.0400
80	0.0338	0.0338	0.0338	0.0338	0.0338	
100	0.0116	0.0116	0.0116	0.0116	0.0116	0.0060
120	0.0040	0.0040	0.0040	0.0040	0.0040	0.0020
140	0.0014	0.0014	0.0014	0.0014	0.0014	
160	0.0005	0.0005	0.0005	0.0005	0.0005	
180	0.0002	0.0002	0.0002	0.0002	0.0002	
200	0.0001	0.0001	0.0001	0.0001	0.0001	

- Notes:
- 1) All concentrations are in mg/L (ppm)
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs).
 - 3) The modeled source is turned "on" for the entire simulation.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area; the enclave boundary is approximately 275 meters downgradient from the source area
 - 5) Benzene MCL is 0.005 mg/L.
 - 6) Shading indicates modeled concentrations exceeding the MCL
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

Benzene

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 1.95
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 4 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS. = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 220 [d]
DECAY CONSTANT (lambda)..... = .315D-02 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 13140 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	2.4367	2.4367	2.4367	0.0006	0.0000	>2.0000
20	0.8364	0.8364	0.8364	0.0019	0.0000	0.6000
40	0.2871	0.2871	0.2871	0.0036	0.0000	
60	0.0985	0.0985	0.0985	0.0049	0.0000	0.0400
80	0.0338	0.0338	0.0338	0.0048	0.0000	
100	0.0116	0.0116	0.0116	0.0036	0.0000	0.0060
120	0.0040	0.0040	0.0040	0.0021	0.0000	0.0020
140	0.0014	0.0014	0.0014	0.0010	0.0000	
160	0.0005	0.0005	0.0005	0.0004	0.0000	
180	0.0002	0.0002	0.0002	0.0002	0.0000	
200	0.0001	0.0001	0.0001	0.0001	0.0000	

- Notes
- 1) All concentrations are in mg/L (ppm).
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs)
 - 3) The modeled source is turned "on" from 1960 to 1996.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area, the enclave boundary is approximately 275 meters downgradient from the source area
 - 5) Benzene MCL is 0.005 mg/L
 - 6) Shading indicates modeled concentrations exceeding the MCL
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

Ethylbenzene

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 13.56
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 4 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS. = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 1050 [d]
DECAY CONSTANT (lambda)..... = .603D-03 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 18250 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	2.1755	2.1788	2.1788	2.1788	2.1788	2.0000
20	0.5314	0.5410	0.5410	0.5410	0.5410	0.1000
40	0.1213	0.1343	0.1343	0.1343	0.1343	0.0200
60	0.0233	0.0333	0.0333	0.0333	0.0334	
80	0.0033	0.0082	0.0082	0.0083	0.0083	
100	0.0003	0.0020	0.0020	0.0020	0.0021	
120	0.0000	0.0005	0.0005	0.0005	0.0005	<0.0005
140	0.0000	0.0001	0.0001	0.0001	0.0001	
160	0.0000	0.0000	0.0000	0.0000	0.0000	
180	0.0000	0.0000	0.0000	0.0000	0.0000	
200	0.0000	0.0000	0.0000	0.0000	0.0000	

- Notes:
- 1) All concentrations are in mg/L (ppm).
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs).
 - 3) The modeled source is turned "on" for the entire simulation.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area; the enclave boundary is approximately 275 meters downgradient from the source area.
 - 5) Ethylbenzene MCL is 0.700 mg/L.
 - 6) Shading indicates modeled concentrations exceeding the MCL.
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

Ethylbenzene

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 13.56
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 4 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS. = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 1050 [d]
DECAY CONSTANT (lambda)..... = .603D-03 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 13140 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	2.1755	2.1788	2.1788	0.1818	0.0046	2.0000
20	0.5314	0.5410	0.5410	0.3064	0.0132	0.1000
40	0.1213	0.1343	0.1343	0.1277	0.0170	
60	0.0233	0.0333	0.0333	0.0333	0.0123	0.0200
80	0.0033	0.0082	0.0082	0.0083	0.0056	
100	0.0003	0.0020	0.0020	0.0020	0.0018	
120	0.0000	0.0005	0.0005	0.0005	0.0005	<0.0005
140	0.0000	0.0001	0.0001	0.0001	0.0001	
160	0.0000	0.0000	0.0000	0.0000	0.0000	
180	0.0000	0.0000	0.0000	0.0000	0.0000	
200	0.0000	0.0000	0.0000	0.0000	0.0000	

- Notes:
- 1) All concentrations are in mg/L (ppm).
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs).
 - 3) The modeled source is turned "on" from 1960 to 1996.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area. The enclave boundary is approximately 275 meters downgradient from the source area.
 - 5) Ethylbenzene MCL is 0.700 mg/L.
 - 6) Shading indicates modeled concentrations exceeding the MCL.
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

Xylenes

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 10.48
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 50 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS. = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 350 [d]
DECAY CONSTANT (lambda)..... = .198D-02 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 18250 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	20.3965	20.3965	20.3965	20.3965	20.3965	20.0000
20	1.8155	1.8155	1.8155	1.8155	1.8155	0.8000
40	0.1616	0.1616	0.1616	0.1616	0.1616	
60	0.0144	0.0144	0.0144	0.0144	0.0144	0.0020
80	0.0013	0.0013	0.0013	0.0013	0.0013	
100	0.0001	0.0001	0.0001	0.0001	0.0001	
120	0.0000	0.0000	0.0000	0.0000	0.0000	<0.00084
140	0.0000	0.0000	0.0000	0.0000	0.0000	
160	0.0000	0.0000	0.0000	0.0000	0.0000	
180	0.0000	0.0000	0.0000	0.0000	0.0000	
200	0.0000	0.0000	0.0000	0.0000	0.0000	

- Notes:
- 1) All concentrations are in mg/L (ppm).
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs).
 - 3) The modeled source is turned "on" for the entire simulation.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area; the enclave boundary is approximately 275 meters downgradient from the source area.
 - 5) Xylene MCL is 10,000 mg/L.
 - 6) Shading indicates modeled concentrations exceeding the MCL.
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

Xylenes

Input Parameters:

GROUNDWATER (SEEPAGE) VELOCITY = 0.07 [m/d]
LONGITUDINAL DISPERSIVITY..... = 12 [m]
RETARDATION FACTOR..... = 10.48
INITIAL CONCENTRATION..... = 0 [mg/l]
CONCENTRATION AT SOURCE..... = 50 [mg/l]
DISTANCE INCREMENT..... = 20 [m]
NUMBER OF DISTANCE INCREMENTS = 10
NUMBER OF TIME PERIODS..... = 5
1 TIME..... = 5475 [d]
2 TIME..... = 12775 [d]
3 TIME..... = 13140 [d]
4 TIME..... = 14600 [d]
5 TIME..... = 18250 [d]
HALF-LIFE (0 if no decay)..... = 350 [d]
DECAY CONSTANT (lambda)..... = .198D-02 [1/d]
HALF-LIFE at source..... = 0 [d]
DECAY CONSTANT (alpha)..... = .000D+00 [1/d]
DURATION OF SOLUTE PULSE..... = 13140 [d]

Output:

DISTANCE [m]	1975 5475[days]	1995 12775[days]	1996 13140[days]	2000 14600[days]	2010 18250[days]	1995 Calibration Targets
0	20.3965	20.3965	20.3965	0.1482	0.0000	20.0000
20	1.8155	1.8155	1.8155	0.2602	0.0001	0.8000
40	0.1616	0.1616	0.1616	0.0969	0.0001	
60	0.0144	0.0144	0.0144	0.0135	0.0001	0.0020
80	0.0013	0.0013	0.0013	0.0013	0.0000	
100	0.0001	0.0001	0.0001	0.0001	0.0000	
120	0.0000	0.0000	0.0000	0.0000	0.0000	<0.00084
140	0.0000	0.0000	0.0000	0.0000	0.0000	
160	0.0000	0.0000	0.0000	0.0000	0.0000	
180	0.0000	0.0000	0.0000	0.0000	0.0000	
200	0.0000	0.0000	0.0000	0.0000	0.0000	

- Notes:
- 1) All concentrations are in mg/L (ppm)
 - 2) Distance is the distance from the source areas (waste oil and gasoline USTs).
 - 3) The modeled source is turned "on" from 1960 to 1996.
 - 4) Monitoring well XGM-94-06X is approximately 115 meters downgradient from the source area; the enclave boundary is approximately 275 meters downgradient from the source area.
 - 5) Xylenes MCL is 10,000 mg/L.
 - 6) Shading indicates modeled concentrations exceeding the MCL.
 - 7) The 1995 calibration targets were derived from the estimated distribution of organic groundwater contamination in December 1994 (see Figure 2).

AOC 43G

WELL	TEST TYPE	MEDIA SCREENED	Overburden Hydraulic Conductivities		Bedrock Hydraulic Conductivities	
			Hvorslev (cm/sec)	Bouwer & Rice (cm/sec)	Hvorslev (cm/sec)	Bouwer & Rice (cm/sec)
XGM-94-03X	RISING HEAD	BEDROCK/OVERBURDEN				
XGM-94-04X	RISING HEAD	BEDROCK				
XGM-94-06X	RISING HEAD	OVERBURDEN	8.4E-04	2.9E-03	1.1E-04	4.3E-04
XGM-94-07X	RISING HEAD	BEDROCK/OVERBURDEN				
XGM-94-08X	RISING HEAD	BEDROCK/OVERBURDEN				
XGM-94-09X	RISING HEAD	OVERBURDEN	1.4E-03	2.3E-03		
XGM-94-10X	RISING HEAD	OVERBURDEN	5.7E-05	7.3E-05		
AAFES-1D	RISING HEAD	BEDROCK/OVERBURDEN				
AAFES-2	RISING HEAD	BEDROCK/OVERBURDEN				
AAFES-3	RISING HEAD	OVERBURDEN	4.1E-04	6.2E-04		
AAFES-5	RISING HEAD	OVERBURDEN	2.7E-05	4.9E-05		
AAFES-6	RISING HEAD	OVERBURDEN	5.0E-03	5.9E-03		
AAFES-7	FALLING HEAD	OVERBURDEN	5.3E-04	2.0E-03		
AAFES-7	RISING HEAD	OVERBURDEN	5.4E-04	2.2E-03		
XGP-94-01X	RISING HEAD	BEDROCK/OVERBURDEN				
XGP-94-02X	RISING HEAD	OVERBURDEN	5.0E-04	9.1E-04		
XGP-94-03X	RISING HEAD	OVERBURDEN	1.6E-04	6.7E-04		
XGP-94-04X	RISING HEAD	OVERBURDEN	1.4E-04	2.7E-04		
XGP-94-05X	RISING HEAD	BEDROCK			1.4E-05	3.6E-05
XGP-94-06X	FALLING HEAD	BEDROCK			4.1E-06	2.0E-05
XGP-94-06X	RISING HEAD	BEDROCK			4.1E-06	1.9E-05
XGP-94-07X	RISING HEAD	BEDROCK			4.5E-05	5.0E-05

Geom. Mean of Ks (cm/sec):		Overburden	Bedrock
Groundwater Velocity (m/day)		5.3E-04	2.8E-05
		7.3E-02	3.9E-03

Note: For computing GW Velocity, $i=0.04$ and $n=0.25$ (see AOC 43G Draft RI Report, 1995).

Last Revised:

18-Jan-96

**Fort Devens - AOC 43G Feasibility Study
Solute Transport Modeling**

Dispersivity Calculations

Longitudinal Dispersivity (α_L) = $0.1x_r$

where x_r = distance to the receptor well (Gelhar and Axness, 1981)

To be conservative (allowing for maximum contaminant dispersion), assume x_r = distance from the source area to XGM-94-06X (along the estimated groundwater flow path).

Therefore,

x_r = 120 meters

and

Longitudinal Dispersivity (α_L) = 12.0 meters

Calculation of Fraction of Organic Carbon in Soils

<u>Boring</u>	<u>Sample Depth (ft)</u>	<u>TOC (ug/g)</u>	<u>foc</u>
XGM-93-01X	19	2490	0.00249
XGM-93-02X	24	576	0.000576
XGB-94-13X	25	829	0.00083
XGB-94-12X	15	3490	0.00349
XGB-94-10X	20	2539	0.002539
XGB-94-11X	25	1248	0.001248
Geom. Mean:		1427	0.00143

Calculation of Kd for Site-Specific Contaminants of Concern

$$K_d = K_{oc} * f_{oc}$$

<u>Compound</u>	<u>Koc (mL/g)</u>	<u>foc</u>	<u>Kd (cu m/kg)</u>
Benzene	83	0.00143	1.18E-04
Ethylbenzene	1100	0.00143	1.57E-03
Xylenes	830	0.00143	1.18E-03

Calculation of Site-Specific Retardation Factors

$$\text{Retardation Factor (R)} = [1 + (p/n)(K_d)]$$

where: $p = 2000 \text{ kg/cu meter}$
 $n = 0.25$

<u>Compound</u>	<u>Kd (cu m/kg)</u>	<u>R</u>
Benzene	1.18E-04	1.95
Ethylbenzene	1.57E-03	13.56
Xylenes	1.18E-03	10.48

No Site/Reference	Contaminant Info	V (m/d)	Results	Notes	Reference
1 Borden, Ontario	BTX stock soln injected into aquifer	0.09	benzene toluene o-xylene m-xylene p-xylene	30 mg/d 37 mg/d 47 mg/d 55 mg/d 33 mg/d	Barker et al. 1987 Barker et al. 1987 Barker et al. 1987 Barker et al. 1987 Barker et al. 1987
2 Rocky Point, NC	residual gasoline from UST	0.08	benzene toluene ethylbenzene o-xylene m,p-xylene	0.0002 1/d 0.0021 1/d 0.0015 1/d 0.0021 1/d 0.0013 1/d	(Borden et al. 1995 (Borden et al. 1995 (Borden et al. 1995 (Borden et al. 1995 (Borden et al. 1995
3 Kalkaska, MI	natural gas condensate	0.2	benzene	Rates from mas balance	Chiang et al. 1989
4 Columbus, MS	stock solutions		benzene	Tritium used as nonreactive tracer, mineralization proven using 14Cp-xyl	MacIntyre et al. 1993
Columbus, MS			p-xylene		MacIntyre et al. 1993
Columbus, MS			naphthalene		MacIntyre et al. 1993
Columbus, MS			o-DCB		MacIntyre et al. 1993
5 Sleeping Bear, MI	residual gasoline from UST release	0.4	benzene toluene ethylbenzene o-xylene m-xylene p-xylene	N.S. Rates from conc. vs. travel time using 2,3-dimethylpentane as an internal standard	Wilson et al. 1994b Wilson et al. 1994b Wilson et al. 1994b Wilson et al. 1994b Wilson et al. 1994b Wilson et al. 1994b
6 Sleeping Bear, MI	residual gasoline from UST release	0.4	benzene toluene ethylbenzene o-xylene m-xylene p-xylene	Rates from conc. vs. travel time using 2,3-dimethylpentane as an internal standard	Schafer, 1994 Schafer, 1994 Schafer, 1994 Schafer, 1994 Schafer, 1994 Schafer, 1994
7 Indian River, FL	gasoline from UST	0.06	benzene	concentration vs. travel time	Kembowski et al. 1987
8 Morgan Hill, CA	gasoline	0.05	benzene	concentration vs. travel time	Kembowski et al. 1987
9 Eglin AFB, FL	JP-4 from POL depot	1.3	benzene	averages used here	Wilson et al. 1994a
Eglin AFB, FL			toluene	Rates from conc. vs. travel time	Wilson et al. 1994a
Eglin AFB, FL			ethylbenzene		Wilson et al. 1994a
Eglin AFB, FL			o-xylene	1,2,4-trimethylbenzene as internal standard	Wilson et al. 1994a
Eglin AFB, FL			m-xylene		Wilson et al. 1994a
Eglin AFB, FL			p-xylene		Wilson et al. 1994a

No Site/Reference	Contaminant Info	V (m/d)	Results	Notes	Reference
10 Hill AFB, UT	JP-4 from POL depot	0.5	benzene	averages used here	Wiedemeier et al. 1994
Hill AFB, UT			toluene	Rates from conc. vs.	Wiedemeier et al. 1994
Hill AFB, UT			ethylbenzene	travel time	Wiedemeier et al. 1994
Hill AFB, UT			o-xylene	total trimethylbenzene as	Wiedemeier et al. 1994
Hill AFB, UT			m-xylene	internal standard	Wiedemeier et al. 1994
Hill AFB, UT			p-xylene		Wiedemeier et al. 1994
11 Patrick AFB, FL	700 gal gasoline	0.13	benzene	averages used here	Wiedemeier et al. 1994
Patrick AFB, FL			toluene	Rates from conc. vs	Wiedemeier et al. 1994
Patrick AFB, FL			ethylbenzene	travel time	Wiedemeier et al. 1994
Patrick AFB, FL			o-xylene	using methane as	Wiedemeier et al. 1994
Patrick AFB, FL			m-xylene	internal standard	Wiedemeier et al. 1994
Patrick AFB, FL			p-xylene		Wiedemeier et al. 1994
12 Fairfax, VA		0.015	benzene	Rates from conc. vs.	Buscheck et al. 1993
Fairfax, VA			toluene	travel time	Buscheck et al. 1993
Fairfax, VA			ethylbenzene		Buscheck et al. 1993
Fairfax, VA			tot-xylenes		Buscheck et al. 1993
13 San Francisco, CA		0.03	benzene	Rates from conc. vs.	Buscheck et al. 1993
San Francisco, CA			toluene	travel time	Buscheck et al. 1993
San Francisco, CA			ethylbenzene		Buscheck et al. 1993
San Francisco, CA			tot-xylenes		Buscheck et al. 1993
14 Alameda Co., CA	gasoline	0.01	benzene	Rates from conc. vs.	Buscheck et al. 1993
Alameda Co., CA			toluene	travel time	Buscheck et al. 1993
Alameda Co., CA			ethylbenzene		Buscheck et al. 1993
Alameda Co., CA			tot-xylenes		Buscheck et al. 1993
15 Elko Co, NV	gasoline	0.04	benzene	Rates from conc. vs.	Buscheck et al. 1993
				travel time	Buscheck et al. 1993
16 Sampson Co, NC	gasoline from UST	0.04	MTBE	High NO3 in GW,	Borden, 1995
Sampson Co, NC			benzene	1st order rates from	Borden, 1995
Sampson Co, NC			toluene	mass flux	Borden, 1995
Sampson Co, NC			ethylbenzene		Borden, 1995
Sampson Co, NC			o-xylene		Borden, 1995
Sampson Co, NC			m,p-xylene		Borden, 1995
17 Travers City	aviation gas	1.5	benzene	Rates from conc. vs.	Wilson et al. 1990
Travers City			toluene	travel time	Wilson et al. 1990
Travers City			tot-xylenes		Wilson et al. 1990
18 Broward Co, FL	gasoline from UST	0.1	BTEX	match w/ Bioplume model	Caldwell et al. 1992

No Site/Reference	Contaminant Info	V (m/d)	Results	Notes	Reference
19 Perth, Australia	gasoline from UST	0.4	naphthalene	0.004 1/d	Thierrin et al. 1993
Perth, Australia			benzene	N.S.	Thierrin et al. 1993
Perth, Australia			toluene	0.006 1/d	Thierrin et al. 1993
Perth, Australia			ethylbenzene	0.003 1/d	Thierrin et al. 1993
Perth, Australia			o-xylene	0.006 1/d	Thierrin et al. 1993
Perth, Australia			m,p-xylene	0.004 1/d	Thierrin et al. 1993
20 Hill AFB	18,000 gal UST	0.14	TPH	0.005 1/d	DuPont et al. 1994
Hill AFB			benzene	0.02 kg/d	DuPont et al. 1994
Hill AFB			ethylbenzene	0.06 kg/d	DuPont et al. 1994
Hill AFB			p-xylene	0.06 kg/d	DuPont et al. 1994
21 George AFB, CA			1 benzene	0.0079 1/d	Wilson et al. 1995
George AFB, CA			toluene	0.046 1/d	Wilson et al. 1995
George AFB, CA			ethylbenzene	0.0086 1/d	Wilson et al. 1995
George AFB, CA			o-xylene	0.02 1/d	Wilson et al. 1995
George AFB, CA			m-xylene	0.04 1/d	Wilson et al. 1995
George AFB, CA			p-xylene	0.023 1/d	Wilson et al. 1995

Literature Search Degradation Rate Summaries - Rates include Biodegradation and Dispersion

Compound	Minimum Rate (1/day)	Half-Life (days)	Maximum Rate (1/day)	Half-Life (days)	Average Rate (1/day)	Half-Life (days)
benzene	0.0002	3466	0.045	15	0.0010	663
toluene	0.00045	1540	0.2	3	0.0022	319
ethylbenzene	0.0002	3466	0.0375	18	0.0013	549
o-xylene	0.0009	770	0.21	3	0.0038	181
m,p-xylene	0.0013	533	0.004	173	0.0018	380
m-xylene	0.0016	433	0.04	17	0.0058	120
p-xylene	0.0015	462	0.032	22	0.0047	149

Summary Data from Studies - Rates are Biodegradation Only

Compound	Minimum Rate (1/day)	Half-Life (days)	Maximum Rate (1/day)	Half-Life (days)	Average Rate (1/day)	Half-Life (days)
benzene	0.0008	866	0.045	15	0.0021	327
toluene	0.001	693	0.07	10	0.0036	193
ethylbenzene	0.0002	3466	0.0375	18	0.0010	722
o-xylene	0.004	173	0.21	3	0.0092	76
m-xylene	0.0016	433	0.033	21	0.0050	140
p-xylene	0.0015	462	0.032	22	0.0041	168

Intrinsic Bioremediation Rate Summary

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IGWMC GROUNDWATER MODELING SOFTWARE

SOLUTE

A Program Package of Analytical Models for Solute Transport in Groundwater

by

Milovan S. Beljin
Hydrolink, Inc., Cincinnati, Ohio
for
Holcomb Research Institute,
Butler University

BAS 15
Version 2.0
July 1989
Released March 1990

INTERNATIONAL GROUND WATER MODELING CENTER

Holcomb Research Institute,
Butler University
4600 Sunset Avenue
Indianapolis, Indiana 46208
USA

TNO-DGV Institute
of Applied Geoscience
P.O. Box 285, 2600 AG Delft
The Netherlands

ONED3

PROGRAM IDENTIFICATION

Program Title: Analytical Model for Solute Transport in a Semi-Infinite Column,
Third-Type Boundary Condition

Program Code Name: ONED3

Programmer: Milovan S. Beljin

Program Organization: International Ground Water Modeling Center
Holcomb Research Institute, Butler University
Indianapolis, Indiana 46208, USA. Tel: 317/283-9458

Date: January 1989

Version: 2.00

Source Language: Microsoft QuickBASIC 4.0

Memory Requirements: 320K

Availability: ONED3 is a nonproprietary code distributed by IGWMC.
A copy of the program on a 5-1/4" or 3-1/2" diskette is available.

Abstract: This program gives the concentration distribution along a
semi-infinite column with the third-type inlet boundary condition.

Comments: ONED3 is based on the van Genuchten and Alves (1982) equation.

ONED3

MATHEMATICAL MODEL

This one-dimensional problem again involves the transport of a nonconservative solute. The governing equation is

$$D \frac{\partial^2 C}{\partial x^2} - \bar{v} \frac{\partial C}{\partial x} - \lambda RC = R \frac{\partial C}{\partial t} \quad (3.2.1)$$

with all terms having been defined previously.

The initial and boundary conditions for this problem are

$$C(x, 0) = C_i \quad (3.2.2)$$

$$\left(-D \frac{\partial C}{\partial x} + \bar{v} C \right) \Big|_{x=0} = \bar{v} C_0 \exp(-\alpha t) \quad (3.2.3)$$

$$\frac{\partial C}{\partial x}(\infty, t) = 0 \quad (3.2.4)$$

where C_0 is a concentration constant of the injected fluid, and α is the decay constant of the solute at the source.

Van Genuchten and Alves (1982) give the following analytical solutions:

Case 1. $\alpha = \lambda$

$$C(x, t) = (C_i - C_0) A(x, t) + C_0 \exp(-\alpha t) \quad (3.2.5)$$

Case 2. $\alpha \neq \lambda$

$$C(x, t) = C_i A(x, t) + C_0 E(x, t) \quad (3.2.6)$$

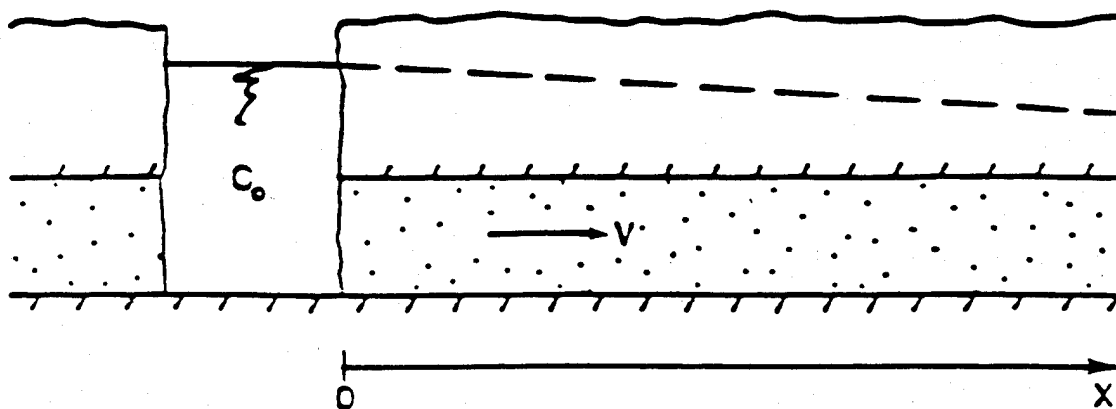
where

$$\begin{aligned}
A(x, t) = & \exp(-\lambda t) \left\{ 1 - \frac{1}{2} \operatorname{erfc} \left[\frac{Rx - \bar{v}t}{2\sqrt{DRt}} \right] \right. \\
& - \left[\frac{\bar{v}^2 t}{\pi DR} \right] \exp \left[-\frac{(Rx - \bar{v}t)^2}{4DRt} \right] + \frac{1}{2} \left[1 + \frac{\bar{v}x}{D} + \frac{\bar{v}^2 t}{DR} \right] \cdot \\
& \left. \exp \left[\frac{\bar{v}x}{D} \right] \operatorname{erfc} \left[\frac{Rx + \bar{v}t}{2\sqrt{DRt}} \right] \right\}
\end{aligned} \tag{3.2.7}$$

$$\begin{aligned}
E(x, t) = & \exp(-\alpha t) \left\{ \left(\frac{\bar{v}}{\bar{v} + w} \right) \exp \left[\frac{(\bar{v} - w)x}{2D} \right] \operatorname{erfc} \left[\frac{Rx - wt}{2\sqrt{DRt}} \right] \right. \\
& + \left(\frac{\bar{v}}{\bar{v} - w} \right) \exp \left[\frac{(\bar{v} + w)x}{2D} \right] \operatorname{erfc} \left[\frac{Rx + wt}{2\sqrt{DRt}} \right] \\
& \left. + \frac{\bar{v}^2}{2DR(\lambda - \alpha)} \exp \left[\frac{\bar{v}x}{D} - \lambda t \right] \operatorname{erfc} \left[\frac{Rx + \bar{v}t}{2\sqrt{DRt}} \right] \right\}
\end{aligned} \tag{3.2.8}$$

and

$$w = \bar{v} \left[1 + \frac{4DR}{\bar{v}^2} (\lambda - \alpha) \right]^{1/2} \tag{3.2.9}$$



$$\text{Boundary Condition: } \left(-D \frac{\partial C}{\partial x} + \bar{v} C \right) = \bar{v} C_0 \exp(-\alpha t)$$

Figure 2. One-dimensional solute transport, third-type boundary condition.

ASSUMPTIONS OF ONED3 MODEL:

- uniformly porous confined aquifer
- the aquifer is homogeneous, isotropic, semi-infinite in the areal extent, and constant in thickness
- a stream (source) fully penetrates the aquifer
- there is one-dimensional steady-state uniform regional groundwater flow from the stream
- the density and viscosity of the solute in the stream and the aquifer are the same
- no solute advection or dispersion occurs through the aquicludes into or out of the aquifer.

**RESPONSE TO COMMENTS
FEASIBILITY STUDY REPORTS
AREAS OF CONTAMINATION (AOCs) 43G AND 43J**

The following is the Army's response to comments which have been received on the Draft Feasibility Study Reports for AOC 43G and 43J submitted for review on February 9, 1996. Comments addressed in this response package were received from:

U.S. Environmental Protection Agency (USEPA) - Comments dated April 25, 1996; and
Massachusetts Department of Environmental Protection (MADEP) - Comments dated May 10, 1996.

USEPA COMMENTS ON AOC 43G

GENERAL COMMENTS

1. **Comment:** Establishing a case for intrinsic bioremediation (Table 2-3 and Figure 2-1 were consulted in formulating this comment). The demonstration of the occurrence of intrinsic bioremediation is insubstantial and contains inconsistencies. Table 2-3 shows the expected trend of increasing redox potential, increasing nitrate concentration, and increasing phosphate concentration moving down gradient from the source within the organic plume. However, the lowest sulfate concentration was observed at the down gradient edge of the plume rather than at the center of the plume. Furthermore, chloride concentrations, which should remain fairly constant within the aquifer, are significantly lower in the down gradient plume and down gradient edge. Thus, other phenomena may also be occurring which would then be obscuring some of the alleged biodegradation effects. Please address these inconsistencies in the FS.

Intrinsic bioremediation in the FS is based solely on indirect evidence. A clearer case would be a demonstration of decreasing organic contaminant concentrations over time, coupled with favorable redox and inorganic conditions. Establishing the destruction of the organic contaminants is crucial.

Response: The Army believes that the two "inconsistencies" referenced (sulfate and chloride concentrations in the downgradient zone) are minor exceptions of the general trend shown in Table 2-3 and do not negate evidence that biodegradation is occurring at the site. The results still indicate a noticeable decrease in sulfate concentration in the source area compared with upgradient, perimeter and downgradient plume ($>5 \mu\text{g/L}$ benzene) areas. Under ideal model conditions, one would expect an increase of sulfate in the farthest downgradient wells ($<5 \mu\text{g/L}$ benzene area). However, the apparent decrease in sulfate could be contributed to the smaller data set collected for the downgradient wells (4 sampling points/events each zone) than for the source area and the perimeter area (15 and 8 sampling points/events, respectively). Due to the general variability in the data within many wells between sampling rounds (i.e., AAFES 6 sulfate concentrations jumped from $11,000 \mu\text{g/L}$ in Round 5 to $25,000 \mu\text{g/L}$ in Round 6) a smaller data set is not as likely to be as representative of the true average.

Road salt most likely contributes to the variability of the chlorides as is evident by observing the generally higher concentrations and seasonal fluctuations in wells that are close and downgradient of roadside or parking areas (AAFES-3, AAFES-5, XGM-94-05X, -07X) as compared with more remote wells such as (XGM-94-09X, 10X and AAFES-7). Similar wording will be added to the FS Report.

**RESPONSE TO COMMENTS
FEASIBILITY STUDY REPORT,
AREAS OF CONTAMINATION (AOCs) 43G AND 43J
(continued)**

It should also be noted that water quality parameter concentrations from XGM-94-06X were mistakenly excluded from the downgradient (<5 ppm benzene area) averages in Table 2-3. Average chloride and sulfate concentrations will be corrected in the final FS Report and are slightly higher than those reported in the draft FS Table 2-3 (15,500 µg/L versus 14,000 µg/L for sulfates and 78,625 µg/L versus 35,000 µg/L for chlorides.)

The Army agrees that a clearer case of intrinsic biodegradation would be a demonstration of decreasing organic contaminant concentrations over time. This will be modeled upon collecting additional groundwater data during the predesign phase of the remediation as specified in the FS Report.

2. **Comment: Long-term groundwater monitoring.** To assess the progress of intrinsic bioremediation and to detect any migration of contaminants off-site, annual groundwater monitoring is proposed. This frequency of groundwater monitoring is inadequate to follow the proposed processes and to detect any effects of seasonality which can be very important in the interpretation of results.

Consider the following alternative long-term groundwater monitoring proposal. Monitor groundwater on a quarterly basis for at least 8 quarters and until a statistically significant decrease in contaminant concentrations has been demonstrated (e.g., by the Mann-Whitney test at a 90% confidence level). Then go to annual monitoring until cleanup goals have been achieved for 3 consecutive years.

Response: In the Draft FS, the Army has proposed that additional sampling and modeling be performed as part of the predesign phase (prior to implementing the long-term monitoring plan). Additionally, more groundwater monitoring wells are to be installed. The Army recognizes the importance of collecting a statistically significant data set and will evaluate the need of performing more frequent long-term monitoring (during the initial years) upon reviewing the results of the predesign modeling.

3. **Comment: Hydrogeological Aspects.** Groundwater flow and the interaction between the bedrock and overburden systems remain unclear at this time. This uncertainty affects the evaluation of the groundwater collection alternative.

The groundwater pump tests completed in the overburden and in the bedrock monitoring wells indicated that the flow characteristics and hydraulic properties were different in the two strata. Although hydraulic communication exists between the upper fractured/weathered bedrock zone and the overburden, the groundwater flow in the two systems is governed by different physical properties respective of the geologic strata. Grain size, porosity, and similar properties govern flow in the overburden while fractures and joints control flow in the bedrock. The net effect of these differences may produce variability in flow and contaminant recovery under groundwater pumping conditions. Please state the design criteria for the groundwater collection system. Is the system designed for groundwater collection from the overburden system only? How will collection of contaminants in bedrock groundwater be assured? Is the system designed as a groundwater collection system, groundwater control system, or contaminant recovery system?

**RESPONSE TO COMMENTS
FEASIBILITY STUDY REPORT,
AREAS OF CONTAMINATION (AOCs) 43G AND 43J
(continued)**

Response: Design criteria will be determined following the collection of additional predesign hydrogeologic data, including the installation, sampling, and hydraulic testing of additional bedrock wells.

The groundwater modeling (Appendix A) was performed to estimate the pumping flow rates required to contain the plume at the source area. As described in the Draft FS (pg 4-15), the objective of the groundwater extraction is to intercept the major portion of the plume at the highest concentrations of CPCs, thereby minimizing the potential for migration of CPCs exceeding PRGs. The system would serve mostly as a means of hydraulic containment of the highest concentrations of CPCs in the overburden groundwater. Due to the complex hydrogeology of bedrock, not all contaminants in the bedrock groundwater would be expected to be captured. However, the intrinsic biodegradation component in Alternative 3 and the passive bioremediation component in Alternative 4 would provide treatment of the portion of the plume downgradient of the extraction wells.

SPECIFIC COMMENTS

4. Comment: Page ES-3, line 17: Please explain why residential receptors were not considered. (i.e. land reuse is classified as industrial).

Response: Current and future use of the site will be explained. Also the Devens Reuse Plan (Vanasse Hangen Brustlin, 1994) will be referenced. This plan states that the area will be used for Innovation and Technology Business and open space/recreation. This addition is more appropriate on ES-2 where the risk evaluation is first discussed.

5. Comment: Page 1-10, Section 1.3 Nature and Distribution of Contamination at Areas 2 and 3: The nature and extent of bedrock groundwater contamination has not been conclusively evaluated down gradient from the source area at the site. The limits of groundwater contamination in wells exclusively screened in bedrock has not been determined. How will the success of a groundwater collection system and or intrinsic bioremediation be evaluated without this data or the presence of adequate monitoring points?

Response: Installation of additional groundwater monitoring wells (to further evaluate bedrock hydrogeology during the predesign phase) is a component of all alternatives evaluated except the No Action Alternative. The success of groundwater collection will be evaluated based upon the results of the predesign data collected (hydrogeological data and modeling) as specified for Alternative 3 and 4 and long-term monitoring. The success of intrinsic bioremediation will be evaluated based upon the results of the predesign groundwater sampling and intrinsic biodegradation modeling as specified for Alternatives 2, 3 and 4.

6. Comment: Page 1-20, line 30: Please include the depth to which subsurface is referring to.

Response: A sentence stating this depth is already provided on line 3 of page 1-20 of the draft FS Report.

**RESPONSE TO COMMENTS
FEASIBILITY STUDY REPORT,
AREAS OF CONTAMINATION (AOCs) 43G AND 43J
(continued)**

7. Comment: **Page 1-21 and 22:** Please elaborate for each case on why the receptor evaluated was a future commercial/industrial worker as opposed to residential. Also include a site map which clearly illustrates site boundaries with respect to the reuse/landbank parcel.

Response: Current and future use of the site will be explained. Also the Devens Reuse Plan (Vanasse Hangen Brustlin, 1994) will be referenced. This plan states that the area will be used for Innovation and Technology Business and open space/recreation. A site map which clearly illustrates the Enclave property with respect to the reuse/landbank parcel is already provided in the FS (Figure 4-1).

8. Comment: **Page 1-23, lines 31-33:** The scheduled removal action is expected to remove the contaminated soils associated with the former gasoline USTs. However, the limits of contaminated soil and the nature and extent of bedrock contamination below the former gasoline USTs have not been presented. How will the limits of the excavation be defined and what assurances will be made that all potential source materials will be removed? Please reference 43G Action Memorandum.

Response: This paragraph will be revised in its entirety based upon the results of a meeting held between the regulators and the Army on May 2, 1996 at Fort Devens. The primary discussion at this meeting concerned the residual soil contamination that remains below the existing AAFES gasoline USTs and the possible repercussions on groundwater remediation at AOC 43G. These soils are approximately 20 to 28 feet bgs and would require considerable effort to remove under the COE tank removal action due to soil depth and the proximity to adjacent structures and roadways. Groundwater remediation benefits from removing or in-situ treating this soil are not readily definable at this time. Groundwater sampling results from the RI infer that intrinsic biodegradation is occurring but intrinsic modeling using site-specific degradation rates is not yet possible without collection of data from additional groundwater sampling.

As concluded in this meeting, the Army proposes to remove the three existing gasoline USTs and the sand & gas (S&G) trap and adjacent S&G trap contaminated soils. The Army does not plan to remove the concrete slab on which the existing gasoline USTs rest; the residual contamination within soils 20 to 28 feet bgs that are below the USTs; and any residual contaminated soils adjacent the former waste oil tank excavation. Intrinsic bioremediation data collection and modeling will be performed as part of the design phase to assess intrinsic bioremediation at AOC 43G. However, should modeling and/or long-term groundwater monitoring indicate that the remedial objectives will not be met, the Army will implement further remedial action (i.e., residual soil contamination and/or more aggressive groundwater remedial action). Implementation of the contingency alternative for these two sites will be discussed in the Record of Decision (ROD).

Per request of USEPA, the Army will add an alternative to the final FS that includes residual soil contamination control below the gasoline USTs. (Previously included in the Alternatives Screening Report but removed in the Draft FS because the Army was proposing to remove the soil prior to signing the ROD).

9. Comment: **Figure 1-10: Water Table Elevation Contours:** This figure presents the presumed water table based on water levels taken from monitoring wells regardless of the screened interval and geologic

**RESPONSE TO COMMENTS
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(continued)**

formation being monitored. Although the overburden groundwater system and the shallow bedrock groundwater system appear to be in direct communication, does the comparison of head values in bedrock wells and overburden wells produce a true representation of groundwater flow and contaminant flow paths at the site? What are the presumed vertical flow gradients and conceptual flow components?

Response: Figure 1-10 presents the interpretive water table elevation contours based on data from both overburden and bedrock water table wells. The water table at AOC 43G occurs locally in both overburden and bedrock; therefore, in order to accurately depict potentiometric contours it is necessary to use data from both types of wells. Contaminant distribution indicates that at least some portion of groundwater flow and contaminant transport occurs along the flowlines perpendicular to the interpretive water table elevation contours. Predesign installation of monitoring wells in bedrock will evaluate the potential for vertical flow gradients, and thereby provide more data for the conceptual flow model of the site.

10. Comment: Table 2-3: In the list of down gradient wells, the well listed as AAFES-6 should be AAFES-7. Please supply a list of perimeter wells, none are given. As a result, it is unclear what is meant by perimeter.

Response: AAFES 6 will be corrected to AAFES 7. The wells identified in the footnote as downgradient plume wells should be re-identified as perimeter wells. Wells considered to be in the downgradient plume (5 µg/L benzene) in Table 2-3 were XGM-94-08X and -10X and will be added to the footnote.

11. Comment: Page 4-6, lines 12 through 17: The modeling of contaminant biodegradation used an average of degradation rates found in a literature search. Since the actual site biodegradation rate is unknown, and might be quite low, the lowest of the literature rates should also be used to establish a reasonable range of conditions (average to slow degradation). Please illustrate this possible condition.

Response: As discussed in Appendix C, model calibration was achieved by varying the half-life and source concentration to obtain a best-fit match with the 1995 groundwater data. Input of the longest half-lives (from the literature search) for individual compounds resulted in very poor matches with the 1995 calibration targets. Inputting a source concentration equivalent to the 1995 source concentration resulted in higher than observed downgradient concentrations; attempts at matching the concentrations at the leading edge of the 1995 plume resulted in modeled source concentrations that were drastically lower than 1995 observed source concentrations.

As part of the predesign phase, the Army will perform additional sampling/analysis to further evaluate the potential for intrinsic biodegradation at the site. The predesign data will be used to further refine the contaminant transport modeling.

12. Comment: Appendix A. Figure 2: The groundwater contours produced under pumping conditions indicate the groundwater table will be at or below the bedrock/overburden contact in the area of the pumping wells. It appears the overburden will be dewatered and the wells will be collecting groundwater controlled by the bedrock geology (i.e. fractures, joints, etc.). As indicated in the pump

**RESPONSE TO COMMENTS
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(continued)**

test data and in the slug test analysis of some bedrock wells, there are highly productive bedrock zones and areas that are nonproductive. How will the bedrock/recovery wells be located to assure contaminated groundwater is collected?

Response: Additional hydrogeologic data from pumping tests will be collected as part of the predesign phase to aid in placement and design of the recovery wells. The intent of the groundwater extraction system is to generally provide hydraulic containment of the plume to minimize the potential for migration of the most contaminated portion of the plume (overburden). Intrinsic biodegradation or passive bioremediation would be used for remediation of the downgradient portion of the plume.

**RESPONSE TO COMMENTS
FEASIBILITY STUDY REPORT,
AREAS OF CONTAMINATION (AOCs) 43G AND 43J
(continued)**

MADEP COMMENTS ON AOC 43G

Rebuttals to Army Response to Comments for Alternatives Screening Report, AOC 43G

1. MADEP Rebuttal (General Comment 2).

Comment: An AUL will be required unless all soils at the site are remediated to MCP background levels; a MADEP Grant of Environmental Restriction (GER) would be required to limit groundwater exposures. Also, MCP groundwater standards (e.g., GW-1) would apply to the Site if MCP criteria are more restrictive than MCLs. Even though the Army plans to retain AOC 43G within the Army Enclave, an AUL or similar institutional control would be required to limit exposures until the entire site is remediated to MCP Background levels.

Response: Upon property sale of AOC 43G, the Army will either implement AULs or similar institutional control, or re-evaluate the potential risks assuming a residential exposure scenario. However, as long as the property remains part of the Army Reserve Enclave, there is no unacceptable exposure associated with soil or groundwater on site. Implementation of 5-year site reviews under CERCLA serves to further ensure that the site remedy remains protective of human health and the environment.

Comments on the Draft Feasibility Study Report, AOC 43G

General Comments

1. Comment: The comparative analysis of remedial alternatives cannot be effectively conducted at this time due to limitations inherent within three of the proposed alternatives (Alternatives 2, 3, and 4). These limitations include significant uncertainties with respect to: 1) the effectiveness and time frame of intrinsic bioremediation; and 2) groundwater flow interaction and contaminant fate and transport between the overburden and bedrock. These uncertainties preclude implementation of an objective comparison of the remedial alternatives. For instance, the actual cost to implement Alternative 2 (intrinsic bioremediation and long-term monitoring) could eventually exceed the costs for Alternatives 3 and 4 or another engineered remedial action (e.g., enhanced bioremediation).

Response: The Army believes that the alternative costs are sufficient for comparison purposes. Because the perceived uncertainties impact all the alternatives (i.e., even the more aggressive groundwater containment alternative requires intrinsic biodegradation and is influenced by the bedrock/overburden groundwater flow interaction), alternative costs have been developed using similar conservative assumptions and are believed to be accurate for relative comparisons. Page 5-6 examines some of these uncertainties and presents a brief discussion regarding the sensitivity of the costs.

2. Comment: As noted during the May 2, 1996 meeting at Fort Devens to discuss these sites, MADEP has outstanding concerns on the following:

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- the adequacy of source control regarding the contaminated soil to be left in place;
- the presence of contamination in the bedrock groundwater;
- the need for further studies regarding on-site intrinsic bioremediation; and
- the need for a contingency plan to be included in the ROD in the event that further studies and monitoring do not demonstrate that groundwater conditions are improving and that further migration is not taking place.

MADEP's acceptance of intrinsic remediation for this site is contingent on the Army's resolution of the above concerns.

Response: These concerns were all discussed and solutions agreed upon during the May 2, 1996 meeting at Fort Devens with the regulators. The primary discussion concerned the residual soil contamination that remains below the existing AAFES gasoline USTs and the possible repercussions on groundwater remediation at AOC 43G. These soils are approximately 20 to 28 feet bgs and would require considerable effort to remove under the COE tank removal action due to soil depth and the proximity to adjacent structures and roadways. Groundwater remediation benefits from removing or in-situ treating this soil are not definable at this time making the effort to remove this soil difficult to justify. Groundwater sampling results from the RI infer that intrinsic biodegradation is occurring but intrinsic modeling using site-specific degradation rates is not yet possible without collection of data from additional sampling rounds.

The solutions discussed and agreed upon were as follows:

- Prior to signing the ROD, the Army will remove the three existing gasoline USTs and the sand & gas (S&G) trap and adjacent S&G trap contaminated soils. The Army will not be removing the concrete slab on which the existing gasoline USTs rest; the residual contamination within soils 20 to 28 feet bgs that are below the USTs; and any residual contaminated soils adjacent the former waste oil tank excavation.
- Data collection (groundwater sampling) and modeling will be performed as part of the predesign phase to assess intrinsic biodegradation at the site. The presence of contamination in the bedrock groundwater and advancement of the overburden plume will be investigated through installation of additional groundwater monitoring wells and by implementing a long-term groundwater monitoring program; and
- Should modeling and/or long-term groundwater monitoring indicate that the remedial objectives will not be met, the Army will implement further remedial action (i.e., residual soil contamination control and/or more aggressive groundwater remedial action). The need for implementing the contingency alternative will be made part of the Record of Decision (ROD).

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Page-Specific Comments

1. Comment: Section 1, Page 1-9, Paragraph 2. Depth to groundwater is reported to range from 12 to 23 feet. Therefore, potential migration of groundwater vapors to indoor should be considered. The risk assessment presented in the RI report (Section 9.3.1) indicates that groundwater vapors are not likely to migrate to indoor air because the depth to groundwater is 15 to 19 feet. This inconsistency needs to be corrected.

Response: The depth to groundwater is incorrectly reported on page 1-9 of the FS Report but accurately depicts this depth on Figures 1-6 to 1-8. The depths will be changed to reflect 15 to 29 bgs as is accurately stated in Section 9.3.1 of the RI.

2. Comment: Section 1, Page 1-20, Paragraph 2. Additional discussion needs to be provided pertaining to known and/or potential downgradient human receptors (e.g., possible residential use/development).

Response: The Devens Reuse Plan (Vanasse Hangen Brustlin, 1994) will be referenced in this paragraph. This plan states that the area will be used for open space/recreation and Innovation and Technology Business.

3. Comment: Section 1, Page 1-23, Paragraph 4. The document indicates that contaminated soils associated with the former gasoline USTs will be removed. Based on discussions during the May 2, 1996 meeting at Fort Devens, MADEP understood that the Army was proposing to leave potentially contaminated soils in place beneath the concrete slab at the UST area. Additional text should be provided to clarify the extent of the removal actions.

Response: This paragraph will be revised in its entirety due to the changes in the proposed removal action. See the first bullet in the response to General Comment No. 2.

4. Comment: Section 2, Page 2-2, Paragraph 1. Reference should be made to the Army's Various Removals project since the Army's intention is to remove contaminant sources and associated contaminated soil. This reference should be included to support the lack of Preliminary Remediation Goals for Soil.

Response: See MADEP Page-Specific Comment No. 3 and the Army's response. There are no PRGs established for subsurface soils because the baseline human health risk assessment did not identify CPCs that present risks greater than USEPA criteria. This is covered on page 2-6 of the draft FS Report.

5. Comment: Section 2, Page 2-3, Paragraph 4. The preliminary remediation goals for groundwater should be based on compliance with MCP provisions which can be considered ARARs. The allowable contaminant concentrations specified for soil and groundwater in the MCP should be considered ARARs since they are substantive numerical standards. Other MCP provisions, such as

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implementation of an Activities and Use Limitation (AUL) and/or a Grant of Environmental Restriction (GER) are also ARARs. The FS text and associated tables, should be amended as appropriate to incorporate these and all other MCP ARARs.

Response: The MCP provides that response actions at CERCLA sites shall be deemed adequately regulated for purposes of compliance with the MCP. The Army has chosen not to use MCP Method 1 risk-based standards or Method 3 risk characterization for evaluation of the site. Instead, the Army has conducted a CERCLA risk assessment. Therefore, the Army has not considered the MCP an ARAR.

6. Comment: Section 2, Page 2-7, Paragraph 1. See comment to Page 2-2, paragraph 1.

Response: See response to Page-Specific Comment No. 4.

7. Comment: Section 3, Page 3-6, Paragraph 2. As requested in MADEP Specific Comment 3 to the Alternatives Screening Report, further details regarding the impracticability of aerobic bioremediation of the entire groundwater plume were added to Section 3.1.4/Page 3-6 of the FS text. However, a table similar to Table 2-9 of the Alternatives Screening Report, was not included in the FS. The requested details regarding limitations of aerobic bioremediation for the entire plume should be tabulated in the FS.

It should be noted that if the proposed intrinsic (anaerobic) bioremediation or the contingent passive (aerobic) biodegradation of the plume do not effectively remediate site groundwater, aerobic biodegradation for the entire plume may be a viable alternative to expensive long-term monitoring.

It is unclear why fouling of the aquifer is cited a concern only for the aerobic bioremediation of the entire plume. Fouling should also be a concern for the "passive" aerobic bioremediation of the downgradient plume, since fouling can result from the introduction of oxygen into the aquifer regardless of the methodology of its introduction.

Response: Page 5 of Table 2-7 in the draft FS (formally Table 2-9 of the Alternative Screening Document) does discuss the same limitations of aerobic bioremediation as discussed on page 3-6.

The Army believes that aerating the entire groundwater plume by injection is impractical due to the limiting characteristics detailed on page 3-6. Fouling is also a concern for passive aerobic bioremediation (p 4-23 discusses anticipated maintenance requirements) but not to the degree of total plume oxygenation. First, there is likely to be less fouling in the passive wells because these wells are placed downgradient of the heavily contaminated area where iron is not as soluble. (Manganese still remains dissolved in the downgradient plume). Secondly, because the passive system generates small amounts of oxygen over an extended period, iron precipitation is minimized. Reportedly, the iron hydroxide has a tendency to deposit on the filter sock which provides a convenient means for capture and cleaning.

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8. Comment: Section 4, Page 4-6, Paragraph 1. The selection of the thirty-year maximum period used to estimate the time frame for intrinsic bioremediation is arbitrary, and does not reflect a reasonable period to base the cost estimate for intrinsic remediation. The first simulation (on/off source) of the ONED8 analytical model for solute transport, in which the contaminant source was removed in 1996 is not readily applicable for this site because: 1) the model does not take into consideration that the bedrock serves as a continuing source of contamination; and 2) the model does not take into account groundwater flow through fractured media. Therefore, presentation of the on/off source simulation and the prediction of achieving groundwater levels below PRGs within four years should not be included in the FS. The second simulation (continuing source), which includes a continuing source of contamination and an infinite time to remediate the site groundwater is more applicable, however, the uncertainties associated with groundwater flow in bedrock remain. A quantitative or semi-quantitative analysis of the intrinsic bioremediation is necessary to substantiate the maximum period. Such an analysis would be based on the results of a biofeasibility study (which is representative of in-situ, intrinsic conditions) and incorporation of site historic analytical data if statistically significant trends are observed over time.

Response: The assumptions and limitations (sources are removed and heterogeneities of the aquifer) of the first model are clearly described on page 3-9 and 4-6. The Army does not believe that these assumptions negate the appropriateness of the model. The first simulation represents the best possible condition and will be retained in the FS Report for comparison with the continuous source simulation (worst condition). Liberally, it can be argued that the source was effectively removed during the UST removals and that the residual soil contamination has little influence on groundwater contamination. Intrinsic bioremediation modeling will be performed, as requested, to substantiate the anticipated cleanup period. Modeling will be performed as part of the predesign phase and will incorporate site historical analytical data if statistically significant trends are observed over time.

9. Comment: Section 4, Page 4-15, Paragraph 2. The groundwater model used for the preliminary design of a groundwater collection system is based on groundwater flow through porous media (e.g., overburden sand and till); however, a significant portion of VOC contamination is reported to be present within the fractured bedrock. The groundwater model used to support the groundwater collection design does not appear to be appropriate, since the model does not account for the uncertainties associated with fractured flow. Therefore, the model is not representative of actual site conditions. The efficiency and implementability of the proposed groundwater collection systems included in Alternatives 3 and 4 cannot be evaluated until additional data are collected or another model is used which more accurately represents the complicated interaction between groundwater flow within the overburden and bedrock.

Response: The purpose of the groundwater collection and treatment system component in Alternatives 3 and 4 is to contain the overburden groundwater plume thereby minimizing the potential for migration of the most contaminated portion of the plume. The purpose of the modeling was to verify that containment of the overburden groundwater is achievable and to estimate, within an order of magnitude, what pumping rates would be required. The model is not intended to examine migration of contaminants within fractured flow to ensure all contamination

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within the bedrock is captured and treated. The intrinsic biodegradation or passive bioremediation components address contamination downgradient of the extraction system. The text will be strengthened to clarify this point. The Army believes that the model is appropriate for Feasibility Study cost purposes. Additional hydrogeological data and groundwater monitoring data are to be collected during the predesign phase to support design (i.e., sizing, placement, and operation of the extraction system) and to verify that the downgradient plume is reflective of intrinsic biodegradation modeling results.

10. Comment: Section 4, Page 4-23, Paragraph 2. The FS refers to use of Passive Bioremediation as a component of Alternative 4. Passive bioremediation is synonymous with intrinsic bioremediation and does not involve human interference or modification of subsurface conditions. The proposed introduction of oxygen and perhaps mineral nutrients into the aquifer to promote biodegradation is an example of active, enhanced, or engineered bioremediation, not passive bioremediation. The FS text and tables should be modified accordingly.

Response: The term "passive" is also a common term to the industry and is used in the FS to identify a treatment level that is between intrinsic biodegradation (modeling and monitoring) and more active bioremediation techniques (injection of nutrients and oxygen or ex-situ treatment). Changing terminology at this time in the review process would only unnecessarily confuse the alternatives being evaluated.

11. Comment: Section 4, Table 4-3. This table of intrinsic bioremediation parameters for long-term monitoring should be amended to include the following: carbon dioxide (metabolic byproduct), number of bacteria (hydrocarbon degraders), number of protozoa, carbon isotopes (organic and inorganic), alkyl benzoates and alkyl phenols (BTEX intermediate metabolites). The carbon isotopes ratios should be evaluated to measure transformation of organic to inorganic carbon (confirmation of intrinsic bioremediation). The ratio of non-degradable to degradable compounds should also be compared to evaluate intrinsic bioremediation effectiveness.

Response: The parameters listed in Table 4-3 are believed to be the basic parameters necessary for evaluating and modeling intrinsic biodegradation. The additional parameters listed by the MADEP can also be helpful in the absence of other indicators but would be best added on a case-by-case basis as needed during the predesign and design phase. Carbon dioxide can be used as an aerobic biodegradation indicator but can be greatly impacted by pH/alkalinity and other geochemical sources and sinks. The BTEX intermediate metabolites are very transitory and their absence does not necessarily infer that biodegradation is not occurring. The ratio of non-degradable to degradable compounds can be beneficial should it become important to assess whether observed contaminant reduction is a result of biodegradation or other natural attenuation processes such as diffusion and dispersion.

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12. Comment: Section 5, Page 5-7, Paragraph 3. Although the comparative analysis of remedial alternatives indicate that Alternative 2 is most cost effective, the actual costs associated with indefinite monitoring of the intrinsic bioremediation may exceed the costs estimated for Alternatives 3 and 4. An increased frequency and expanded list of analytical parameters will be required in order to effectively monitor and evaluate intrinsic bioremediation at the site and add to monitoring costs. Since the thirty-year period for remediation may be optimistic, it may be desirable (less costly) to enhance the intrinsic bioremediation with an engineered remedy to modify subsurface conditions (e.g., addition of nutrients or modification of oxygen levels) to maximize contaminant destruction and minimize the remediation time frame and remedial costs. Alternative 4 of the FS could be modified to include a contingency for more aggressive enhanced or engineered bioremediation of the entire plume.

Response: See response to General Comment No. 1. All alternatives rely on intrinsic biodegradation as a component and are subject to similar inherent uncertainties. The Army maintains that it would be impractical to attempt to aerate and add nutrients to the entire plume due to the site-limiting conditions specified on page 3-6 of the Draft FS Report.

13. Comment: Appendix A. As requested in MADEP's Specific Comment 6 to the Alternatives Screening Report, the Army should provide a detailed explanation, justifying the hydraulic conductivity values utilized as input parameters in the QuickFlow Model. Also, it is unlikely that either the QuickFlow or MODFLOW models can adequately simulate site groundwater flow conditions considering the complexities of bedrock/overburden interaction. Consequently, the value of the model simulations (and hence, groundwater collection alternative analyses) provided are questionable.

Figure 2 needs to be revised such that the elevations of the contours are legible and the identities of the wells used to generate the contour are shown.

Response: The Army's response to the MADEP's Specific Comment 6 to the Alternatives Screening Report was that the hydraulic conductivity would be investigated and the model revised for the FS Report as necessary. The hydraulic conductivity was investigated and changed from 2.02 ft/day in the Alternative Screening Report to 6 ft/day in the Draft FS Report. A detailed explanation of how it was derived and discussion of overburden aquifer thickness is provided on page 2 of Appendix A of the Draft FS Report.

Figure 2 contour elevations will be made more legible. Identifying specific wells would only make the figure less legible. Figure 2 states that contours are based on the May 9, 1995 water level measurements. The reader can readily reference Figure 1-10 for monitoring well identification.

14. Comment: Appendix B, Page 4-1, Paragraph 1. The Biofeasibility Study provided in Appendix B is relevant only for an engineered or enhanced bioremediation for the site. The effectiveness of site intrinsic bioremediation cannot be inferred from the Biofeasibility Study because oxygen and nutrients were added to the study samples. This study is not representative of in-situ conditions relative to intrinsic bioremediation for the site.

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It appears that intrinsic bioremediation is occurring; however, the intrinsic bioremediation assumed by the Army to be occurring at the site is based solely on indirect evidence. Before the intrinsic bioremediation can be properly evaluated, additional data establishing the degree and effectiveness of site intrinsic bioremediation must be provided.

A key factor has not been determined: the rate and effectiveness of the apparent intrinsic biodegradation. While aerobic biodegradation of BTEX compounds has been well documented, there are currently no field data demonstrating significant removal of petroleum hydrocarbons in anaerobic environments. Benzene is particularly resistant to anaerobic biodegradation.

There are many factors which can limit the rate of intrinsic biodegradation. As indicated in Section 4 of the FS, the time frame for remediation is likely between 30 years and infinite. The time frame uncertainty precludes a proper evaluation of intrinsic bioremediation for the site. In order to reduce the uncertainty, the entire subsurface ecosystem must be considered as a whole in order to establish the rate limiting factor affecting intrinsic bioremediation. Without establishing the rate limiting factor, efforts may be wasted by modifying a condition (i.e., oxygen addition) that is not rate limiting. Additional data are required in order to evaluate the rate limiting factors of intrinsic bioremediation.

The general strategy for demonstrating that intrinsic bioremediation is working should include collection of these types of evidence:

- documented loss of contaminants from the site;
- laboratory studies indicating microbes in Site samples have the potential to transform the contaminants under the expected in-situ conditions;
- evidence indicating that the biodegradation potential is actually realized in the field.

Additional information regarding demonstrating the effectiveness of intrinsic bioremediation may be found in the following sources:

- National Research Council on In-Situ Bioremediation Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, 1993. *In-Situ Bioremediation: When Does It Work?* National Research Council, Washington, D.C.
- U.S. EPA, 1993, Guide for Conducting Treatability Studies under CERCLA - Biodegradation Remedy Selection, Interim Guidance, EPA/540/R-93/519a, August 1993.
- U.S. EPA, 1993, Bioremediation Resource Guide, EPA/542-B-98-004, September 1993.
- Baker, C.H. and Henson, D.S., 1994. *Bioremediation*. McGraw-Hill, Inc., New York, NY.

Response: Appendix B is only referenced in the FS Report for discussions pertaining to Passive Bioremediation (Alternative 4) and not intrinsic bioremediation (Alternative 2). The conclusions on

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page 4-1 of the Biofeasibility Study Report simply state that intrinsic biodegradation should continue to be considered as a remedial alternative. This is because the results of the microbial analysis indicated that the unaltered sample contained a healthy population of bacteria.

The Army recognizes that the only observed evidence of intrinsic biodegradation at AOC 43G to date is through indirect measurements (water quality parameters and indicators). As presented in the draft FS Report and during the May 2, 1996 meeting at Fort Devens, the Army proposes to collect additional groundwater data, implement intrinsic biodegradation modeling, install additional groundwater monitoring wells, perform long-term monitoring, and establish a contingency plan to be included in the ROD in the event that modeling/monitoring indicates that groundwater remedial objectives are not being met. The field activities would be performed during predesign and design. Through implementation of these components, the Army intends to provide the necessary evidence that biodegradation potential is actually being realized in the field.

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USEPA COMMENTS ON AOC 43J

GENERAL COMMENTS

1. **Comment:** Establishing a case for intrinsic bioremediation (Table 2-3 and Figure 2-2 were consulted in formulating this comment). The demonstration of the occurrence of intrinsic bioremediation is weak and contains inconsistencies. The case for intrinsic bioremediation is made based solely on indirect evidence. Table 2-3 shows the expected trend of increasing redox potential moving down-gradient from the source within the organic plume. However, the lowest nitrate, sulfate, and phosphate concentrations were observed at the downgradient edge of the plume rather than at the center of the plume as would be expected. This is inconsistent and requires at least a speculative explanation. Furthermore, chloride concentrations, which should remain fairly constant within the aquifer, are significantly lower in the upgradient well. Thus, other phenomena may also be occurring which would then be obscuring some of the alleged biodegradation effects. This inconsistency should be addressed.

A demonstration of decreasing organic contaminant concentrations over time, which coupled with favorable redox and inorganic conditions, would make a much clearer case for the occurrence of intrinsic bioremediation. Establishing the destruction of the organic contaminants is crucial and is further addressed in the next comment.

Response: Because the "source area" wells may actually be slightly upgradient of the true center of the plume (as noted by the soil concentration contours in Figure 2-3 through 2-8), nitrate, sulfate and phosphate concentrations may decrease farther downgradient as appears to be observed in downgradient wells. Lovely, Chapelle, and Woodward (Lovely, 1994) note that when shallow aquifers are heavily contaminated with organic compounds, it is generally difficult to delineate the distribution of the anoxic redox processes. They further state that reduced products that are actively produced near the source of organic contamination may persist in the groundwater as it moves downgradient into areas where there is little or no ongoing production of these compounds. Therefore observation of reduced nitrate, phosphate and sulfate are not necessarily inconsistent with expected trends and does not negate the evidence that biodegradation is occurring at the site.

Also as part of the Final FS, XJM-93-02X will be regrouped from a source well to a perimeter well. Similar to XJM-93-04X, XJM-93-02X is actually on the fringe of the plume and is may be more representative of upgradient groundwater parameters than plume groundwater. As a result of the regrouping, nitrate within the source area drops from 161 to 58 $\mu\text{g/L}$ which becomes even more consistent with the expected trend. Phosphate concentrations within the source area actually increase slightly as a result of the regrouping of XJM-93-02X (from 687 to 789 $\mu\text{g/L}$). However, a close review of the data reveals unusually large variations in phosphate concentration (increases of up to 2,770 $\mu\text{g/L}$) between 12/94 and 3/95 for wells 2446-2, 2446-3, and 2446-4. These concentrations are not likely to be naturally occurring. Deleting these 3/95 concentrations from the data set brings the average phosphate concentration within the source area down to only 141 $\mu\text{g/L}$ which is also consistent with the expected trend.

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Sulfate concentrations within the source area also increased slightly as a result of the regrouping of XJM-93-02X (from 14,666 to 16,600 $\mu\text{g/L}$). The observed reduction in sulfate in the downgradient area are not necessarily unexpected considering the above discussions (Lovely, 1994). The observed chloride concentrations are not believed to be "significantly" lower in the upgradient well, considering the frequent variations noted often within the same well (i.e., XJM-94-04X: from <2,120 to 15,400 $\mu\text{g/L}$ between 12/94 and 3/95). Application of road salt most likely contributes to the variability of the chlorides.

The Army agrees that intrinsic biodegradation would be more evident by observing a decrease in organic contaminant concentrations over time. Intrinsic biodegradation will be modeled upon collecting additional groundwater data during the predesign phase of the remediation as specified in the FS Report.

2. Comment: **Long-term groundwater monitoring.** To assess the progress of intrinsic bioremediation and to detect any migration of contaminants off-site, annual groundwater monitoring is proposed. This frequency of groundwater monitoring is inadequate to follow the proposed processes and to detect any effects of seasonality which can be very important in the interpretation of results.

Consider the following alternative long-term groundwater monitoring proposal. Monitor groundwater on a quarterly basis for at least 8 quarters and until a statistically significant decrease in contaminant concentrations has been demonstrated (e.g., by the Mann-Whitney test at a 90% confidence level). Then go to annual monitoring until cleanup goals have been achieved for 3 consecutive years.

Response: In the Draft FS, the Army has proposed that additional sampling and modeling be performed as part of the predesign phase (prior to implementing the long-term monitoring plan). Additionally, more groundwater monitoring wells are to be installed. The Army recognizes the importance of collecting a statistically significant data set and will evaluate the need of performing more frequent long-term monitoring (during the initial years) upon reviewing the results of the predesign modeling.

3. Comment: **Hydrogeological Aspects.** The characterization of the nature and extent of contaminants in the bedrock remains incomplete. Although one bedrock groundwater sampling point has been monitored (XJM-93-04X), this location is not located directly downgradient from the gasoline UST area. Additional monitoring wells are necessary, screened within the bedrock, to evaluate groundwater contamination in this area.

Response: Installation of additional monitoring wells is a component of every alternative (except No Action) in the Draft FS Report. The text will be clarified to reflect that some of these wells are to be bedrock wells.

4. Comment: The groundwater collection alternative does not specify the design criteria for the system. Is the purpose of the system to collect contaminated groundwater from the overburden only? Please state the design criteria.

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Response: As specified in the Draft FS Report (pg 4-19 and pg 4-29), the purpose of the groundwater collection/treatment component in Alternatives 4 and 5 is to hydraulically contain the plume. Use of the collection/treatment system as the sole means of remediation is impractical due to extremely low hydraulic conductivity in the soils. Based on the RI, only the overburden aquifer is believed to contain contaminants that exceed the PRGs. As a result, the groundwater extraction system specified for Alternatives 4 and 5 would collect groundwater only from the overburden. This will be clarified in the text. Long-term groundwater monitoring will be performed to observe contaminant migration in bedrock and the overburden.

5. Comment: The definition of groundwater flow between the bedrock and overburden systems remain unclear at this time. This uncertainty affects the evaluation of the groundwater collection alternative.

Response: See the response to Comment No. 4. On May 2, 1996 the Army held a meeting with the regulators at Fort Devens to discuss the draft feasibility study (FS) reports for AOC 43G and 43J. AOC 43J discussions pertained to detection of carbon tetrachloride in Round 6 of groundwater sampling at AOC 43J and the possibility of deeper (bedrock) chlorinated solvent groundwater contamination that may be present at the site. Because soils at the site did not present elevated levels of chlorinated solvents, they are not believed to be an issue within bedrock groundwater. Based upon the results of the meeting, installation of bedrock groundwater monitoring wells and long-term groundwater monitoring would be an acceptable solution in response to the above bedrock/overburden groundwater flow uncertainty.

SPECIFIC COMMENTS

6. Comment: Page ES-2, line 18: Please change "on" to "off".

Response: "On" will be changed to "off".

7. Comment: Page ES-2: please include a paragraph describing why industrial/commercial scenario was used for the downgradient receptor and a site map delineating reuse parcels and Army parcels.

Response: A paragraph will be added describing the planned reuse for downgradient locations. A site map delineating reuse parcels and Army parcels is already included in the draft FS report (Figure 4-1 and 4-2).

8. Comment: Table 2-3, Notes: The upgradient well is incorrectly identified as XJM-03-01X. It should be XJM-93-01X. In the list of perimeter wells, the well listed as XJM-94-04X should be XJM-93-04X. Note number 4 is missing. It should read "(4)By Kjeldahl Method."

Response: Table 2-3 will be corrected as noted.

9. Comment: Page 4-6, lines 18 through 22: Modeling of contaminant biodegradation used an average of degradation rates found in a literature search. Since the actual site biodegradation rate is unknown, and might be quite low, the lowest of the literature rates should also be used to establish a reasonable range of conditions (average to slow degradation).

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Response: The biodegradation modeling did not specifically use an average degradation rate, but used a rate which resulted in contaminant concentrations that most closely simulated the 1995 observed calibration target concentrations as discussed in Appendix C. As a result, degradation rates actually used in the model are close to the minimum rates found in literature and reported in Appendix C. The Army recognizes the unknown variables associated with the site and the limitations of the model. A more accurate estimate of degradation rates will be obtained as part of the predesign phase when the Army performs additional sampling and intrinsic biodegradation modeling.

10. Comment: Page 4-7, line 18: Objection to the word "verify." The so-called intrinsic bioremediation indicator data cannot verify the occurrence of intrinsic bioremediation, they can only provide additional evidence.

Response: The wording in this sentence will be revised as recommended.

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MADEP COMMENTS ON AOC 43J

Rebuttals to Army Response to Comments for Alternatives Screening Report, AOC 43J

1. **Comment:** MADEP Rebuttal (General Comment 3). The limited temporal trend exhibited for BTEX in groundwater collected from XJM-93-04X is not statistically significant and the vertical characterization of VOCs in groundwater may not be adequate to rule out the need to address contamination in saturated bedrock. Further consideration of bedrock remediation and additional characterization may be required.

Response: On May 2, 1996 the Army held a meeting with the regulators at Fort Devens to discuss the draft feasibility study (FS) reports for AOC 43G and 43J. AOC 43J discussions pertained to the detection of carbon tetrachloride in Round 6 of groundwater sampling at AOC 43J and the possibility of deeper (bedrock) chlorinated solvent groundwater contamination. Because elevated levels of chlorinated solvents were not detected in the soils at the site, they are not believed to be an issue within bedrock groundwater. Based upon the results of the meeting, installation of bedrock groundwater monitoring wells and long-term groundwater monitoring as part of the predesign program for the alternatives were considered acceptable in response to the uncertainty regarding vertical characterization of contaminants.

2. **Comment:** MADEP Rebuttal (Specific Comment 7). The first order degradation rates contain data from sites that may not be representative of AOC 43J. The case study data likely reflect aerobic environments, while the site appears to be an anaerobic environment. Therefore, use of the first order degradation rates should be replaced with data obtained from a site-specific Biofeasibility Study.

Response: Due to the orderly succession of oxidation-reduction reactions, most field occurrences of intrinsic biodegradation involve both aerobic and anaerobic processes. Aerobic processes typically occur on the fringe of the plume where oxygen is an available electron acceptor. While anaerobic degradation is believed to be the predominant process underway at 43J, one cannot exclude the probability that aerobic activity is also occurring at least on the upgradient fringe of the plume. The same applies to the numerous case studies referenced which involve both anaerobic and aerobic processes. These studies represent a range of degradation rates that are appropriate for Feasibility Study purposes. Site-specific degradation rates will be developed from the intrinsic biodegradation modeling to be performed during the predesign phase.

3. **Comment:** MADEP Rebuttal (Specific Comment 9). Alternative 5 would be more effective if in-situ sparging of the groundwater plume was incorporated with the SVE and groundwater collection components. The in-situ air sparging could remove some of the contaminants within the smear zone, and aid in biodegradation by increasing oxygen levels in the source area. This modification should be considered in the FS.

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Response: Because of the high soluble iron and manganese concentrations in groundwater and the low permeable soils, the air sparge wells would likely be fouled within a very short period of time. Therefore, the Army is reluctant to incorporate sparging as a component of Alternative 5.

Comments on the Draft Feasibility Study Report, AOC 43J

General Comments

1. Comment: The comparative analysis of remedial alternatives cannot be effectively completed at this time due to limitations inherent within the four remedial alternatives, other than Alternative 1 (No Action). These limitations include significant uncertainties with respect to: 1) the degree and extent of contamination; 2) adequate monitoring locations to detect migration of contaminants into the Zone 2 of the Sheboken well field; 3) the effectiveness and time frame of intrinsic and "passive" in-situ bioremediation alternatives (lack of Biofeasibility Study); 4) groundwater flow interaction and contaminant fate and transport between the overburden and bedrock; and 5) the effectiveness of the proposed SVE upon contamination within the smear zone (secondary source). These uncertainties preclude implementation of an objective comparison of the remedial alternatives. For instance, the actual cost to implement Alternative 2 (intrinsic bioremediation and long-term monitoring) could eventually exceed the costs for Alternatives 3, 4, 5, or another engineered remedial action.

Response: The Army believes that a comparative analysis can be readily completed at this time. Based on the conclusions of the May 2, 1996 meeting at Fort Devens, the Army was under the perception that many of these "limitations" had been addressed. A discussion and proposed solution based upon the May 2, 1996 meeting follow:

1) Degree and extent of contamination: With the exception of questions regarding vertical gradients, the RI has sufficiently defined the degree and extent of contamination within the overburden. Although the Army continues to believe that bedrock contamination is not an issue, bedrock wells will be installed and incorporated into the long-term monitoring program to monitor for the presence/absence of contamination at deeper gradients. The wells would be installed and monitored during the predesign phase and performed regardless of the alternative selected. A contingency plan will be included in the ROD in the event that modeling/monitoring indicates that groundwater remedial objectives are not being met.

2) Adequate monitoring locations to detect migration of contaminants into the Zone 2 of the Sheboken well field: As discussed in the draft FS Report, all Alternatives entail installation of monitoring wells and long-term monitoring to observe for any migration of contaminants off-site. The exact location of wells is a design issue and impacts all alternatives equally. It does not prevent an effective FS comparative analysis from being performed.

3) Effectiveness and time frame of intrinsic and "passive" in-situ bioremediation alternatives (lack of Biofeasibility Study): Intrinsic bioremediation is a component of every alternative evaluated and impacts the remedial time similarly for each alternative. Even Alternative 5 costs are based on the same intrinsic biodegradation time frame for cost purposes (otherwise Alternative 5 would require

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56 years to remediate by removing contamination by pumping alone). As discussed on p. 5-7 of the draft FS Report, an evaluation of the sensitivity of costs revealed that total costs associated with all alternatives consist primarily of long-term O&M costs and are subject to "across the board" impacts with regard to treatment duration (e.g., this limitation should not impact an effective FS comparative analysis and relative comparison of costs from being performed).

4) Groundwater flow interaction and contaminant fate and transport between the overburden and bedrock: See response to limitation No. 1.

5) Effectiveness of SVE upon contamination within the smear zone (secondary source): This "limitation" was not discussed at the May 2, 1996 meeting. However, the Army believes that there is enough information for FS purposes to evaluate the SVE component of Alternative 5. There is no observed "smear zone" at the site. Soil contaminants are believed to be in equilibrium with the groundwater (page 2-7 of the draft FS Report). Alternatives 4 and 5 create a potential condition where, over time, soil and groundwater will become in disequilibrium. The anticipated effects of this disequilibrium on treatment time are accounted for in Alternative 4 and 5 (pages 4-20 and 4-33 of the draft FS Report). The Army has made simplified, but conservative, assumptions regarding the SVE system for purposes of performing a relative cost comparison of the alternatives. A pilot test is recommended in the draft FS prior to commencing with the actual SVE design.

2. Comment: As noted during the May 2, 1996 meeting at Fort Devens to discuss this site, MADEP has outstanding concerns on the following:

- the presence of contamination in the groundwater which is within the Zone II of the Sheboken wells;
- the need for further studies regarding on-site intrinsic bioremediation; and
- the need for a contingency plan to be included in the ROD in the event that further studies and monitoring do not demonstrate that groundwater conditions are improving and that further migration is not taking place

MADEP's acceptance of intrinsic remediation for this site is contingent on the Army's resolution of the above concerns.

Response: See response to General Comment No. 1.

3. Comment: Since the Army appears to prefer an intrinsic bioremediation (Alternative 2), additional data demonstrating the appropriateness of intrinsic bioremediation will be necessary. These data can only be obtained through additional sampling and analyses and completion of a Biofeasibility Study. Comments pertaining to implementation of a Biofeasibility Study have been provided at the end of this review.

Response: Additional groundwater sampling, installation of groundwater monitoring wells and intrinsic biodegradation modeling will be performed as part of the predesign/design phase.

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4. Comment: Additional consideration should be given to the alternatives evaluated. Alternative 3 of the FS could be modified to include a contingency for more aggressive enhanced or engineered bioremediation. The addition of in-situ air sparging would complement the soil vapor extraction and groundwater extraction to assist in removal of contamination in the smear zone and aid aerobic biodegradation. Another remedy to consider would be in-situ chemical oxidation for the saturated zone.

Response: See response to Alternative Screening Document Rebuttal No. 3.

Page-specific comments

1. Comment: **Section 1, Page 1-20.** The chemical-specific risks are presented in this section (1.4.4). As noted in previous review comments, the document needs to clearly indicate that risk-based decisions will be based on total risks for the environmental medium and on maximum detected concentrations for groundwater exposures.

Response: Page 1-20 describes the baseline assessment that was performed. Discussion of the risk decisions in developing PRGs are covered under in Section 2.0 (2.2).

2. Comment: **Section 1, Page 1-23.** MCP Method 1 GW-2 standards should not be used to evaluate a pathway from the quantitative baseline risk assessment. The purpose of the baseline risk assessment is to evaluate site-specific conditions that may promote or limit migration potential (e.g., depth to groundwater, likelihood of building development, etc.), even if the pathway is not evaluated quantitatively.

Response: The risk assessment was performed following relevant guidance and standards developed by the USEPA and not in accordance with MCP Method 3 procedures. Use of the MCP Method 1 GW-2 standards as a qualitative screening tool is consistent with the Preliminary Risk Evaluation (PRE) approach used to identify those exposure pathways likely to be significant contributors to human health risk. The screening used at AOC 43J showed that vapor migration into building foundations is not expected to pose significant risk at AOC 43J.

3. Comment: **Section 1, Page 1-20, Paragraph 2.** As noted during the May 2, 1996 meeting at Fort Devens, MADEP is concerned about groundwater contamination at this site because it lies within the Zone II (draft Zone II) of the Sheboken well. Additional discussion needs to be provided pertaining to known and/or potential downgradient human receptors (e.g., possible residential use/development).

Response: The Devens Reuse Plan (Vanasse Hangen Brustlin, 1994) will be referenced in this paragraph. This plan indicates that the area immediately downgradient (across Patton Road) will be retained by the federal government for use as the Federal Bureau of Prisons Medical Center. The cemetery, which is comprised of an approximate 450- by 350-foot parcel of land immediately across

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Patton Road will be retained as Army Reserve Enclave property. Therefore drinking water supplies for residential recipients would not be expected within these immediate downgradient areas.

A recent delineation of Zone II aquifer areas by tracing groundwater velocity vectors at Fort Devens shows AOC 43J as being near the edge but within the Zone II aquifer area of the Sheboken Well (Koch, 1995). This delineation is only in draft form at this time and is still under investigation. AOC 43J is located approximately 4,000 feet from the Sheboken Well which is outside the 0.5 mile default radius.

4. Comment: Section 2, Page 2-2, Paragraph 1. Preliminary Remediation Goals were not provided for soil, yet Alternative 5 discusses soil treatment with soil vapor extraction to remove secondary sources of contamination to groundwater. It is unclear how the Army plans to address the residual soil contamination under the other alternatives which address soil contamination. A preliminary remediation goal should be proposed for soil. In addition, a preliminary remediation goal for groundwater should include cleanup protective of the Zone II (draft Zone II) of the Sheboken well.

Response: PRGs are not required for soil at AOC 43J because the baseline risk assessment shows that estimated carcinogenic risks did not exceed the USEPA target risk range or the MADEP MCP target risk level. Similarly, estimated noncarcinogenic risks did not exceed the MADEP target level of 1. There are also no observed "secondary sources" at the site. Soil contaminants are believed to be in equilibrium with the groundwater (page 2-7 of the draft FS Report). Alternatives 4 and 5 create a potential condition where, over time, soil and groundwater will become in disequilibrium. SVE (Alternative 5 only) is used to hasten groundwater remediation and is not required to reduce risk. Groundwater PRGs that are protective of residential exposures are not necessary at this time because there is no evidence indicating that contaminants are migrating off the Army Enclave property and there is no exposure to residential receptors. AOC 43J is outside the 0.5 mile default radius of the Sheboken well. Predesign sampling and intrinsic biodegradation modeling in addition to long-term groundwater monitoring will ensure that a contingency plan is readily implemented in the event that contaminants are migrating off the Army Enclave property.

5. Comment: Section 2, Page 2-3, Paragraph 3. The preliminary remediation goals for groundwater (and soil) should also be based on compliance with MCP provisions which can be considered ARARs. The allowable contaminant concentrations specified for soil and groundwater in the MCP should be considered ARARs since they are substantive numerical standards. Other MCP provisions, such as implementation of an Activities and Use Limitation (AUL) and/or a Grant of Environmental Restriction (GER) are also ARARs. The FS text and associated tables should be amended as appropriate to incorporate these and all other MCP ARARs.

Response: The MCP provides that response actions at CERCLA sites shall be deemed adequately regulated for purposes of compliance with the MCP. The Army has chosen not to use MCP Method 1 risk-based standards or Method 3 risk characterization for evaluation of the site. Instead, the Army has conducted a CERCLA risk assessment and has not considered the MCP an ARAR.

6. Comment: Section 3, Page 3-4, Paragraph 2. The FS refers to use of Passive Bioremediation as a component of Alternative 3. Passive bioremediation is synonymous with intrinsic bioremediation and

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does not involve human interference or modification of subsurface conditions. The proposed introduction of oxygen and perhaps mineral nutrients into the aquifer to promote biodegradation is an example of active, enhanced, or engineered bioremediation. The FS text and tables should be modified accordingly.

Response: The term "passive" is also a common term to the industry and is used in the FS to identify a treatment level that is between intrinsic biodegradation (modeling and monitoring) and more active bioremediation techniques (injection of nutrients and oxygen or ex-situ treatment). Changing terminology at this time in the review process would only unnecessarily confuse the alternatives being evaluated.

7. Comment: Section 3, Page 3-4, Paragraph 5. It should be noted that if the proposed intrinsic (anaerobic) bioremediation or the contingent passive (anaerobic) bioremediation of the plume do not effectively remediate site groundwater, aerobic biodegradation for the entire plume may be a viable alternative to expensive long-term monitoring.

It is unclear why fouling of the aquifer is cited a concern only for the aerobic bioremediation of the entire plume. Fouling should also be a concern for the "passive" aerobic bioremediation of the downgradient plume, since fouling can result from the introduction of oxygen into the aquifer regardless of the methodology of its introduction.

Response: See response to Alternative Screening Document Rebuttal No. 3. Fouling is also a concern for passive aerobic bioremediation but not to the degree of total plume oxygenation (p 4-18 of the draft FS Report discusses anticipated maintenance requirements for passive bioremediation). First, there is likely to be less fouling in the passive wells because these wells are placed downgradient of the heavily contaminated area where iron is not as soluble. (Manganese still remains dissolved in the downgradient plume). Secondly, because the passive system generates small amounts of oxygen over an extended period, iron precipitation is minimized. Reportedly, the iron hydroxide has a tendency to deposit on the filter sock which provides a convenient means for capture and cleaning.

8. Comment: Section 3, Page 3-6, Paragraph 3. The groundwater model used for the preliminary design of a groundwater collection system is based on groundwater flow through porous media (e.g., overburden sand and till). However, a significant portion of VOC contamination is reported to be present within the fractured bedrock. The groundwater model used to support the groundwater collection design does not appear to be appropriate since the model does not account for the uncertainties associated with fractured flow. Therefore, the model is not representative of actual site conditions. The efficiency and implementability of the proposed groundwater collection systems included in Alternatives 4 and 5 can not be evaluated until additional data are collected or another model is used which more accurately represents the complicated interaction between groundwater flow within the overburden and bedrock.

Response: A significant portion of VOC contamination is not expected to be in bedrock downgradient of the source as inferred by the comment. See response to Alternative Screening Document Rebuttal No. 1.

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9. Comment: Section 4, Table 4-3. This table of intrinsic bioremediation parameters for long-term monitoring should be amended to include the following: carbon dioxide (metabolic byproduct), number of bacteria (hydrocarbon degraders), number of protozoa, carbon isotopes (organic and inorganic), alkyl benzoates and alkyl phenols (BTEX intermediate metabolites). The carbon isotopes ratios should be evaluated to measure transformation of organic to inorganic carbon. The ratio of non-degradable to degradable compounds should also be compared to evaluate intrinsic bioremediation effectiveness.

Response: The parameters listed in Table 4-3 are believed to be the basic parameters necessary for evaluating and modeling intrinsic biodegradation. The additional parameters listed by the MADEP can also be helpful in the absence of other indicators but would be best added on a case-by-case basis as needed during the predesign and design phase. Carbon dioxide can be used as an aerobic biodegradation indicator but can be greatly impacted by pH/alkalinity and other geochemical sources and sinks. The BTEX intermediate metabolites are very transitory and their absence does not necessarily infer that biodegradation is not occurring. The ratio of non-degradable to degradable compounds can be beneficial should it become important to assess whether observed contaminant reduction is a result of biodegradation or other natural attenuation processes such as diffusion and dispersion.

10. Comment: Section 5, Page 5-6, Paragraph 4. Although the comparative analysis of remedial alternatives indicates that Alternative 2 is most cost effective, the actual costs associated with indefinite monitoring of the intrinsic bioremediation may exceed the costs estimated for Alternatives 3, 4, and 5. An increased frequency and expanded list of analytical parameters will be required in order to effectively monitor and evaluate intrinsic bioremediation at the site. It may be less costly to enhance the intrinsic bioremediation with an engineered remedy to modify subsurface conditions (e.g., addition of nutrients or modification of oxygen levels) to maximize contaminant destruction and minimize the remediation time frame and remedial costs. Alternative 3 of the FS could be modified to include a contingency for more aggressive enhanced or engineered bioremediation. The addition of in-situ air sparging of groundwater to Alternative 5 should also be considered. Air sparging would complement the soil vapor extraction and groundwater extraction to assist in removal of contamination in the smear zone and aid aerobic biodegradation. Another remedy to consider would be in-situ chemical oxidation for the saturated zone.

Response: See response to Alternative Screening Document Rebuttal No. 3. The aggressive aeration/injection technologies are all subject to the site limiting restrictions described on page 3-5 of the draft FS Report.

11. Comment: Appendix A, Table A-1. The table should also include partitioning data for carbon tetrachloride and the other chlorinated VOCs present at the site.

Response: Table A-1 is based upon detected soil concentrations. Carbon tetrachloride was not detected in the soil (nor were any other chlorinated solvents detected in soil that exceeded MCLs in groundwater).

12. Comment: Appendix B, Page B-1, Section 1. See comment to page 3-6, paragraph 3.

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Response: See response to Page-Specific Comment No. 8 and Alternative Screening Document Rebuttal No. 1.

13. Comment: **Appendix B, Figures 1, 2, & 3.** Much of the text and characters in these figures are illegible. These figures should be presented in a larger format.

Response: The Quickflow model's graphics resolution using converted Autocad drawings as presented in Figures 1, 2, and 3 cannot be improved. All the relevant data for review of the model output (well location, groundwater elevations, and flow) are clearly depicted. The remaining typed text or site features that are lost due to poor resolution are not pertinent to the overall model evaluation.

14. Comment: **Appendix C, Page C-2, Paragraph 4.** The on/off source simulations used in the ONED8 analytical model for solute transport, in which the contaminant source was removed in 1992 is not readily applicable for this site because: 1) the model does not take into consideration that the overburden smear zone and possibly bedrock serve as a continuing source of contamination; and 2) the model does not take into account groundwater flow through fractured media. Therefore, presentation of the on/off source simulation may not be appropriate for inclusion in the FS.

Response: The model is applicable for its intended purpose of simulating existing and potential future concentrations of contaminants of concern in the overburden groundwater to assist in evaluating FS remedial alternatives. There is no observed "smear zone" at the site. Soil contaminants are believed to be in equilibrium with the groundwater (page 2-7 of the draft FS Report). Alternatives 4 and 5 create a potential condition where, over time, soil and groundwater will become in disequilibrium. The anticipated effects of this disequilibrium on treatment time are already accounted for in Alternative 4 and 5 (pages 4-20 and 4-33 of the draft FS Report). Refer to the response to Alternative Screening Document Rebuttal Comment No. 1 regarding groundwater flow through fractured media.

15. Comment: **Intrinsic Bioremediation Case Study (Appendix C, 13 pages in).** It is not clear that the data compiled in this summary table are relevant or appropriate for the site. Since the site groundwater is apparently an anaerobic environment, the case study data, which are likely associated with aerobic sites, may not be representative. The case study data do not include sites with carbon tetrachloride contamination. Also, there are apparently no site data indicating whether the unsaturated overburden is aerobic or anaerobic, therefore comparison with the case study data may not be appropriate. Therefore, presentation of these data may not be appropriate for inclusion in the FS.

Response: See response to Alternative Screening Document Rebuttal No. 2.

16. Comment: **Appendix D, Page D-1, Paragraph 1.** The solute transport model used to calculate 'Flush' times for site VOCs may not be appropriate for the following reasons: 1) the model is based on groundwater flow modeling that may not be representative (see comment to page 3-6, paragraph 3); 2) the model apparently does account for continued releases of VOC via fluctuating groundwater

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contact with the smear zone; and 3) the model apparently does not account for "flushing" of contaminants from the vadose zone via rainwater infiltration. Therefore, the portions of the FS which rely upon this modeling may not be appropriate.

Response: The solute transport model is appropriate for FS purposes. The above issues do not negate the appropriateness of the model for the following reasons: 1) See response to Page-Specific Comment No. 8 regarding the groundwater flow model; 2) There is no "smear zone" as discussed in response to Page-Specific Comment No. 14.; and 3) Minimal flushing from groundwater infiltration is expected because the entire site is paved and source soils within the vadose zone have been removed (page 2-7 of the draft FS Report).

17. Comment: Appendix E, Table E-1. Further explanation of this table is required in the text. It is not clear that the data compiled in this summary table is relevant or appropriate for the site. Because there are apparently no site-specific data indicating whether the unsaturated overburden is aerobic or anaerobic, the estimated remediation times predictions based on intrinsic bioremediation are difficult to evaluate. Therefore, the remediation time frames may not be appropriate.

Response: Calculations used first order degradation coefficients from the solute transport evaluation, averaged measured soil concentrations, and theoretical soil concentrations that would exist in soil if groundwater CPCs were at PRGs. These calculations are considered adequate for FS purposes (see response to Alternative Screening Document Rebuttal No. 2.) An explanation of this table is provided on pages 3-16 and 4-20 of the draft FS Report.

18. Comment: Recommendations for a Biofeasibility Study. A Biofeasibility Study demonstrating the effectiveness of Site intrinsic bioremediation should be completed to further evaluate the intrinsic bioremediation alternatives included in the FS. The Biofeasibility Study completed for AOC 43G is not sufficient because oxygen and nutrients were added to the study samples. This study is not representative of in-situ conditions relative to intrinsic bioremediation for the site.

It appears that intrinsic bioremediation is occurring at the site. However, the intrinsic bioremediation assumed by the Army to be occurring at the site is based solely on indirect evidence. Before the intrinsic bioremediation can be properly evaluated, additional data establishing the degree and effectiveness of intrinsic bioremediation should be provided.

A key factor has not been determined: the rate and effectiveness of the apparent intrinsic biodegradation. While aerobic biodegradation of BTEX compounds has been well documented, there are currently no field data demonstrating significant removal of petroleum hydrocarbons in anaerobic environments. Benzene is particularly resistant to anaerobic biodegradation and the ability of site microorganisms to degrade chlorinated VOCs (e.g., carbon tetrachloride) has not been evaluated.

There are many factors which can limit the rate of intrinsic biodegradation. As indicated in Section 4 of the FS, the time frame for remediation is likely greater than 56 years. The time frame uncertainty precludes a proper evaluation of intrinsic bioremediation for the Site. In order to reduce the uncertainty, the entire subsurface ecosystem must be considered as a whole in order to establish

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the rate limiting factor affecting intrinsic bioremediation. Without establishing the rate limiting factor, money may be wasted by modifying a condition (i.e. oxygen addition) that is not rate limiting. Additional data are required in order to evaluate the rate limiting factors of intrinsic bioremediation.

The general strategy for demonstrating that intrinsic bioremediation is working should include collection of three types of evidence:

- documented loss of contaminants from the Site;
- laboratory studies indicating microbes in Site samples have the potential to transform the contaminants under the expected in-situ conditions;
- evidence indicating that the biodegradation potential is actually realized in the field.

Additional information regarding demonstrating the effectiveness of intrinsic bioremediation may be found in the following sources:

- National Research Council Committee on In-Situ Bioremediation Water Science and Technology Board, Commission on Engineering and Technical Systems, National Research Council, 1993. *In-Situ Bioremediation: When Does It Work?* National Research Council, Washington, D.C.
- U.S. EPA, 1993, Guide for Conducting Treatability Studies under CERCLA - Biodegradation Remedy Selection, Interim Guidance, EPA/540/R-93/519a, August 1993.
- U.S. EPA, 1993, Bioremediation Resource Guide, EPA/542-B-93-004, September 1993.
- Baker, C.H. and Herson, D.S., 1994. *Bioremediation*. McGraw-Hill, Inc., New York, NY.

Response: The Biofeasibility Study completed for AOC 43G was not intended to be representative of intrinsic bioremediation conditions. It was included in the draft FS Report for AOC 43G to be supportive of the passive (aerobic) bioremediation alternative component as referenced in the draft AOC 43G FS Report (page 3-6).

The Army intends to perform additional groundwater sampling and intrinsic bioremediation modeling as part of the predesign phase to provide evidence indicating that the biodegradation potential is occurring in the field and that remedial objectives are being achieved.

The time frame of 56 years specified in Section 4 of the draft FS report is based upon pumping remediation alone (excluding abiotic removal or biological degradation effects).

REFERENCES

- Koch, Donald, 1995. Transmittal Memo to the Fort Devens Zone II Designation Process Action Team and attached map "Zone II Delineations Based on Manual Tracing of Velocity Vectors 7/28/95"; August 1.
- Lovely, Derek R., F. H. Chapelle, and J. C. Woodward, 1994. "Use of Dissolved H₂ Concentrations to Determine Distribution of Microbially Catalyzed Redox Reactions in Anoxic Groundwater." Environmental Science and Technology; Vol 28, No. 7, July.
- Vanasse Hangen Brustlin, Inc. (1994) "Devens Reuse Plan". Prepared for The Boards of Selectmen - Town of Ayer, Town of Harvard, Town of Lancaster, Town of Shirley, and the Massachusetts Government Land Bank; November 14.

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