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FINAL

TREATABILITY STUDY IN SUPPORT OF
INTRINSIC REMEDIATION

for

SITE ST41

ELMENDORF AIR FORCE BASE

ANCHORAGE, ALASKA

October 1995

Prepared for:

AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS

AND

ELMENDORF AIR FORCE BASE
ANCHORAGE, ALASKA

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EXECUTIVE SUMMARY

This report presents the results of a treatability study (TS) performed by Parsons Engineering Science, Inc. (Parsons ES) at Elmendorf Air Force Base, Alaska to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) contamination in the shallow saturated zone in the vicinity of Site ST41 (locally known as Four Million Gallon Hill). For this report, Site ST41 was studied only in the vicinity of the BTEX plume emanating from Tank 601. Soil and groundwater contamination is known to occur at the site, with contamination being present in the dissolved and gaseous phases and as residual light nonaqueous-phase liquid (LNAPL) within the aquifer matrix. There is also evidence of mobile LNAPL (free product) at this site. This study focused on the impact of dissolved BTEX on the shallow groundwater system at the site. Site history and the results of soil and groundwater investigations conducted previously are also summarized in this report.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from Site ST41 to potential receptors. The *Bioplume II* model was used to estimate the rate and direction of dissolved BTEX movement through the shallow saturated zone under the influence of advection, dispersion, sorption, and biodegradation. Input parameters for the *Bioplume II* model were obtained from existing site characterization data, supplemented with data collected by Parsons ES in conjunction with personnel from the United States Environmental Protection Agency (USEPA) Robert S. Kerr Environmental Research Laboratory. Extensive site-specific data were used for model implementation. Model parameters that were not measured at the site or calculated from site data were estimated using reasonable literature values.

The results of this study suggest that dissolved BTEX contamination present in groundwater poses no significant risk to human health or the environment in its present, or predicted future, concentrations and distribution. Whether in conjunction with the interim remedial action system already in place or not, intrinsic remediation with LTM is a viable option for remediating dissolved BTEX contamination found in shallow groundwater at this site. Model results suggest that intrinsic remediation could reduce dissolved BTEX concentrations below regulatory limits in less than 30 years and possibly in less than

22 years, depending upon the effectiveness of the interim remedial action (IRA) system in reducing source loading rates. The IRA has been in operation since October 1993, but portions of the system may be shut down.

On the basis of Air Force Center for Environmental Excellence intrinsic remediation guidance, it is suggested that four LTM wells and three point-of-compliance (POC) monitoring wells be used to monitor the long-term migration and degradation of the dissolved BTEX plume. Regular sampling and analysis of groundwater from these sampling points will allow the effectiveness of intrinsic remediation to be monitored and should allow sufficient time to implement engineering controls to contain the plume if BTEX compounds are detected in the POC wells. Based on modeled contaminant fate and transport, these wells should be sampled on an annual basis for at least 15 years. Along with other analyses used to verify the effectiveness of intrinsic remediation, the groundwater samples should be analyzed for BTEX compounds by USEPA Method SW8020. If BTEX concentrations in groundwater from the POC wells exceed the federal regulatory standards of 5 micrograms per liter ($\mu\text{g/L}$) for benzene, 1,000 $\mu\text{g/L}$ for toluene, 700 $\mu\text{g/L}$ for ethylbenzene, or 10,000 $\mu\text{g/L}$ for total xylenes, additional corrective actions may be required to remediate groundwater at the site.

SECTION 1

INTRODUCTION

This report was prepared by Parsons Engineering Science, Inc. (Parsons ES) [formerly Engineering-Science, Inc. (ES)] and presents the results of treatability study (TS) conducted to evaluate the use of intrinsic remediation (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater at Site ST41, Elmendorf Air Force Base (AFB), Alaska. Previous investigations determined that fuel hydrocarbons had been released into the soil and shallow groundwater at the site. The main emphasis of the work described herein was to evaluate the potential for naturally occurring degradation mechanisms to reduce dissolved benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations in groundwater to levels that are protective of human health and the environment.

1.1 SCOPE AND OBJECTIVES

Parsons ES, in conjunction with researchers from the United States Environmental Protection Agency (USEPA) Robert S. Kerr Environmental Research Laboratory (RSKERL), was retained by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct site characterization and groundwater modeling in support of intrinsic remediation with long-term monitoring (LTM).

The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of the program and this specific Elmendorf AFB study is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons in groundwater so that this information can be used by the base and its prime environmental contractor(s) to develop an effective groundwater remediation strategy. As a result, these studies are not necessarily intended to fulfill specific federal or state requirements regarding site assessments, remedial action plans, or other such mandated investigations and reports. A secondary goal of this multi-site initiative is to provide a database from multiple sites that demonstrates that natural

processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential receptor exposure pathways, and do so in a cost-effective manner.

The scope of work for this project involved the following tasks:

- Reviewing existing hydrogeologic and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination and to collect geochemical data in support of intrinsic remediation;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Determining if naturally occurring processes of contaminant destruction are occurring in groundwater at the site;
- Performing contaminant fate and transport modeling based on site hydrogeologic conditions using the Bioplume II model;
- Evaluating a range of model input parameters to determine the sensitivity of the model to those parameters and to consider several contaminant fate and transport scenarios;
- Determining if naturally occurring processes are sufficient to minimize BTEX plume expansion so that groundwater quality standards can be met at a downgradient point of compliance (POC);
- Suggesting remedial action objectives (RAOs) based on the results of the field investigation and modeling, and reviewing available remedial technologies for comparison with the intrinsic remediation option;
- Using the results of modeling to suggest an appropriate remedial option based on effectiveness, implementability, and cost criteria, in light of the evidence presented in support of intrinsic remediation; and
- Providing an LTM plan that includes LTM and POC well locations and a sampling and analysis plan.

Site characterization activities in support of intrinsic remediation included soil borehole drilling with soil sample collection and analysis, monitoring well installation, light nonaqueous-phase liquid (LNAPL) sampling, and sampling and analysis of groundwater from newly installed and existing monitoring wells.

Site-specific data were used to develop a fate and transport model for the site using Bioplume II and to conduct a preliminary exposure pathway analysis. The Bioplume II

model was used to simulate the movement of dissolved BTEX in the shallow saturated zone under the influence of advection, dispersion, sorption, and biodegradation. As part of the TS, this modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved BTEX plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible completion of exposure pathways to potential downgradient receptors; and 3) to provide technical support for the intrinsic remediation with LTM remedial option during regulatory negotiations, as appropriate.

All hydrogeologic and groundwater chemical data necessary to evaluate multiple remedial options were collected under this program; however, the field work conducted under this program was oriented toward the collection of hydrogeologic data to be used as input into the Bioplume II groundwater model in support of intrinsic remediation with LTM for restoration of fuel-hydrocarbon-contaminated groundwater.

This report contains nine sections, including this introduction, and four appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the Bioplume II model and design of the conceptual model for the site, lists model assumptions and input parameters, and describes sensitivity analysis, model output, and the results of the Bioplume II modeling. Section 6 presents a comparative analysis of remedial alternatives. Section 7 presents a suggested LTM plan for the site. Section 8 presents the conclusions of this work and provides recommendations for further work at the site. Section 9 lists the references used to develop this document. Appendix A contains boring logs and well completion diagrams. Appendix B presents soil and groundwater analytical results. Appendix C contains calculations and model input parameters. Appendix D contains Bioplume II model input and output in ASCII format on a diskette.

1.2 FACILITY BACKGROUND

Site ST41 is located in the southwestern portion of the base, near the west end of the east-west runway. The site occupies approximately 20 acres north of Loop Road, approximately

2,200 feet east of the Knik Arm of Cook Inlet. Figure 1.1 shows the location of this site relative to Elmendorf AFB. In the early 1940's, four 1,000,000-gallon aviation gasoline (AVGAS) underground storage tanks (USTs) were installed at this site. Locations of these USTs, numbered 601 through 604, are indicated on Figure 1.2. In addition to the UST system, a fuel product distribution line runs through the area. This line is currently in use and is not considered to be a source of contamination (Jacobs Engineering Group, 1994b). Another potentially significant site feature is a 1-acre area on the western edge of Site ST41, where tank sludge is suspected to be buried. However, base personnel have indicated that sludge was disposed of elsewhere on the base, and there are no records of sludge disposal in this area (Jacobs Engineering Group, 1994b).

Source areas at the site, originally called SP-5 and SP-5A, included an area adjacent to the USTs and an oil seep just south of Loop Road. Under the Installation Restoration Program (IRP), Site ST41 is part of operable unit (OU) 2.

The USTs are known to have leaked, and numerous aboveground spills also have occurred at this site. Spills suspected or known to have occurred include a 60,000-gallon AVGAS spill in the 1960's and a 33,000-gallon spill in 1964. Several hundred thousand gallons of JP-4 jet fuel were reportedly spilled in this area between 1975 and 1984 (Engineering-Science, Inc., 1983; Black & Veatch, 1990). In the 1970's and early 1980's, a concrete dam and an oil/water separator were installed in an effort to intercept fuel discharging from seeps on the south side of Site ST41. In late 1990, testing indicated that all four USTs were leaking, and all the tanks and piping were emptied and taken out of service in early 1991. It is also possible that petroleum has been released from piping, including valve fittings, valve pits, and cracks in the piping.

In October 1993, two groundwater extraction wells and three groundwater extraction trenches were installed in the area on either side of a groundwater divide running through the site as an interim remedial action (IRA). The IRA system was constructed to intercept mobile LNAPL and contaminated water. During construction of the IRA system, two wood stave condensate pipes were uncovered. These pipes allowed condensed fuel and water to drain away from Tanks 601 and 604 and discharge at the ground surface. Locations of these features are indicated on Figure 1.3. These pipes may have been connected to sump pumps that were used to remove water from the bottoms of the tanks.

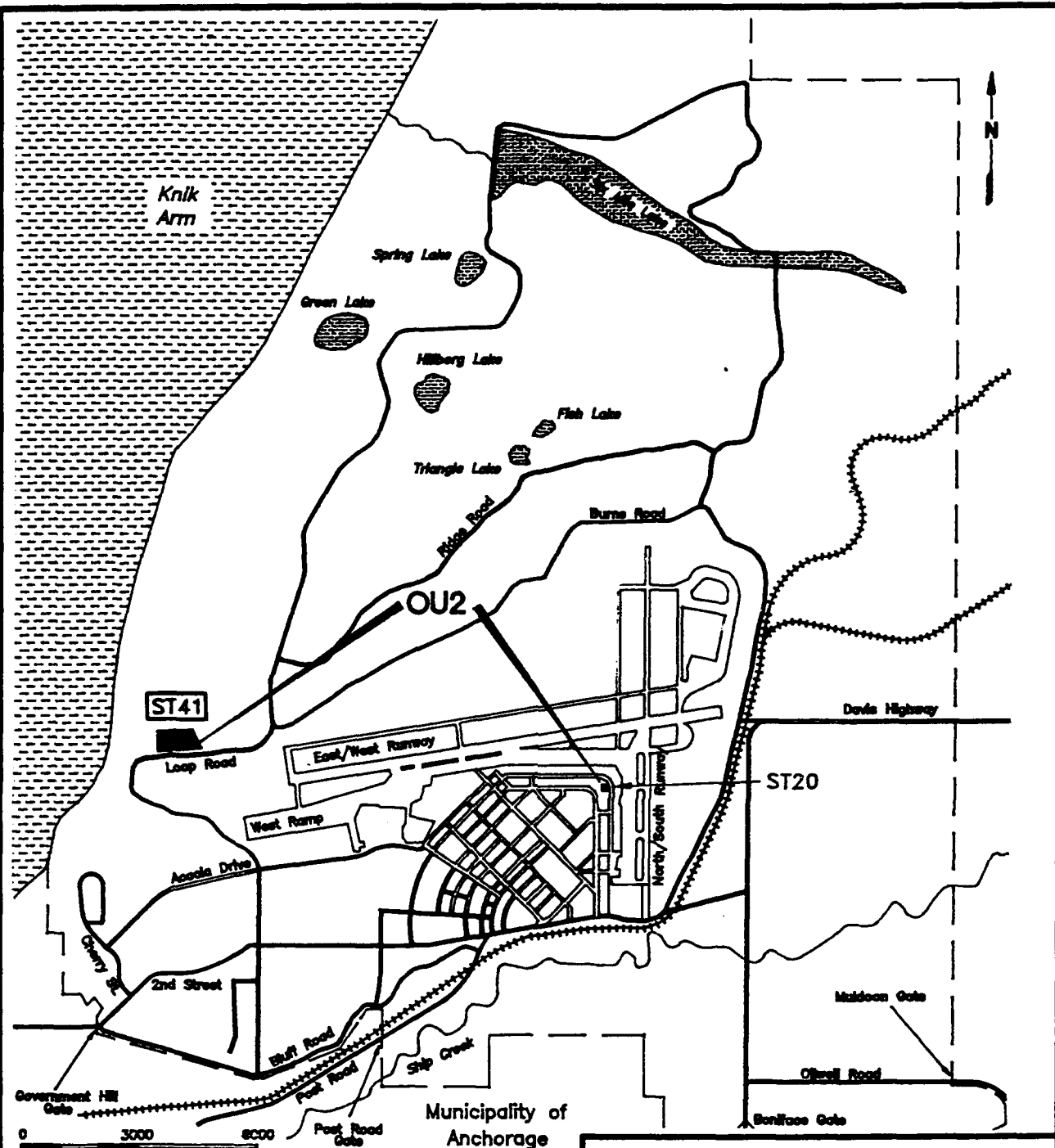


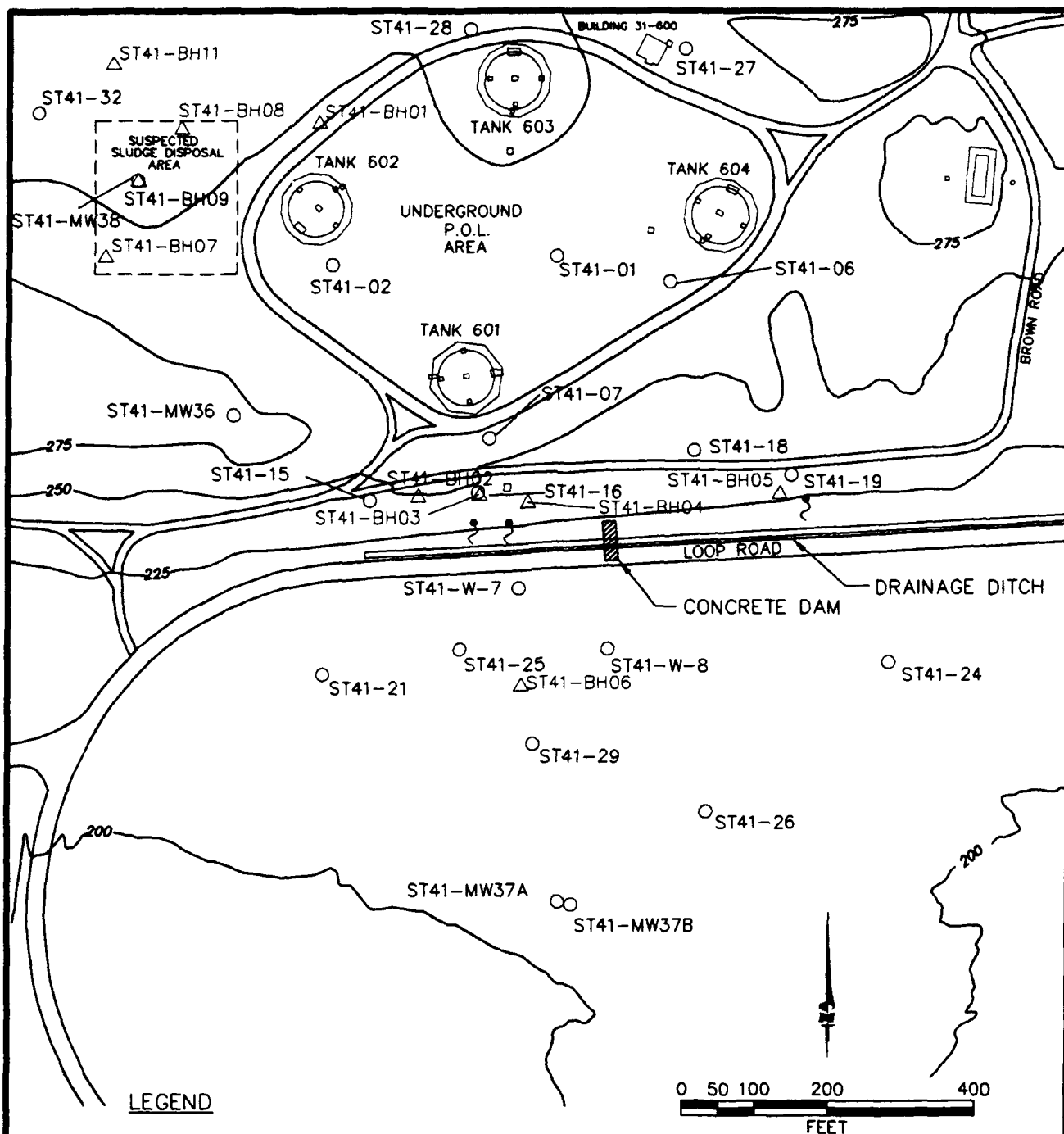
FIGURE 1.1
SITE LOCATION MAP

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

PARSONS
ENGINEERING SCIENCE, INC.

Denver, Colorado

Source: Jacobs Engineering Group, 1994b.



LEGEND

- | | |
|--|--|
| | ROAD |
| | BUILDING |
| | GROUNDWATER SEEP |
| | MONITORING WELL (1988-1992) |
| | SOIL BORING (1994) |
| | GROUND SURFACE ELEVATION CONTOURS (FEET ABOVE MSL) |
| | CONTOUR INTERVAL = 25 FEET |

Source: Jacobs Engineering Group, 1994b.

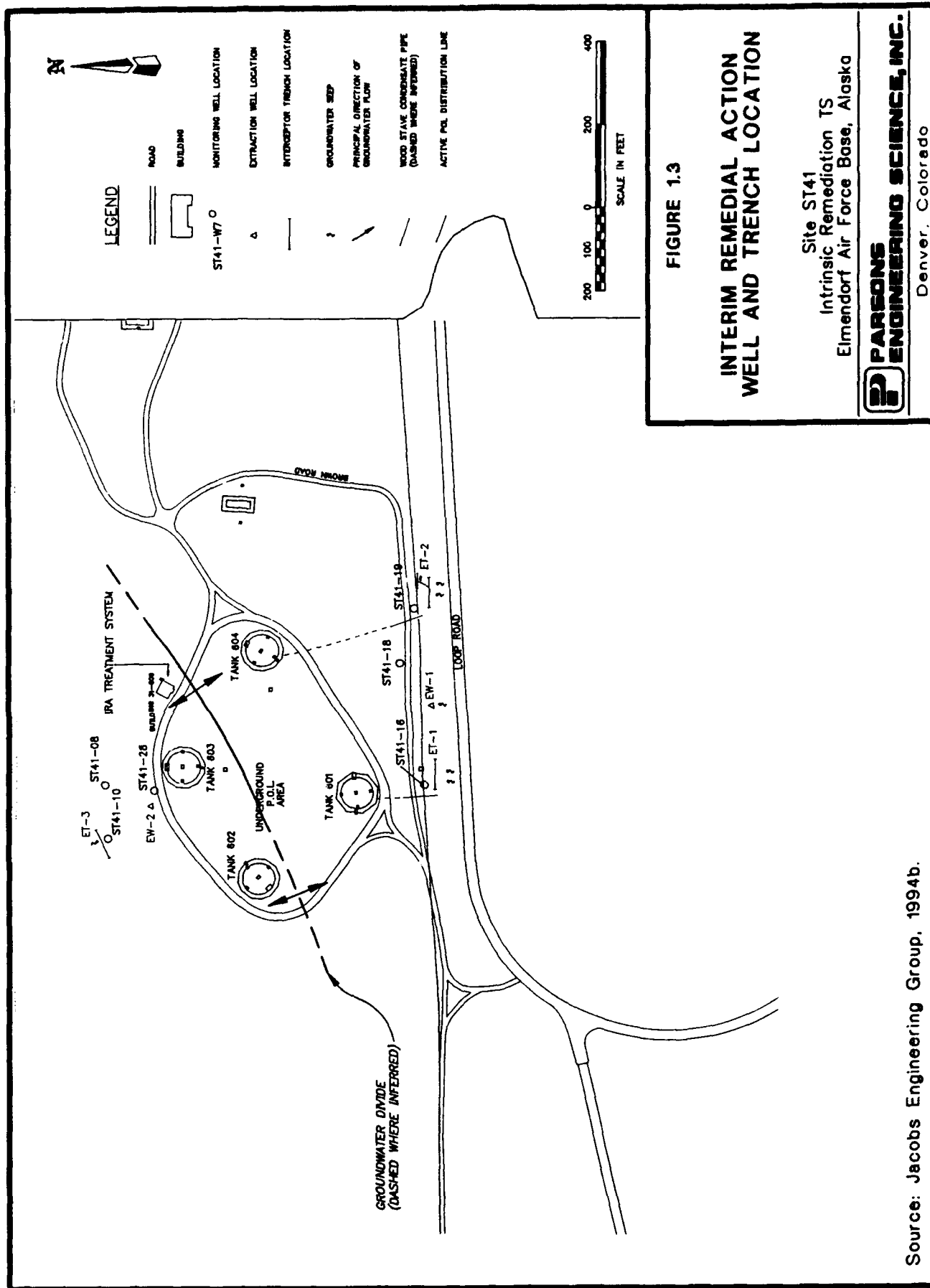
FIGURE 1.2

SITE LAYOUT

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado



Source: Jacobs Engineering Group, 1994b.

L:\45007\DRAWINGS\ST41\94DN0479, 10/20/95 at 10:29

Through December 1993, the extraction trenches and wells were pumped 5 days per week for 7 to 8 hours per day. The combined flow from the trenches and wells was 9 to 10 gallons per minute (gpm). As of mid-December 1993, approximately 70 gallons of product were recovered, and 65,300 gallons of water were treated in an air stripper (Jacobs Engineering Group, 1994b).

Results of IRP investigations that included Site ST41 are presented in several reports, including:

- Phase I Records Search (Engineering-Science, Inc., 1983);
- Stage 3 Remedial Investigation / Feasibility Study (RI/FS) (Black & Veatch, 1990); and
- Operable Unit 2 RI/FS Report (Jacobs Engineering Group, 1994b).

Site-specific data presented in Sections 3, 4, and 5 are based on a review of these documents and on data collected by ES and researchers from the RSKERL under this program. A synopsis of site characterization activities conducted to date is provided by Jacobs Engineering Group (1994b).

While there are three distinct plumes of contaminated water emanating from the site, this study focused on the plume emanating from the vicinity of Tank 601. This area was chosen for study because the dissolved BTEX concentrations are highest within this plume, the plume has a greater extent than other plumes at Site ST41, and the downgradient extent of the plume was not well-defined. For the remainder of the document, the term "Site ST41" will often be used to designate this specific area of study rather than the entire site. Conclusions reached from the study of this plume may potentially apply to the other plume areas.

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods used by Parsons ES and RSKERL personnel to collect site-specific data at Elmendorf AFB, Alaska. To meet the requirements of the intrinsic remediation demonstration, several investigative techniques, including soil and groundwater sampling, were utilized. Soil sampling was accomplished during this investigation using hollow-stem auger (HSA) drilling in conjunction with continuous split-barrel sampling. Previous investigations conducted at the site utilized standard HSA drilling and soil sampling as well as sampling of groundwater via monitoring wells. Groundwater sampling was accomplished during this investigation using newly installed and previously existing monitoring wells. Aquifer slug tests were conducted at existing wells.

In addition to the work conducted under this program, Jacobs Engineering Group (1994b) collected soil and groundwater data as part of an RI/FS for OU2. Data collected by Jacobs Engineering Group and data collected under this program were integrated to develop the conceptual site model and to aid interpretation of the physical setting (Section 3) and contaminant distribution (Section 4).

The physical and chemical hydrogeologic data listed below were collected during the field work phase of the TS:

- Depth from measurement datum to the water table or potentiometric surface in monitoring wells and monitoring points;
- Location of potential groundwater recharge and discharge areas;
- Stratigraphic analysis of subsurface media;
- Estimation of extent and thickness of mobile-phase LNAPL;
- Hydraulic conductivity as determined from slug test data;
- Dissolved oxygen (DO), nitrate, ferrous iron, sulfate, methane, and chloride concentrations in groundwater;

- Temperature, specific conductance, reduction/oxidation (redox) potential, total alkalinity, and pH of groundwater;
- BTEX and trimethylbenzene (TMB) concentrations in groundwater;
- BTEX, TMB, and total petroleum hydrocarbon (TPH) concentrations in soil; and
- TOC concentrations in soil and groundwater samples; and
- Chemical analysis of mobile LNAPL to determine the mass fraction of BTEX.

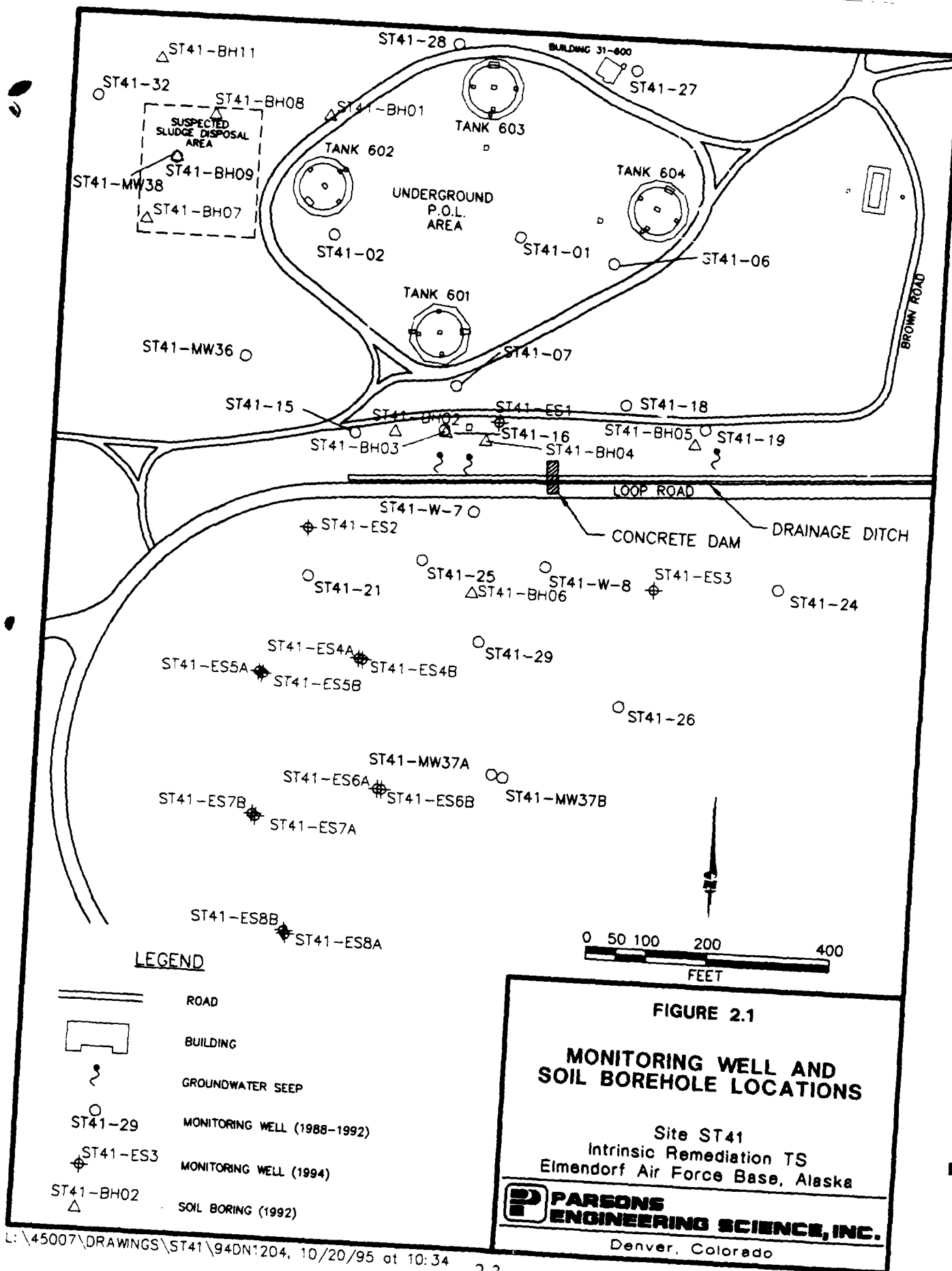
The following sections describe the procedures that were followed when collecting site-specific data. The applied drilling, soil sampling, lithologic logging, and monitoring well development procedures are described in Section 2.1. Groundwater sampling procedures are described in Section 2.2. Additional details regarding investigative activities are presented in the draft work plan (Engineering-Science, Inc., 1994).

2.1 DRILLING, SOIL SAMPLING, AND MONITORING WELL INSTALLATION

Field work occurred during June 1994, and consisted of drilling, soil sampling, and monitoring well installation for wells ST41-ES1 through ST41-ES8B. These activities were performed according to the procedures described in the work plan (Engineering-Science, Inc., 1994) and in the following sections.

2.1.1 Well Locations and Completion Intervals

Thirteen new groundwater monitoring wells were installed to help characterize the shallow groundwater flow system in the vicinity of Site ST41. These wells are identified as ST41-ES1, ST41-ES2, ST41-ES3, ST41-ES4A, ST41-ES4B, ST41-ES5A, ST41-ES5B, ST41-ES6A, ST41-ES6B, ST41-ES7A, ST41-ES7B, ST41-ES8A, and ST41-ES8B. The new monitoring wells were installed in the locations shown on Figure 2.1. Table 2.1 presents well completion details. Nested wells (e.g., ST41-ES1A and ST41-ES1B) were installed adjacent to each other, with one well (designated by the suffix "A") screened across the water table, and with the other well screened 4 to 8 feet below the bottom of the first well. The well locations were selected to provide the hydrogeologic data necessary for successful implementation of the Bioplume II model and to support intrinsic remediation.



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TABLE 2.1

**WELL COMPLETION INFORMATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Well Location	State Plane Coordinates		Datum ^a Elevation (ft msl) ^b	Ground Elevation (ft msl)	Total Depth (ft bgs) ^c	Casing Diameter (inches)	Screen Length (feet)	Depth to Screen		Screen Elevation	
	Northing	Eastng						Top (feet bgs)	Bottom (feet bgs)	Top (feet msl)	Bottom (feet msl)
ST41-01	2649168.41	1664579.69	279.96	275.0	45.27	2.00	NA ^d	30.0	45.0	245.0	230.0
ST41-02	2649156.85	1664274.36	265.68	261.4	34.53	2.00	NA	20.0	35.0	241.4	226.4
ST41-07	2648919.89	1664488.50	268.43	263.3	54.6	2.00	NA	NA	NA	NA	NA
ST41-15	2648834.14	1664326.78	252.52	248.3	20.33	2.00	10.0	8.0	18.0	240.3	230.3
ST41-16	2648845.84	1664473.95	253.8	249.3	20.0	2.00	10.0	10.0	20.0	239.3	229.3
ST41-18	2648902.91	1664769.10	243.01	238.0	16.14	2.00	10.0	6.0	16.0	232.0	222.0
ST41-21	2648595.60	1664262.72	220.61	215.6	19.02	2.00	5.0	14.0	19.0	201.6	196.6
ST41-25	2648630.54	1664449.39	220.77	215.4	12.68	2.00	7.8	4.9	12.7	210.5	202.7
ST41-26	2648407.87	1664786.53	215.42	210.1	18.12	2.00	10.0	6.5	16.5	203.6	193.6
ST41-29	2648501.03	1664549.03	216.50	211.8	NA	NA	NA	NA	NA	NA	NA
ST41-W-7	2648714.40	1664529.38	218.44	216.4	20.01	2.00	NA	NA	NA	NA	NA
ST41-W-8	2648630.61	1664651.70	216.30	213.1	23.76	2.00	NA	NA	NA	NA	NA
ST41-MW37A	2648284.66	1664583.81	211.03	206.6	25.0	4.00	15.0	8.9	23.9	197.7	182.7
ST41-MW37B	2648280.51	1664601.81	210.52	206.5	65.0	4.00	15.0	46.0	61.0	160.5	145.5
ST41-ES1	2648863.39	1664562.33	247.19	244.5	20.0	2.00	10.0	10.0	20.0	234.5	224.5
ST41-ES2	2648674.19	1664258.26	222.71	219.9	9.0	2.00	5.0	4.0	9.0	215.9	210.9
ST41-ES3	2648601.95	1664832.28	215.44	212.6	9.0	2.00	5.0	4.0	9.0	208.6	203.6
ST41-ES4A	2648464.08	1664353.96	213.69	211.0	9.0	2.00	5.0	4.0	9.0	207.0	202.0
ST41-ES4B	2648462.47	1664360.44	213.58	210.7	18.0	2.00	5.0	13.0	18.0	197.7	192.7
ST41-ES5A	2648434.19	1664191.11	213.63	210.7	9.0	2.00	5.0	4.0	9.0	206.7	201.7
ST41-ES5B	2648430.86	1664197.64	213.23	210.6	22.0	2.00	5.0	17.0	22.0	193.6	188.6
ST41-ES6A	2648251.37	1664398.10	205.86	202.8	14.0	2.00	5.0	9.0	14.0	193.8	188.8
ST41-ES6B	2648251.04	1664405.16	205.89	203.1	27.0	2.00	5.0	22.0	27.0	181.1	176.1
ST41-ES7A	2648196.13	1664199.49	198.88	195.9	10.0	2.00	5.0	5.0	10.0	190.9	185.9
ST41-ES7B	2648200.38	1664193.75	199.04	195.7	20.0	2.00	5.0	15.0	20.0	180.7	175.7
ST41-ES8A	2648005.19	1664259.86	193.80	191.1	10.0	2.00	5.0	5.0	10.0	186.1	181.1
ST41-ES8B	2648010.28	1664256.69	193.89	191.1	23.0	2.00	5.0	18.0	23.0	173.1	168.1

^a Datum is top of PVC casing.^b ft msl = Feet above mean sea level^c ft bgs = Feet below ground surface^d NA = Data not available

Data for previously installed wells from Jacobs Engineering Group (1994b).

L:\45007\TABLES\ST41WELL.XLS

2.1.2 Well Drilling and Soil Sampling Procedures

This section describes the procedures that were used for drilling and installation of new monitoring wells. All new monitoring wells were installed in accordance with general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (USEPA, 1987).

2.1.2.1 Pre-Drilling Activities

All necessary digging, drilling, and groundwater monitoring well installation permits were obtained prior to mobilizing to the field. In addition, all utility lines were located, and proposed drilling locations were cleared prior to any drilling activities.

Water used in drilling, equipment cleaning, or grouting was obtained from an onsite potable water supply. Water use approval was verified by contacting the appropriate facility personnel.

2.1.2.2 Equipment Decontamination Procedures

Prior to arriving at the site, and between each drilling location, the augers, drilling rods, bits, casing, samplers, tools and other downhole equipment were decontaminated using a high-pressure, steam/hot water wash. Only potable water was used for decontamination.

During drilling operations, the drill rig, augers, and any downhole drilling and/or sampling equipment were decontaminated at the Elmendorf AFB decontamination pad. Water from the decontamination operations was allowed to collect in the decontamination pad collection sump, then pumped into holding tanks. After conditioning (using granular carbon canisters), water from the holding tanks was released into the sanitary sewer. Precautions were taken to minimize any impact to the area surrounding the decontamination pad that might result from the decontamination operations.

All sampling tools were cleaned onsite, prior to use and between each sampling event, with a clean water/phosphate-free detergent mix and a clean water rinse. All well completion materials were factory sealed. All decontamination activities were conducted in a manner so that the excess water was controlled and not allowed to flow into any open borehole.

Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials were not stored near or in areas that could be affected by these substances.

2.1.2.3 Drilling and Soil Sampling

Drilling was accomplished by using the HSA method. The borings were drilled and continuously sampled to the total depth of the borehole. Where two wells were installed adjacent to each other (i.e., nested), only the deeper well was logged and sampled. In many instances, sand heave below the water table prevented collection of continuous samples. A *final borehole diameter* of at least 8 inches was used for the installation of wells with a 2-inch inside-diameter (ID) casing.

Continuous soil samples were obtained using a 2.5-inch-ID split-barrel sampling device (also known as a split spoon). Where possible, samples were collected continuously over the full depth of the soil borehole. One soil sample was removed from the lower 10 to 12 inches of the spoon and placed in a clean glass jar for laboratory analysis. In addition, a portion of the soil sample was placed in an unused, sealable plastic bag for photoionization detector (PID) headspace measurements for volatile organic compounds (VOCs). Soil remaining in the spoon was used for lithologic and stratigraphic logging. Bags containing soil samples collected for the headspace procedure were quickly sealed and held for 15 minutes at an ambient temperature of 65 degrees Fahrenheit (°F) or greater. Semiquantitative measurements were made by puncturing the bag seal with the PID probe and reading the concentration of the headspace gases. The PID relates the concentration of total VOCs in the sample to an isobutylene calibration standard. The PID was also used to monitor the worker breathing zone.

The Parsons ES field hydrogeologist observed drilling and well installation activities and maintained a detailed descriptive log of subsurface materials recovered. Final geologic boring logs are presented in Appendix A. These logs contain:

- Sampled interval (top and bottom depth);
- Presence or absence of contamination based on odor, staining, and/or PID readings;

- Soil description, including color, major textural constituents, minor constituents, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, and any other significant observations; and,
- Lithologic contacts, with the depth of lithologic contacts and/or significant textural changes recorded to the nearest 0.1 foot (1 inch).

At all borehole locations, one or two soil samples from the vicinity of the water table were selected for laboratory analysis. Where no elevated PID headspace readings were encountered, samples were collected from immediately above and/or immediately below the water table. Where PID readings were elevated, one of the samples submitted for laboratory analysis was from the interval giving the highest reading.

Sample containers and appropriate container lids were provided by the USEPA Mobile Laboratory. The sample containers were filled as full as possible to eliminate creation of headspace in the jars, and the container lids were tightly closed. A sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Sample identification;
- Sample depth;
- Sampling date; and,
- Sample collector's initials.

After the samples were sealed and labeled, they were placed in a cooler with ice and held for transport to the onsite USEPA Mobile Laboratory. Samples were analyzed for BTEX and TMBs, TPH, and TOC.

Soils exhibiting petroleum hydrocarbon contamination based on PID screening was to have been drummed and stored onsite during the drilling operations (Engineering-Science, Inc., 1994). However, none of the soil displayed contamination (based on PID readings that were all at or below background). As a result, all extraneous sample material and cuttings were thin-spread in the vicinity of the borehole.

2.1.3 Monitoring Well Installation

Groundwater monitoring wells were installed in 13 soil borings under this program. Detailed well installation procedures are described in the following paragraphs. Well completion diagrams are included in Appendix A.

2.1.3.1 Well Materials Decontamination

Well completion materials were inspected by the field hydrogeologist and determined to be clean and acceptable prior to use. All well completion materials were factory sealed. Pre-packaged casing, sand, bentonite, and concrete mix were used in well construction, and the bags were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field hydrogeologist were not used.

2.1.3.2 Well Casing

Upon completion of drilling to the proper boring termination depth, monitoring well casing was installed. Well construction details were noted on a Monitoring Well Installation Record form. This information became part of the permanent field record for the site. Monitoring well installation forms for Site ST41 are presented in Appendix A.

Blank well casing was constructed of Schedule 40 polyvinyl chloride (PVC) with an ID of 2 inches. All well casing sections were flush threaded, and glued joints were not used. The casing at each well was fitted with a vented top cap constructed of the same type of material as the well casing.

The field hydrogeologist verified and recorded the boring depth, the lengths of all casing sections, and the depth to the top of all well completion materials placed in the annulus between the casing and borehole wall. All lengths and depths were measured to the nearest 0.1 foot.

2.1.3.3 Well Screen

Well screens were constructed of flush-threaded, Schedule 40 PVC with an ID of 2 inches. The screens were factory slotted with 0.010-inch openings. Each shallow well was screened

so that seasonal fluctuations of the water table can be measured and so that mobile LNAPL (if present) can be detected. Well screen positions were selected by the field hydrogeologist after consideration was given to the geometry and hydraulic characteristics of the stratum in which the wells were screened.

2.1.3.4 Sand Filter Pack

A graded sand filter was placed around the screened interval from the bottom of the casing to approximately 2 feet above the top of the screen. Number 10-20 Colorado silica sand was used for the sand filter pack.

2.1.3.5 Annular Sealant

A filter pack seal of sodium bentonite chips was placed above the sand pack in all wells. The filter pack seal was a minimum of 2 feet thick and, where placed above the water table, was hydrated in place with potable water. In all but one well at Site ST41, the remainder of the annular seal up to the surface also consisted of hydrated bentonite chips. This was done because the water table was shallow at most locations and the depth of the wells did not warrant the mixing of bentonite grout. At one well (ST41-ES6B), the filter pack seal was overlain with a sodium bentonite grout extending from the top of the pellet seal to approximately 3 feet below ground surface (bgs). The sodium bentonite grout mix consisted of one 50-pound sack of granular bentonite for each 15 gallons of water used. The grout was topped by hydrated bentonite chips to provide better support for the protective casing.

For both shallow and deep wells, the protective pipes were set into the upper 2 to 2.5 feet of the annular seal. The pipes were not cemented in place in order to minimize frost heave impacts. Use of such a seal reduces the potential of frost heave damage because bentonite remains plastic at low temperatures, minimizing shear between the annular seal, the surrounding earth, and the protector pipe. Pure sodium bentonite has a permeability low enough to provide a sufficient borehole seal. To minimize dehydration and protect the bentonite, a 6-inch thick gravel pad was placed on top of the seal surrounding the protector pipe.

2.1.3.6 Protective Cover

Each monitoring well was completed with a 5-inch-diameter aboveground protective cover with a locking cap. The covers were placed approximately 3 feet above grade, with a gravel pad surrounding the cover. Brass tags were affixed to each cover, and a set of dies was used to stamp the well name onto the tags.

2.1.4 Well Development

Before being sampled, newly installed monitoring wells were developed. Well development removes sediment from inside the well casing and flushes fines, cuttings, and drilling fluids from the sand pack and the portion of the formation adjacent to the well screen.

Well development was accomplished using a peristaltic pump. The pump was regularly raised and lowered in the well to agitate fines collected in the casing and to remove them from the well in the development water. Because all the wells purged dry, even at low flow rates, development consisted of purging each well dry, allowing it to recover, and purging it again. This process was repeated up to three times at each well. All well development waters were collected in a 400-gallon polyethylene tank and transported to the Elmendorf AFB water conditioning facility for conditioning and disposal.

2.2 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater quality samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Engineering-Science, Inc., 1994) and summarized in the following sections were followed.

Groundwater sampling occurred during June 1994, and consisted of collecting groundwater samples from new and existing monitoring wells. Personnel from Parsons ES and USEPA RSKERL participated in groundwater sampling. USEPA RSKERL was responsible for sample analysis. The procedures used to sample groundwater monitoring wells is described in Section 2.2.3.2.

Activities that occurred during groundwater sampling are summarized below:

- Assembly and preparation of equipment and supplies;
- Inspection of the well integrity, including
 - Protective cover, cap and lock,
 - External surface seal and pad,
 - Well casing, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including
 - Water level measurements,
 - Visual inspection of water,
 - Well casing evacuation, and
 - Sampling;
- Sample preservation and packaging, including
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records; and
- Sample delivery to the USEPA Mobile Laboratory.

Detailed groundwater sampling and sample handling procedures that were used are presented in following sections.

2.2.1 Groundwater Sampling Locations

Groundwater samples were collected from existing and newly installed monitoring wells by Parsons ES and USEPA RSKERL personnel. Thirteen new monitoring wells, including five nested well pairs, were installed in the locations shown on Figure 2.1. After completion of well installation and development activities, these wells were sampled using a peristaltic pump with dedicated polyethylene tubing. Thirteen previously existing monitoring wells also were sampled under this program. Existing wells that were sampled included ST41-01, ST41-02, ST41-07, ST41-W-7, ST41-W-8, ST41-15, ST41-16, ST41-18, ST41-21, ST41-25, ST41-29, ST41-MW37A, and ST41-MW37B. Well completion data for the newly installed and previously installed wells are provided on Table 2.1.

2.2.2 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials were gathered prior to leaving the office.

2.2.2.1 Equipment Cleaning

All portions of sampling and test equipment that contacted the sample were thoroughly cleaned before use. This equipment included the water level probe and cable, lifting lines, test equipment for onsite use, and other equipment that contacted the samples. The following cleaning protocol was used:

- Cleaned with potable water and phosphate-free laboratory detergent;
- Rinsed with potable water;
- Rinsed with distilled or deionized water;
- Rinsed with reagent-grade acetone; and
- Air dried prior to use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form.

2.2.2.2 Equipment Calibration

As required, field analytical equipment was calibrated according to the manufacturers' specifications prior to field use. This requirement applied to equipment used for onsite chemical measurements of DO and temperature.

2.2.3 Sampling Procedures

Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment. Water level probes and cable used to determine static water levels and well total depths were thoroughly cleaned before and after field use and between uses at different sampling locations according to the

procedures presented in Section 2.2.2.1. In addition, a clean pair of new, disposable nitrile gloves was worn each time a different well was sampled.

2.2.3.1 Groundwater Monitoring Well Sampling

2.2.3.1.1 *Preparation of Location*

Prior to starting the sampling procedure, the area around the well was cleared of foreign materials, such as brush, rocks, and debris. These procedures prevented sampling equipment from inadvertently contacting debris around the monitoring well.

2.2.3.1.2 *Water Level and Total Depth Measurements*

Prior to removing any water from the well the static water level was measured. An electrical water level probe was used to measure the depth to groundwater below the well datum to the nearest 0.01 foot. After measurement of the static water level, the water level probe was lowered to the bottom of the well for measurement of total well depth (recorded to the nearest 0.01 foot). Based on these measurements, the volume of water to be purged from the wells was calculated.

2.2.3.1.3 *Well Purging*

Where possible, three times the calculated casing volume was removed from each well prior to sampling; however, most wells purged dry. All purge water was placed in a 400-gallon polyethylene tank and transported to the Elmendorf AFB conditioning unit for conditioning and disposal. A peristaltic pump with dedicated polyethylene tubing was used for well evacuation.

2.2.3.1.4 *Sample Extraction*

A peristaltic pump with dedicated polyethylene tubing was used to extract groundwater samples from the well. The sample was transferred directly into the appropriate sample container. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample bottles for BTEX and TMB analysis were filled so that there was no headspace or air bubbles within the container.

2.2.4 Onsite Chemical Parameter Measurement

2.2.4.1 Dissolved Oxygen Measurements

DO measurements were taken using an Orion® model 840 DO meter in a flow-through cell at the outlet of the peristaltic pump. DO concentrations were recorded after the readings stabilized, and in all cases represent the lowest DO concentration observed.

2.2.4.2 pH and Temperature Measurements

Because the pH and temperature of the groundwater change significantly within a short time following sample acquisition, these parameters were measured in the field or at the EPA Mobile Laboratory as soon as possible after acquisition. The measurements were made in a clean glass container separate from those intended for laboratory analysis, and the measured values were recorded in the groundwater sampling record.

2.2.5 Sample Handling

2.2.5.1 Sample Preservation

The USEPA Mobile Laboratory added any necessary chemical preservatives to sample containers prior to collection of samples.

2.2.5.2 Sample Container and Labels

Sample containers and appropriate container lids were provided by the USEPA Mobile Laboratory. The sample containers were filled as described in Sections 2.2.3.1.4, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (groundwater);
- Sampling date;

- Sampling time;
- Preservatives added; and
- Sample collector's initials.

2.2.5.3 Sample Shipment

After the samples were sealed and labeled, they were packaged for transport to the onsite USEPA Mobile Laboratory. The following packaging and labeling procedures were followed:

- Sample was packaged to prevent leakage or vaporization from its container;
- Shipping container was labeled with
 - Sample collector's name, address, and telephone number;
 - Description of sample;
 - Quantity of sample; and
 - Date of shipment.

The packaged samples were hand-delivered to the USEPA Mobile Laboratory. Delivery occurred shortly after sample acquisition.

2.3 AQUIFER TESTING

Slug tests were conducted to estimate the hydraulic conductivity of the shallow saturated zone at Site ST41. Slug tests are single-well hydraulic tests used to determine the hydraulic conductivity of an aquifer in the immediate vicinity of the tested well. Slug tests can be used for both confined and unconfined aquifers that have a transmissivity of less than 7,000 square feet per day (ft^2/day). Slug testing can be performed using either a rising head or a falling head test. Both rising head and falling head tests were used at this site. Slug tests were performed in monitoring wells ST41-ES2, ST41-ES4A, ST41-ES4B, ST41-ES8A, and ST41-ES8B (Figure 2.1). Detailed slug testing procedures are presented in the *Draft Technical Protocol for Implementing the Intrinsic Remediation with Long-Term Monitoring Option for Natural Attenuation of Dissolved-Phase Fuel Contamination in Groundwater* (Wiedemeier *et al.*, 1995), hereafter referred to as the Technical Protocol document.

2.3.1 Slug Test Data Analysis

Data obtained during slug testing were analyzed using AQTESOLV software and the methods of Bouwer and Rice (1976) and Bouwer (1989) for unconfined conditions. The results of slug testing are presented in Section 3.3.

2.4 SURVEYING

After completion of field work, all new monitoring well locations and elevations were surveyed by a professional land surveyor. The horizontal locations were measured relative to existing monitoring wells. Vertical location of the ground surface adjacent to the well casing and the measurement datum (top of the PVC well casing) were measured relative to existing wells tied to a US Geological Survey (USGS) mean sea level (msl) datum. Horizontal location was surveyed to the nearest 0.1 foot. Datum and ground surface elevations were surveyed to the nearest 0.01 foot. Horizontal control was based on previous data for wells ST41-18 and ST41-MW37B, and the previously reported elevation for the PVC casing of well ST41-MW37B (Jacobs Engineering Group, 1994b) was used as a local elevation benchmark.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section incorporates data collected during investigations as summarized by Jacobs Engineering Group (1994b) and more recent investigations conducted by Parsons ES in conjunction with researchers from USEPA RSKERL in June 1994. Investigative techniques used by Parsons ES and RSKERL researchers to determine the physical characteristics of Site ST41 are discussed in Section 2.

3.1 SURFACE FEATURES

3.1.1 Topography and Surface Water Hydrology

Site ST41 is located on and near the Elmendorf Moraine, a broad, southwest to northeast trending ridge with hummocky topography. The four USTs at the site are on the crest of the moraine. In the vicinity of the plume emanating from Tank 601, the ground surface slopes to the south and southwest, with a relatively steep grade near the moraine that flattens out south of Loop Road.

There are no naturally occurring surface water bodies in the immediate vicinity of the study area. A drainage ditch is located on the south side of the moraine, running along the north side of Loop Road. This ditch receives water from overland flow of surface water due to precipitation or snowmelt, and from groundwater seeps along the southern flank of the moraine that reportedly discharge into the ditch (Jacobs Engineering Group, 1994b). The ditch flows east for approximately 1 mile before it is diverted south under Loop Road, where it discharges near the flight line and infiltrates into the ground. Several seeps on the north side of the moraine (out of the area of interest for this investigation) formerly drained to a small wetland. Some of these seeps exhibited petroleum contamination, and the flow to these seeps was contained by the extraction trenches installed as part of the IRA.

3.1.2 Manmade Features

Obvious man-made features at the site include the POL tanks and the roads, as well as a few associated buildings or equipment housings. Surface cover at Site ST41 consists largely of grass, although Loop Road is paved and Brown Road has a gravel surface. Precipitation either infiltrates directly into the ground surface or via runoff from the paved areas or sloped areas. The site map (Figure 1.2) shows the location of roads, buildings, and other features.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Elmendorf AFB is located immediately north of Anchorage, Alaska, west of the Chugach Mountain Front. The base lies within the Cook Inlet - Susitna Lowland physiographic province, referred to as the "Anchorage Lowland." The Anchorage Lowland is a large alluvial fan on the eastern shore of the Knik Arm of Cook Inlet, surrounded by the Kenai, Chugach, and Talkeetna mountains. Local topography is generally flat, with a slight regional rise toward the east. Ship Creek flows along the southern boundary of the base, approximately 2 miles south of Site ST41 (Figures 1.1 and 1.3). Site ST41 is approximately 2,200 feet east of Knik Arm.

Surficial deposits in the vicinity of Elmendorf AFB consist of Pleistocene glacial drift that was deposited during several glacial advances and retreats. During the most recent phase of glaciation, the ice reached a position overlying the current location of Elmendorf AFB. The ice temporarily stagnated, and poorly sorted sediment (till) was deposited at the ice front. Deposition of till produced a terminal moraine, called the Elmendorf Moraine. The moraine is expressed topographically as a broad, northeast-to-southwest trending ridge running through Site ST41. After the ice retreated, meltwaters moving away from the ice margin deposited sediment (mostly sand and gravel), producing a relatively flat, broad outwash plain upon which most of the base facilities are located.

Two aquifers are present in the vicinity of Elmendorf AFB. In order of increasing depth, these aquifers are 1) the shallow aquifer (in either till or outwash deposits, depending on location); and 2) the deep confined aquifer, consisting of sand and gravel outwash deposits, alluvial sand, and mixed deposits of glacial till. Between the shallow and deep aquifers is a regional aquitard known as the Bootlegger Cove Formation. This unit consists of interbedded silt and clay deposits and is approximately 125 to 250 feet thick in the Anchorage area (Udike and Carpenter, 1986). Approximately 2 miles east of the site, the Bootlegger Cove Formation is approximately 50 feet thick, as determined from a borehole penetrating the full thickness of the

unit (Jacobs Engineering Group, 1994b). The upper portion of the Bootlegger Cove Formation is generally silty, while the lower unit is generally clayey. A generalized cross-section showing the relationships between the shallow (outwash) aquifer, the Bootlegger Cove Formation, and the deep aquifer is presented in Figure 3.1. The shallow outwash aquifer ranges from 35 to over 120 feet thick, while the depth to groundwater ranges from 5 to 50 feet bgs. The shallow till aquifer in the vicinity of the moraine ranges from 1 to 60 feet thick, with depth to groundwater ranging between 1 and 30 feet bgs.

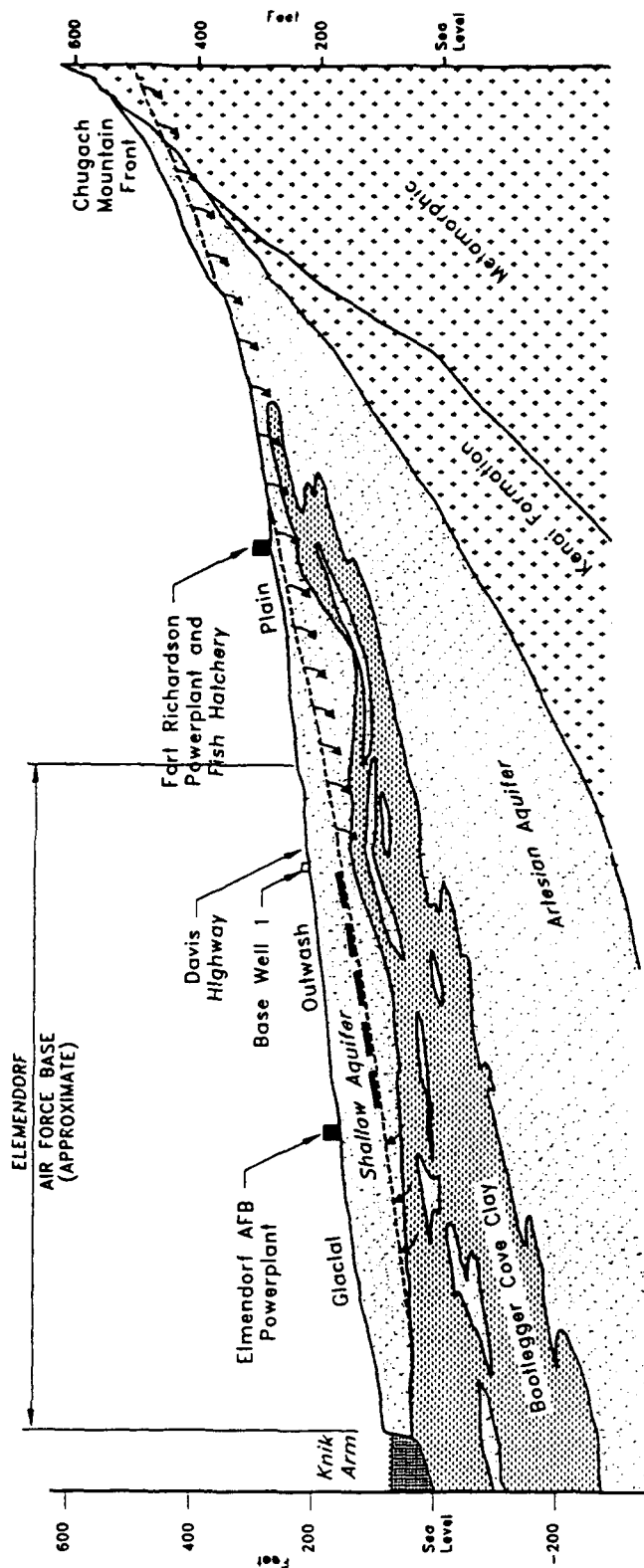
There is reportedly no communication between the shallow and deep aquifers. A hydraulic communication test between the two aquifers was performed in 1992. Data from this test suggest that there is no correlation between flow directions or water level elevations and elevation changes in the shallow and deep aquifers (Jacobs Engineering Group, 1993). In addition, a review of analytical data from several base water supply wells screened in the deep aquifer was conducted by Radian (1994). This review concluded that minor contamination observed in the deep aquifer was not attributable to the sources of shallow groundwater contamination observed in OU2, and given the results of the 1992 communication test, that the Bootlegger Cove Formation is an effective confining unit.

A groundwater divide roughly coincides with the crest of the moraine, with flow diverging away from the divide and down the flanks of the moraine. On the south side of the moraine, local groundwater flow is to the south. Away from the moraine the regional flow is to the south and southwest, towards Ship Creek (Jacobs Engineering Group, 1994a). Water levels are highest in late spring, decreasing through the summer until fall rains cause another rise. This rise continues through late fall, and is followed by decreasing levels through the winter until the spring thaw.

Data from previous studies indicate that the till aquifer is unconfined throughout the ST41 area, although it is possible that scattered lenses of clayey material create local areas of confined or semi-confined conditions. These lenses may also locally perch shallow groundwater. Relatively impermeable silts and clays of the Bootlegger Cove Formation form the basal boundary of this aquifer. The Bootlegger Cove Formation is also the principal confining layer for the deep aquifer, although this aquifer may be overlain by additional thicknesses of other fine-grained deposits. In the ST41 area, the top of the Bootlegger Cove Formation ranges from approximately 1 foot bgs to 45 feet bgs (Jacobs Engineering Group, 1994b).

(WEST)

(EAST)



LEGEND

-  Permeable coarse-grained deposits
-  Relatively impermeable fine-grained deposits
-  Bedrock
-  Area where Ship Creek may either be losing water or gaining water to/from the shallow aquifer depending on stream flow.
-  Ship Creek profile with diversion dam structure.
-  Arrows indicate direction of groundwater movement to or from the creek.

Source: Radian, 1994.

Vertical Exaggeration $\pm 20X$
(Modified From Jacobs Engineering, 1993)

FIGURE 3.1

GENERALIZED HYDROGEOLOGIC
CROSS-SECTION
ALONG SHIP CREEK

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

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3.3 SITE GEOLOGY AND HYDROGEOLOGY

In the Site ST41 area, 44 soil borings have been completed, of which 29 have been completed as monitoring wells. Figure 2.1 shows the locations of most of the previously existing wells in the vicinity of Site ST41. During June 1994, Parsons ES, in conjunction with researchers from the RSKERL, drilled 13 soil borings in which groundwater monitoring wells were installed. These soil boreholes/monitoring wells are designated as ST41-ES1, ST41-ES2, ST41-ES3, ST41-ES4A, ST41-ES4B, ST41-ES5A, ST41-ES5B, ST41-ES6A, ST41-ES6B, ST41-ES7A, ST41-ES7B, ST41-ES8A, and ST41-ES8B. Borehole depths ranged from 9 to 27 feet bgs. Locations of these wells are presented on Figure 2.1. Table 2.1 presents available well completion information.

3.3.1 Lithology and Stratigraphic Relationships

Site ST41 is underlain by glacial till of the Elmendorf Moraine. The moraine consists of unconsolidated deposits of silt, clay, and sand, with occasional intervals containing up to 15 percent coarse sand and gravel (Jacobs Engineering Group, 1994b). As is typical of glacial till, these deposits are massive (nonstratified), poorly sorted, and heterogeneous. Near the center of the hill, the till is directly over the silty unit of the Bootlegger Cove Formation, which is underlain by the clayey unit of the same formation. At the flanks of the hill, the till is not present, and the Bootlegger Cove Formation is overlain by a silty sand to sandy silt unit, known as "cover sand". This unit is described as well sorted, possibly of alluvial origin, and older than the till, but younger than the Bootlegger Cove Formation (Jacobs Engineering Group, 1994b).

Soils encountered south of the moraine flank during drilling activities conducted by Parsons ES in June 1994 largely consisted of sand and silty sand. These deposits were generally poorly sorted, and contained silt, cobbles, gravel, and pebbles to varying degrees. On top of the sandy unit was relatively fine-grained topsoil containing some gravel. In some places, this unit appeared to be till washed down from the flanks of the hill or topsoil formed in such material. In one location (ST41-ES6B), a gravelly unit was encountered at the base of the sandy unit, just above the Bootlegger Cove Formation. One borehole, ST41-ES1, was drilled on the moraine. In this borehole, the till was largely silt with sand and gravel, with some clayey intervals and occasional silty sand intervals. In this location, the Bootlegger Cove Formation was encountered at approximately 16 feet bgs.

Most of the boreholes south of the moraine reached the top of the Bootlegger Cove Formation, which typically was a dense blue-grey clay, silty clay, or clayey silt. The Bootlegger Cove Formation was encountered at depths ranging from 8 to 22.5 feet bgs. and the upper surface of the unit generally slopes to the south, away from the moraine.

These stratigraphic relationships are illustrated by hydrogeologic sections A - A' and B - B', which include data from previously installed wells and borings and newly installed wells. Figure 3.2 shows the locations of these sections. Figure 3.3 shows hydrogeologic section A - A', which is approximately parallel to the groundwater flow direction. Figure 3.4 presents hydrogeologic section B - B', which is approximately perpendicular to the direction of groundwater flow.

3.3.2 Grain Size Distribution

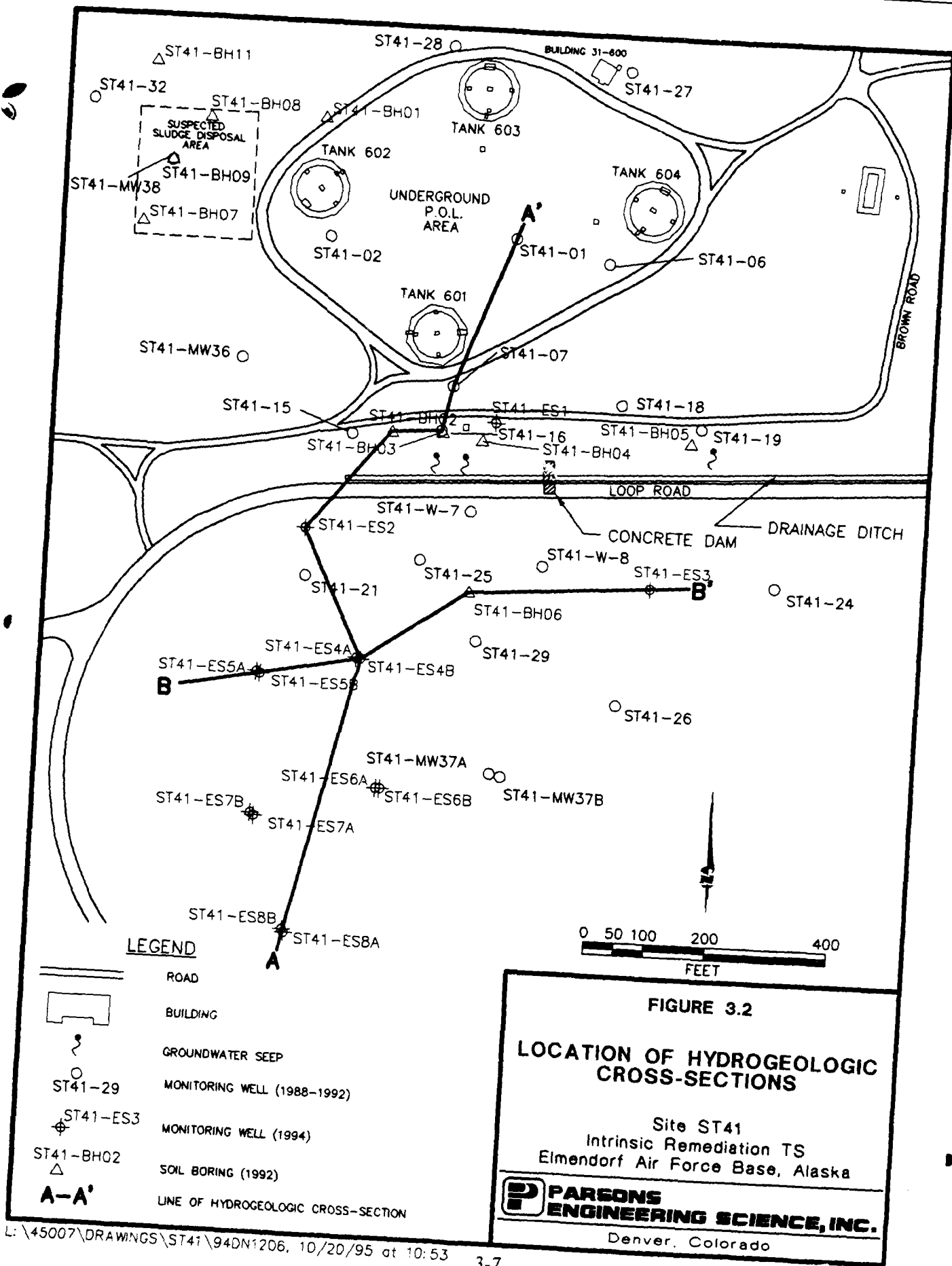
Jacobs Engineering Group (1994b) submitted two soil samples from boring ST41-BH04 (samples collected from approximately 5 and 10 feet bgs) for grain size analysis. This boring is in the vicinity of monitoring well ST41-ES1. Both samples are from the till of the Elmendorf Moraine. The samples contained 46 and 58 percent silt and clay, respectively. No information is available regarding the sand and gravel contents of these samples.

Samples from the Bootlegger Cove Formation were also submitted for grain size analysis. Two samples were collected from ST41-MW37B at a depth of 65 feet bgs. These samples contained 99.5 and 99.2 percent silt and clay, indicating the fine-grained nature of the Bootlegger Cove Formation (Jacobs Engineering Group, 1994b).

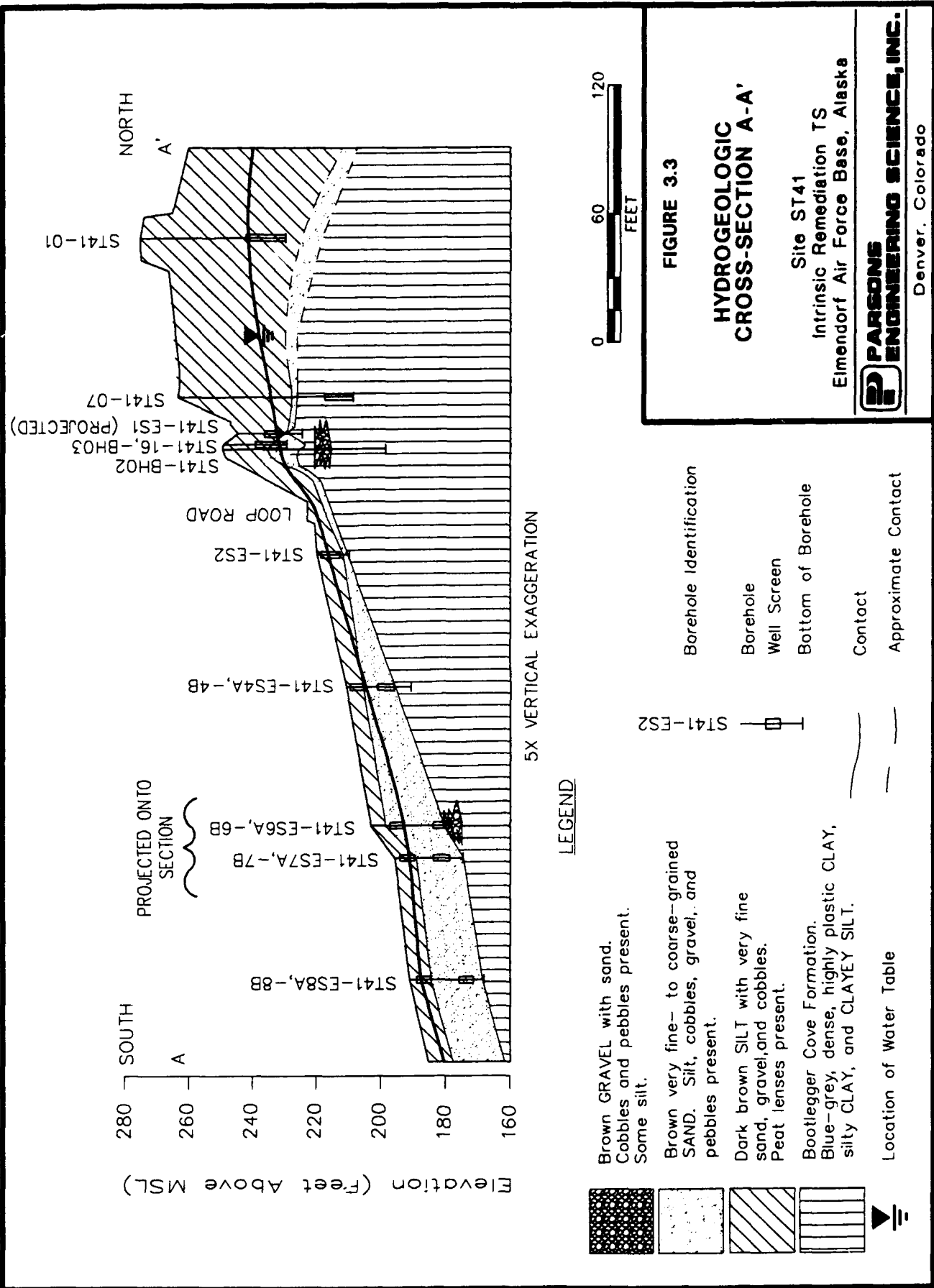
3.3.3 Groundwater Hydraulics

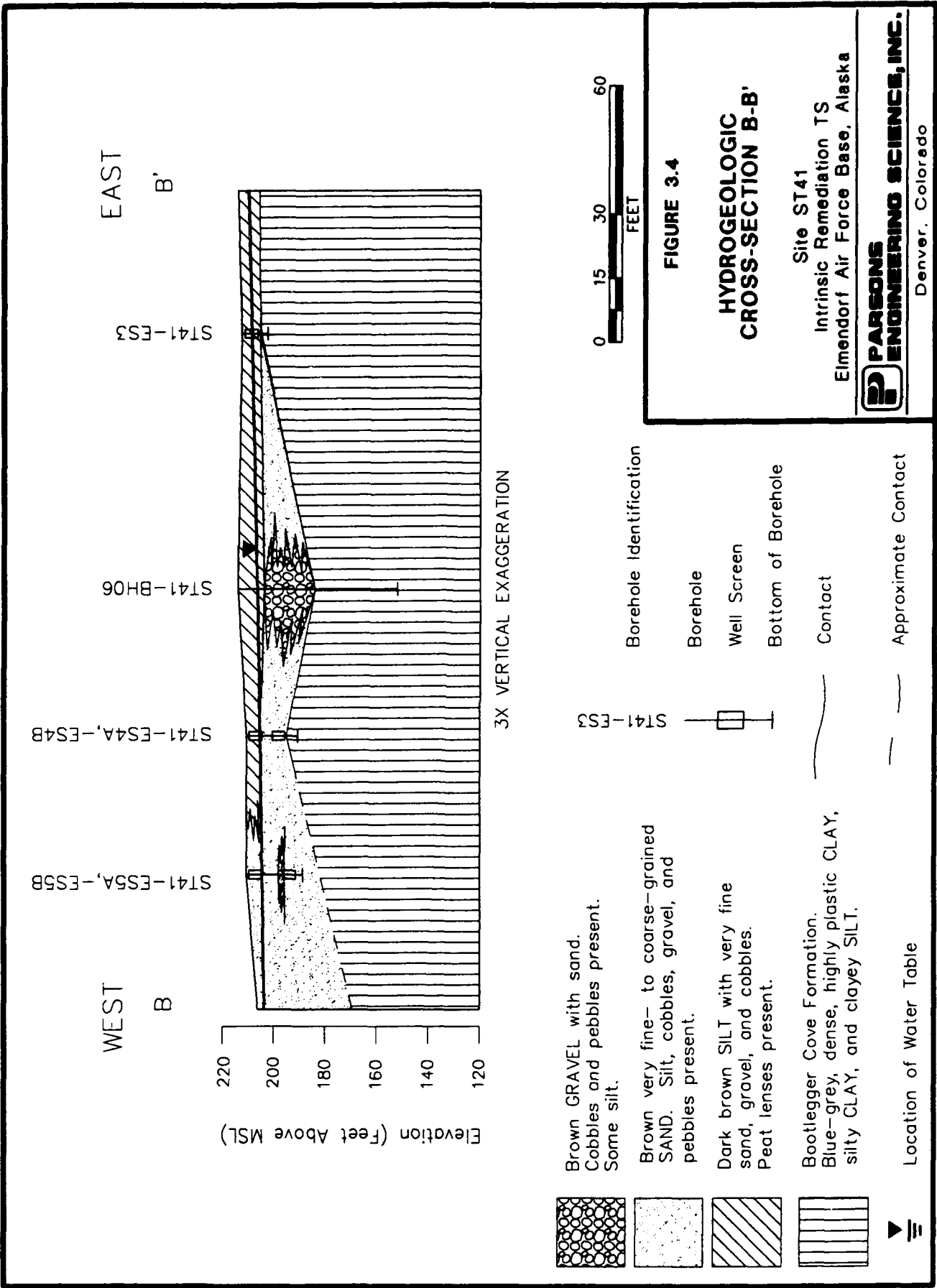
3.3.3.1 Flow Direction and Gradient

Depth to groundwater in the vicinity of Site ST41 ranges from 1 to 35 feet bgs. In general, depths are greatest along the moraine crest, and shallowest along the limbs. A groundwater divide is present in the vicinity of Site ST41, running northeast to southwest along the crest of the moraine, and between the USTs. Groundwater flow, generally following the local topography, is to the northwest on the north limb of the moraine, and to the south or southeast on the south limb of the moraine. Basewide elevation data indicate that away from the moraine, the flow trends to the south and eventually southwest. Local horizontal flow gradients are generally



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in the range of 0.05 to 0.06 foot per foot (ft/ft) on and near the moraine (Jacobs Engineering Group, 1994a).

As indicated by groundwater elevation data collected in June 1994, groundwater flow in the Tank 601 area of ST41 is to the south and southeast. South of Loop Road, the average horizontal flow gradient is approximately 0.063 ft/ft (Figure 3.5). North of Loop Road, on the moraine, the gradient ranges from 0.05 ft/ft to 0.16 ft/ft. Vertical gradients measured at well nests range from 0.14 ft/ft downward at ST41-ES5 to 0.07 ft/ft upward at ST41-ES8. Table 3.1 presents groundwater elevation data collected in June 1994. Based on the data in Table 3.1 and Figure 3.5, it does not appear that operation of the IRA extraction system has significantly affected local groundwater flow. Flow patterns on Figure 3.5 are nearly identical to those indicated by Jacobs (1994b) for the fall of 1991 and the spring and fall of 1992. These data were collected before the IRA system began operation, further suggesting that operation of the IRA has not significantly affected groundwater flow in the vicinity of the BTEX plume associated with Tank 601.

Results of previous site investigations show that there are slight seasonal variations in the groundwater levels at the site (Jacobs Engineering Group, 1994a). Water levels are highest in late spring, decreasing through the summer until fall, when rains cause another rise. This rise continues through late fall, and is followed by decreasing levels through the winter, until the spring thaw. Significant changes in flow direction have not been observed (Jacobs Engineering Group, 1994a).

It appears, based on geologic and hydrogeologic information, including the periodic presence of seeps, that the shallow aquifers in the Site ST41 area are unconfined. Variable till stratigraphy could produce locally confined conditions, but there is no evidence that this occurs in the vicinity of Site ST41.

3.3.3.2 Hydraulic Conductivity

Several slug tests were performed in Site ST41 monitoring wells by Jacobs Engineering Group (1994b). Results of these tests suggest that the unconsolidated deposits in this area have hydraulic conductivities ranging from 1×10^{-5} to 6×10^{-3} foot per minute (ft/min) [6×10^{-6} to 3×10^{-3} centimeter per second (cm/sec)]. In the area of Tank 601 and the associated hydrocarbon plume, conductivities estimated at wells ST41-07, ST41-15, ST41-MW-37A, and ST41-MW37B, ranged from 5×10^{-5} to 6.0×10^{-3} ft/min.

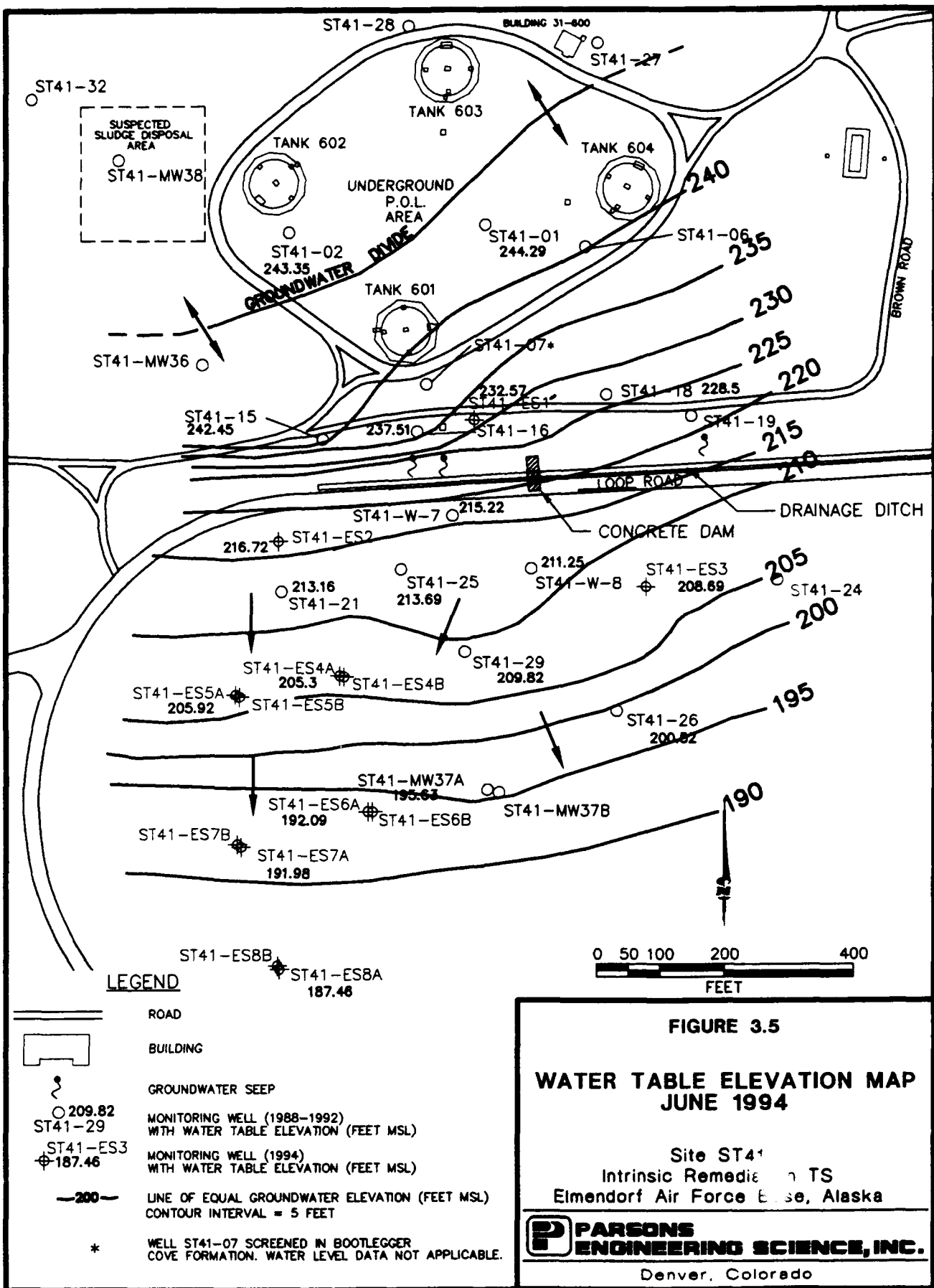


TABLE 3.1
WATER LEVEL ELEVATION AND LNAPL THICKNESS DATA
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Well Location	Date	State Plane Coordinates		Datum ^a Elevation (ft msl) ^b	Ground Elevation (ft msl)	Total Depth (ft bgs) ^c	Depth to LNAPL ^d (feet)	Depth to Water ^e (feet)	LNAPL Thickness (feet)	Corrected Depth to Water ^f (feet)	Water Elevation (feet msl)
		Northing	Easting								
ST41-01	6/21/94	2649168.41	1664579.69	279.96	275.0	45.27	-- ^g	35.67	--	--	244.29
ST41-02	6/21/94	2649156.85	1664274.36	265.68	261.4	34.53	--	22.33	--	--	243.35
ST41-07 ^h	6/21/94	2648919.89	1664488.50	268.43	263.3	54.6	--	34.32	--	--	234.11
ST41-15	6/21/94	2648834.14	1664326.78	252.52	248.3	20.33	--	10.07	--	--	242.45
ST41-16	6/21/94	2648845.84	1664473.95	253.8	249.3	20.0	15.62	16.29	0.67	15.79	238.01
ST41-18	6/21/94	2648902.91	1664769.10	243.01	238.0	16.14	--	14.51	--	--	228.50
ST41-21	6/21/94	2648595.60	1664262.72	220.61	215.6	19.02	--	7.45	--	--	213.16
ST41-25	6/21/94	2648630.54	1664449.39	220.77	215.4	12.68	--	7.08	--	--	213.69
ST41-26	6/21/94	2648407.87	1664786.53	215.42	210.1	18.12	--	14.90	--	--	200.52
ST41-29	6/21/94	2648501.03	1664549.03	216.50	211.8	NA	--	6.7	--	--	209.82
ST41-W-7	6/21/94	2648714.40	1664529.38	218.44	216.4	20.01	--	3.22	--	--	215.22
ST41-W-8	6/21/94	2648630.61	1664651.70	216.30	213.1	23.76	--	5.05	--	--	211.25
ST41-MW37A	6/21/94	2648284.66	1664583.81	211.03	206.6	25.0	--	15.40	--	--	195.63
ST41-MW37B	6/21/94	2648280.51	1664601.81	210.52	206.5	65.0	--	18.31	--	--	192.21
ST41-ES1	6/21/94	2648863.39	1664562.33	247.19	244.5	20.0	--	14.62	--	--	232.57
ST41-ES2	6/21/94	2648674.19	1664258.26	222.71	219.9	9.0	--	5.99	--	--	216.72
ST41-ES3	6/21/94	2648601.95	1664832.28	215.44	212.6	9.0	--	6.75	--	--	208.69
ST41-ES4A	6/21/94	2648464.08	1664353.96	213.69	211.0	9.0	--	8.39	--	--	205.30
ST41-ES4B	6/21/94	2648462.47	1664360.44	213.58	210.7	18.0	--	8.98	--	--	204.60
ST41-ES5A	6/21/94	2648434.19	1664191.11	213.63	210.7	9.0	--	7.71	--	--	205.92
ST41-ES5B	6/21/94	2648430.86	1664197.64	213.23	210.6	22.0	--	9.39	--	--	203.84
ST41-ES6A	6/21/94	2648251.37	1664398.10	205.86	202.8	14.0	--	13.77	--	--	192.09
ST41-ES6B	6/21/94	2648251.04	1664405.16	205.89	203.1	27.0	--	13.80	--	--	192.09
ST41-ES7A	6/21/94	2648196.13	1664199.49	198.88	195.9	10.0	--	6.90	--	--	191.98
ST41-ES7B	6/21/94	2648200.38	1664193.75	199.04	195.7	20.0	--	7.92	--	--	191.12
ST41-ES8A	6/21/94	2648005.19	1664259.86	193.80	191.1	10.0	--	6.32	--	--	187.48
ST41-ES8B	6/21/94	2648010.28	1664256.69	193.89	191.1	23.0	--	6.13	--	--	187.76

^a Datum is top of PVC casing.

^b ft msl = Feet above mean sea level

^c ft bgs = Feet below ground surface

^d Corrected Depth to Water = Depth to water - (0.75)(LNAPL Thickness)

^e -- = Not Applicable

^f ST41-07 is screened in a sand layer within the Bootlegger Cove Formation; water level data do not apply to shallow aquifer.

Data for previously installed wells from Jacobs Engineering Group (1994b).

Hydraulic conductivity, was estimated at wells installed by Parsons ES using rising-head and falling head slug tests as described in Section 2. Slug tests were performed in monitoring wells ST41-ES2, ST41-ES4A, ST41-ES4B, ST41-ES8A, and ST41-ES8B. The results of these slug tests are summarized in Table 3.2. The average hydraulic conductivity for the saturated zone as determined from these tests is 2.9×10^{-3} ft/min or 1.5×10^{-3} cm/sec. Conductivity did not vary significantly between shallow and deep wells at locations ST41-ES4 and ST41-ES8.

TABLE 3.2
SLUG TEST RESULTS
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

WELL	TEST	HYDRAULIC CONDUCTIVITY (ft/min)	HYDRAULIC CONDUCTIVITY (cm/sec)
ST41-ES2	Rising Head	7.3×10^{-4}	3.7×10^{-4}
ST41-ES4A	Rising Head	1.2×10^{-3}	6.0×10^{-4}
ST41-ES4B	Rising Head	7.8×10^{-3}	3.9×10^{-3}
ST41-ES8A	Rising Head	3.6×10^{-3}	1.8×10^{-3}
ST41-ES8A	Falling Head	1.4×10^{-3}	7.0×10^{-4}
ST41-ES8B	Rising Head	2.2×10^{-3}	1.1×10^{-3}
ST41-ES8B	Falling Head	3.2×10^{-3}	1.6×10^{-3}
	AVERAGE	2.9×10^{-3}	1.5×10^{-3}

3.3.3.3 Effective Porosity

Jacobs Engineering Group (1994b) submitted several samples from Site ST41 for geotechnical analyses, including the determination of porosity. Results of these tests indicated that aquifer materials in the site area have porosities ranging from 0.21 to 0.46. This range is

similar to the range given by Freeze and Cherry (1979) for silt and sand (0.25 to 0.50). Based on the previous data, the effective porosity for sediments of the shallow saturated zone is assumed to be 0.35.

3.3.3.4 Advective Groundwater Velocity

The advective velocity of groundwater in the direction parallel to groundwater flow is given by:

$$\bar{v} = \frac{K}{n_e} \frac{dH}{dL}$$

Where: $\bar{v}$ = Average advective groundwater velocity (seepage velocity) [L/T]

K = Hydraulic conductivity [L/T] (0.0029 ft/min)

dH/dL = Gradient [L/L] (0.06 ft/ft)

n_e = Effective porosity (0.35).

Using this relationship in conjunction with site-specific data, the average advective groundwater velocity south of Loop Road is 0.72 foot per day (ft/day), or approximately 260 feet per year.

3.3.3.5 Preferential Flow Paths

No preferential contaminant migration pathways were identified during the field work phase of this project. The seeps reported to be present on the hill slope south of ST41-16 were not observed at that time. However, operation of an extraction trench in that area may now prevent discharge of groundwater to the ditch. Stratigraphic data do not indicate the presence of any high-conductivity zones of material that could influence subsurface flow.

3.3.4 Groundwater Use

Groundwater from the shallow aquifer at Elmendorf AFB is not extracted for potable uses. Water supplementing on-base requirements is obtained from deep supply wells tapping the confined unconsolidated deposits. Previous investigations (Jacobs Engineering Group, 1993; and Radian, 1994) have indicated that the Bootlegger Cove Formation is a competent confining unit, and that contamination from the shallow aquifer is unlikely to reach the deep aquifer.

3.4 CLIMATOLOGICAL CHARACTERISTICS

Climatic information contained in this section was compiled by Black & Veatch (1990). Elmendorf AFB is located in a transitional climatic zone, located between the maritime climatic zone to the south and the interior or continental zone to the north (Selkregg, 1972). The St. Elias and Chugach Mountains to the south act as a barrier to the influence of the northern Pacific Ocean, while the Alaska Range to the north protects the area from the extremely cold Arctic air masses of the state's interior region. As a result, the area experiences a moderate climate lacking extremes in precipitation or temperature. However, because of the northern latitude the area has reduced solar radiation, resulting in low mean annual temperatures.

Monthly mean high temperatures range from about 12°F in January to about 58°F in July. Record extreme high and low temperatures for the period from 1941 through 1984 were 86°F and -43°F, respectively (Leslie, 1986). Mean annual precipitation is 15.9 inches, of which 36 percent falls as snow.

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCE OF CONTAMINATION

Several sources likely contributed to the contamination observed in the vicinity of Site ST41. All four USTs failed tightness tests in 1990, and several large spills of AVGAS and JP-4 are known to have occurred between 1960 and 1984. In the area of Tank 601, the condensate drain pipe running from the UST to an area near well ST41-16 probably released petroleum hydrocarbons to the soil and groundwater. The USTs and associated piping were taken out of service in 1991, so it is unlikely that any more petroleum has been released at this site. Removal of mobile LNAPL and extraction of some of the contaminated groundwater began in late 1993, with the startup of the IRA system.

4.2 SOIL CHEMISTRY

4.2.1 Mobile LNAPL Contamination

Mobile LNAPL is defined as the LNAPL that is free to flow in the aquifer and that will flow from the aquifer matrix into a well under the influence of gravity. In the vicinity of Tank 601, mobile LNAPL has only been detected in well ST41-16 (Jacobs Engineering Group, 1994b). In June 1994, the LNAPL thickness measured in ST41-16 was approximately 0.67 foot (Table 3.1). The full extent of suspected mobile LNAPL contamination cannot be accurately determined from the available measurements. However, because LNAPL is present in only one well, the extent appears limited.

Concentrations of BTEX and TMB constituents in the mobile LNAPL were quantitated using a sample of LNAPL collected from ST41-16 in June 1994. Concentrations of BTEX in this sample indicate that the petroleum comprising the LNAPL plume in this area is weathered. Table 4.1 compares BTEX concentrations in

fresh JP-4 and gasoline to those observed in LNAPL from ST41-16. Compared to JP-4, the LNAPL is not significantly weathered and contains toluene, ethylbenzene, and xylenes, in concentrations greater than indicated for fresh product. However, compared to gasoline, the LNAPL is more significantly weathered. Given these data and the site history, the LNAPL body is most likely a weathered mixture of JP-4 and AVGAS.

TABLE 4.1
COMPARATIVE FRESH AND WEATHERED LNAPL
BTEX ANALYTICAL RESULTS
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Compound	Concentration in Fresh JP-4 ^{a/} (mg/L)	Concentration in Fresh Gasoline ^{b/} (mg/L)	Concentration in Weathered Product from ST41-16 (June 1994) ^{c/} (mg/L)
benzene	3,750	6,800 - 33,200	2,310
toluene	9,975	30,200 - 153,000	11,400
ethylbenzene	2,775	7,110 - 17,500	5,750
<i>o</i> -xylene	7,575	--	4,480
<i>m</i> -xylene	7,200	--	14,100
<i>p</i> -xylene	2,625	--	4,670
total xylenes	17,400	32,100 - 78,400	23,250

^{a/} Data from Martel (1987).

^{b/} Data from Potter (1988), IRP (1987), and Sigsby *et al.* (1987).

^{c/} Analyzed by USEPA RSKERL using a gas chromatograph/mass spectrometer (GC/MS).

The relationship between measured LNAPL thickness and the amount of mobile LNAPL in the subsurface at a site is extremely difficult to quantify. It is well documented that LNAPL thickness measurements taken in groundwater monitoring wells are not indicative of actual mobile LNAPL thicknesses in the formation (Kemblowski and Chiang, 1990; Abdul *et al.*, 1989; Testa and Paczkowski, 1989; Hughes *et al.*, 1988;

Blake and Hall, 1984; Hall *et al.*, 1984; Mercer and Cohen, 1990; de Pastrovich *et al.*, 1979; Lehnard and Parker, 1990; Ballesterio *et al.*, 1994). It has been noted by these authors that the thickness of LNAPL measured in a monitoring well is greater than the actual mobile LNAPL thickness present in the aquifer and, according to Mercer and Cohen (1990), measured LNAPL thickness in wells is typically 2 to 10 times greater than the actual mobile LNAPL thickness in the formation.

The volume of mobile LNAPL present in the vicinity of ST41-16 can be estimated based on three conservative assumptions. First, it is assumed that mobile LNAPL is present in an area 100 feet by 100 feet. Second, it is assumed that the porosity of the soil containing mobile LNAPL is 0.35. Finally, it is assumed that the actual thickness of LNAPL in the aquifer is one-half of the thickness observed in ST41-16 (0.67 foot). Therefore, approximately 1,170 cubic feet (8,770 gallons) of mobile LNAPL may be present downgradient of Tank 601. This is likely an overestimate, based on the conservative nature of the assumptions used in this calculation and the small quantities of LNAPL accumulating in the IRA extraction system.

4.2.2 Residual-Phase Contamination

Residual-phase LNAPL is defined as the LNAPL that is trapped in the aquifer by the processes of cohesion and capillarity, and therefore will not flow within the aquifer and will not flow from the aquifer matrix into a well under the influence of gravity. Results of previous soil sampling efforts are described in the site investigation reports (Black & Veatch, 1990; Jacobs Engineering Group 1994b). Results of June 1994 investigation activities are described below.

4.2.2.1 Soil BTEX Contamination

Two soil samples from the vicinity of the water table in boreholes for wells ST41-ES1 through ST41-ES8B were submitted for laboratory analysis of BTEX and TMBs using method RSKSOP-124 (RSKSOP refers to RSKERL standard operating procedures). Table 4.2 presents soil BTEX and TMB data. Only 4 of the 15 samples contained quantifiable concentrations of BTEX compounds. All four of these samples contained benzene, at concentrations ranging from 0.0151 to 0.0917 mg/kg. Only one of the samples, collected from 4 to 6 feet bgs in borehole ST41-ES2, contained any of the other

TABLE 4.2

**SOIL ANALYTICAL RESULTS SUMMARY
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Sample Location	Sample Depth (feet)	Benzene (mg/kg)	Toluene (mg/kg)	Ethylbenzene (mg/kg)	p-Xylene (mg/kg)	m-Xylene (mg/kg)	o-Xylene (mg/kg)	Total Xylenes (mg/kg)	Total BTEX (mg/kg)	1,3,5-TMB (mg/kg)	1,2,4-TMB (mg/kg)	1,2,3-TMB (mg/kg)	JP-4 ^a (mg/kg)	TOC (percent)
ST41-ES1	12-14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	BLQ ^b	0.173
	14-16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	BLQ	0.193
ST41-ES2	4-6	0.0181	3.340	0.444	ND ^c	ND	ND	<0.01	3.8	ND	ND	ND	BLQ	25.9
	6-8	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	10.6
ST41-ES3	2-4	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	0.138
	4-6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	BLQ	0.107
ST41-ES4B	4-6	ND	<0.01	ND	ND	ND	ND	ND	<0.01	ND	ND	ND	BLQ	0.86
	6-8	0.0151	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0151	ND	<0.01	ND	BLQ	0.467
ST41-ES5B	4-6	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	0.107
	6-8	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	BLQ	0.129
ST41-ES6B	8-10	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	0.071
	10-12	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	0.076
ST41-ES7B	6-8	0.0162	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0162	ND	<0.01	ND	BLQ	0.264
	10-12	0.0917	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.0917	ND	<0.01	ND	BLQ	0.203
ST41-ES8B	6-8	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	BLQ	0.457
	10-12	ND	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	ND	ND	ND	BLQ	0.149

^a JP-4 = Total fuel carbon quantified against a JP-4 standard.

^b ND = Not detected

^c BLQ = Below limit of quantitation (14.79 mg/kg).

Note: BTEX and TMB compounds in soil were analyzed using RSKSOP-124 (GC/MS)

JP-4 in soil was analyzed using RSKSOP-72, Revision #1.

TOC was analyzed using RSKSOP-120.

BTEX compounds. This sample had a benzene concentration of 3.34 mg/kg and an ethylbenzene concentration of 0.444 mg/kg. TMBs were not detected in quantifiable concentrations in any of the soil samples.

4.2.2.2 Soil TPH Contamination

Table 4.2 also presents soil TPH data. TPH concentrations were quantified as total fuel carbon in comparison to a JP-4 fuel standard, using RSKSOP-72, revision 1. TPH concentrations were below the laboratory's quantification limit of 14.79 mg/kg in all soil samples collected from monitoring well boreholes at Site ST41.

4.2.3 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed on soil particles or trapped in the interstitial passages of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially be sorbed to the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the average advective groundwater velocity. Measurements of TOC were taken for all soil samples obtained from Site ST41. The TOC content of the soil at this site ranges from 0.071 to 25.9 percent (Table 4.1).

The two highest TOC contents were in samples from the borehole for monitoring well ST41-ES2. At 4 to 6 feet bgs, the TOC content was 25.9 percent, while at 6 to 8 feet bgs, the TOC content was 10.6 percent. The boring log for ST41-ES2 indicates that the soil at these depths contained peat and some plant matter, accounting for the high TOC contents at this location. Similar organic matter was not encountered in the vicinity of the water table at any other location, so a more representative range of soil TOC contents for the site is 0.071 to 0.457 percent.

4.3 GROUNDWATER CHEMISTRY

Three lines of evidence can be used to document the occurrence of natural attenuation: 1) documented loss of contaminant mass at the field scale; 2) geochemical evidence; and 3) laboratory microcosm studies. The second line of evidence (geochemical evidence) is used herein to support the occurrence of natural attenuation, as described in the following

sections. Because this line of evidence strongly suggests that natural attenuation is occurring at this site, laboratory microcosm studies were not deemed necessary.

4.3.1 Dissolved Contamination

Laboratory analytical results for groundwater samples collected during previous site investigations indicated the presence of fuel hydrocarbon contamination in the shallow saturated zone in the vicinity of Tank 601. Groundwater samples collected in June 1994, by Parsons ES and RSKERL personnel confirmed these results. Table 4.3 summarizes groundwater contaminant data for these samples.

Previous data for the Tank 601 plume were presented by Jacobs Engineering Group (1994b). In fall 1992, BTEX compounds were detected in wells ST41-07, ST41-16, and ST41-25. Total BTEX concentrations ranged from 913 $\mu\text{g/L}$ at ST41-07 and 1,530 $\mu\text{g/L}$ at ST41-25 to 57,700 $\mu\text{g/L}$ in ST41-16. At that time, TPH concentrations were measured at 9.4 mg/L in ST41-25 and 1,100 mg/L in ST41-16. According to a trend analysis performed by Jacobs Engineering Group (1994b), the fall 1992 analytical data are representative of BTEX and TPH concentrations through three rounds of sampling from fall 1990 through fall 1992.

4.3.1.1 BTEX in Groundwater

Figure 4.1 is an isopleth map showing the distribution of total BTEX dissolved in groundwater in June 1994. Where nested wells are present, isopleths are drawn based on the maximum concentration detected at each location. Dissolved BTEX contamination emanating from the vicinity of Tank 601 is migrating to the south, in the direction of groundwater flow. As indicated by the 1 $\mu\text{g/L}$ isopleth, the BTEX plume is approximately 700 feet long and 500 feet wide at its widest point. Based on groundwater flow data and previous evidence of a contaminant plume originating from Tank 604 (Jacobs Engineering Group, 1994b), contamination found in wells ST41-18 and ST41-ES3 is presumed to be unrelated to the plume emanating from Tank 601. The sample data from those wells therefore were ignored when drawing isopleths.

Where detected, total BTEX concentrations range from 1.1 to 43,280 $\mu\text{g/L}$. The maximum observed concentration of 43,280 $\mu\text{g/L}$ was detected at monitoring well ST41-16. This concentration may be unrealistically high. The work of Smith *et al.* (1981)

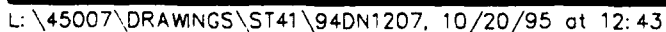
TABLE 4.3

**FUEL HYDROCARBON COMPOUNDS DETECTED IN GROUND WATER
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Sample Location	Sample Date	Benzene (µg/L)	Toluene (µg/L)	Ethylbenzene (µg/L)	p-Xylene (µg/L)	m-Xylene (µg/L)	o-Xylene (µg/L)	Total Xylenes (µg/L)	Total BTEX (µg/L)	1,3,5-TMB (µg/L)	1,2,4-TMB (µg/L)	1,2,3-TMB (µg/L)	Total Fuel Carbon (µg/L)
ST41-01	6/9/94	ND ^a	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-02	6/8/94	41.30	93.5	18.9	15.7	44.1	20.4	80.2	233.90	2.8	10.3	4.26	281
ST41-07	6/9/94	493.00	557	154	113	259	162	534	1738.00	18.9	71.7	30.9	2000
ST41-W-7	6/7/94	9.96	<1	<1	<1	<1	ND	<1	9.96	ND	ND	ND	10.9
ST41-W-8	6/7/94	<1	<1	<1	<1	<1	ND	<1	<1	<1	<1	1.08	6.37
ST41-15	6/8/94	<1	<1	<1	<1	1.1	<1	1.1	1.10	<1	<1	<1	3.83
ST41-16	6/8/94	16500.00	17300	1920	1580	4360	1620	7560	43280.00	183	631	283	42300
ST41-18	6/8/94	101.00	155	27.9	23.1	63.4	26.3	112.8	396.70	3.52	14.1	5.92	480
ST41-21	6/8/94	2.20	3.88	<1	<1	1.27	ND	1.27	7.35	ND	ND	ND	7.41
ST41-25	6/7/94	49.00	8.39	983	791	ND	ND	791	1831.39	88	15.9	1.1	11000
ST41-29	6/7/94	<1	1.34	1.15	1.09	<1	ND	1.09	3.58	ND	ND	ND	22.0
ST41-MW37A	6/7/94	ND	ND	<1	ND	ND	ND	ND	<1	ND	<1	ND	<1
ST41-MW37B	6/7/94	ND	<1	<1	<1	<1	<1	<1	<1	ND	ND	ND	<1
ST41-ES1	6/10/94	63.20	1.3	ND	<1	<1	ND	<1	64.50	ND	ND	<1	60.7
ST41-ES2	6/10/94	3.02	2.19	ND	ND	<1	ND	<1	5.21	ND	<1	1.4	22.1
ST41-ES3	6/11/94	2.24	3.18	ND	ND	ND	ND	ND	5.42	ND	<1	1.25	<1
ST41-ES4A	6/10/94	ND	<1	ND	ND	ND	ND	ND	<1	<1	ND	ND	<1
ST41-ES4B	6/10/94	<1	ND	ND	<1	ND	ND	<1	<1	ND	ND	ND	<1
ST41-ES5A	6/10/94	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	<1
ST41-ES5B	6/10/94	4.34	2.91	ND	ND	ND	ND	ND	7.25	ND	ND	ND	NA ^b
ST41-ES6A	6/11/94	ND	<1	ND	ND	ND	ND	ND	<1	ND	ND	ND	NA
ST41-ES6B	6/11/94	ND	ND	ND	ND	ND	ND	ND	ND	ND	<1	ND	NA
ST41-ES7A	6/11/94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
ST41-ES7B	6/11/94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
ST41-ES8A	6/11/94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA
ST41-ES8B	6/11/94	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	NA

^a ND = Not Detected.^b NA = Not Analyzed.

Note: BTEX, TMB, and Total Fuel Carbon analyses performed using RSKSOP-133.



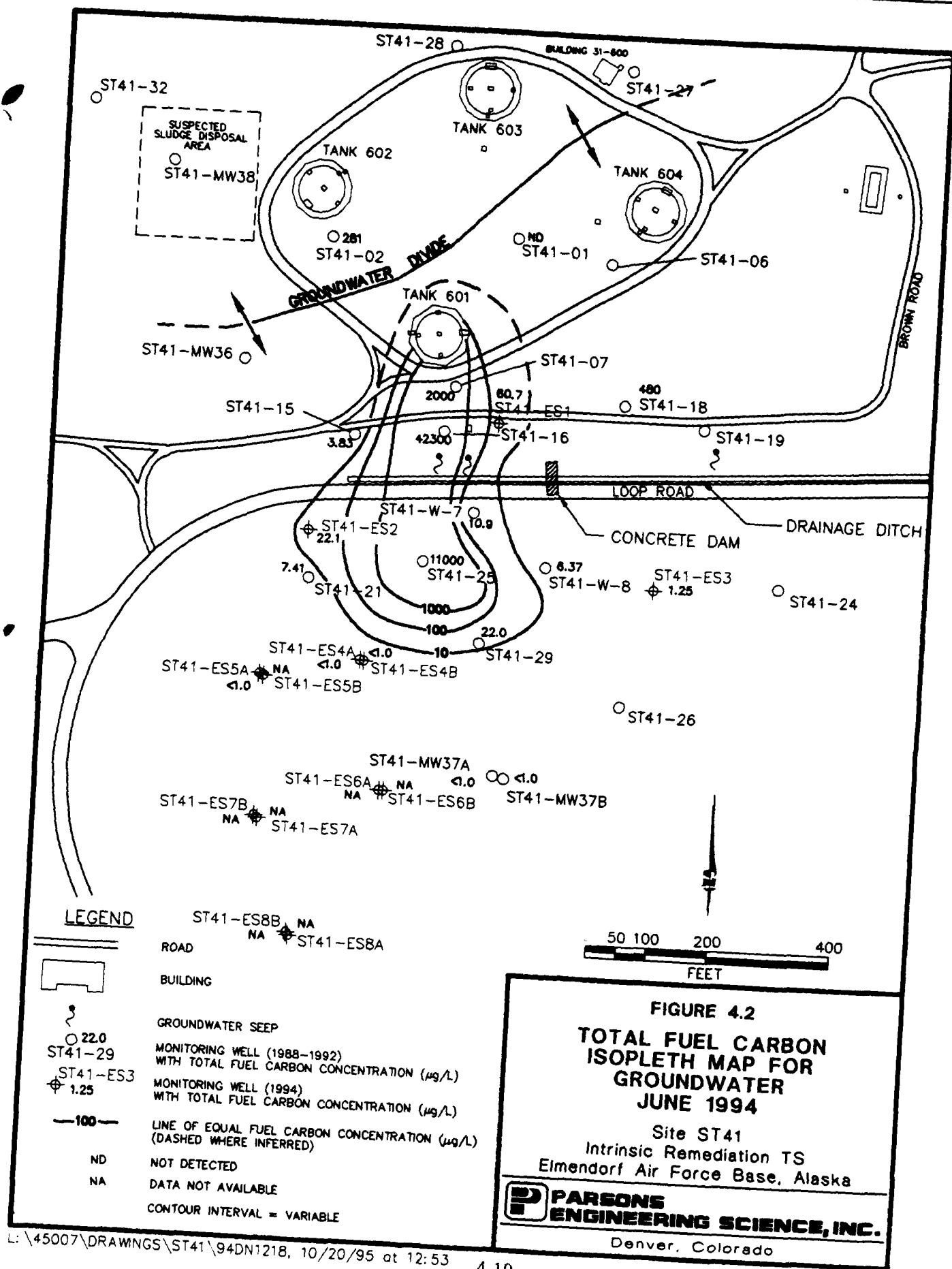
suggests that the maximum dissolved BTEX concentration that can result from the equilibrium partitioning of BTEX compounds from JP-4 into groundwater is approximately 30 mg/L (30,000 µg/L). In addition, mobile LNAPL composition data can be used to estimate the maximum possible dissolved BTEX concentrations. Using mass-fraction data from the LNAPL analysis (Table 4.1) and the fuel-water partitioning model of Bruce *et al.* (1991), the maximum dissolved benzene, toluene, ethylbenzene, and total xylenes concentrations expected in groundwater were calculated (Appendix C). These calculations indicate that the maximum total BTEX concentration at equilibrium would be approximately 30,600 µg/L. Unrealistically high total BTEX concentrations generally result from LNAPL emulsification during sampling.

Benzene concentrations, where detected, ranged from 2.24 to 16,500 µg/L. At seven locations, the benzene concentration exceeded the federal maximum contaminant level (MCL) of 5 µg/L. Toluene concentrations ranged from 1.3 to 17,300 µg/L, but the federal MCL of 1,000 µg/L was exceeded only at ST41-16. Ethylbenzene concentrations ranged from 1.15 to 1,920 µg/L, with concentrations at ST41-16 and ST41-25 (1,920 µg/L and 983 µg/L, respectively) exceeding the federal MCL of 700 µg/L. Total xylenes concentrations ranged from 1.1 to 7,560 µg/L; the federal MCL of 10,000 µg/L was not exceeded at any location.

The observed extent of BTEX contamination suggests that natural attenuation is limiting plume migration. Given that releases of petroleum hydrocarbons have occurred in the site vicinity since the early 1960s (and possibly earlier), and given the average advective groundwater velocity calculated in Section 3.3.3.4 (261 ft/yr), it is reasonable to expect that the plume would be much longer than was observed in 1994. In addition, BTEX concentrations decrease quite rapidly downgradient from the core of the plume. For example, June 1994 analytical data indicate that total BTEX concentrations decrease from 43,280 µg/L at ST41-16 to 1,831 µg/L at ST41-25, a distance of approximately 210 feet. At an additional 200 feet downgradient of ST41-25, the total BTEX concentration is below 1 µg/L, as observed at ST41-ES4A.

4.3.1.2 Total Fuel Carbon in Groundwater

Figure 4.2 is an isopleth map showing the distribution of total fuel carbon (analyzed using RSKSOP-133) dissolved in groundwater in June 1994. Dissolved fuel carbon contamination patterns describe a pattern very similar to the BTEX plume shown



L:\45007\DRAWNGS\ST41\94DN1218, 10/20/95 at 12:53

on Figure 4.1. Where detected, total fuel carbon concentrations range from 1.25 to 42,300 µg/L.

4.3.2 Inorganic Chemistry and Geochemical Indicators of Biodegradation

Microorganisms obtain energy for cell production and maintenance by facilitating the transfer of electrons from electron donors to electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at Site ST41 are natural organic carbon and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states, and include oxygen, nitrate, ferrous iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). Under aerobic conditions, DO is utilized first as the prime electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferric iron hydroxide, sulfate, and finally carbon dioxide.

Depending on the types and concentrations of electron acceptors present (e.g., nitrate, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese reduction may dominate if the physical and chemical conditions in the subsurface favor use of these electron acceptors. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.*, 1990; Wilson *et al.*, 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in an aquifer with fuel hydrocarbon contamination.

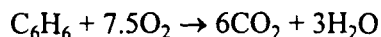
DO data for Site ST41 suggest that aerobic biodegradation of hydrocarbons is occurring. In addition, Site ST41 groundwater data for electron acceptors such as nitrate and sulfate also suggest that intrinsic remediation of hydrocarbons in the shallow aquifer by denitrification and sulfate reduction is occurring. Data for ferrous iron (Fe^{2+}) and methane also suggest that anaerobic degradation via ferric iron reduction and

methanogenesis is occurring. Further indication of intrinsic remediation is provided by results of volatile fatty acids analyses performed on select groundwater samples. Geochemical parameters for Site ST41 groundwater are discussed in the following sections.

4.3.2.1 Dissolved Oxygen

DO concentrations were measured at monitoring wells in June 1994. Table 4.4 summarizes DO concentrations, and Figure 4.3 is an isopleth map showing the distribution of DO concentrations in groundwater. Comparison of Figures 4.1 and 4.3 shows graphically that areas with elevated total BTEX concentrations correlate with areas with depleted DO concentrations. This is an indication that aerobic biodegradation of the BTEX compounds is occurring at the site. Based on the background DO levels measured at the site (up to 12.6 mg/L outside of the BTEX plume), it appears that DO is an important electron acceptor in Site ST41 vicinity.

The following equations describe the overall stoichiometry of aromatic hydrocarbon mineralization caused by aerobic microbial biodegradation. In the absence of microbial cell production, the oxidation (mineralization) of benzene to carbon dioxide and water is given by:



Therefore, 7.5 moles of oxygen are required to metabolize 1 mole of benzene. On a mass basis, the ratio of oxygen to benzene is given by:

Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Oxygen	$7.5(32) = 240 \text{ gm}$

$$\text{Mass Ratio of Oxygen to Benzene} = 240/78 = 3.08:1$$

Therefore, in the absence of microbial cell production, 3.08 mg of oxygen are required to completely metabolize 1 mg of benzene.

Similar calculations can be completed for toluene (3.13 mg oxygen to 1 mg toluene), ethylbenzene (3.17 mg oxygen to 1 mg ethylbenzene), and the xylenes (3.17 mg oxygen to 1 mg xylene). The average mass ratio of oxygen to total BTEX is thus 3.14:1. This means that approximately 0.32 mg of BTEX is mineralized for every 1.0 mg of DO

TABLE 4.4

**GROUND WATER GEOCHEMICAL DATA
SITE ST 41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Sample Location	Sample Date	Temperature (°C)	Dissolved Oxygen (mg/L)	Redox Potential (mV)	Total Alkalinity (mg/L)	Conductivity (umhos)	pH	Chloride (mg/L)	Sulfate (mg/L)	Ferrous Iron (mg/L)	NO ₂ +NO ₃ Nitrogen (mg/L)	Methane (mg/L)	TOC (mg/L)
ST41-01	6/9/94	6.0	0.1	NA [*]	512	945	7.1	4.36	15.0	<0.05	0.7	<0.001	2.9
ST41-02	6/8/94	5.9	5.1	121	554	1040	6.7	37.3	35.4	<0.05	1.03	0.008	13.7
ST41-07	6/9/94	6.4	1.4	NA	270	697	7.2	73.9	10.4	0.2	<0.05	0.054	7.2
ST41-W-7	6/7/94	5.6	3.5	115	388	855	7.5	54.3	24.6	<0.05	<0.05	0.489	4.6
ST41-W-8	6/7/94	6.8	0.8	20	49	391	6.9	33.6	7.19	<0.05	1.04	<0.001	1.8
ST41-15	6/8/94	5.4	5.4	15	375	942	6.8	74	18.9	1	<0.05	0.001	6.4
ST41-16	6/8/94	4.5	0.1	-30	1210	2050	6.6	36.6	9.52	40.5	<0.05	0.046	109.0
ST41-18	6/8/94	4.4	0.1	110	223	642	6.4	31.9	55	<0.05	12.1	0.04	11.4
ST41-21	6/8/94	4.5	0.1	258	150	734	6.3	126	10.3	<0.05	<0.05	0.003	8.8
ST41-25	6/7/94	5.0	0.1	-53	460	1150	6.8	135	<0.5	10.5	<0.05	0.922	24.4
ST41-29	6/7/94	4.8	5.7	10	92	226	6.1	14.5	8.26	0.7	<0.05	0.044	8.5
ST41-MW37A	6/7/94	5.7	11.2	104	50	114	7.1	3.5	4.14	<0.05	<0.05	<0.001	0.5
ST41-MW37B	6/7/94	5.6	0.4	-25	170	388	7.4	6.94	8.44	<0.05	<0.05	0.002	2.4
ST41-ES1	6/10/94	5.5	12.6	110	481	965	6.8	0.8	21.4	<0.05	61.4	0.004	7.3
ST41-ES2	6/10/94	7.1	3.5	11	271	686	6.7	0.1	59.3	3.6	13.1	1.481	7.6
ST41-ES3	6/11/94	11.7	8.6	46	176	7	7.9	0.17	28.2	<0.05	31.1	0.002	3.5
ST41-ES4A	6/10/94	3.4	5.0	168	76	176	6.1	0.11	8.45	<0.05	4.72	0.001	19.1
ST41-ES4B	6/10/94	5.6	1.9	20	251	593	6.6	0.07	50.3	2.1	12.2	0.051	13.1
ST41-ES5A	6/10/94	7.6	8.4	126	47	101	6.7	0.18	4.18	<0.05	2.07	<0.001	2.0
ST41-ES5B	6/10/94	5.1	0.9	91	115	259	7.9	0.14	8.23	<0.05	9.97	0.052	4.8
ST41-ES6A	6/11/94	5.6	6.9	105	63	112	6.6	0.28	0.71	<0.05	3.44	<0.001	3.3
ST41-ES6B	6/11/94	5.0	0.6	42	109	198	7.8	0.12	1.34	<0.05	5.4	0.006	3.1
ST41-ES7A	6/11/94	5.4	0.3	-10	325	568	6.5	0.06	10.3	29.8	3.1	1.553	38.1
ST41-ES7B	6/11/94	4.1	0.4	47	210	450	6.5	0.06	27.8	1.1	5.38	0.194	11.2
ST41-ES8A	6/11/94	6.2	3.0	-12	159	303	6.5	0.23	3.0	14.3	8.28	0.811	6.8
ST41-ES8B	6/11/94	5.5	0.1	-12	167	306	7.6	0.08	3.38	<0.05	7.21	0.007	3.6

* NA = Data not available.

Note: Analytical methods as follows:

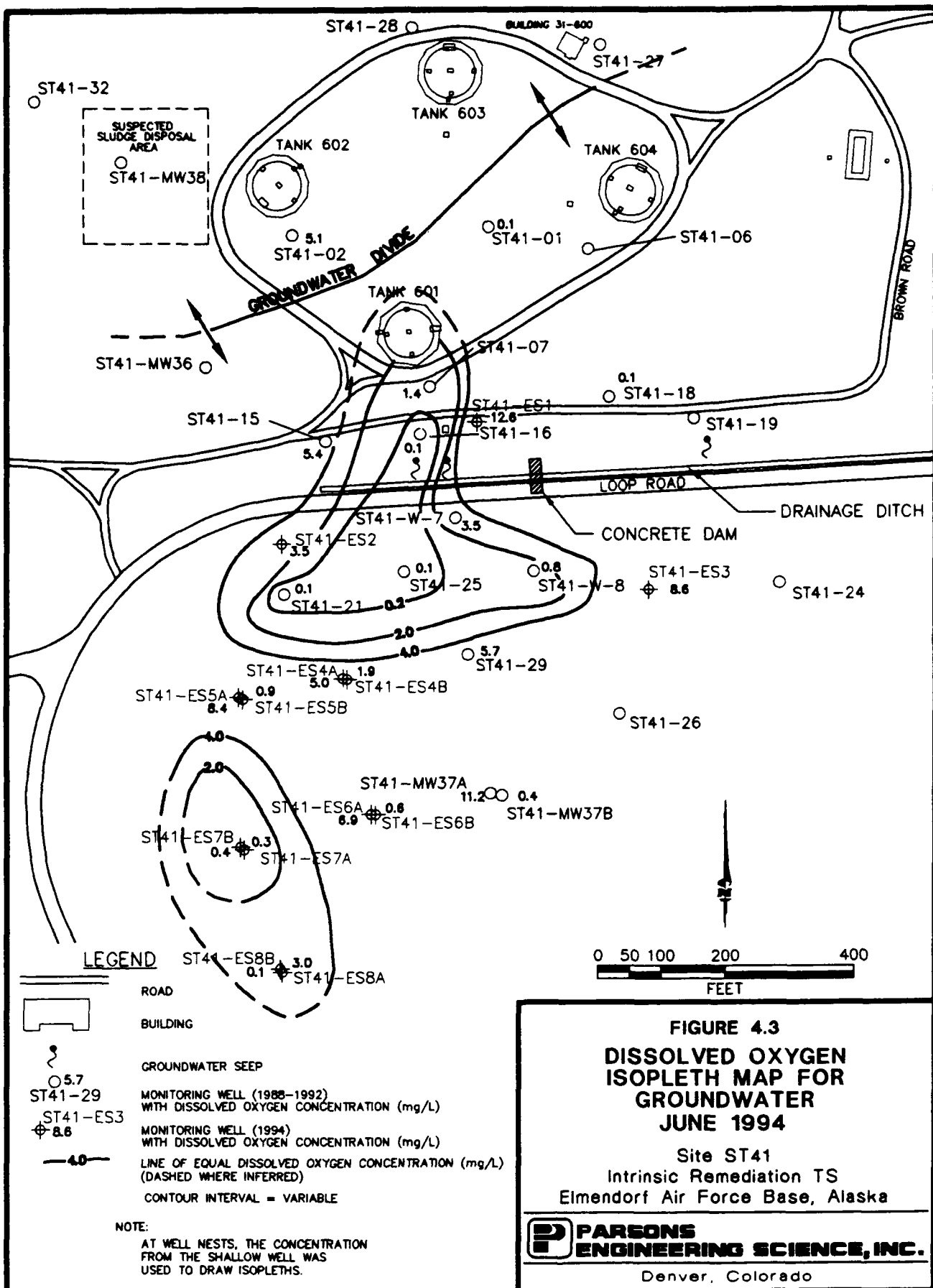
Temperature, dissolved oxygen, redox potential, conductivity, pH - direct reading meter (field)

Alkalinity - EPA Method 150.1, titrimetric

Chloride, Sulfate - Water's Capillary Electrophoresis Method N-601

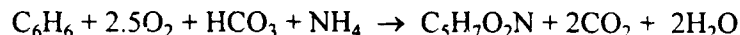
Ferrous Iron - Hach method 8146 (field)

NO₂ + NO₃ (as Nitrogen) - EPA Method 353.1
Methane - RSKSOP-147 (FID)
TOC - RSKSOP-102



consumed. With a possible background DO concentration of up to approximately 12.6 mg/L, the shallow groundwater at this site has the capacity to assimilate 4.03 mg/L (4,030 µg/L) of total BTEX through aerobic biodegradation. This is a conservative estimate of the assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry shown above.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:



From this it can be seen that only 2.5 moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

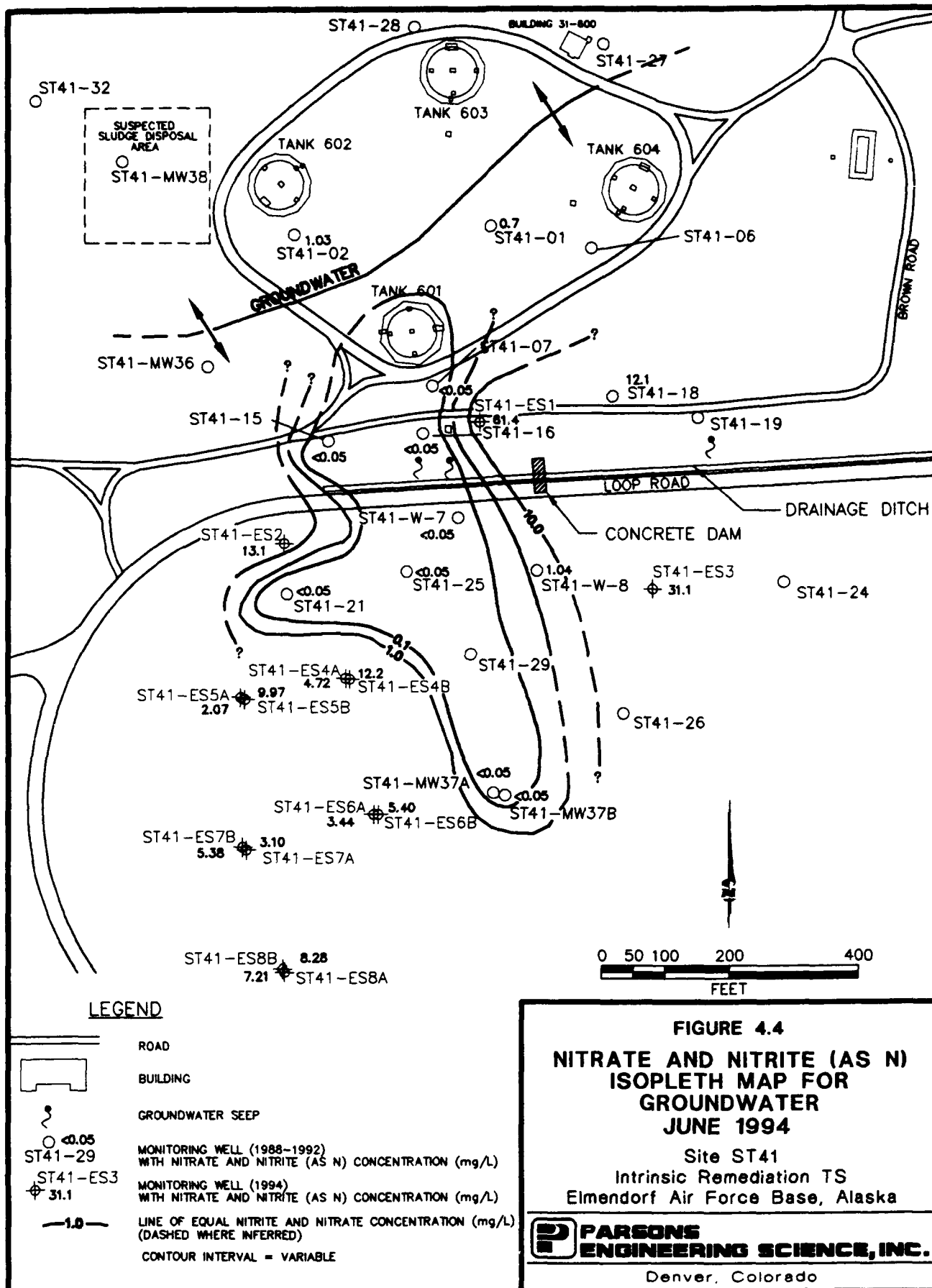
Benzene	$6(12) + 1(6) = 78 \text{ gm}$
Oxygen	$2.5(32) = 80 \text{ gm}$

$$\text{Mass Ratio of Oxygen to Benzene} = 80/78 = 1.03:1$$

Based on these stoichiometric relationships, 1.03 mg of oxygen are required to mineralize 1 mg of benzene. Similar calculations can be made for toluene, ethylbenzene, and the xylenes. Based on these calculations, approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. With a background DO concentration of approximately 12.6 mg/L, the shallow groundwater at this site has the capacity to assimilate 12.2 mg/L (12,200 µg/L) of total BTEX if microbial cell mass production is taken into account.

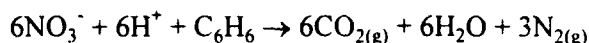
4.3.2.2 Nitrate/Nitrite

Concentrations of nitrate + nitrite [as nitrogen (N)] were measured at groundwater monitoring wells in June 1994. Nitrate concentrations at the site range from <0.5 mg/L to 61.4 mg/L. Table 4.4 summarizes measured nitrate and nitrite (as N) concentrations. Figure 4.4 is an isopleth map showing the distribution of nitrate + nitrite (as N) in groundwater in June 1994. Comparison of this figure with Figure 4.1 shows graphically that areas with elevated total BTEX concentrations have depleted nitrate + nitrite concentrations. Comparison of Figures 4.3 and 4.4 shows graphically that areas with depleted DO concentrations also have depleted nitrate + nitrite concentrations. These



relationships provide strong evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of denitrification.

In the absence of microbial cell production, the biodegradation of benzene via denitrification to carbon dioxide and water is given by:



Based on this relationship, 6 moles of nitrate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of nitrate to benzene is given by:

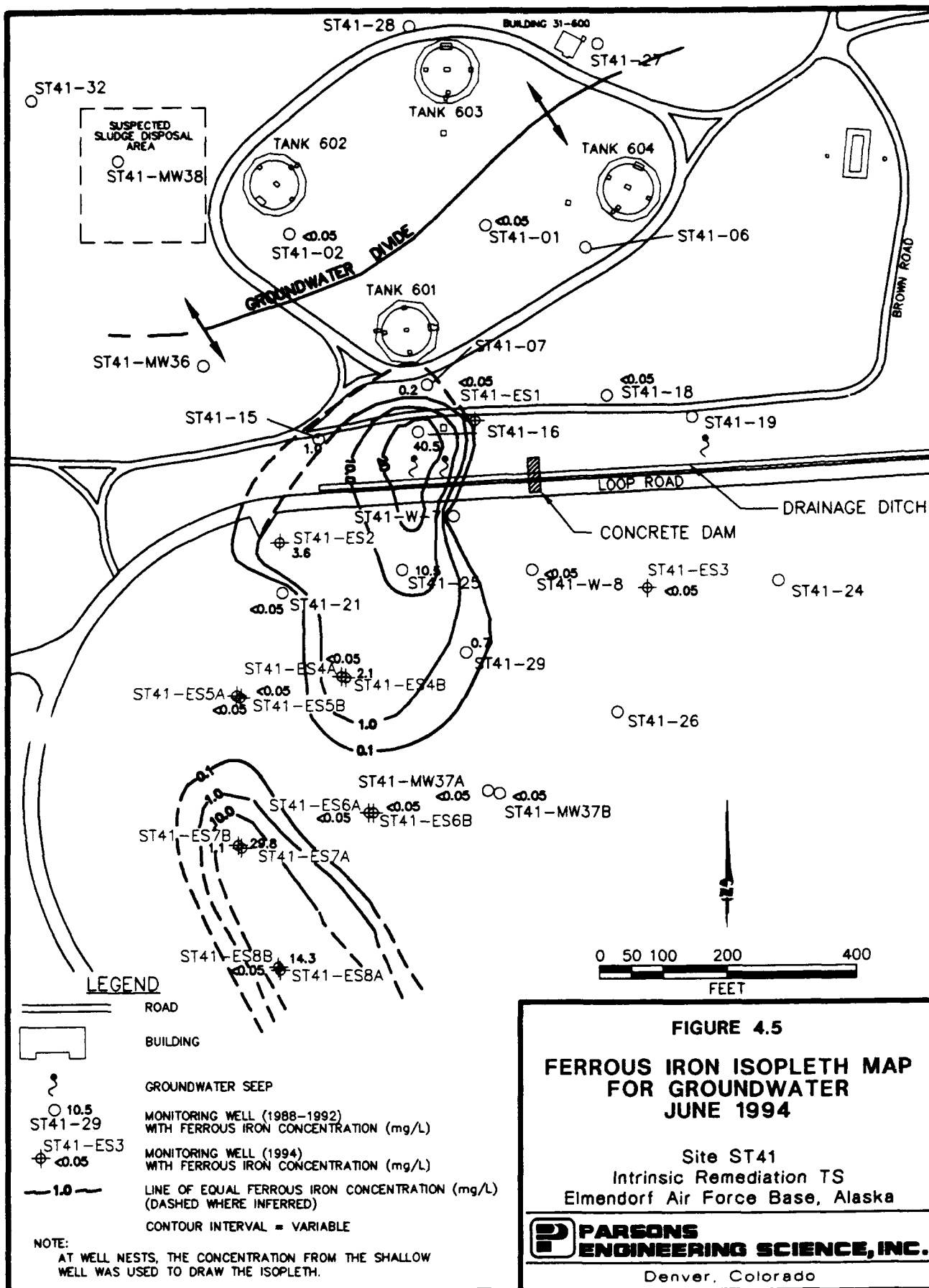
Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Nitrate	$6(62) = 372 \text{ gm}$

$$\text{Mass ratio of nitrate to benzene} = 372/78 = 4.77:1$$

In the absence of microbial cell production, 4.77 mg of nitrate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for toluene (4.85 mg nitrate to 1 mg toluene), ethylbenzene (4.92 mg nitrate to 1 mg ethylbenzene), and the xylenes (4.92 mg nitrate to 1 mg xylene). The average mass ratio of nitrate consumed to total BTEX degraded is 4.9:1. This means that approximately 0.20 mg of BTEX is mineralized for every 1.0 mg of nitrate consumed. With a maximum observed nitrate concentration of approximately 61.4 mg/L, the shallow groundwater at this site has the capacity to assimilate 12.3 mg/L (12,300 µg/L) of total BTEX during denitrification. This is a conservative estimate of the assimilative capacity of nitrate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.3.2.1).

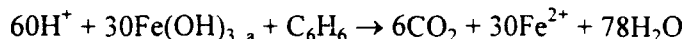
4.3.2.3 Ferrous Iron

Ferrous iron (Fe^{2+}) concentrations were measured at groundwater monitoring wells in June 1994. Table 4.4 summarizes ferrous iron concentrations. Figure 4.5 is an isopleth map showing the distribution of ferrous iron in groundwater. Comparison of Figures 4.5 and 4.1 shows graphically that most of the area with elevated total BTEX concentrations has elevated ferrous iron concentrations. This suggests that ferric iron hydroxide (Fe^{3+}) is being reduced to ferrous iron during biodegradation of BTEX compounds. The highest measured ferrous iron concentration, 40.5 mg/L, was observed at ST41-16, which is also the location with the highest total BTEX concentration.



Background levels of ferrous iron are generally at or below the detection limit of 0.05 mg/L, as measured at wells with little or no known BTEX contamination.

The following equations describe the overall stoichiometry of benzene oxidation by iron reduction caused by anaerobic microbial biodegradation. In the absence of microbial cell production, the mineralization of benzene is given by:



Therefore, 30 moles of ferric iron are required to metabolize 1 mole of benzene. On a mass basis, the ratio of ferric iron to benzene is given by:

Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Ferric Iron	$30(106.85) = 3205.41 \text{ gm}$

$$\text{Mass ratio of ferric iron to benzene} = 3205.41/78 = 41.1:1$$

Therefore, in the absence of microbial cell production, 41.1 mg of ferric iron are required to completely metabolize 1 mg of benzene. Alternatively, the mass ratio of ferrous iron produced during respiration to benzene degraded can be calculated and is given by:

Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Ferrous Iron	$30(55.85) = 1675.5 \text{ gm}$

$$\text{Mass ratio of ferrous iron to benzene} = 1675.5/78 = 21.5:1$$

Therefore, 21.5 mg of ferrous iron are produced during mineralization of 1 mg of benzene.

Similar calculations can be completed for toluene (21.86 mg of Fe^{2+} produced during mineralization of 1 mg of toluene), ethylbenzene (22 mg of Fe^{2+} produced during mineralization of 1 mg of ethylbenzene), and the xylenes (22 mg of Fe^{2+} produced during mineralization of 1 mg of xylene). The average mass ratio of Fe^{2+} produced during total BTEX mineralization is thus 21.8:1. This means that approximately 1 mg of BTEX is mineralized for every 21.8 mg of Fe^{2+} produced. The highest measured Fe^{2+} concentration was 40.5 mg/L. This suggests that the shallow groundwater at this site has the capacity to assimilate 1.86 mg/L (1,860 $\mu\text{g/L}$) of total BTEX during iron reduction. This is a conservative estimate of the assimilative capacity of iron because microbial cell mass production has not been taken into account by the stoichiometry shown above (see

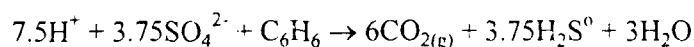
Section 4.3.2.1). In addition, this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, the iron assimilative capacity of site groundwater could be much higher.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at Site ST41 are the strongest indicators of microbial activity.

4.3.2.4 Sulfate

Sulfate concentrations were measured at groundwater monitoring wells in June 1994. Sulfate concentrations at Site ST41 range from <0.05 mg/L to 59.3 mg/L. Table 4.4 summarizes measured sulfate concentrations. Figure 4.6 is an isopleth map showing the distribution of sulfate in groundwater in June 1994. Comparison of Figures 4.6 and 4.1 shows graphically that areas with elevated total BTEX concentrations have depleted sulfate concentrations. This is a strong indication that anaerobic biodegradation of BTEX compounds is occurring at the site through the microbially mediated process of sulfate reduction.

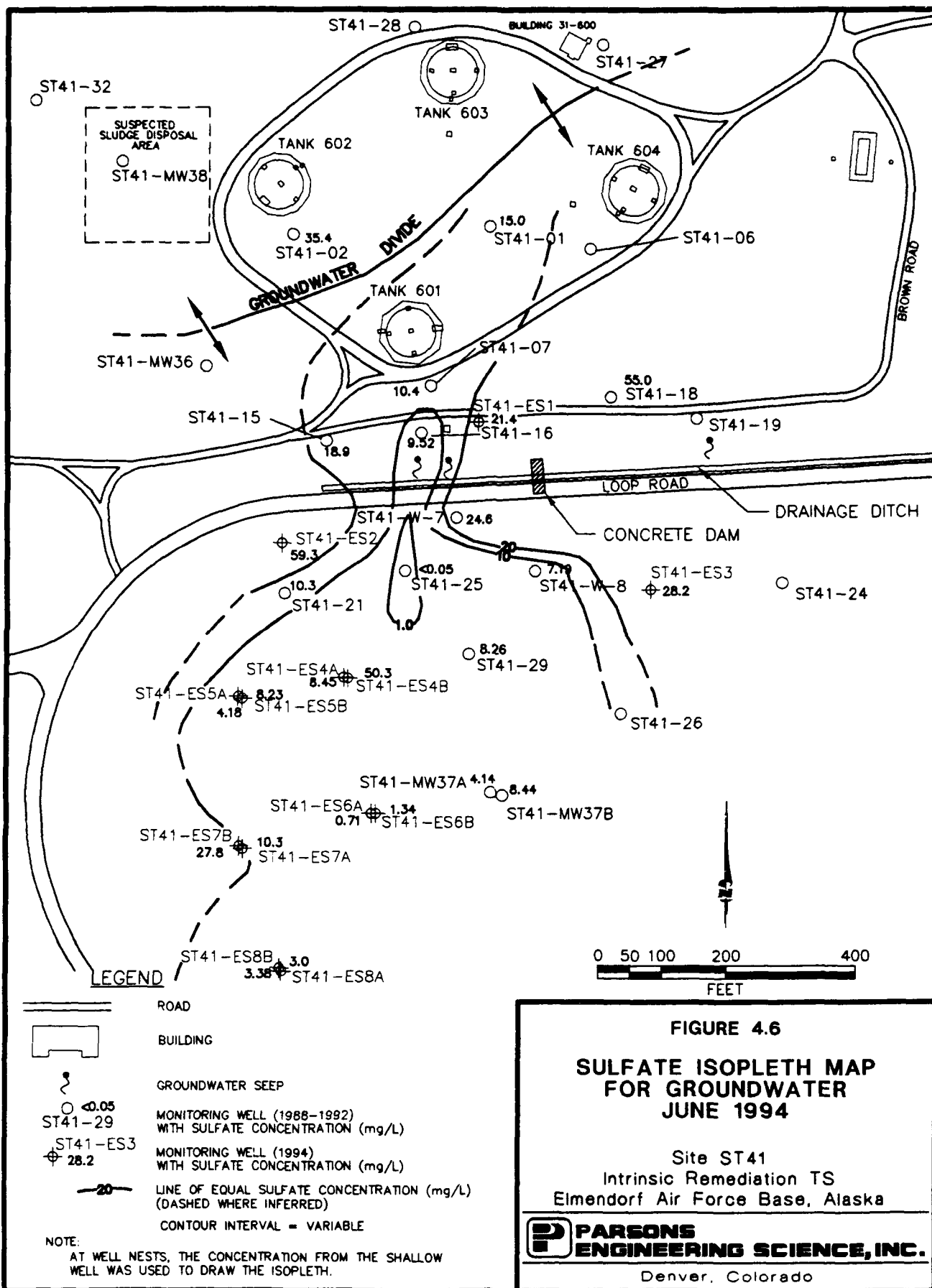
The following equations describe the overall stoichiometry of BTEX oxidation by sulfate reduction caused by anaerobic microbial biodegradation. In the absence of microbial cell production, the biodegradation of benzene is given by:



Therefore, 3.75 moles of sulfate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of sulfate to benzene is given by:

Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Sulfate	$3.75(96) = 360 \text{ gm}$

$$\text{Mass ratio of sulfate to benzene} = 360/78 = 4.6:1$$



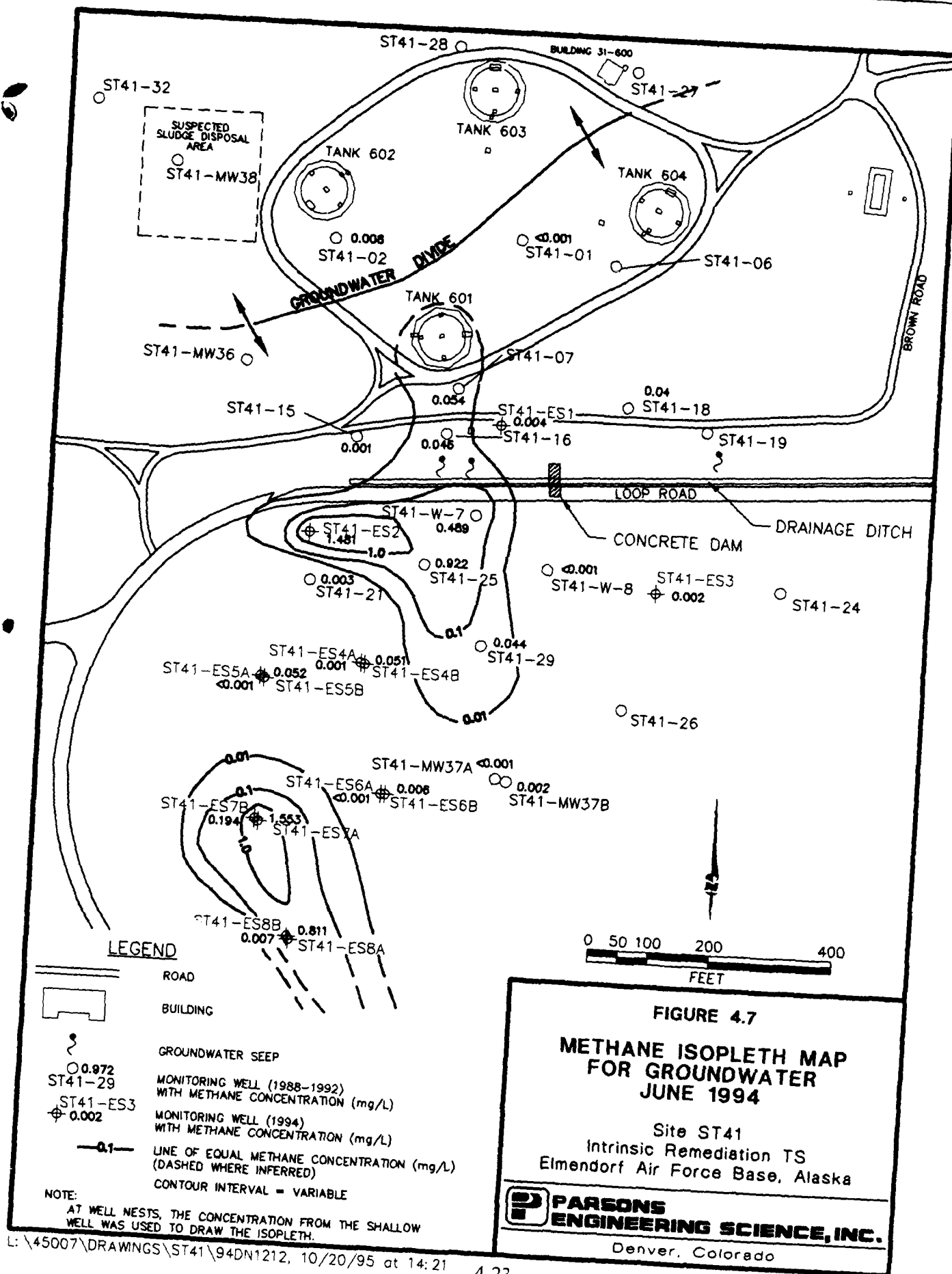
Therefore, in the absence of microbial cell production, 4.6 mg of sulfate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for toluene (4.7 mg sulfate to 1 mg toluene), ethylbenzene (4.75 mg sulfate to 1 mg ethylbenzene), and the xylenes (4.75 mg sulfate to 1 mg xylene). The average mass ratio of sulfate to total BTEX is thus 4.7:1. This means that approximately 0.21 mg of BTEX is mineralized for every 1.0 mg of sulfate consumed. Assuming a background sulfate concentration of 59.3 mg/L, the shallow groundwater at this site has the capacity to assimilate 12.4 mg/L (12,400 μ g/L) of total BTEX during sulfate reduction. Again, this is a conservative estimate of the assimilative capacity of sulfate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.3.2.1).

4.3.2.5 Methane in Groundwater

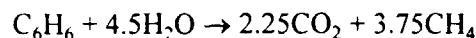
Methane concentrations were measured at groundwater monitoring wells in June 1994. Table 4.4 summarizes methane concentrations. Figure 4.7 is an isopleth map showing the distribution of methane in groundwater. Comparison of Figures 4.1 and 4.7 shows graphically that areas with elevated total BTEX concentrations correlate with elevated methane concentrations. This is a strong indication that anaerobic biodegradation of the BTEX compounds is occurring at the site. This is consistent with other electron acceptor data for this site, with the area having elevated methane concentrations corresponding with the areas with depleted DO, nitrate, and sulfate concentrations and elevated ferrous iron concentrations.

Methane concentrations ranged from <0.001 mg/L to 1.481 mg/L. Background levels of methane at wells outside areas with known BTEX contamination are below 0.01 mg/L. Samples collected from monitoring wells located near the area with the highest BTEX concentrations contain the highest methane concentrations. In these locations, methane concentrations range from about 0.046 to 1.481 mg/L. The highest methane concentration observed at the site was in ST41-ES2, with significantly elevated concentrations also present in wells ST41-07, ST41-W-7, ST41-16, ST41-25, and ST41-29.

The following equations describe the overall stoichiometry of benzene oxidation by methanogenesis. In the absence of microbial cell production, the mineralization of benzene is given by:



L:\45007\DRAWINGS\ST41\94DN1212, 10/20/95 at 14:21



The mass ratio of methane produced during respiration to benzene degraded can be calculated and is given by:

Benzene	$6(12) + 6(1) = 78 \text{ gm}$
Methane	$3.75(16) = 60 \text{ gm}$

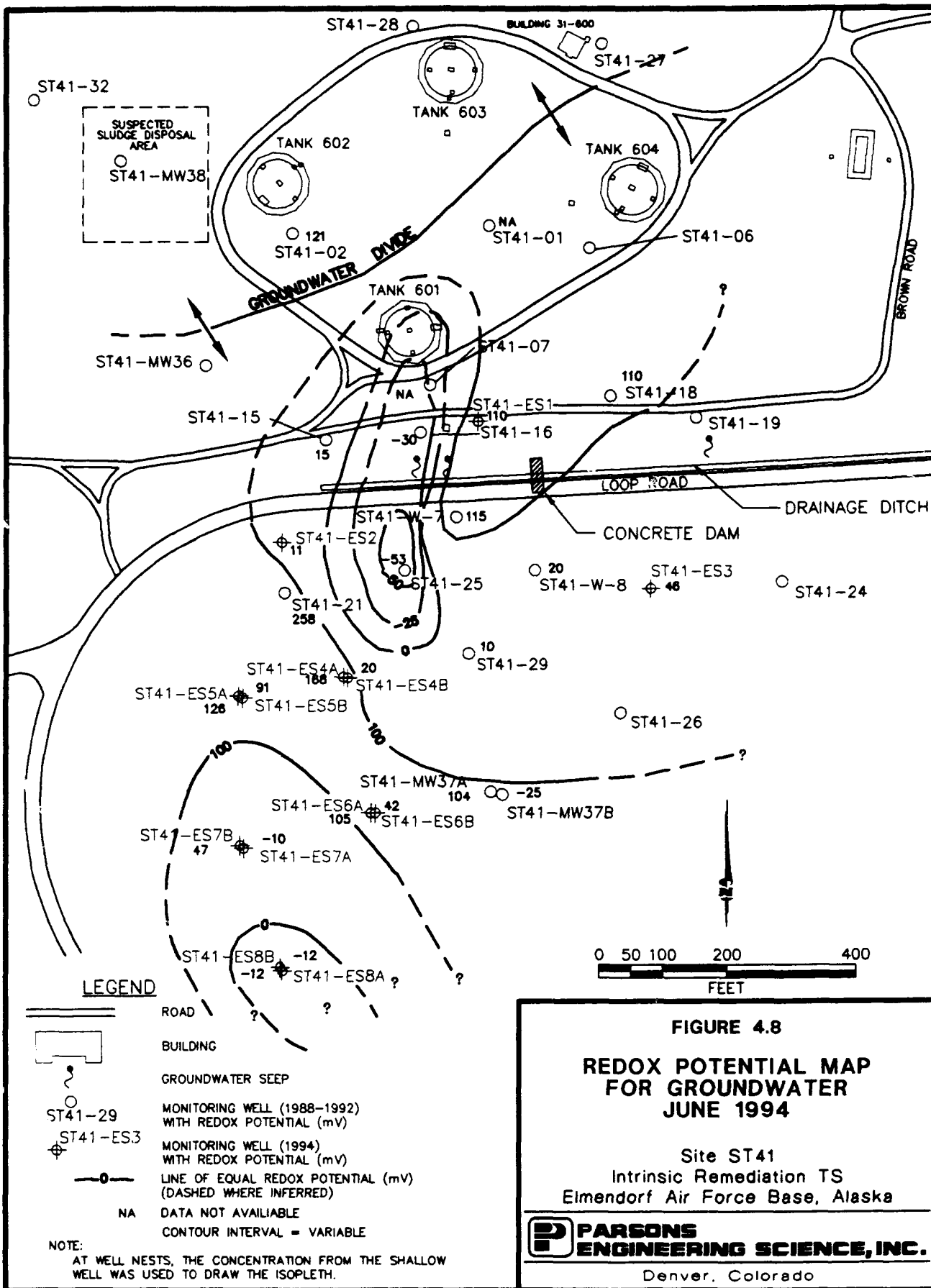
$$\text{Mass ratio of methane to benzene} = 60/78 = 0.77:1$$

Therefore, 0.77 mg of methane is produced during mineralization of 1 mg of benzene.

Similar calculations can be completed for toluene (0.78 mg of methane produced during mineralization of 1 mg of toluene), ethylbenzene (0.79 mg of methane produced during mineralization of 1 mg of ethylbenzene), and the xylenes (0.79 mg of methane produced during mineralization of 1 mg of xylene). The average mass ratio of methane produced during total BTEX mineralization is thus 0.78:1. This means that approximately 1 mg of BTEX is mineralized for every 0.78 mg of methane produced. The highest measured methane concentration was 1.481 mg/L. This suggests that the shallow groundwater at this site has the capacity to assimilate up to 1.9 mg/L (1,900 µg/L) of total BTEX during methanogenesis. Again, this is a conservative estimate of the assimilative capacity of methanogenesis because microbial cell mass production is not taken into account by the stoichiometry shown above (see Section 4.3.2.1). Moreover, these calculations are based on observed methane concentrations and not on the amount of carbon dioxide available in the aquifer. Therefore, methanogenic assimilative capacity could be much higher.

4.3.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring wells in June 1994. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptor is being reduced by microbes during BTEX oxidation. The redox potential at Site ST41 ranges from 2581 millivolts (mV) to -53 mV. Table 4.4 summarizes available redox potential data. Figure 4.8 is a map that graphically illustrates the distribution of redox potentials. Redox is decreased to values below 0 mV in the vicinity of the plume center. As expected, areas at the site with low redox potentials appear to coincide with



areas of high BTEX contamination, low DO, nitrate, and sulfate concentrations, and elevated ferrous iron and methane concentrations (compare Figure 4.8 with Figures 4.1, 4.3, 4.4, 4.5, 4.6, and 4.7).

4.3.2.7 Volatile Fatty Acids

At ST41-16 and ST41-25, USEPA researchers collected samples for volatile fatty acids analysis. This test is a GC/MS method wherein the samples are compared to a standard mixture containing 13 phenols, 25 aliphatic acids, and 19 aromatic acids. Compounds in the standard mixture are generally associated with microbial processes that break down petroleum hydrocarbons.

USEPA researchers reported that the sample from ST41-16 contained 43 of the 57 compounds in the standard mixture, and that the chromatogram for the sample from ST41-25 was similar. In both samples, benzoic acid was the compound with the greatest detected concentrations. Jacobs Engineering Group (1994b) also reported detections of benzoic acid at ST41-16 during previous sampling rounds. USEPA correspondence regarding these analyses is presented along with analytical results in Appendix B.

4.3.2.8 Alkalinity

Total alkalinity (as calcium carbonate) was measured at groundwater monitoring wells in June 1994. These measurements are summarized in Table 4.4. Alkalinity is a measure of a groundwater's ability to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site is in the low to moderate range for groundwater, varying from 47 mg/L at ST41-ES5A to 1210 mg/L at ST41-16. This amount of alkalinity should be sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions.

4.3.2.9 pH

pH was measured at groundwater monitoring points and existing monitoring wells in June 1994. These measurements are summarized in Table 4.4. The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. Groundwater pH at Site ST41 ranges from 6.3 to 7.9. This range of pH is within the optimal range for BTEX-degrading microbes.

4.3.2.10 Temperature

Groundwater temperature was measured at groundwater monitoring points and existing monitoring wells in June 1994. Table 4.4 summarizes groundwater temperature readings. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow aquifer varied from 4.1 degrees Celsius (°C) to 11.7°C.

4.3.3 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, iron and sulfate reduction, and methanogenesis. Based on the stoichiometry presented in these sections, the expressed BTEX assimilative capacity of groundwater at Site ST41 is at least 32,490 µg/L (Table 4.5). The calculations presented in the earlier sections are conservative because they do not account for microbial cell mass production. In addition, the measured concentrations of ferrous iron and methane may not be the maximum achievable.

The highest observed dissolved total BTEX concentration observed at the site was 43,280 µg/L, at ST41-16. As indicated in Section 4.3.1.1, that concentration may be unrealistically high due to sample emulsification. A maximum dissolved phase BTEX concentration of 30,000 µg/L may be more likely, based on previous studies of BTEX partitioning (Smith *et al.*, 1981) and on partitioning calculations utilizing composition data for the mobile LNAPL found in well ST41-16. Based on the calculations presented in the preceding sections, and on site observations, groundwater at Site ST41 has sufficient assimilative capacity to degrade the observed dissolved BTEX and limit plume migration.

TABLE 4.5
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Electron Acceptor or Process	Expressed BTEX Assimilative Capacity ($\mu\text{g/L}$)
Dissolved Oxygen	4,030
Nitrate	12,300
Iron Reduction	1,860
Sulfate	12,400
Methanogenesis	1,900
Expressed Assimilative Capacity	32,490
Highest Observed Total BTEX Concentration, June 1994	43,280 ^{a/}
Highest Likely Total BTEX Concentration (Based on Partitioning Calculations)	30,600

^{a/} Concentration may be a result of emulsification during sampling.

SECTION 5

GROUNDWATER MODEL

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX compounds at Site ST41 and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible risk to potential downgradient receptors; and 3) to provide technical support for the natural attenuation remedial option at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from the process of natural attenuation is expected to *exceed model predictions*. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II code was used to estimate the potential for dissolved BTEX migration and degradation by naturally occurring mechanisms operating at Site ST41. The Bioplume II model incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. Based on the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the instantaneous, biologically-mediated, reaction between hydrocarbons and oxygen.

In recent years it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic'-Galic', 1990; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic'-Galic', 1992, Grbic'-Galic' and Vogel, 1987; Lovley *et al.*, 1989; Hutchins, 1991). Because there is geochemical evidence that anaerobic biodegradation processes are occurring at Site ST41, these processes were accounted for during Bioplume II modeling using a first-order anaerobic decay coefficient. The following subsections discuss in more detail the model setup, input parameters and assumptions, model calibration, and simulation results.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation is occurring at the site. The Bioplume II model assumes that the limiting factors for biodegradation are: 1) the presence of an indigenous hydrocarbon degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation.

Based on the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a shallow unconfined aquifer composed of silty sand (Figures 3.3 and 3.4). The use of a 2-D model is appropriate at Site ST41 because the saturated interval is relatively homogenous, and the local flow system, as defined by gradients and the basal confining unit, will likely prevent significant downward vertical migration of dissolved BTEX contamination. Existing evidence suggests the presence of mobile LNAPL downgradient of Tank 601. In addition, contaminated soils at the site have not been remediated. As a result, model simulations included continuing sources of dissolved BTEX contamination.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on site data. Where site-specific data were not available (e.g., effective porosity), reasonable assumptions for the types of materials comprising the shallow aquifer were made based on widely accepted literature values. The following sections describe the basic model setup. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows. The dimension of each column and row can range from 0.1 to 999.9 feet. A 20- by 20-cell grid was used to model Site ST41. Each grid cell was 100 feet long by 75 feet wide. The grid was oriented so that the longest dimension was parallel to the overall direction of groundwater flow. The model grid covers an area of 2.28 million square feet, or approximately 52 acres. The full extent of the model grid is indicated on Figure 5.1.

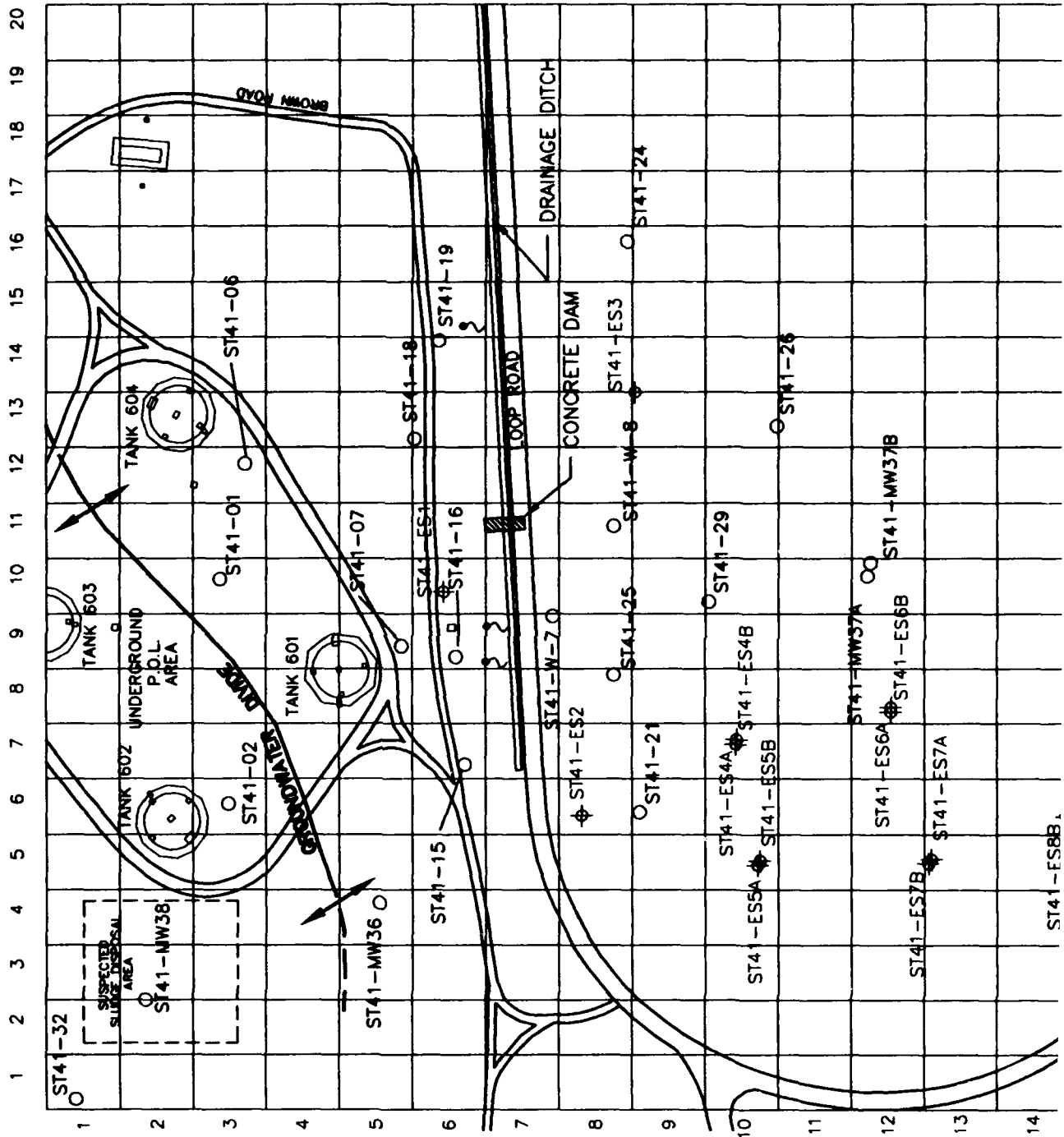
Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (e.g., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

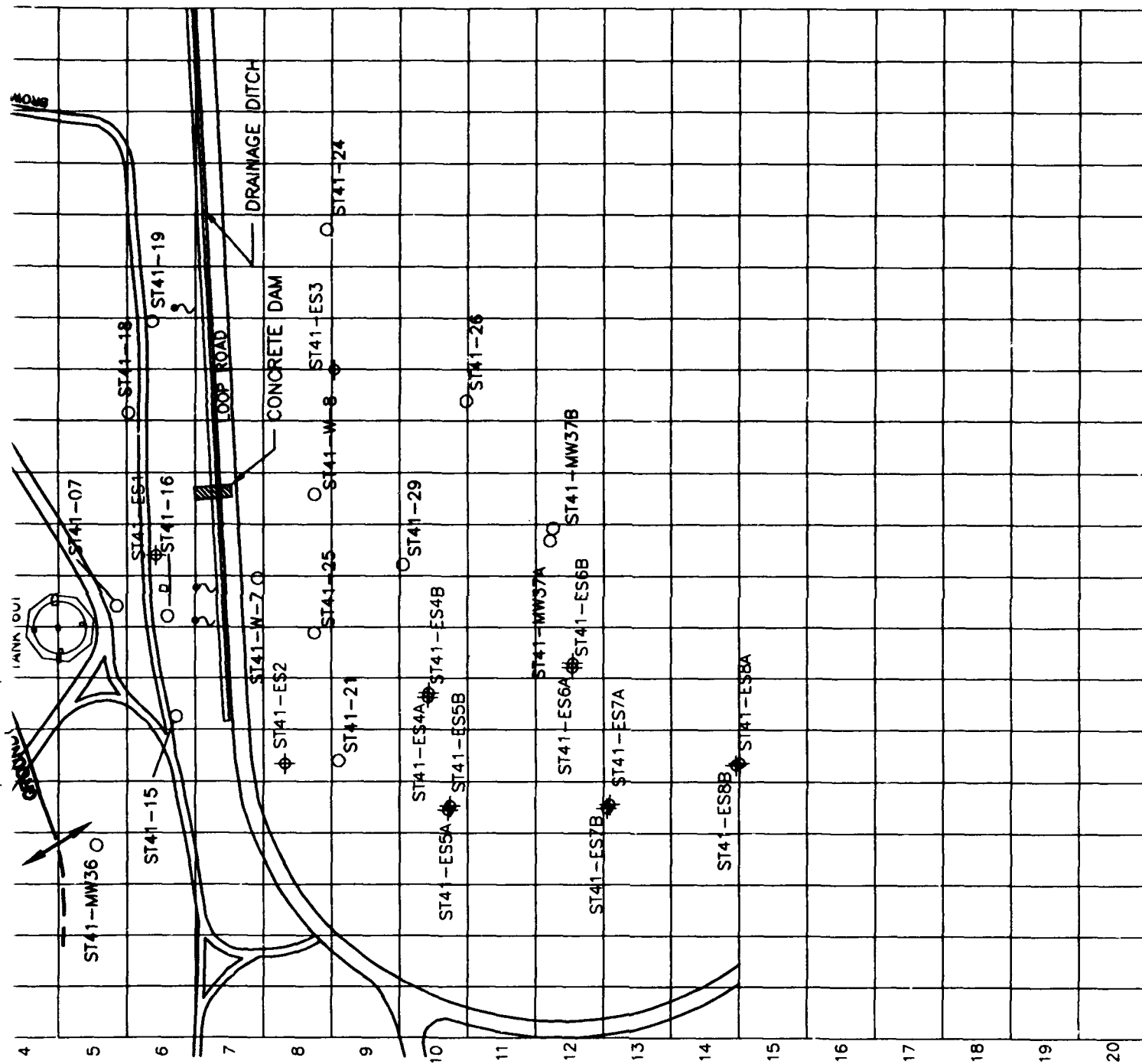
- Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant head conditions. Specified-head boundaries are expressed mathematically as:

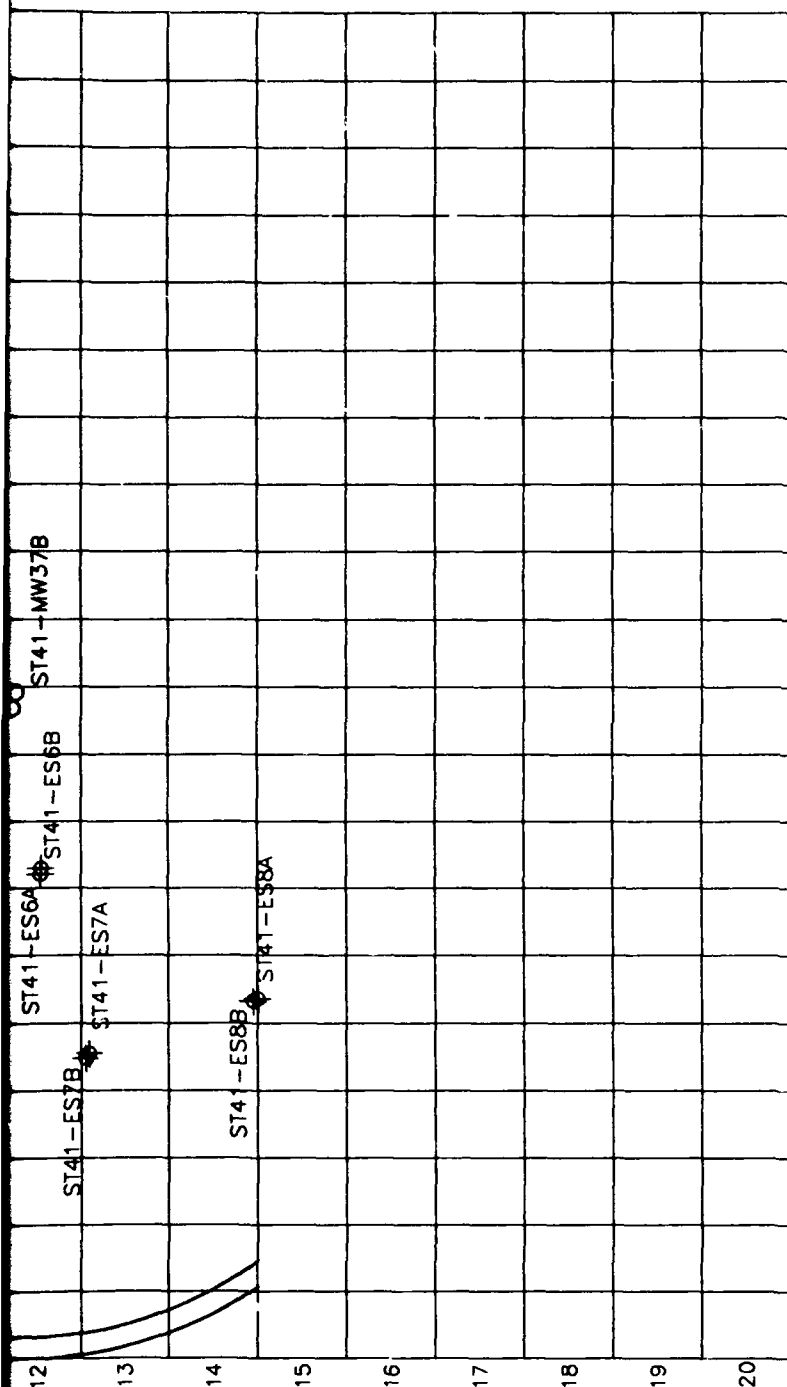
$$Head = f(x, y, z, t)$$

where f is the function symbol, x , y , and z are position coordinates, and t is time.

- Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (e.g., $\text{ft}^3/\text{ft}^2/\text{day}$). No-flow boundaries are a special type of specified flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and







LEGEND

-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
-  ST41-29
MONITORING WELL (1988-1992)
WITH TOTAL BTEX CONCENTRATION (g/L)
-  ST41-ES3
MONITORING WELL (1994)
WITH TOTAL BTEX CONCENTRATION (g/L)
- ND NOT DETECTED
- CONTOUR INTERVAL = VARIABLE



FIGURE 5.1

MODEL GRID

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

 **PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:

$$Flux = f(x, y, z, t)$$

- 3) Head-dependent flow boundaries (Cauchy or mixed-boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):

$$Flux = \frac{(H_0 - H)K'}{B'}$$

Where: H = Head in the zone being modeled (generally the zone containing the contaminant plume)
 H_0 = Head in external zone (separated from plume by semipermeable layer)
 K' = Hydraulic conductivity of semipermeable layer
 B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be specified at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

Specified-head boundaries for the model were set on the northern and southern perimeter of the model grid to simulate groundwater flow to the south as observed at the site. The western portion of the northern boundary was set in the approximate location of the divergent groundwater divide. The remaining specified-head boundaries were set in the approximate location of the water table indicated by water level data. The head of the northeastern boundary was estimated to be from 233 to 249 feet above msl. The

southwestern model boundary was defined by the assumed downgradient position of the 175-foot water table contour. The location of this contour was estimated from available water table elevation and flow gradient data. These constant-head cells were placed as far away from the BTEX plume as possible to avoid potential boundary interferences. However, the plume is close to the groundwater divide, so the northern boundary is relatively close to the plume.

The eastern and western model boundaries were configured as no-flow (specified flux) boundaries. In this case, the flux through these boundaries is assumed to be zero because flow is generally parallel to these boundaries. The base or lower boundary of the model is also assumed to be no-flow, and is defined by the upper surface of the confining Bootlegger Cove Formation. The upper model boundary is defined by the simulated water table surface.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.5 was used to define the starting heads input into the Bioplume II model. Groundwater flow in the vicinity of Site ST41 is to the south with an average gradient of approximately 0.05 ft/ft over the total extent of the modeled area. Data quantifying seasonal variations in groundwater flow direction and gradient at the site are presented by Jacobs Engineering Group (1994a). These data suggest that there are no significant seasonal variations in groundwater flow direction, and that seasonal gradients consistently vary around the average of approximately 0.05 ft/ft. As a result, it was assumed that the observed water levels were representative of steady-state conditions. As described in Section 5.4.1, the model was calibrated to the observed water table.

5.3.3 BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical results for each well location were used for model development. At well nests, the highest BTEX concentration observed at that location was used as the representative concentrations. Table 4.3 presents dissolved BTEX concentration data. Figure 4.1 shows the spatial distribution of dissolved BTEX compounds in June 1994.

The BTEX plume observed in June 1994 covers an area of approximately 236,000 square feet (5.4 acres). The shape and distribution of the total BTEX plume is the result of advective-dispersive transport, sorption, and biodegradation of dissolved BTEX contamination. As described in Section 5.4.2, the simulated BTEX plume was calibrated to match the observed BTEX plume.

5.3.4 Dissolved Oxygen

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 4 suggests that DO, nitrate, ferric iron, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for biodegradation of BTEX compounds at Site ST41. To be conservative, the total BTEX plume at the site was modeled assuming that DO was the only electron acceptor being utilized for the biodegradation of BTEX compounds at a rate that is instantaneous relative to the advective groundwater flow velocity.

Groundwater samples collected in uncontaminated portions of the aquifer suggest that background DO concentrations at the site range from 5 to 12.6 mg/L. Therefore, to be conservative, background oxygen levels were assumed to be 6 mg/L (near the low end of the observed range of background DO concentrations) for Bioplume II model development. Table 4.4 contains DO data for the site. Figure 4.3 is a DO isopleth map.

The upgradient specified-head cells in the Bioplume II model require background DO concentrations to be input as constant concentrations to simulate incoming electron acceptors. To be conservative, a DO concentration of 6.0 mg/L was used for these cells.

5.3.5 Anaerobic Degradation Rates

In order to calculate anaerobic rate constants, the apparent degradation rate must be normalized for the effects of dilution caused by advective-dispersive processes. This is accomplished by normalizing the concentration of each contaminant to the concentration of a component of jet fuel or AVGAS (a tracer) that has similar sorptive properties but that is fairly recalcitrant. Observed concentration data can be normalized to 1,3,5-TMB, 1,2,4-TMB, and 1,2,3-TMB or another tracer with similar physiochemical properties. The TMB suite serves as a good tracer because it is known to be recalcitrant to microbial

degradation under anaerobic conditions, and has sorptive properties similar to the BTEX compounds (Cozzarelli *et al.*, 1990, and Cozzarelli *et al.*, 1994).

Anaerobic rate constants were calculated based on BTEX and TMB data from June 1994 (presented in Table 4.3). Rate constant calculations are included in Appendix C. Calculated rate constants for Site ST41 range from 0.003 day^{-1} to 0.03 day^{-1} . A review of recent literature indicates that similar rate constants have been observed at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic conditions, the anaerobic rate constants were both approximately 0.01 day^{-1} . Wilson *et al.* (1994) report first-order anaerobic biodegradation rates of 0.05 to 1.3 week^{-1} (0.007 to 0.185 day^{-1}). Stauffer *et al.* (1994) report rate constants of 0.01 day^{-1} and 0.018 day^{-1} for benzene and p-xylene, respectively.

Based on the site-specific calculations and the literature values, an anaerobic rate constant of 0.005 day^{-1} was originally used in the Bioplume II model. This value was selected because it is in the lower range of the site-specific values and is more conservative than the range of the values reported in the literature.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity in a trial-and-error fashion until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow model, the numerical transport model was calibrated by altering hydraulic parameters and transport parameters in a trial-and-error fashion until the simulated BTEX plume approximated observed field values. Table 5.1 lists input parameters used for the modeling effort. Model input and output is included in Appendix D.

TABLE 5.1
BIOPLUME II MODEL INPUT PARAMETERS
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Parameter	Description	Calibrated Model Setup	Model Runs	
			ST41A	ST41B
NTIM	Maximum number of time steps in a pumping period	10	10, 20	10, 1, 20
NPMP	Number of Pumping Periods	1	2	13
NX	Number of nodes in the X direction	20	20	20
NY	Number of nodes in the Y direction	20	20	20
NPMAX	Maximum number of Particles $NPMAX = (NX-2)(NY-2)(NPTPND) + (Ns^*) (NPTPND) + 250$	3600	3600	3600
NPNT	Time step interval for printing data	1	1	1
NITP	Number of iteration parameters	7	7	7
NUMOBS	Number of observation points	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP ^a	200	200	200
NREC	Number of pumping or injection wells	4	4	4
NPTPND	Initial number of particles per node	9	9	9
NCODES	Number of node identification codes	2	2	2
NPNTMV	Particle movement interval (IMOV)	0	0	0
NPNTVL	Option for printing computed velocities	2	2	2
NPNTD	Option to print computed dispersion equation coefficients	0	0	0
NPDELC	Option to print computed changes in concentration	0	0	0
NPNCHV	Option to punch velocity data	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1
PINT	Pumping period (years)	30	30, 20	30, 1, 40
TOL	Convergence criteria in ADIP	0.001	0.001	0.001
POROS	Effective porosity	0.35	0.35	0.35
BETA	Characteristic length (long. dispersivity; feet)	30	30	30
S	Storage Coefficient	0 (Steady-State)	0	0
TIMX	Time increment multiplier for transient flow	-	-	-
TINIT	Size of initial time step (seconds)	-	-	-
XDEL	Width of finite difference cell in the x direction (feet)	75	75	75
YDEL	Width of finite difference cell in the y direction (feet)	100	100	100
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.3	0.3	0.3
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5
ANFCTR	Ratio of T _{yy} to T _{xx} (1 = isotropic)	1	1	1
DK	Distribution coefficient	0.191	0.191	0.191
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.6	1.6	1.6
THALF	Half-life of the solute	-	-	-
DEC1	Anaerobic decay coefficient (day ⁻¹)	0.004	0.004	0.004
DEC2	Reaeration coefficient (day ⁻¹)	0.002	0.002	0.002
F	Stoichiometric Ratio of Hydrocarbons to Oxygen	3.1	3.1	3.1

^a Ns = Number of nodes that represent fluid sources (wells or constant head cells)

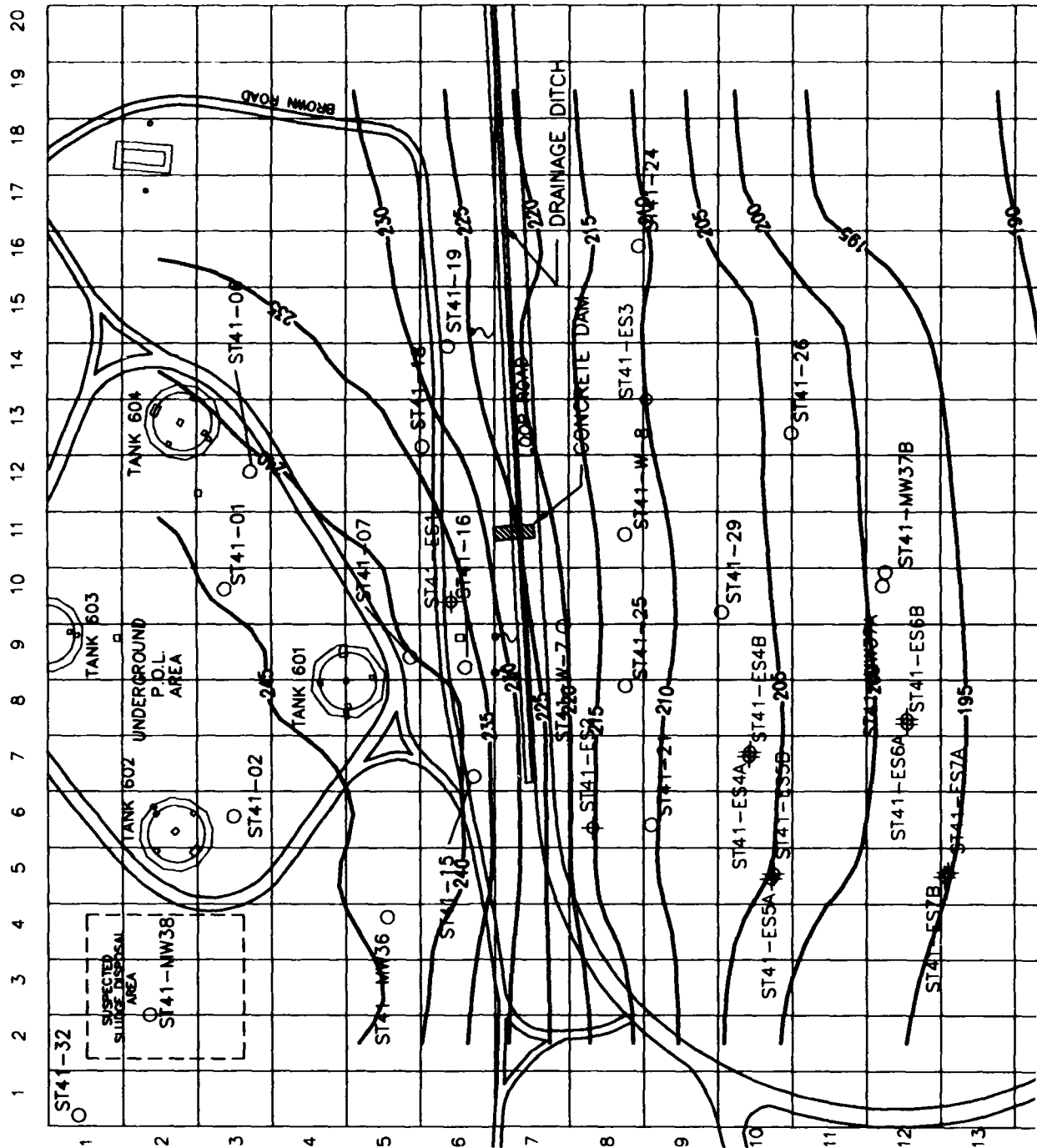
^b ADIP = Alternating-direction implicit procedure (subroutine for solving groundwater flow equation)

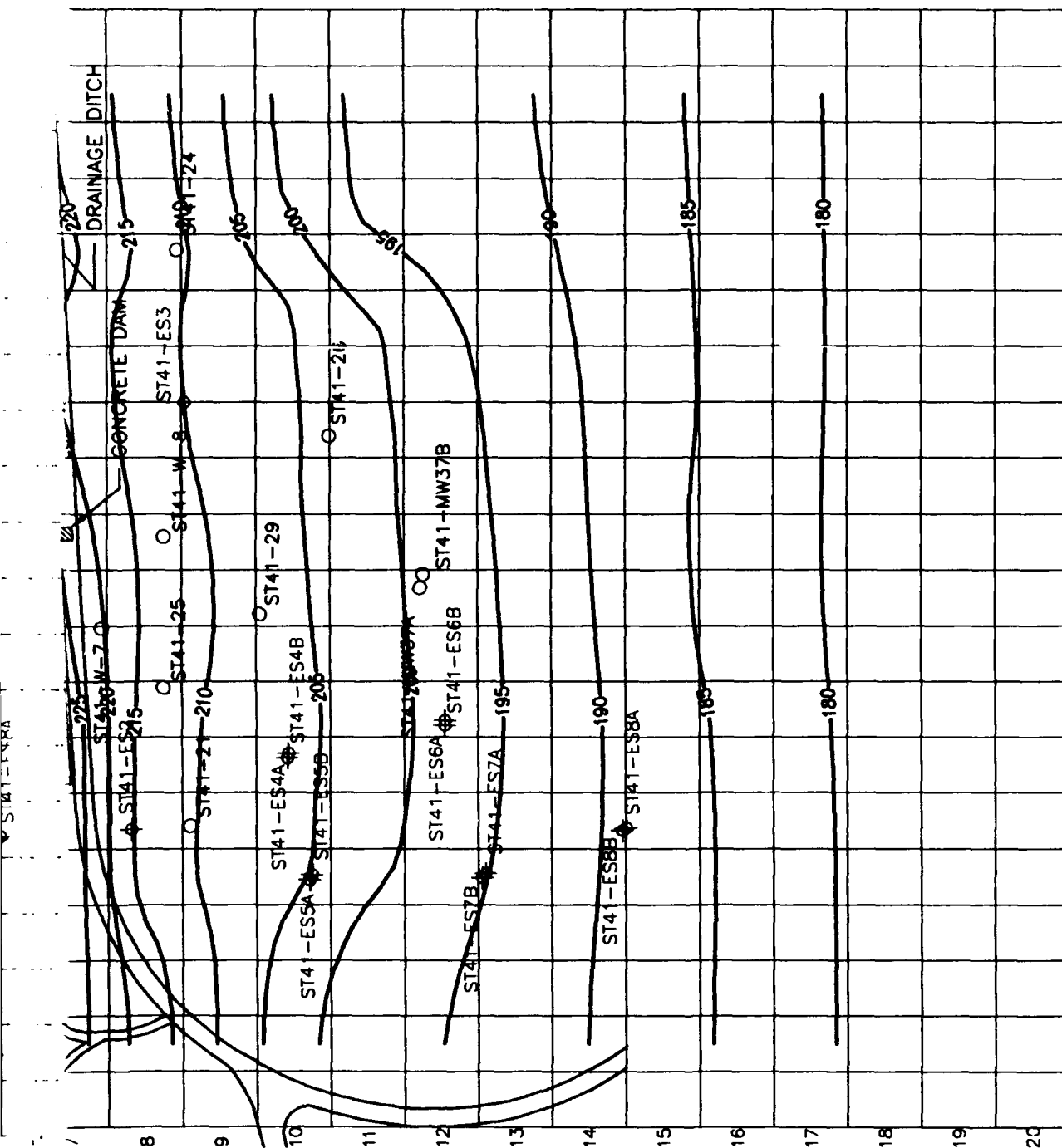
5.4.1 Water Table Calibration

The shallow water table at Site ST41 was assumed to be influenced only by continuous recharge and discharge at the constant-head cells established at the upgradient and downgradient model boundaries. To be conservative, recharge of the aquifer through rainfall (which would add water, thereby increasing dilution of the plume) was not included in the model. Potential recharge by other sources was omitted because of a lack of reliable data. Only the initial water levels at the constant-head cells and the transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

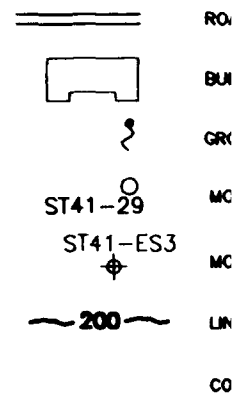
Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. Based on the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume that degrades at a slower rate because less oxygen, nitrate, iron, sulfate, and carbon dioxide is available for biodegradation. Higher values of hydraulic conductivity result in a faster-moving plume that degrades faster because more electron acceptors are available for biodegradation.

Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the average hydraulic conductivity as determined from slug tests performed by Parsons ES in 1994 (1.0×10^{-4} ft/min to 8.0×10^{-3} ft/min) and by Jacobs Engineering (1994b) in an earlier study (3.0×10^{-6} ft/min to 6×10^{-3} ft/min) to estimate an initial uniform transmissivity for the entire model domain. To better match heads in the model to observed values, the transmissivities were progressively varied in blocks and rows until the simulated water levels for cells corresponding to selected well locations matched the observed water levels as closely as possible. Figure 5.2 shows the calibrated water table. Calibrated model hydraulic conductivities ranged from 3.3×10^{-6} foot per second (ft/sec) to 3.0×10^{-4} ft/sec (1.9×10^{-4} ft/min to 1.9×10^{-2} ft/min).





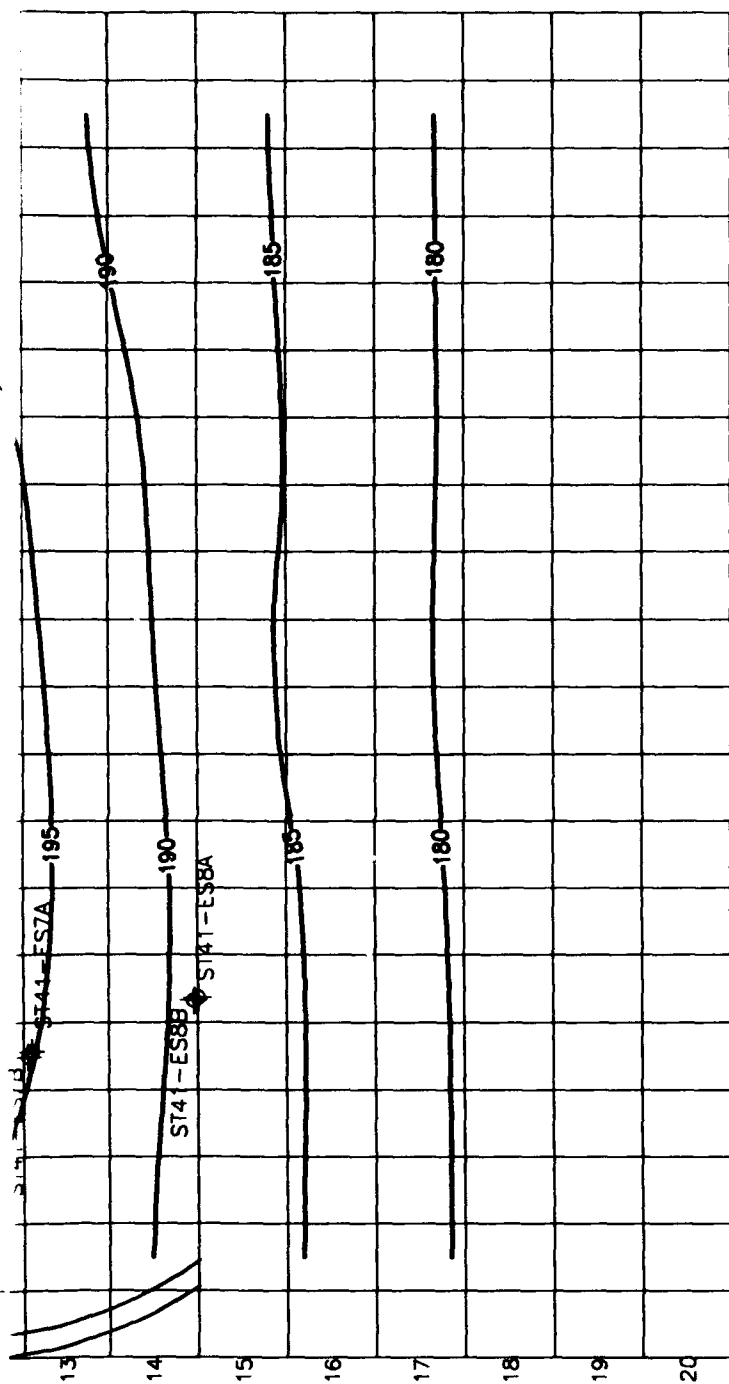
LEGEND



CALIBRA

Element





LEGEND

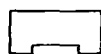
-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
-  ST41-29 MONITORING WELL (1988-1992)
-  ST41-ES3 MONITORING WELL (1994)
-  200 LINE OF EQUAL GROUNDWATER ELEVATION
- CONTOUR INTERVAL = 5 FEET



FIGURE 5.2

CALIBRATED WATER TABLE MAP

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



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Denver, Colorado

Water level elevation data from cells associated with 16 monitoring well locations were used to compare measured and simulated heads for calibration. The 16 selected cell locations each contained one of the following wells: ST41-ES1, ST41-15, ST41-W7, ST41-ES2, ST41-21, ST41-25, ST41-W8, ST41-ES3, ST41-ES4A, ST41-ES5A, ST41-29, ST41-26, ST41-MW37A, ST41-ES6A, ST41-ES7A, and ST41-ES8A.

The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured heads. RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$RMS = \left[\frac{1}{n} \sum_{i=1}^n (h_m - h_s)_i^2 \right]^{0.5}$$

Where: n = the number of points where heads are being compared
 h_m = measured head value
 h_s = simulated head value.

The RMS error between observed and calibrated values at the 16 comparison points was 3.06 feet, which corresponds to a calibration error of 4.71 percent (water levels dropped 70 feet over the length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured vs. calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of points from a straight line should be randomly distributed in such a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. The hydraulic mass balance for the calibrated model was excellent, with 99.7 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.3-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

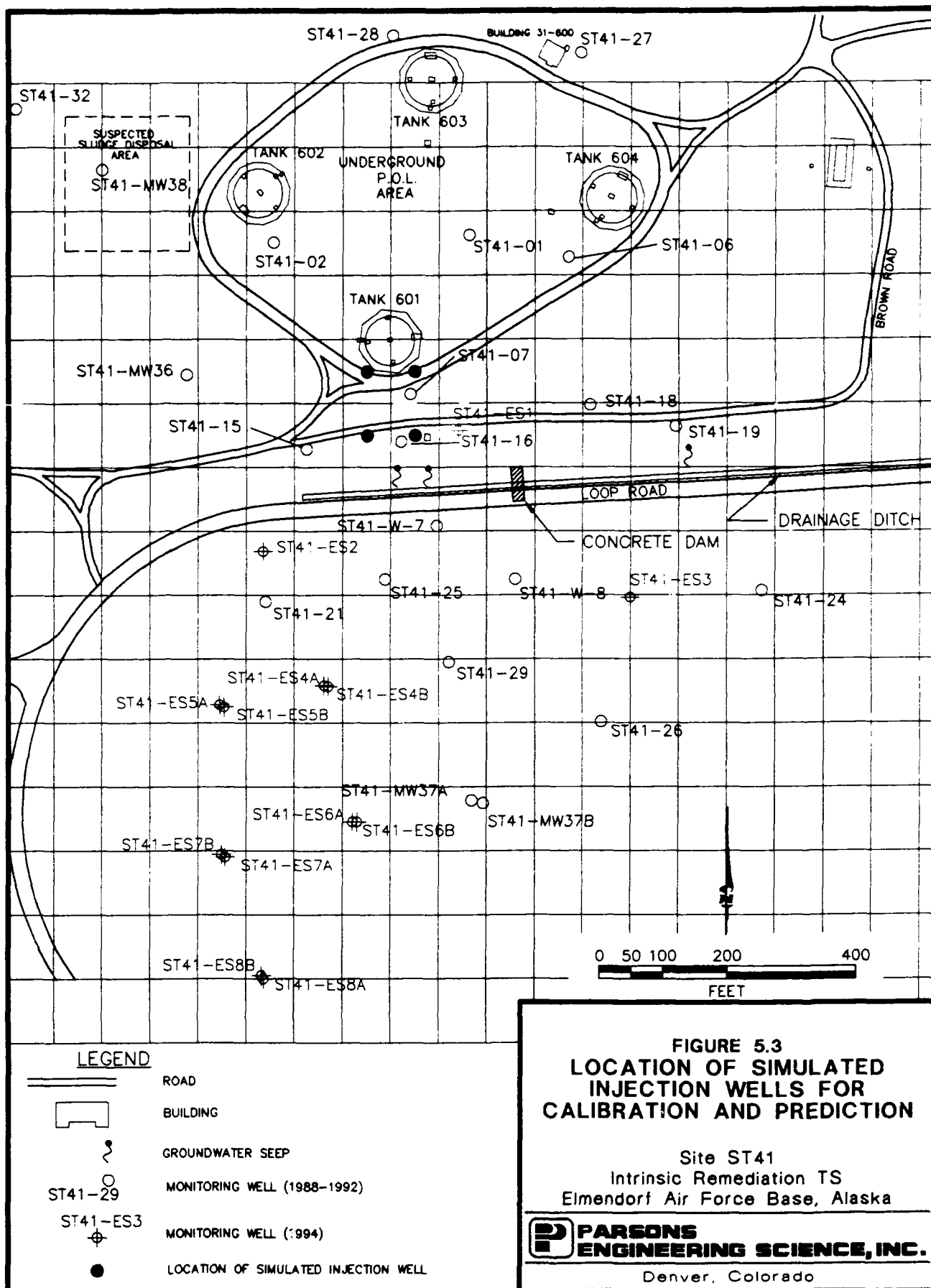
Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX

concentrations observed in June 1994. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. At this site, the calibration also involved a time element, because spills have been known to occur at the site since the early 1960s. As a result, the plume calibration simulations were made with a time constraint of 30 years; in other words, computed BTEX plume concentrations and configurations were compared to June 1994 data after 30 years of simulation time incorporating the introduction of contaminants into the groundwater.

Because mobile and residual-phase LNAPL are present in the vicinity of the water table at the site, it was necessary to include model injection wells to simulate partitioning of BTEX compounds from the residual phase into the groundwater. The location of the injection wells is shown on Figure 5.3. Locations of injection wells were based on the known location of the mobile LNAPL phase, the extent of groundwater contamination indicated on Figure 4.2, and the locations of the UST (Tank 601) and condensate drain line that were known to have released fuel to the subsurface.

While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was set at 5×10^{-5} cubic foot per second (ft^3/sec), a value low enough so that the flow calibration and water balance was not affected. Relatively high BTEX concentrations were injected in upgradient injection wells because of the low pumping rate and the influx of oxygen introduced at the upgradient constant head cells. Replenishment of oxygen quickly degraded BTEX concentrations at the head of the plume, which in turn required larger injection concentrations of BTEX to produce observed BTEX contours. Based on assumptions outlined in Section 5.3.4, it was assumed that the initial DO concentration in the shallow aquifer was uniformly 6.0 mg/L, and that water with that DO concentration would be continually introduced at the northern boundary.

Total BTEX injection concentrations were determined by varying the injection concentration for the various wells until the modeled total BTEX plume approximated the total BTEX plume observed in June 1994. By varying the injection well concentrations, the coefficient of retardation, dispersivity, the anaerobic decay coefficient, and the reaeration coefficient, the BTEX plume was calibrated reasonably well to the existing



plume in terms of migration distance and BTEX concentrations in the source area. The calibrated plume configuration is shown on Figure 5.4.

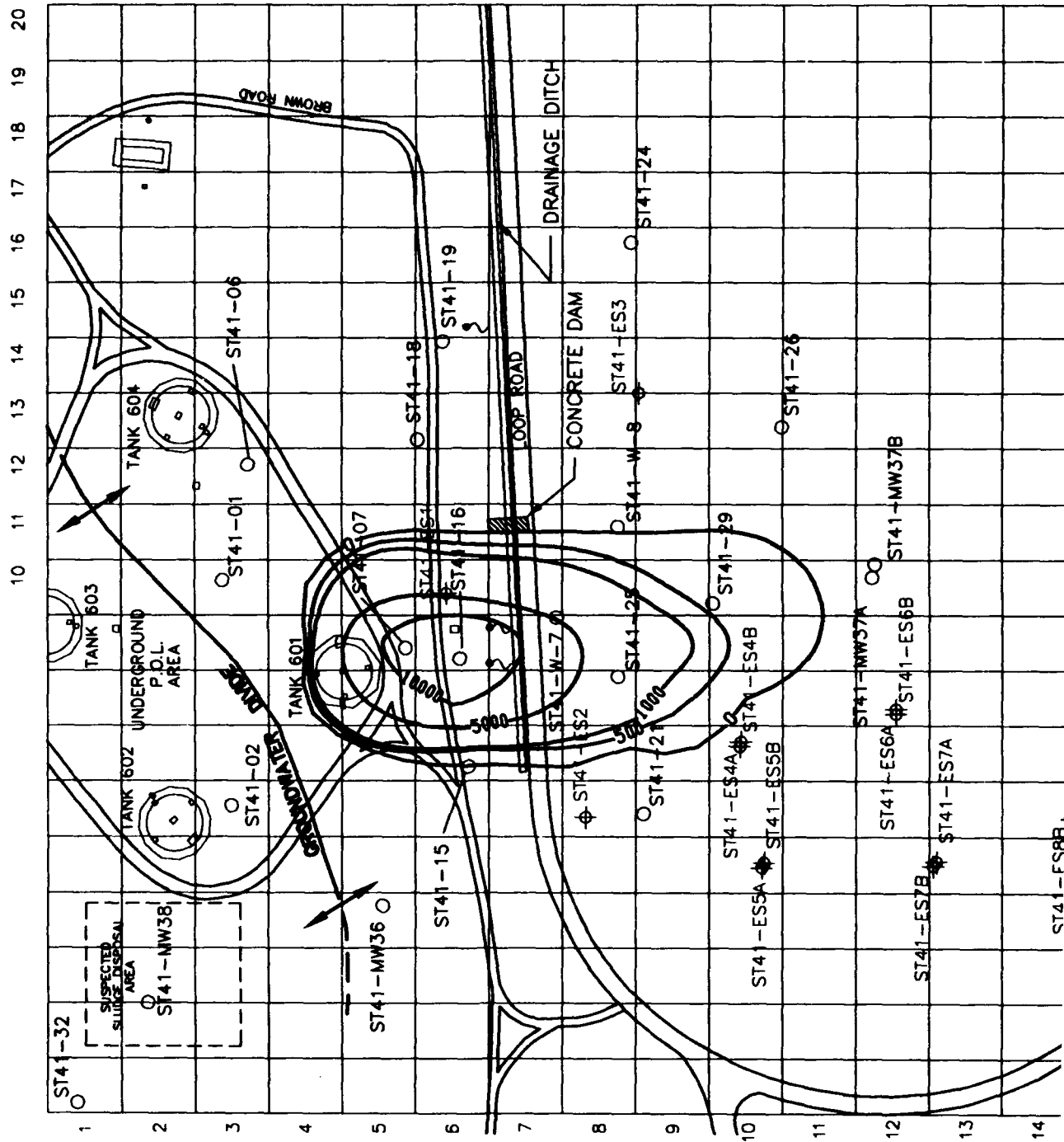
The calibrated model plume, while not identical to the observed BTEX plume, is very similar. The downgradient extent of the computed 0- $\mu\text{g/L}$ contour is similar to the observed 1.0- $\mu\text{g/L}$ contour, and the computed 1,000- $\mu\text{g/L}$ BTEX contour is similar to the 1,000- $\mu\text{g/L}$ contour interpreted from the observed concentrations. The area delineated by the computed 1,000- $\mu\text{g/L}$ contour is greater than the area of the 1,000- $\mu\text{g/L}$ contour indicated by the observed concentrations. In addition, the computed 500- $\mu\text{g/L}$ BTEX contour describes an area similar to that of the 100- $\mu\text{g/L}$ contour interpreted from site data.

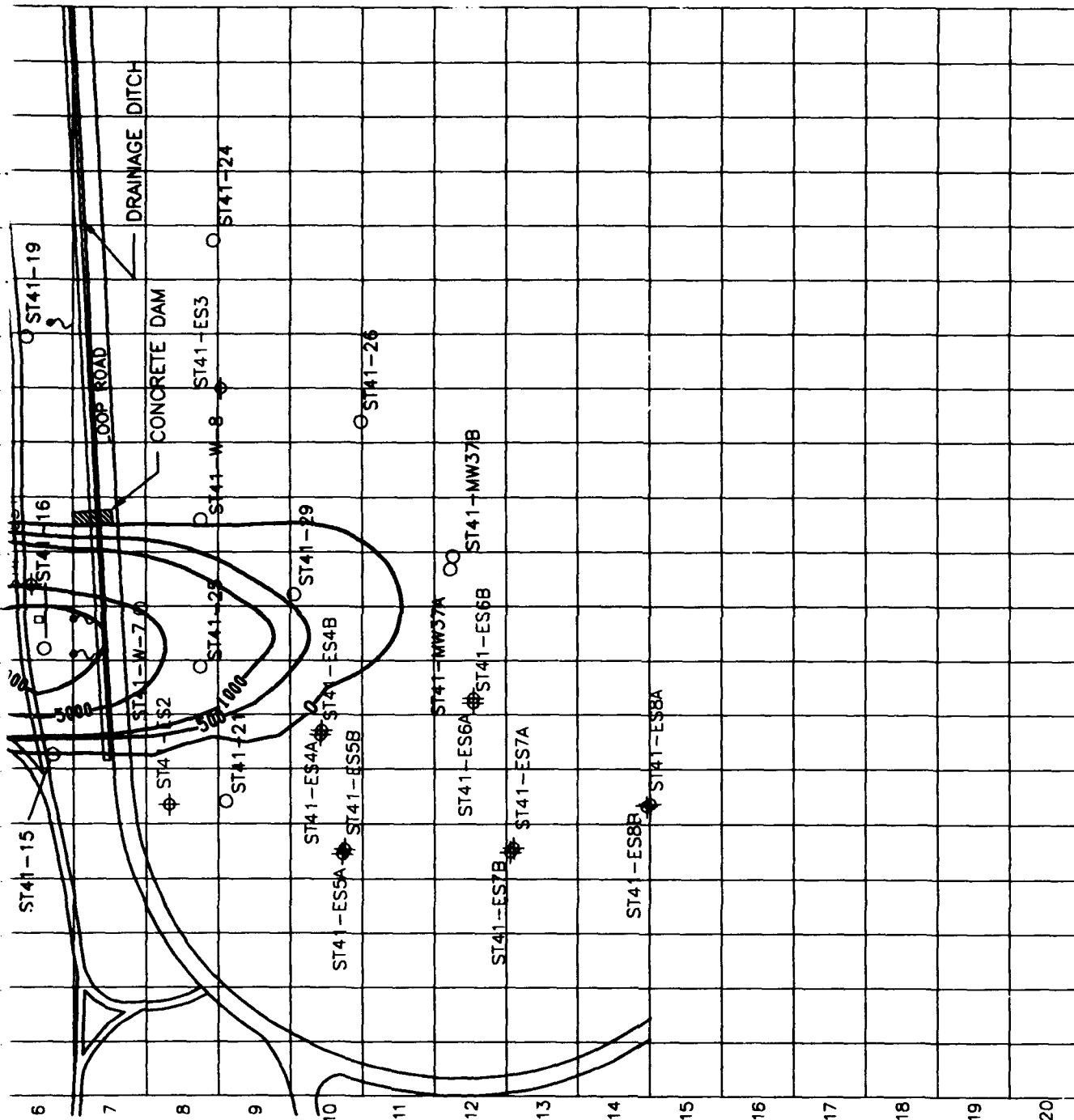
The computed plume does not have concentrations as high as the concentration observed at ST41-16 (43,280 $\mu\text{g/L}$), with a maximum simulated concentration of 17,700 $\mu\text{g/L}$ computed for the cell containing ST41-16. However, the measurement at ST41-16 was made at a point, while the model is indicating a concentration that is averaged for the entire model cell representing that area. Increasing the BTEX loading rates high enough to produce concentrations over 25,000 $\mu\text{g/L}$ in the source area resulted in a plume that was much longer than the observed plume. In addition, the simulated 5,000- $\mu\text{g/L}$ and 10,000- $\mu\text{g/L}$ contours are wider than the observed 1,000- $\mu\text{g/L}$ contour in the area just downgradient of Tank 601. As a result, the calibrated BTEX plume model is also conservative because it assumes a greater initial BTEX mass than has been observed during recent monitoring.

The "arm" of the observed BTEX plume that extends southwest to the vicinity of well ST41-ES5B could not be reproduced. This is likely due to localized flow conditions that could not be accurately reproduced in the model, due either to insufficient data or limitations of the model set-up (i.e., representation of a heterogeneous continuous domain with a discretized numerical model).

5.4.2.1 Discussion of Parameters Varied During Plume Calibration

As noted previously, the transport parameters varied during plume calibration were dispersivity, the coefficient of retardation, the reaeration coefficient, and the anaerobic decay coefficient. Those parameters were generally varied with intent of altering plume migration so that the observed plume extent was reproduced. While these parameters

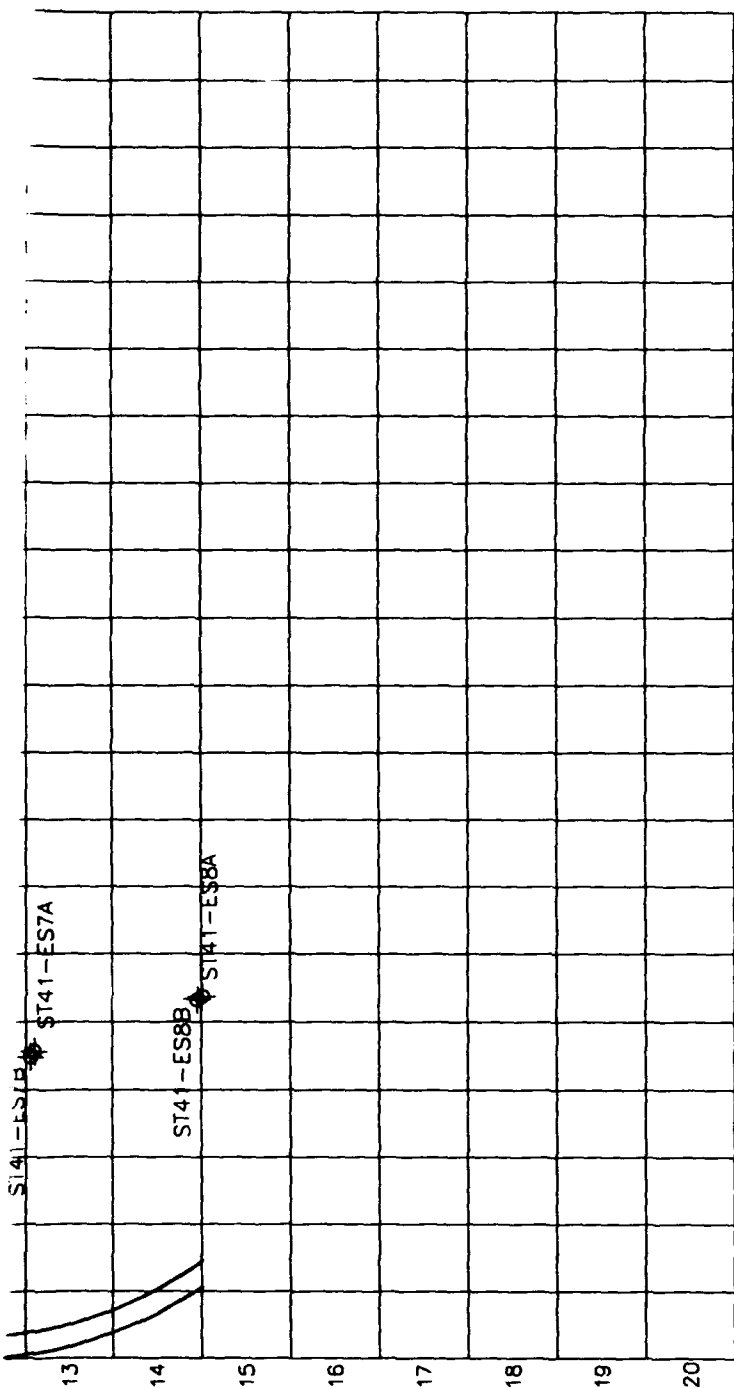




LEGEND

- 
-  ST41-29
-  ST41-E
-  100





LEGEND

- ROAD
- BUILDING
- GROUNDWATER SEEP
- ST41-29 MONITORING WELL (1988-1992)
- ST41-ES3 MONITORING WELL (1994)
- LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE



FIGURE 5.4

CALIBRATED BTEX PLUME

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

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were varied with this common intent, each had a slightly different impact on the size and shape of the simulated plume.

5.4.2.1.1 *Dispersivity*

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values for sediment similar to those found at the site range from 0.1 to 200 feet (Walton, 1988). Longitudinal dispersivity was originally estimated as 18 feet, using one-tenth (0.1) of the distance between Tank 601 and the longitudinal centroid of the June 1994 plume (see Figure 4.1). Dispersivity estimation calculations are included in Appendix C. Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was raised to 30 feet from the original estimate of 18 feet. This was done to prevent the computed plume from extending too far downgradient (by dispersing BTEX at the margins of the plume so that it degraded more rapidly) and also to help increase the lateral extent of the plume to better match the observed extent. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was increased to 0.3 (for the reasons).

5.4.2.1.2 *Anaerobic Decay Coefficient*

As discussed in Section 5.3.5, the anaerobic decay coefficient was originally estimated to be 0.005 day^{-1} . This value was varied slightly during plume calibration, with the calibrated model incorporating a value of 0.004 day^{-1} . This prevented the plume from migrating too far in the calibration runs, and at the same time prevented contaminant concentrations in the center portion of the plume from being excessively high.

5.4.2.1.3 *Coefficient of Retardation*

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation for the BTEX compounds were calculated based on measured TOC concentrations in the soils in and near the saturated zone at the site an assumed bulk density of 1.6 grams/cubic centimeter (Freeze and Cherry, 1979), and published values of the soil sorption coefficient (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.2. To be

TABLE 5.2

**CALCULATION OF RETARDATION COEFFICIENTS
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Compound	K_{oc} (L/kg ^{a/})	Maximum Fraction Organic Carbon ^{b/}	Minimum Fraction Organic Carbon ^{b/}	Average Fraction Organic Carbon	Distribution Coefficient K_d (L/kg)			Bulk Density (kg/L) ^{d/}	Effective Porosity	Coefficient of Retardation	
					Maximum ^{c1/}	Minimum ^{c2/}	Average ^{c3/}			Maximum	Average
Benzene	79	0.0086	0.00071	0.00242	0.679	0.056	0.191	1.60	0.35	4.11	1.87
Toluene	190	0.0086	0.00071	0.00242	1.634	0.135	0.460	1.60	0.35	8.47	3.10
Ethylbenzene	468	0.0086	0.00071	0.00242	4.025	0.332	1.133	1.60	0.35	19.40	6.18
m-xylene	405	0.0086	0.00071	0.00242	3.483	0.288	0.980	1.60	0.35	16.92	5.48
o-xylene	422	0.0086	0.00071	0.00242	3.629	0.300	1.021	1.60	0.35	17.59	5.67
p-xylene	357	0.0086	0.00071	0.00242	3.070	0.253	0.864	1.60	0.35	15.04	4.95

NOTES:

^{a/} From technical protocol document (Wiedemeier *et al.*, 1994)^{b/} From ST41 site data^{c1/} K_d = Maximum Fraction Organic Carbon x K_{oc} ^{c2/} K_d = Minimum Fraction Organic Carbon x K_{oc} ^{c3/} K_d = Average Fraction Organic Carbon x K_{oc} ^{d/} Literature values

conservative, the minimum range of retardation coefficients calculated for the BTEX compounds (1.45 to 3.67) was used as a constraint for model input. The coefficient of retardation originally used as model input was 1.26. The lower the assumed coefficient of retardation, the farther the BTEX plume will migrate downgradient.

During plume calibration, the coefficient of retardation was gradually raised from the initial value of 1.26 to a value of 1.9. As with dispersivity and the anaerobic decay coefficient, this variable was altered in response to model predictions of BTEX concentrations extending beyond the observed limits.

5.4.2.1.4 Reaeration Coefficient

The reaeration coefficient is a first-order rate constant used by Bioplume II to simulate the replenishment of oxygen into the groundwater by soil-gas diffusion and rainwater infiltration. A reaeration coefficient of 0.003 day^{-1} was originally estimated, based on other documented Bioplume modeling efforts (see, for example, Rifai *et al.*, 1988). Use of the reaeration coefficient is justified at this site because of the shallow water table and the relatively high DO concentrations observed in site groundwater.

The reaeration coefficient had a significant effect on limiting plume migration, and was also important in controlling the concentrations at the fringes of the plume. At its originally estimated value of 0.003 day^{-1} , the simulated plume did not extend as far as the observed plume. This coefficient was reduced to 0.002 day^{-1} , and the calculated plume extent was more realistic.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of reaeration, the coefficient of anaerobic decay, and the hydraulic conductivity of the media, and is less sensitive to changes in the retardation factor, porosity, and dispersivity. Because the porosity was not varied and the dispersivity was not significantly changed, the sensitivity analysis was conducted by varying transmissivity, the reaeration coefficient, the coefficient of retardation, and the coefficient of anaerobic decay.

To perform the sensitivity analyses, an individual run of the plume calibration model was made with the same input as the calibrated model, except that one of the aforementioned parameters was varied. The models were run for a 30-year period, just as the original was, so that the independent effect of each variable could be assessed. As a result, eight sensitivity runs of the calibrated model were made, with the following variations:

- 1) Transmissivity uniformly increased by a factor of 5;
- 2) Transmissivity uniformly decreased by a factor of 5;
- 3) Coefficient of reaeration increased by a factor of 5;
- 4) Coefficient of reaeration decreased by a factor of 5;
- 5) Coefficient of anaerobic decay increased by a factor of 5;
- 6) Coefficient of anaerobic decay decreased by a factor of 5;
- 7) Coefficient of retardation increased by a factor of 2; and
- 8) Coefficient of retardation decreased by a factor of 2.

The results of the sensitivity analyses are shown graphically in Figures 5.5, 5.6, 5.7, and 5.8. These figures display the modeled BTEX concentrations versus distance along the centerline of the plume (in the ninth model column). This manner of displaying data is useful because BTEX concentrations are highest in the ninth column, the plume is relatively symmetrical, and the plume migrates in a direction parallel to the model grid. Furthermore, the figures allow easy visualization of the changes in BTEX concentration caused by varying model input parameters.

The effects of varying transmissivity are shown by Figure 5.5. Uniformly increasing the transmissivity by a factor of five increased the biodegradation rate of the plume such that the maximum observed concentrations in the source cell area were only about 5,700 $\mu\text{g/L}$, compared to the calibrated maximum of 17,700 $\mu\text{g/L}$. In addition, the BTEX plume extended all the way to the southern model boundary. The lower concentrations result from the greater flux of water through the model area bringing a greater mass of DO and other electron acceptors into contact with the plume. Because more electron acceptors are available, biodegradation occurs more rapidly. Also, the faster groundwater velocity produced by the higher transmissivity initially results in greater plume travel rates and distances, further exposing the BTEX to oxygenated water. In contrast,

Concentration Distribution for Various Values of Transmissivity

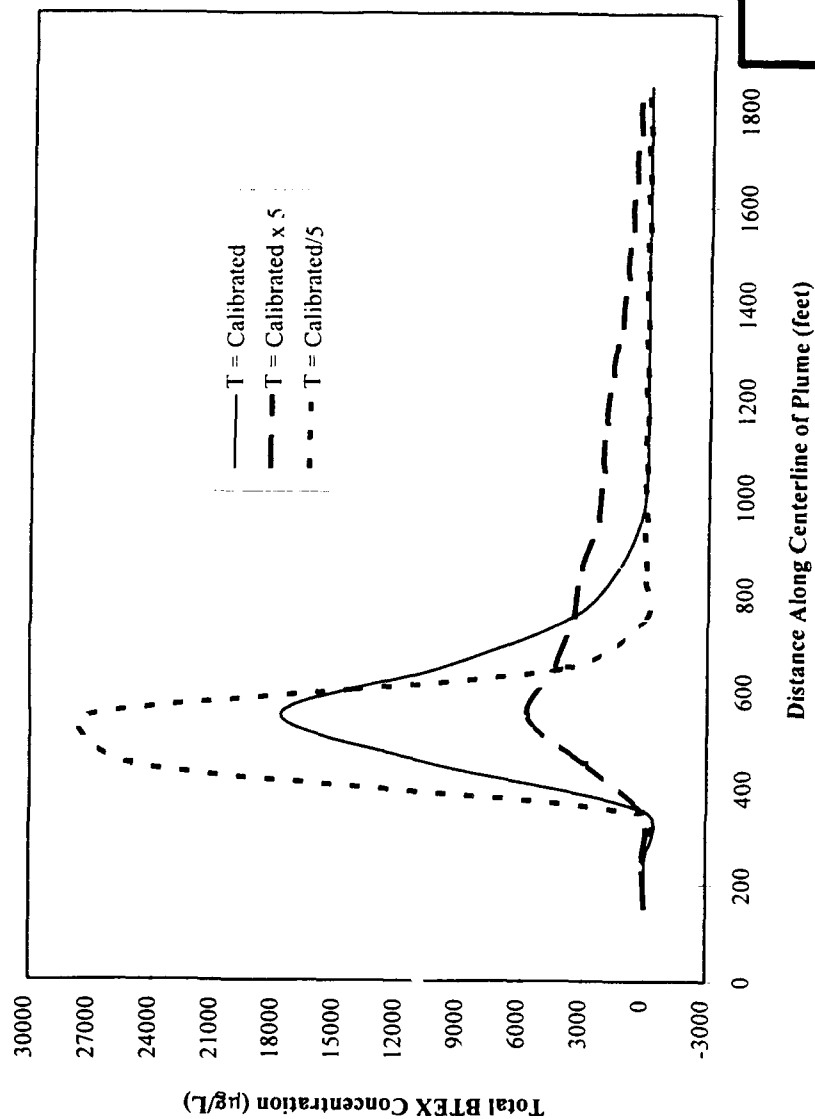


FIGURE 5.5

MODEL SENSITIVITY TO
VARIATIONS IN TRANSMISSIVITY

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



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Concentration Distribution for Various Values of the Reaeration Coefficient (DEC2)

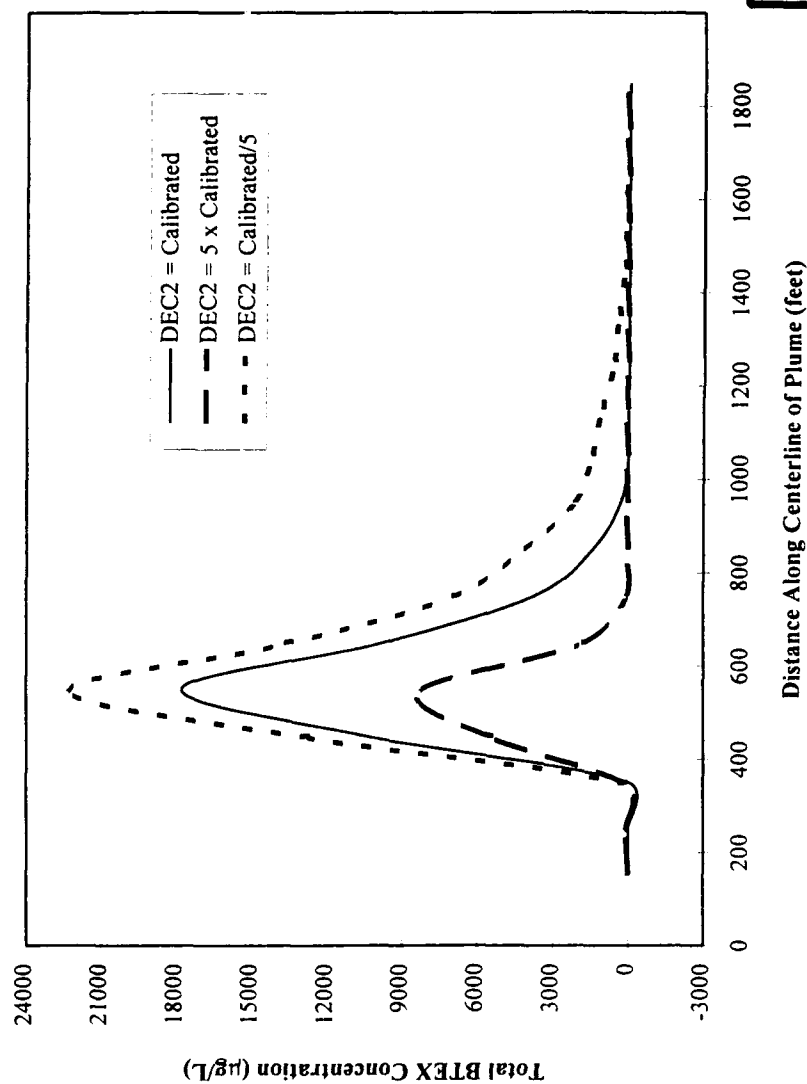


FIGURE 5.6

**MODEL SENSITIVITY TO
VARIATION IN THE
REAERATION COEFFICIENT**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



Denver, Colorado

Concentration Distribution for Various Values of the Anaerobic Decay Coefficient (DEC1)

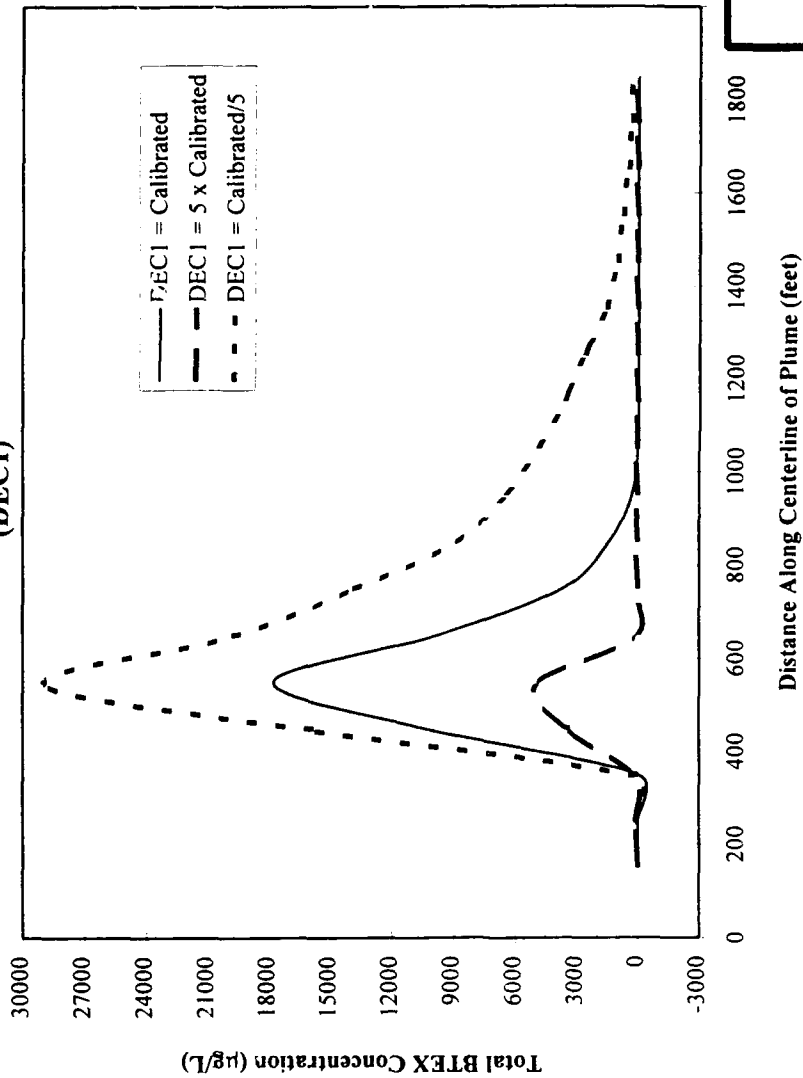


FIGURE 5.7

MODEL SENSITIVITY TO
VARIATIONS IN THE
ANAEROBIC DECAY COEFFICIENT

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



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Denver, Colorado

Concentration Distribution for Various Values of the Coefficient of Retardation (R)

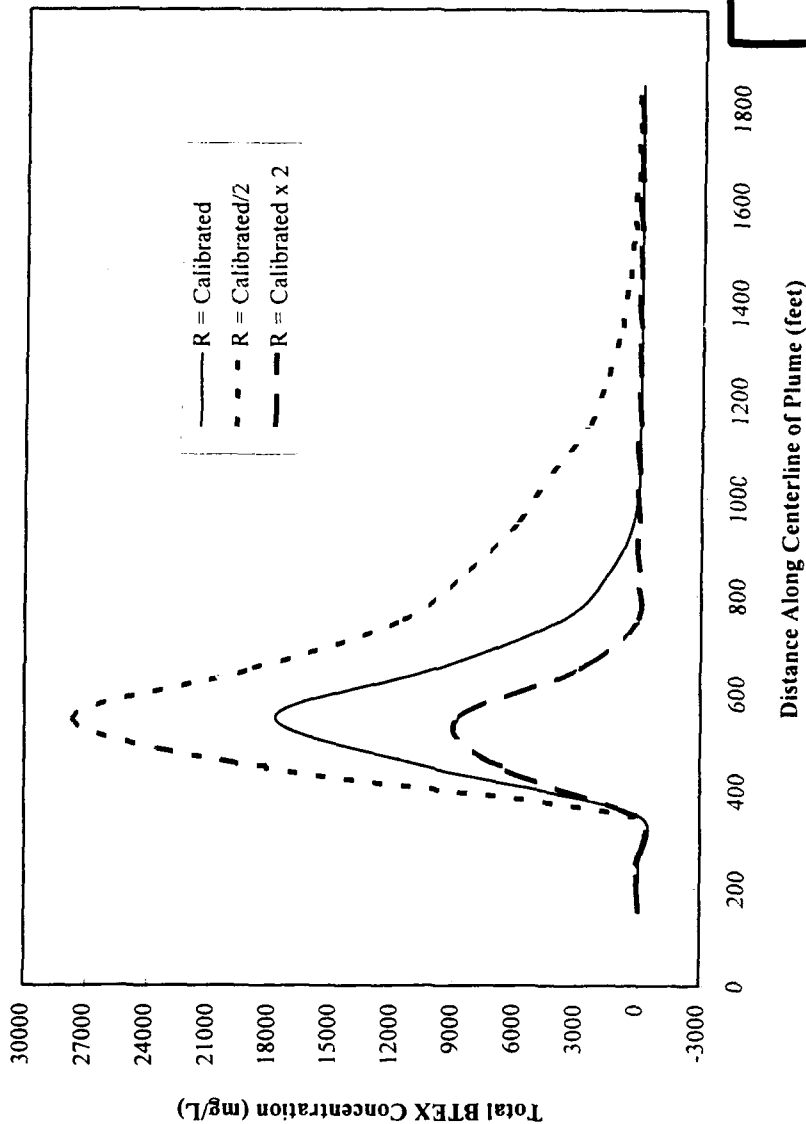


FIGURE 5.8

MODEL SENSITIVITY TO
VARIATIONS IN THE
COEFFICIENT OF RETARDATION

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



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Denver, Colorado

decreasing the transmissivity by a factor of five slowed overall plume migration, which shortened the plume and in turn caused an increase in maximum BTEX levels. Increased BTEX concentrations in the plume area are caused by a reduction in the plume travel rate and the amount of oxygen being brought into contact with the contaminants from upgradient locations.

The effects of varying the reaeration coefficient are illustrated by Figure 5.6. Increasing this parameter by a factor of five results in a much smaller plume with maximum BTEX concentrations less than one-half those of the calibrated plume. This is a result of increased biodegradation. Conversely, decreasing the coefficient of reaeration by a factor of five decreases biodegradation, increasing the length of the plume by 500 feet and increasing the computed maximum BTEX concentrations to approximately 23,000 $\mu\text{g/L}$.

Figure 5.7 shows the effects of varying the anaerobic decay coefficient. Increasing this parameter by a factor of five results in rapid degradation of dissolved BTEX and results in a very small plume. This dramatic reduction in contaminant mass is the result of the large increase in the decay rate caused by increasing the coefficient, because the anaerobic decay coefficient is exponentiated in the equation expressing the decay rate (see Section 5.3.5). Conversely, decreasing the anaerobic decay coefficient by a factor of five greatly decreases the rate of degradation, resulting in a large increase of the computed maximum BTEX concentration to approximately 29,000 $\mu\text{g/L}$ accompanied by an increase in plume length.

The effects of varying the coefficient of retardation (R) are shown on Figure 5.8. Increasing R by a factor of 2 has a fairly significant effect on the contaminant distribution. Due to the increase in sorption in the model, the maximum BTEX concentration is approximately one-half that of the calibrated model, and the plume is approximately 300 feet shorter than in the calibrated model. On the other hand, decreasing R by a factor of two produces a plume that extends about 800 feet further downgradient than the original model plume and has a much higher maximum concentration. These results suggest that the R used for the calibrated simulation is acceptable.

The results of the sensitivity analysis suggest that the calibrated model used for this report is reasonable. The calibrated model is most sensitive to transmissivity and the anaerobic decay coefficient, although the coefficient of retardation and the coefficient of

reaeration are also important parameters. Increasing the anaerobic decay coefficient or the transmissivity greatly diminishes the predicted BTEX concentrations. Lowering the values of the anaerobic decay coefficient, the reaeration coefficient, and the coefficient of retardation lengthens the plume beyond distances indicated by site observations.

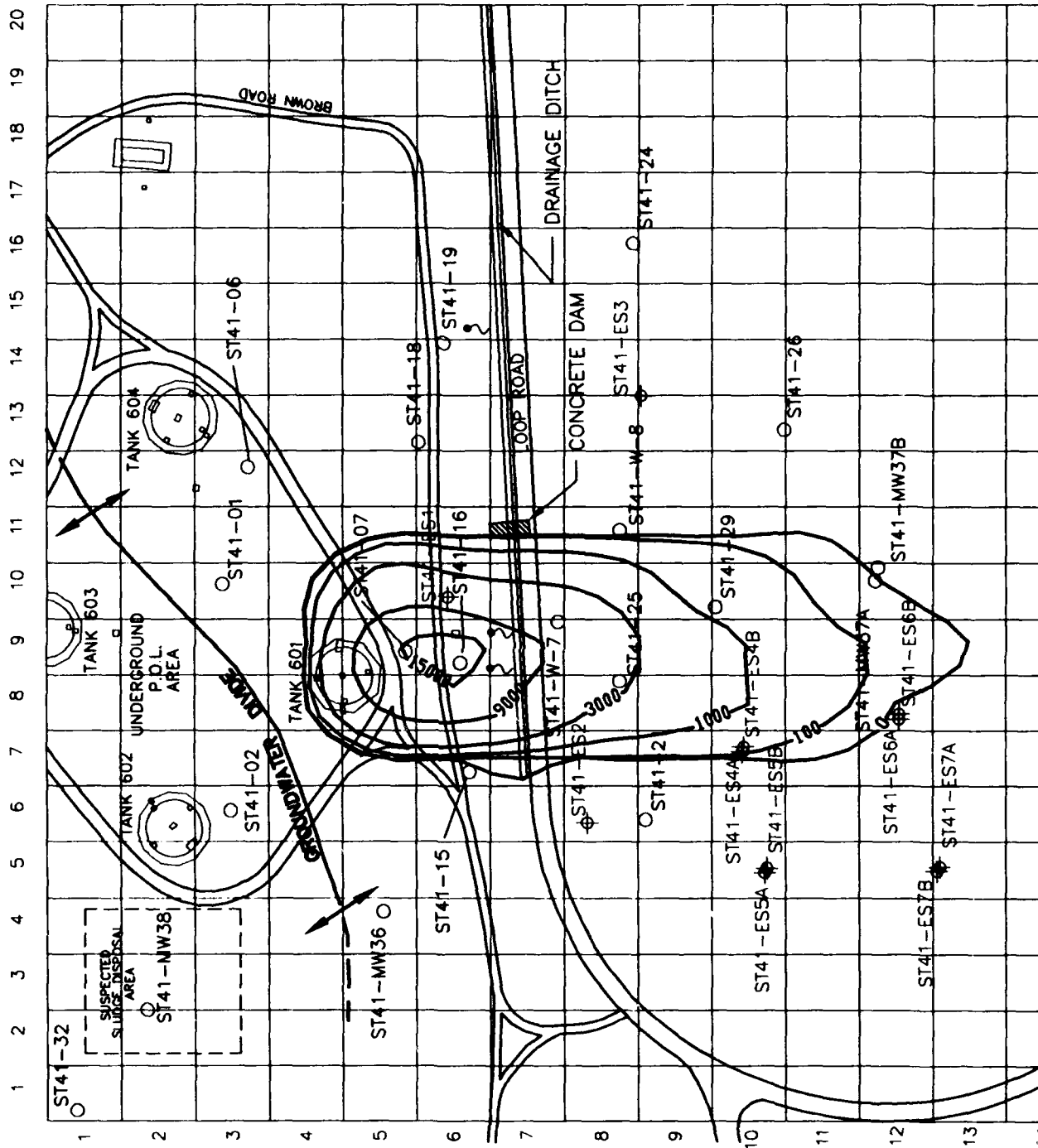
5.6 MODEL RESULTS

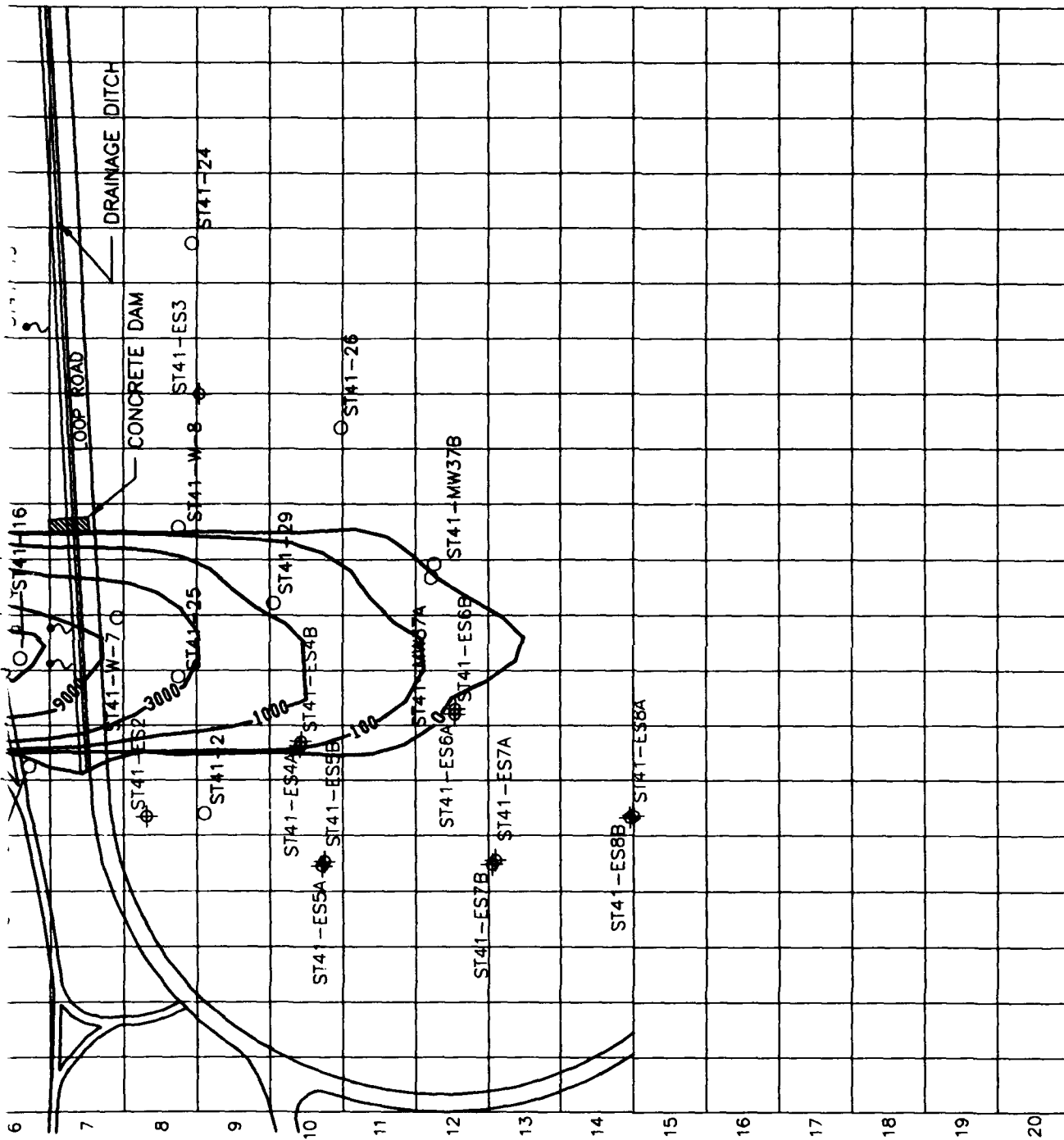
To predict fate and transport of dissolved BTEX compounds at Site ST41, three Bioplume II simulations (ST41A, ST41C, and ST41D) were run under steady-state conditions. The first simulation (a worst-case scenario) assumed that conditions that produced the calibrated model continue (i.e., contamination continues to be introduced at the same rate that produced the calibrated model). The second simulation assumed that the IRA extraction system would operate for 5 years [as suggested in the RI/FS for OU2 (Jacobs, 1994b)], and that after wards, the BTEX loading rates would continue to be reduced by weathering and biodegradation. The third simulation assumed that the IRA would not continue to operate, and that weathering alone would reduce BTEX loading rates. Complete input and output files are presented in Appendix D. Model results are described in the following sections.

5.6.1 Continuation of Calibrated Conditions (Model ST41A)

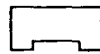
Model ST41A was used to simulate the migration and biodegradation of the BTEX plume assuming that the conditions that produced the calibrated model continue, including a continuing source of dissolved BTEX compounds. This model was run as a worst-case scenario, and to illustrate the ability of intrinsic remediation to limit plume migration even if a continuing source of contamination is present. The calibrated simulation was run to predict conditions up to 20 years beyond the original calibrated model end time, or 20 years after 1994.

Figure 5.9 shows the plume after 2 years of simulation time. Modeled BTEX concentrations rise slightly, to a maximum of 18,300 $\mu\text{g/L}$, and the plume (as defined by the 0 $\mu\text{g/L}$ isopleth) is approximately 250 feet longer than observed in June 1994. After 5 years of simulation time (Figure 5.10), the maximum simulated BTEX concentration is 19,000 $\mu\text{g/L}$, and the leading edge of the plume reaches approximately 350 feet farther than observed in 1994. Beyond 5 years of simulation time the plume stabilizes, with a configuration similar to that predicted for 2 years beyond 1994. Figure 5.11 shows the





LEGE



ST41-29

ST41-ES

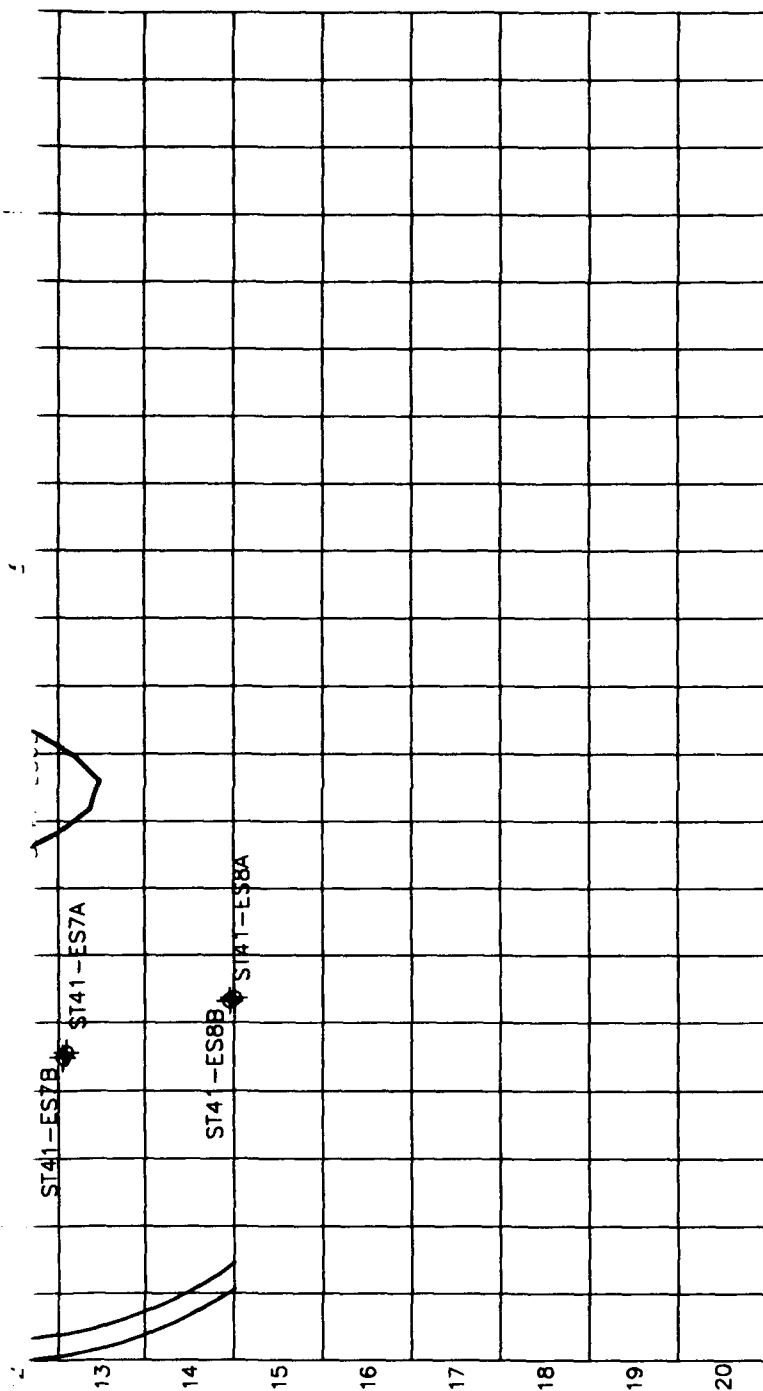


—●—

AFT

El





LEGEND

- ROAD
- BUILDING
- GROUNDWATER SEEP
- ST41-29 MONITORING WELL (1988-1992)
- ST41-ES3 MONITORING WELL (1994)
- 0 — LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE



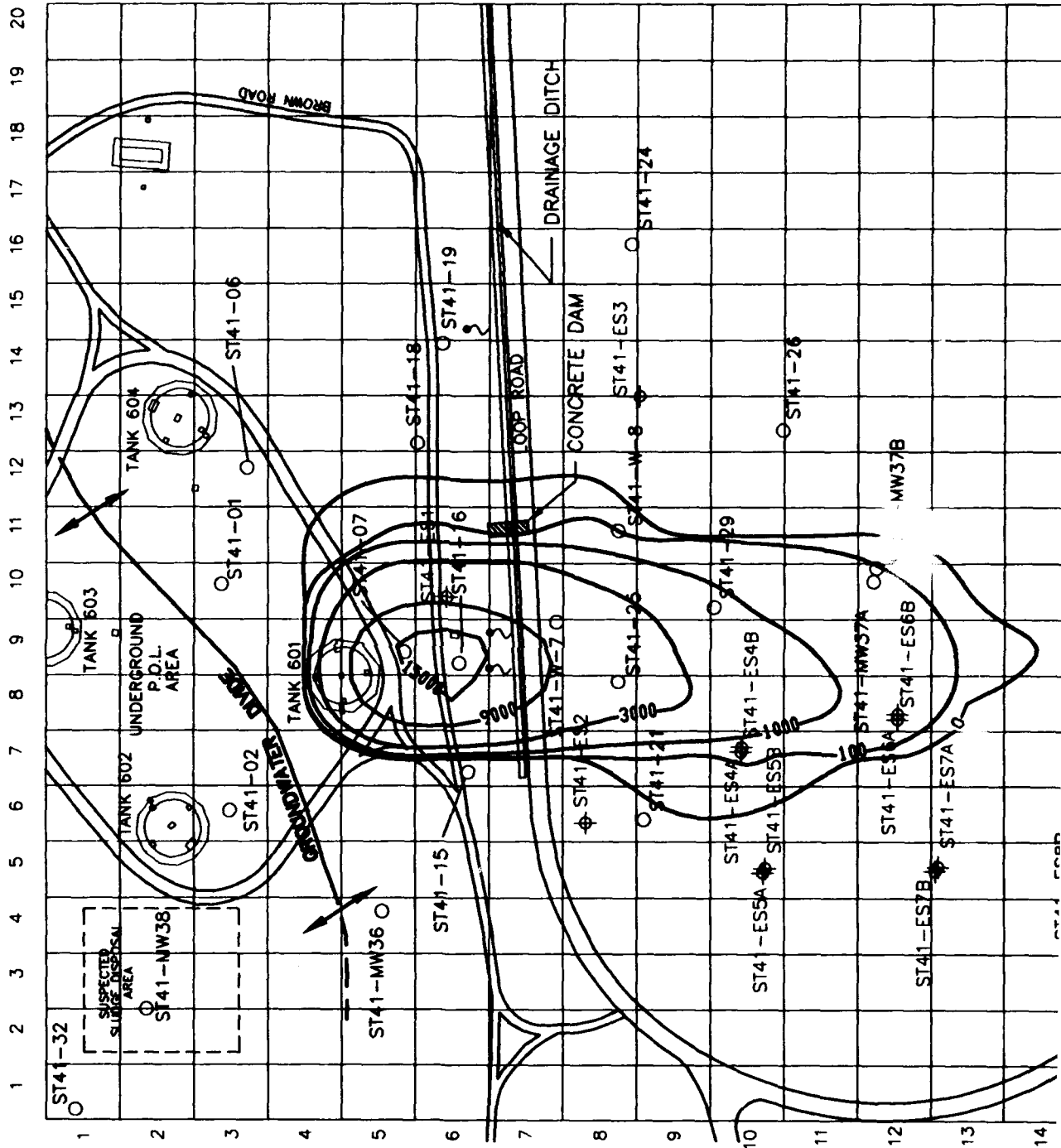
FIGURE 5.9

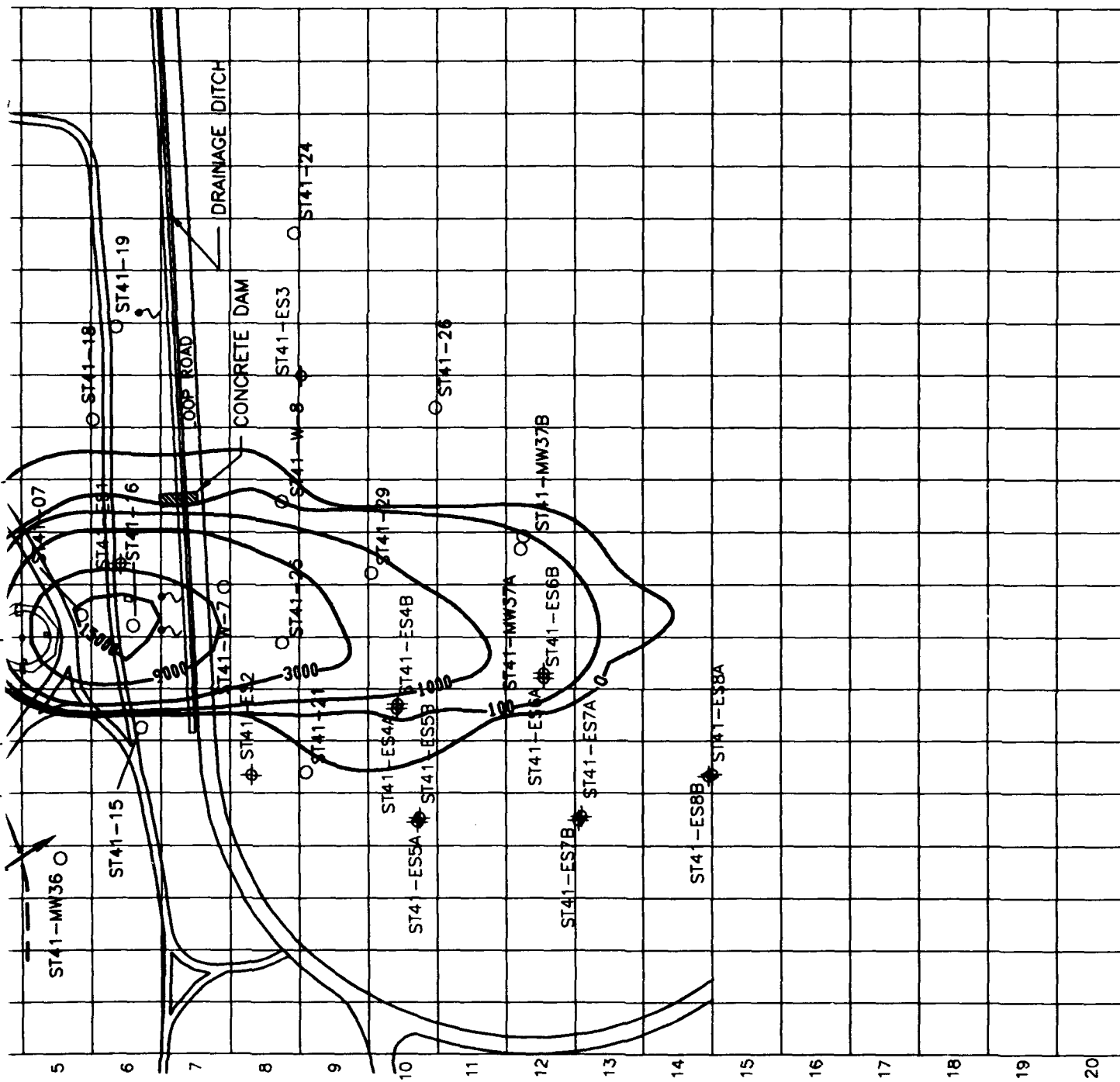
**PREDICTED BTEX PLUME
AFTER 2 YEARS, MODEL ST41A
(NO SOURCE REDUCTION)**

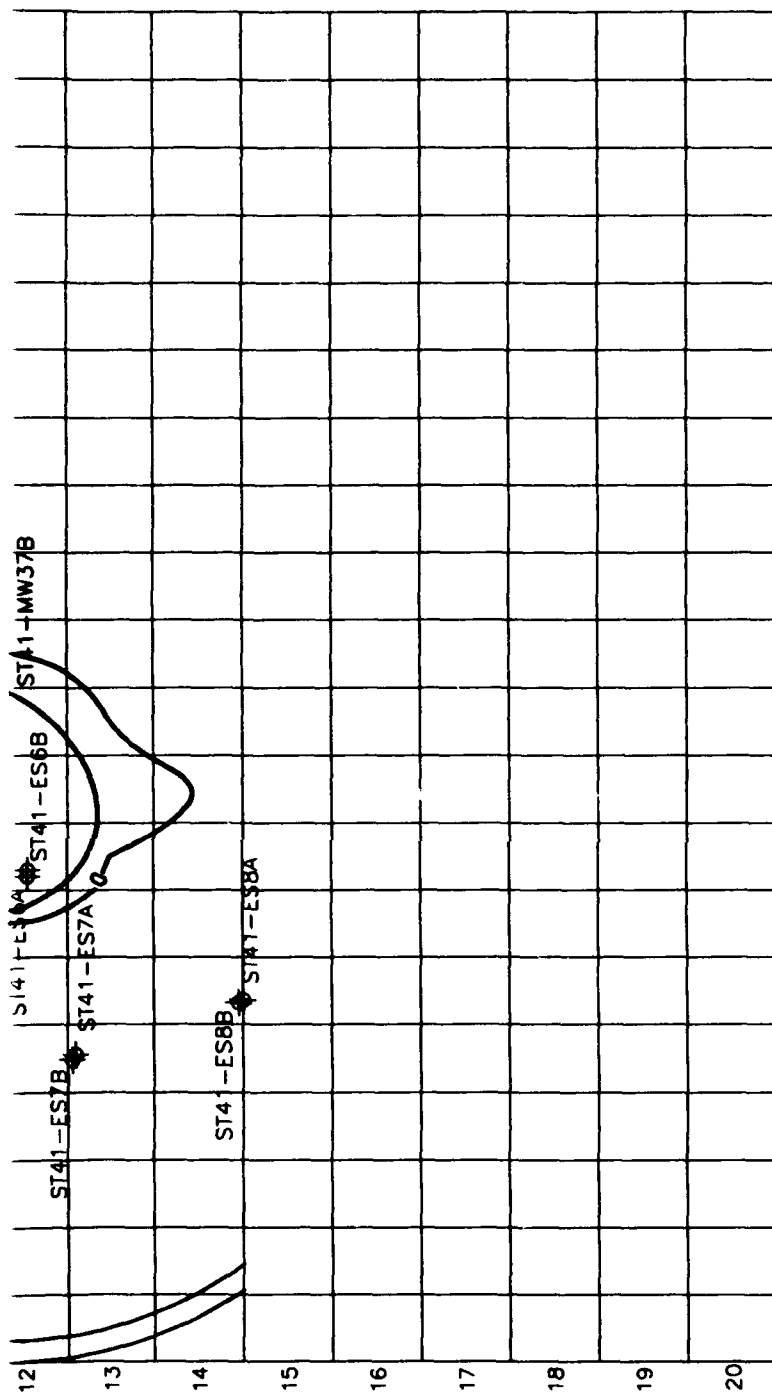
Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado







LEGEND

- ROAD
- BUILDING
- GROUNDWATER SEEP
- ST41-29
MONITORING WELL (1988-1992)
- ST41-ES3
MONITORING WELL (1994)
- 0 —
LINE OF EQUAL SIMULATED BTEX
CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE

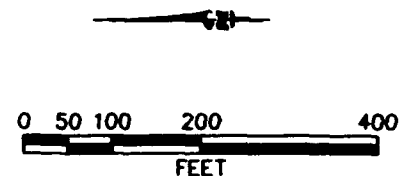
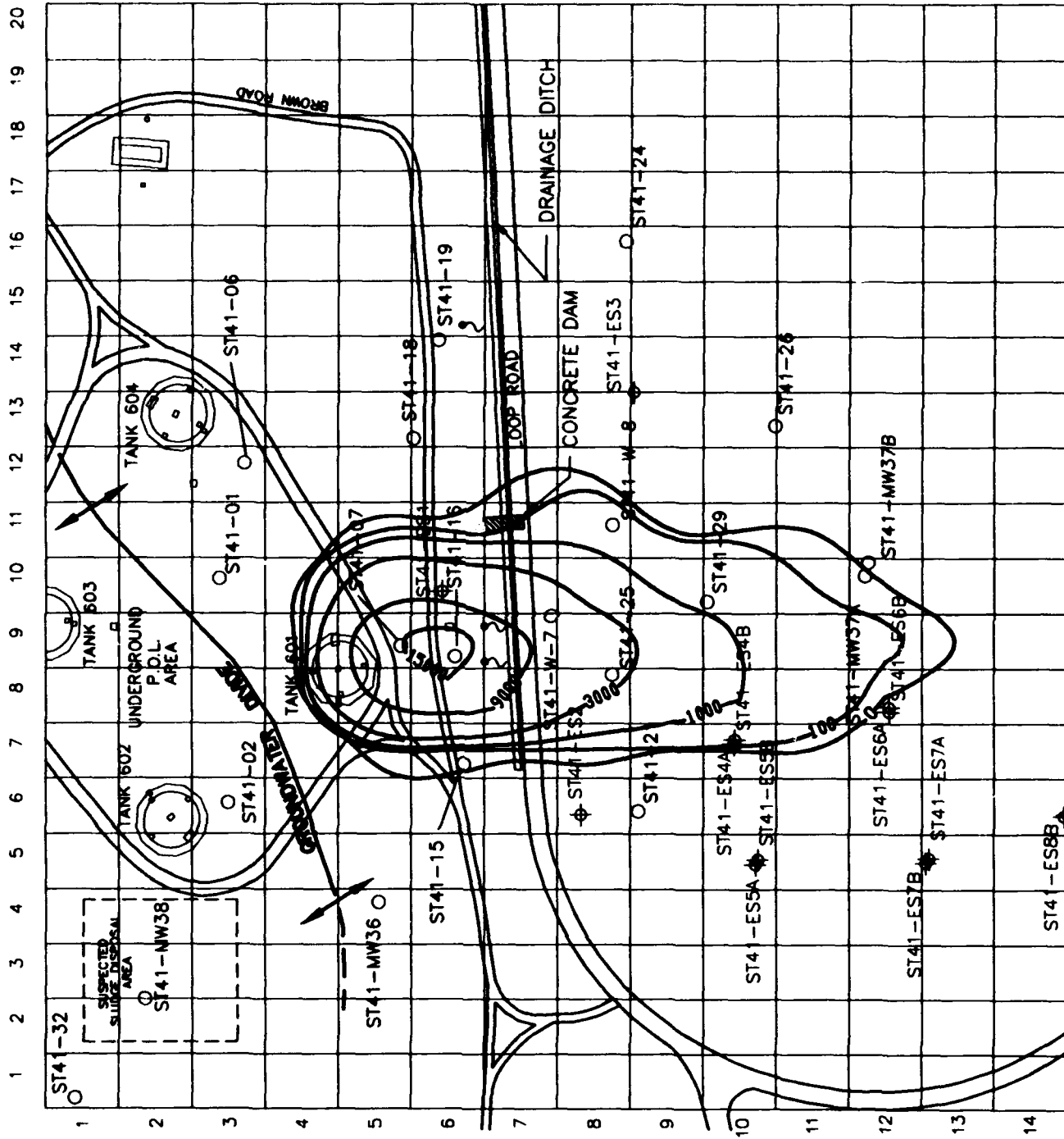


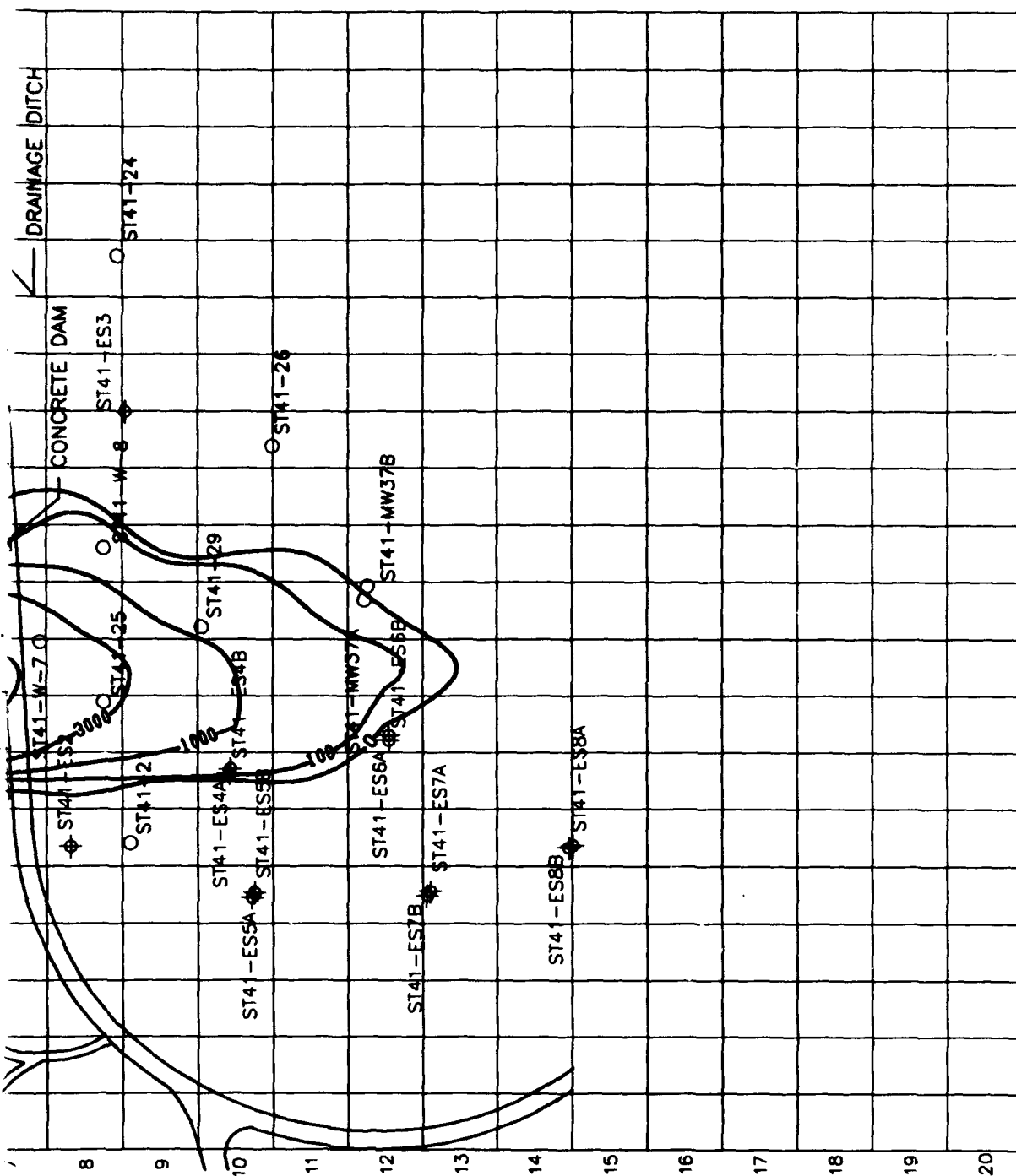
FIGURE 5.10

**PREDICTED BTEX PLUME
AFTER 5 YEARS, MODEL ST41A
(NO SOURCE REDUCTION)**

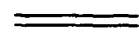
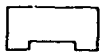
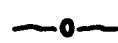
Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

**PARSONS
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Denver, Colorado





LEGEND

-  ROAD
-  BUILDING
-  GROUNDWATER
-  ST41-29 MONITORING
-  ST41-ES3 MONITORING
-  LINE OF CONCENTRATION

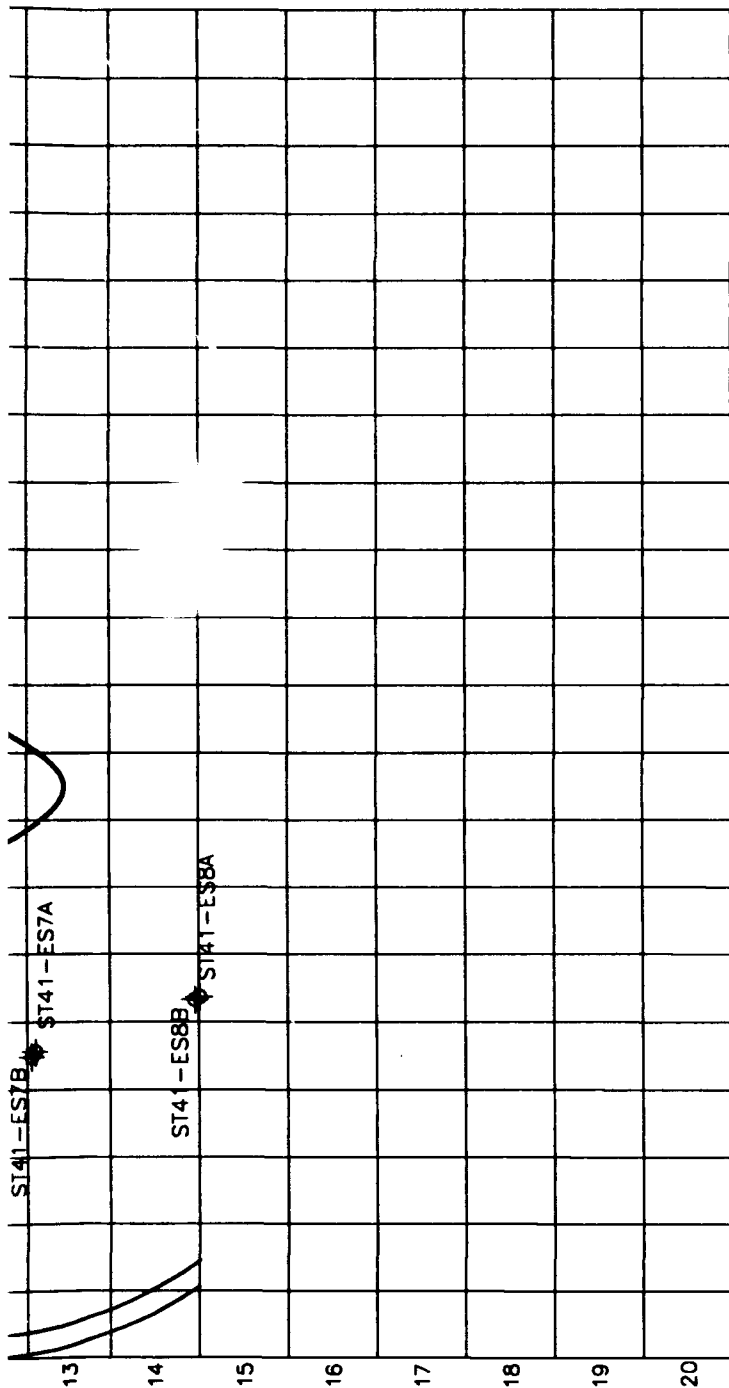
0 50 100

PREDICTED
AFTER 20 YEARS
(NO SOIL)

Intrinsic
Elmendorf

 PARSCO
ENGINE

De



LEGEND

- ROAD
- BUILDING
- GROUNDWATER SEEP
- ST41-29 MONITORING WELL (1988-1992)
- ST41-ES3 MONITORING WELL (1994)
- 0 — LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE

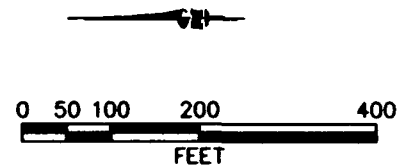


FIGURE 5.11

**PREDICTED BTEX PLUME
AFTER 20 YEARS, MODEL ST41A
(NO SOURCE REDUCTION)**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

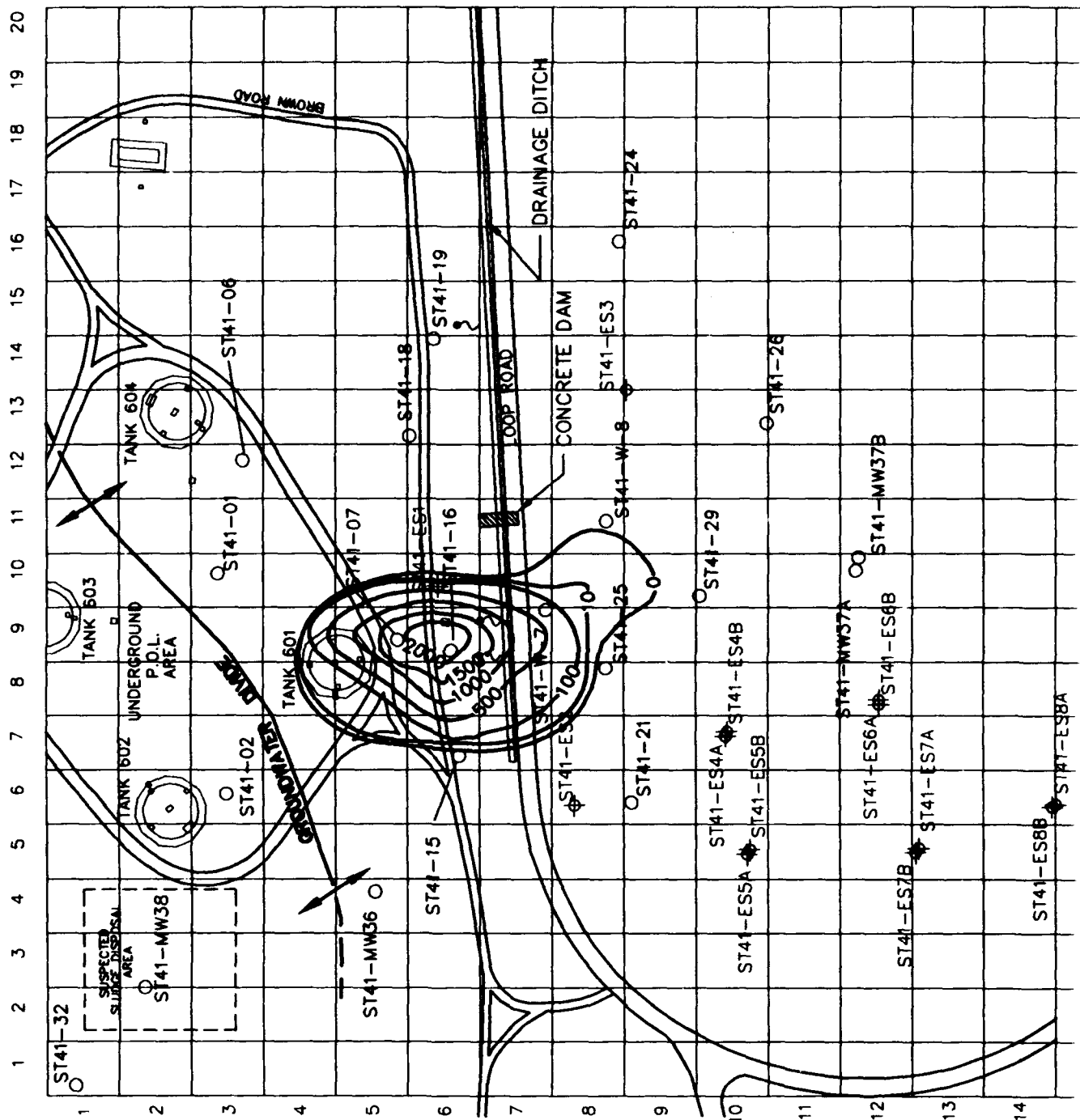
stabilized BTEX plume after 20 years of prediction time. After the plume stabilizes, the maximum concentration (in the source area) varies in a cyclical fashion between 18,500 and 19,500 µg/L.

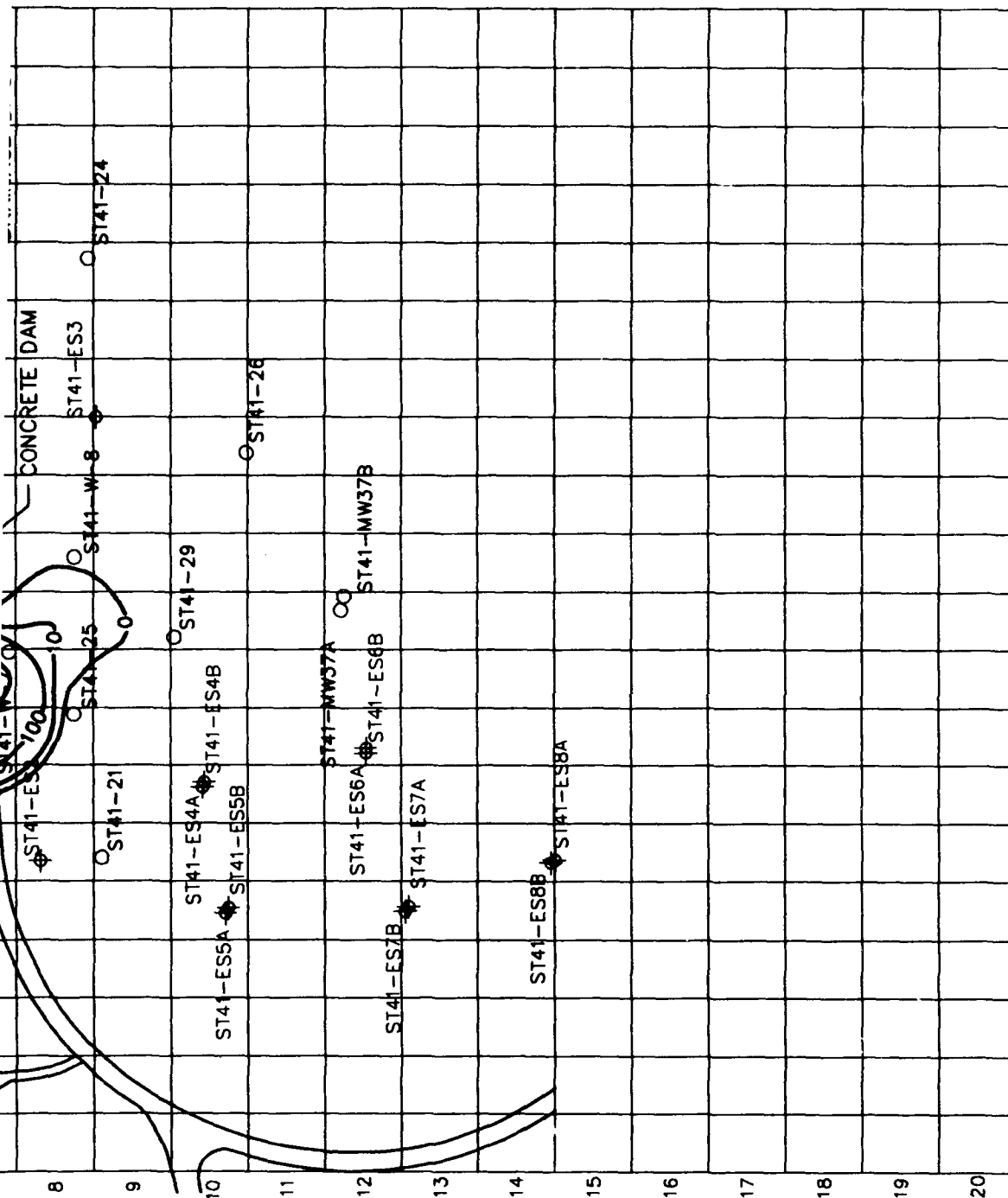
5.6.2 Source Reduction (Model ST41C)

Mobile LNAPL and groundwater recovery operations have been underway at Site ST41 since October 1993. The system may operate for another 5 years and if so, it is expected to significantly reduce contaminant loading in the source areas (Jacobs, 1994b). To simulate these conditions, it was assumed that the IRA system would operate for 5 years to reduce the introduction of BTEX into the groundwater south of Tank 601 so that after 5 years, the final loading rate was 30 percent of the original calibrated rate. This assumes that the IRA will be able to facilitate removal of 70 percent of the BTEX mass in the source area. This assumption is comparable to (but slightly more conservative than) the assumption made in the RI/FS (Jacobs, 1994b), namely that the IRA would eliminate the sources of BTEX (i.e., LNAPL) at ST41 and allow natural attenuation processes to reduce BTEX concentrations to below MCLs.

After that rapid reduction, the source loading rates were tapered off by 8 percent per year to account for continued weathering and biodegradation of residual fuel hydrocarbons in the source area. Evidence on the rates of weathering and degradation of residual LNAPL sources is scant; one study at Eglin AFB (Wiedemeier *et al.*, 1995) provided evidence that a 5-year-old body of residual gasoline (formerly containing some mobile LNAPL) was only capable of introducing a maximum of about 27 mg/L (27,000 µg/L) of BTEX into the site groundwater. When such a source is fresh, it is capable of introducing up to 130 mg/L of BTEX into groundwater (API, 1985; Cline *et al.*, 1991). Natural weathering and biodegradation mechanisms therefore decreased the loading capability of the source by about 80 percent in 5 years, or over 15 percent per year. With this evidence providing a reasonable upper bound to source degradation rates, assuming an 8 percent per year reduction for the Site ST41 model is conservative. An 8 percent per year rate is equivalent to 0.0002 day^{-1} , or about 20 times slower than the anaerobic decay rate for dissolved BTEX that was used in all of the model runs.

Model ST41C was run to predict conditions up to 30 years beyond those observed in 1994. Figure 5.12 shows the plume after 10 years of prediction time. The plume shrinks considerably, and the maximum BTEX concentrations decrease to about 2,700 µg/L.





LEGEND

- ROAD
- BUILD
- GROUP
- ST41-29 ○ MONI
- ST41-ES3 ◆ MONI
- LINE CONTOUR
- CONTOUR

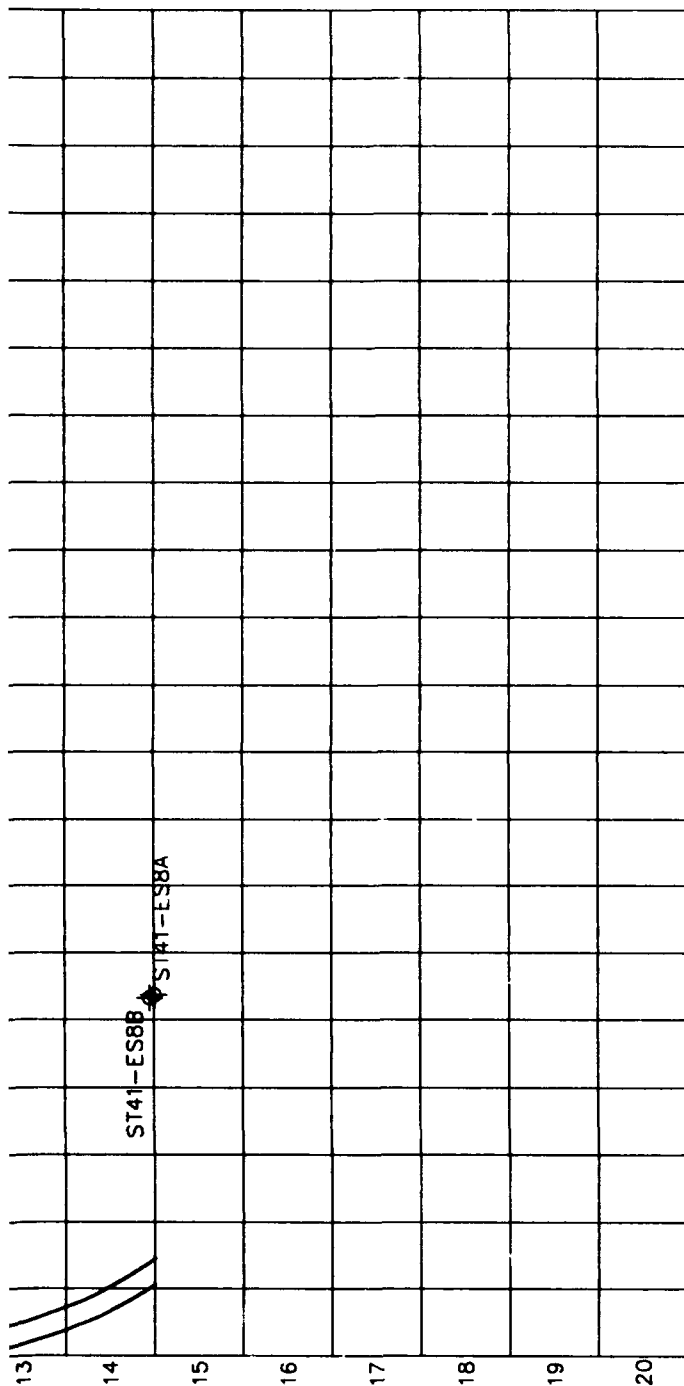
0 50 100

PREDICTED
AFTER 10 YEARS
(SOURCE)

Intrinsic
Elmendorf A

PARSON ENGINEERING

Derivation



LEGEND

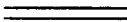
-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
- ST41-29 ○ MONITORING WELL (1988-1992)
- ST41-ES3  MONITORING WELL (1994)
-  LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE



FIGURE 5.12

**PREDICTED BTEX PLUME
AFTER 10 YEARS, MODEL ST41C
(SOURCE REDUCTION)**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

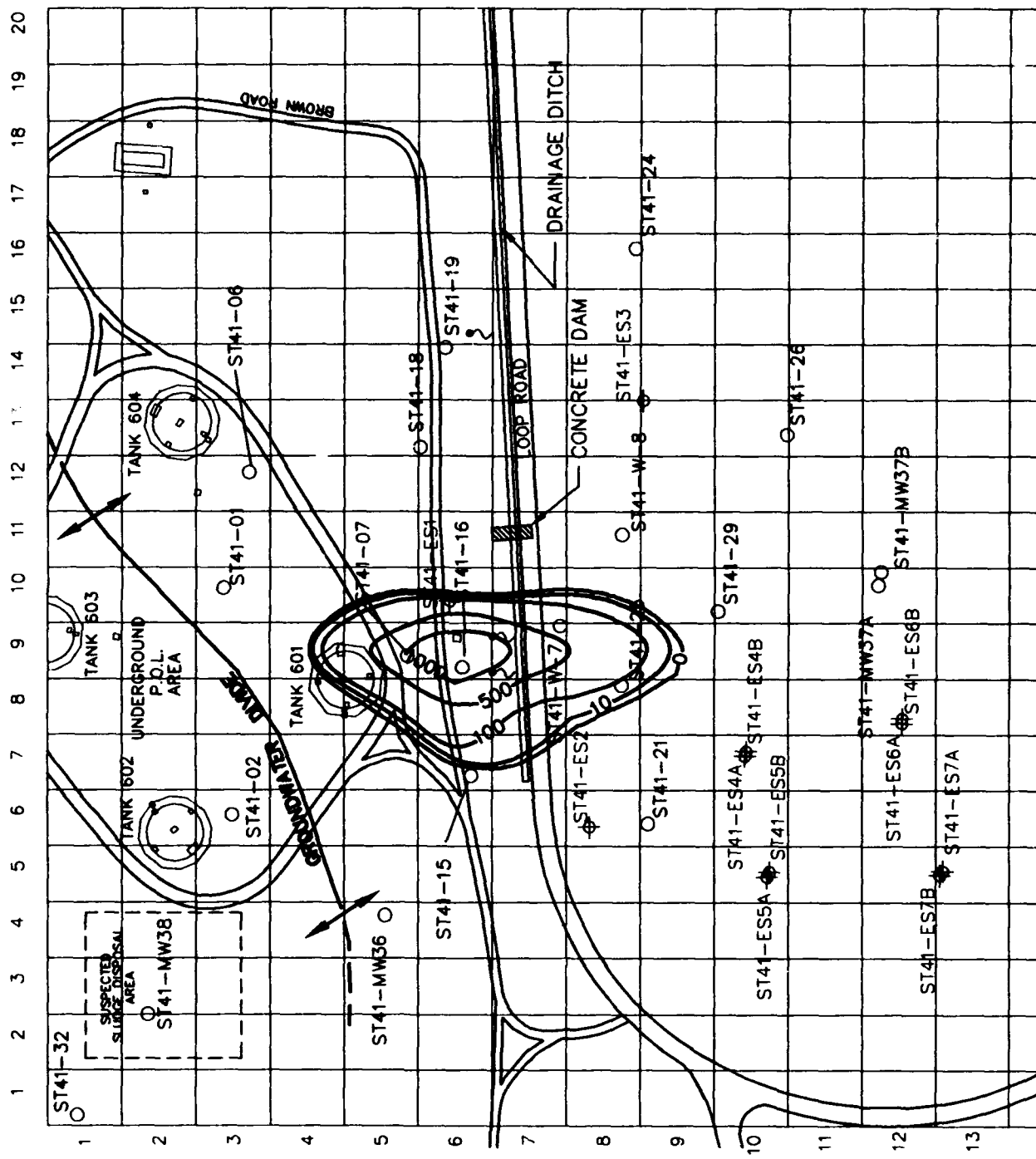
For later prediction times, the plume continues to recede, and maximum concentrations continue to decrease. For example, Figure 5.13 shows the BTEX plume predicted for 17 years after 1994. The plume is slightly shorter than shown in Figure 5.12, and the maximum model BTEX concentration is approximately 1,700 $\mu\text{g/L}$. Figure 5.14 shows that after 21 years, the plume front has receded further, and the maximum concentration is approximately 750 $\mu\text{g/L}$. For simulation times of 22 years and greater, dissolved BTEX concentrations in the model are all reduced to zero.

These results suggest that if the IRA is successful at decreasing contaminant loading rates within the 5-year time frame indicated in the RI/FS (Jacobs, 1994b), dissolved BTEX concentrations should be below MCLs in 21 to 22 years. The time at which concentrations of individual compounds decrease below MCLs will depend on the efficiency of the IRA system, the fraction of each compound present in the plume, and the behavior of each compound in the hydrogeological and microbiological environment present at ST41.

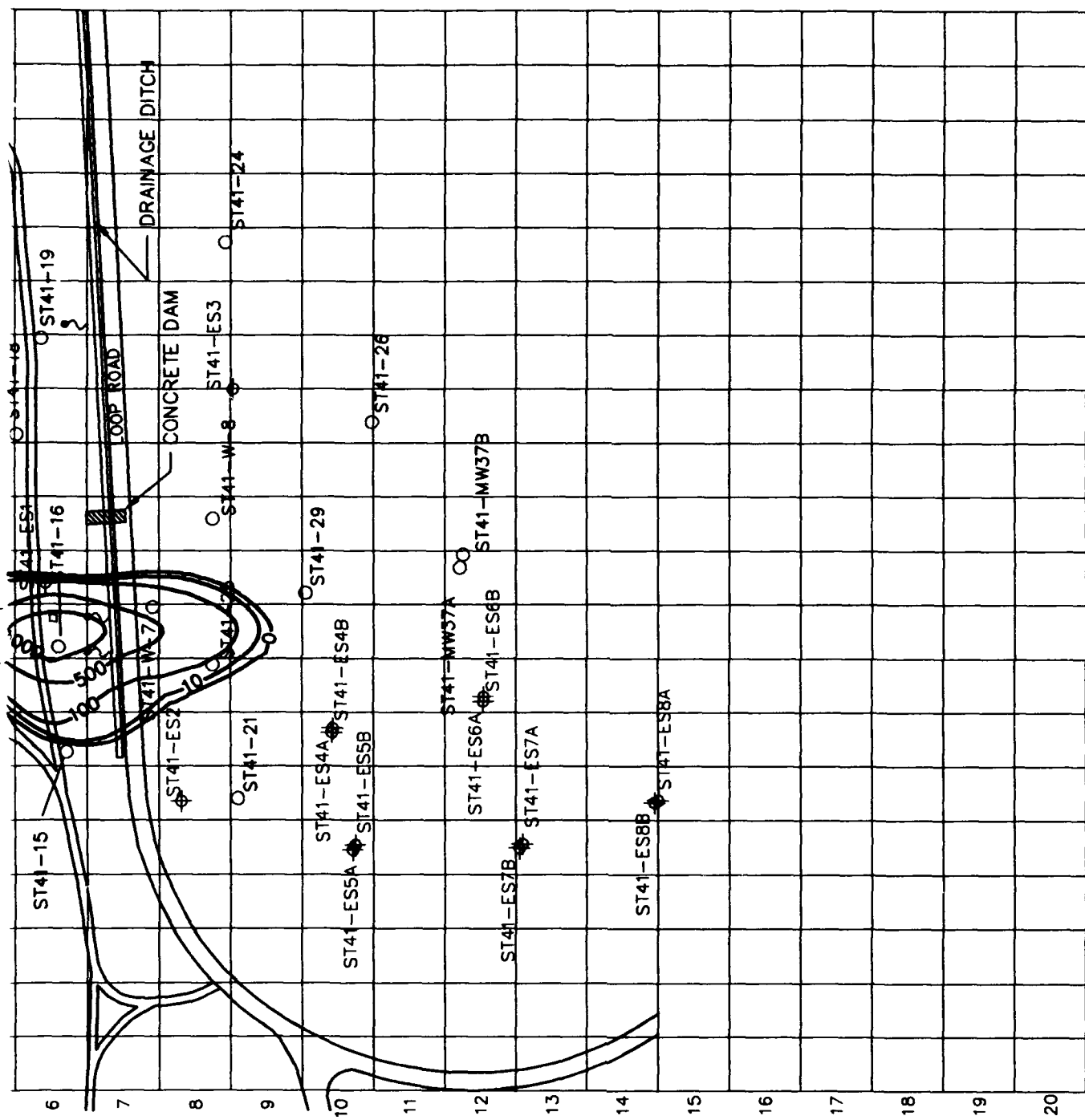
5.6.3 Weathering Source (Model ST41D)

It is possible that the IRA will not remain in operation. Model ST41D was run to simulate the fate of the plume with only natural weathering acting to reduce source loading. For this model it was assumed that BTEX dissolution rates would decrease at 8 percent per year, the same rate used in model ST41C to account for source weathering after the initial rapid source reduction. In this case, there is no rapid initial source reduction due to operation of the IRA.

Model ST41D was run to predict conditions up to 35 years beyond those observed in 1994. Figure 5.15 shows the plume after 15 years of prediction time. The plume shrinks considerably, and the maximum BTEX concentration decreases to about 5,000 $\mu\text{g/L}$. For later prediction times, the plume continues to recede and maximum concentrations continue to decrease. For example, Figure 5.16 shows the BTEX plume predicted for 25 years after 1994. The plume is much shorter than shown in Figure 5.15, and the maximum model BTEX concentration is approximately 2,000 $\mu\text{g/L}$. Figure 5.17 shows that after 29 years, the plume front has receded further, and the maximum concentration is approximately 1,100 $\mu\text{g/L}$. For simulation times beyond 30 years, dissolved BTEX concentrations in the model are all reduced to zero, even though loading rates are still about one-twentieth of the original rates.

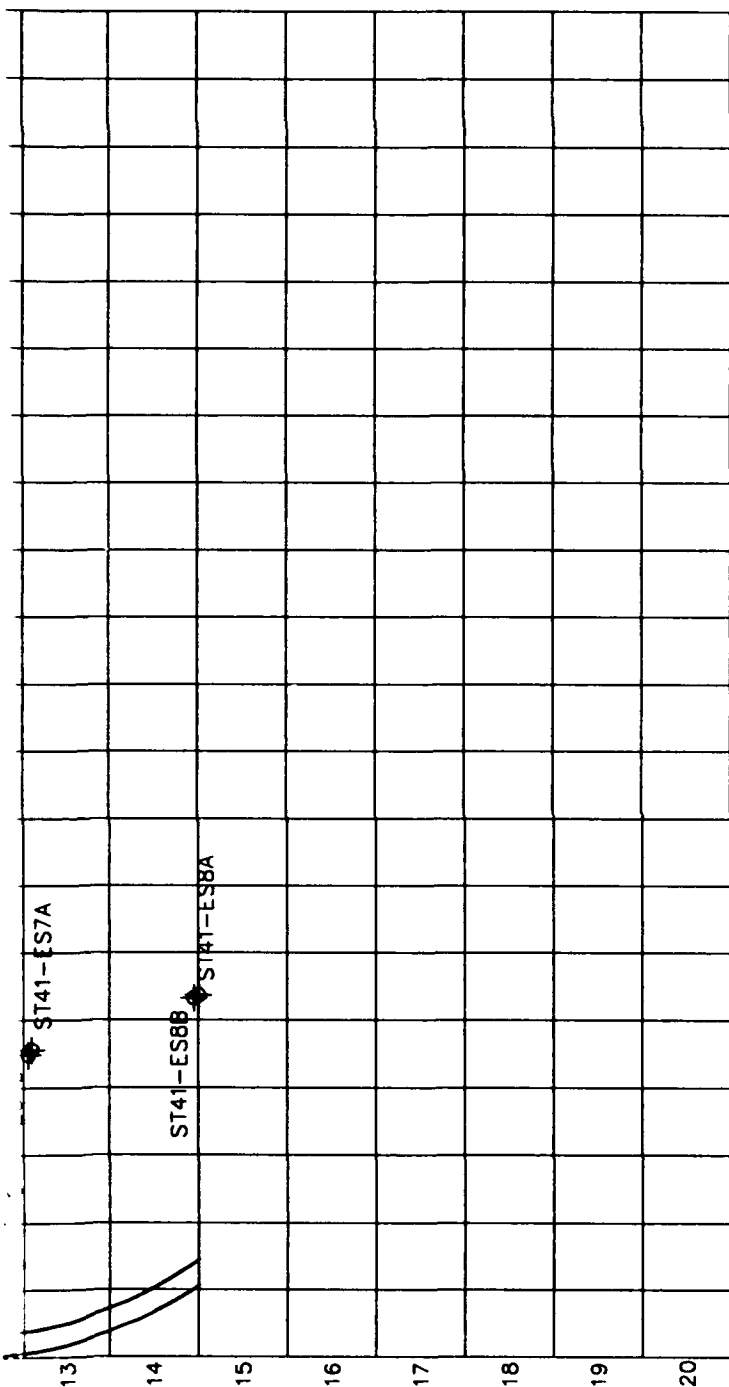


ST41-ES6A



ST41-

ST41-



LEGEND

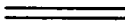
-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
- ST41-29 ○ MONITORING WELL (1988-1992)
- ST41-ES3 ⊕ MONITORING WELL (1994)
-  LINE OF EQUAL SIMULATED BTEX CONCENTRATION (μg/L)
- CONTOUR INTERVAL = VARIABLE

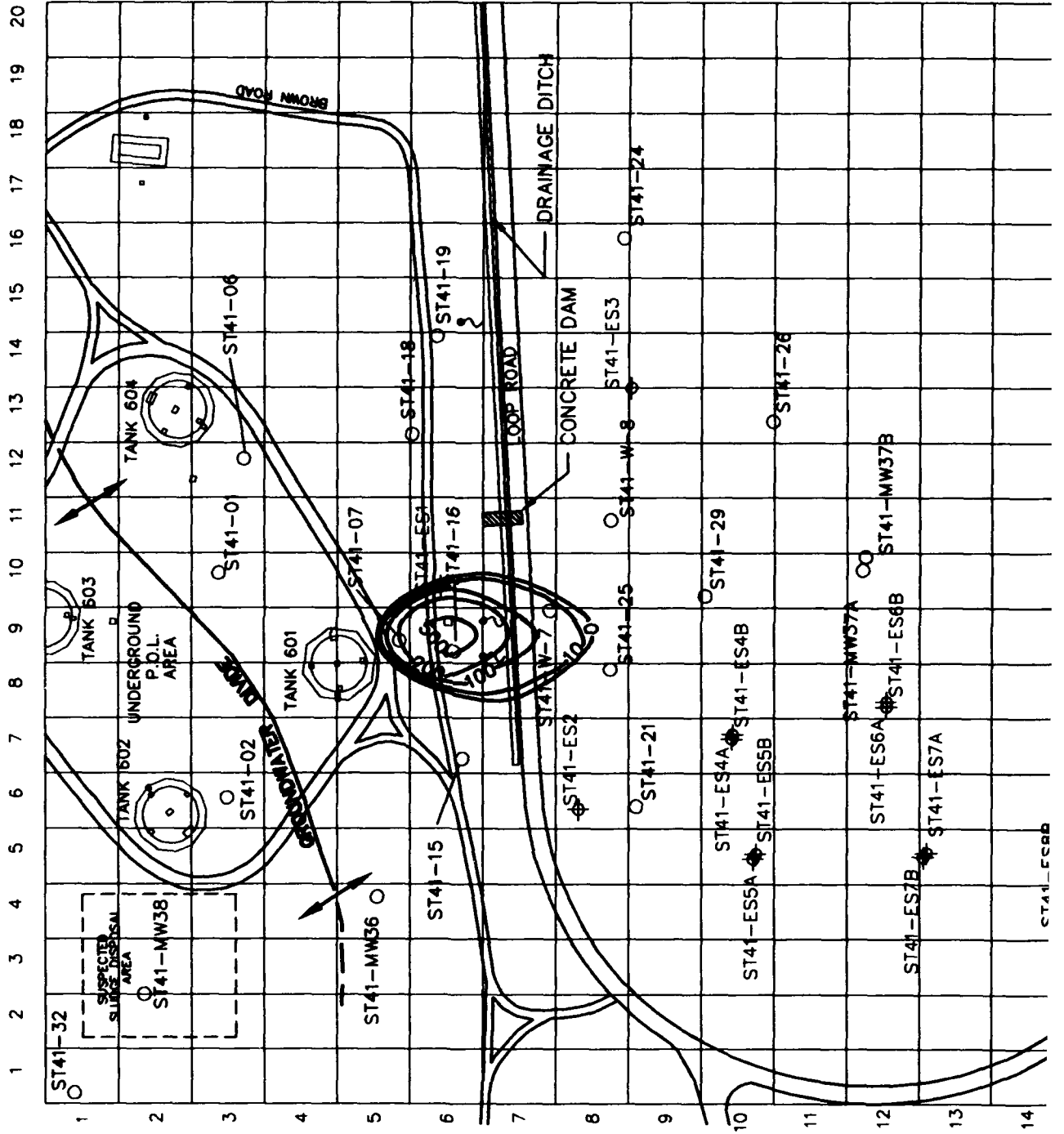


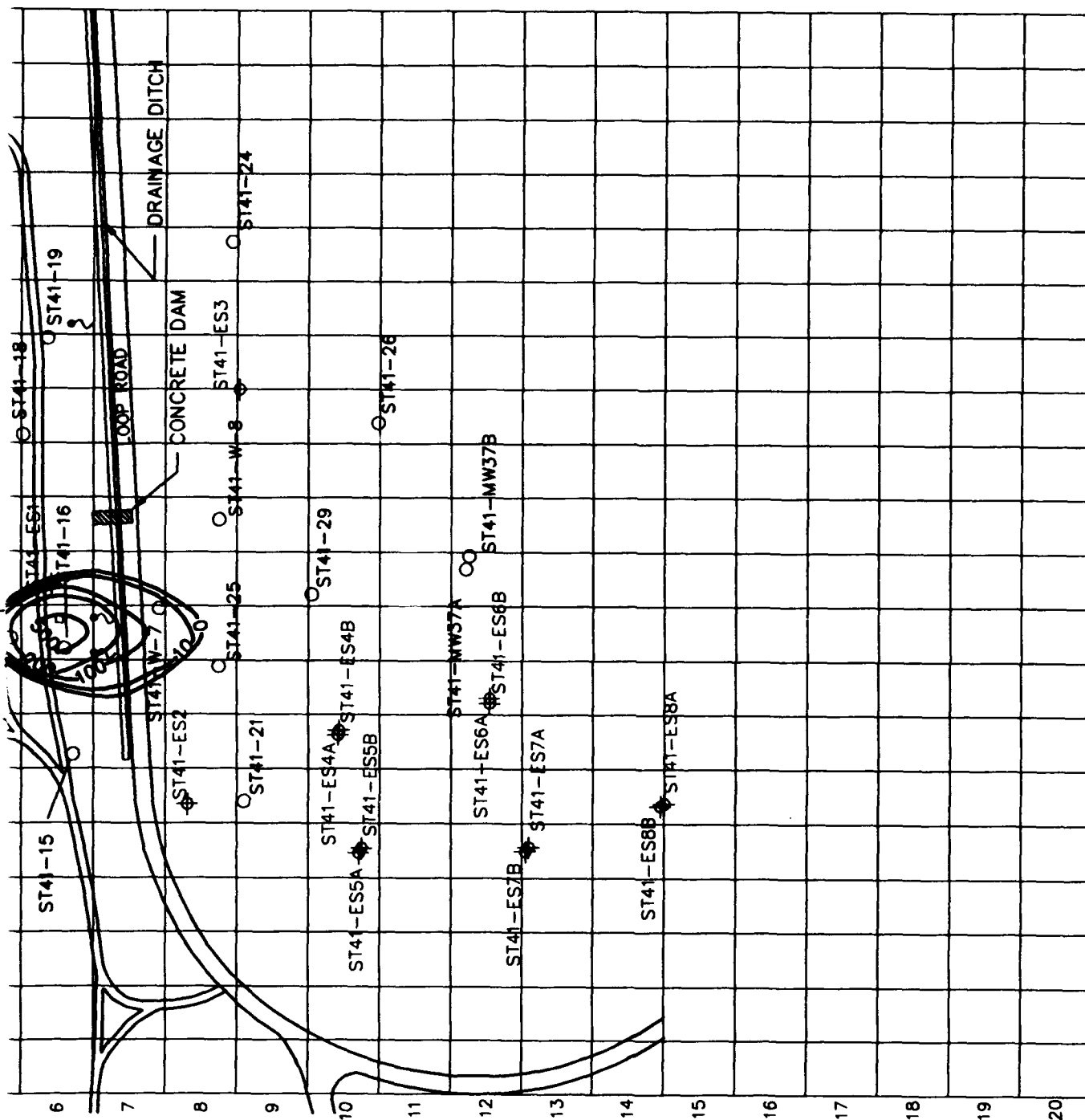
FIGURE 5.13
PREDICTED BTEX PLUME
AFTER 17 YEARS, MODEL ST41C
(SOURCE REDUCTION)

Site ST41
 Intrinsic Remediation TS
 Elmendorf Air Force Base, Alaska

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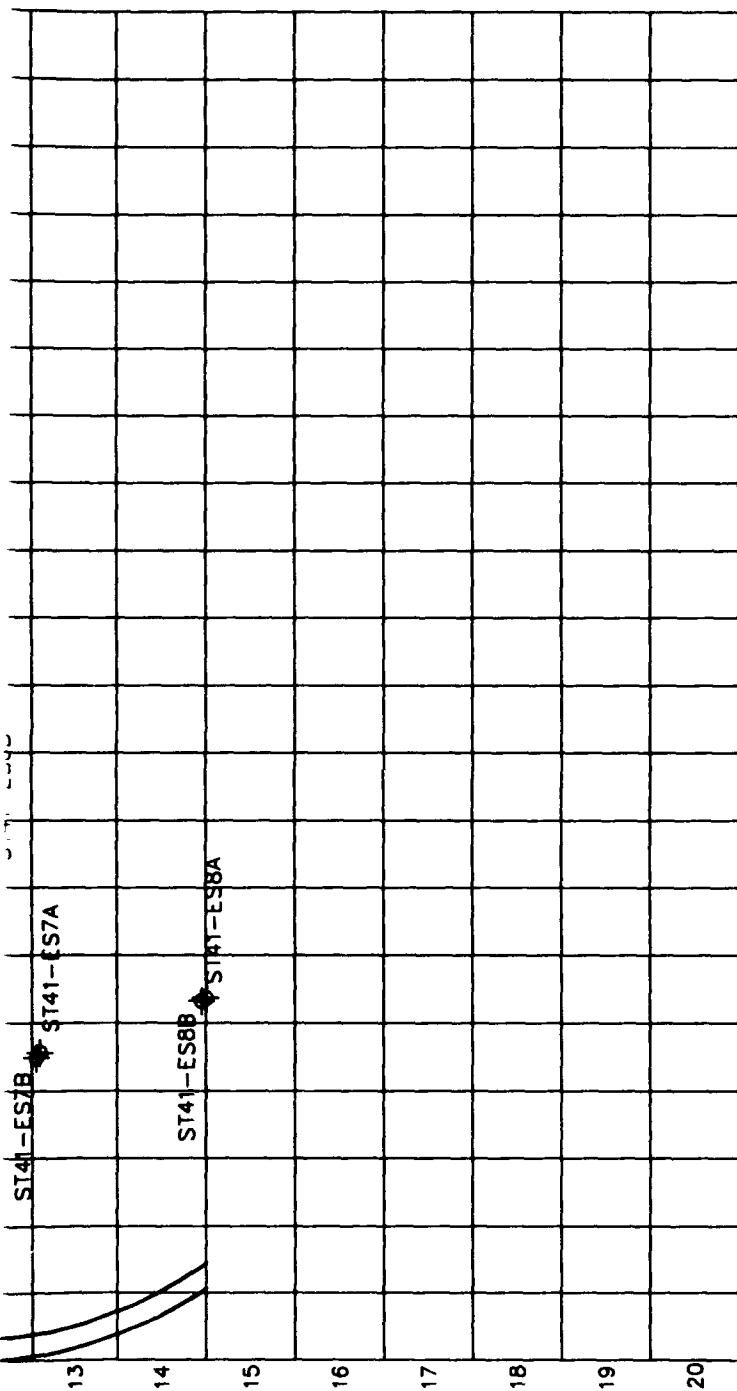




ST41-29

ST41-ES:

A



LEGEND

-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
- ST41-29 ○ MONITORING WELL (1988-1992)
- ST41-ES3  MONITORING WELL (1994)
-  LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE



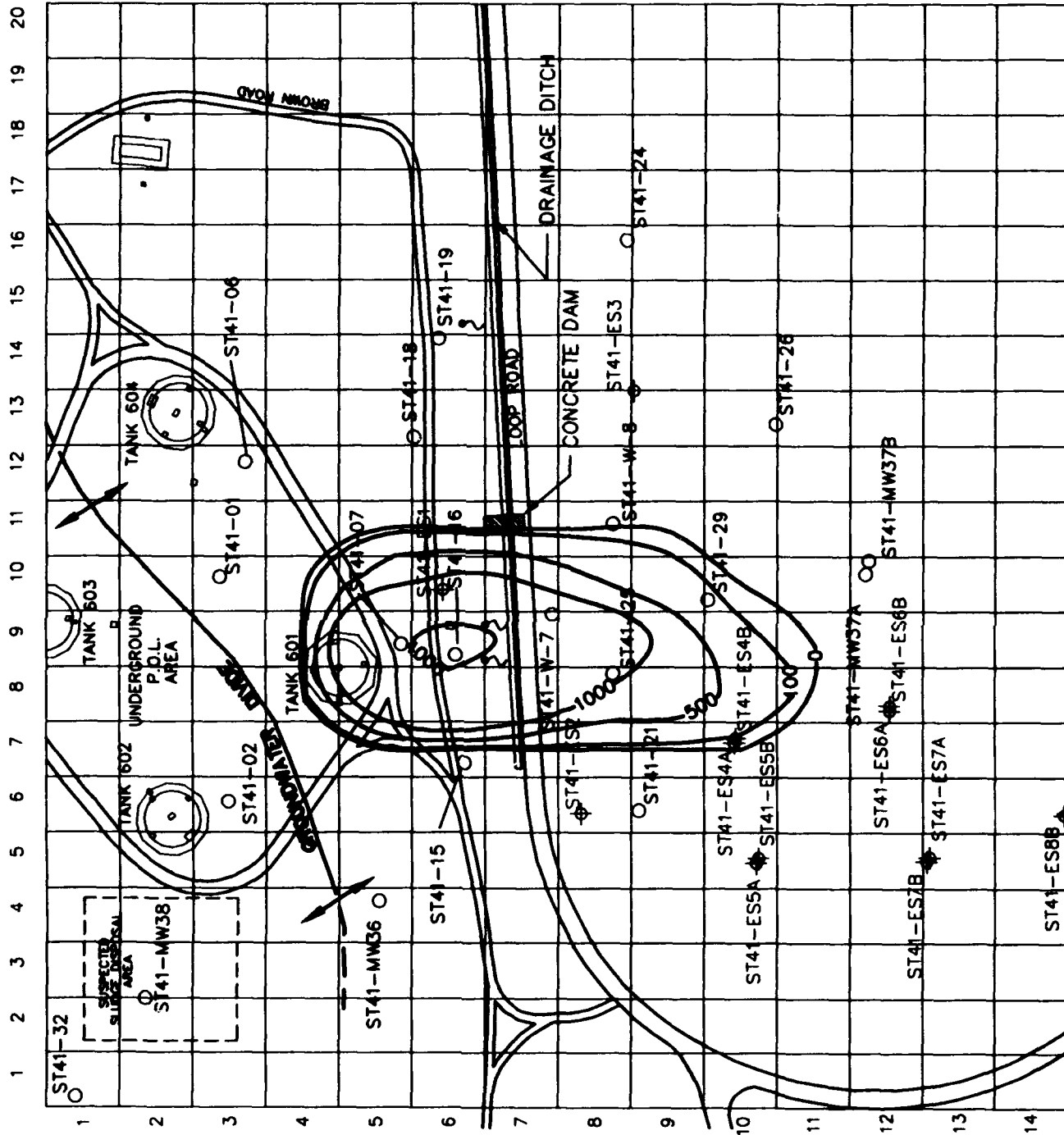
FIGURE 5.14

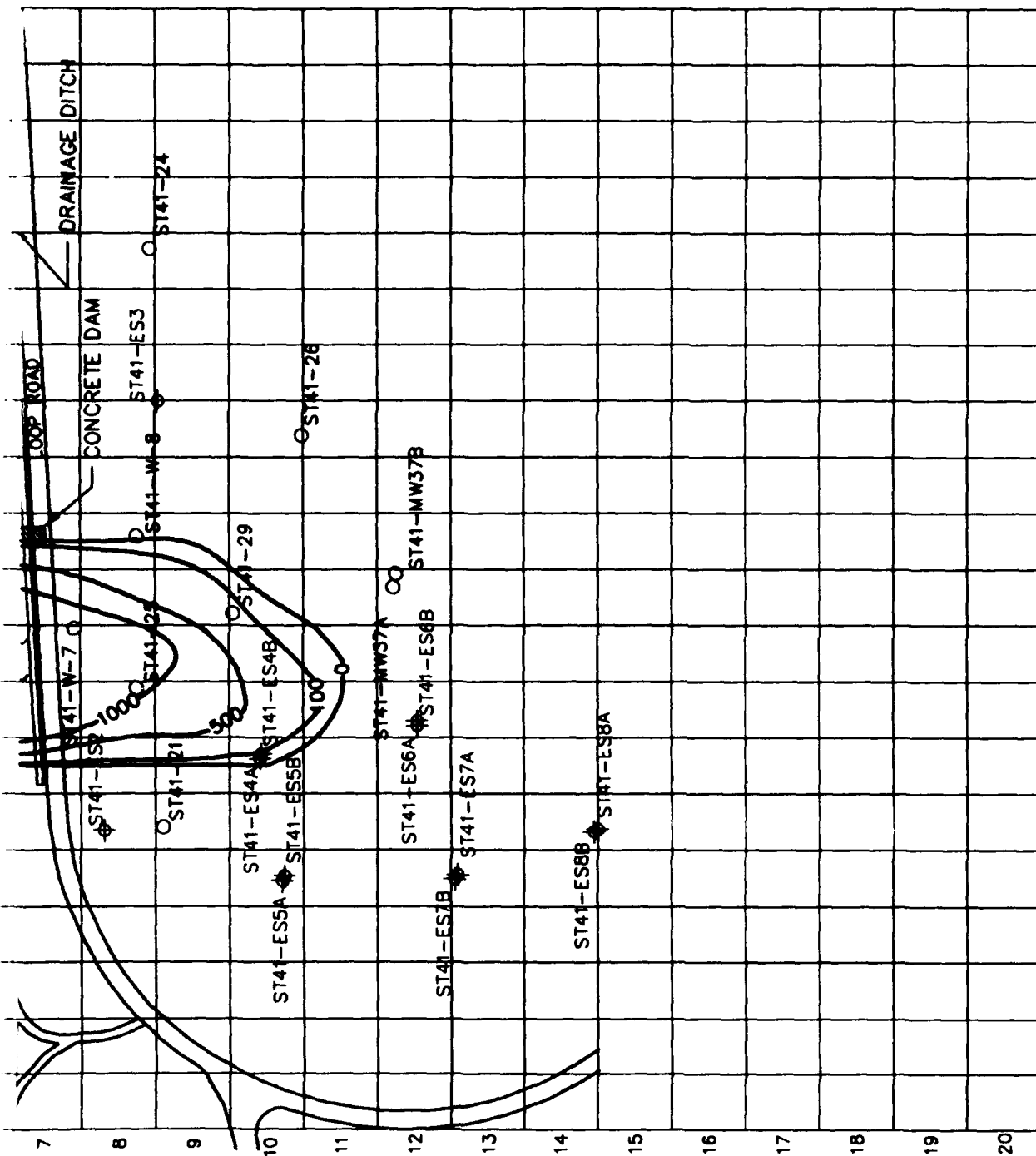
**PREDICTED BTEX PLUME
AFTER 21 YEARS, MODEL ST41C
(SOURCE REDUCTION)**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

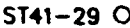
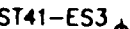
**P PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado





LEGEND

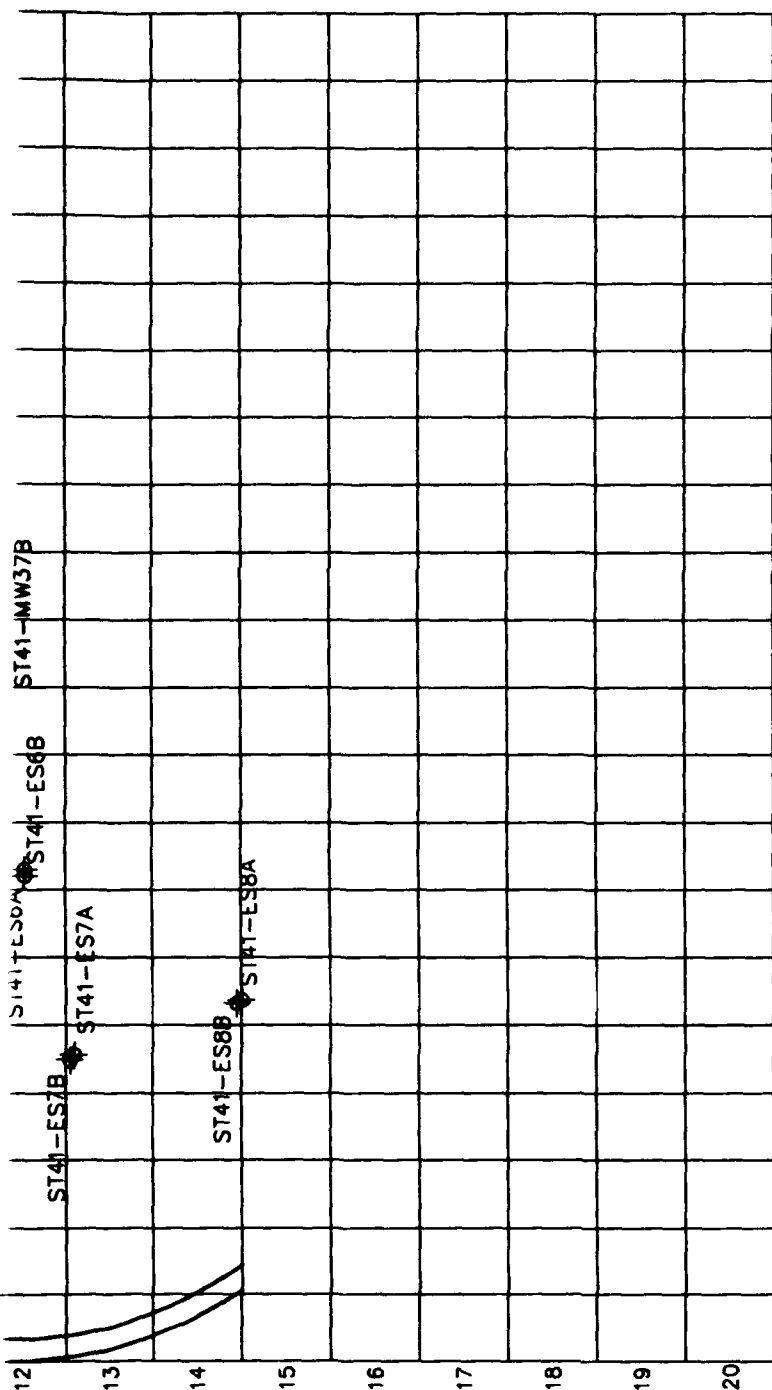
-  RO
-  BU
-  GR
-  ST41-29 M
-  ST41-ES3 M
-  Q E
-  Q

0 50

PREDI
AFTER 15
(WEA)

Intri
Elmendor





LEGEND

-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
- ST41-29  MONITORING WELL (1988-1992)
- ST41-ES3  MONITORING WELL (1994)
-  LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE



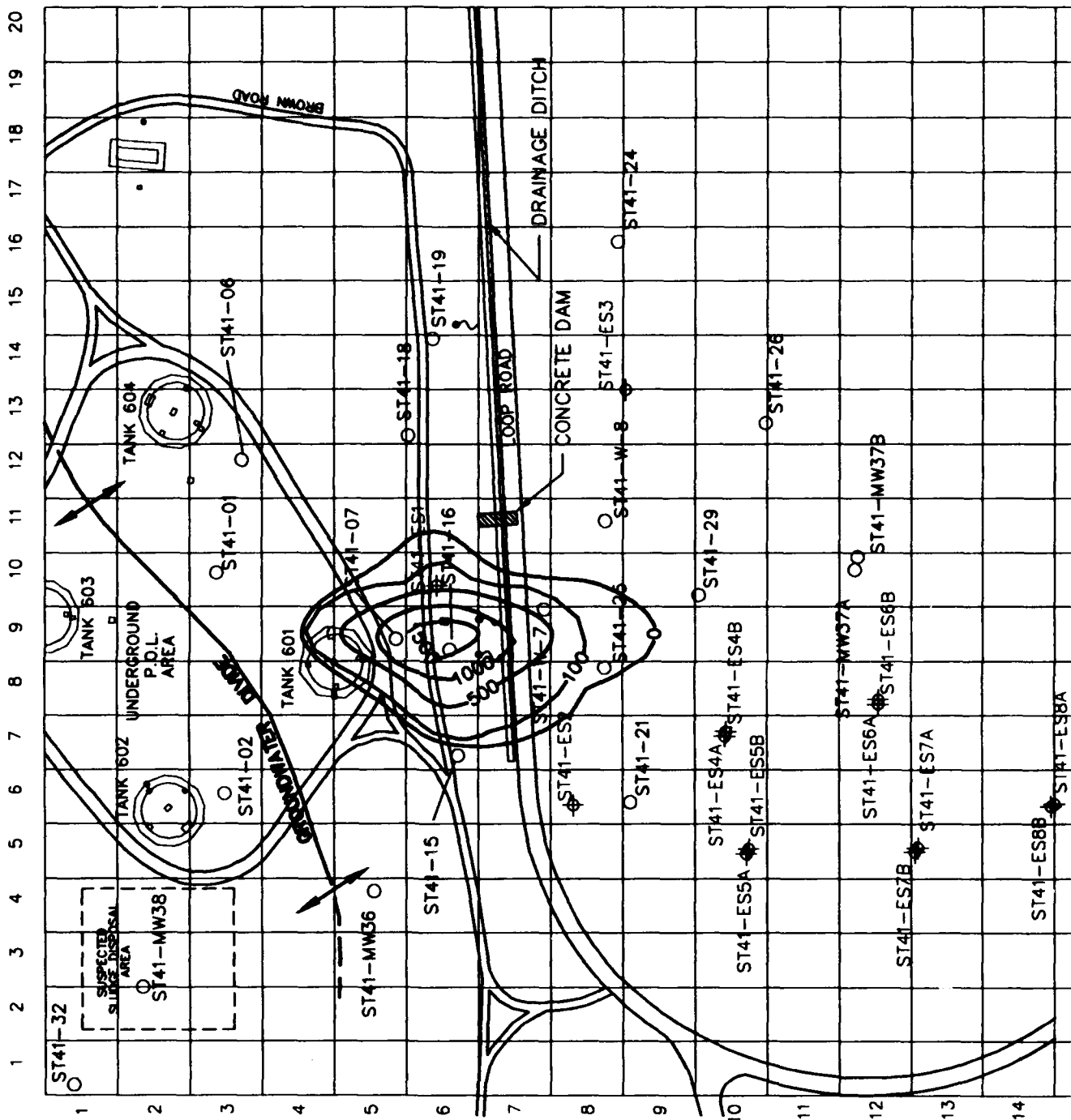
FIGURE 5.15

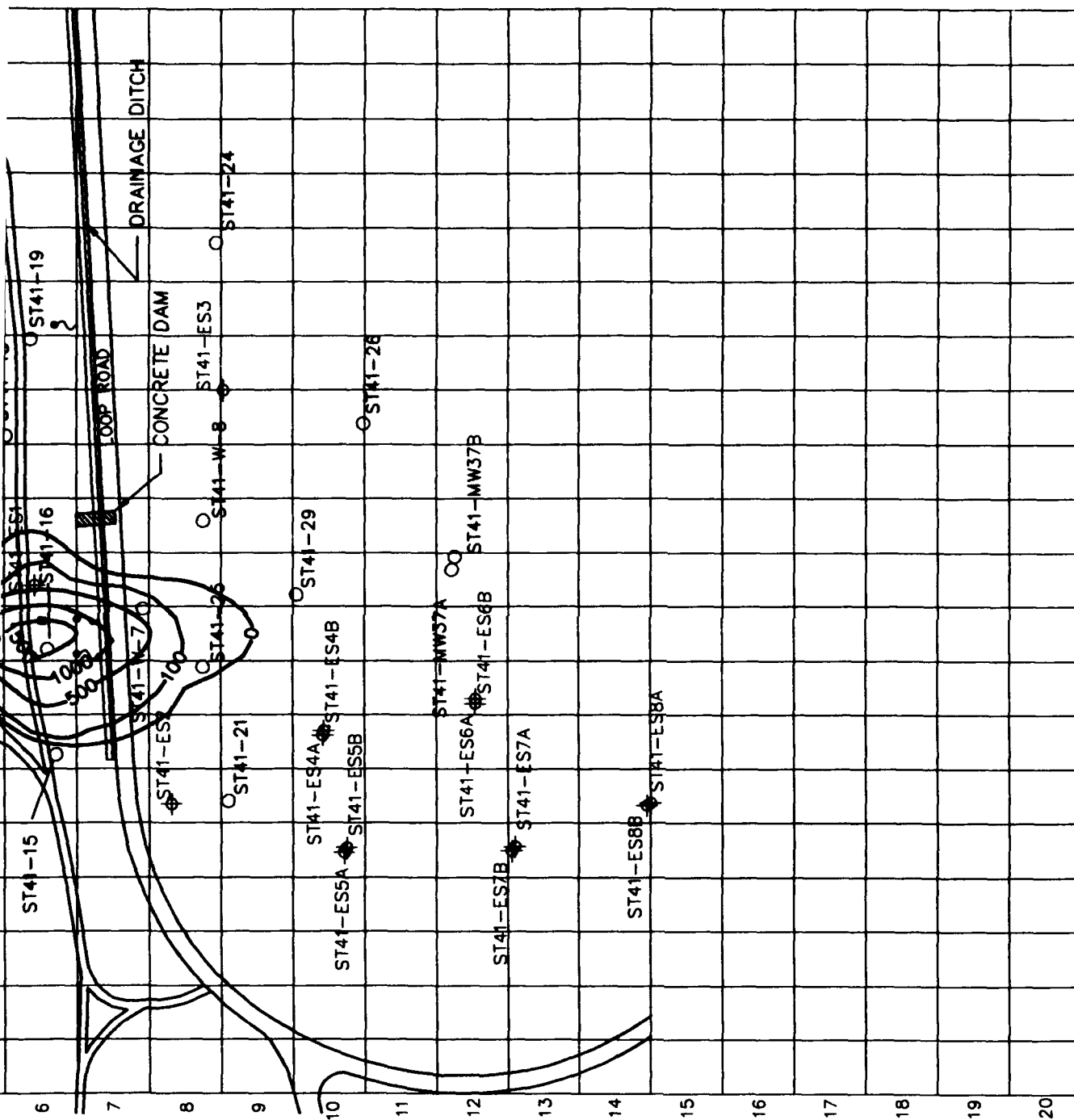
PREDICTED BTEX PLUME
AFTER 15 YEARS, MODEL ST41D
(WEATHERING SOURCE)

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

 **PARSONS
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Denver, Colorado



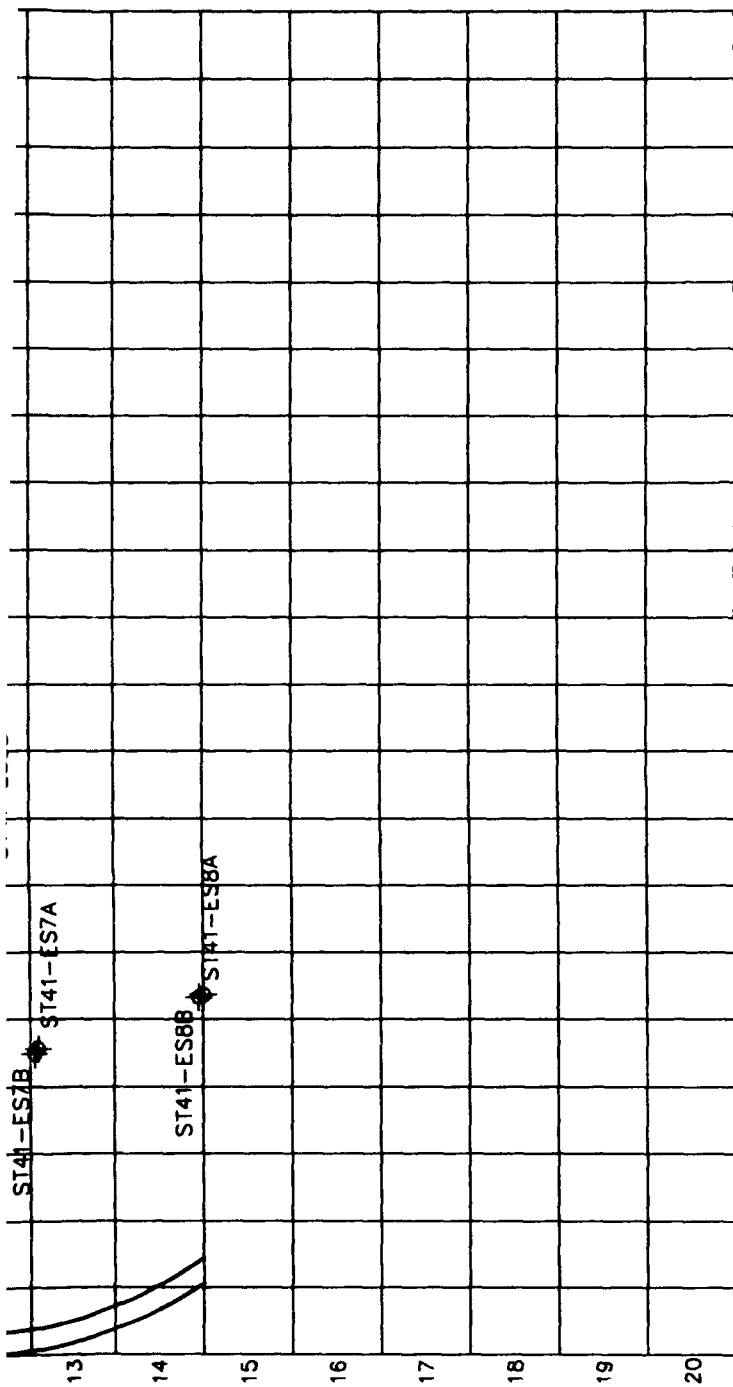


LE

ST41-29 ○

ST41-ES3 ◆

—○—



LEGEND

-  ROAD
-  BUILDING
-  GROUNDWATER SEEP
- ST41-29  MONITORING WELL (1988-1992)
- ST41-ES3  MONITORING WELL (1994)
-  LINE OF EQUAL SIMULATED BTEX CONCENTRATION ($\mu\text{g/L}$)
- CONTOUR INTERVAL = VARIABLE

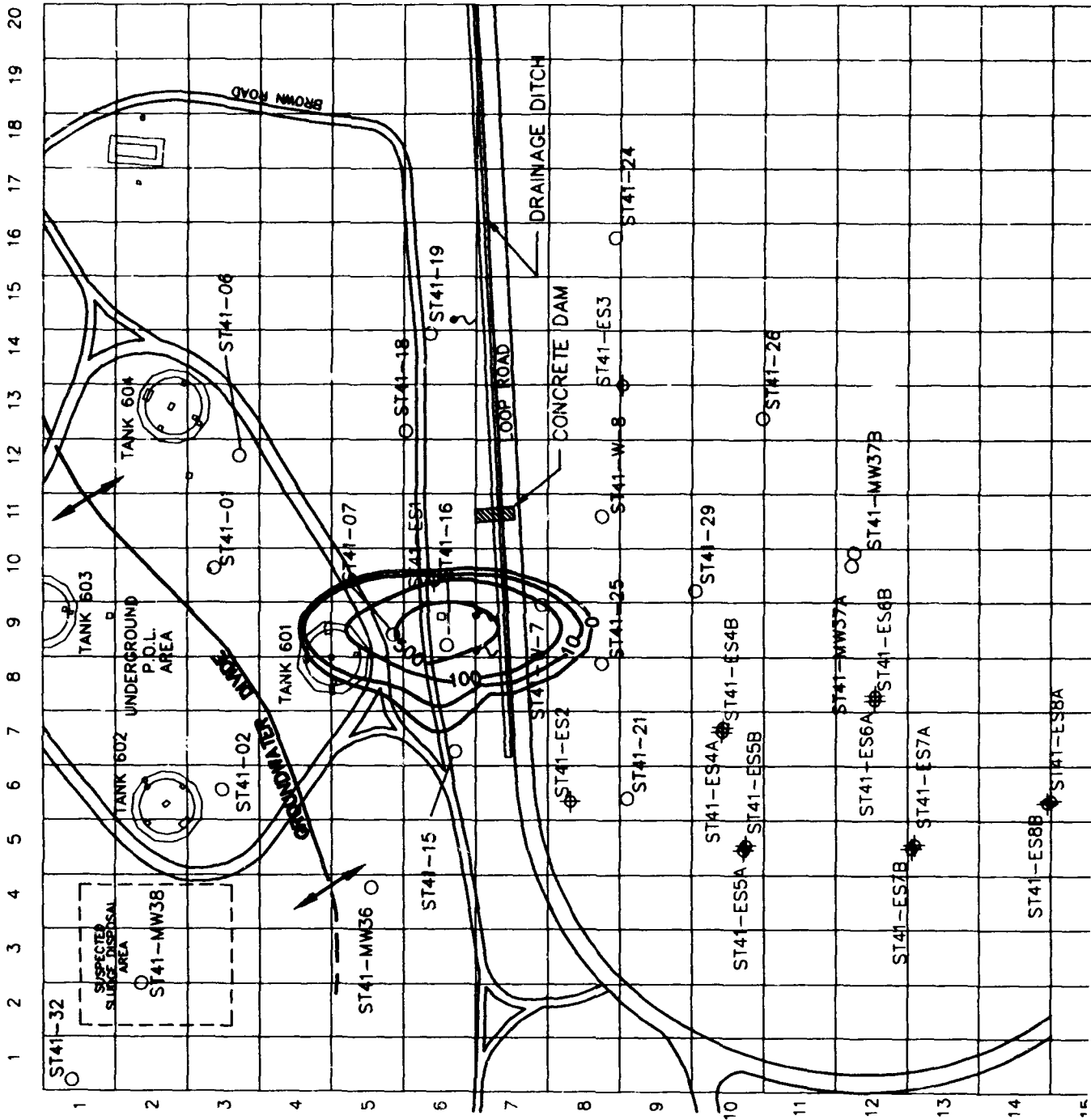


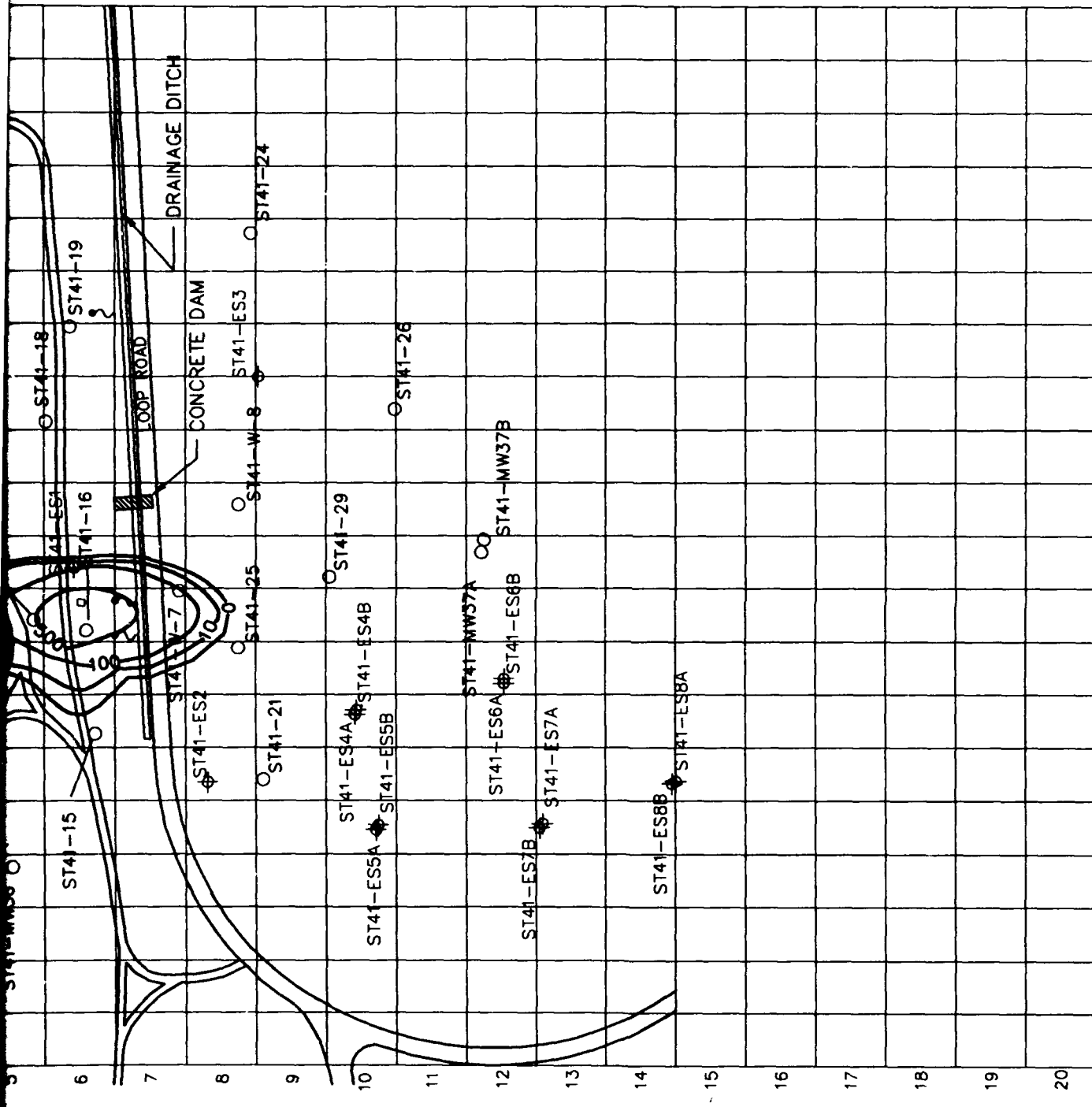
FIGURE 5.16

**PREDICTED BTEX PLUME
AFTER 25 YEARS, MODEL ST41D
(WEATHERING SOURCE)**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska

 **PARSONS
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Denver, Colorado





LE

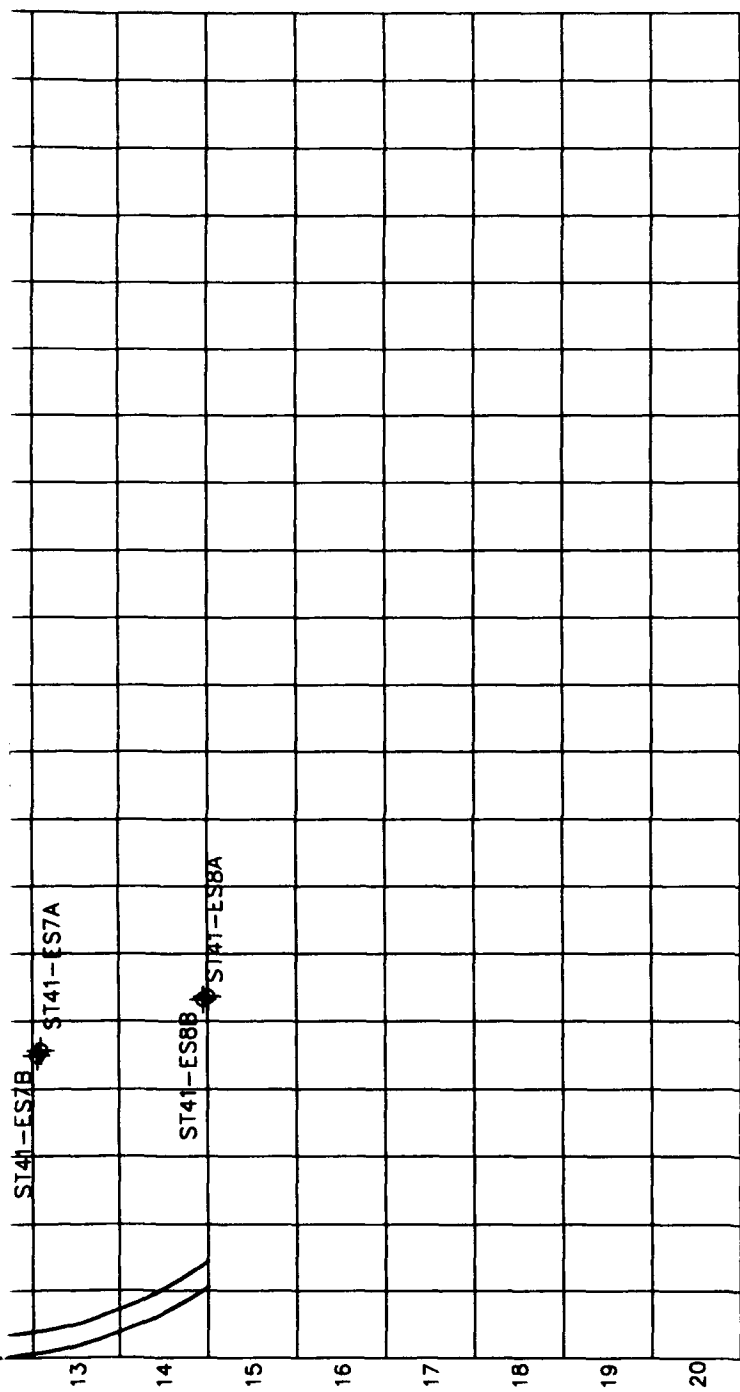
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⊕

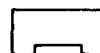
—○—



LEGEND



ROAD



BUILDING



GROUNDWATER SEEP

ST41-29 ○

MONITORING WELL (1988-1992)

ST41-ES3 ⊕

MONITORING WELL (1994)



LINE OF EQUAL SIMULATED BTEX CONCENTRATION (μg/L)

CONTOUR INTERVAL = VARIABLE



FIGURE 5.17

PREDICTED BTEX PLUME
AFTER 29 YEARS, MODEL ST41D
(WEATHERING SOURCE)

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



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ENGINEERING SCIENCE, INC.

Denver, Colorado

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These results suggest that even if the IRA does not continue to operate, dissolved BTEX concentrations should be below MCLs in about 30 years. Concentrations of individual compounds may decrease below MCLs sooner, depending on the fraction of each compound present in the plume and the behavior of each compound in the hydrogeological and microbiological environment present at ST41.

5.7 CONCLUSIONS AND DISCUSSION

The results of three Bioplume II model scenarios for Site ST41 suggest that the dissolved BTEX plume front is not likely to migrate more than 350 feet downgradient of its June 1994 position, and will more likely retreat and degrade. The rate at which the plume retreats and degrades will be controlled by the rate at which BTEX loading from the source area diminishes. The first scenario, model ST41A, assumed that conditions that produced the calibrated model would remain constant (i.e., there would be no reduction in source loading). The second scenario, model ST41C, assumed that due to operation of the IRA system, the source loading rates would gradually decrease to 30 percent of the calibrated rates over a period of 5 years and would continue to decrease due to weathering and biodegradation. Model ST41D, the third scenario, assumed that natural weathering processes alone would reduce BTEX loading rates (in the event the IRA was shut down).

As a worst-case, ST41A results suggest that after 5 years, the BTEX plume would reach its maximum extent, approximately 350 feet downgradient from the source area, before receding slightly and stabilizing. However, it is more likely that the amount of BTEX entering groundwater at the site will continue to decrease. Model ST41C results suggest that if the IRA continues to operate effectively for five years, the dissolved BTEX plume will shrink back from the 1994 plume front and that concentrations will fall below measurable concentrations within 22 years. Results of ST41D suggest that it would take about 30 years for BTEX concentrations to decrease below MCLs if the source area was only left to weather and biodegrade naturally.

The limited migration of BTEX compounds and the stabilization or degradation of the plumes predicted by the simulations is largely a function of anaerobic biodegradation. The moderately high hydraulic conductivity of the "cover sand" plays an important role by flushing water containing DO and other electron acceptors through the BTEX plume, which is retarded with respect to the advective groundwater velocity. As a result, both

aerobic and anaerobic biodegradation is increased due to the continuous influx of electron acceptors.

Bioplume II does not account for desorption of contaminants from the aquifer matrix. However, a review of mass-balance computations for models ST41A and ST41C indicates that the mass of BTEX sorbed onto the aquifer solids is at most 0.9 percent of the total dissolved mass that is removed by aerobic and anaerobic biodegradation. As a result, the concentrations of BTEX that may desorb after the aqueous plume diminishes will be very minor compared to observed concentrations. In addition, as the compounds enter the aqueous phase, they will be diluted and will be more readily available for biodegradation.

In all cases, model simulations are conservative for several reasons, including:

- 1) Aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis are all occurring at this site; however, only aerobic respiration is considered to react instantaneously (relative to the solute velocity) during model simulations, and the anaerobic decay coefficient used in the calibrated model is lower than indicated by site-specific calculations.
- 2) The stoichiometry used to determine the ratio between DO and total BTEX assumed that no microbial cell mass was produced during the reaction. As discussed in Section 4.3.2.1, this approach may be conservative by a factor of three.
- 3) The highest DO concentration observed at the site was 12.6 mg/L. The highest DO concentration assumed during model simulations was 6.0 mg/L.
- 4) A midrange coefficient of retardation for benzene (1.9) was used for model simulations. Minimum coefficient of retardation values for the other BTEX compounds range from 1.26 to 2.52. The use of the low coefficient of retardation tends to increase the distance traveled by the simulated BTEX plume, but may provide a more accurate estimate of benzene transport.

Model ST41A serves as an example to indicate that even under worst-case conditions (i.e., undiminished dissolution of BTEX at the source), natural attenuation processes would limit the migration of the BTEX plume to within 350 feet of the plume front

observed in June 1994. In addition, the observed site conditions strongly suggest that natural attenuation mechanisms have already limited plume migration, as indicated in Section 4.3.1.1. It is possible that, given the conservative assumptions used in the modeling, the observed BTEX plume has already stabilized or started to retreat.

Together, the results of models ST41C and ST41D provide a time frame (i.e., 22 to 30 years) in which BTEX concentrations are likely to decrease below MCLs. Model ST41C shows that reduction of source loading due to operation of the IRA [based on the assumptions made in the FS that the IRA will "eliminate the source of dissolved contaminants in groundwater by removing the floating hydrocarbons and reduce 'hot spots' of groundwater contamination" (Jacobs, 1994b)] and continued weathering of the LNAPL will cause the BTEX plume to shrink and eventually degrade. If these assumptions provide reasonable approximations of actual processes at the site, then the conservative assumptions used for the other parts of the model will also make the predictions of ST41C reasonably conservative. However, if the IRA is less effective than assumed for this model, the time for BTEX concentrations to decrease below MCLs will increase, depending on the actual effect of the IRA on the source areas.

In the event the IRA is shut down, model ST41D results show that that source weathering alone could reduce concentrations below MCLs in about 30 years. The rate at which the source loading was reduced in this model was about one-twentieth of the anaerobic degradation rate of the dissolved BTEX. This should be conservative because mobile and residual LNAPL at the site would be subject to volatilization and continuing dissolution in addition to biodegradation.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of two groundwater remedial alternatives for Site ST41 at Elmendorf AFB. The intent of this evaluation is to largely to illustrate that intrinsic remediation is an appropriate and cost-effective remedial technology to consider when developing final remedial strategies for Site ST41, especially when combined with other innovative and conventional remedial technologies. This discussion is intended for use as a case study and should not be interpreted as replacing conclusions and recommendations in other site documents.

Section 6.1 presents the evaluation criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify the appropriate remedial alternative for shallow groundwater contamination at Site ST41 were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites (OSWER Directive 9355.3-01). These criteria included (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This report does not include a complete discussion of potential applicable or relevant and appropriate requirements (ARARs) for the site. Rather, this report focuses on the potential use of intrinsic remediation and source reduction technologies to reduce BTEX concentrations within the shallow groundwater to levels that pose no risk to human health or the environment.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial technologies such as intrinsic remediation and institutional controls) was analyzed to determine how effectively it will minimize groundwater plume expansion so that groundwater quality standards can be achieved at a downgradient POC. The expected technical effectiveness based on case histories from other sites with similar conditions is also evaluated. The ability to minimize potential impacts on surrounding facilities and operations is considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential risks associated with site-related contamination in shallow groundwater is qualitatively assessed by conservatively estimating if a potential exposure pathway involving groundwater could be completed, either now or in the future. This evaluation criterion also included permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are described. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, is also evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls such as LTM and land use restrictions are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (present worth) of each remedial alternative was estimated for relative comparison. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls is included. An annual inflation factor of 5 percent was assumed in present worth calculations.

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at Site ST41. Factors considered included the objectives of the natural attenuation demonstration program; contaminant, groundwater, and soil properties; present and future land use; and potential exposure pathways. The following section briefly describes each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the suggested remedial alternatives considered for Site ST41.

6.2.1 Program Objectives

The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of this program and the specific Site ST41 study is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (vadose zone soil, soil gas, etc.), technologies have been evaluated based primarily on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater have also been evaluated. Many of the source removal technologies evaluated in this section will also reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated media. Additional program objectives set forth by AFCEE include cost effectiveness and minimization of waste. Technologies that may meet these criteria include institutional controls, soil vapor extraction, bioventing, biosparging, groundwater pump and treat, and intrinsic remediation. Soil excavation, slurry walls, sheet piling, carbon adsorption, *ex situ* biological or chemical treatment, and onsite/offsite disposal are not attractive technology candidates for this site.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at Site ST41 are the BTEX compounds. The source of this contamination is weathered petroleum (i.e., JP-4 fuel and/or AVGAS) present as residual contamination in capillary fringe and saturated soil in the vicinity of Tank 601. The physiochemical characteristics of JP-4, AVGAS, and the individual BTEX compounds will greatly influence the effectiveness and selection of a remedial technology.

Petroleum hydrocarbon mixtures, such as JP-4 or AVGAS, are composed of over 300 compounds with different physiochemical characteristics. JP-4 is classified as an LNAPL with a liquid density of 0.75 gram per cubic centimeter (g/cc) at 20 °C (Smith *et al.*, 1981). AVGAS is also an LNAPL, and liquid densities for gasoline products range from 0.68 to 0.76 g/cc at 20 °C.

Many compounds in JP-4 and AVGAS sorb very well to soil and are concentrated in the capillary fringe because the mixture is less dense than water. JP-4 and AVGAS are slightly soluble in water, with maximum solubilities (BTEX fraction only) of approximately 30 mg/L and 120 to 130 mg/L, respectively. JP-4 and AVGAS are also primary substrates for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures, such as JP-4 or gasoline, may be faster than mineralization of the individual constituents as a result of cometabolic pathways (Jamison *et al.*, 1975; Perry, 1984).

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil than other hydrocarbons in a petroleum mixture. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater, and to migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly amenable to *in situ* degradation by both biotic and abiotic mechanisms. As indicated in Section 4.3.1.1, maximum dissolved BTEX concentrations derived from JP-4 and/or AVGAS are typically in the range of 30 mg/L.

Benzene is very volatile, with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20 °C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic meters per mole (atm-m³/mol) at 25 °C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of pure benzene in water at 20 °C has been reported to be 1,780 mg/L (Verschueren, 1983). Benzene is normally biodegraded to carbon dioxide, with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile, with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about 0.0067 atm-m³/mol at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluene sorbs more readily to soil media relative to benzene, but still is very mobile. The solubility of pure toluene in water at 20°C is approximately 515 mg/L at 20°C (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson *et al.*, 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and a Henry's Law Constant of 0.0066 atm-m³/mol (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene but less strongly than toluene (Abdul *et al.*, 1987). Pure ethylbenzene is also less soluble than benzene and toluene in water at 152 mg/L at 20°C (Verschueren, 1983; Miller *et al.*, 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and 0.007 atm-m³/mol at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1975; Pankow and Rosen, 1988). Of all of the BTEX compounds, xylenes sorb most strongly to soil, but still can leach from soil into the groundwater (Abdul *et al.*, 1987). Pure xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and Lambert, 1988). Xylenes can degrade to carbon dioxide via pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

Based on these physiochemical characteristics, intrinsic remediation, soil vapor extraction, bioventing, biosparging, and groundwater extraction and air stripping technologies could all be effective at collecting, destroying, and/or treating BTEX contaminants at Site ST41.

6.2.3 Site-Specific Conditions

Two general categories of site-specific characteristics were considered when identifying remedial technologies for comparative evaluation as part of this demonstration project. The first category was physical characteristics such as groundwater depth, gradient, flow direction, and soil type, which influence the types of remedial technologies most appropriate for the site. The second category involved assumptions about future land use and potential exposure pathways. Each of these site-specific characteristics have influenced the selection of remedial alternatives included in the comparative evaluation.

6.2.3.1 Groundwater and Soil Characteristics

Site geology and hydrogeology will have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Aquifer slug tests conducted at Site ST41 indicate moderately high conductivity values for the "cover sand" unit bounding the Elmendorf Moraine and moderately low conductivity values for glacial till in and on the moraine. Estimated hydraulic conductivities ranged from 5×10^{-5} to 7.9×10^{-3} ft/min. The source area is in glacial till, for which hydraulic conductivity is relatively low. Much of the plume body is present in the "cover sand" unit, which has moderately high hydraulic conductivity. The hydraulic conductivity at this site directly influences the fate and transport of contaminants. Migration of the groundwater plume increases the areal extent of contamination (i.e., plume expansion) but decreases the average concentration within the aquifer via dilution and increased biodegradation.

Hydraulic conductivity affects plume expansion and migration, and will also impact the effectiveness of other remedial technologies, such as groundwater extraction, LNAPL removal, and intrinsic remediation. For example, it would be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in areas of high hydraulic conductivity than in areas of low conductivity. Contaminant recovery may also be maximized when contaminants are not significantly sorbed to and retarded by phreatic soil. However, Site ST41 soils have moderate to high TOC contents (up to 25.9 percent), and field observations and hydraulic conductivity testing suggest that pumping rates, even in the "cover sand", would be relatively low.

The movement of contaminants within the subsurface away from the source will also increase the effectiveness of natural biodegradation processes by distributing the contaminant mass into areas enriched with electron acceptors. To satisfy the requirements of indigenous microbial activity and intrinsic remediation, the aquifer must also provide an adequate and available carbon or energy source, electron acceptors, essential nutrients, proper ranges of pH, temperature, and redox potential.

Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this document indicate that, in the vicinity of Tank 601, Site ST41 is characterized by adequate and available carbon/energy sources and electron acceptors to support

measurable biodegradation of fuel hydrocarbon contamination by indigenous microorganisms. DO, nitrate, ferric iron, sulfate, and carbon dioxide (which is utilized during methanogenesis) represent sources of electron acceptor capacity for the biodegradation of BTEX compounds at the site. Further, because fuel hydrocarbon-degrading microorganisms have been known to thrive under a wide range of temperature and pH conditions (Freeze and Cherry, 1979), the physical and chemical conditions of the groundwater and phreatic soil at Site ST41 are not likely to inhibit microorganism growth, although growth rates might be slowed by the relatively low temperatures.

Fuel hydrocarbon-degrading microorganisms are ubiquitous, and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1977; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Microbe addition was not considered a viable remedial technology for Site ST41.

6.2.3.2 Potential Exposure Pathways

A pathways analysis identifies the potential human and ecological receptors that could potentially come into contact with site-related contamination and the pathways through which these receptors might be exposed. To have a completed exposure pathway, there must be a source of contamination, a potential mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining if the approach will be sufficient and adequate to minimize plume expansion so that potential exposure pathways involving shallow groundwater are incomplete.

Assumptions about current and future land uses at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated. The source area consists of USTs and related

facilities, including piping, distribution lines, and former condensate drain lines. North, west, and east of Site ST41, the land is generally undeveloped except for gravel roads and utility corridors. The area immediately south of the site is a clear zone for the east-west runway; immediately south of the clear zone, the land is generally undeveloped. The groundwater plume originating from Site ST41 is migrating to the south, and has impacted groundwater in an area extending from the tank vicinity to an area just south of Loop Road (Figures 4.1 and 4.2). Because this area is within and under the control of Elmendorf AFB, the current land use within and downgradient of the contaminant plume is entirely military/industrial. Other base facilities are located over 2,500 feet south and southeast of the site. The nearest base housing is approximately 1 mile south of ST41. Ultimately, groundwater from the shallow aquifer discharges into Ship Creek, which is more than 2 miles south of the site.

Under reasonable current land use assumptions, potential receptors only include worker populations. It is unlikely that workers could be exposed to site-related contamination in phreatic soils or shallow groundwater unless this material is removed during future construction excavations or remedial activities. Previous soil data did not indicate any widespread areas of soil contamination, and because the IRA trench appears to be limiting groundwater discharge from the seeps south of Tank 601, exposure to the groundwater is also unlikely. Groundwater from the shallow aquifer is not currently used to meet any demands at Elmendorf AFB. On-base water demands are met by supply wells screened in the deep confined aquifer. Exposure pathways involving other environmental media such as shallow soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions. Migration to and discharge of contaminated shallow groundwater into Ship Creek could complete an exposure pathway to human or ecological receptors via dermal contact or possible ingestion, but it is very unlikely that detectable BTEX concentrations from Site ST41 could reach the creek, based on predictive fate and transport modeling (Section 5).

Assumptions about hypothetical future land uses must also be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is adequate and sufficient to provide long-term protection. No future changes in land use in the area of potential site influence are anticipated, so a military/industrial land use assumption is most appropriate. Thus, potential future receptors include only worker populations. The potential future exposure pathways involving workers are identical to those under current conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of the intrinsic remediation technology at this site will require that the source area be maintained as industrial property and that restrictions on shallow groundwater use be enforced in areas downgradient of

Site ST41 until natural attenuation reduces contaminants to levels that pose no risk. If additional source removal technologies such as soil vapor extraction, bioventing, biosparging, or groundwater pump and treat are implemented, they will have some impact on the short- and long-term land use options and will require some level of institutional control and worker protection during remediation.

6.2.3.3 Remediation Goals for Shallow Groundwater

Model results suggest that BTEX compounds are not likely to move more than 350 feet downgradient of the observed plume front. Therefore, an area approximately 400 feet beyond the June 1994 plume boundary has been identified as a possible POC for groundwater remedial activities because this appears to be the maximum extent of future contaminant migration. This is a suitable location for monitoring and for demonstrating compliance with protective groundwater quality standards, such as promulgated groundwater MCLs.

This remedial strategy assumes that compliance with promulgated, single-point remediation goals is not necessary if site-related contamination does not pose a threat to human health or the environment (i.e., the exposure pathway is incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted use. A primary RAO for shallow groundwater within and downgradient of Site ST41 could be limitation of plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX in groundwater at levels that pose a risk. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. A suggested RAO for shallow groundwater at the POC is attainment of federal drinking water MCLs for each of the BTEX compounds listed in Table 6.1. Although it is unlikely that groundwater would be ingested by humans, this level of long-term protection is appropriate.

In summary, available data suggest that there is no complete potential exposure pathway involving shallow groundwater under current conditions. Moreover, it is likely that no potential exposure pathways involving shallow groundwater would be complete under future land use assumptions, provided use of shallow groundwater as a potable or industrial source of water is prohibited by institutional controls within the plume area and within an area approximately 400 feet downgradient of the 1994 plume front. Thus, institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required

duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater.

TABLE 6.1

**SUGGESTED POINT-OF-COMPLIANCE REMEDIATION GOALS
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

Compound	Federal MCL ($\mu\text{g/L}$)	POC Remediation Goal ($\mu\text{g/L}$)
Benzene	5	<5
Toluene	1,000	<1,000
Ethylbenzene	700	<700
Total Xylenes	10,000	<10,000

6.2.4 Summary of Remedial Technology Screening

Several remedial technologies have been identified and screened for use in treating the shallow groundwater at Site ST41. Table 6.2 identifies the initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE intrinsic remediation demonstration, physiochemical properties of the BTEX compounds, and other site-specific characteristics such as hydrogeology, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, and mobile LNAPL removal. Biosparging was considered as a means for containing the plume, but the site data and model results suggest that there would be no significant advantage in pursuing this option due to the amount of DO already present in the shallow aquifer.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
Long-Term Monitoring	Periodic Ground Water Monitoring	Confirmation Wells	Many existing wells are available to confirm the progress of remediation.	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Yes
Institutional Controls	Ground Water Use Control	Land Use Control/Regulate Well Permits	Plume area is currently within the base boundary and land use and ground water use are under base jurisdiction.	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the existing or predicted plume area.	No
		Point-of-Use Treatment	No shallow ground water is extracted from the plume area for any use.	No
		Meetings/Newsletters	Base public relations and environmental management offices have many information avenues to workers and residents.	Yes
Containment of Plume	Hydraulic Controls	Passive Drain Collection	No likely receptors downgradient of site. Installation could disrupt base operations.	No
		Minimum Pumping/Gradient Control	Hydraulic conductivities of site soils are relatively low and may make extraction of sufficient volumes of ground water difficult. No likely receptors downgradient of site.	No
	Physical Controls	Slurry Walls/Grout Curtains	Requires significant disruption of base operating area. Limited effectiveness.	No
		Sheet Piling	Requires significant disruption of base operating area. Limited effectiveness.	No
	Reactive/Semi-Permeable Barriers	Biologically Active Zones	Natural biodegradation of BTEX compounds can be stimulated by allowing contaminated ground water to flow through an aquifer zone which has enhanced oxygen and nutrient conditions.	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
In Situ Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected downgradient of plume to limit plume migration by enhancing biodegradation and reducing BTEX concentrations as the plume moves downgradient from the source area. Limited saturated thickness of aquifer would limit effective radius of sparging wells.	No
		Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Ground water sampling at Hangar 10 indicates that this is a major, ongoing remediation process.	Yes
	Chemical/Physical	Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Limited radius of influence and short-circuiting are common problems.	No
		Vertical Pumping Wells	Entire groundwater plume is pumped by installing numerous wells with submersible pumps. High cost and major disruption to area.	No
		Downgradient Horizontal Drains	See Passive Drain Collection.	No
	Biological	Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	No
		Air Stripping	Cost-effective technology for removing varying concentrations of BTEX at higher flow rates. Already in use as part of IRA.	Yes
	Chemical/Physical	Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem. Carbon is used to treat off-gas from IRA air stripper.	Yes
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	No

TABLE 6.2 (Continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
Aboveground Treatment	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)		Viable option when an IWWTP is readily available and capable of handling BTEX and hydraulic loading.	No
	Discharge to IWWTP or Sanitary Sewer	IWWTP	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Ground water extraction is unlikely.	No
Treated Ground Water Disposal	Treated Ground Water Reinjection	Sanitary Sewer	Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Water from IRA system is currently discharged to sanitary sewer.	Yes
		Vertical Injection Wells	Not recommended due to clogging and high maintenance.	No
	Discharge to Surface Waters	Injection Trenches	Require large trenches and can be subject to injection well permitting.	No
		Storm Drains	Viable option but generally requires NPDES or other discharge permit. Ground water extraction is unlikely.	No
	Free Product Recovery	Dual-Pump Systems	Best suited for sites with >1 foot free product where aboveground ground water treatment already exists	No
Source Removal/Soil Remediation		Skimmer Pumps/Bailers/Wicks	Best suited for sites with <1 foot free product where ground water pumping is undesirable.	No
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive ground water will not be pumped. Utilized in extraction trenches already in place at ST41 as part of IRA.	Yes
		Bioslurping	Combined vapor extraction, bioventing and free product recovery system has been operated at some sites with limited success.	No
	Excavation/Treatment	Biological Landfarming	Excavation may be feasible at this site, but soil remediation appears unnecessary (Jacobs Engineering Group, 1994b).	No

TABLE 6.2 (Concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUND WATER REMEDIATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

General Response Action	Technology Type	Process Option	Implementability	Retain
	Excavation/ Treatment (cont'd)	Thermal Desorption	Excavation may be feasible at this site, but soil remediation appears unnecessary (Jacobs Engineering Group, 1994b).	No
	<i>In Situ</i>	Bioventing	Air injection to stimulate biodegradation of fuel residuals. Heterogeneous, low permeability soil in source area will limit effectiveness.	No
		Soil Vapor Extraction	Vapor extraction has been successfully implemented at other sites. Requires source definition and expansive off-gas treatment. Soils in the source area are not amenable to this option.	No

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into two potential remedial alternatives for the Site ST41. Sufficient information on each remedial alternative is provided to facilitate a comparative analysis of effectiveness, implementability, and cost in Section 6.4.

6.3.1 Alternative 1 - Intrinsic Remediation and Institutional Controls with Long-Term Monitoring

Intrinsic remediation is achieved when naturally occurring attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. Intrinsic remediation results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, intrinsic remediation will reduce dissolved contaminant concentrations below numerical concentration goals, thus protecting human health and the environment. Based on the existing evidence of intrinsic remediation described in Section 4, these processes are occurring at Site ST41 site and will continue to reduce contaminant mass in the plume area. Under this alternative, it is assumed that the IRA system would not continue to operate.

Results of the worst-case model ST41A suggest that the dissolved BTEX plume should reach its maximum extent within 5 years before stabilizing. This plume could extend to a maximum of 350 feet downgradient of the plume front indicated by June 1994 data. This scenario does not account for additional BTEX source reduction due to weathering of the LNAPL in the unsaturated zone. It is likely that as the LNAPL weathers and loading rates decrease further, the dissolved BTEX plume would shrink and concentrations would diminish to levels well below those indicated by ST41A. Model ST41D indicates that with a source weathering rate of 8 percent per year, concentrations of BTEX compounds in groundwater would drop below MCLs in about 30 years.

Implementation of Alternative 1 would require the use of institutional controls such as land use restrictions and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area and long-term restrictions on groundwater well installations within and downgradient of the plume area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within

areas affected by site-related contamination. The two previously discussed model scenarios delineate the maximum estimated plume migration distance. To be conservative, the results of model ST41A should be considered in making decisions regarding groundwater monitoring and potential land use restrictions.

As a minimum, groundwater monitoring would be conducted annually as part of this remedial technology to evaluate the progress of natural attenuation processes. Based on the worst-case plume migration suggested by model ST41A, it is unlikely that benzene concentrations exceeding the MCL of 5 µg/L would be present more than 350 feet downgradient of the 1994 plume front (this would be true even if it were assumed that model contaminant concentrations are composed of benzene only rather than total BTEX). More frequent sampling appears unnecessary because model results suggest that the plume is very close to stabilizing, if it has not done so already. Every 5 years during the monitoring process, sampling data should be evaluated. On the basis of these evaluations, the monitoring schedule can be modified or eliminated as the data indicate.

Because there are no apparent downgradient receptors, three POC wells should be placed downgradient of the modeled maximum extent (i.e., slightly more than 350 feet downgradient of the June 1994 plume front, or approximately 1,000 feet downgradient of Tank 601). In addition, four LTM wells within, upgradient and immediately downgradient of the existing BTEX plume would be used to monitor the effectiveness of intrinsic remediation. LTM wells are further described in Section 7.2.1. Detection of benzene in excess of 5 µg/L at downgradient LTM wells may require additional evaluation and modeling to assess BTEX migration and to determine the probable extent of BTEX migration, or to determine if additional corrective action would be necessary. Land use restrictions would also require reevaluation.

Public education on the selected alternative would be developed to inform base personnel and residents of the scientific principles underlying source reduction and intrinsic remediation. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted every year using data collected from the long-term groundwater monitoring program. The purpose of these periodic reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Continued Mobile LNAPL Removal, Intrinsic Remediation, and Institutional Controls with Long-Term Groundwater Monitoring

Mobile LNAPL recovery operations have been underway at Site ST41 since October 1993. Between mid-October and mid-December 1993, approximately 70 gallons of LNAPL were recovered from three trenches and two wells located across the entire site. One of the trenches and one of the wells are located in the vicinity of the plume emanating from Tank 601. In addition, the IRA system is removing small quantities of contaminated groundwater in areas with relatively high BTEX concentrations. The IRA system is projected to operate for about 5 years (Jacobs, 1994b).

It is important to note that under optimum conditions in coarse-grained soils, a 30- to 50-percent recovery of the spilled fuel is considered excellent. Much of the remaining 50 to 70 percent of the fuel is more tightly occluded and bound in the micropore structure of the soil. Removal of this residual fuel could be accomplished using either soil vapor extraction or bioventing technologies. However, neither of these technologies would be suitable for use in the heterogeneous, fine-grained glacial till in the source area. It is possible that hundreds to thousands of gallons of LNAPL would remain bound to the soil matrix. However, this material would be subjected to continued volatilization, biodegradation, and leaching.

A scenario incorporating source reduction was modeled with Bioplume II (model ST41C), and the results of this simulation are presented in Section 5.6.2. As indicated previously, results of model ST41C suggest that source reduction by removal and weathering of mobile LNAPL would result in plume shrinkage, with total BTEX concentrations decreasing through time. The model suggests that BTEX concentrations will be thoroughly degraded in about 22 years.

Under this alternative, existing mobile LNAPL removal activities would be continued, but no additional source removal technologies would be employed. As with Alternative 1, institutional controls and LTM would be required. POC and LTM wells would be installed and sampled as indicated in the previous section.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis of each of the remedial alternatives based on the effectiveness, implementability, and cost criteria. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - Intrinsic Remediation and Institutional Controls with Long-Term Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II modeling completed to support the intrinsic remediation alternative at Site ST41. Three models (ST41A, ST41C, and ST41D) were used to illustrate a range of potential future conditions at the site.

Model results predicted that natural attenuation mechanisms will significantly limit contaminant migration and reduce contaminant mass and toxicity. Benzene concentrations should not exceed the federal MCL at the POC wells. The Bioplume II model is based upon numerous conservative assumptions. Groundwater monitoring at the LTM and POC wells will ensure the protectiveness of this alternative. While this alternative would not cease to be protective if the benzene plume was intercepted by the POC wells, such an instance would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that excavations or drilling within the source area be conducted only by properly protected site workers. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring saturated soil to the surface. Long-term land use restrictions will be required to ensure that shallow groundwater will not be pumped or removed for potable use within, and approximately 500 feet in all directions from, the existing BTEX plume. Existing health and safety plans should be enforced to reduce risks from installing and monitoring additional POC wells.

Compliance with program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 will satisfy program objectives designed to promote intrinsic remediation as a component of site remediation and to scientifically document naturally occurring processes.

Alternative 1 is based on the effectiveness of enhanced naturally occurring processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. As described earlier, an investigation of the potential effectiveness of naturally occurring processes at Site ST41 using field data and the Bioplume II model demonstrated that the BTEX plume migration will be significantly limited. The model sensitivity analysis completed for this site (Section 5.5) suggests that even under the most conservative (i.e., worst-case) conditions, the naturally occurring processes at Site ST41 should

reduce contaminant migration so that the maximum distance traveled by the plume is unlikely to be beyond the proposed POC wells. The actual maximum migration distance is likely to be less than the maximum predicted distance of 350 feet beyond the June 1994 plume front. It is likely that the plume will fully degrade within 30 years.

Aside from the administrative concerns associated with enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial alternative should provide reliable, continued protection. Worst-case model results suggest that the plume will stabilize within 5 years. However, due to uncertainty about how long the source area would continue to produce dissolved BTEX contamination, it is assumed for cost comparison purposes that monitoring to insure that dissolved benzene concentrations do not exceed federal MCLs at the POC will continue for approximately 15 years under Alternative 1.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Installation of LTM and POC wells and annual groundwater monitoring are standard procedures. Long-term management efforts will be required to ensure proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and verify the effectiveness of this remediation approach. There may also be administrative concerns associated with long-term enforcement of groundwater use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. Regulators and the public will have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement, and the initial regulatory reaction to this alternative has been positive.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. Existing wells would be used for three of the four LTM wells. Therefore, capital costs are limited to the construction of three new POC wells and one new LTM well. Included in the \$172,000 total present worth cost estimate for Alternative 1 are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 15 years.

TABLE 6.3

**ALTERNATIVE 1 - COST ESTIMATE
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA**

<u>Capital Costs</u>	<u>Cost</u>
Design/Construct 3 POC Wells and 1 LTM Well	\$16,000
<u>Operation, Maintenance and Monitoring Costs</u>	<u>Annual Cost</u>
Conduct Annual Groundwater Monitoring at 7 wells (15 years)	\$6,000
Maintain Institutional Controls/Public Education (15 years)	\$5,000
Project Management (15 years)	\$6,000
<u>Present Worth of Alternative 1</u> ^{a/}	\$172,000

^{a/} Based on an annual inflation factor of 5 percent.

6.4.2 Alternative 2 - Continued Mobile LNAPL Removal, Intrinsic Remediation and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

Assuming the IRA LNAPL recovery system and natural weathering processes continue to reduce the mass of BTEX entering groundwater from mobile and residual LNAPL, model results suggest that the BTEX plume front should gradually retreat, and that total BTEX concentrations should diminish throughout the plume. However, because the IRA system would not address dissolved BTEX contamination beyond the trench and may not fully contain dissolved contamination in the trench area, dissolved BTEX concentrations downgradient would continue to be reduced by intrinsic remediation alone. As with Alternative 1, this alternative would require long-term land use restrictions and enforcement of health and safety plans to reduce risks from installing and monitoring LTM and POC wells.

Alternative 2 should provide reliable, continuous protection with little risk from temporary IRA system failures. This alternative also complies with the program goals because intrinsic remediation remains the predominant decontamination method for the site. However, this remedial alternative will result in the generation of other wastes requiring treatment and/or disposal.

As in Alternative 1, it is assumed monitoring to insure that dissolved benzene concentrations do not exceed federal MCLs at the POC will continue for approximately 15 years under Alternative 2. Annual groundwater monitoring will be required during that time to ensure that LNAPL recovery and intrinsic remediation will uniformly reduce BTEX concentrations to levels below MCLs. Costs for operation of the LNAPL recovery system are based on the information presented by Jacobs Engineering Group (1994b).

6.4.2.2 Implementability

Installation and operation of an LNAPL and water recovery/treatment system has already been accomplished as part of the IRA for Site ST41. The technical and administrative implementability concerns associated with the intrinsic remediation and LTM component of this remedial alternative are identical to those discussed in Alternative 1

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are shown in Table 6.4. The total present worth cost of Alternative 2 is \$1,142,000. The increased cost of Alternative 2 over Alternative 1 is solely the result of the addition of operation and maintenance costs for the IRA system, although monitoring would be continued for the same length of time to verify that the plume continues to degrade and that any part of the plume does not reach the POC wells. Annual LTM would continue for 15 years to ensure that intrinsic remediation is preventing BTEX concentrations exceeding MCLs from reaching the POC.

TABLE 6.4
ALTERNATIVE 2 - COST ESTIMATE
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

<u>Capital Costs</u>	<u>Cost</u>
Design/Construct 3 POC Wells and 1 LTM Well	\$16,000
<u>Operation, Maintenance and Monitoring Costs</u>	<u>Annual Cost</u>
Operate and Maintain LNAPL/Water Recovery System (5 years)	\$224,000 ^{a/}
Conduct Annual Groundwater Monitoring of 7 wells (15 years)	\$6,000
Maintain Institutional Controls/Public Education (15 years)	\$5,000
Project Management (15 years)	\$6,000
<u>Present Worth of Alternative 2</u> ^{b/}	<u>\$1,142,000</u>

^{a/} Cost for operating the system for the entire site, from Jacobs Engineering Group (1994b).

^{b/} Based on an annual inflation factor of 5 percent.

6.5 SUGGESTED REMEDIAL APPROACH

Two remedial alternatives have been evaluated for remediation of the shallow groundwater at Site ST41. Components of the alternatives evaluated include mobile LNAPL recovery, intrinsic remediation with LTM, and institutional controls. Table 6.5 summarizes the results of the evaluation based upon effectiveness, implementability, and cost criteria. Based on this evaluation, Alternative 2 appears to be the most favorable approach. Alternative 2 was selected because the removal of additional LNAPL will reduce the long-term toxicity of groundwater at the site and because the capital expenditure has already been made. Alternative 2 should also produce a more rapid reduction in the plume size and more thoroughly reduce the potential of downgradient exposure.

TABLE 6.5

SUMMARY OF REMEDIAL ALTERNATIVES EVALUATION
GROUND WATER REMEDIATION
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1			\$172,000
- Intrinsic Remediation - Long-Term Monitoring	Contaminant mass, volume, and toxicity will be significantly reduced and plume migration should be halted. MCLs for BTEX not likely to be exceeded at POC wells.	Readily implementable. Long-term management, ground water use controls and monitoring required for an estimated 15 years. Minimal exposure of site workers if excavation is carefully controlled in source area. If MCLs are exceeded at POC, additional remedial work may be required.	
Alternative 2			\$1,142,000
- Continued LNAPL Recovery - Intrinsic Remediation - Long-Term Monitoring	Similar to Alternative 1, with the continued operation of the IRA system. Contaminant mass, volume, and toxicity will be reduced slightly more rapidly than in Alternative 1. Less likely that MCLs will be exceeded at POC.	Readily implementable. IRA system already in place and operating. LNAPL recovery estimated to continue for 5 years. Long-term management, ground water controls, and monitoring required for an estimated 15 years. If MCLs are exceeded at POC, additional remedial work may be required.	

Based on all effectiveness criteria, both alternatives make maximum use of intrinsic remediation mechanisms to reduce plume migration and toxicity. Alternative 2 would provide additional protection against further plume migration, but would still rely on intrinsic remediation mechanisms to reduce plume toxicity downgradient of the LNAPL recovery system. Implementation of Alternative 2 could decrease the time frame for remediation, but would not meet AFCEE's waste minimization objective as well as would Alternative 1. However, the recovery system has already been installed and has been operating since October 1993.

Both of the remedial alternatives are implementable, and both alternatives effectively reduce potential hydrocarbon migration and toxicity. Both alternatives should be acceptable to the public and regulatory agencies because they are protective of human health and the environment and reduce groundwater contamination in a relatively short time frame. Implementation of either alternative will require land use and groundwater use controls to be enforced for approximately 15 years, along with annual groundwater monitoring for the same period (unless evaluation of future sampling data indicates that a shorter time frame is appropriate).

The final evaluation criterion used to compare each of the two remedial alternatives was cost. Although the considerable additional cost of Alternative 2 over Alternative 1 may not be justified by the minimal additional protection it provides, the LNAPL recovery system is already installed and has been operating for over a year. In addition, model results suggest that source removal will result in more rapid decreases in BTEX concentrations.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the suggested remedial alternative for Site ST41 (continued LNAPL/source reduction and intrinsic remediation with LTM), a long-term groundwater monitoring plan should be developed. The purpose of this component of the suggested remedial alternative for Site ST41 is to assess site conditions over time, confirm the effectiveness of LNAPL recovery and/or naturally occurring processes at reducing contaminant mass and minimizing contaminant migration, and evaluate the need for additional remediation. The LTM plan presented herein is based on considerations detailed in the AFCEE intrinsic remediation protocol document, and is only a recommended plan. Site-specific physical or administrative considerations may require use of a different plan.

To demonstrate attainment of site-specific remediation goals and to verify the predictions of the Bioplume II model developed for Site ST41, the suggested LTM plan consists of identifying the location of two separate groundwater monitoring networks and developing a groundwater sampling and analysis strategy. The strategy described in this section is designed to monitor plume migration over time and to verify that intrinsic remediation is occurring at rates sufficient to protect potential receptors. In the event that data collected under this LTM program indicate that naturally occurring processes (in addition to the IRA system) are insufficient to protect human health and the environment, contingency controls to augment the beneficial effects of intrinsic remediation would be necessary.

7.2 MONITORING NETWORKS

Two separate sets of wells would be installed at the site as part of the intrinsic remediation with LTM remedial alternative. The first set will consist of four LTM wells located in, upgradient, and downgradient of the observed BTEX plume to verify the results of the

Bioplume II modeling effort and to ensure that natural attenuation is occurring at rates sufficient to minimize plume expansion (i.e., meet the first level of RAOs for the site). This network of wells will consist of existing and proposed wells screened within the shallow aquifer to provide short-term confirmation and verification of the quantitative groundwater modeling results. The second set of groundwater monitoring wells would be located along a line approximately 1,000 feet downgradient from Tank 601 (the suggested POC for this demonstration project). The purpose of the POC wells is to verify that no BTEX compounds exceeding federal MCLs migrate beyond the area under institutional control (i.e., meet the second level of RAOs for the site). This network would consist of three groundwater monitoring wells screened across the first 10 feet of the shallow aquifer. The LTM and POC wells will be sampled for analysis of the parameters listed in Tables 7.1 and 7.2, respectively.

7.2.1 Long-Term Monitoring Wells

At four locations, groundwater wells within, upgradient, and downgradient of the existing BTEX contaminant plume should be used to monitor the effectiveness of intrinsic remediation in reducing total contaminant mass and minimizing contaminant migration at Site ST41. As at all sites, one well upgradient of the existing plume would be monitored. Of the remaining wells, one would be placed in the anaerobic treatment zone, one in the aerobic treatment zone, and the last well would be placed downgradient of the aerobic treatment zone.

At three of the locations, existing wells would be used for this purpose. Well ST41-25 could be used to monitor conditions near the plume core, while monitoring well ST41-ES4A could be used to monitor conditions in the aerobic treatment zone. Monitoring well ST41-ES6A would be used for monitoring downgradient of the plume. Upgradient of the plume, one new well should be installed. Figure 7.1 identifies the proposed locations of the new well and the existing wells to be used for LTM. This network will supplement the POC wells to provide early confirmation of model predictions and to allow additional response time if necessary. The new LTM well would be constructed with a 10-foot screen, with approximately 8 feet of the screen below the water table. All LTM wells should be sampled and analyzed for the parameters listed in Table 7.1 to verify the effectiveness of the intrinsic remediation remedial alternative.

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TABLE 7.1
LONG-TERM MONITORING ANALYTICAL PROTOCOL
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous Iron (Fe ²⁺)	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous Iron (Fe ²⁺)	Colorimetric HACH 25140-25	Alternate method; field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^a	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100-250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Collect 100-250 mL of water in a glass or plastic container	Field
Nitrate (NO ₃ ⁻)	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-Base

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TABLE 7.1 (CONCLUDED)
LONG-TERM MONITORING ANALYTICAL PROTOCOL
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or HACH Sulfaver 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. HACH method is Photometric	Substrate for anaerobic microbial respiration	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for HACH method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions; the redox potential of ground water may range from more than 200 mV to less than -400 mV	Annually	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the US Environmental Protection Agency Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis)	Annually	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base

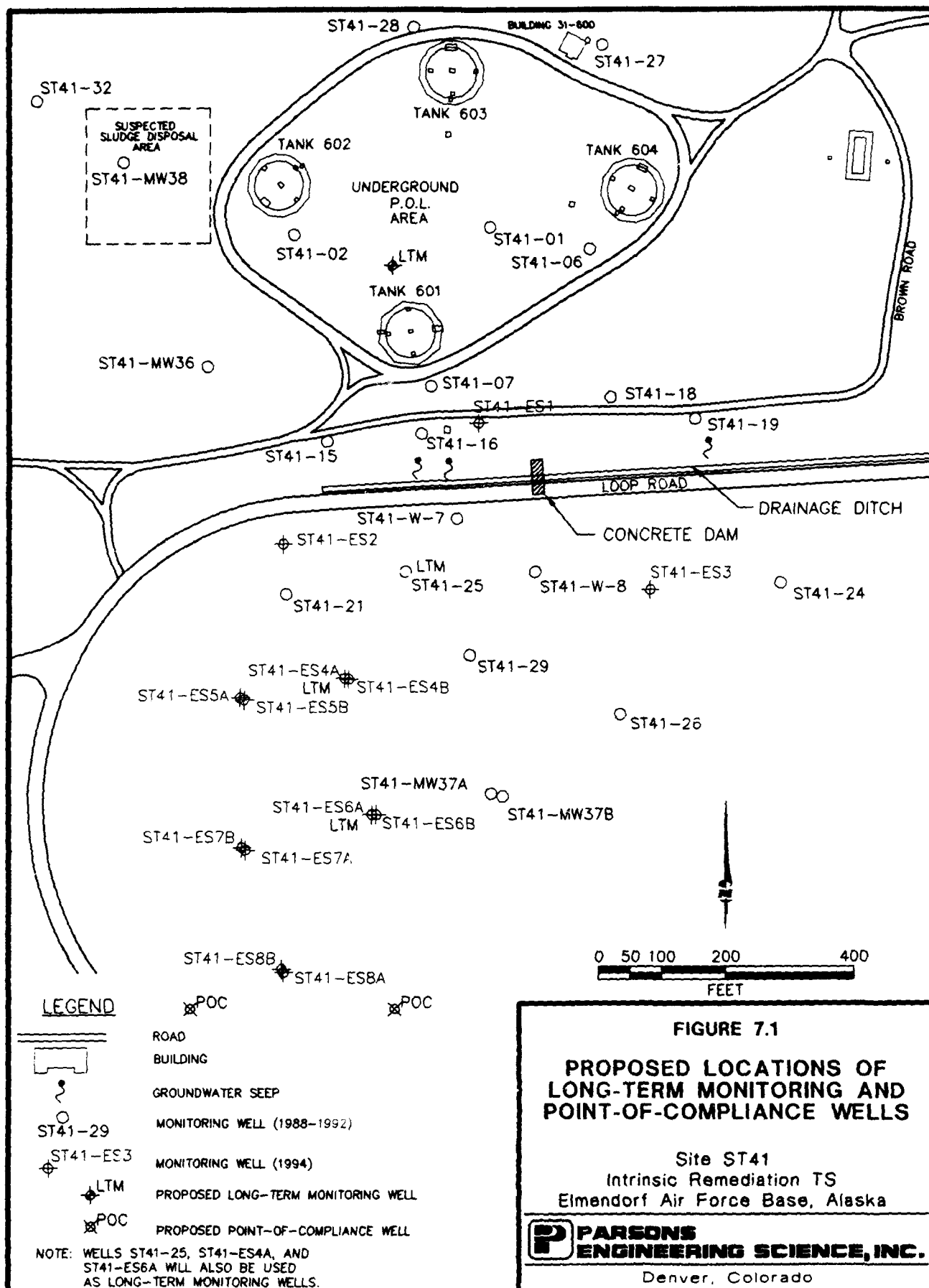
a/ Protocol methods are presented by Wiedemeier *et al.* (1995).

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TABLE 7.2
POINT-OF-COMPLIANCE MONITORING ANALYTICAL PROTOCOL
SITE ST41 INTRINSIC REMEDIATION TS
ELMENDORF AFB, ALASKA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Well development	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in bottles; analyze immediately; alternately, measure dissolved oxygen in situ	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^a	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100-250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Annually	Collect 100-250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of ground water influences and is influenced by biologically mediated reactions; the redox potential of ground water may range from more than 200 mV to less than -400 mV	Annually	Collect 100-250 mL of water in a glass container, filling container from bottom, analyze immediately	Field
Aromatic hydrocarbons (BTEx)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEx is the primary target analyte for monitoring natural attenuation; BTEx concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤ 2	Fixed-base

^a Protocol methods are presented by Wiedemeier *et al.* (1995).



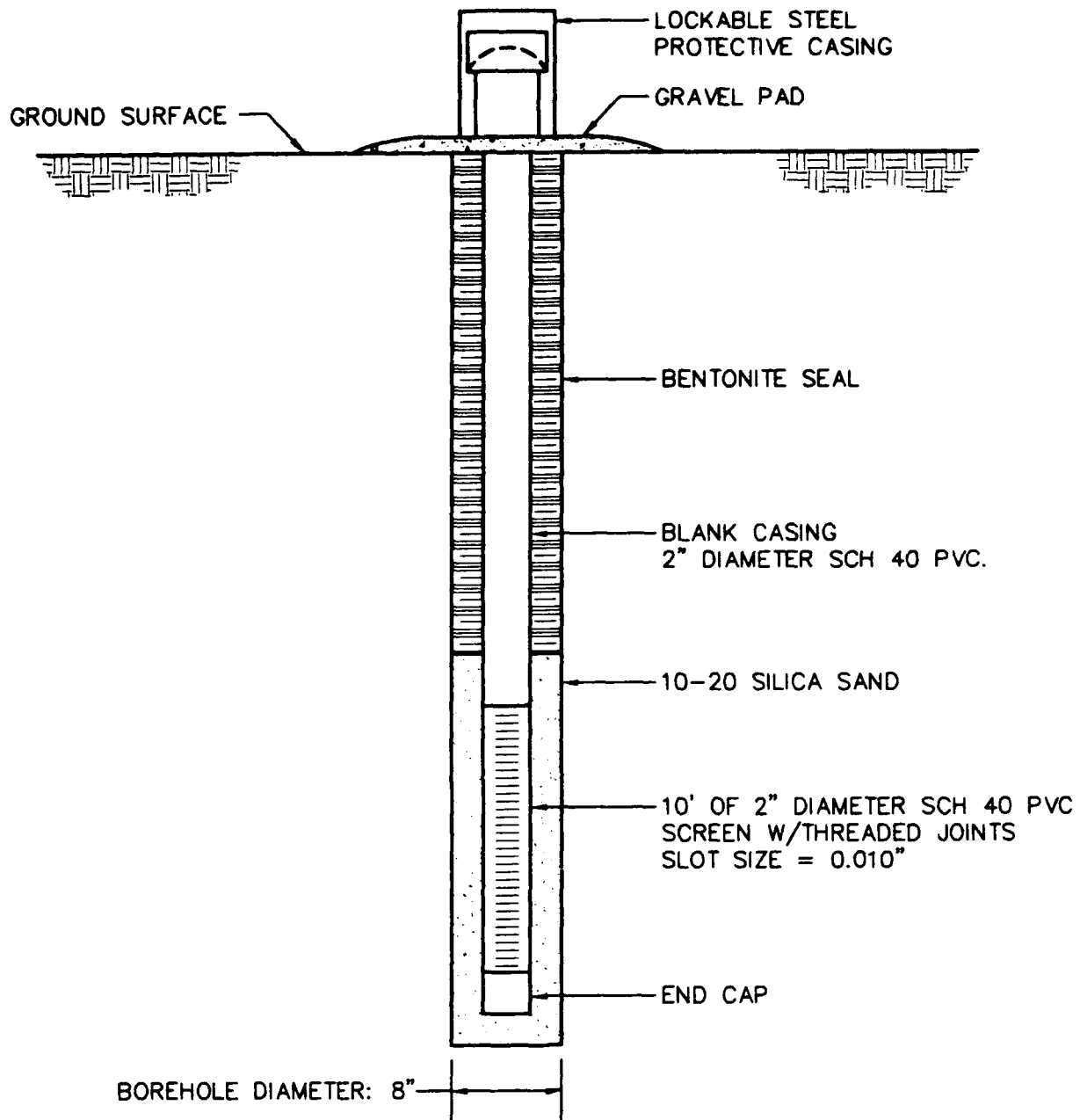
7.2.2 Point-of-Compliance Wells

Three POC monitoring wells should be installed approximately 400 feet downgradient of the existing BTEX plume (approximately 1,000 feet downgradient of Tank 601). Figure 7.1 shows the proposed locations of these wells. The purpose of the POC wells is to verify that no contaminated groundwater exceeding federal MCLs migrates beyond the area under institutional control. Although model results suggest that the contaminant plume will not migrate beyond this location at concentrations exceeding chemical-specific federal MCLs, these POC wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with site-specific numerical remediation goals. These wells would be installed and monitored for the parameters listed in Table 7.2 to assure that the selected remedy is providing the anticipated level of risk reduction and remediation at the site.

As with the LTM wells, the POC wells would also be screened in the same hydrogeologic unit as the contaminant plume. Data presented in this report concerning the nature and extent of contamination at the site suggest that a 10-foot screen with approximately 8 feet of screen below the groundwater surface will be sufficient to intercept the contaminant plume at this site. Figure 7.2 is a proposed groundwater monitoring well completion diagram for both the LTM well and the POC wells.

7.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at Site ST41 to protect human health and the environment and meet site-specific remediation goals, the suggested long-term groundwater monitoring plan includes a comprehensive sampling and analysis plan. Both LTM and POC wells would be sampled and analyzed annually to verify that naturally occurring processes are *effectively reducing contaminant mass and mobility*. Reductions in toxicity would be implied by mass reduction. The sampling and analysis plan would also be aimed at assuring intrinsic remediation can achieve site-specific remediation concentration goals for BTEX compounds and protect human health and the environment.



NOT TO SCALE

FIGURE 7.2

**PROPOSED MONITORING WELL
COMPLETION DIAGRAM**

Site ST41
Intrinsic Remediation TS
Elmendorf Air Force Base, Alaska



**PARSONS
ENGINEERING SCIENCE, INC.**

Denver, Colorado

7.3.1 Analytical Protocol

All LTM and POC wells in the LTM program would be sampled and analyzed to determine compliance with chemical-specific remediation goals and to verify the effectiveness of intrinsic remediation at the site. Water level measurements should be made during each sampling event. Groundwater samples would be analyzed for the parameters listed in Tables 7.1 and 7.2. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating the LTM program.

7.3.2 Sampling Frequency

Each of the LTM and POC sampling points will be sampled once each year for 15 years. If the data collected during this time period supports the anticipated effectiveness of the intrinsic remediation alternative at this site, the sampling frequency can be reduced to once every year for all wells in the LTM program, or eliminated. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a TS conducted to evaluate the use of intrinsic remediation (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater in the vicinity of Tank 601 at Site ST41, Elmendorf AFB, Alaska. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of fuel hydrocarbon compounds dissolved in groundwater. Groundwater contaminant and geochemical data strongly suggest that biodegradation of fuel hydrocarbons is occurring at the site via aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis.

To collect the data necessary for the intrinsic remediation demonstration, Parsons ES and USEPA researchers collected soil and groundwater samples from the site. Physical and chemical data collected under this program were supplemented with data collected during previous site characterization events. Site-specific geologic, hydrologic, and laboratory analytical data were then used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume. Extensive site-specific data were used for model calibration and implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for sediments similar to those found at the site. Conservative aquifer parameters were used to construct the Bioplume II model for this study, and therefore, the model results presented herein represent conservative scenarios.

Model ST41A was run as an illustrative scenario to show that intrinsic remediation is capable of limiting plume migration, even in the extreme case of a continuing source of undiminished strength. For this model, it was assumed that conditions that produced the calibrated model (including BTEX loading rates) would persist for the duration of the simulation. This is a worst-case scenario, because BTEX loading rates will decrease over time as the LNAPL in the source area weathers and is degraded by biota present in the soil

column, and because IRA source removal is already taking place. This model suggested that the plume would migrate no more than 350 feet beyond the limits observed in 1994 before stabilizing.

On the basis of statements in the RI/FS (Jacobs, 1994b), model ST41C assumed that operation of the IRA system would result in a 70-percent reduction in BTEX loading rates within 5 years. After the IRA operation ceased, it was assumed that natural weathering processes would continue to reduce BTEX loading rates by 8 percent per year. Results of this model suggested that the plume would begin to shrink, and that within 22 years, BTEX concentrations in the source area would be reduced below MCLs. Because future operation of the IRA system is uncertain, model ST41D was run to simulate the effects of source weathering alone. In this model, the source loading rates were decreased by 8 percent per year, with no initial reductions due to operation of the IRA. Results of ST41D suggest that the plume will shrink and that dissolved BTEX concentrations will be reduced below MCLs in about 30 years.

The main uncertainty in the model simulations run for this site is the time frame in which contaminant mass loading into the aquifer will be reduced to the point that natural attenuation mechanisms can thoroughly degrade the dissolved BTEX plume. However, results of all three models suggest that biodegradation mechanisms operating at the site should be quite effective in preventing migration of dissolved BTEX compounds introduced by dissolution within the source area, particularly as the volume of LNAPL in the source area diminishes.

The results of this study suggest that natural attenuation of BTEX compounds is occurring at Site ST41 to the extent that the dissolved concentrations of these compounds in groundwater should be reduced to levels below current regulatory guidelines long before potential downgradient receptors could be adversely affected (i.e., the potential contaminant migration pathway will not be complete for any of the potential receptors described in Section 6.2). Based on the distance to potential downgradient receptors (at least 2,500 feet) and rates of BTEX plume migration and degradation predicted by models ST41A, ST41C, and ST41D, a combination of free product recovery, natural attenuation, institutional controls, and LTM would be a suitable remedial option for BTEX-impacted groundwater near Site ST41. Construction activities in the plume area and groundwater use in and downgradient from the plume area should be restricted for a period of approximately 15 years.

To verify the results of the Bioplume II modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to protect potential downgradient receptors, it is suggested that groundwater from existing monitoring wells ST41-25, ST41-ES4A, ST41-ES6A, and one additional proposed LTM well be sampled annually and analyzed for the parameters listed in Table 7.1. In addition, three POC groundwater monitoring wells should be installed downgradient from the predicted maximum travel distance of the BTEX plume and sampled semiannually for the parameters listed in Table 7.2. Figure 7.1 shows suggested locations for the three new POC monitoring wells and the new LTM well. These wells should be sampled annually for 15 years. If dissolved BTEX concentrations in groundwater in the POC wells are found to exceed the federal MCLs of 5 µg/L for benzene, 1,000 µg/L for toluene, 700 µg/L for ethylbenzene, or 10,000 µg/L for total xylenes, additional evaluation or corrective action may be necessary at this site.

SECTION 9

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APPENDIX A

BORING LOGS, WELL COMPLETION DIAGRAMS, AND
SLUG TEST RESULTS

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES3 CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/8/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL.: 6/8/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 212.6 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No sample. Organic matter/ topsoil.								
			SW	Dark brown, fine to v. coarse SAND with gravel.		2-4		4,4 1,3	1.7			
			ML	Gray-tan clayey SILT with gravel. Increased amounts of cobbles with depth.						1.7		
	5		SP			4-8		4,3 3,6	1.7			
			+	SAND lens from 7.0 to 7.5 bgs.		6-8		3,5 5,7	1.7		1.7	
			ML	Clayey SILT with gravel and cobbles.								
			CH			8-10		3,7 9,12	1.7			
	10			Gray-blue, silty CLAY beginning at 8.1 feet bgs. Bootlegger Cove Formation. Total depth at 10 feet bgs.								
	15											
	20											
	25											
	30											
	35											

CONTINUOUS DRIVE

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level
 During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska

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 Denver, Colorado

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES4B CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/8/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL: 6/8/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 210.7 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ	TOTAL	TPH
	1			No Sample.								
			ML	Tan to brown SILT. Trace of sand. Plant matter at 2.5 bgs. 1 foot lens of dark brown silty PEAT.		2-4		1,1 1,1	1.7			
			PT									
			ML	Dark brown SILT w/ trace of clay. Organic matter.		4-6		1,1 2,3	1.7			
	5		SW-SM	Grey-brown, v. fine to coarse SAND w/ silt. Moist.		6-8		3,5 5,8	1.7			
				SAA with trace of gravel. Saturated.		8-10		2,1 8,12	1.7			
				Blue-grey, silty, v. fine to coarse SAND at 9' bgs.		10-12		6,6 11,12	1.7			
	10			Blue-grey, gravelly SAND at 10' bgs. Massive.		12-14		9,10 21,16	1.7			
						14-16			1.7			
	15		MH	Dark grey, clayey and sandy SILT. Dense and stiff. Massive. Probably Bootlegger Cove Formation.		16-18		5,11 11	1.7			
						18-20		6,8 8,12	1.7			
	20			Total depth at 20 feet bgs.								
	25											
	30											
	35											

CONTINUOUS DRIVE

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level
 During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska



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Sheet 1 of 1

BORING NO.: ST41-ES5B CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/9/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL.: 6/9/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 210.6 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No Sample.								
				Brown, silty, gravelly SAND to gravelly, sandy SILT. Occasional cobbles. 6" recovery from 2'-4' caused by cobble in spoon tip. Saturated at 5' bgs.		2-4			1.7			
						4-6			1.7			
						6-8			3.4			
						8-10		1.2 5.6	1.7			
	10			1" SAND lenses present from 10' to 12' bgs.		10-12		5.8 9.4	1.7			
				Dark reddish-brown sandy GRAVEL. Fine to coarse gravel with v. fine to medium sand. Massive.		12-14		10.17 14.14	3.4			
	15		GP	Silty, gravelly SAND as above.		14-16		7.10 10.12	1.7			
			SP	Sandy GRAVEL as above.		16-18			1.7			
			SP-SM	Brown, silty, v. fine to fine SAND with traces of clay. Dense and Massive.		18-20		9.17 10.27	1.7			
	20		SP-SM	Grey, silty v. fine to fine SAND.								
				Total depth to 22' bgs.								
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

Water level
 During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska

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GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES1 CONTRACTOR: HUGHES DATE SPUD: 6/7/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL.: 6/7/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 244.5 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	TLV(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No Sample. Area Excavated.								
									1.7			
				Dark brown SILT with very fine sand. Trace of gravel. Friable. Massive. Areas of oxidation present.	2-4			4.5 2.3	1.7			
	5		ML		4-6			3.3 5.6	1.7			
				SAA with a trace of clay present. Blocky and dense.	6-8			2.4 6.6	1.7			
					8-10			3.5 6.7	1.7			
	10				10-12			3.6 6.10	1.7			
				SAA with increased moisture near bottom. Dense.	12-14			6.10 11.14	1.7			
					14-16			5.7 9.11	1.7			
	15		SP	Alternating 3-4" layers of silty, fine- to medium-grained SAND with 6" layers of SILT as above.	16-18			3.8 10.11	1.7			
			CH	Dark, blue-gray CLAY. Stiff, massive. Possibly the Bootlegger Cove Formation.	18-20			3.3 7.10	1.7			
	20			Total Depth at 20 feet								
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

 Water level
 During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska

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Denver, Colorado

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES2 CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/7/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL.: 6/7/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 219.9 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No Sample. 1 foot of topsoil.								
			PT	PEAT with abundant organic plant matter. Loose. Wood fragments present.	2-4			2.2 3.2	3.4			
	5		OL	Dark brown, peaty SILT. Plant matter present. Gravel and cobbles at base. Saturated at 6 feet bgs.	4-6			3.1 2.2	1.7			
			SP	Blue-grey, fine- to very fine-grained SAND.	6-8			4.4 12.21	1.7			
	10		CH	Blue-grey silty CLAY. Bootlegger Cove Formation. Total depth at 10 feet bgs.	8-10			2.2 3.4	1.7			
	15											
	20											
	25											
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level
 During Drilling

GEOLOGIC BORING LOG

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GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES88 CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/10/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL: 6/10/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 191.1 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No Sample. Topsoil and peaty material.								
			ML	Brown, sandy SILT. V. loose. Some plant fragments.		2-4		1 w/w (1')	1.7			
			PT	Peat								
			ML	Brown SILT as above.		4-6		1 w/w (1')	1.7			
	5		PT	Peat, as above. Moist.								
			SM	Grey, silty v. fine to fine SAND. Moderately loose. Massive. Saturated at 7.3' bgs.		6-8		2.3 7.8	1.7			
				V. fine to v. coarse SAND w/ gravel. Occasional cobbles.		8-10		5.7 12	1.7			
	10		SW	Brown SAND as above.		10-12			1.7			
						12-14		4.7 8.9	1.7			
	15					14-16		5.5 5.0	1.7			
						16-18		2.3 4	1.7			
									1.7			
	20			No sample- heaving SAND								
				Bootlegger Cove Formation reported by "feel" by driller at 22.5' bgs.								
	25			Total depth at 23' bgs.								
	30											
	35											

CONTINUOUS DRIVE

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

 Water level
 During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska

 **PARSONS**
ENGINEERING SCIENCE, INC.
 Denver, Colorado

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES6B CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/8/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL.: 6/8/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 203.1 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PLTY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTEX(ppm)	TPH (ppm)
	1			No Sample.								
			ML	Brown SILT with traces of v. fine sand and gravel. Moist.		2-4		1,2 2,4	1.7			
	5		SP	Brown, fine to coarse SAND with traces of gravel. Loose. Occasional stringers of silt present.		4-6		5,5 6,7	3.4			
						6-8		6,7 6,10	1.7	1.7		
				Moist at 8' bgs.		8-10		4,8 8,10	3.4			
	10		ML			10-12		6,6 7,7	3.4			
			SW	Brown SILT w/ traces of clay and sand stringers. Dark brown, v. fine to v. coarse SAND with traces of gravel and silt. Loose and massive. Saturated. Decreasing fine sand with depth.		12-14		3,6 6,8	1.7			
	15					14-16		3,6 7,7	1.7			
						16-18		4,8 9,9	1.7			
	20			Stopped sampling- heaving SAND.		18-20		5,10 10	1.7	1.7		
									1.7			
									1.7			
	25		GP/ GW	Driller reports GRAVEL at 22.5 bgs.					1.7			
				Total depth at 25' bgs.								
	30											
	35											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

▼ Water level
 ≡ During Drilling

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska



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 ENGINEERING SCIENCE, INC.**

Denver, Colorado

GEOLOGIC BORING LOG

Sheet 1 of 1

BORING NO.: ST41-ES7B CONTRACTOR: HUGHES DRILLING DATE SPUD: 6/9/94
 CLIENT: AFCEE RIG TYPE: CME 75 DATE CMPL: 6/9/94
 JOB NO.: 722450.07 DRLG METHOD: HOLLOW STEM AUGER ELEVATION: 195.7 feet MSL
 LOCATION: ELMENDORF AFB BORING DIA.: 8 INCHES TEMP: 60 F
 GEOLOGIST: MS/KC DRLG FLUID: NONE WEATHER: PTLY CLOUDY
 COMMENTS: PID BACKGROUND = 1.7 ppm

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample No.	Sample Depth (ft)	Sample Type	Penet Res	PID(ppm)	BZ PID(ppm)	TOTAL BTX(ppm)	TPH (ppm)
	1		ML	No Sample.								
				Brown sandy SILT w/ clay. Trace of gravel. Gray-brown, silty SAND w/ gravel	2-4			2.8 5.4	1.7			
	5		ML	Gray SILT w/ a trace of v. fine sand. Oxidized zones present. Occasional plant fragments.	4-6			1.2 4.3	1.7			
			GP	Gray SILT w/ gravel and sand grading to sandy GRAVEL w/ depth. Saturated at 7' bgs.	6-8			7.7 8.7	1.7			
			SW	Gray, gravely very fine to very coarse SAND. Sub- angular to subrounded, fine to coarse gravel.	8-10			5.6 10.12	1.7			
	10				10-12			4.10 17.21	1.7			
				Driller changed to 18" drives at 12' bgs to avoid over- fill and bending of spoons.	12-13.5			4.8 11	1.7			
	15				14-15.5			12.17 14	1.7			
			SP	Gray fine to coarse SAND with some gravel. Grading down to fine to medium SAND	16-17.5			2.12 11	1.7			
	20			No sample- heaving SAND.					1.7			
			MH	Blue-gray, clayey SILT. Dense and stiff. Probably Bootlegger Cove Formation. Total depth at 21' bgs.	21-22			7.8	1.7			
	25											
	30											
	35											

GEOLOGIC BORING LOG

Site ST41
 Intrinsic Remediation EE/CA
 Elmendorf Air Force Base, Alaska

PARSONS
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NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above
 BZ - Breathing Zone

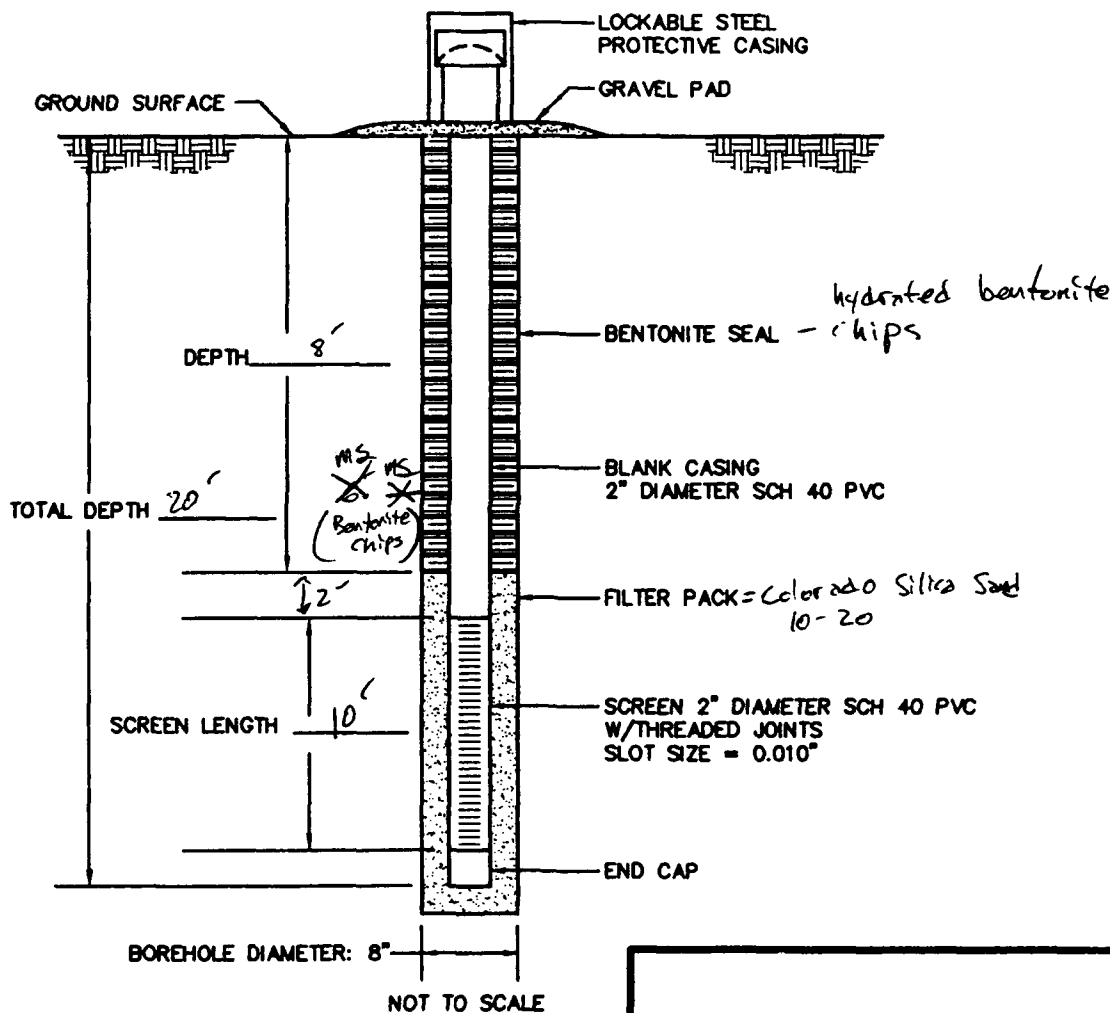
SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

Water level
 During Drilling

FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-E-51
 JOB NUMBER 722450.07 INSTALLATION DATE 6/7/94 LOCATION SITE ST41
 DATUM ELEVATION 247.19' MSL GROUND SURFACE ELEVATION 244.5' MSL
 DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL ~~Colorado Silica Sand~~ MS ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes Drilling Inc.



STABILIZED WATER LEVEL 14.62 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 22.63 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

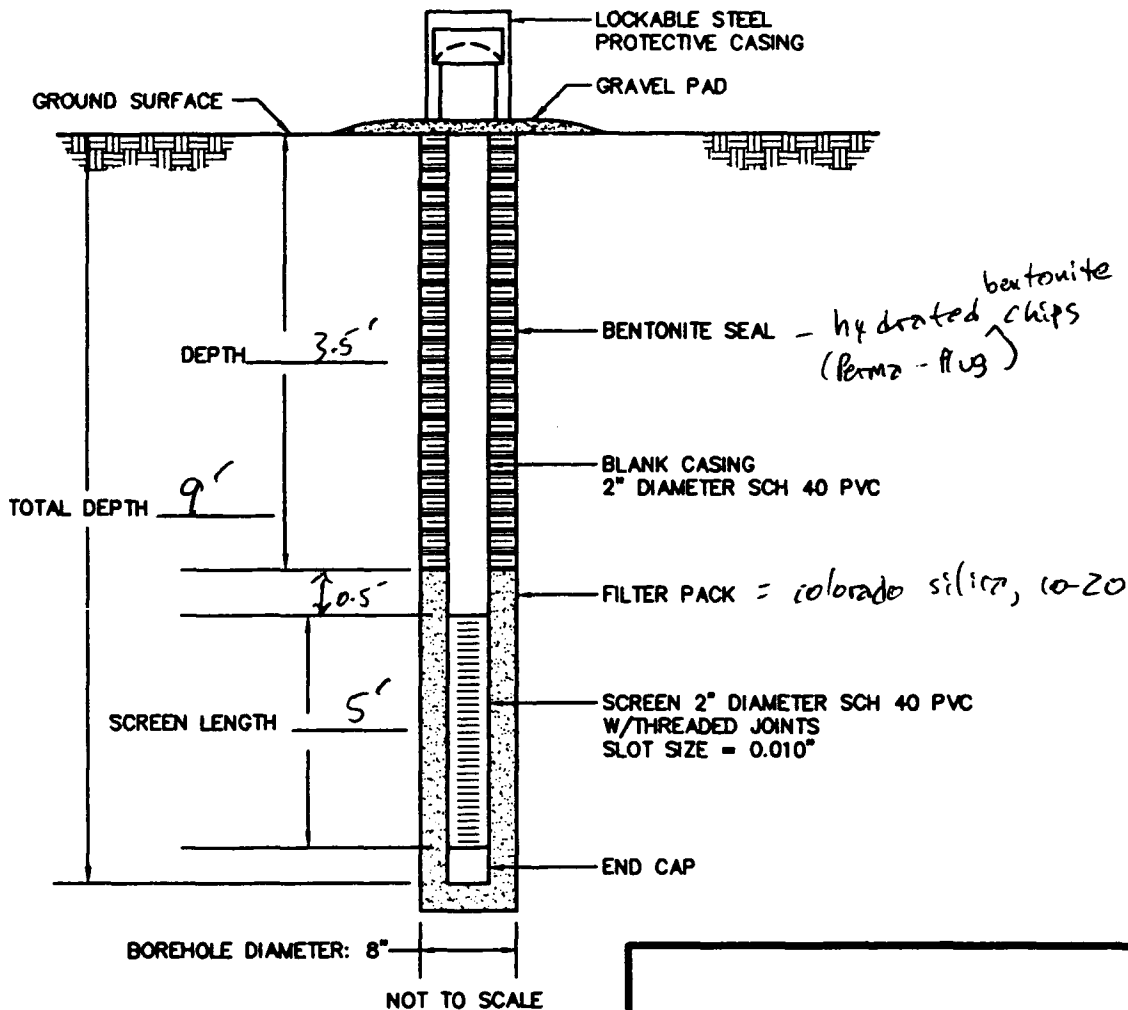
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES2
 JOB NUMBER 722450.07 INSTALLATION DATE 6/7/94 LOCATION SITE ST41
 DATUM ELEVATION 222.71 feet msl GROUND SURFACE ELEVATION 219.9 feet
 DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL ~~S&S~~ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 5.99 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 11.75 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

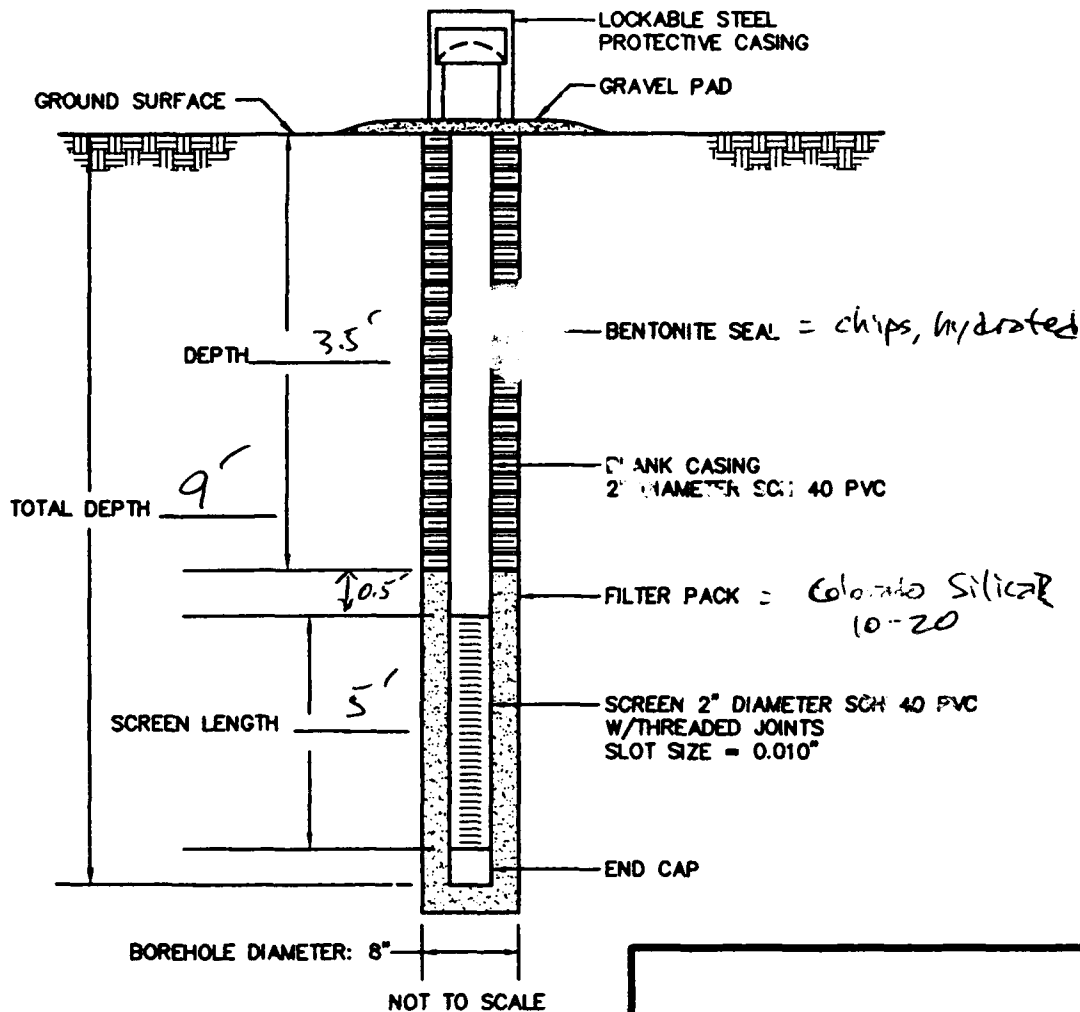
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES3
 JOB NUMBER 722450.07 INSTALLATION DATE 6/8/94 LOCATION SITE ST41
 DATUM ELEVATION 215.44 feet MSL GROUND SURFACE ELEVATION 212.6' MSL
 DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATE 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL M/ L ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 6.75 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 11.93 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

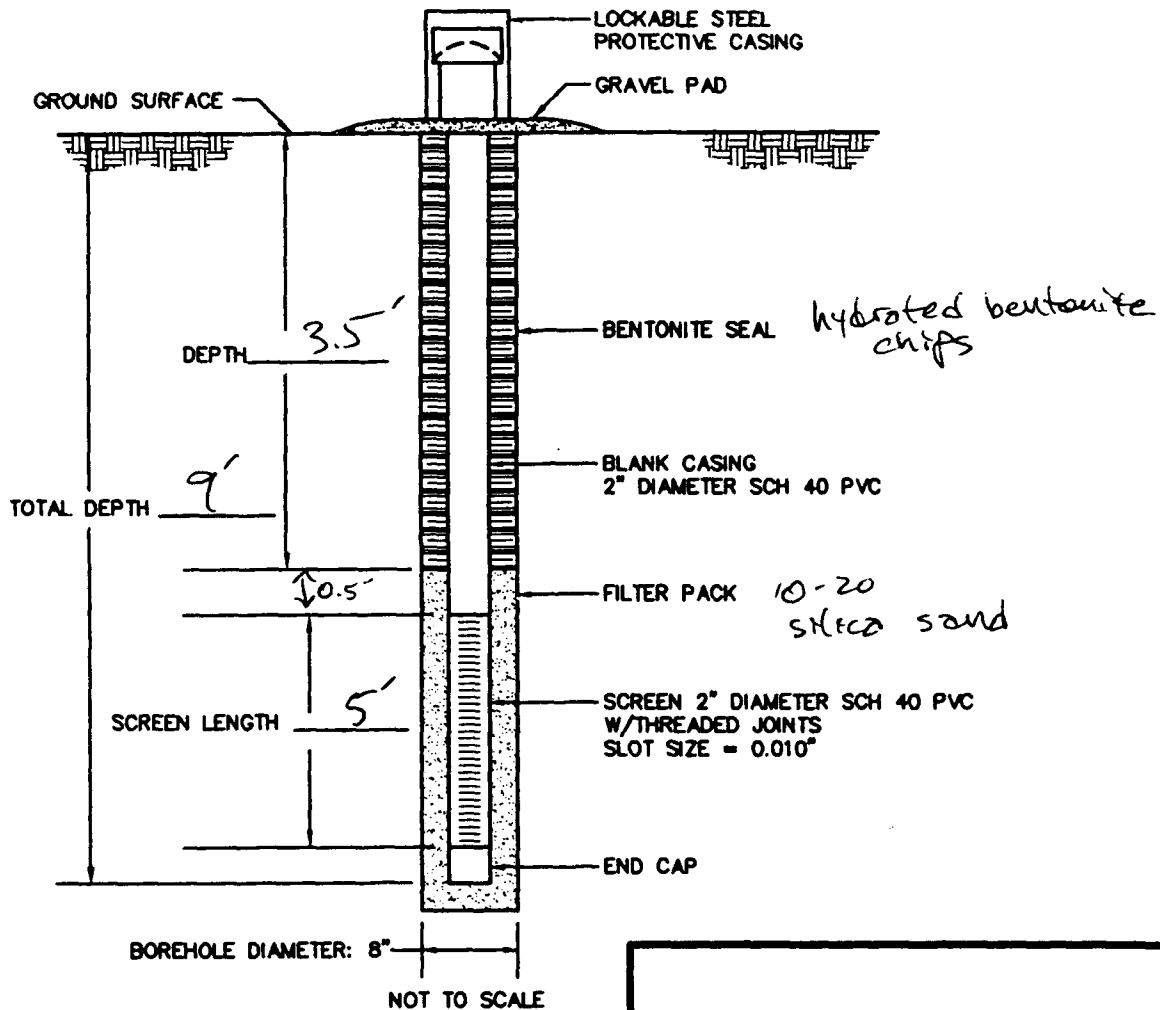
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES4A
JOB NUMBER 722450.07 INSTALLATION DATE 6/9/94 LOCATION SITE ST41
DATUM ELEVATION 213.69 feet msl GROUND SURFACE ELEVATION 211.0 feet
DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 8.39 FEET
BELOW DATUM.
TOTAL WELL DEPTH 11.59 FEET
BELOW DATUM.
MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

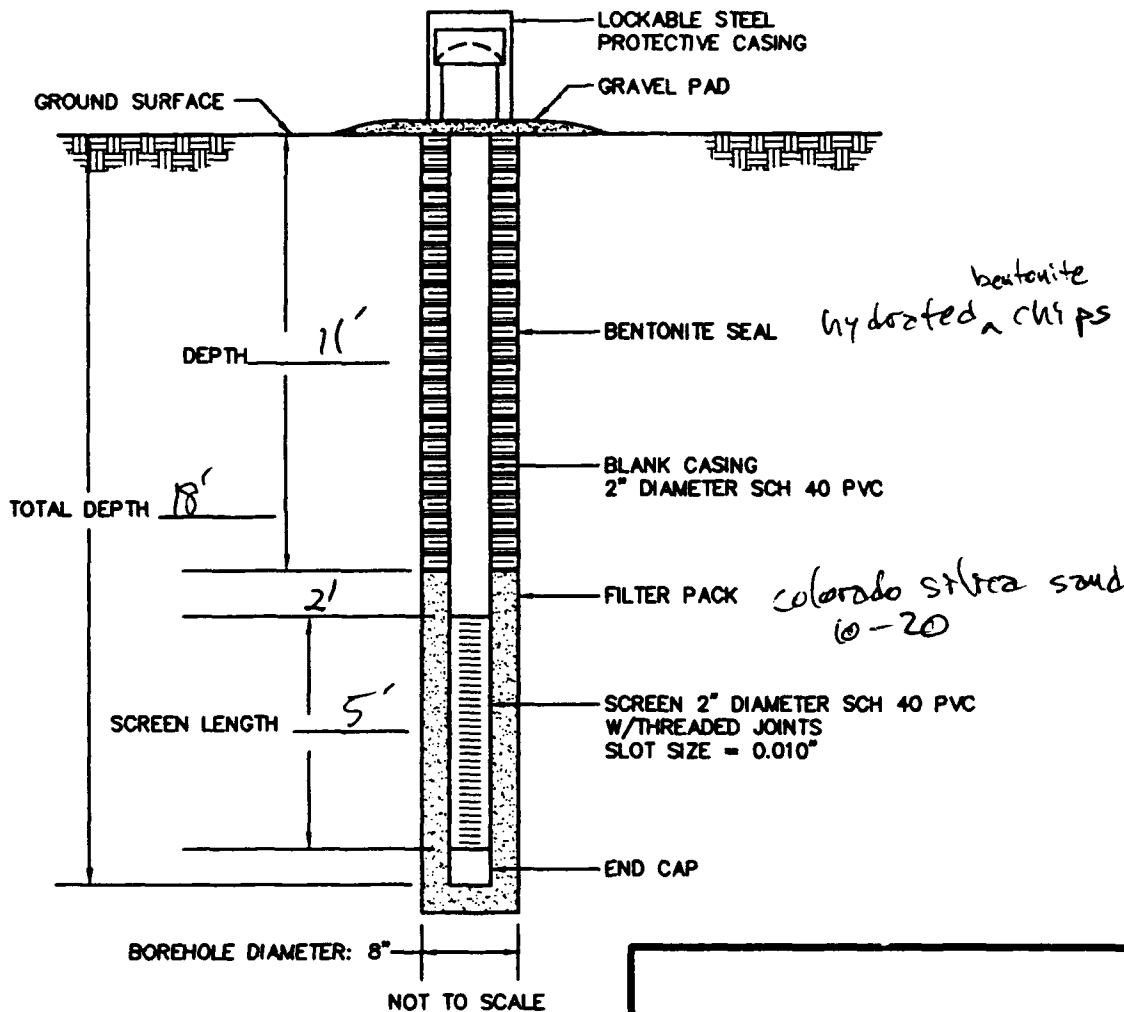
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES4B
 JOB NUMBER 722450.07 INSTALLATION DATE 6/8/94 LOCATION SITE ST41
 DATUM ELEVATION 213.58 feet msl GROUND SURFACE ELEVATION 210.7 feet msl
 DATUM FOR WATER LEVEL MEASUREMENT Top PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 8.98 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 20.86 FEET
 BELOW DATUM.
 MEASURED ON 25 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

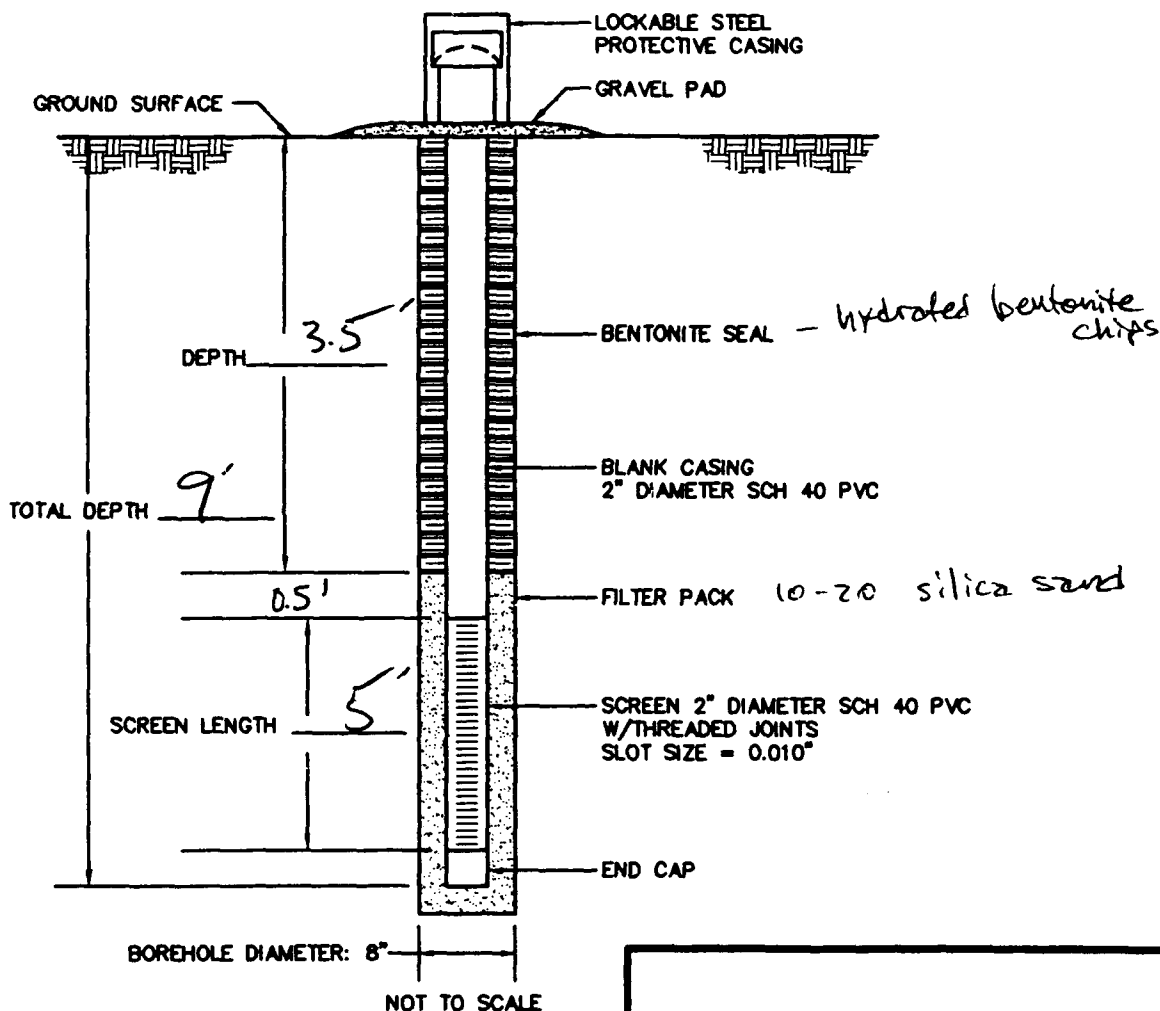
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-E55A
 JOB NUMBER 722450.07 INSTALLATION DATE 6/9/94 LOCATION SITE ST41
 DATUM ELEVATION 213.63' msl GROUND SURFACE ELEVATION 210.7' msl
 DATUM FOR WATER LEVEL MEASUREMENT Top PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 7.71 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 12.01 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

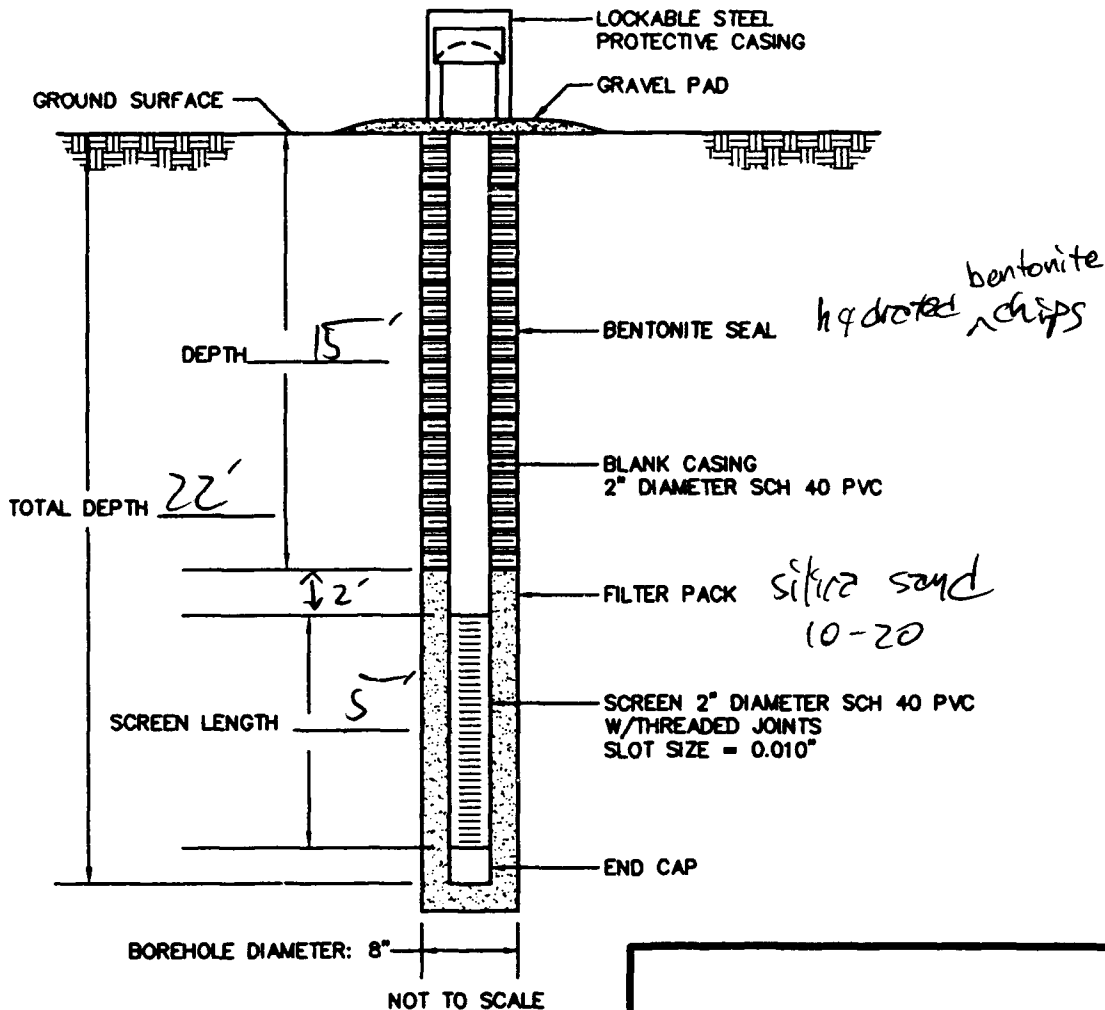
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ESSB
 JOB NUMBER 722450.07 INSTALLATION DATE 6/9/94 LOCATION SITE ST41
 DATUM ELEVATION 213.23 feet msl GROUND SURFACE ELEVATION 210.6 feet msl
 DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 9.39 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 24.48 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

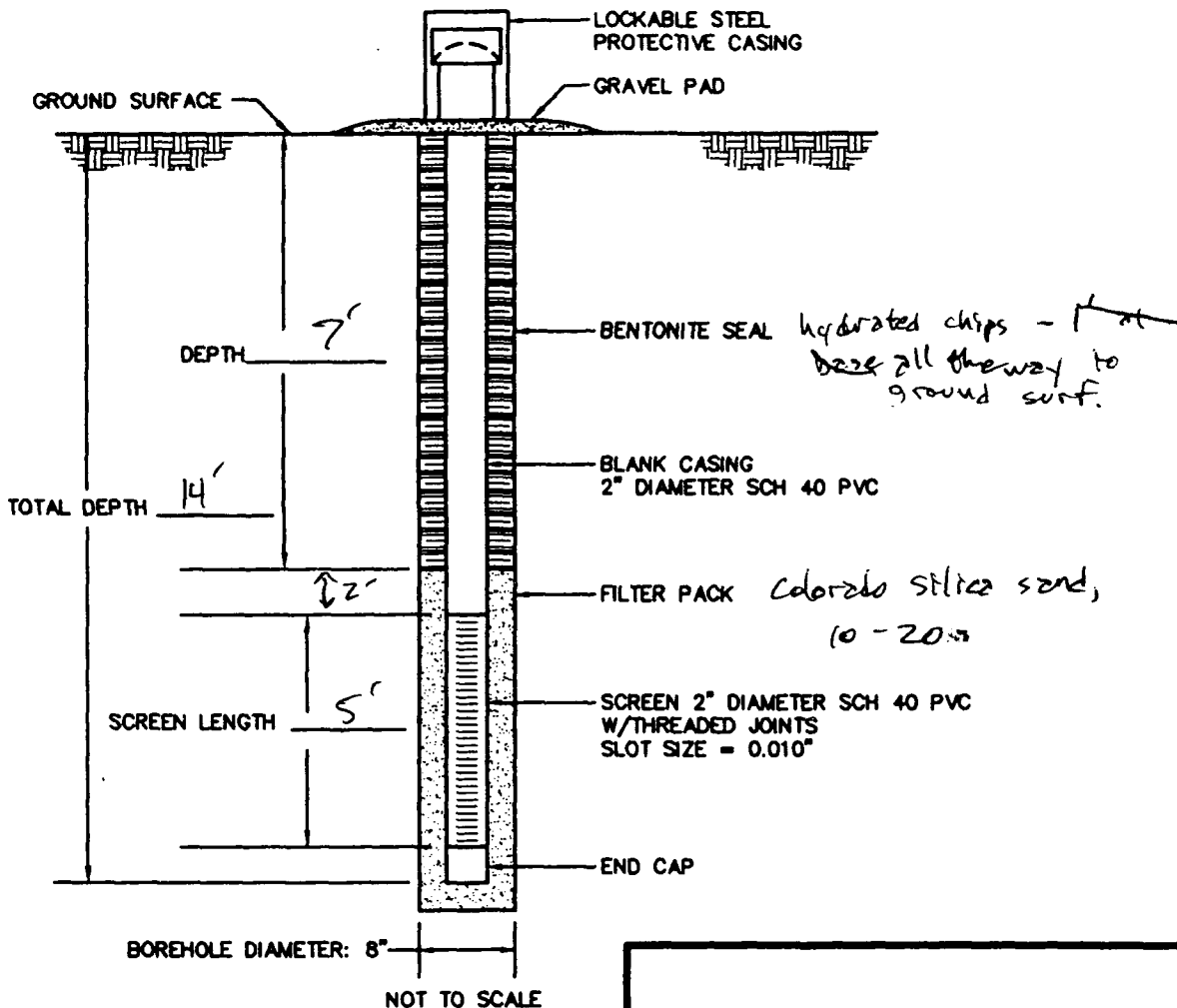
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES6A
 JOB NUMBER 722450.07 INSTALLATION DATE 6/8/94 LOCATION SITE ST41
 DATUM ELEVATION 205.86 MSL GROUND SURFACE ELEVATION 207.8 M
 DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 13.77 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 17.17 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

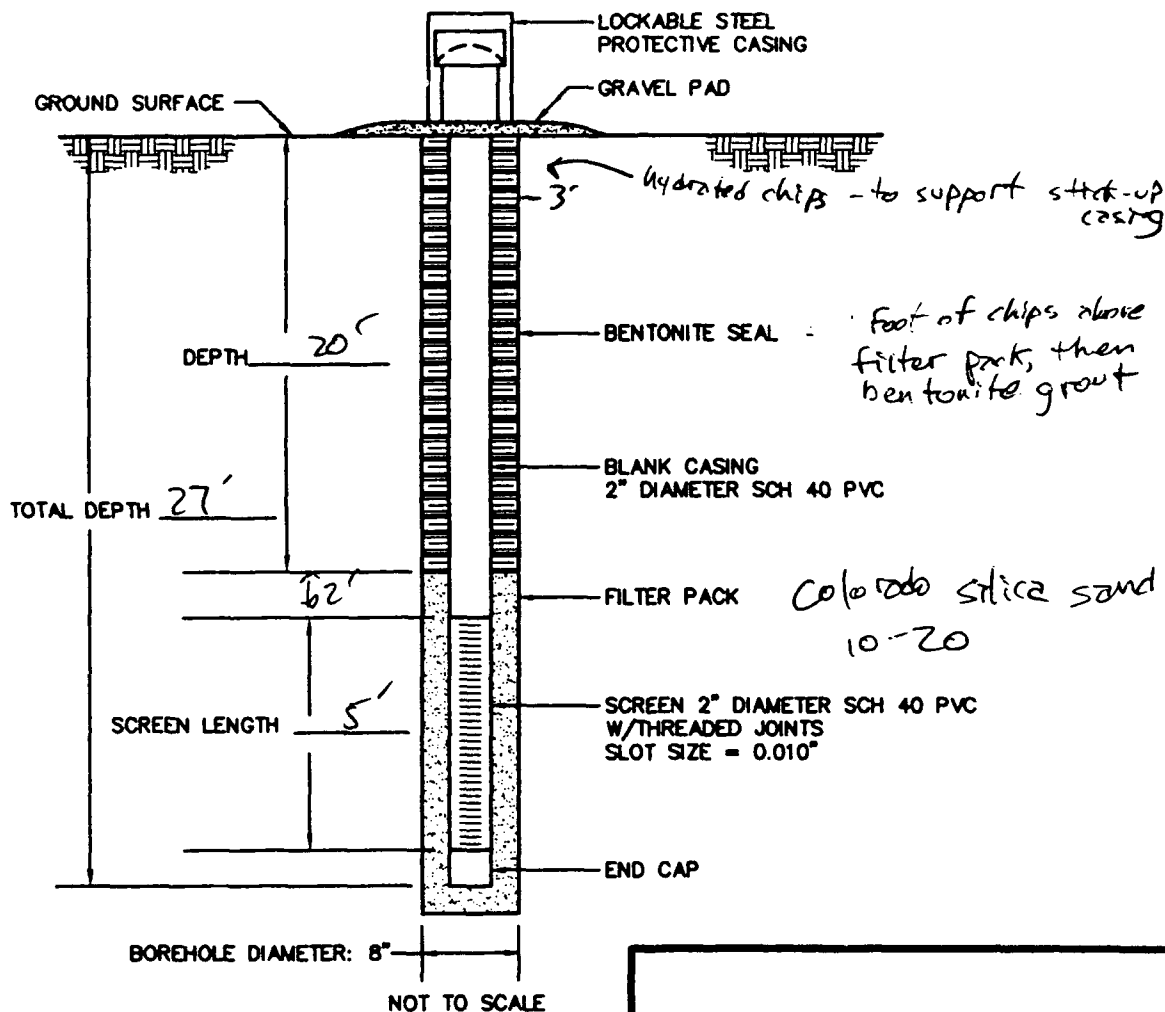
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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-E56B
 JOB NUMBER 722450.07 INSTALLATION DATE 6/8/94 LOCATION SITE ST41
 DATUM ELEVATION 205.89 feet msl GROUND SURFACE ELEVATION 203.1 feet msl
 DATUM FOR WATER LEVEL MEASUREMENT top of PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 13.80 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 30.18 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

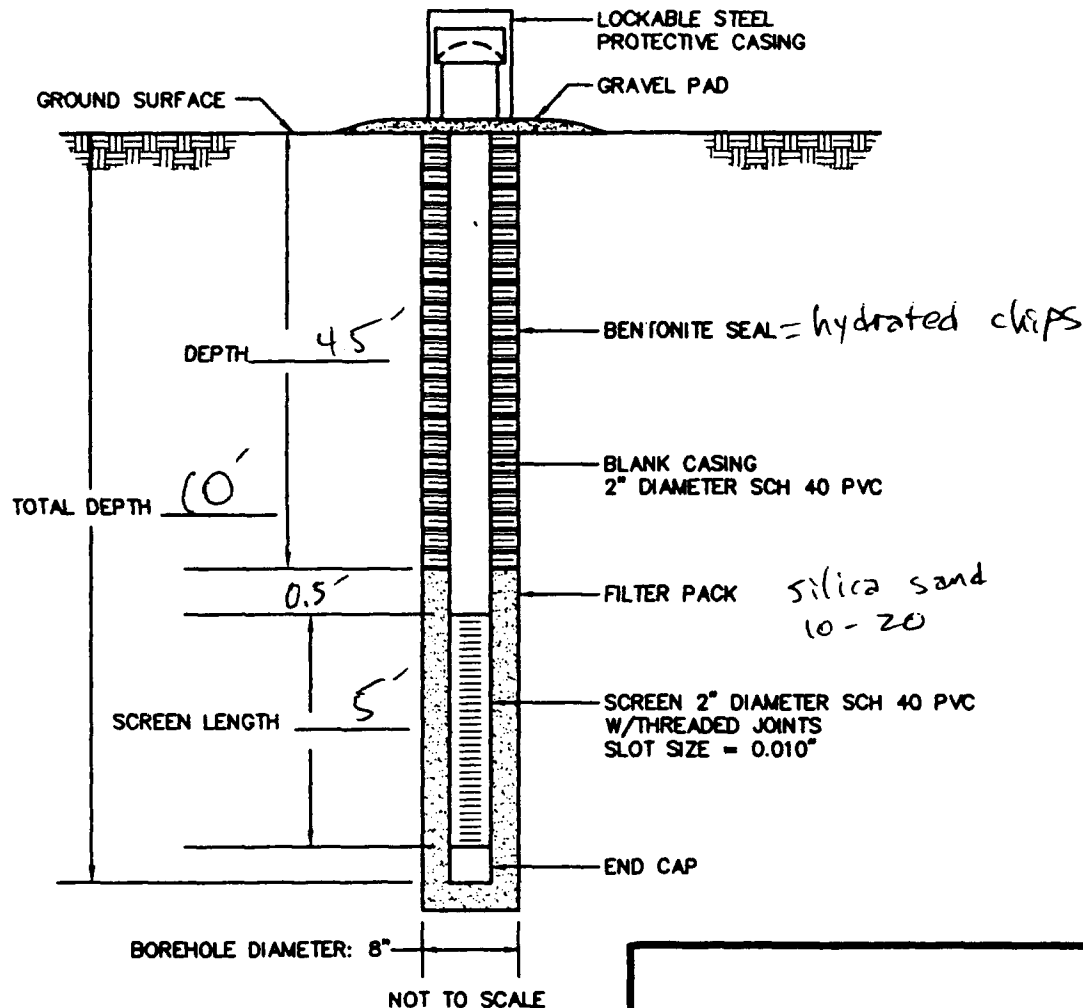
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 Elmendorf Air Force Base, Alaska

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FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES7A
JOB NUMBER 722450.07 INSTALLATION DATE 6/10/94 LOCATION SITE ST41
DATUM ELEVATION 198.88 feet msl GROUND SURFACE ELEVATION 195.9 feet
DATUM FOR WATER LEVEL MEASUREMENT Top of PVC
SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 6.90 FEET
BELOW DATUM.
TOTAL WELL DEPTH 12.99 FEET
BELOW DATUM.
MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

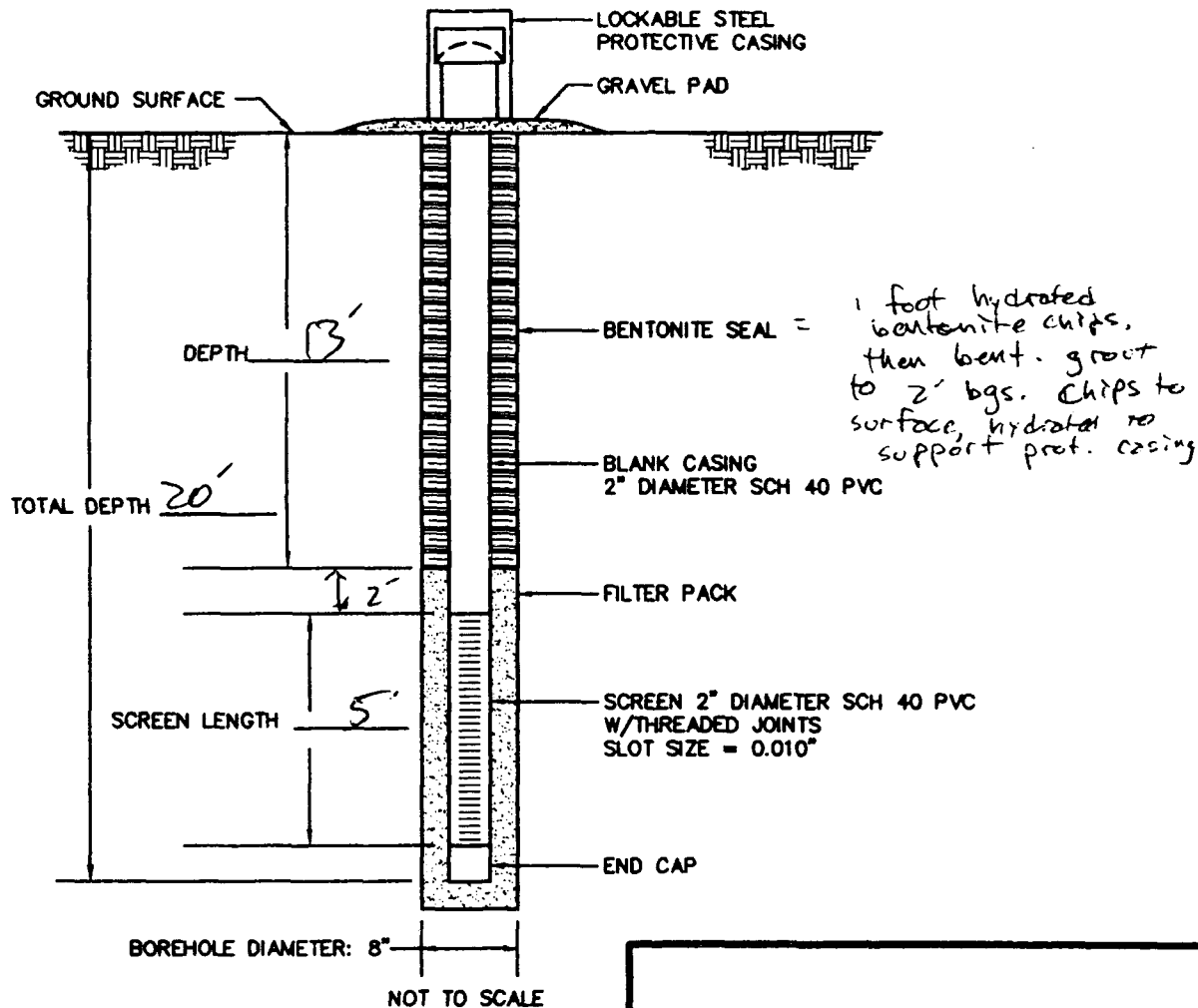
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Elmendorf Air Force Base, Alaska

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Denver, Colorado

FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES7B
JOB NUMBER 722450.07 INSTALLATION DATE 6/9/94 LOCATION SITE ST41
DATUM ELEVATION 199.04 msl GROUND SURFACE ELEVATION 195.7 msl
DATUM FOR WATER LEVEL MEASUREMENT Top casing (PVC)
SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



STABILIZED WATER LEVEL 7.92 FEET
BELOW DATUM.
TOTAL WELL DEPTH 23.19 FEET
BELOW DATUM.
MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

Intrinsic Remediation Demonstration
Elmendorf Air Force Base, Alaska

ENGINEERING-SCIENCE, INC.

Denver, Colorado

FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE

WELL NUMBER ST41

JOB NUMBER 722450.07

INSTALLATION DATE 6/10/94

LOCATION SITE ST41

DATUM ELEVATION Top (93.80 feet msl)

GROUND SURFACE ELEVATION 191.1 feet

DATUM FOR WATER LEVEL MEASUREMENT Top casing

SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC

SLOT SIZE 0.01"

RISER DIAMETER & MATERIAL 2" SCH 40 PVC

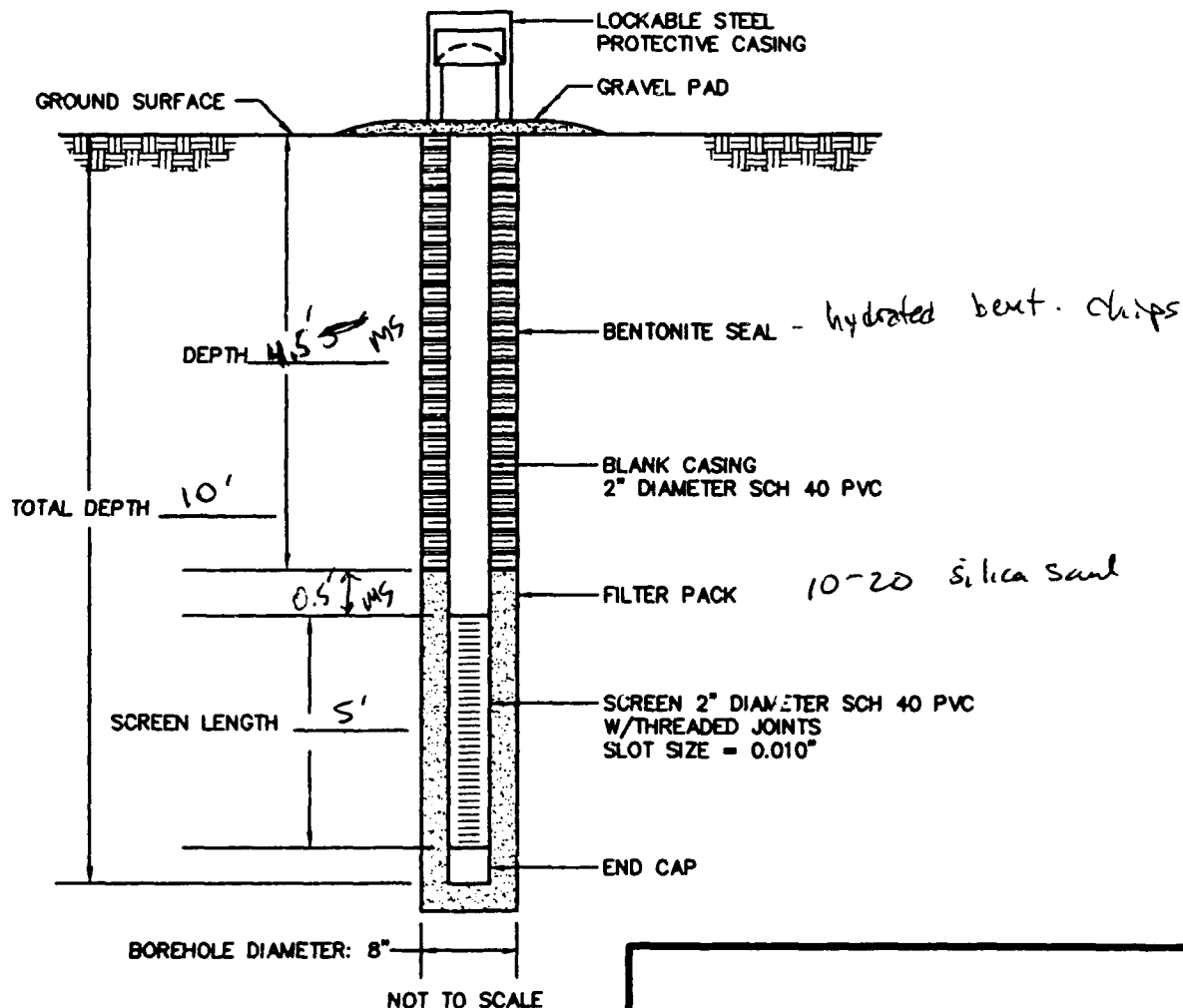
BOREHOLE DIAMETER 8 INCHES

GRANULAR BACKFILL MATERIAL

ES REPRESENTATIVE MS/KC

DRILLING METHOD HOLLOW STEM AUGER

DRILLING CONTRACTOR Hughes



FROST HEAVE MONITORING WELL INSTALLATION RECORD

Intrinsic Remediation Demonstration,
Elmendorf Air Force Base, Alaska

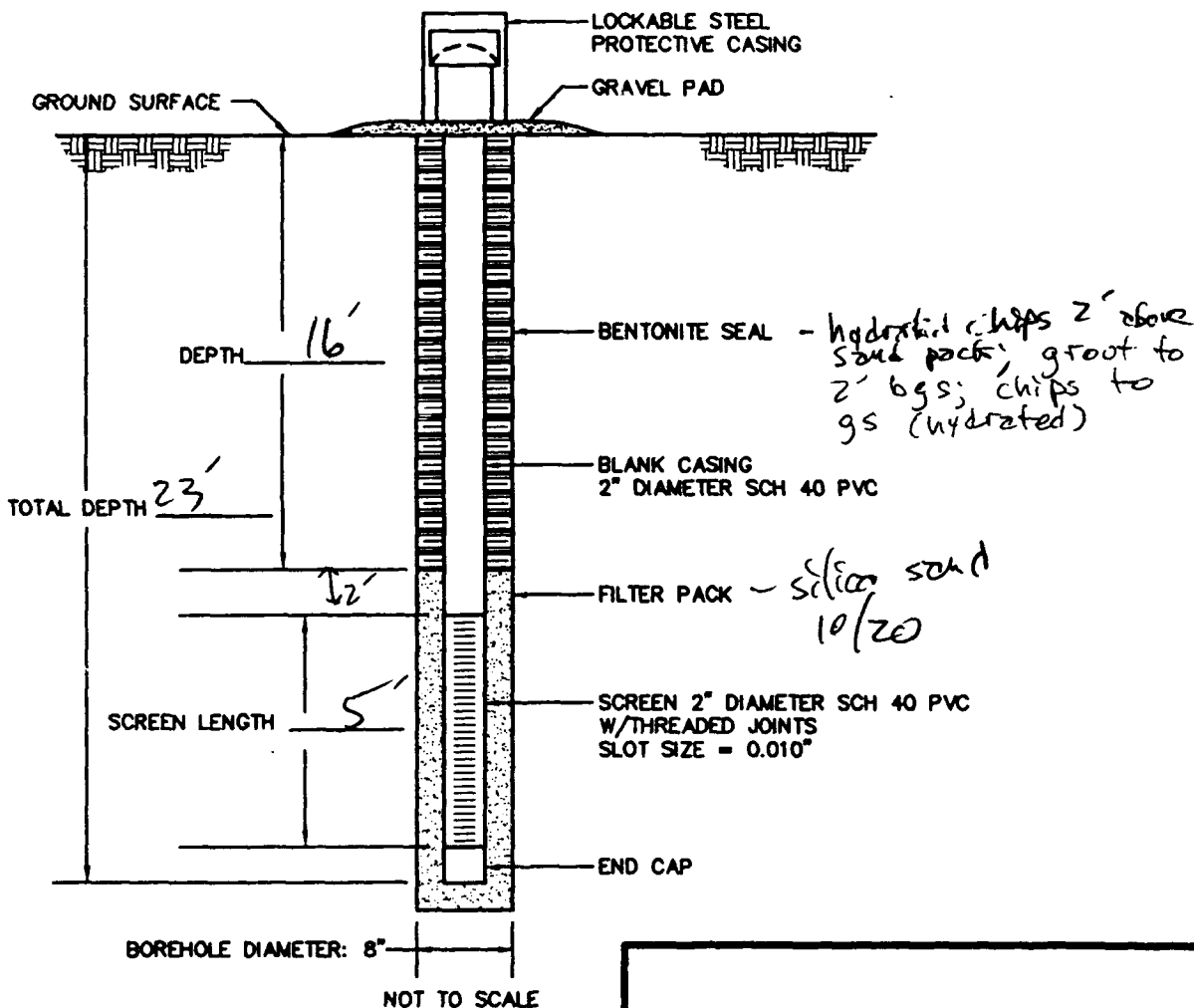
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STABILIZED WATER LEVEL 6.32 FEET
BELOW DATUM.
TOTAL WELL DEPTH 12.92 FEET
BELOW DATUM.
MEASURED ON 6/21/94

FROST HEAVE MONITORING WELL INSTALLATION RECORD

JOB NAME ELMENDORF AIR FORCE BASE WELL NUMBER ST41-ES88
 JOB NUMBER 722450.07 INSTALLATION DATE 6/94 LOCATION SITE ST41
 DATUM ELEVATION 193.89 feet msl GROUND SURFACE ELEVATION 191.1' msl
 DATUM FOR WATER LEVEL MEASUREMENT Top PVC
 SCREEN DIAMETER & MATERIAL 2" SCH 40 PVC SLOT SIZE 0.01"
 RISER DIAMETER & MATERIAL 2" SCH 40 PVC BOREHOLE DIAMETER 8 INCHES
 GRANULAR BACKFILL MATERIAL _____ ES REPRESENTATIVE MS/KC
 DRILLING METHOD HOLLOW STEM AUGER DRILLING CONTRACTOR Hughes



FROST HEAVE MONITORING WELL INSTALLATION RECORD

Intrinsic Remediation Demonstration
 Elmendorf Air Force Base, Alaska

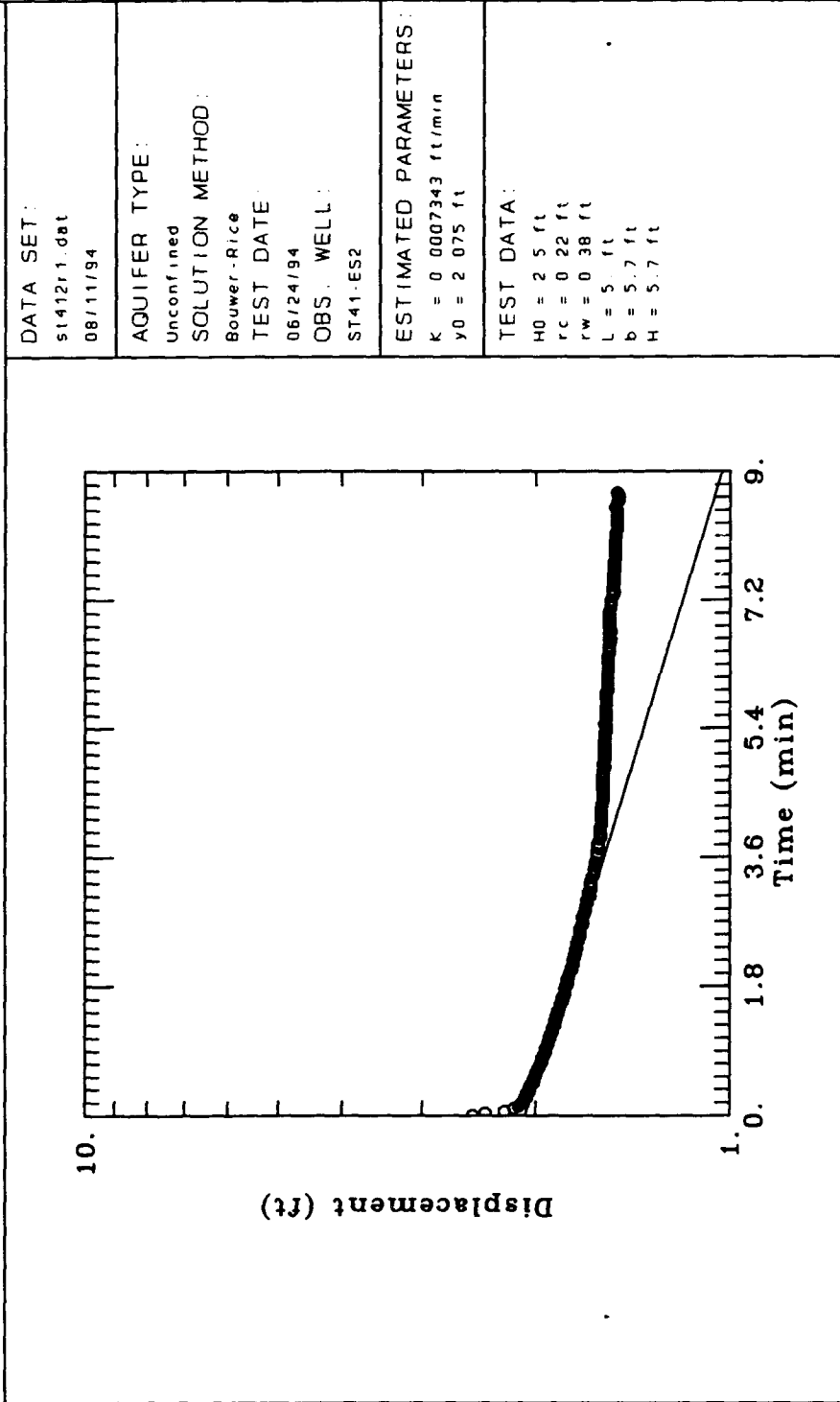
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Denver, Colorado

STABILIZED WATER LEVEL 6.13 FEET
 BELOW DATUM.
 TOTAL WELL DEPTH 25.84 FEET
 BELOW DATUM.
 MEASURED ON 6/21/94

Engineering - Science, Inc.	Client: AFCEE/Elmendorf AFB
Project No.: 722450.07020	Location: Elmendorf AFB

Rising Head Test, ST41-ES2



DATA SET: st412r1.dat 08/11/94	AQUIFER TYPE: Unconfined SOLUTION METHOD: Bouwer-Rice TEST DATE: 06/24/94 OBS. WELL: ST41-ES2	ESTIMATED PARAMETERS: $K = 0.0007343 \text{ ft/min}$ $y_0 = 2.075 \text{ ft}$	TEST DATA: $H_0 = 2.5 \text{ ft}$ $r_c = 0.22 \text{ ft}$ $r_w = 0.38 \text{ ft}$ $L = 5.1 \text{ ft}$ $b = 5.7 \text{ ft}$ $H = 5.7 \text{ ft}$
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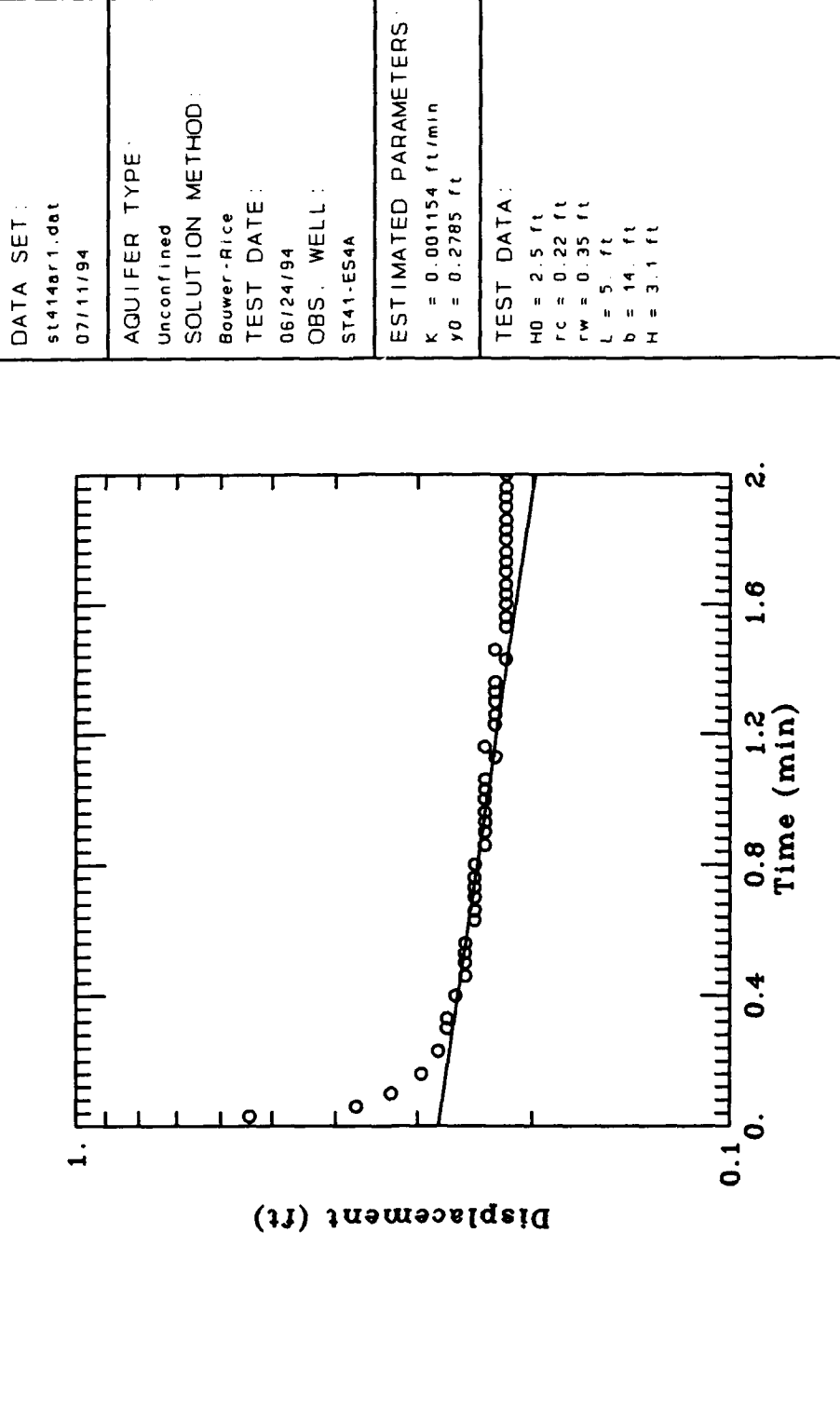
Engineering - Science, Inc.

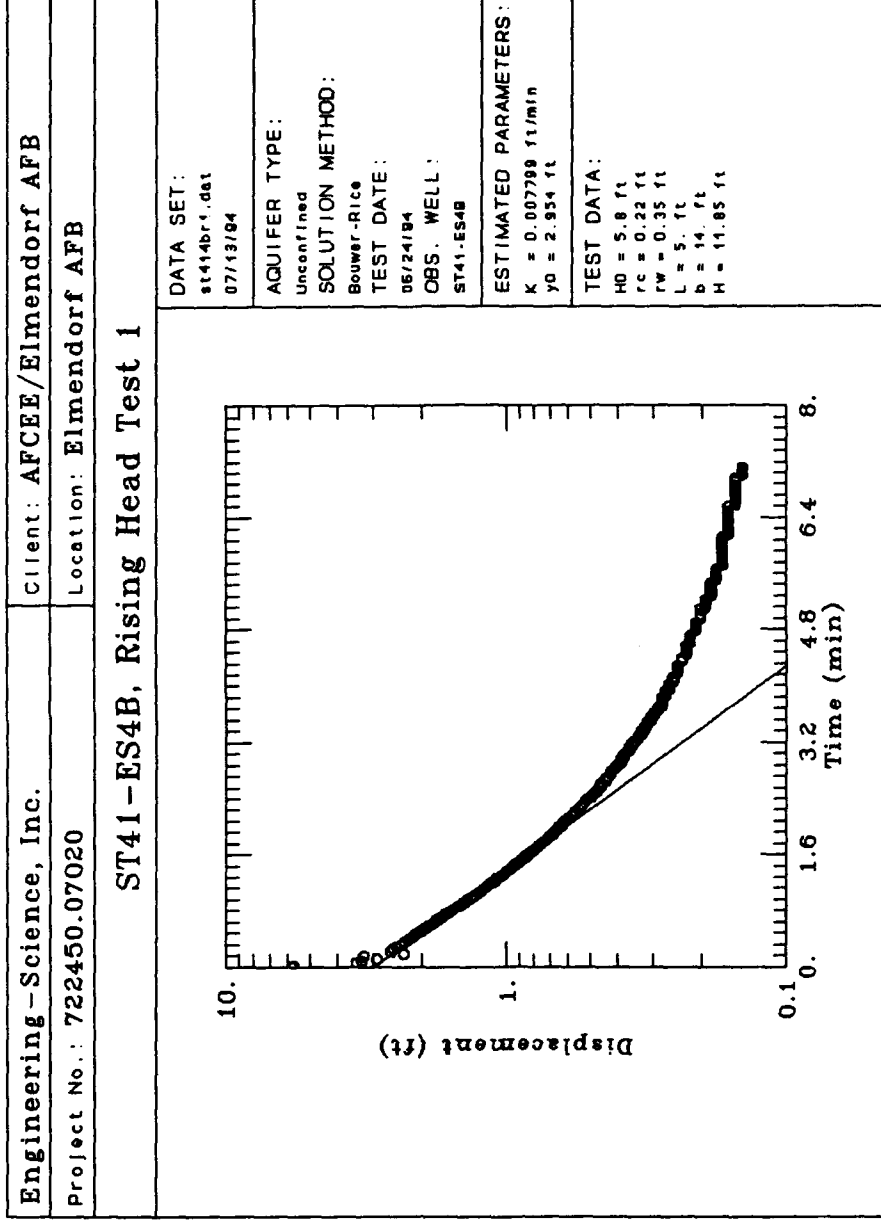
Client: AFCEE/Elmendorf AFB

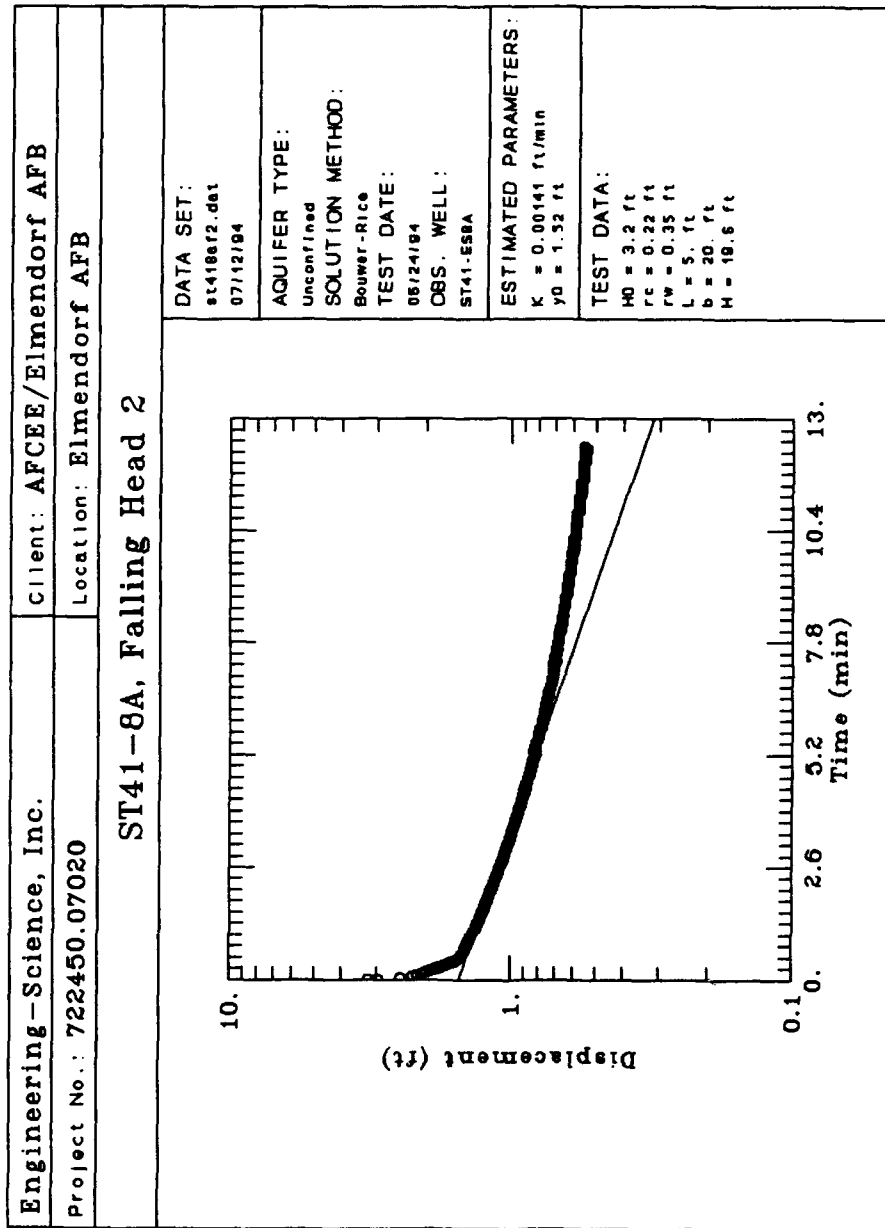
Project No.: 722450.07

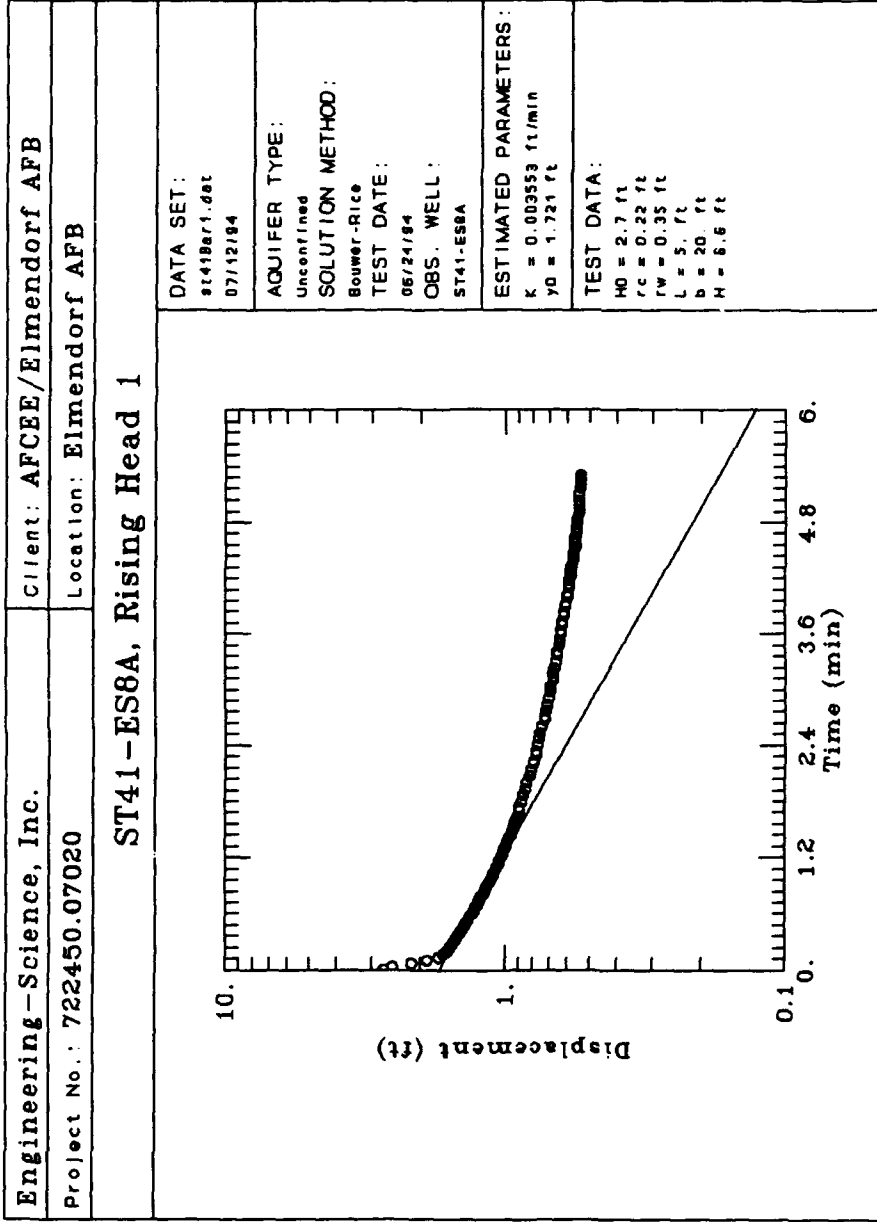
Location: Elmendorf AFB

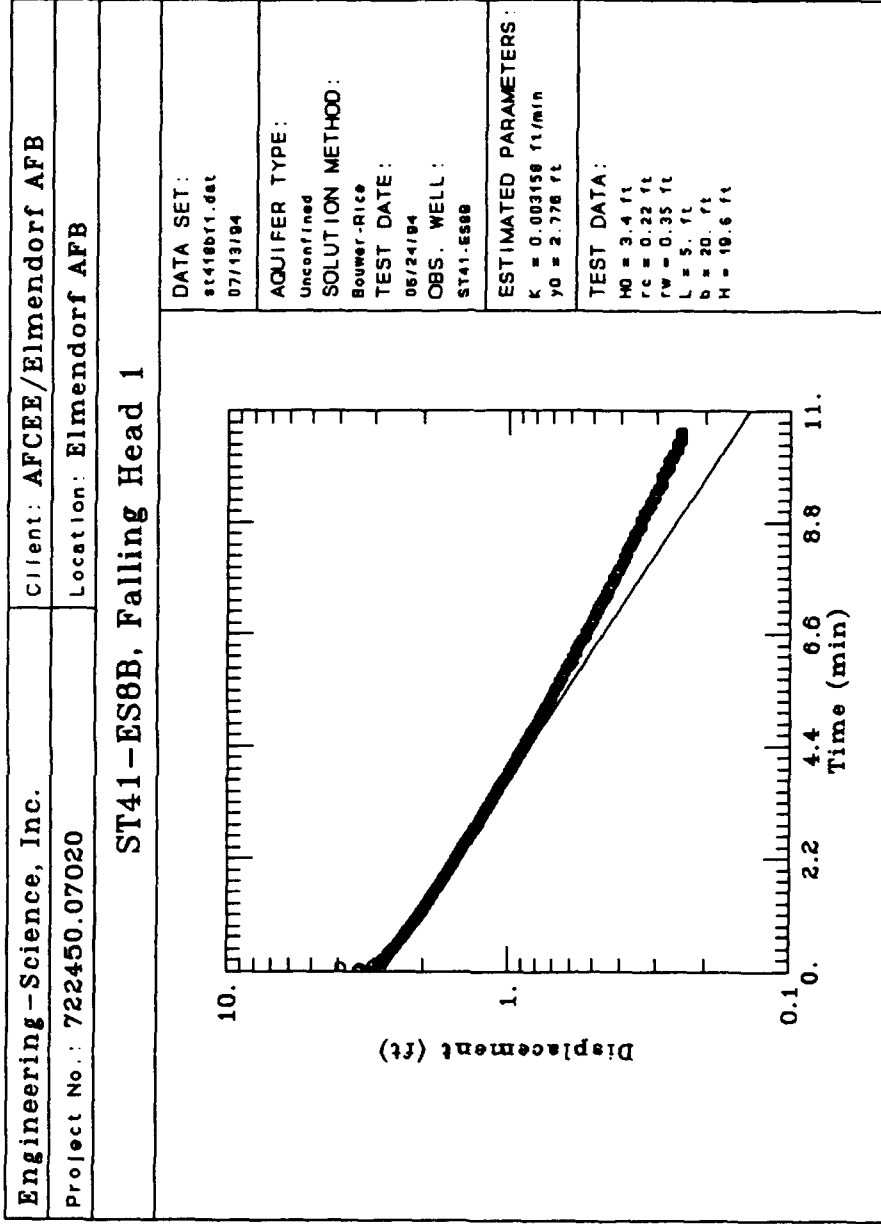
ST41-ES4A, Rising Head Test 1



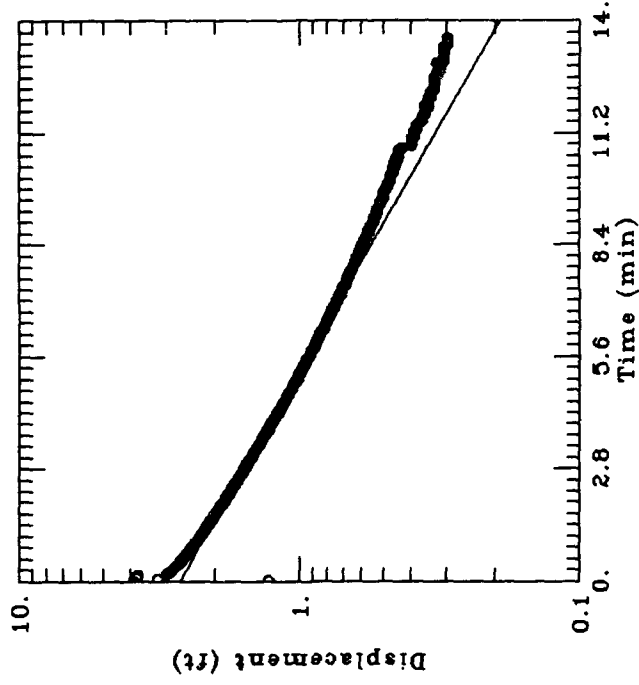








Engineering-Science, Inc.		Client: AFCEE/Elmendorf AFB	
Project No.: 722450.07020		Location: Elmendorf AFB	
ST41-ES8B, Rising Head 2			
DATA SET: st418br2.dat 07/12/94		AQUIFER TYPE: Unconfined	
SOLUTION METHOD: Bouwer-Rice		TEST DATE: 06/24/94	
OBS. WELL: ST41-ES8B		ESTIMATED PARAMETERS: K = 0.002179 ft/min YD = 2.858 ft	
TEST DATA: H0 = 3.9 ft rc = 0.22 ft rw = 0.35 ft L = 5. ft b = 20 ft H = 19.5 ft			



APPENDIX B

LABORATORY ANALYTICAL DATA

MANTECH

Ref: 94-DK14/vg

July 21, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SW*

Dear Don:

This report contains the results of my GC/MSD analysis of methylene chloride core extracts from Elmendorf AFB for quantitation of benzene, toluene, ethylbenzene (EB), p-Xylene, m-Xylene, o-Xylene, 1,3,5-trimethylbenzene (1,3,5-TMB), 1,2,4-trimethylbenzene (1,2,4-TMB) and 1,2,3-trimethylbenzene (1,2,3-TMB) performed under Service Request #SF-0-65.

The analytical method was a modification of RSKSOP-124. Cool (38°C) on-column injection (0.5 µl) was used with electronic pressure control (EPC) set for a constant flow of 0.9 ml/min. A 30M X 0.25 mm Restek Stabilwax (Crossbonded Carbowax-PEG, 0.5 µm film) capillary GC column with 1 foot long X 0.53 mm ID uncoated capillary precolumn was used. Quantitation was based on calibration curves of a single target ion for each compound with the addition of up to two qualifier ions recorded to verify chromatographic separation or purity. The ions chosen were those listed in EPA method 524.2 Revision 3.0. Standards calibration ranged from 0.01 to 10 µg/ml. A complete report detailing the acquisition method and calibration has been recorded. The samples were extracted by Mark Blankenship on June 15, 1994 and were analyzed for fuel carbon (GC/FID) by Randy Callaway. This GC/MSD data was acquired July 13-14, 1994.

If I can be of further assistance, please feel free to contact me.

Sincerely,

David A. Kovacs
David A. Kovacs

xc: R.L. Cosby
J.L. Seeley *jls*
G. Smith

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SR	-65 Dr. Kampbell	GC/MSD of Elmendo B MeCl2 extracted cores						un	-mg/kg
SAMPLE	BENZENE	TOLUENE	EB	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
ES-MW1B-22-24'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ES-MW1B-26-28'	BLQ	7.78E-03	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
ES-MW2-22-24'	ND	BLQ	ND	ND	BLQ	ND	ND	ND	ND
ES-MW2-24-26'	ND	BLQ	ND	ND	BLQ	ND	ND	ND	ND
ES-MW4B-20-22'	ND	BLQ	ND	ND	ND	BLQ	ND	ND	ND
ES-MW4B-24-26'	ND	BLQ	ND	ND	BLQ	ND	ND	ND	ND
ES-MW5b-14-16'	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
ES-MW7B-17-18'	ND	BLQ	ND	ND	ND	BLQ	ND	ND	ND
ST41-ES1-12-14'	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND
ST41-ES1-14-16'	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
ST41-ES1-14-16' Rep.	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
ST41-ES2-4-6'	1.81E-02	3.34E+00	4.44E-01	ND	ND	BLQ	ND	ND	ND
ST41-ES2-6-8'	ND	BLQ	BLQ	ND	BLQ	ND	ND	ND	ND
ST41-ES3-3-4'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES3-4-6'	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
ST41-ES4B-4-6'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES4B-6-8'	1.51E-02	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
ST41-ES5-4-6'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES5-6-8'	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND
ST41-ES6B-10-12'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES6B-8-10'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES7B-10-12'	9.17E-02	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
ST41-ES7B-6-8'	1.62E-02	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	ND
ST41-ES8B-6-8'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	ND
ST41-ES8B-10-12'	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND

QC Summary

Method Blank 1	ND	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	ND
Method Blank 2	ND	ND	ND	ND	ND	ND	ND	ND	ND
0.1 µg/ml	9.98E-02	9.99E-02	1.00E-01	9.86E-02	9.80E-02	1.00E-01	1.01E-01	1.00E-01	1.00E-01
1 µg/ml	9.50E-01	9.60E-01	9.66E-01	9.64E-01	9.39E-01	1.02E+00	9.64E-01	9.57E-01	9.50E-01
1 µg/ml	1.05E+00	1.04E+00	1.04E+00	1.04E+00	1.06E+00	1.04E+00	1.04E+00	1.04E+00	1.05E+00
10 µg/ml	1.02E+01	9.91E+00	9.88E+00	9.73E+00	9.87E+00	9.72E+00	1.00E+01	1.00E+01	1.01E+01
10 µg/ml	9.87E+00	9.74E+00	9.53E+00	9.51E+00	9.82E+00	9.67E+00	9.53E+00	9.47E+00	9.51E+00
10 µg/ml	1.07E+01	1.06E+01	1.07E+01	1.08E+01	1.06E+01	1.03E+01	1.08E+01	1.07E+01	1.08E+01
10 µg/ml QC	1.01E+01	1.03E+01	1.05E+01	1.04E+01	1.04E+01	1.03E+01	1.05E+01	1.05E+01	1.05E+01

Analy David A. Kovacs

BLQ = 2 µg/ml

Print /21/94

MANTECH TECH

Ref: 94-PR68/rc
94-MW63/rc
94-TH66/rc

June 14, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

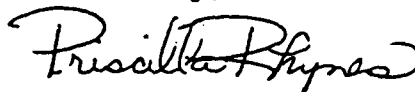
THRU: S.A. Vandegrift *SAV*

Dear Don:

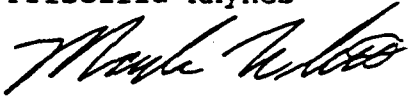
Attached are the results of 2 sets of Elmendorf AFB samples submitted to ManTech Environmental as part of Service Request # RE-0-65. The samples were received on June 9 and 10 and analyzed June 9 and 13. The methods used for analysis were EPA methods 120.1 and 353.1, and Water's Capillary Electrophoresis Method N-601. Blanks, spikes, duplicates and known AQC samples were analyzed along with the samples for quality assurance.

If you have any questions concerning these results, please feel free to contact us.

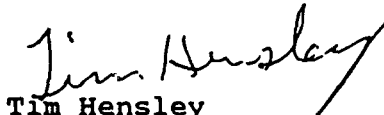
Sincerely,



Priscilla Rhynes



Mark White



Tim Hensley

xc: R.L. Cosby
J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

06/07/94

<u>Sample</u>	<u>mg/l</u> <u>Cl⁻</u>	<u>mg/l</u> <u>SO₄⁼</u>	<u>mg/l</u> <u>NO₂⁻+NO₃⁻(N)</u>	<u>Conductivity</u>
ST41 W7	54.3	24.6	<.05	855
ST41 W7 Dup				859
ST41 W8	33.6	7.19	1.04	391
ST41 15	74.0	18.9	<.05	942
ST41 15 Dup	73.6	18.8		
ST41 16	36.6	9.52	<.05	2050
ST41 18	31.9	55.0	12.1	642
ST41 21	126	10.3	<.05	734
ST41 21 Dup			<.05	
ST41 25	135	<.5	<.05	1150
ST41 29	14.5	8.26	<.05	226
46WL 01	41.1	5.04	<.05	410
46WL 01 Dup	40.9	5.09		411
46WL 02	17.7	5.83	<.05	184
46WL 03	33.1	7.60	.54	333
MW37A	3.50	4.14	<.05	112
MW37B	6.94	8.44	<.05	387
MW37B Dup			<.05	
Blanks	<.5	<.5	<.05	----
AQCWPO31	44.9	96.2	.45	----
True Value	42.0	92.0	.52	----
Spike Recovery	101%	103%	98%	----

06/08/94

<u>Sample</u>	<u>mg/l</u> <u>Cl⁻</u>	<u>mg/l</u> <u>SO₄⁼</u>	<u>mg/l</u> <u>NO₂⁻+NO₃⁻(N)</u>	<u>Conductivity</u>
OU4W-2	13.3	13.0	3.23	670
OU4W-4	7.71	8.41	1.71	713
OU4W-4 Rep	7.68	8.76	1.90	703
OU4W-5	19.5	13.6	8.88	659
OU4W-5 Dup			8.88	
ST41-01	4.36	15.0	.70	945
ST41-01 Rep	4.55	14.9	.65	938
ST41-2	37.3	35.4	1.03	1040
ST41-2 Dup	37.8	35.2		
ST41-07	73.9	10.4	<.05	697
ST41-07 Rep	74.0	10.2	<.05	713
W-18	7.40	10.3	.29	877
W-18 Dup			.30	
W-19	13.7	21.6	7.44	776
W-19 Dup				776
Blanks	<.5	<.5	<.05	----
AQCWPO31	42.5	93.0	.50	----
True Value	42.0	92.0	.52	----
Spike Recovery	97%	104%	100%	----

Rep - field duplicates

Dup - analytical duplicates

Cook

THIS REPORT ([CLARK.ICAP]LIST.LST;3293) WAS GENERATED FROM [CLARK.ICAP]OUTPUT.DAT;1867

PROJECT: ELMENDORF AFB, ALASKA
COOK
TA5

Note: High Mn.

CONCENTRATION IN: MG/L

TAG NO. 5051 MDUP
STATION W18 6-8-9
TIME 15:48
DATE 26-JUL-94
PR DIL 1.1100
DIL 1.0000

5052
ST 41-01 D
14:24
26-JUL-94
1.1100
1.0000

5053
ST 41 ES4B
14:25
26-JUL-94
1.1100
1.0000

5054
OU 4W-1 6-
14:27
26-JUL-94
1.1100
1.0000

ELEMENT	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	VALUE	STDV +/-	LOD
Na-1	4.70	0.49	12.0	1.2	14.9	1.5	4.30	0.46	0.1502
K	2.12	0.21	3.20	0.21	2.17	0.20	2.08	0.21	0.1803
Ca	165.	16.	144.	14.	68.5	6.8	182.	18.	0.0176
Mg	20.0	1.9	42.6	4.2	33.6	3.3	22.7	2.2	0.0129
Fe	<0.078	0.078	<0.078	0.078	4.03	0.40	2.77	0.28	0.0709
Mn	4.98	0.50	<0.021	0.021	2.64	0.27	3.34	0.34	0.0192
Co	0.0093	0.0029	0.0041	0.0029	0.0065	0.0029	0.0080	0.0029	0.0026
Mo	0.0067	0.0028	0.0051	0.0027	0.0030	0.0027	0.0068	0.0028	0.0024
Al	0.025	0.074	<0.074	0.074	0.101	0.074	0.084	0.074	0.0670
As	0.040	0.011	0.023	0.010	<0.010	0.010	0.032	0.010	0.0093
Se	0.0312	0.0043	0.0248	0.0041	0.0189	0.0037	0.0373	0.0046	0.0031
Cd	0.0047	0.0013	0.0055	0.0013	0.0033	0.0012	0.0054	0.0013	0.0011
Be	<0.0014	0.0014	<0.0012	0.0012	<0.0007	0.0007	<0.0015	0.0015	0.0004
Cu	<0.0021	0.021	<0.021	0.021	<0.021	0.021	<0.021	0.021	0.0193
Cr	<0.0042	0.0042	<0.0042	0.0042	<0.0042	0.0042	<0.0042	0.0042	0.0038
Ni	0.0156	0.0032	0.0090	0.0031	0.0469	0.0045	0.0188	0.0032	0.0027
Zn	0.0234	0.0027	0.0182	0.0025	0.0154	0.0020	0.0269	0.0028	0.0016
Ag	0.0188	0.0045	0.0159	0.0044	0.0089	0.0043	0.0211	0.0045	0.0038
Tl	0.034	0.016	0.033	0.015	0.036	0.015	0.037	0.016	0.0143
Pb	0.0343	0.0094	0.0294	0.0093	0.0297	0.0092	0.0425	0.0095	0.0082
Li	<0.0020	0.0020	0.0070	0.0024	0.0030	0.0012	<0.0023	0.0023	0.0006
Sr	0.966	0.095	0.685	0.068	0.340	0.034	0.995	0.099	0.0003
V	0.027	0.010	0.022	0.010	0.015	0.010	0.034	0.010	0.0090
Ba	0.0449	0.0046	0.0487	0.0048	0.0524	0.0052	0.0487	0.0049	0.0008
B	<0.079	0.079	<0.080	0.080	<0.079	0.079	<0.079	0.079	0.0720
Tl	0.036	0.021	0.023	0.021	<0.021	0.021	0.036	0.021	0.0193

< VALUE-LIMIT OF DETECTION DETERMINED BY INSTRUMENT SENSITIVITY, SAMPLE DILUTION, AND MATRIX INTERFERENCE.
RESULTS ACCURATE TO 2 SIGNIFICANT DIGITS
EPA/RSKRL/ADA, OK

MANTECH TECH

Ref: 94-LB4
June 29, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74821-1198

THRU: Steve Vandegrift *SV*

Dear Don:

Please find attached the analytical results for Service Request SF-0-65 for the analysis of aqueous samples from Elmendorf AFB to be analyzed for BTEXXX & TMBs. A total of 53 Samples were received in duplicate in capped, 40 mL VOA vials between the dates of June 17-27, 1994. All samples were stored at 4°C until analyzed and were acquired and processed using the MAXIMA data system. A 4 point (1-500 ppb) external calibration curve was used to determine compound concentration.

At your request sample "OU4W-3" was analyzed for Vinyl Chloride, 1,1-DCE, trans- & cis-DCE, and TCE. A 3 point (1-100 ppb) external standard curve was used for this analysis.

RSKSOP-133 "Simultaneous Analysis of Aromatics and Total Fuel Carbon by Dual Column-Dual Detector for Ground Water Samples" and RSKSOP-146 "Automated Purge and Trap/GC Analysis of Vinyl Chloride and other Volatile Chlorocarbons in Aqueous Samples Containing Particulates" were used for these analyses.

Sincerely,



Lisa R. Black

xc: R.L.Cosby
J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SAMPLE NAME	BENZENE	TOLUENE	ETHYLBENZENE	P-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	Fuel Carbon
100 PPB	9.75E+01	9.50E+01	1.00E+02	9.91E+01	9.92E+01	9.60E+01	9.75E+01	9.57E+01	9.80E+01	N/A
QC, OBSERVED, PPB	5.00E+01	5.40E+01	5.33E+01	5.41E+01	5.41E+01	5.48E+01	5.89E+01	4.89E+01	5.53E+01	N/A
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	N/A
46WL01	1.86E+01	1.12E+00	1.93E+00	2.01E+00	1.23E+00	9.08E-01	1.46E+00	3.06E+00	1.68E+00	1.78E+02
46WL01 Duplicate	1.91E+01	BLQ	9.89E-01	1.16E+00	BLQ	ND	ND	1.07E+00	ND	1.85E+02
46WL02	ND	ND	BLQ	BLQ	ND	ND	ND	ND	ND	BLQ
46WL03	ND	ND	BLQ	BLQ	BLQ	ND	ND	ND	ND	BLQ
46WLCREEK	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-02	4.13E+01	9.35E+01	1.89E+01	1.57E+01	4.41E+01	2.04E+01	2.80E+00	1.03E+01	4.26E+00	2.81E+02
ST41-07	4.93E+02	5.57E+02	1.54E+02	1.13E+02	2.59E+02	1.62E+02	1.89E+01	7.17E+01	3.09E+01	2.00E+03
ST41-W7	9.96E+00	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	ND	1.09E+01
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
10 PPB	1.09E+01	1.08E+01	9.35E+00	1.03E+01	9.22E+00	9.22E+00	1.01E+01	1.01E+01	1.08E+01	N/A
ST41-W8	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	BLQ	1.08E+00	N/A
ST41-15	BLQ	BLQ	BLQ	BLQ	1.10E+00	BLQ	BLQ	BLQ	BLQ	3.83E+00
ST41-16 1/100	1.65E+02	1.73E+04	1.92E+03	1.58E+03	4.36E+03	1.62E+03	1.83E+02	6.31E+02	2.83E+02	4.23E+04
ST41-18	1.01E+02	1.55E+02	2.79E+01	2.31E+01	6.34E+01	2.63E+01	3.52E+00	1.41E+01	5.92E+00	4.80E+02
ST41-18 Duplicate	9.75E+01	1.48E+02	2.61E+01	2.10E+01	5.88E+01	2.69E+01	4.37E+00	1.29E+01	4.38E+00	4.33E+02
ST41-21	2.20E+00	3.88E+00	BLQ	BLQ	1.27E+00	ND	ND	ND	ND	7.41E+00
ST41-25	4.90E+01	8.39E+00	9.83E+02	7.91E+02	ND	ND	8.80E+01	1.59E+01	1.10E+00	1.10E+04
ST41-29	BLQ	1.34E+00	1.15E+00	1.09E+00	BLQ	ND	ND	ND	2.20E+01	1.45E+01
W-9	1.26E+00	1.81E+00	9.06E-01	BLQ	1.37E+00	1.07E+00	BLQ	BLQ	BLQ	1.61E+02
W-18	7.01E+00	3.45E+01	1.08E+01	9.33E+00	2.63E+01	1.13E+01	2.39E+00	8.63E+00	3.35E+00	N/A
100 PPB	9.44E+01	9.32E+01	9.61E+01	9.54E+01	1.01E+02	9.84E+01	9.85E+01	9.88E+01	9.81E+01	N/A
W-19	1.83E+01	6.08E+01	1.71E+01	1.50E+01	4.02E+01	1.73E+01	4.76E+00	1.28E+01	6.45E+00	2.04E+02
W-19 Duplicate	1.62E+01	5.85E+01	1.47E+01	1.22E+01	3.51E+01	1.66E+01	2.63E+00	1.09E+01	4.42E+00	2.14E+02
MW37-A	ND	ND	BLQ	ND	ND	ND	ND	BLQ	ND	BLQ
MW37-B	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	BLQ
ST41-ES1	6.32E+01	1.30E+00	ND	BLQ	BLQ	ND	ND	ND	BLQ	6.07E+01
ST41-ES1 Duplicate	6.44E+01	1.56E+00	ND	BLQ	BLQ	ND	ND	ND	BLQ	5.99E+01
ST41-ES2	3.02E+00	2.19E+00	ND	ND	BLQ	ND	ND	BLQ	BLQ	2.21E+01
QC	4.85E+01	4.99E+01	5.10E+01	5.04E+01	4.67E+01	4.96E+01	5.32E+01	5.54E+01	5.40E+01	N/A
10 PPB	9.71E+00	9.60E+00	9.06E+00	9.75E+00	9.51E+00	9.71E+00	1.07E+01	1.05E+01	1.08E+01	N/A
ST41-ES4A	ND	BLQ	ND	ND	ND	ND	BLQ	ND	ND	BLQ
ST41-ES4B	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND	BLQ
ST41-ES5A	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	BLQ
OU4W-1	2.16E+00	3.02E+00	1.61E+00	1.07E+00	3.52E+00	1.61E+00	BLQ	2.75E+00	1.41E+00	2.26E+01
OU4W-2	2.84E+00	1.68E+01	5.27E+00	4.33E+00	1.26E+01	6.05E+00	1.32E+00	5.01E+00	2.26E+00	6.51E+01
OU4W-3	1.36E+00	2.80E+00	1.79E+00	1.88E+00	3.94E+00	1.90E+00	BLQ	2.63E+00	1.71E+00	3.80E+01
OU4W-4	2.03E+02	8.84E+00	8.58E+01	5.58E+01	6.24E+01	6.24E+01	1.54E+01	4.26E+01	2.45E+01	1.03E+03
OU4W-5	1.48E+00	3.82E+00	2.80E+00	2.40E+00	6.82E+00	3.16E+00	BLQ	3.45E+00	1.42E+00	3.47E+01
OU4W-10	1.41E+00	2.21E+00	1.39E+00	1.07E+00	2.97E+00	1.31E+00	BLQ	2.22E+00	1.86E+00	1.02E+02
SP7/10-02	BLQ	BLQ	ND	ND	9.69E-01	ND	ND	BLQ	BLQ	8.14E+00
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	N/A
500 PPB	5.22E+02	4.83E+02	5.07E+02	5.18E+02	5.18E+02	5.11E+02	4.85E+02	5.15E+02	5.10E+02	N/A

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb

SAMPLE	BENZENE	TOLUENE	ETHYLBENZENE	LENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
100 PPB	9.75E+01	9.50E+01	1.00E+02	9.91E+01	9.92E+01	9.60E+01	9.75E+01	9.57E+01	9.80E+01
QC, OBSERVED, PPB	5.00E+01	5.40E+01	5.35E+01	5.41E+01	5.41E+01	5.48E+01	5.69E+01	4.69E+01	5.53E+01
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
46WL01	1.96E+01	1.12E+00	1.93E+00	2.01E+00	1.23E+00	9.08E-01	1.46E+00	3.06E+00	1.66E+00
46WL01 Duplicate	1.91E+01	BLQ	9.89E-01	1.16E+00	BLQ	ND	ND	1.07E+00	ND
46WL02	ND	ND	BLQ	BLQ	ND	ND	ND	ND	ND
46WL03	ND	ND	BLQ	ND	BLQ	ND	ND	ND	ND
46WL CREEK	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-01	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-02	4.13E+01	9.35E+01	1.89E+01	1.57E+01	4.41E+01	2.04E+01	2.80E+00	1.03E+01	4.26E+00
ST41-07	4.93E+02	5.57E+02	1.54E+02	1.13E+02	2.59E+02	1.62E+02	1.89E+01	7.17E+01	3.09E+01
ST41-W7	9.96E+00	BLQ	BLQ	BLQ	BLQ	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB	1.09E+01	1.08E+01	9.35E+00	1.03E+01	9.22E+00	9.22E+00	1.01E+01	1.01E+01	1.08E+01
ST41-W8	BLQ	BLQ	BLQ	BLQ	BLQ	ND	BLQ	BLQ	1.08E+00
ST41-15	BLQ	BLQ	BLQ	BLQ	1.10E+00	BLQ	BLQ	BLQ	BLQ
ST41-16 1/100	1.65E+04	1.73E+04	1.92E+03	1.58E+03	4.36E+03	1.62E+03	1.83E+02	6.31E+02	2.83E+02
ST41-18	1.01E+02	1.55E+02	2.79E+01	2.31E+01	6.34E+01	2.63E+01	3.52E+00	1.41E+01	5.92E+00
ST41-18 Duplicate	9.75E+01	1.48E+02	2.61E+01	2.10E+01	5.88E+01	2.69E+01	4.37E+00	1.29E+01	4.38E+00
ST41-21	2.20E+00	3.88E+00	BLQ	BLQ	1.27E+00	ND	ND	ND	ND
ST41-25	4.90E+01	8.39E+00	9.83E+02	7.91E+02	ND	ND	8.80E+01	1.59E+01	1.10E+00
ST41-29	BLQ	1.34E+00	1.15E+00	1.09E+00	BLQ	ND	ND	ND	ND
W-9	1.26E+00	1.81E+00	9.06E-01	BLQ	1.37E+00	1.07E+00	BLQ	BLQ	BLQ
W-18	7.01E+00	3.45E+01	1.08E+01	9.33E+00	2.63E+01	1.13E+01	2.39E+00	8.63E+00	3.35E+00
100 PPB	9.44E+01	9.32E+01	9.61E+01	9.54E+01	1.01E+02	9.84E+01	9.85E+01	9.88E+01	9.81E+01
W-19	1.83E+01	6.08E+01	1.71E+01	1.50E+01	4.02E+01	1.73E+01	4.76E+00	1.28E+01	6.45E+00
W-19 Duplicate	1.62E+01	5.85E+01	1.47E+01	1.22E+01	3.51E+01	1.66E+01	2.63E+00	1.09E+01	4.42E+00
MW37-A	ND	ND	BLQ	ND	ND	ND	ND	BLQ	ND
MW37-B	ND	BLQ	BLQ	BLQ	BLQ	BLQ	ND	ND	ND
ST41-ES1	6.32E+01	1.30E+00	ND	BLQ	BLQ	ND	ND	ND	BLQ
ST41-ES1 Duplicate	6.44E+01	1.56E+00	ND	BLQ	BLQ	ND	ND	ND	BLQ
ST41-ES2	3.02E+00	2.19E+00	ND	ND	BLQ	ND	ND	BLQ	1.40E+00
QC	4.85E+01	4.99E+01	5.10E+01	5.04E+01	4.67E+01	4.96E+01	5.32E+01	5.54E+01	5.40E+01
10 PPB	9.71E+00	9.60E+00	9.06E+00	9.75E+00	9.51E+00	9.71E+00	1.07E+01	1.05E+01	1.08E+01
ST41-ES4A	ND	BLQ	ND	ND	ND	ND	BLQ	ND	ND
ST41-ES4B	BLQ	ND	ND	BLQ	ND	ND	ND	ND	ND
ST41-ES5A	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
OU4W-1	2.16E+00	3.02E+00	1.61E+00	1.07E+00	3.52E+00	1.61E+00	BLQ	2.75E+00	1.41E+00
OU4W-2	2.84E+00	1.68E+01	5.27E+00	4.33E+00	1.26E+01	6.05E+00	1.32E+00	5.01E+00	2.26E+00
OU4W-3	1.36E+00	2.80E+00	1.79E+00	1.88E+00	3.94E+00	1.90E+00	BLQ	2.63E+00	1.71E+00
OU4W-4	2.03E+02	8.84E+00	6.58E+01	5.58E+01	6.18E+01	6.24E+01	1.54E+01	4.26E+01	2.45E+01
OU4W-5	1.48E+00	3.82E+00	2.80E+00	2.40E+00	6.82E+00	3.16E+00	BLQ	3.45E+00	1.42E+00
OU4W-10	1.41E+00	2.21E+00	1.39E+00	1.07E+00	2.97E+00	1.31E+00	BLQ	2.22E+00	1.86E+00
SP7/10-02	BLQ	BLQ	ND	ND	9.69E-01	ND	ND	BLQ	BLQ
GC LAB BI	ND	ND	ND	ND	ND	ND	ND	NC	ND
500 PPB	5.22E+02	4.83E+02	5.07E+02	5.18E+02	5.18E+02	5.11E+02	4.85E+02	5.15E+02	5.10E+02

SAMPLE NAME	BENZENE	TOLUENE	ETHYLBENZENE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
100 PPB	9.53E+01	1.01E+02	9.75E+01	9.71E+01	1.01E+02	9.79E+01	1.01E+02	9.89E+01	9.57E+01
QC, OBSERVED, PPB	4.69E+01	5.00E+01	5.10E+01	5.07E+01	4.93E+01	4.92E+01	4.87E+01	5.25E+01	5.05E+01
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
ES-MW1A	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND
ES-MW1B	5.30E+00	2.35E+00	2.97E+01	4.33E+01	4.24E+01	5.37E+01	2.27E+01	7.17E+01	3.86E+01
ST41-ES3	2.24E+00	3.19E+00	ND	ND	ND	ND	ND	BLQ	1.25E+00
ST41-ES5B	4.34E+00	2.91E+00	ND	ND	ND	ND	ND	ND	ND
ST41-ES6A	ND	BLQ	ND	ND	ND	ND	ND	BLQ	ND
ST41-ES6B	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-ES6B Duplicate	ND	ND	ND	ND	ND	ND	ND	BLQ	ND
ST41-ES7A	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-ES7B	ND	ND	ND	ND	ND	ND	ND	ND	ND
ST41-ES8A	ND	ND	ND	ND	ND	ND	ND	ND	ND
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND
10 PPB	1.03E+01	9.85E+00	9.97E+00	9.71E+00	9.14E+00	9.19E+00	9.31E+00	9.40E+00	9.71E+00
ST41-ES8B	ND	ND	ND	ND	ND	ND	ND	ND	ND
ESMW-02	2.15E+00	2.29E+00	1.50E+00	1.53E+00	1.36E+00	1.09E+00	1.54E+00	1.81E+00	1.79E+00
ESMW-3A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	BLQ
ESMW-3B	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND
ESMW-04A	1.52E+00	1.54E+00	ND	ND	ND	ND	ND	ND	ND
ESMW-04B	ND	BLQ	ND	ND	ND	ND	ND	ND	ND
ESMW-5A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND
ESMW-5B	ND	1.34E+00	ND	ND	ND	ND	ND	ND	ND
ESMW-6A	ND	BLQ	ND	ND	BLQ	ND	ND	ND	ND
ESMW-6B	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND
500 PPB	4.93E+02	4.59E+02	4.71E+02	4.72E+02	4.77E+02	4.97E+02	5.37E+02	5.55E+02	5.95E+02
ESMW-7A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND
ESMW-7B	BLQ	9.65E+01	ND	ND	ND	ND	ND	ND	ND
10 PPB	1.06E+01	1.04E+01	1.01E+01	1.01E+01	1.03E+01	1.06E+01	1.02E+01	9.44E+00	9.90E+00

SAMPLE NAME	Vinyl Chloride	1,1-DCE	trans-DCE	cis-DCE	TCE
OU4W-3	BLQ	9.98E-01	5.56E+00	BLQ	1.51E+00
QC, OBSERVED, PPB	1.99E+01	4.50E+01	5.09E+01	5.31E+01	5.51E+01
QC, TRUE VALUE, PPB	2.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
10 PPB	1.03E+01	1.10E+01	1.10E+01	1.08E+01	1.09E+01

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb

SAMPLE I	BENZENE	TOLUENE	ETHYLBENZE	p-XYLENE	m-XYLENE	o-XYLENE	1,3,5-TMB	1,2,	B	1,2,3-TMB
100 PPB	9.53E+01	1.01E+02	9.75E+01	9.71E+01	1.01E+02	9.79E+01	1.01E+02	9.89E+01	9.57E+01	
QC, OBSERVED, PPB	4.69E+01	5.00E+01	5.10E+01	5.07E+01	4.93E+01	4.92E+01	4.87E+01	5.25E+01	5.05E+01	
QC, TRUE VALUE, PPB	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01	
ES-MW1A	BLQ	ND	ND	ND	BLQ	ND	ND	ND	ND	
ES-MW1B	5.30E+00	2.35E+00	2.97E+01	4.33E+01	4.24E+01	5.37E+01	2.27E+01	7.17E+01	3.86E+01	
ST41-ES3	2.24E+00	3.18E+00	ND	ND	ND	ND	ND	BLQ	1.25E+00	
ST41-ES5B	4.34E+00	2.91E+00	ND	ND	ND	ND	ND	ND	ND	
ST41-ES6A	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	
ST41-ES6B	ND	ND	ND	ND	ND	ND	ND	ND	ND	
ST41-ES6B Duplicate	ND	ND	ND	ND	ND	ND	ND	ND	ND	
ST41-ES7A	ND	ND	ND	ND	ND	ND	ND	BLQ	ND	
ST41-ES7B	ND	ND	ND	ND	ND	ND	ND	ND	ND	
ST41-ES8A	ND	ND	ND	ND	ND	ND	ND	ND	ND	
GC LAB BLANK, PPB	ND	ND	ND	ND	ND	ND	ND	ND	ND	
10 PPB	1.03E+01	9.85E+00	8.97E+00	9.71E+00	9.14E+00	9.19E+00	9.31E+00	9.40E+00	9.71E+00	
ST41-ES8B	ND	ND	ND	ND	ND	ND	ND	ND	ND	
ESMW-02	2.15E+00	2.29E+00	1.50E+00	1.53E+00	1.36E+00	1.09E+00	1.54E+00	1.61E+00	1.79E+00	
ESMW-3A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	BLQ	
ESMW-3B	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	
ESMW-04A	1.52E+00	1.54E+00	ND	ND	ND	ND	ND	ND	ND	
ESMW-04B	ND	BLQ	ND	ND	ND	ND	ND	ND	ND	
ESMW-5A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	
ESMW-5B	ND	1.34E+00	ND	ND	ND	ND	ND	ND	ND	
ESMW-6A	ND	BLQ	ND	ND	BLQ	ND	ND	ND	ND	
ESMW-6B	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	
500 PPB	4.93E+02	4.59E+02	4.71E+02	4.72E+02	4.77E+02	4.97E+02	5.37E+02	5.55E+02	5.95E+02	
ESMW-7A	BLQ	BLQ	ND	ND	ND	ND	ND	ND	ND	
ESMW-7B	BLQ	9.65E-01	ND	ND	ND	ND	ND	ND	ND	
10 PPB	1.06E+01	1.04E+01	1.01E+01	1.01E+01	1.03E+01	1.06E+01	1.02E+01	9.44E+00	9.90E+00	

SAMPLE NAME	Vinyl Chloride	1,1-DCE	trans-DCE	cis-DCE	TCE
OU4W-3	BLQ	9.98E-01	5.56E+00	BLQ	1.51E+00
QC, OBSERVED, PPB	1.99E+01	4.50E+01	5.09E+01	5.31E+01	5.51E+01
QC, TRUE VALUE, PPB	2.00E+01	5.00E+01	5.00E+01	5.00E+01	5.00E+01
10 PPB	1.03E+01	1.10E+01	1.10E+01	1.08E+01	1.09E+01

ND = None Detected; BLQ = Below Limit of Quantitation, 1 ppb

ELMENDORF AIR FORCE BASE - ALASKA
FIELD DATA

Sample #	Date	Redox	Cond	pH	Total alk mg/l CaCO ₃	Ferrous iron mg/l	Hydrogen sulfide mg/l
46WL01	6-07-94	-24	432	6.3	150	9.1	<.1
46WL02	6-07-94	102	190	6.1	61	2.1	---
46WL03	6-07-94	119	340	6.7	108	<.05	---
MW37A	6-07-94	104	114	7.1	50	<.05	---
MW37B	6-07-94	-25	388	7.4	170	<.05	<.1
ST41-29	6-07-94	10	232	6.1	92	.7	<.1
ST41-W8	6-07-94	20	402	6.9	49	<.05	---
ST41-W7	6-07-94	115	880	7.5	388	<.05	---
ST41-25	6-07-94	-53	1224	6.8	460	10.5	<.1
ST41-21	6-08-94	258	755	6.3	150	<.05	<.1
ST41-15	6-08-94	15	961	6.8	375	1.0	---
ST41-16	6-08-94	-30	2170	6.6	1210	40.5	---
ST41-18	6-08-94	110	647	6.4	223	<.05	<.1
ST41-2	6-08-94	121	1039	6.7	554	<.05	---
W-19	6-08-94	165	876	7.0	347	<.05	---
W-18	6-08-94	-120	902	7.0	467	4.3	<.1
OU4W-2	6-08-94	33	683	7.2	326	<.05	---

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ELMENDORF AIR FORCE BASE - ALASKA FIELD DATA						
Sample #	Date	Redox	Cond	pH	Total alk mg/l CaCO ₃	Ferrous iron mg/l
ST41-01	6-09-94	---	954	7.1	512	<.05
ST41-07	6-09-94	---	702	7.2	270	.2
OU4W-4	6-09-94	-80	733	7.1	353	4.6
OU4W-5	6-09-94	60	662	7.1	274	<.05
OU4W-3	6-09-94	-20	834	7.0	428	.4
OU4W-10	6-09-94	20	544	6.9	265	.3
OU4W-1	6-09-94	-39	1013	6.9	456	2.9
SP7/10-02	6-09-94	40	790	6.9	269	<.05
W-9	6-09-94	123	812	7.0	345	<.05
ST41ES4A	6-10-94	168	214	6.1	76	<.05
ST41ES4B	6-10-94	20	660	6.6	251	2.1
ST41ES5A	6-10-94	126	109	6.7	47	<.05
ST41ES5B	6-10-94	91	280	7.9	115	<.05
ST41ES1	6-10-94	110	1060	6.8	481	<.05
ST41ES2	6-10-94	11	747	6.7	271	3.6

ELMENDORF AIR FORCE BASE - ALASKA
FIELD DATA

[illegible]

MANTECH TECH

Ref: 94-PR77/vg

July 1, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

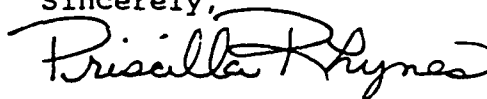
THRU: S.A. Vandegrift, AV

Dear Don:

Attached are the results of 11 Elmendorf AFB samples submitted to ManTech as part of S.R. #SF-0-65. The samples were received on June 24 and 27 and analyzed June 27, 28, and 29, 1994. The methods used for analysis were EPA Methods 120.1, 310.1, and 353.1 and Water's capillary electrophoresis method N-601. Quality assurance measures performed on this set of samples included spikes, duplicates, known AQC samples and blanks.

If you have any questions concerning these results please feel free to contact me.

Sincerely,



Priscilla Rhynes

xc: R.L. Cosby
J.L. Seeley jls
M. Cook

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501



<u>Sample</u>	<u>mg/l</u> <u>NO₂⁻+NO₃⁻(N)</u>	<u>mg/l</u> <u>Cl⁻</u>	<u>mg/l</u> <u>SO₄²⁻</u>	<u>Cond.</u>	<u>Total</u> <u>Alkalinity</u>
ES MW 02	9.10	3.14	21.3	865	365
ES MW 3A	7.64	8.04	2.12	817	386
ES MW 3B	1.13	5.64	8.14	793	385
ES MW 3B Dup	1.09	5.79	8.28		
ES MW 4A	9.98	3.09	26.7	388	115
ES MW 4B	.24	2.74	27.7	272	93.9
ES MW 5A	4.58	4.26	15.0	558	230
ES MW 5B	.68	1.72	22.5	312	114
ES MW 6A	49.2	5.36	17.3	1140	368
ES MW 6B	.60	6.89	4.32	780	380
ES MW 7A	3.08	4.69	4.47	799	393
ES MW 7A Dup	3.02			800	393
ES MW 7B	.23	4.82	8.78	827	406
Blanks	<.05	<.05	<.05	---	---
AQCWP031	.54	40.7	89.1	---	---
True Value	.52	41.2	92.0	---	---
Spike Rec.	96%	97%	95%	---	---

MANTECH TECH

Ref: 94-BN36/vg

July 5, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SAV*

Dear Don:

Find attached results for methane on Elmendorf AFB samples as per Service Request #SF-0-65. Samples were received on June 9, 10, 14, 24, and 27, 1994 and analyzed on June 13, 16, and 29, 1994. Samples were prepared as described in the paper "Dissolved Oxygen and Methane in Water by a GC Headspace Equilibration Technique", by Kampbell et al., in International Journal of Environmental Analytical Chemistry, Volume 36, pp.249-257. Analysis and calculations were performed as per RSKSOP-147.

If you have any questions, please feel free to see me.

Sincerely,

Bryan Newell

Bryan Newell

xc: R.L. Cosby
J.L. Seeley *js*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SF-0-65 DATA

ANALYZED 6/13/94

SAMPLE	METHANE
LAB BLANK	BLQ
ST41-01	BLQ
ST41-02	0.008
ST41-07	0.054
ST41-W7	0.489
* FIELD DUP	0.503
ST41-W8	BLQ
ST41-15	0.001
ST41-16	0.046
ST41-18	0.040
ST41-21	0.003
ST41-25	0.922
ST41-29	0.044
MW37A	BLQ
MW37B	0.002
OU4W-2	0.008
OU4W-4	0.993
OU4W-5	0.001
W-18	6.020
W-19	0.004
* LAB DUP	0.003
46WL01	0.519
46WL02	BLQ
46WL03	0.001

ANALYZED 6/16/94

SAMPLE	METHANE
LAB BLANK	BLQ
OU4W-1	4.079
* FIELD DUP	4.774
OU4W-3	0.136
W-9	0.002
OU4W-10	BLQ
ESMW-1A	2.373
ESMW-1B	8.500
ST41-ES1	0.004
ST41-ES2	1.481
ST41-ES3	0.002
ST41-ES4A	0.001
ST41-ES4B	0.051
ST41-ES5A	BLQ
ST41-ES5B	0.052

SAMPLE	METHANE
ST41-ES6A	BLQ
ST41-ES6B	0.006
ST41-ES7A	1.553
ST41-ES7B	0.194
* LAB DUP	0.180
ST41-ES8A	0.811
ST41-ES8B	0.007
SP7/10-02	0.001
* FIELD DUP	0.001

ANALYZED 6/29/94

SAMPLE	METHANE
LAB BLANK	BLQ
ESMW2	BLQ
ESMW3A	0.063
ESMW3B	0.192
ESMW4A	BLQ
ESMW4B	0.063
ESMW5A	BLQ
ESMW5B	0.133
ESMW6A	BLQ
ESMW6B	0.344
ESMW7A	0.002
ESMW7B	0.008
* LAB DUP	0.007

STANDARDS	METHANE
10 PPM CH4	9.57
100 PPM CH4	103.54
1060 PPM CH4	999.65
1 % CH4	1.04
4 % CH4	3.81
10 % CH4	10.07

LOWER LIMIT OF QUANTITATION

0.001

ND DENOTES NONE DETECTED.

BLQ DENOTES BELOW LIMIT OF QUANTITATION.

UNITS FOR SAMPLES ARE mg/L
UNITS FOR STANDARDS CORRESPOND TO THE UNITS
IN THE SAMPLE COLUMN.

MANTECH TECHNOLOGY

Ref: 94-RC25/vg

July 7, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SAV*

Dear Don:

Attached is a report of the data-generated from the analyses of 24 sample core extracts from Elmendorf AFB, AK. The extracts, which were submitted under Service Request #SF-0-65, were analyzed for total fuel content as JP-4 jet fuel only. The reported values for fuel carbon were computed from the JP-4 determinations. I have also attached a report of the quality control analyses that were performed concurrently with the sample analyses.

Data quantification, peak identification, component concentration calculations, and dilution factor corrections were performed with MAXIMA chromatography software. JP-4 data was quantified with a 7-point external standard calibration curve ranging from 50-50,000 ng/ μ l.

The Minimum Quantifiable Limit of JP-4 in these samples is 14.79 μ g/g. Please refer to Mantech report letter 93-RC19/vg, dated October 29, 1993, for a detailed explanation of the calculations used to arrive at this value.

Sample extracts were received June 16 and 27, 1994. Analyses were started June 16, 1994 and completed June 28, 1994. Sample extracts and quality control samples were analyzed according to RSKSOP-72, Rev. #1, excepting the modifications listed in the attached outline.

Sincerely,

Randy Callaway
Randy Callaway

xc: R.L. Cosby
J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SR4SF 3 / Kampbell / Elmendorf AFB, AK all conc. a 1g/g

Sample I.D.	Dilution Factor	JP-4	Fuel Carbon (JP-4 x 0.85)
ST41 ES MW1B 22-24'	1	0.06	0.05
ST41 ES MW1B 26-28'	1	0.07	0.06
ST41 ES MW2 22-24'	1	0.21	0.18
ST41 ES MW2 24-26'	1	1.10	0.94
ST41 ES MW4B 20-22'	1	0.15	0.13
ST41 ES MW4B 24-26'	1	0.80	0.68
ST41 ES MW5B 14-16'	1	0.34	0.29
ST41 ES MW7B 17-18'	1	0.12	0.10
ST41 ES 1 12-14'	1	0.12	0.10
ST41 ES 1 14-16'	1	0.21	0.17
ST41 ES 2 4-6'	1	12.80	10.90
ST41 ES 2 6-8'	1	1.77	1.50
ST41 ES 3 3-4'	1	0.15	0.13
ST41 ES 3 4-6'	1	0.15	0.13
ST41 ES 4B 4-6'	1	0.05	0.04
ST41 ES 4B 6-8'	1	0.20	0.17
ST41 ES 5 4-6'	1	0.09	0.08
ST41 ES 5 6-8'	1	0.11	0.10
ST41 ES 6B 8-10'	1	0.13	0.11
ST41 ES 6B 10-12'	1	0.19	0.16
ST41 ES 7B 6-8'	1	0.30	0.26
ST41 ES 7B 10-12'	1	1.44	1.22
ST41 ES 8B 6-8'	1	0.35	0.30
ST41 ES 8B 10-12'	1	0.32	0.27

NOTE: all reported values are corrected for dilution factors where applicable
nd = none detected

SR/SF-C / Kampbell / QC Table all conc. are ng/ul

Sample I.D.	Date Analyzed	JP-4
blank MeCl2	16JUN94	2.23
Method blank		0.19
500 ng/ul jp4		506.00
5000 ng/ul jp4		5060.00
50000 ng/ul jp4		44400.00
blank MeCl2	27JUN94	1.80
Method blank		0.67
100 ng/ul jp4		98.50
1000 ng/ul jp4		1010.00

nd = none detected
 MeCl2 = methylene chloride solvent blank
 jp4 = JP-4 fuel standard

I. HP5890 GC - OPERATING CONDITIONS

- A. Instrument Control
 - 1. Analyses: "EGLIN AFB"
 - 2. Program: "RWC-AS10"
 - 3. Calibration: "BTEX-13JUN94"
- B. Temperature Program
 - 1. Initial Temp & Time: 10°C for 3.00 min
 - 2. Level 1: Rate = 4°C/min to 70°C, Final Time = 0.00
 - 3. Level 2: Rate = 1.0°C/min to 75°C, Final Time = 0.00
 - 4. Level 3: Rate = 10°C/min to 290°C, Final Time = 15.50
 - 5. Run Time: 60.00 min
 - 6. Oven Equilibration Time: 1.00 min
- C. Miscellaneous
 - 1. Peak Width: 0.02
 - 2. Attenuation: 2^5
 - 3. Chart Speed: 0.50
 - 4. Threshold = 0
 - 5. Offset = 10%

II. MAXIMA PEAK INTEGRATION

- A. Peak Detection Parameters
 - 1. Baseline Points: 18
 - 2. Filter Window (in points): 9
 - 3. Intg. Sensitivity (coarse): 10.50 $\mu\text{V/sec}$
 - 4. Intg. Sensitivity (fine): 5.00 $\mu\text{V/sec}$
 - 5. Skim Ratio: 100.00
- B. Peak Rejection Criteria
 - 1. Minimum Area: 2000 $\mu\text{V-sec}$
 - 2. Minimum Height: 300.0 μV
 - 3. Minimum Width: 3.00 sec
- C. Integration Events
 - 1. 0.00: Disable Peak Skimming
 - 2. 0.00: Disable Peak Detection
 - 3. 7.00: Enable Peak Detection
 - 4. 21.97: Set Baseline
 - 5. 27.13: Set Baseline
 - 6. 32.30: Set Baseline
 - 7. 36.80: Set Baseline
 - 8. 39.59: Set Baseline
 - 9. 41.52: Set Baseline

III. MAXIMA DATA ACQUISITION

- A. Preacquisition Delay: 7.00 min
- B. Duration: 43.00 min
- C. Rate: 3.00 points/sec
- D. Run Time: 50.00 min

IV. MAXIMA CALIBRATION CURVES

- A. JP-4
 - 1. Calibration Range = 50 - 50,000 ng/ μl
 - 2. Summation of all peaks detected from 7.00 - 50.0 minutes

**MANTECH
TECH**

Ref: 94-MB9/rc

July 7, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *for SAV*

Dear Don:

The fuel carbon extractions of the Elmendorf core samples, as requested by Service Request SF-0-65, have been completed. The samples were placed on a wrist action shaker for 30 minutes and sonicated approximately 2 minutes prior to the extraction procedure. A total of 24 samples and 2 method blanks were delivered to Randy Callaway June 27, 1994 for GC analysis.

Please find attached a copy of the % moisture determinations from my lab book.

If you have any questions, please contact me at your convenience.

Sincerely,

Mark Blankenship
Mark Blankenship

xc: R.L. Cosby
J.L. Seeley *jl*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

SE-0-65

Elmendorf AFB AK

7-5-94

Dry Wt. Basis

% moisture determinations

6.

Sample	Tare	Tare + Wet	Tare + Dry	% moisture
ES MW 1B 22-24	50.87	67.81	66.78	6.4%
ES MW 1B 26-28	48.95	78.64	76.79	6.6%
ST 41 ES 1 12-14	30.42	43.97	42.45	12.6%
ST 41 ES 1 14-16	29.77	40.41	38.67	19.5%
ES 2 4-6	29.12	35.81	34.56	22.9%
ES 2 6-8	28.23	35.28	34.48	12.8%
ES 3 3-4	46.28	90.35	88.26	9.5%
ES 3 4-6	49.39	71.66	69.95	8.3%
ES 4B 4-6	50.94	73.25	69.59	19.6%
ES 4B 6-8	31.48	43.50	41.33	16.7%
• ES 5 4-6	30.24	47.53	46.68	5.1%
ES 5 6-8	26.12	38.75	37.28	13.5%
ES 6B 8-10	50.53	76.19	74.44	7.3%
ES 6B 10-12	31.15	53.23	50.12	16.3%
ES 7B 6-8	31.15	47.04	45.81	8.3%
ES 7B 10-12	29.25	50.78	48.65	10.2%
ES 8B 6-8	49.25	70.94	67.72	17.4%
ST ES 8B 10-12	55.49	78.69	77.16	7.1%
MW 3B 24-25				
MW 3B 22-24				
MW 2 22-24				
MW 2 24-26				
MW 4B 20-22				
MW 4B 24-26				
MW 5B 14-16				
MW 7B 17-18				

no % moisture
for these samples

ELMENDORF AIR FORCE BASE - ALASKA
FIELD DATA

Sample #	Date	Redox	Cond	pH	Total alk mg/l CaCO ₃	Ferrous iron mg/l	Hydrogen sulfide mg/l
46WL01	6-07-94	-24	432	6.3	150	9.1	<.1
46WL02	6-07-94	102	190	6.1	61	2.1	---
46WL03	6-07-94	119	340	6.7	108	<.05	---
MW37A	6-07-94	104	114	7.1	50	<.05	---
MW37B	6-07-94	-25	388	7.4	170	<.05	<.1
ST41-29	6-07-94	10	232	6.1	92	.7	<.1
ST41-W8	6-07-94	20	402	6.9	49	<.05	---
ST41-W7	6-07-94	115	880	7.5	388	<.05	---
ST41-25	6-07-94	-53	1224	6.8	460	10.5	<.1
ST41-21	6-08-94	258	755	6.3	150	<.05	<.1
ST41-15	6-08-94	15	961	6.8	375	1.0	---
ST41-16	6-08-94	-30	2170	6.6	1210	40.5	---
ST41-18	6-08-94	110	647	6.4	223	<.05	<.1
ST41-2	6-08-94	121	1039	6.7	554	<.05	---
W-19	6-08-94	165	876	7.0	347	<.05	---
W-18	6-08-94	-120	902	7.0	467	4.3	<.1
OU4W-2	6-08-94	33	683	7.2	326	<.05	---

ELMENDORF AIR FORCE BASE - ALASKA
FIELD DATA

Sample #	Date	Redox	Cond	pH	Total alk mg/l CaCO ₃	Ferrous iron mg/l
ST41-01	6-09-94	---	954	7.1	512	<.05
ST41-07	6-09-94	---	702	7.2	270	.2
OU4W-4	6-09-94	-80	733	7.1	353	4.6
OU4W-5	6-09-94	60	662	7.1	274	<.05
OU4W-3	6-09-94	-20	834	7.0	428	.4
OU4W-10	6-09-94	20	544	6.9	265	.3
OU4W-1	6-09-94	-39	1013	6.9	456	2.9
SP7/10-02	6-09-94	40	790	6.9	269	<.05
W-9	6-09-94	123	812	7.0	345	<.05
ST41ES4A	6-10-94	168	214	6.1	76	<.05
ST41ES4B	6-10-94	20	660	6.6	251	2.1
ST41ES5A	6-10-94	126	109	6.7	47	<.05
ST41ES5B	6-10-94	91	280	7.9	115	<.05
ST41ES1	6-10-94	110	1060	6.8	481	<.05
ST41ES2	6-10-94	11	747	6.7	271	3.6

[illegible][illegible]

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MANTECH
TECH

Ref: 94-LP46/vg

July 18, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift SAV

Dear Don:

Attached are TOC results for a set of 18 soils from Elmendorf AFB submitted to ManTech Environmental June 15, 1994 as a part of Service Request #SF-0-65 Mod. 1. The samples were stored at 6°C until analyses were begun June 30 using RSKSOP-120.

A Leco standard soil was analyzed along with your samples for quality control.

If you have any questions concerning this data, please feel free to contact me.

Sincerely,

Lynda Pennington
Lynda Pennington

xc: R.L. Cosby
J.L. Seeley *jl*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
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25

MANTECH
TECHNOLOGY

Ref: 94-LP38/lm

June 17, 1994

Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift *SAV*

Dear Don:

Attached are TOC results for 44 liquid samples from Elmendorf AFB submitted to ManTech as a part of Service Request # SF-0-65 Mod. 1. Dates of sample receipt and analysis are included with sample data on the following pages.

Blanks, duplicates, and known AQC samples were analyzed along with your samples for quality control.

If you have any questions concerning this data, please feel free to ask me.

Sincerely,

Lynda Pennington
Lynda Pennington

xc: R.L. Cosby
J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-9660 FAX 405-436-8501

Samples Received: 06/09/94
Samples Analyzed: 06/10/94

<u>Sample</u>	<u>mg/L</u> <u>TOC</u>
46 WL 01	15.2
46 WL 02	3.7
46 WL 03	2.8
ST 41-15	6.4
ST 41-16	109
ST 41-W7	4.6
ST 41-W7 (FD)	4.8
ST 41-W8	1.8
ST 41-21	8.8
ST 41-21 (LD)	8.8
ST 41-25	24.4
ST 41-29	8.5
ST 41-18	11.4
MW 37 A	0.5
MW 37 B	2.4
MW 37 B (LD)	2.5
Millipore H ₂ O	<0.1
WPO31 I	28.3
	28.5
WPO31 I T.V.	28.0

Samples Received: 06/10/94
Samples Analyzed: 06/10/94

<u>Sample</u>	<u>mg/L</u> <u>TOC</u>
OU 4W-2	1.1
OU 4W-4	2.0
OU 4W-5	1.6
ST41-01	2.9
ST41-02	13.7
ST41-02 (LD)	13.6
ST41-07	7.2
W-18	1.6
W-19	1.3
Millipore	<.01
WPO31 I	27.5
WPO31 I T.V.	28.0

Samples Received: 06/14/94
Samples Analyzed: 06/17/94

Note: The samples were analyzed for dissolved gases by Bryan Newell prior to TOC analysis resulting in a 3-day delay between sample receipt and analysis.

<u>Sample</u>	<u>mg/L</u> <u>TOC</u>
OU 4W-1	4.6
OU 4W-1 (FD)	2.4
OU 4W-3	1.3
W-9	1.6
OU 4W-10	1.8
ES-MW-1A	2.3
ES-MW-1B	4.1
ST41-ES-1	7.3
ST41-ES-2	7.6
ST41-ES-3	3.5
ST41-ES-3 (LD)	3.5
ST41-ES-4A	19.1
ST41-ES-4B	13.1
ST41-ES-5A	2.0
ST41-ES-5B	4.8
ST41-ES-6A	3.3
ST41-ES-6B	3.1
ST41-ES-7A	38.1
ST41-ES-7B	11.2
ST41-ES-8A	6.8
ST41-ES-8B	3.6
SP7/10-02	1.2
SP7/10-02 (LD)	1.2
SP7/10-02 (FD)	1.1
Millipore H ₂ O	0.1
WPO31 I	27.6
WPO31 I	27.3
WPO31 I T.V.	28.0

FD = Field Duplicate LD = Lab Duplicate TV - True Value



Ref: 94-PR69/rc
94-TH67/rc

June 15, 1994

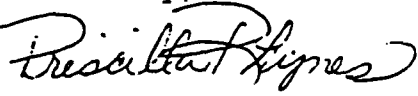
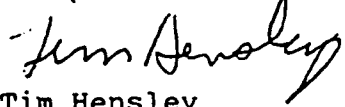
Dr. Don Kampbell
R.S. Kerr Environmental Research Lab
U.S. Environmental Protection Agency
Post Office Box 1198
Ada, OK 74820

THRU: S.A. Vandegrift ^{AV}

Dear Don:

Attached are the results of 21 Elmendorf AFB samples submitted to ManTech Environmental as part of Service Request # SF-0-65. The samples were received on June 15 and analyzed June 15 and 16. The methods used for analysis were EPA methods 120.1 and 353.1, and Water's Capillary Electrophoresis Method N-601. Blanks, spikes, duplicates and known AQC samples were analyzed along with the samples for quality assurance.

If you have any questions concerning these results, please feel free to contact us.

Sincerely,

Priscilla Rhynes

Tim Hensley

xc: R.L. Cosby
J.L. Seeley *jls*

ManTech Environmental Research Services Corporation

R.S. Kerr Environmental Research Laboratory, P.O. Box 1198, 919 Kerr Research Drive
Ada, Oklahoma 74821-1198 405-436-8660 FAX 405-436-8501

<u>Sample</u>	<u>mg/l</u> <u>Cl⁻</u>	<u>mg/l</u> <u>SO₄⁻²</u>	<u>mg/l</u> <u>NO₂⁻+NO₃⁻(N)</u>	<u>Conductivity</u>
W-9	15.5	3.58	15.5	752
OU4W-1	8.87	3.39	9.04	908
OU4W-3	3.48	5.02	15.4	751
OU4W-10	3.04	4.49	8.27	495
ES-MW1A	.13	5.14	15.7	571
ES-MW1B	.07	5.49	<.5	770
ST41-ES1	.80	21.4	61.4	965
ST41-ES2	.10	59.3	13.1	686
ST41-ES2 Dup				679
ST41-ES3	.17	28.2	31.1	422
ST41-ES4A	.11	8.45	4.72	196
STR1-ES4A Dup	.12			
ST41-ES4B	.07	50.3	12.2	593
ST41-ES5A	.18	4.18	2.07	101
ST41-ES5B	.14	8.23	9.97	259
ST41-6A	.28	.71	3.44	112
ST41-6A Dup		.63	3.51	
ST41-ES6B	.12	1.34	5.40	198
ST41-ES7A	.06	10.3	3.10	568
ST41-ES7A Dup	.06			
ST41-ES7B	.06	27.8	5.38	450
ST41-ES8A	.23	3.00	8.28	303
ST41-ES8A Dup				301
ST41-ES8B	.08	3.38	7.21	306
SP7/10-02	25.6	18.6	15.1	742
SP7/10-02 Dup		18.6	15.1	
4B	50.3	12.0	***	604
Blanks	<.05	<.05	<.05	----
AQCWPO31	10.9	40.8	91.6	----
True Value	11.0	40.2	92.0	----
Spike Recovery	100%	99%	103%	----

*** No sample

DON KAMPBELL'S ELEMENTARY AFB 8 TOC RESULTS (SF-0-65)

SAMPLE	SOIL FILT. % OC	SOLIDS % OC	TOTAL SOIL % TOC	MEAN	SAMPLE	SOIL FILT. % OC	SOLIDS % OC	TOTAL SOIL % TOC	MEAN
ESMW-1B-1 22-24'	0.019	3.240	3.259	3.250	ST41-ES7B-1 6-8'	0.072	0.189	0.261	0.264
ESMW-1B-2 22-24'	0.019	3.219	3.238		ST41-ES7B-2 6-8'	0.072	0.195	0.267	
ESMW-1B-1 26-28'	0.005	0.132	0.137	0.125	ST41-ES7B-1 10-12'	0.043	0.167	0.210	0.203
ESMW-1B-2 26-28'	0.005	0.107	0.112		ST41-ES7B-2 10-12'	0.038	0.158	0.196	
ST41-ES1-1 12-14'	0.006	0.201	0.207		ST41-ES8B-1 6-8'	0.082	0.382	0.464	0.457
ST41-ES1-2 12-14'	0.010	0.151	0.161	0.173	ST41-ES8B-2 6-8'	0.079	0.371	0.450	
ST41-ES1-3 12-14'	0.012	0.138	0.150		ST41-ES8B-1 10-12'	0.026	0.114	0.140	0.149
ST41-ES1-1 14-16'	0.009	0.179	0.188	0.193	ST41-ES8B-2 10-12'	0.031	0.126	0.157	
ST41-ES1-2 14-16'	0.010	0.188	0.198		LECO STD. SOIL		0.970		
ST41-ES2-1 4-6'	1.251	24.620	25.870	25.900	LECO STD. SOIL		1.003		
ST41-ES2-2 4-6'	1.216	24.730	25.950		LECO STD. SOIL		0.997		
ST41-ES2-1 6-8'	0.591	12.450	13.040						
ST41-ES2-2 6-8'	0.490	8.195	8.685	10.600					
ST41-ES2-3 6-8'	0.543	9.555	10.100						
ST41-ES3-1 2-4'	0.016	0.148	0.164						
ST41-ES3-2 2-4'	0.014	0.104	0.118	0.138					
ST41-ES3-3 2-4'	0.012	0.119	0.131						
ST41-ES3-1 4-6'	0.008	0.103	0.111	0.107					
ST41-ES3-2 4-6'	0.006	0.096	0.102						
ST41-ES4B-1 4-6'	0.381	0.462	0.843	0.860					
ST41-ES4B-2 4-6'	0.383	0.494	0.877						
ST41-ES4B-1 6-8'	0.219	0.271	0.490	0.467					
ST41-ES4B-2 6-8'	0.203	0.242	0.445						
ST41-ES5-1 4-6'	0.024	0.082	0.106	0.107					
ST41-ES5-2 4-6'	0.025	0.083	0.108						
ST41-ES5-1 6-8'	0.024	0.095	0.119	0.119					
ST41-ES5-2 6-8'	0.025	0.114	0.139						
ST41-ES6B-1 8-10'	0.015	0.054	0.069	0.071					
ST41-ES6B-2 8-10'	0.016	0.056	0.072						
ST41-ES6B-1 10-12'	0.019	0.056	0.075	0.076					
ST41-ES6B-2 10-12'	0.020	0.056	0.076						

TRUE VALUE OF LECO STD. SOIL = 1.00 +/- .04

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
SUBSURFACE PROCESSES BRANCH

P.O. BOX 1198
ADA, OKLAHOMA 74820

FAX NUMBER: 405/436-8703

~~FACSIMILE TRANSMISSION SHEET~~

DATE: 10/27/94

NUMBER OF PAGES (Including cover sheet): 2

TO: Todd Wiedemeier

PHONE: 303-831-8100

FAX: 303-831-8208

FROM: Don Campbell

PHONE: 405-436-9564

COMMENTS/MESSAGE:

Volatile fatty acids analysis.

Volatile Fatty Acids Analyses

Analytical reports have recently been received by me for water sample analyses by GC/MS for phenols and aliphatic/aromatic acids collected at air force bases during the June-September 1994 period. Standard mixtures used contained 13 phenols, 25 aliphatic acids, and 19 aromatic acids. These components are frequently associated with microbial process breakdown products of petroleum fuel hydrocarbons. Detection limit of the analytical method used was five parts per billion.

- Hill AFB - Sample 82J, 82D, and 82O

Forty three of the 57 standard solution compounds were found in sample 82J. Fewer compounds were detected in 82D and 82O, but benzoic acid was a dominant component in all three samples.

- Elmendorf ABF - Sample OU40W-3, ST41-16, ST41-25

Sample ST41-16 contained 43 of the 57 compounds present in the standard phenol/acid mixture. Chromatogram for SET-16 and SET-25 were similar while OUT-3 had fewer detectable components. Benzoic acid was the dominate compound in all three samples. The analyses showed that aromatic acids were present at highest relative levels followed by lower amounts of aliphatic and alkenyl/cycloalkylcarboxylic acids and phenols.

ROBERT S. KERR ENVIRONMENTAL RESEARCH LABORATORY
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
SUBSURFACE PROCESSES BRANCH

P.O. BOX 1198
ADA, OKLAHOMA 74820

FAX NUMBER: 405/436-8703

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DATE: 10/27/94
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TO: Matt Swanson
Parsons Engineering- Science, Inc.
PHONE: 303-831-8100
FAX: 303-831-8208

FROM: Don Campbell
PHONE: 405-436-8564

COMMENTS/MESSAGE:
Elmendorf AFB sample analysis

SR SF-0-b. Jr. Kampbell

Elmendorf AFB Freezing Product

SIM GC/L

SAMPLE	BENZENE	TOLUENE	EB	P-XYLENE	m-XYLENE	O-XYLENE	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB
ST41-16 (mg/ml)	2.31E+00	1.14E+01	5.75E+00	4.48E+00	1.41E+01	4.67E+00	2.35E+00	6.61E+00	2.07E+00
ST41-16 (mg/g)	3.05E+00	1.51E+01	7.60E+00	5.93E+00	1.88E+01	6.18E+00	3.11E+00	8.74E+00	2.73E+00
QC Summary									
10	9.19E+00	9.17E+00	9.11E+00	9.08E+00	9.28E+00	9.10E+00	9.18E+00	9.22E+00	9.20E+00
10	1.04E+01	1.08E+01	1.06E+01	1.05E+01	1.10E+01	1.08E+01	1.07E+01	1.06E+01	1.08E+01
100	9.80E+01	1.04E+02	1.04E+02	1.02E+02	1.03E+02	1.03E+02	1.05E+02	1.04E+02	1.05E+02
100	9.87E+01	1.02E+02	1.03E+02	1.02E+02	1.05E+02	1.03E+02	1.05E+02	1.06E+02	1.06E+02
300	2.71E+02	2.74E+02	2.74E+02	2.71E+02	2.72E+02	2.73E+02	2.73E+02	2.75E+02	2.78E+02
50 QC	4.85E+01	4.99E+01	5.01E+01	4.97E+01	5.08E+01	5.03E+01	5.08E+01	5.10E+01	5.10E+01

TOTAL P. 02

QC Summary

*41-16 Density = 0.756 g/ml

Analyst: David A. Kovacs

Printed: 10/27/94 1 of 1

DCI-27-1994 14:35

USEPA KKKKRL-THH SBR/SFB

APPENDIX C

CALCULATIONS AND MODEL INPUT PARAMETERS

RMS Error Calculations for Calibrated Flow Model
Site ST41, Elmendorf AFB

Cell Location x,y	Measured Head Hm	Simulated Head Hs	Hm - Hs	(Hm - Hs) ²
7,6	244.00	240.73	3.27	10.69
10,6	232.57	236.04	-3.47	12.04
9,7	220.00	225.49	-5.49	30.14
6,8	215.00	212.80	2.20	4.84
8,8	215.00	213.14	1.86	3.46
11,8	213.00	213.82	-0.82	0.67
6,9	210.00	208.81	1.19	1.42
13,9	207.00	208.23	-1.23	1.51
5,10	205.92	205.83	0.09	0.01
7,10	205.30	206.28	-0.98	0.96
10,10	206.00	205.85	0.15	0.02
13,10	202.50	205.41	-2.91	8.47
8,12	192.09	198.34	-6.25	39.06
10,12	194.00	198.02	-4.02	16.16
5,13	190.00	193.73	-3.73	13.91
6,14	188.00	190.60	-2.60	6.76

Sum of Squares of Remainders 150.13

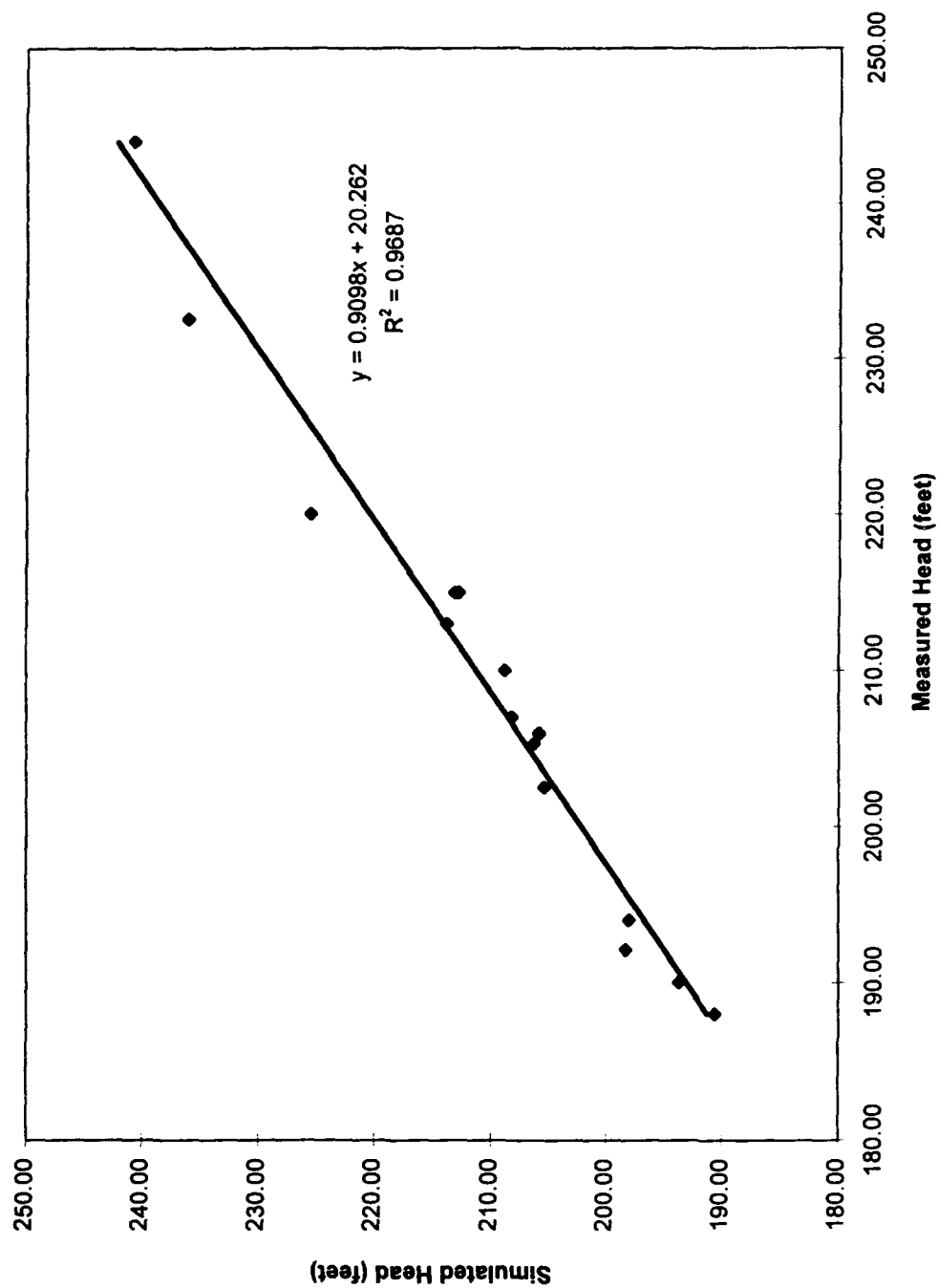
Average of Squares of Remainders 9.38

RMS 3.06

RMS as a percentage of the head drop over the model domain 4.71

Chart1

Measured Heads vs. Simulated Heads



Longitudinal Dispersivity Estimations

Site ST41, Elmendorf AFB

Assume: A) Plume is aligned along the longitudinal axis of the model grid and is relatively symmetric - so that a longitudinal moment can be calculated

B) Longitudinal dispersivity is $1/10$ the distance from the source of contamination to the longitudinal centroid

From the June 1994 BTEX Plume map, the center of mass/centroid will be determined by calculating the longitudinal moment around the center of tank 601. Mass is computed by summing the contaminant concentrations in all cells in a row. Because all cells have equal volume, the concentration within a cell will be directly proportional to the mass of BTEX in the cell.

<u>Row</u>	<u>Mass</u>	<u>Distance from Center Tank 601</u>	<u>Mass x Distance</u>
4	100	50	5000
5	2315	150	347,250
6	46550	250	11,637,500
7	2225	350	778,750
8	3800	450	1,710,000
9	3125	550	1,718,750
10	200	650	130,000
	<u>58315</u>		<u>16,327,250</u>

Estimated longitudinal centroid of plume:

$$16,327,250 / 58315 = 280.0'$$

∴ Estimated Distance from source to centroid = 280'

Estimated Longitudinal Dispersivity: $(280')(0.1) = \underline{28'}$

Calculation of Anaerobic Decay Constant (Based on method outlined in the Intrinsic Remediation Protocol Document)

In the anaerobic portion of the plume, ST41-25 is downgradient from ST41-16.

	B	T	E	X	1,3,5-TMB	1,2,4-TMB	1,2,3-TMB	($\mu\text{g/L}$)
ST41-16	16500	17300	1920	7560	183	631	283	
ST41-25	49	8.39	983	791	89	15.9	1.1	

To correct for dilution & dispersion, BTEX data are normalized to TMB data. TMB is believed to be a suitable tracer because its sorptive properties are similar but ~~it~~ the TMB compounds are recalcitrant under anaerobic cond.

Normalization Factors:

$$\begin{aligned}
 &1,3,5\text{-TMB: } \frac{89}{183} = 0.48 \\
 &1,2,4\text{-TMB: } \frac{15.9}{631} = 0.025 \\
 &1,2,3\text{-TMB: } \frac{1.1}{283} = 0.004
 \end{aligned}
 \left. \vphantom{\begin{aligned} &1,3,5\text{-TMB: } \frac{89}{183} = 0.48 \\ &1,2,4\text{-TMB: } \frac{15.9}{631} = 0.025 \\ &1,2,3\text{-TMB: } \frac{1.1}{283} = 0.004 \end{aligned}} \right\} \text{Avg.} = 0.17$$

Normalized BTEX:

$$B = 49 / 0.17 = 288.24$$

$$T = 8.39 / 0.17 = 49.35$$

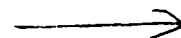
$$E = 983 / 0.17 = 5782.35$$

$$X = 791 / 0.17 = 4652.94$$

Maximum Advective Groundwater Velocity = $\sim 580 \text{ ft/yr}$

distance btwn ST41-16 & ST41-25 = $\sim 220 \text{ ft}$.

Travel time = $220 \text{ ft} / 580 \text{ ft/yr} = 0.38 \text{ yr}$.



Calculation of Anaerobic Decay Constant (cont.)

$$\frac{C}{C_0} = e^{-kt}$$

where C = concentration at time t
 C_0 = initial concentration

k = coefficient of anaerobic decay

t = time

For benzene:

$$\frac{C}{C_0} = \frac{289.24}{16500} = 0.017 = e^{-kt}; \quad -4.04 = -kt$$

$k = 10.05 \frac{1}{yr} = 0.03 \frac{1}{day}$

For toluene:

$$\frac{C}{C_0} = \frac{49.35}{17300} = 0.003 = e^{-kt}; \quad -5.86 = -kt$$

$k = 15.42 \frac{1}{yr} = 0.04 \frac{1}{day}$

For ethylbenzene:

$$\frac{C}{C_0} = \frac{5752.35}{1920} = 3.01 = e^{-kt}; \quad -kt = 1.10$$

$k = -2.9 \frac{1}{yr} = -0.008 \frac{1}{day}$

(disregard)

For xylenes:

$$\frac{C}{C_0} = \frac{4652.94}{7560} = 0.62 = e^{-kt}; \quad -kt = -0.49$$

$k = 1.28 \frac{1}{yr} = 0.003 \frac{1}{day}$

Fuel-water Partitioning Calculations

Density of Free-Product/Mobile LNAPL = 0.756 g/ml = ρ_f

Solubility of Compounds (values recommended in Intrinsic Remediation Protocol Document [Wiedemeier et al., 1998])

Benzene	1780	mg/L
Toluene	537	mg/L
Ethylbenzene	140	mg/L
o-xylene	152	mg/L
m-xylene	162	mg/L
p-xylene	198	mg/L

Mass Fraction (F) from product analysis:

	F	$C_F = F \rho_f$ (Volumetric Concentration)
Benzene	0.00305	0.00231 g/ml
Toluene	0.0151	0.01142 g/ml
Ethylbenzene	0.0076	0.00575 g/ml
o-xylene	0.0186	0.01406 g/ml
m-xylene	0.00618	0.00467 g/ml
p-xylene	0.00593	0.00448 g/ml

From the Bruce et al. (1991) method for estimation of partitioning:

$$\log K_{fw} = 6.099 - 1.15 \log S, \quad \text{where } K_{fw} = \text{fuel-water partition coefficient}$$

$$\therefore K_{fw} = 10^{6.099 - 1.15 \log S}$$

S = Solubility of pure compound in H_2O

Compound	K_{fw}
Benzene	229.624
Toluene	911.023
Ethylbenzene	4275.16
m-xylene	3614.58
o-xylene	3889.38
p-xylene	2868.69



Fuel - Water Partitioning Calculations (cont.)

K_{fw} = fuel-water partitioning coefficient = concentration in fuel / conc in H_2O

$$K_{fw} = C_f / C_w$$

$$\therefore C_w = C_f / K_{fw}$$

	$C_f (\mu g/l)$	K_{fw}	$C_w (\mu g/l)$	$C_w (\mu g/l)$
Benzene	2310	229.624	10.060	10060
Toluene	11420	911.023	12.535	12535
Ethylbenzene	5750	4275.16	1.345	1345
m-Xylene	14060	3614.58	3.890	3890
o-Xylene	4670	3889.38	1.201	1201
p-Xylene	4480	2869.69	1.561	1561
Total BTEX:			30.592	30,592
			mg/l	$\mu g/l$

Client _____
 Subject ELMENDORF AFB - ST41 MODEL
MODEL BOUNDARIES

Job No. _____
 By MAS
 Checked _____

Sheet ____ of ____
 Date _____
 Rev. _____

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	I	I	I	I	I	I	I	I	I	X
3	X	X	X	X	X	X	X	X	I	I										X
4	X	X	X	X	X	I	I	I												X
5	X	I	I	I	I															X
6	X																			X
7	X																			X
8	X																			X
9	X																			X
10	X																			X
11	X																			X
12	X																			X
13	X																			X
14	X																			X
15	X																			X
16	X																			X
17	X																			X
18	X																			X
19	X	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

↑
N

X = INACTIVE CELL

I = CONSTANT HEAD CELL

Client _____
 Subject ELMENDORF AFB - ST41 MODEL
CONSTANT HEAD CELLS - HEAD VALUES

Job No. _____
 By MAS
 Checked _____

Sheet _____ of _____
 Date _____
 Rev. _____

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	246	243.5	242	240	238	235	233	230	227	X
3	X	X	X	X	X	X	X	X	246	244										X
4	X	X	X	X	X	249	246.5	243												X
5	X	244	245	244	242															X
6	X																			X
7	X																			X
8	X																			X
9	X																			X
10	X																			X
11	X																			X
12	X																			X
13	X																			X
14	X																			X
15	X																			X
16	X																			X
17	X																			X
18	X																			X
19	X	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	175	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = INACTIVE CELL

HEAD VALUES IN FEET MSL

Client _____
 Subject ELMENDORF AFB - ST41 MODEL
CALIBRATED TRANSMISSIVITY GRID

Job No. _____
 By MAS
 Checked _____

Sheet _____ of _____
 Date _____
 Rev. _____

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	E	E	E	E	E	E	E	E	E	X
3	X	X	X	X	X	X	X	X	E	E	E	E	E	E	E	E	E	E	E	X
4	X	X	X	X	X	E	E	E	H	H	H	H	E	E	E	E	G	G	G	X
5	X	A	A	A	I	I	I	I	H	H	H	H	D	D	D	D	A	A	A	X
6	X	A	A	A	I	I	I	I	C	C	C	C	D	D	D	D	A	A	A	X
7	X	A	A	A	B	B	B	B	B	B	B	B	D	D	D	D	A	A	A	X
8	X	A	A	A	E	E	E	E	D	D	D	D	E	E	E	E	A	A	A	X
9	X	A	A	A	F	F	F	F	D	D	D	D	F	F	F	F	A	A	A	X
10	X	A	A	A	F	F	F	F	I	I	I	I	F	F	F	F	A	A	A	X
11	X	E	E	E	E	E	E	E	D	D	D	D	E	E	E	E	C	G	G	X
12	X	E	E	E	E	E	E	E	D	D	D	D	E	E	E	E	E	E	E	X
13	X	E	E	E	E	E	E	E	D	D	D	D	E	E	E	E	E	E	E	X
14	X	E	E	E	E	E	E	E	D	D	D	D	E	E	E	E	E	E	E	X
15	X	E	E	E	E	E	E	E	D	D	D	D	E	E	E	E	E	E	E	X
16	X	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	X
17	X	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	X
18	X	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	X
19	X	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

$$A = 1.0 \times 10^{-4} \text{ ft}^2/\text{sec}$$

$$F = 3.0 \times 10^{-3} \text{ ft}^2/\text{sec}$$

$$B = 3.0 \times 10^{-4} \text{ ft}^2/\text{sec}$$

$$G = 5.0 \times 10^{-3} \text{ ft}^2/\text{sec}$$

$$C = 5.0 \times 10^{-4} \text{ ft}^2/\text{sec}$$

$$H = 5.47 \times 10^{-3} \text{ ft}^2/\text{sec}$$

$$D = 8.0 \times 10^{-4} \text{ ft}^2/\text{sec}$$

$$I = 8.0 \times 10^{-3} \text{ ft}^2/\text{sec}$$

$$E = 1.47 \times 10^{-3} \text{ ft}^2/\text{sec}$$

Client _____

Job No. _____

Sheet _____ of _____

Subject ELMENDORF AFB - ST41 MODEL

By MAS

Date _____

AQUIFER THICKNESS GRID

Checked _____

Rev. _____

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
2	X	X	X	X	X	X	X	X	X	X	30	30	30	30	30	30	30	30	30	X
3	X	X	X	X	X	X	X	X	30	30	30	30	30	30	30	30	30	30	30	X
4	X	X	X	X	X	30	30	30	30	30	30	30	30	30	30	30	30	30	30	X
5	X	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	X
6	X	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	X
7	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
8	X	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	X
9	X	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	X
10	X	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	X
11	X	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	X
12	X	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	X
13	X	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	X
14	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
15	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
16	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
17	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
18	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
19	X	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	X
20	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

X = INACTIVE CELL

THICKNESSES IN FEET

APPENDIX D

MODEL INPUT AND OUTPUT FILES