FINAL

Remedial Action Plan for the Risk-Based Remediation of Site ST14 (SWMU 68) LPSTID 104819; the Former Base Refueling Area (A0C7); the French Underdrain System (SWMU 64); and the North Oil/Water Separator (SWMU 67).



Carswell Air Force Base
Naval Air Station Fort Worth Joint Reserve Base
Texas

Volume I: Report

Prepared For

Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas

and

Carswell Air Force Base
Naval Air Station Fort Worth Joint Reserve Base

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FINAL

REMEDIAL ACTION PLAN
FOR THE RISK-BASED REMEDIATION OF SITE ST14(SWMU 68) LPST ID 104819; THE FORMER BASE REFUELING AREA (AOC7); THE FRENCH UNDERDRAIN SYSTEM (SWMU 64); AND THE NORTH OIL/WATER SEPARATOR (SWMU 67).

VOLUME I: REPORT

CARSWELL AIR FORCE BASE
NAVAL AIR STATION FORT WORTH JOINT RESERVE BASE
TEXAS

JULY 1997

Prepared for

Air Force Center for Environmental Excellence
Brooks Air Force Base
San Antonio, Texas

and

Carswell Air Force Base/Naval Air Station Fort Worth Joint Reserve Base, Texas

Prepared by
Parsons Engineering Science, Inc.
Denver and Austin (CAS #RCAS00101B)

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SECTION 1

INTRODUCTION

1.1 PURPOSE AND SCOPE

Parsons Engineering Science, Inc. (Parsons ES), formerly Engineering-Science, Inc. (ES) was retained by the United States (US) Air Force Center for Environmental Excellence (AFCEE) to prepare a remedial action plan (RAP) in support of a risk-based remediation decision for soil and groundwater contaminated with fuel hydrocarbons at Site ST14 at Carswell Air Force Base (AFB), Texas. Parsons ES is an environmental consulting firm registered as a Corrective Action Specialist (CAS) (RCA00101B). Site ST14 consists of the petroleum, oil, and lubricant (POL) tank farm (Site ST14B) and the fuel loading area (Site ST14A). TNRCC has directed that Site ST14 (also known as Solid Waste Management Unit (SWMU) 68) and associated areas be remediated under Title 31 Texas Administrative Code (TAC) Chapter 334, the Petroleum Storage Tank (PST) rules. This RAP also has been prepared in support of a risk-based remediation decision for Site SD13 which is downgradient from Site ST14, and is regulated under Title 31 TAC Chapter 335, the Resource Conservation and Recovery Act (RCRA) rules. Site SD13 consists of several permit-defined subsites, including SWMU 64 (the french underdrain system), SWMU 67 (the oil/water separator), and area of concern (AOC) 7 (the former base refueling area).

Risk-based remediation is designed to combine natural physical, chemical, and biological processes with low-cost source reduction technologies such as *in situ* bioventing, as necessary, to economically reduce potential risks to human health and the environment posed by anthropogenic contamination. This RAP is prepared as part of a multi-site initiative sponsored by AFCEE to develop a handbook on how risk information and quantitative fate and transport calculations based on site-specific data can be integrated to quickly determine the type and magnitude of remedial action required at fuel-contaminated sites to minimize contaminant migration and potential receptor risks. Site ST14 is one of several sites nationwide that will be used as a case study in the development of the handbook.

This RAP combines into a single document the documentation elements specified by the PST Division of the Texas Natural Resource Conservation Commission (TNRCC, 1993, 1994a, 1994b, 1995a, 1995b, and 1995c) for a limited site assessment, Plan A and Plan B comprehensive assessments, a Plan B exposure assessment, and a proposal for implementing an appropriate remedial action at Site ST14. Plan A remedial actions are designed to establish cleanup levels based on specified methods, conservative assumptions regarding potential human exposure, and a limited number of site-specific factors. Plan A target concentrations have been defined for both unrestricted (i.e., residential) and industrial/commercial land use assumptions. Plan A evaluations have

been defined by TNRCC (1994a) as screening-level evaluations. TNRCC (1994a) recommends that all sites be initially evaluated under Plan A. In the event that measured concentrations exceed the applicable Plan A target concentrations, however, a Plan B evaluation may be necessary to establish reasonable, risk-based target cleanup objectives for a specific site. Plan B remedial actions are based on the outcome of a limited risk assessment to evaluate current and potential human health risks and short-term and long-term fate of the contaminants at the site. Although Plan B evaluations usually involve more rigorous analysis and may require use of institutional controls to ensure that exposure conditions do not change over time, they can result in a more focused remediation (TNRCC, 1994a). Alternate, health-protective remedial concentration goals for a site can be proposed as part of a Plan B evaluation.

This RAP also addresses the documentation elements specified by the TNRCC to document attainment of Risk Reduction Standard Number 2 and/or to specify media cleanup requirements pursuant to Risk Reduction Standard Number 3 for Site SD13. Risk Reduction Standard Number 2 levels are derived either by conservative quantitative health-based risk assessment procedures or by directly using other appropriate promulgated standards (30 TAC 335.556). Compliance with Risk Reduction Standard Number 2 requires that contaminated media must be removed or decontaminated to numeric cleanup levels such as medium specific concentrations (MSCs) so that no post-closure care or engineering or institutional control measures are required. In contrast, compliance with Risk Reduction Standard Number 3 allows the use of measures to control the contaminated materials or the property where any residual contamination is located. These controls can be engineered or institutional in nature. These standards require remediation such that any substantial present or future threat to human health or the environment is eliminated or reduced to the maximum degree practicable.

This RAP documents the actual or reasonable potential risks to human and ecological receptors due to exposure to chemical contaminants originating from Sites ST14 and SD13 under current conditions. The RAP also estimates the potential risks to human and ecological receptors due to exposure to chemical contaminants over time, accounting for the effects of natural chemical attenuation processes. Finally, the RAP develops and describes a recommended remedial approach for fuel hydrocarbon contamination in soils and groundwater at and downgradient from Site ST14 and for organic and inorganic contamination in soil and groundwater at Site SD13, that can achieve the target remediation goals. The RAP demonstrates that compliance with Plan A or Plan B cleanup levels at Site ST14 will not jeopardize long-term attainment of applicable numeric cleanup levels for soil and groundwater at Site SD13. This RAP is being submitted for review and approval consistent with the TNRCC PST program requirements (TNRCC, 1994a and 1995c), and with the TNRCC IHW program requirements.

1.1.1 Overview of Project Activities

It is the intent of the Air Force to pursue a site-specific risk-based remediation of Sites ST14 and SD13. The activities conducted pursuant to determining the type, magnitude, and timing of remediation required to achieve the desired level of risk reduction at these sites included focused site investigation activities and data analysis to characterize:

- The nature and extent of fuel hydrocarbon contamination at Site ST14;
- The nature and extent of anthropogenic organic and inorganic contamination at Site SD13;
- The location of potential groundwater recharge and discharge areas, including an assessment of the effectiveness of the subsurface drain system and the effects of other major hydrogeologic features (the french underdrain system and oil/water separator were investigated and partially removed by Parsons ES in 1996, under the supervision of TNRCC);
- The local geology, hydrogeology, and hydrology that may affect contaminant transport;
- The proximity of the site to drinking water aquifers, surface water, and other sensitive environmental resources;
- The estimated flux rate of volatile organic compounds (VOCs) into the atmosphere from site soils;
- The expected persistence, mobility, chemical form, and environmental fate of hazardous substances in soils and groundwater under the influence of natural physical, chemical, and biological processes;
- The current and potential future uses of land, including groundwater, and the likelihood of exposure of receptors to other potentially impacted environmental media over time;
- The potential risks associated with chemical contamination under current and foreseeable future conditions;
- The long-term target remedial objectives and chemical-specific concentration goals required to protect human health and the environment; and
- The treatability of residual and dissolved fuel hydrocarbon contamination using low-cost source reduction technologies such as bioventing and biosparging.

1.1.2 Summary of Proposed Type of Cleanup for Site ST14

Carswell AFB was placed on the 1991 Defense Base Closure and Realignment Commission's list for closure. The AFB was officially closed on September 30, 1993. However, in 1993, the Commission recommended realignment of several military reserve and guard units to Carswell, such that portions of the property will be retained by the Department of Defense (DOD). The US Navy has assumed command of that property required to support long-term operations associated with the realigning military units. Based on the proposed land reuse plan for Carswell AFB (US Air Force, 1994), Site ST14 is planned to be maintained as a military fueling yard in the foreseeable future.

Several remedial approaches that relied on both natural processes and engineered solutions were evaluated for Site ST14. A site-specific exposure pathways analysis involving environmental media impacted by chemical contamination at and migrating from Site ST14 was completed to ensure that existing and predicted future concentrations of hazardous substances would not pose a threat to current and foreseeable future onsite and offsite receptors. The site-specific exposure pathways analysis indicates that only onsite intrusive workers may actually be exposed to site-related contamination, although other potential exposure pathways do exist. Because measured concentrations of benzene and hexachlorobenzene, which are presented in this RAP, exceeded TNRCC (1994b) Plan A criteria, a Plan B limited risk assessment was prepared to determine whether any unacceptable and imminent threats to human health or the environment exist at the site. The limited risk assessment indicated that existing concentrations of all chemicals detected in soil and groundwater at and downgradient from Site ST14 do not result in a cumulative hazard index (HI) greater than 1 or a cumulative carcinogenic risk greater than one-in-ten-thousand (1.0×10^{-4}). However, the cumulative carcinogenic risk for intrusive workers was estimated to be greater than one-in-one-million (10^{-6}), which is greater than the TNRCC-specified target risk for receptors where actual exposure is possible (TNRCC, 1994a). This means that remediation and/or control measures to supplement those already in place at the site are required to provide the regulatory-defined level of protectiveness for human health and the environment (TNRCC, 1994a).

A site-specific chemical fate assessment also was completed as part of the exposure pathways analysis to identify the potential for, and risks associated with, exposure to chemical contamination over time at the site. The potential for exposure to chemical contamination originating from Site ST14 over time depends on anticipated future site conditions and the persistence, mobility, chemical form, toxicity, and fate of site-related contaminants.

Site characterization data relevant to documenting natural chemical attenuation, specifically bioattenuation, were collected and are documented in this RAP, pursuant to the requirements of the TNRCC (1994a). The quantitative fate and transport models used to assess chemical concentrations in air, soil, and groundwater over time include only those natural physical, chemical, and biological attenuation processes documented to be occurring at the site. The fate and transport model results suggest that engineered remediation is required to attain the TNRCC target carcinogenic risk level of 1×10^{-6} within the next few years. Removal of volatile organics from the ST14A source area will reduce potential chemical hazards associated with deep excavations in this area and will reduce the time to attain both Plan A and Plan B target cleanup goals.

The Plan B limited risk assessment included in this RAP indicates that no unacceptable risk to current nonintrusive workers exists at Site ST14. This means that existing levels of all detected concentrations of chemicals will not result in carcinogenic or noncarcinogenic risks to nonintrusive workers above the TNRCC-established thresholds, given the types of exposures likely to occur at Site ST14. However, the Plan B limited risk assessment does identify the potential for existing concentrations of all detected compounds to result in a cumulative cancer risk total for (hypothetical) intrusive workers slightly above the TNRCC-specified target of 1×10^{-6}, although no pathway-specific risk estimate exceeded this threshold. The 1×10^{-6} point-of-departure is identified by the TNRCC as the target risk level if there is actual human exposure

(which was conservatively assumed). In comparison, Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance identifies acceptable risk ranges of 10^{-6} to 10^{-4} for carcinogenic chemicals. The Plan B limited risk assessment demonstrates that natural attenuation processes are expected to be sufficient alone to reduce Site ST14 concentrations to levels that result in a cumulative cancer risk for (hypothetical) intrusive workers of almost 1×10^{-6} by the year 1998 (i.e., the year in which the site is planned to be transferred and re-used in accordance with the approved land use plan). The evaluation in this RAP clearly demonstrates that use of bioventing at Site ST14A will decrease the mass of benzene that can partition from soils and dissolve into underlying groundwater. Application of this source reduction technology was projected to be sufficient to reduce the cumulative cancer risk for (hypothetical) intrusive workers below the TNRCC-defined 1×10^{-6} threshold by the year 1998.

Both quantitative risk estimates and Plan B target concentrations are used in this RAP to identify site-specific risk reduction requirements. Bioventing/biosparging is proposed as a low-cost method of attaining the TNRCC-stipulated target risk level by 1998. A groundwater monitoring program and institutional controls will be necessary to confirm that the predicted degree of remediation is being attained and to ensure that no unacceptable or unanticipated exposures to chemical contamination occur over time at the site.

1.1.3 Summary of Proposed Type of Cleanup for Site SD13

As mentioned in Section 1.1.2, Carswell AFB was placed on the 1991 Defense Base Closure and Realignment Commission's list for closure, and was officially closed on September 30, 1993. The US Navy has assumed command of that property required to support long-term operations associated with the realigning military units. Based on the proposed land reuse plan for Carswell AFB (US Air Force, 1994), Site SD13 is scheduled to be used as an open space/recreational area, although retained under the authority of DOD. Additionally, although the shallow groundwater underlying Site SD13 could be classified as a potential beneficial use category II water source pursuant to TNRCC (1994a) guidance, it may eventually discharge into downgradient surface water bodies (i.e., the unnamed stream and/or Farmers Branch Creek). For these reasons, the shallow groundwater underlying Site SD13 will be considered a potential beneficial use I water source for purposes of this RAP.

Remedial approaches that rely on both natural processes and engineered solutions were also examined for Site SD13. A separate site-specific exposure pathways analysis was performed for Site SD13. The analysis indicates that current and future intrusive construction workers may be exposed and that future recreators may potentially be exposed to site related contamination. After eliminating background levels of inorganics, the most recently detected maximum contaminant levels of all remaining chemicals detected at Site SD13 were initially compared to Risk Reduction Standard Number 2 levels calculated based on a conservative assumption of residential exposure. Risk Reduction Standard Number 2 levels based on an assumption of residential exposure were used at this point in the evaluation because of the potential for chemicals from this site to migrate outside of the Base fenceline and because of the potential for groundwater to impact the unnamed stream, which is also outside of the base boundary.

As detailed in Section 5, a number of chemicals exceeded the Risk Reduction Standard Number 2 levels. Because detected levels of some chemicals exceeded the Risk Reduction Standard Number 2 levels, a quantitative risk assessment was performed for Site SD13, based on the site-specific exposure pathways analysis. This risk assessment indicates that exposure to existing concentrations of all detected chemicals will result in a cancer risk below 1×10^{-5} for current and future (hypothetical) intrusive construction workers, and below 1×10^{-6} for current and future trespassers/recreators. Although the cancer risk for the intrusive construction worker is above the target risk level of 1×10^{-6} for situations where actual exposure is taking place or is likely to take place, the risk level is well below the 1×10^{-4} level at which remediation or appropriate control measures are required, and there is no current exposure to this receptor. Levels for non-carcinogenic effects were below the target level of 1 for both intrusive construction workers and trespassers/recreators.

Estimated risks to future potential receptors are based on current maximum detected concentrations for all chemicals detected at Site SD13, and therefore do not include the effects of natural attenuation, which has been demonstrated to be occurring at this site. As detailed in Sections 5 and 6, several inorganic chemicals have been detected above background concentrations and above Risk Reduction Standard Number 2 levels. Localized geochemical conditions, created as a result of the ongoing biodegradation of organic compounds, have resulted in the increased mobility of several inorganics. This increased mobility will be reduced as organic mass is reduced and local geochemical conditions are restored to pre-release conditions.

The removal of portions of the french underdrain in 1996 has interrupted this transport pathway from groundwater underlying Site SD13 to surface water. It is expected that mobility of groundwater underlying Site SD13 will be greatly reduced by this remedial action, providing a longer time frame for natural attenuation processes to reduce the levels of contaminants in groundwater. Natural attenuation processes also will be sufficient to decontaminate engineered components remaining in place following the 1996 interim removal action.

1.2 REPORT ORGANIZATION

This RAP consists of 13 sections, including this introduction, and 10 appendices. Site background, including operation history and a review of environmental site investigations conducted to date, are provided in Section 1. Section 2 summarizes the 1994/1995 site characterization activities performed by Parsons ES and the results of the ongoing long-term groundwater monitoring at both Sites ST14 and SD13 through January 1997. Physical characteristics of Sites ST14 and SD13 are described in Section 3. Section 4 describes the nature and extent of soil and groundwater contamination at Site ST14 and presents the results of the Plan A screening evaluation for Site ST14. The nature and extent of soil, groundwater, and surface water contamination and the identification of chemicals of potential concern (COPCs) for Site SD13 are presented in Section 5. Section 6 presents a quantitative exposure pathways analysis, which incorporates the effects of natural chemical attenuation processes that are documented to be occurring at each of the sites. Section 7 evaluates the potential risks to current and hypothetical future receptors, and identifies target remedial goals for Site ST14. Potential risks to current and hypothetical future receptors and target remedial goals for Site SD13 are evaluated in Section 8. Section 9 presents contaminant treatability pilot

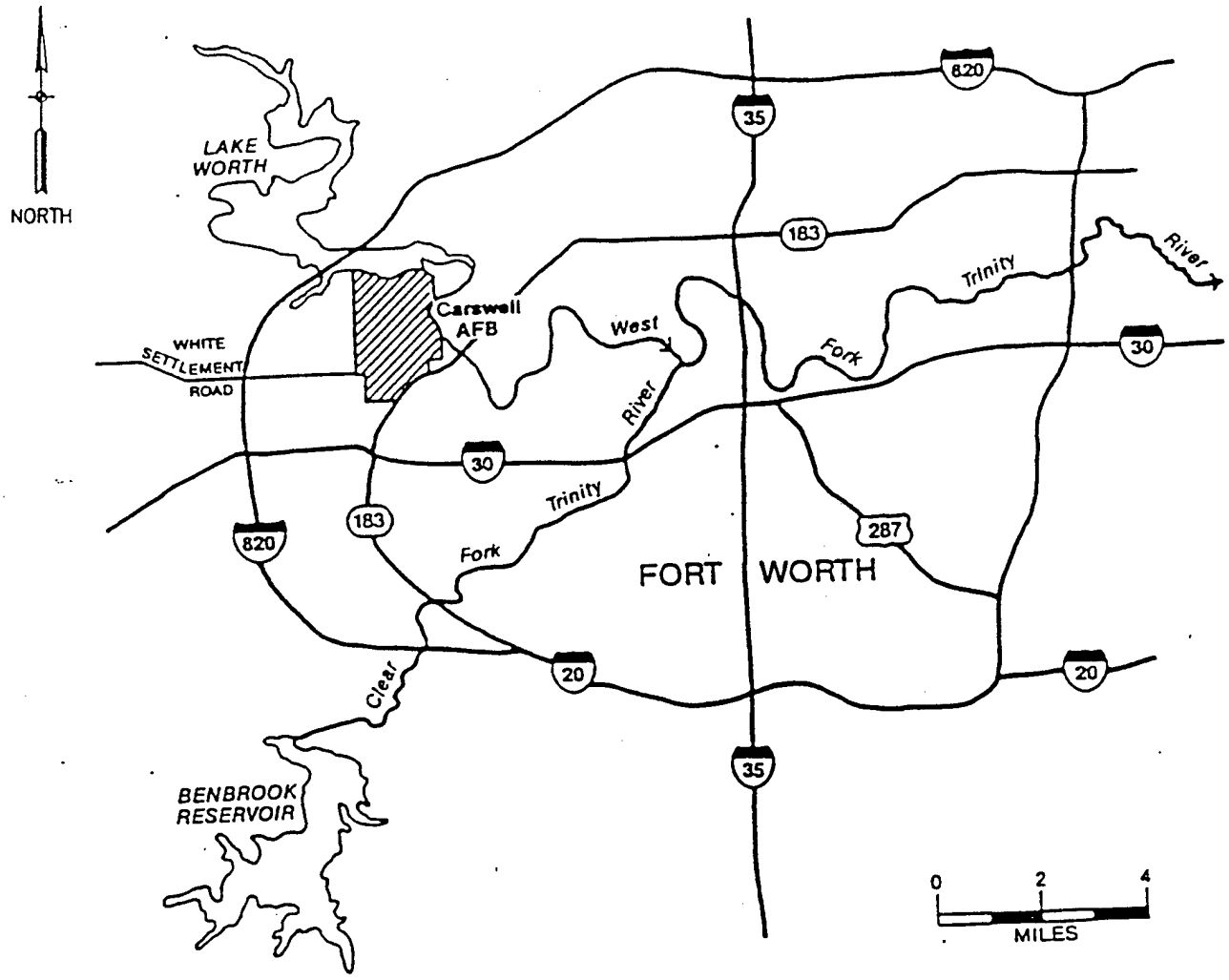
test results and evaluates several low-cost source reduction technologies. Section 10 presents a comparative analysis of three candidate remedial alternatives. Section 11 is a more detailed implementation plan for the recommended remedial alternative, and a detailed monitoring plan for each of the sites is presented in Section 12. Section 13 presents references used in preparing this RAP.

Appendix A presents soil gas, soil flux, soil, groundwater, and surface water analytical results and data validation results from the ES (1993) bioventing pilot test, the 1994/1995 risk-based sampling event conducted by Parsons ES, and recently collected 1995/1997 groundwater monitoring data. Appendix B contains the boring logs, well construction diagrams, and well development data for all sampling activities completed by Parsons ES at Sites ST14 and SD13. Appendix C contains a report on all inventoried wells within a 0.5-mile radius of the study area. Aquifer test data and analyses, the stream flow calculations, and the tracer test data are presented in Appendix D. Appendix E contains the quantitative calculations and fate and transport model results used in the predictive chemical fate assessment. Appendix F presents the derivation of Plan A and Plan B target concentrations and risk estimates for both current and hypothetical future receptors, in accordance with TNRCC (1994a and 1994b) PST program guidance. Summary information from the study to determine naturally occurring levels of inorganics at Carswell AFB, and analysis performed to allow comparison of site-specific concentrations to background levels is presented in Appendix G. Appendix H presents the derivation of the Risk Reduction Standard Number 2 numeric cleanup levels and the Risk Reduction Standard Number 3 risk estimates for both current and hypothetical future receptors at Site SD13. Appendix H summarizes the screening and development of remedial alternatives considered in detail within this RAP. Appendix I presents a site-specific sampling and analysis plan (SAP) for use during bioventing and monitoring at the site. The 10 appendices to this RAP are included in Volume II.

1.3 SITE BACKGROUND

Carswell AFB is located in Tarrant County approximately 6 miles west of downtown Fort Worth, Texas (Figure 1.1). The Base is bounded on the north by Lake Worth, on the east by the West Fork Trinity River, and on the south by Highway 183. Air Force Plant 4, which shares the Base runway, is located west of the Base. Carswell AFB has recently undergone realignment, and is now a joint reserve base named Naval Air Station (NAS) Fort Worth Joint Reserve Base (JRB). There were 674 full-time employees on Base in September 1993. The total number of projected employees by 1998 is 5,353. On-Base residents include 1,270 military personnel, 328 civilians, and 1,100 federal inmates (US Air Force, 1994). The communities surrounding the Base include White Settlement to the south and west, River Oaks to the east to northeast, Fort Worth to the east and southeast, and Lake Worth to the north. The combined populations of these communities exceed 385,000 people.

Four discrete sites have been identified in the East Area of Carswell AFB/NAS Fort Worth JRB that may be potential sources of contamination (Radian Corporation [Radian], 1991). These sites include Site LF01 (landfill), Site BSS (Base service station), Site ST14 (POL tank farm and adjacent fuel loading area), and Site SD13 (unnamed stream and abandoned gasoline station). Figure 1.2 shows the location of the East Area with respect to the entire Base and surrounding environs. Sites ST14 and



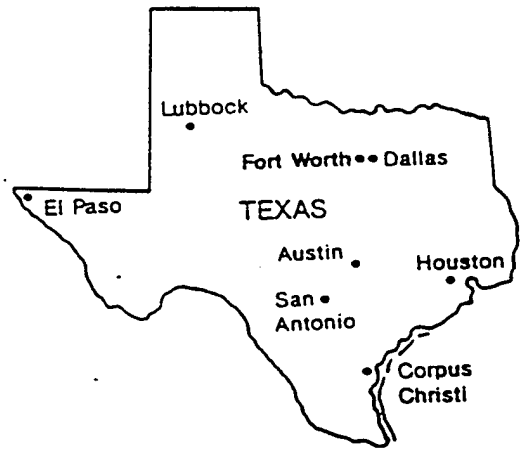


FIGURE 1.1

REGIONAL LOCATION OF CARSWELL AFB

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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SD13 are located in the southern portion of the East Area. Because Site SD13 is downgradient from Site ST14, dissolved contamination originating from the POL tank farm and adjacent fueling areas may have migrated to and impacted this area. The potential for contaminants from Site ST14 to impact Site SD13, under current and future conditions, is examined in this RAP. The other two East Area sites are located north of (essentially upgradient from) the dissolved plume originating at Site ST14.

1.3.1 Operational History

Site ST14A consists of the fuel loading area along the eastern side of Desert Storm Drive, and the area southeast and downgradient from the fuel loading area. The tank farm portion of the site (ST14B) consists of two aboveground storage tanks (ASTs) surrounded by earthen berms, and is located on the west side of Desert Storm Drive. A third, larger AST is located north of these tanks and is surrounded by a concrete berm. Three additional tanks, which were formerly located at Site ST14B, have been dismantled. All of Site ST14 has been an area of fuel storage during most of the Base's operating history (i.e., from 1942 to the present). Figure 1.3 shows the location and approximate boundaries of Sites ST14 and SD13 on Carswell AFB/NAS Fort Worth JRB.

During the early 1960s, JP-4 jet fuel was discovered in soil and groundwater at and downgradient from Site ST14. Leaking underground fuel lines are the suspected source of subsurface contamination at this site. A french underdrain system constructed of perforated ceramic tile, and interceptor box, and a pumphouse was apparently installed downgradient from the site to collect fuel product leaking from Site ST14 and possibly Site SD13. The installation date and construction details of the french drain system are unknown; no as-built drawings have been located (Law Environmental Government Services [Law], 1994). In the mid 1960s, the interceptor box and pumphouse were replaced with an oil/water separator. The french underdrain system was connected to this underground oil/water separator (Facility 38), which is located south of the Whitehouse communications building (Building 1337) and immediately south of the fenced civil engineering storage yard. Although the age of the oil/water separator is also uncertain, an as-built drawing of the system dated February 1964 has been identified (Law, 1994). The oil/water separator was installed to replace an interceptor box and a pump house formerly used for pumping water from the french underdrain to the unnamed stream. Based on information gathered as part of the 1990 Installation Restoration Program (IRP) sampling event, the french underdrain system was used to collect small quantities of fuel product (Radian, 1991). As part of the IRP, an oil skimmer was installed in the oil/water separator in 1991 (Environmental Science & Engineering, Inc. [ESE], 1994). In 1996 portions of the french underdrain system and the oil/water separator were removed by Parsons ES under TNRCC supervision. Prior to removal, the oil/water separator discharged into the perennial unnamed stream, which flows about 200 feet east into Farmers Branch, which in turn discharges to the Trinity River along the eastern boundary of Carswell AFB/NAS Fort Worth JRB.

Site SD13 is located immediately downgradient from Site ST14. This area consists of a paved lot near an abandoned gasoline station and the unnamed stream itself. The gasoline station was removed, and the only visible evidence of the station is the concrete pump island. Free petroleum product and detectable concentrations of petroleum hydrocarbons in both soil and groundwater were measured at the site during

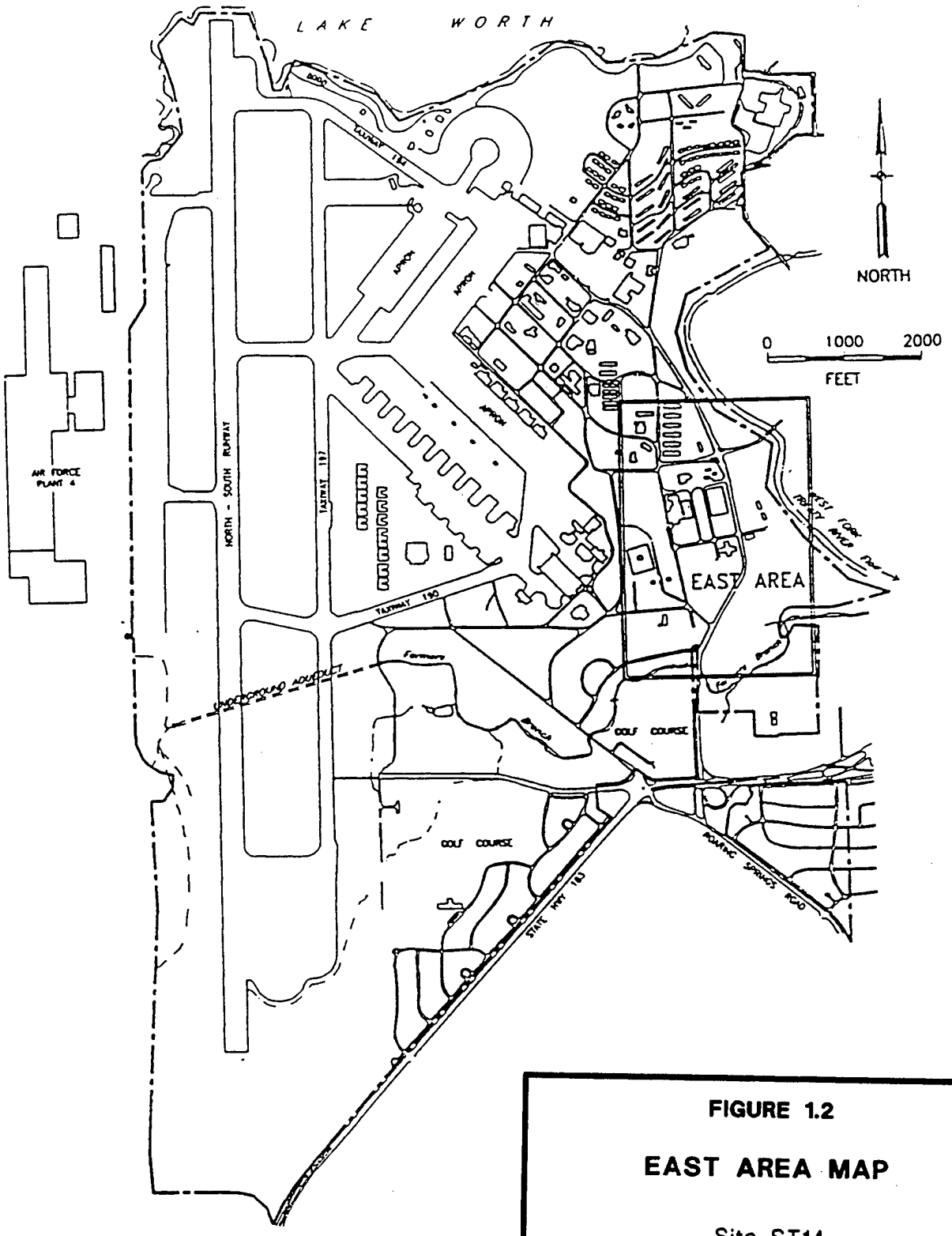


FIGURE 1.2

EAST AREA MAP

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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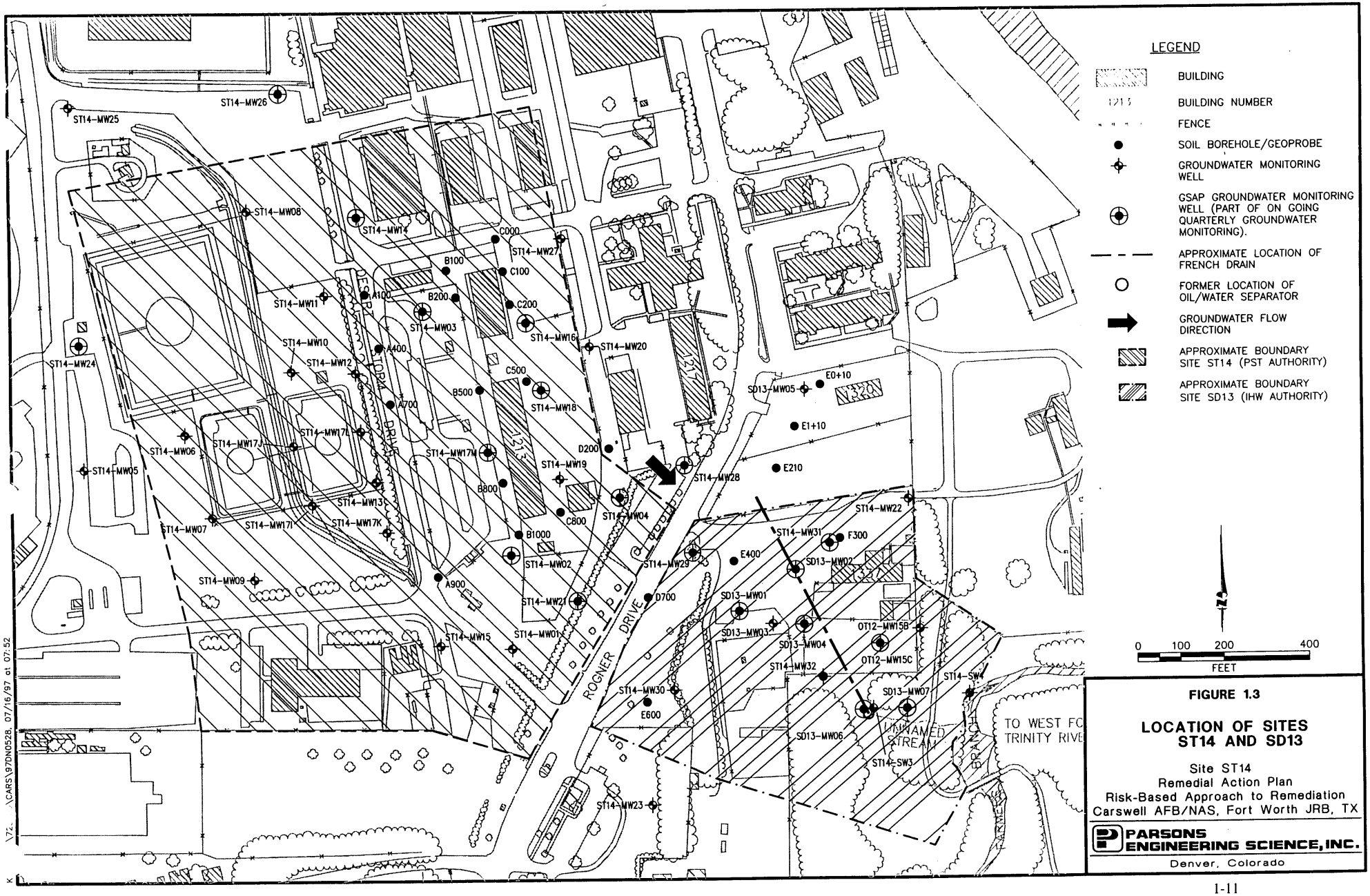


FIGURE 1.3

LOCATION OF SITES ST14 AND SD13

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

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the 1990 IRP Remedial Investigation (RI) (Radian, 1991), the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) (Law, 1994), and the 1994 risk-based sampling events. Quarterly compliance monitoring events are being conducted at Site SD13 in accordance with the Base-wide groundwater sampling and analysis program (GSAP).

1.3.2 Previous Remedial Investigations

Sites ST14A, ST14B, and SD13 have been characterized under the US Air Force IRP (Radian, 1985, 1988, 1989, and 1990). Additional site investigation data were collected at these sites as part of the 1993 bioventing pilot test program sponsored by AFCEE (ES, 1993), the 1994 RFI completed by Law, and the 1994/1995 risk-based investigation conducted by Parsons ES. Additional site data are currently being collected under the GSAP. This program includes sampling locations at Sites ST14A, ST14B, and SD13. All available data from these sampling events are used in this RAP to characterize the nature and extent of contamination and to determine the type, magnitude, and timing of remediation necessary to protect human health and the environment. The following briefly summarizes the site characterization data available prior to 1994.

1.3.2.1 Site ST14

The results of two soil gas surveys conducted in 1987 (Radian, 1988) and 1993 (ES, 1993) at Site ST14A both indicated a soil gas plume centered near groundwater monitoring well ST14-17M (Figure 1.3). Compound-specific data were collected in this area as part of the 1993 bioventing pilot test. Compound-specific soil gas analytical results indicated that fuel hydrocarbons were the principal contaminants. No chlorinated volatile organic compounds (VOCs) were detected. Soil gas samples collected in 1993 from contaminated soils at Site ST14A had high concentrations of total volatile hydrocarbons (TVH), but relatively low concentrations of specific compounds such as ethylbenzene and xylenes. Although benzene was detected in soil gas during the survey completed in 1987, benzene and toluene were not detected in soil gas samples taken from the same general area in 1993. Laboratory TVH concentrations from samples taken in 1993 ranged between 21,000 and 28,000 parts per million, volume per volume (ppmv). Maximum ethylbenzene and toluene concentrations measured during the 1993 sampling event were 7.9 and 21 ppmv, respectively. These soil gas samples also were depleted in gaseous oxygen (ranging from 0.8 to 3.8 percent) and had elevated carbon dioxide, suggesting that significant biological fuel degradation may be occurring in fuel-contaminated soils at the site (ES, 1993).

An initial soil gas investigation also was conducted in 1987 on Site ST14B to determine areas delineated by total VOC concentrations greater than 1,000 ppmv. This criterion was identified based on the maximum quantifiable limit of the methods employed in this survey (Radian, 1988 and 1991). No compound-specific soil gas samples were collected at Site ST14B prior to 1994. The results of this preliminary investigation indicated a soil vapor plume underlying Tanks 1156 and 1157 (Figure 1.3). The area encompassed by this soil gas plume was estimated to be about 100 feet wide and 300 feet long (Radian, 1991).

Although no soil samples were collected at Site ST14B for chemical analysis prior to 1994, soil data were collected at Site ST14A as part of the early IRP investigations (Hargis and Montgomery, 1983; Radian, 1985, 1988, 1989, and 1991) and the bioventing pilot test (ES, 1993). The previous investigations indicated that aromatic fuel contamination in soil at Site ST14A extends from the surface, or near surface, to a depth of approximately 12 feet bgs, but is most concentrated in the 8- to 11-foot below ground surface (bgs) interval. Elevated concentrations of total recoverable petroleum hydrocarbon (TRPH) and benzene, toluene, ethylbenzene, and xylene (BTEX) in soil samples were measured throughout Site ST14A. Laboratory results for TRPH in soil samples ranged from less than 10 milligrams per kilogram (mg/kg) at soil borings SB4, SB5, and SB6, to 6,500 mg/kg at vent well VW2 at a depth of 10 to 11 feet bgs (Figure 1.3). The distribution of BTEX was similar to that of TRPH, with benzene concentrations ranging from less than 2 micrograms per kilogram (μg/kg) to 67,000 μg/kg at SB1 (MPBG1) at a depth of 10 to 11 feet bgs. On the basis of the 1993 sampling results, the lateral extent of significant soil contamination appeared to be bounded by soil boring SB7 on the north and SB5 on the south (ES, 1993).

More than 2 feet of free product was encountered in 1990 at groundwater monitoring well ST14-MW17M. Limited free product (i.e., a thin film) also was encountered in the vent well and several of the vapor monitoring points installed at Site ST14A in 1993 as part of the bioventing pilot test. All of these sampling locations are within 40 feet of well ST14-MW17M. Base personnel monitored free product thickness in ST14-MW17M for about one year. The average product thickness measured in this well from mid-1993 to mid-1994 was 0.75 inch. Product was hand bailed from the well during each measurement event. Further details on the nature and extent of fuel-related contamination at the site are presented in subsequent sections of this RAP.

Early investigations at Site ST14 suggested the presence of two distinct dissolved hydrocarbon plumes, one originating near Site ST14A and one near ST14B. Several VOCs were detected in the groundwater at Site ST14 during these sampling events, including BTEX and chlorobenzene. Of these VOC contaminants, ethylbenzene was detected most frequently. However, benzene was the only VOC detected at a concentration above the most stringent Plan A target groundwater concentration. The maximum concentration of benzene detected in groundwater at Site ST14 during the 1990 IRP sampling effort was 16 μg/L (ST14-17M) (Radian, 1991) which slightly exceeds the most stringent Plan A target groundwater concentration of 5 μg/L. The highest concentrations of chlorobenzene, toluene, and total xylenes also were recorded at this Site ST14A well location.

Although ethylbenzene was the BTEX compound most frequently detected in the groundwater at Site ST14 during the 1990 IRP sampling event, the maximum reported concentration of 35 μg/L in groundwater monitoring well ST14-MW04 was significantly less than its most stringent Plan A target concentration of 700 μg/L (Radian, 1991). Total xylenes and chlorobenzene also were detected at Site ST14 during the 1990 IRP sampling event. Xylenes were detected in three wells: ST14-MW03, ST14-MW04, and ST14-MW17M. The highest concentration of total xylenes was 300 μg/L (in groundwater monitoring well ST14-MW17M), which did not exceed the most stringent Plan A target concentration of 10,000 μg/L. Chlorobenzene was detected in 1990 at a maximum concentration of 38 μg/L (again at ST14-MW17M),

which is below both its health-based Plan A target concentration of 730 μg/L and its maximum contaminant level (MCL) of 100 μg/L.

It is important to note that detected contaminant concentrations in groundwater samples collected in 1990 were lower than the concentrations of the same analytes detected during previous investigations. Early investigations had reported benzene concentrations as high as 11,000 μg/L (Radian, 1988 and 1989), indicating that a reduction of benzene in the source area has already occurred. This trend is a good indicator that natural chemical attenuation processes may be limiting the persistence, concentration, mobility, mass, and toxicity of dissolved contaminants over time. Specific data relevant to documenting the potential effectiveness of these processes in saturated media were collected as part of the risk-based field investigation, and are presented in this RAP.

1.3.2.2 Site SD13

At Site SD13, initial investigative activities conducted in 1985 revealed high levels of organic compounds in the groundwater underlying the paved lot (the abandoned gasoline station)(Radian 1991). Groundwater sampling conducted in 1990 detected no volatile organic compounds above maximum contaminant levels (MCLs). Benzene and chlorobenzene were detected at single wells, and toluene was detected in two of the four wells sampled. A number of metals were detected in several wells; however, maximum metal concentrations did not exceed MCLs.

During the 1994 RFI, three separate rounds of groundwater sampling were performed at Site SD13. The same wells were sampled during each event. The 1994 RFI identified two isolated areas of petroleum contaminated groundwater at Site SD13 (LAW 1994). Ethylbenzene, toluene, and xylenes were detected in several wells, but not at concentrations above the Risk Reduction Standard Number 2 levels. It should be noted that benzene was not detected in any of the groundwater samples analyzed. Several chlorinated volatile organics were also detected in groundwater during the 1994 RFI. Tetrachloroethylene (PCE) was found in well OT-15B in all three sampling events conducted as part of the RFI. The maximum concentration of PCE was 9.1 micrograms per liter (μg/L), which is above its Risk Reduction Standard Number 2 level of 5 μg/L. Methylene chloride was detected above the Risk Reduction Standard Number 2 level of 5 μg/L in several wells, with a maximum detected level of 12 μg/L. Bromodichloromethane, chloroform, and dibromochloromethane were also detected, all were below Risk Reduction Standard Number 2 levels.

Arsenic, barium, lead and nickel were measured in groundwater samples at concentrations above Risk Reduction Standard Number 2 during the 1994 RFI. Arsenic was consistently detected in wells SD13-01 and SD13-03, with a maximum level of 0.075 milligrams per liter (mg/L). Barium was detected in all wells at low levels ($<$ 1mg/L). However, during one sampling event barium was detected in wells OT-15B and OT-15C at concentrations of 260 and 220 mg/L, respectively. These concentrations are above the Risk Reduction Standard Number 2 level for groundwater under a residential use scenario. Lead was detected in well SD13-03 at a concentration of 7.3 mg/L. Subsequent sampling of this well during the RFI found lead levels of 0.0021 mg/L and non-detect. Nickel was detected in one well (SD13-07) during one sampling event at a concentration of 0.14 mg/L, which is above the Risk Reduction

Standard Number 2 level. Aluminum, cadmium, chromium, manganese, and zinc were also detected, however the maximum contaminant levels for these metals were below Risk Reduction Standard Number 2 levels.

The 1994 RFI also included a geophysical survey of Site SD13 to locate potential buried utilities, and to confirm that no previously unidentified USTs remained at the site. Geophysical anomalies indicative of buried piping, reinforced concrete and other buried metal were identified. Due to the presence of cultural interferences within the site, including a reinforced concrete pad, a chainlink fence, transformer and power lines, the survey was not able to conclusively verify the absence of additional, previously unidentified USTs. Cultural interferences are identified metal objects which would create readings on the survey equipment, making it difficult to interpret survey data in the vicinity of the interference. The Air Force has no information to indicate that there are additional USTs at Site SD13 that may be continuing to release contamination to the subsurface.

Surface water quality data also were collected as part of the early IRP investigations to determine whether fuel hydrocarbon contamination from Site SD13 was being intercepted by the subsurface french underdrain system. Both benzene and toluene were detected in surface water samples collected in the unnamed stream. During the field investigation conducted in 1986, the maximum concentration of benzene detected in the unnamed stream was 120 μg/L, and the maximum concentration of toluene was 19 μg/L (Radian, 1991). Four additional surface water samples were collected as part of the 1990 IRP sampling effort at the unnamed stream. Orange-colored foam and a rusty film were noted on the surface of the water at the time of sampling. Benzene and toluene were again the most frequently detected VOCs, although the concentrations were significantly less than those measured previously. The maximum concentration of benzene detected in the surface water in 1990 was 0.31 μg/L; the maximum concentration of toluene was 0.59 μg/L (Radian, 1991). Concentrations of these contaminants decreased with increasing distance downstream, probably due to photooxidation, volatilization, and dilution. Based on this trend, it appears that any natural groundwater discharge entering the stream at more permeable, downgradient locations does not contribute significant concentrations of contaminants to stream segment 0806 of the West Fork Trinity River. However, the french underdrain system (SWMU 64) and oil/water separator (SWMU 67) could have been the source of measurable concentrations of fuel hydrocarbon contamination in surface water. Although concentrations of dissolved fuel hydrocarbons in surface water have been diminishing over time, the potential for continuing impacts to surface water quality and the need to remediate to prevent adverse environmental impacts is explored in this RAP.

1.4 Need for RAP

A baseline risk assessment (BRA) was prepared for both Site ST14 and Site SD13 using the 1990 IRP analytical data (Radian, 1991) and EPA (1986a) risk assessment guidance, which has since been superseded. Although the BRA indicated that both carcinogenic and noncarcinogenic human health risks associated with exposure to measured concentrations of chemical contamination at Site ST14 and Site SD13 were below levels warranting remedial action, these sites were identified as high-priority sites because they may represent a direct contaminant source or contaminant migration

pathway to Farmers Branch and the Trinity River. Additionally, the RI Report cited significant uncertainty about the processes involved in subsurface contaminant transport and the potential for increased risks over time.

Consequently, the focused site investigation and remedial alternatives analysis described in this RAP were initially designed to evaluate the type, magnitude, and timing of remedial action necessary to protect human health and the environment at and downgradient from Site ST14 (SWMU 68), pursuant to the TNRCC (1994a, 1995a, and 1995b) PST program guidance. The RAP was then expanded to evaluate the type, magnitude, and timing of remedial action necessary to protect human health and the environment at and downgradient from Site SD13 (i.e., SWMU 64, SWMU 67 and AOC 7), pursuant to 30 TAC Chapter 335 program rules. This RAP specifically documents the effects of natural physical, chemical, and biological processes and low-cost source reduction technologies on contaminant persistence, mobility, mass, and toxicity over time. Particular emphasis is given to estimating the likelihood that contaminant concentrations above the most stringent Plan A target concentrations could migrate to and discharge into the unnamed stream.

SECTION 2

RECENT SITE CHARACTERIZATION AND GROUNDWATER MONITORING ACTIVITIES

To fully define the downgradient extent of fuel hydrocarbons in soils and groundwater and collect site-specific data documenting the effects of natural contaminant attenuation processes, a field investigation was conducted by Parsons ES (1994a) at Site ST14 in March 1994 and July through September 1994. Based on preliminary results of this investigation, an additional study area (Site SD13) was identified for inclusion in the risk-based investigation. Free petroleum product and detectable concentrations of fuel hydrocarbons in both soil and groundwater were measured at Site SD13 during the 1990 investigation (Radian, 1991) and during the initial sampling events of the risk-based investigation. These data suggested that dissolved fuel hydrocarbon contamination may be migrating from Site ST14 toward Site SD13, and that contaminant plumes under both sites may be potentially commingled. Low concentrations of BTEX contaminants also were detected at ST14-MW08, which was presumed to be upgradient from the hydrocarbon contamination originating at Site ST14. To reasonably apply the risk-based approach at Sites ST14 and SD13, additional data needed to be collected to:

- Identify any potential unreported sources that may be contributing contaminant mass to the plume(s);

- Establish groundwater characteristics and chemistry upgradient from the plume(s); and

- Gain a greater understanding of the groundwater characteristics between the primary source areas contributing to the plume(s).

A supplemental workplan was prepared in March 1995 (Parsons ES, 1995), and was implemented in March and April 1995. Sufficient data were collected to conduct a quantitative fate and transport analysis, perform an exposure pathways analysis, and evaluate the potential treatability of contaminated media using low-cost remedial technologies and approaches. Emphasis was placed on defining the extent of soil contamination for possible *in situ* source reduction, filling data gaps identified during previous remedial investigations, and collecting data relevant to documenting the natural biodegradation of fuel hydrocarbons in soil and groundwater at the site.

Additional soil samples were taken from the area immediately surrounding the north oil/water separator (SWMU 67) during removal activities in June and July of 1996. The oil/water separator was located in the southeast portion of Site SD13. Sampling

was undertaken to characterize any residual contamination in the area immediately surrounding the oil/water separator.

In addition, quarterly groundwater monitoring has been performed at both Sites ST14 and SD13 during 1995/1996 (LAW, 1994) and in the first quarter of 1997 (CH2MHill, 1996). This groundwater monitoring is part of a basewide effort designed to collect data for regulatory compliance issues, delineate and where appropriate remove LNAPL, monitor off-Base or potential off-Base contamination, and collect data to demonstrate that natural attenuation of contaminants is occurring. These data have been incorporated into the RAP to further evaluate the effects of natural attenuation and to define the current extent of contamination.

2.1 SCOPE OF 1994/1995 DATA COLLECTION ACTIVITIES SITE ST14

The field investigation focused on collecting data on the specific chemical constituents that may drive potential risks and impact the final remedial design for Sites ST14 and SD13. The chemicals of potential concern (COPCs) for the site were identified at this stage based on the 1990 RI results and the chemical composition of the known source (i.e., releases of jet and/or gasoline fuel to soils and groundwater resulting from spills or leaks associated with the POL tank farm, the fuel loading area, and the abandoned gasoline station). Aircraft jet fuel consists predominantly of C_5 through C_{14} hydrocarbons. The major hydrocarbon component categories (and their percentages by weight) in JP-4 are n-alkanes (32 percent), branched alkanes (31 percent), cycloalkanes (16 percent), benzenes and alkylbenzenes (18 percent), and naphthalenes (3 percent). Major hydrocarbon component categories in automotive gasoline are n-alkanes (15 to 17 percent), branched alkanes (28 to 36 percent), cycloalkanes (3 to 5 percent), benzenes and alkylbenzenes (20 to 49 percent), naphthalenes (less than or equal to 1 percent), and olfins (1 to 11 percent) (Arthur D. Little, 1987).

On the basis of the environmental behavior of each group of specific hydrocarbons, the results of previous site characterization activities at the site, and TNRCC (1995a) chemical analysis requirements, the COPCs identified and addressed as part of this study for Site ST14 included the BTEX compounds, chlorobenzene, and naphthalene. Analytical data on other polycyclic aromatic hydrocarbons (PAHs) also were collected to confirm the absence of significant concentrations of these compounds in soils and groundwater at the site. Analytical data on trichloroethene (TCE) also were collected at several locations to verify that upgradient groundwater contamination has not migrated to and impacted Site ST14 and downgradient environs. The COPCs initially identified and addressed as part of this phase of the investigation of Site SD13 included the BTEX compounds, and halogenated volatile and semivolatile compounds. Soils, groundwater, and surfacewater analytical data collected for these compounds were obtained using fixed-base analytical methods. Fixed-base analytical testing was provided by Evergreen Analytical, Inc., located in Wheat Ridge, Colorado. Field and other analytical data relevant to documenting biodegradation and assessing the effectiveness of low-cost source-reduction technologies also were collected.

The investigation activities completed at Site ST14 and Site SD13 during the 1994/1995 risk-based remediation investigation were conducted using the approach and methodologies presented in the *Work Plan for a Remedial Action Plan in Support of the*

Risk-Based Approach to Remediation at Site ST14 (Parsons ES, 1994a) and the *Supplemental Work Plan for a Corrective Measures Study/Corrective Measures Implementation Plan* (Parsons ES, 1995) (hereinafter referred to as the work plans) . The following planned sampling and testing activities were performed by Parsons ES at the two sites as part of this initial focused investigation:

- Collection and field screening of soil gas samples from approximately 60 locations prior to the initial drilling activities.

- Collection of soil gas samples for laboratory analysis (in SUMMA™ canisters) at 8 locations scattered throughout the study area.

- Collection of 17 soil gas samples and 2 soil samples for screening analyses to assess and identify potential source areas upgradient from well ST14-MW08 (referred to as the 1190 Area).

- Collection of 12 soil gas samples in the vicinity of the abandoned gasoline service station (Site SD13) for field screening analysis to locate the potential subsurface soil contaminant source areas and to assist in the field design of the full-scale bioventing system for any identified source areas, if necessary. Based on the soil gas screening results, 14 soil samples were collected for screening analysis of the subsurface soils.

- Collection of 6 soil flux samples to evaluate the naturally occurring diffusion of VOCs from the soil into the atmosphere.

- Collection of 1 soil flux sample located less than 10 feet from an operating air sparging test well to monitor contaminant emissions from the surface resulting from air sparging.

- Drilling and installation of 27 permanent groundwater monitoring wells, 17 bioventing wells, two soil boreholes, one biosparging test well, and two vapor monitoring points.

- Collection of 59 subsurface soil samples for analytical testing from 42 new soil boreholes drilled for completion of monitoring wells, vent wells, or vapor monitoring points (samples were not collected from 7 of the 49 soil borings).

- Collection of 7 surface water samples from 5 locations for analytical testing to evaluate surface water quality of the unnamed stream and Farmers Branch. Five samples were collected under low-flow conditions in August 1994, and 2 additional samples were collected following a heavy rainfall event in April 1995 to assess relative contaminant contribution to the unnamed stream.

- Measurement of stream flows under low and normal flow conditions to evaluate the portion of flow contributed from the unnamed stream to Farmers Branch.

- Collection of 21 groundwater samples from temporary Hydropunch® sampling locations for analytical and field testing (part of 1994 RFI effort).

- Collection of 27 groundwater samples from new monitoring wells for analytical laboratory and field testing.
- Collection of 16 groundwater samples from previously existing monitoring wells for analytical laboratory and field testing.
- Performance of a bioventing and biosparging pilot test.
- Performance of aquifer slug tests and conductivity tracer tests to provide further information on the hydrogeologic conditions of the Upper Zone (shallow) aquifer beneath the East Area sites.

Figures 2.1 and 2.2 show the soil gas sampling locations. Figure 2.3 shows the locations of soil flux sampling. Figure 2.4 shows the subsurface soil sampling locations at Site ST14. Figure 2.5 shows the subsurface soil sampling locations at Site SD13. Figure 2.6 shows the groundwater monitoring wells and Hydropunch® locations used to characterize groundwater quality during this field investigation and identifies those wells included in the long term groundwater monitoring program. Figure 2.7 shows the locations where surface water samples were collected. A descriptive summary of all of the field and analytical testing methods used at the East Area sites are presented in Table 2.1.

Analytical method detection limits (MDLs) were considered before site characterization work was initiated under the 1994/1995 risk-based remediation investigation. Suitable analytical methods and quality control procedures were selected (Parsons ES, 1994a) to ensure that analytical results collected under this program could be compared to TNRCC PST Plan A target concentrations (TNRCC, 1994a and 1995a) and used in a quantitative risk assessment prepared to meet 30 TAC 335 requirements.

Table 2.1 identifies the analytical methods used for the different types of environmental samples collected under this program. This table also lists the laboratory-specified MDLs and practical quantitation limits (PQLs) for each analytical method by analyte and environmental medium. The MDL is the lowest concentration at which a chemical can be measured and distinguished with 99-percent confidence from the normal "noise" of an analytical instrument or method. In contrast, the PQL is the lowest level at which a chemical can be accurately and reproducibly quantitated. There are no target PQLs established by either the TNRCC PST or the TNRCC IHW division; however, the PQLs listed in Table 2.1 are lower than the most stringent target concentrations proposed as initial comparison criteria (i.e., Plan A or Risk reduction Standard Nu. Thus, the project-specific PQLs are sufficient to evaluate the data as it pertains to TNRCC risk-based corrective action requirements.

Table 2.2 summarizes the field and fixed-base analyses used at each sampling location. Field sampling and testing activities are summarized briefly in the following sections.

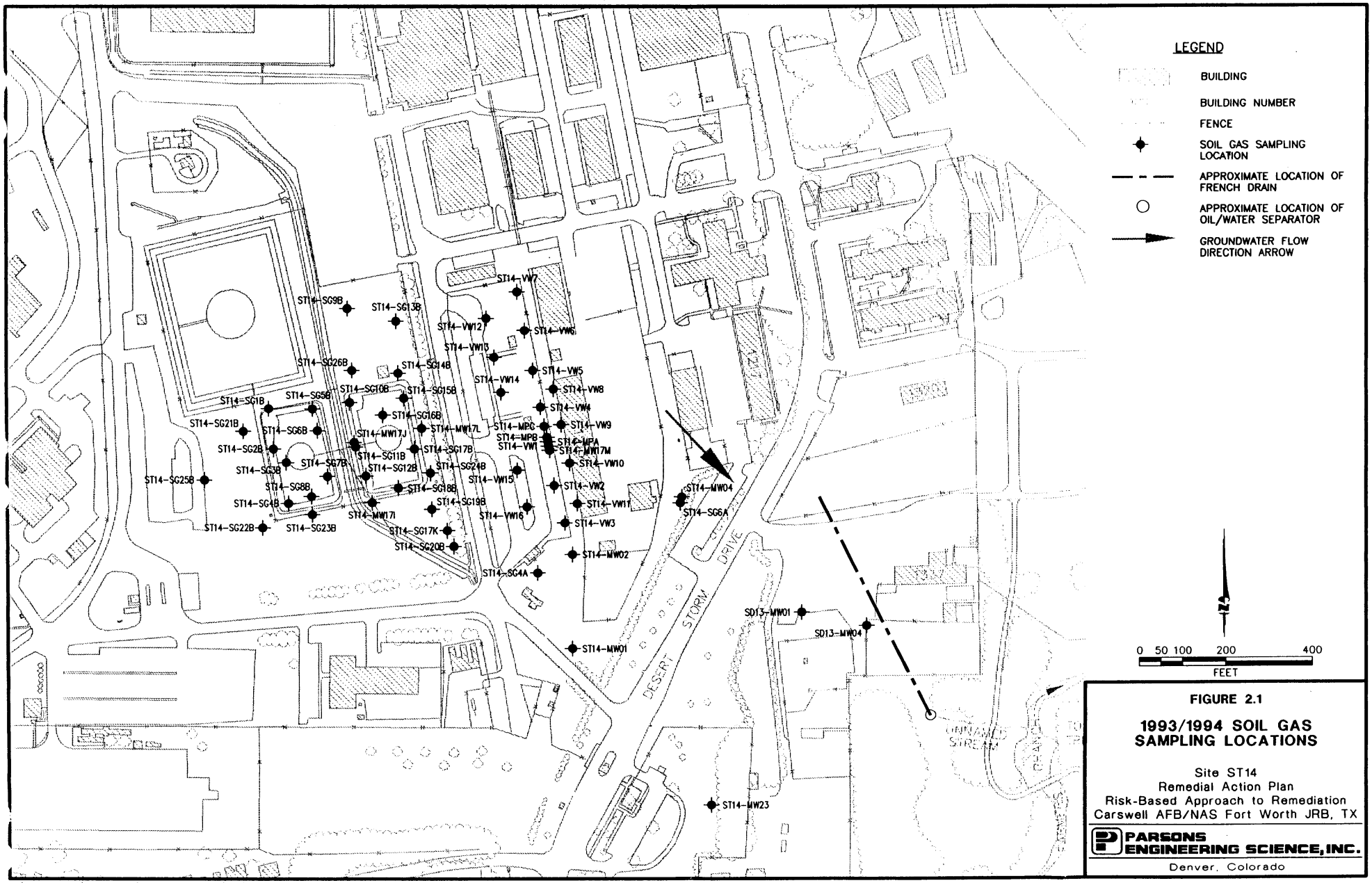


FIGURE 2.1

1993/1994 SOIL GAS SAMPLING LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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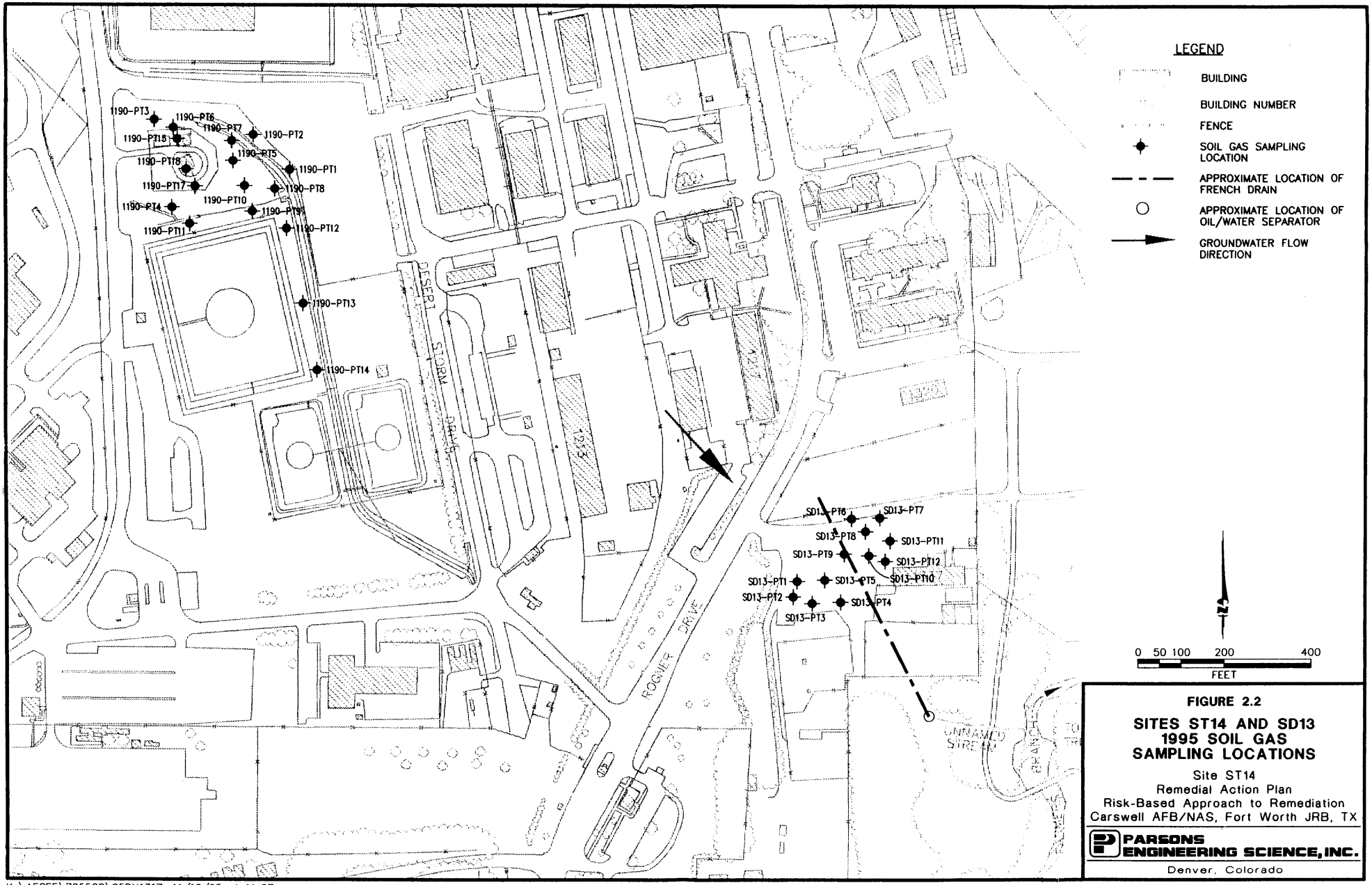


FIGURE 2.2

SITES ST14 AND SD13
1995 SOIL GAS
SAMPLING LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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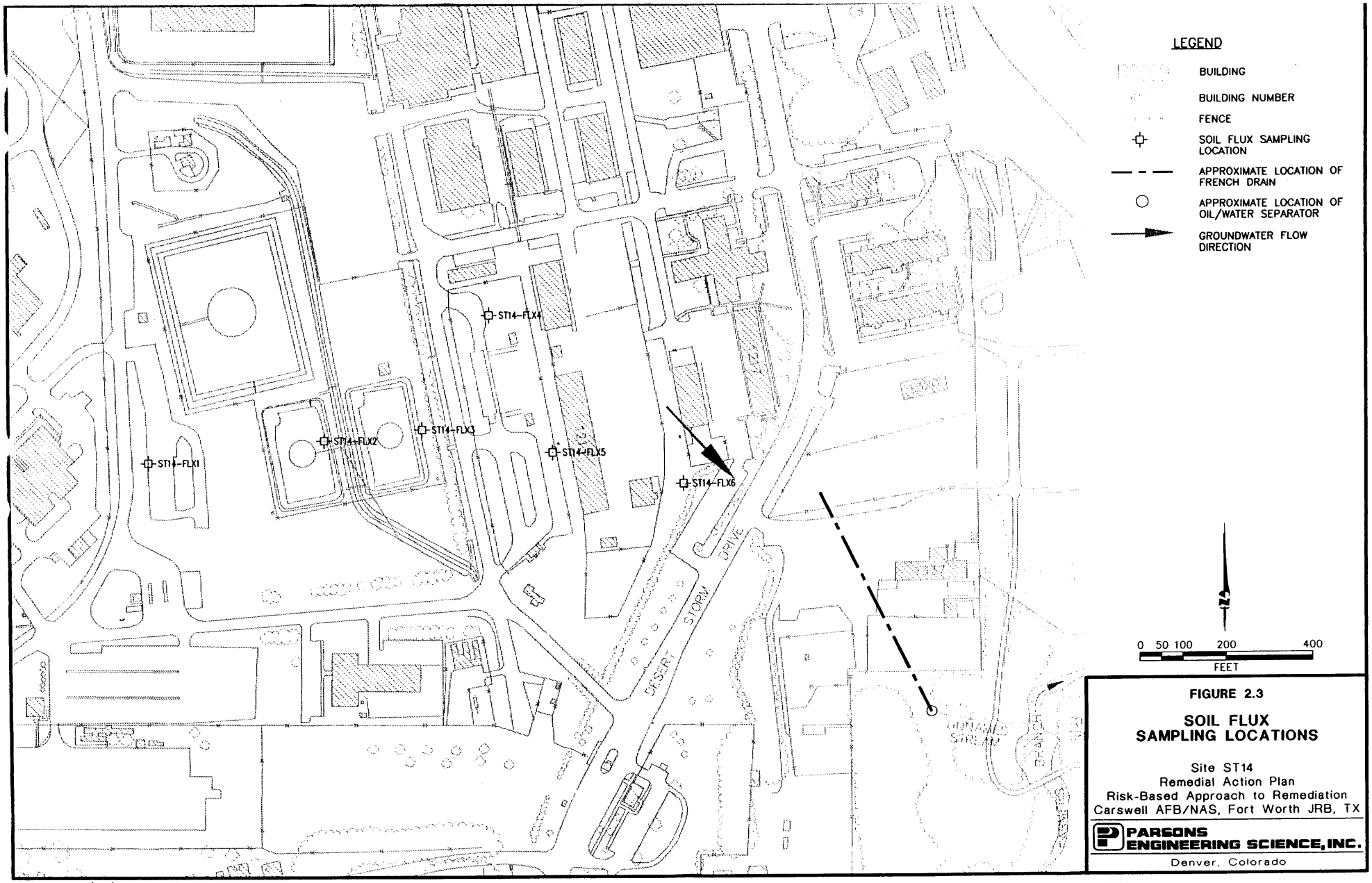


FIGURE 2.3

SOIL FLUX SAMPLING LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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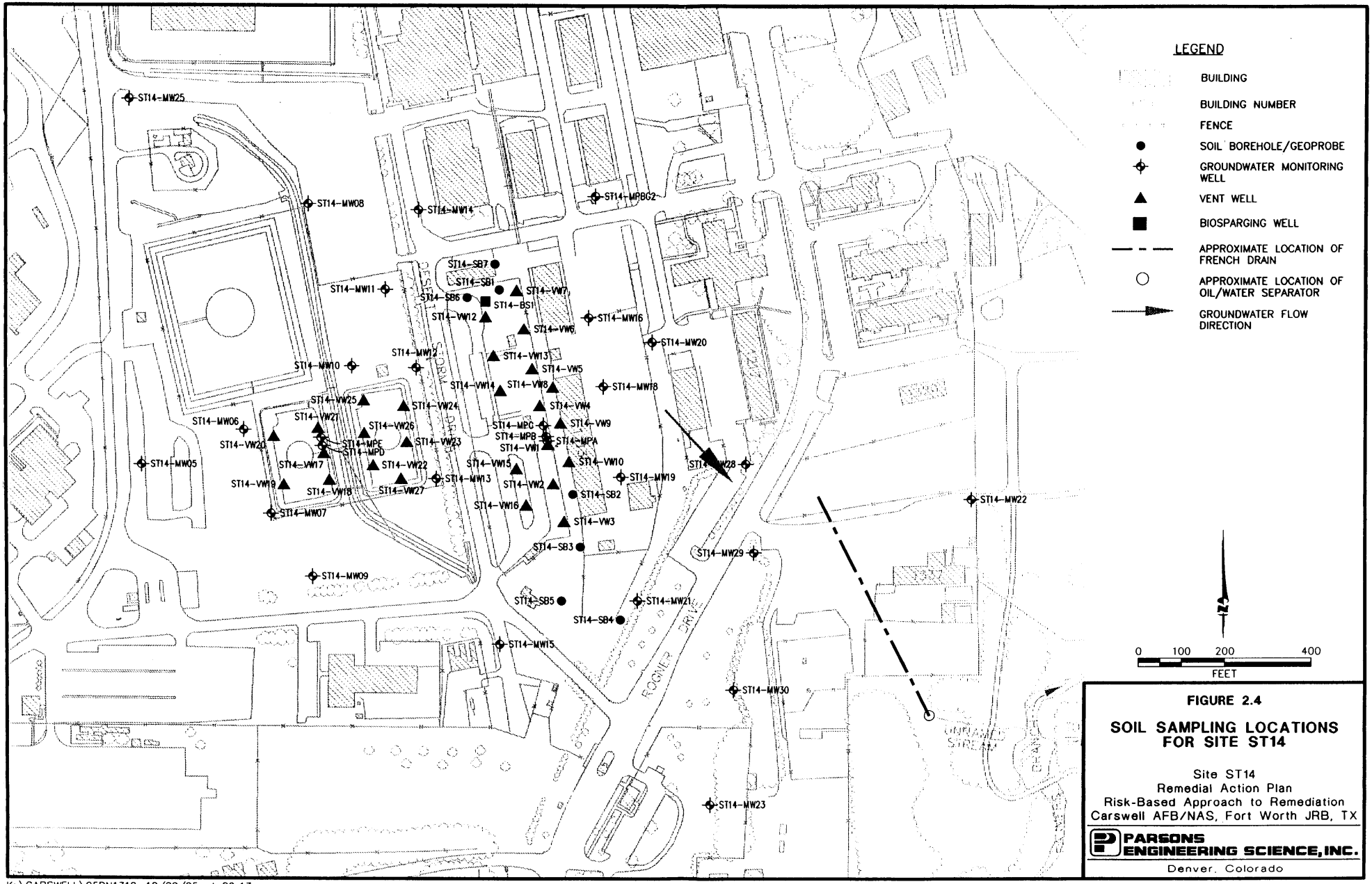


FIGURE 2.4

SOIL SAMPLING LOCATIONS FOR SITE ST14

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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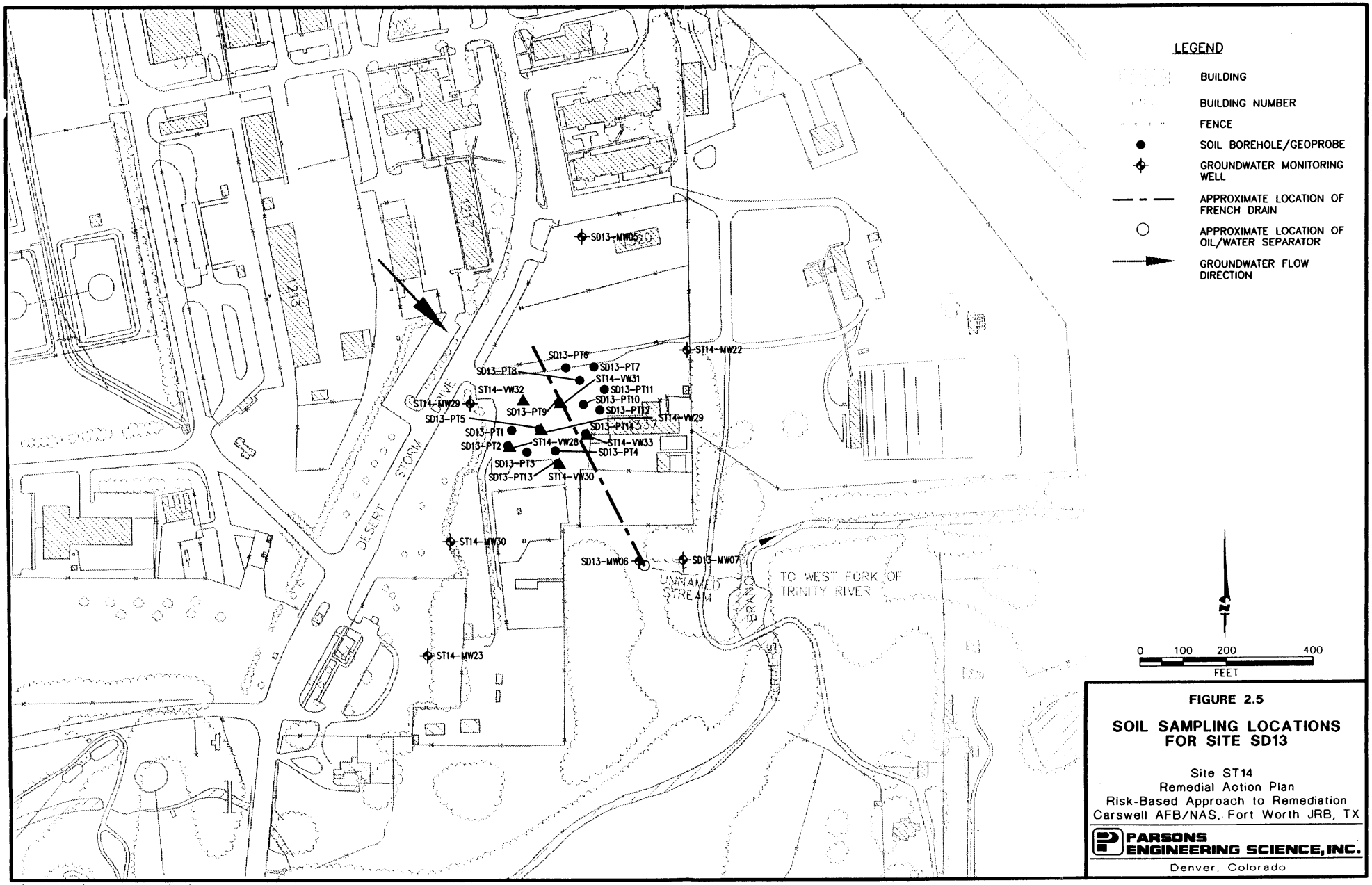


FIGURE 2.5

SOIL SAMPLING LOCATIONS FOR SITE SD13

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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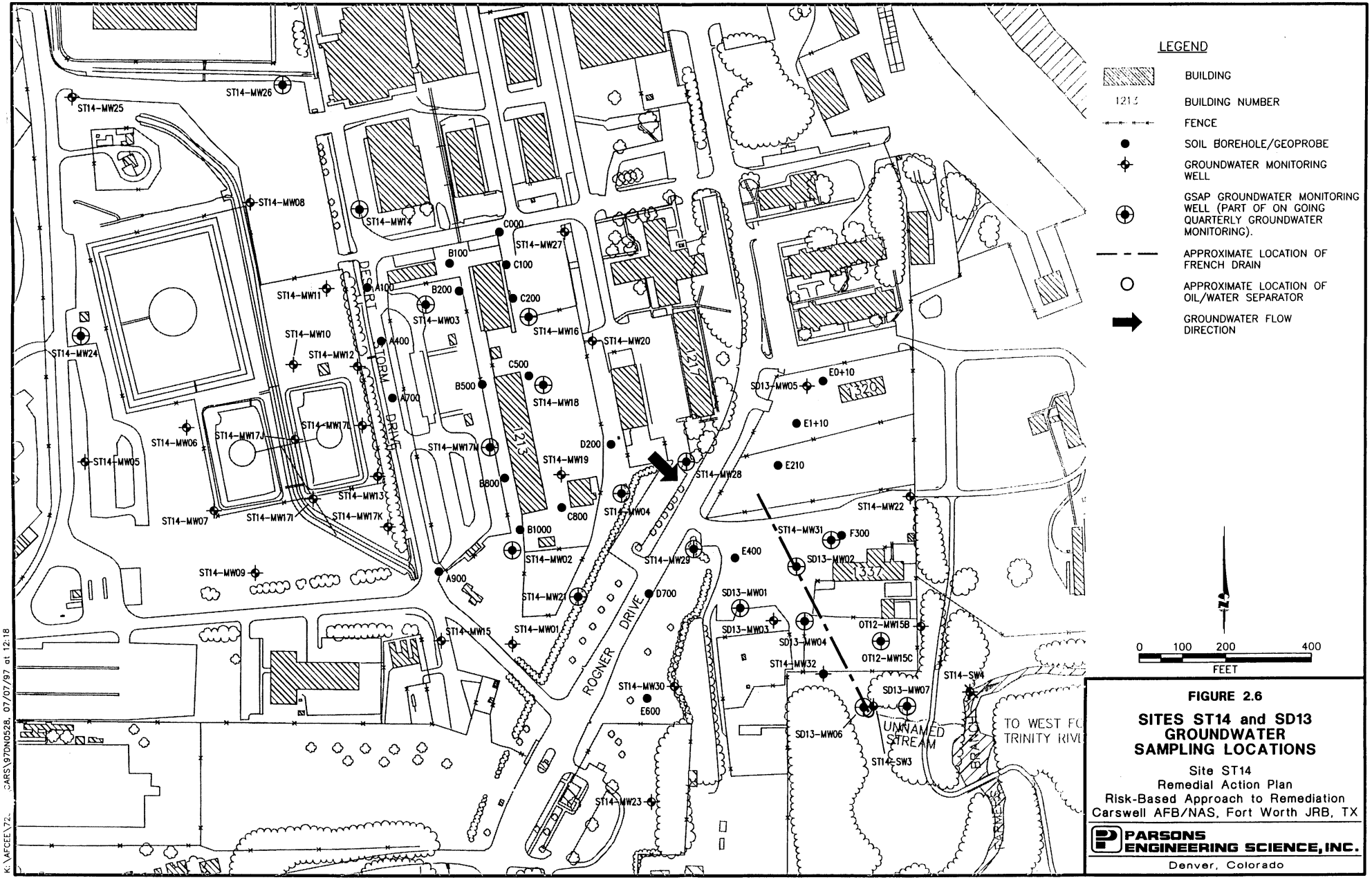


FIGURE 2.6

SITES ST14 and SD13 GROUNDWATER SAMPLING LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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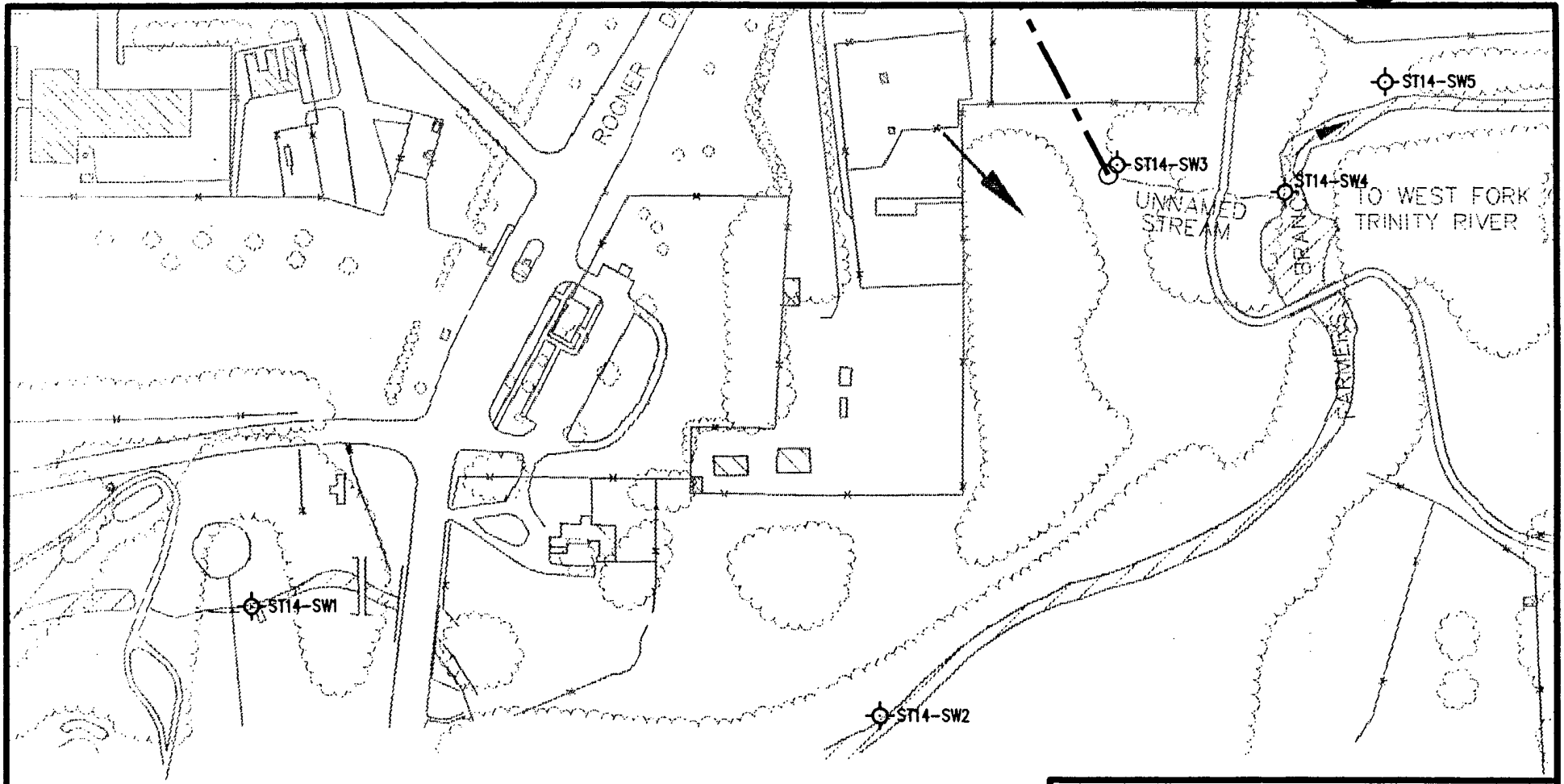


FIGURE 2.7

SURFACE WATER SAMPLING LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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TABLE 2.1
ANALYTE REPORTING LIMITS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil PQL	Soil Units	Site-Specific Water MDL	Water PQL	Water Units
Benzene	TO3	Fixed-Base	0.006	mg/L						
Toluene	TO3	Fixed-Base	0.008	mg/L						
Ethylbenzene	TO3	Fixed-Base	0.009	mg/L						
Xylene (Total)	TO3	Fixed-Base	0.009	mg/L						
Petroleum Hydrocarbons	TO3	Fixed-Base	0.130	mg/L						
Total Extractable Hydrocarbons (TEH)	M8015	Fixed-Base						0.522	5.000	µg/L
Total Volatile Hydrocarbons (TVH)	M8015	Fixed-Base			5.840	110.000	µg/kg	0.089	1.000	µg/L
Benzene	SW8020	Fixed-Base			0.400		µg/kg	0.283	0.400	µg/L
Toluene	SW8020	Fixed-Base			0.400		µg/kg	0.257	4.000	µg/L
Ethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.283	4.000	µg/L
Xylene (Total)	SW8020	Fixed-Base			0.400		µg/kg	0.247	4.000	µg/L
Chlorobenzene	SW8020	Fixed-Base			0.400		µg/kg	0.283	0.400	µg/L
1,2,3-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.153	4.000	µg/L
1,2,4-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.168	4.000	µg/L
1,3,5-Trimethylbenzene	SW8020	Fixed-Base			0.400		µg/kg	0.168	4.000	µg/L
1,3-Dichlorobenzene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
1,4-Dichlorobenzene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
1,2-Dichlorobenzene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Hexachloroethane	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Naphthalene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
2-Methylnaphthalene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Acenaphthylene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Acenaphthene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Dibenzofuran	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Fluorene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Hexachlorobenzene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Phenanthrene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Anthracene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Fluoranthene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Pyrene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Chrysene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Benzo(b)fluoranthene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Benzo(k)fluoranthene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Benzo(a)pyrene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Indeno(1,2,3-cd)pyrene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Dibenzo(a,h)anthrancene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Benzo(g,h,i)perylene	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Phenol	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Pentachlorophenol	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
2,4,5-Trichlorophenol	SW8270	Fixed-Base			330.000	330.000	µg/kg		10	µg/L
Trichloroethene	SW8010	Fixed-Base						0.1	1	µg/L

TABLE 2.1
ANALYTE REPORTING LIMITS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Analyte	Analytical Method	Field or Fixed-Base	Soil Gas MDL	Soil Gas Units	Site-Specific Soil MDL	Soil PQL	Soil Units	Site-Specific Water MDL	Water PQL	Water Units
pH	SW9045	Fixed-Base				0.010	pH Units			
Total Organic Carbon	SW9060	Fixed-Base			0.015	0.050	Percent			
Moisture, Percent	E160.3	Fixed-Base				0.100	Percent			
Phosphorus, Total Orthophosphate (as P)	E300.0	Fixed-Base			0.510	2.500	mg/kg			
Alkalinity, Total (as $CaCO_3$)	E310.1	Fixed-Base				25.000	mg/kg			
Nitrogen, Total Kjeldahl	E351.3	Fixed-Base			5.000	5.000	mg/kg			
Iron	SW6010	Fixed-Base			0.032	1.600	mg/kg			
Benzene	SW8240	Fixed-Base						0.330	0.400	µg/L
Toluene	SW8240	Fixed-Base						0.380	5.000	µg/L
Ethylbenzene	SW8240	Fixed-Base						0.450	5.000	µg/L
Xylene (Total)	SW8240	Fixed-Base						0.220	5.000	µg/L
1,2,3-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
1,2,4-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
1,3,5-Trimethylbenzene	SW8240	Fixed-Base						0.200	5.000	µg/L
Electrical Conductivity	FCOND	Field							0.020	mmhos/cm
Dissolved Oxygen	FDO	Field							0.500	mg/L
pH	FPH	Field							0.000	pH Units
Redox Potential	FREDOX	Field							0.000	pE Units
Temperature	FTEMP	Field							1.000	°C
Iron	H8008	Field						0.010	0.024	mg/L
Nitrate	H8039	Field						0.010	0.066	mg/L
Nitrite	H8040	Field						0.005	0.010	mg/L
Sulfate	H8051	Field						0.010	0.010	mg/L
Hydrogen Sulfide	H8131	Field						0.010	0.024	mg/L
Iron, Ferrous	H8146	Field						0.010	0.024	mg/L
Alkalinity, Total (as $CaCO_3$)	H8221	Field							20.000	mg/L
Carbon Dioxide	H8223	Field						0.010	1.250	mg/L
Manganese	HMANG	Field						0.010	0.050	mg/L
Carbon Dioxide	COU-O2	Fixed-Base						4.000	5.000	mg/L
Methane	RSK175	Fixed-Base						0.004	0.004	mg/L

2.2 SCOPE OF ONGOING CHARACTERIZATION/MONITORING ACTIVITIES

2.2.1 Soil Sampling

Partial removal and abandonment of the french underdrain system and the north oil/water separator was performed in 1996. As part of this activity, three soil samples were taken from the area immediately surrounding the oil/water separator. These soil samples were analyzed for the BTEX compounds, semi-volatile compounds and select metals. Local groundwater elevations were periodically monitored during and after abandonment activities to evaluate the resulting hydrologic responses to these abandonment activities.

2.2.2 Groundwater Sampling

Quarterly groundwater monitoring was performed in 1995 and early 1996 under a Base-wide Groundwater Sampling and Analysis Plan (LAW, 1994). The plan included 25 sampling locations within Sites ST14 and SD13. Ongoing quarterly groundwater monitoring is performed Base-wide under a revised GSAP (CH2MHIll, 1997). This includes sampling of a total of 19 wells at Sites ST14 and SD13. This monitoring is designed to assess the extent and rate of natural attenuation (NA) processes at both sites, and to determine the ability of contaminants to move off-site given the effect of NA. In addition this monitoring is designed to define horizontal or vertical migration of contamination.

2.3 SOIL GAS MEASUREMENTS

The purpose of soil gas sampling was to better define the areal extent of soil contamination in source areas and to determine the potential for lateral and upward diffusion of contaminated soil gas at the site. Three soil gas samples were collected by Parsons ES in June 1993 as part of the bioventing pilot testing project. In July 1994, soil gas samples were collected from 60 sampling locations. The locations of the June 1993 and July 1994 soil gas samples are shown on Figure 2.1.

Additional soil gas testing was performed in March 1995 for the sampling locations shown on Figure 2.2. Soil gas screening samples were collected in 1995 from the 1190 Area and Site SD13 to investigate the existence of potential source areas that may be contributing contamination to the Site ST14 plume. Eight soil gas samples were collected in SUMMA® canisters and shipped to Air Toxics Ltd., Folsom, California, for analytical testing. The remainder of the soil gas samples were field screened for oxygen, carbon dioxide, and TVH.

Soil gas samples were collected using a soil gas probe pushed to depths of 3 to 6 feet bgs or from the existing monitoring wells or vent wells located at both sites. The sampled wells had screened intervals above the water table, which allowed soil gas to be collected from the capillary fringe. All soil gas samples were field-screened for TVH, oxygen, and carbon dioxide using the test equipment and methods specified for field soil gas surveys in the AFCEE protocol documents *Test Plan and Technical Protocol for a Field Treatability Test for Bioventing* (Hinchee *et al.*, 1992) and *Addendum One to Test Plan and Technical Protocol for a Field Treatability Test for*

Bioventing: Using Soil Gas Surveys to Determine Bioventing Feasibility and Natural Attenuation Potential (Downey and Hall, 1994).

Eight of the soil gas samples were collected in SUMMA® and analyzed using EPA analytical Method TO-3 for specific volatile COPCs (i.e., the BTEX compounds) and TVH. Table 2.2 identifies both field and analytical data collected at each soil gas sampling location. One field duplicate and one equipment blank of soil gas samples were collected and analyzed for BTEX and TVH using EPA Method TO-3. All sample handling and field quality assurance (QA)/quality control (QC) procedures for soil gas are specified in Appendix A of the work plans (Parsons ES, 1994a and 1995). Analytical results for soil gas samples are summarized in Section 4 and presented in tabular form in Appendix A.

2.4 SOIL FLUX ANALYSES

Soil flux samples were collected to estimate passive upward diffusion of VOCs from the soil into the atmosphere or potentially into buildings adjacent to the contaminant source area. Six soil flux samples were collected on September 13, 1994, to quantify baseline soil VOC emissions in the area. Additionally, a soil flux sample was collected near the biosparging well (ST14 FLX-4) during the pilot test (see below) to estimate any change in upward diffusion of VOCs during sparging operations. Figure 2.3 shows the soil flux sampling locations used to characterize both baseline and sparging test VOC surface emissions.

Flux samples were collected following the procedures outlined in the EPA guidance document, *Measurement of Gaseous Emissions Rates from Land Surfaces Using an Emission Isolation Flux Chamber* (EPA, 1986b). This approach uses a flux chamber (an enclosed stainless steel container) to sample gaseous emissions from a defined surface area. The flux chamber was placed over the soil surface to be tested, and a seal was created between the chamber and the ground surface. Ultra-zero-grade air (hydrocarbon free) was added to the chamber at a rate of 5 liters per minute (L/min). This sweep air was continuously added to the chamber for 30 minutes to simulate minimal wind action. At a flow rate of 5 L/min, approximately one chamber volume of air is purged through the outlet tubing in 6 minutes. The VOC emissions were measured at 6-minute intervals with a hydrocarbon meter and recorded on flux data sheets. The ambient temperature and temperature inside the flux chamber were measured during sweep air injection.

An air emission sample was collected after 30 minutes of sweep air injection, after the VOC concentrations in the chamber had stabilized. This sample was collected by attaching a SUMMA™ canister to the purge air exit port and opening the valve on the canister to release the vacuum in the canister. Releasing the vacuum pulls the sample into the canister. Once collected, the canister valve was closed, and the samples were labeled and placed into a shipping box for shipment to Air Toxics for chemical analysis via overnight delivery. The samples were analyzed for BTEX and TVH using EPA Method TO-3. Sample handling and field QA/QC procedures for soil flux are specified

in Appendix A of the work plan (Parsons ES, 1994a). One field duplicate and one equipment blank were collected and analyzed for BTEX and TVH using Method TO-3. Analytical results for the soil flux samples are summarized in Section 4 and Appendix A. Table 2.2 (C)

2.5 SUBSURFACE SOIL SAMPLING

Subsurface soil samples were collected at Sites ST14 and SD13 to further delineate the nature and extent of saturated and unsaturated soil contamination at the sites. New soil boreholes were drilled with the goals of expanding the existing groundwater monitoring well network and collecting additional contaminant data. The specific rationale for collecting each soil sample taken in 1994/1995 is presented in the work plan (Parsons ES, 1994a) and the supplemental work plan (Parsons ES, 1995). Drilling of 32 boreholes and installation of 18 monitoring wells, 11 bioventing wells, one biosparging well, and 2 vapor monitoring points initially took place between August 8, 1994 and August 28, 1994. Drilling of an additional 17 boreholes and installation of 9 new monitoring wells, 6 bioventing wells, and abandonment of 2 boreholes took place between March 27 and April 4, 1995. All drilling and subsurface soil sampling was accomplished using a hollow-stem auger (HSA) and following the procedures described in the work plans (Parsons ES, 1994a and 1995). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). Eight field replicates, eight equipment rinseate blanks, eight trip blanks, and one field blank (ambient conditions) were collected during soil sampling at Sites ST14 and SD13.

Fifty-nine subsurface samples were collected for chemical analysis from 42 of the 49 new soil boreholes. Figures 2.4 and 2.5 show the locations of these subsurface soil sampling points and the type of completion (i.e., monitoring well, vent well, etc.). Table 2.2 presents the coordinates and sample interval for each of the subsurface soil sampling locations sampled as part of the risk-based field effort at the two sites. This table also lists the analysis completed on each of the soil samples. Twenty-seven of the new soil boreholes were completed as permanent 2-inch-diameter groundwater monitoring wells. Seventeen of the new boreholes were completed as 4-inch-diameter vent wells in areas of known subsurface soil hydrocarbon contamination. Two shallow vapor monitoring points were constructed in two boreholes (MPD and MPE); one of the new boreholes was completed as a 2-inch biosparging well (BS1); and two boreholes were abandoned.

An additional 16 soil samples were collected (March 6-10, 1995) for chemical analysis using a Geoprobe to screen soils in the 1190 and Site SD13 areas. Fourteen of the soil samples were collected at Site SD13, and 2 were collected in the 1190 area. The sampling locations were selected based on the results of the soil gas screening conducted in these areas.

Three additional subsurface soil samples were collected in 1996 as part of the remedial action conducted at Site SD13. Samples were taken from near the inlet pipe to the oil/water separator, from near the outlet pipe from the north oil/water separator, and from just above the water table directly below the north oil/water separator. All samples were analyzed for BTEX compounds, semi-volatile organic compounds and selected metals. Results of this sampling event are discussed in Section 5 of the RAP.

TABLE 2.2
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
1190-PT1	6964401.2	2299436.2	Soil Gas	4.5-5													X
1190-PT10	6964363.7	2299331.9	Soil Gas	8.5-9													X
1190-PT11	6964276	2299205	Soil Gas	3.5-4													X
1190-PT12	6964266	2299429	Soil Gas	2.5-3													X
1190-PT14	6963943	2299500	Soil Gas	4.5-5													X
1190-PT15	6964470.8	2299176.4	Soil Gas	6-6.5													X
1190-PT17	6964362	2299218	Soil Gas	3.5-4													X
1190-PT18	6964401	2299197	Soil Gas	6-6.5													X
1190-PT2	6964481	2299352	Soil Gas	3-3.5													X
1190-PT3	6964515.1	2299123	Soil Gas	4.5-5													X
1190-PT3	6964515.1	2299123	Soil	3.5-5.5	1	X				X							
1190-PT4	6964314	2299164	Soil Gas	4.5-5													X
1190-PT5	6964420.6	2299305.3	Soil Gas	8.5-9													X
1190-PT5	6964420.6	2299305.3	Soil	6-8	1	X				X							
1190-PT6	6964497	2299167.2	Soil Gas	3-3.5													X
1190-PT7	6964467.1	2299302.5	Soil Gas	2-2.5													X
1190-PT8	6964357	2299402	Soil Gas	3-3.5													X
1190-PT9	6964305	2299350	Soil Gas	3.5-4													X
A100	6964129.235	2299751.57	GW	0-0	1					X	X						
A400	6964006.013	2299784	GW	0-0	1					X	X						
A700	6963874.537	2299809.67	GW	0-0	1					X	X						
A900	6963473.632	2299916.65	GW	0-0	1					X	X						
B100	6964184.027	2299942.5	GW	0-0	1					X	X						
B1000	6963570.486	2300105.84	GW	0-0	1					X	X						
B200	6964121.798	2299964.81	GW	0-0	1					X	X						
B500	6963906.357	2300018.48	GW	0-0	1					X	X						
B800	6963689.852	2300070.61	GW	0-0	1					X	X						
C000	6964256.765	2300058.21	GW	0-0	1					X	X						
C100	6964181.224	2300074.25	GW	0-0	1					X	X						
C200	6964105.331	2300089.85	GW	0-0	1					X	X						
C500	6963926.452	2300132.35	GW	0-0	1					X	X						
C800	6963621.606	2300203.11	GW	0-0	1					X	X						
D200	6963768.013	2300317.13	GW	0-0	1					X	X						
D700	6963423.023	2300405.16	GW	0-0	1					X	X						
E0+10	6963954.656	2300813.75	GW	0-0	1					X	X						
E1+10	6963870.226	2300800.88	GW	0-0	1					X	X						
E210	6963797.414	2300808.56	GW	0-0	1					X	X						
E400	6963519.878	2300772.43	GW	0-0	1					X	X						

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
E600	6963195.651	2300662.21	GW	0-0	1					X	X						
F300	6963557.484	2300855.1	GW	0-0	1					X	X						
OT12-MW15B	6963346.6	2301039.8	GW	0-0	1				X	X							
OT12-MW15C	6963312.686	2300946.95	GW	0-0	1	X			X	X	X						
SD13-MW01	6963389.558	2300620.09	Soil Gas	4.5-5													X
SD13-MW01	6963389.558	2300620.09	GW	0-0	1	X			X	X	X						
SD13-MW02	6963485.133	2300751.3	GW	0-0	1		X	X	X	X	X						
SD13-MW03	6963360.286	2300697.8	GW	0-0	1		X	X	X	X	X						
SD13-MW04	6963358.794	2300769.99	Soil Gas	4.5-5													X
SD13-MW04	6963358.794	2300769.99	GW	0-0	1	X					X						
SD13-MW05	6963902.793	2300775.41	Soil	1-3	1				X	X							
SD13-MW05	6963902.793	2300775.41	Soil	3-5	1				X	X							
SD13-MW05	6963902.793	2300775.41	Soil	5-7	1				X	X							
SD13-MW05	6963902.793	2300775.41	Soil	7-9	1				X	X							
SD13-MW05	6963902.793	2300775.41	GW	0-0	1	X			X	X	X						
SD13-MW06	6963161.396	2300905.73	Soil	0-2	1				X	X							
SD13-MW06	6963161.396	2300905.73	Soil	6-8	1				X	X							
SD13-MW06	6963161.396	2300905.73	GW	0-0	1				X	X							
SD13-MW07	6963164.116	2301007.62	Soil	2-4	1				X	X							
SD13-MW07	6963164.116	2301007.62	Soil	8-10	1				X	X							
SD13-MW07	6963164.116	2301007.62	GW	0-0	1	X			X	X	X						
SD13-PT1	6963461	2300612	Soil Gas	8-8.5													X
SD13-PT1	6963461	2300612	Soil	7.5-9.5	1	X				X							
SD13-PT10	6963520	2300778	Soil Gas	7.5-8													X
SD13-PT10	6963520	2300778	Soil	6.5-8.5	1	X				X							
SD13-PT11	6963554	2300827	Soil Gas	7.5-8													X
SD13-PT11	6963554	2300827	Soil	7.5-9.5	1	X				X							
SD13-PT12	6963507	2300816	Soil Gas	8-8.5													X
SD13-PT12	6963507	2300816	Soil	6.5-8.5	1	X				X							
SD13-PT13	6963386	2300718	Soil	6.5-8.5	1	X				X							
SD13-PT14	6963453	2300783	Soil	6.5-8.5	1	X				X							
SD13-PT2	6963426	2300603	Soil Gas	8-8.5													X
SD13-PT2	6963426	2300603	Soil	6.5-8.5	1	X				X							
SD13-PT3	6963411	2300647	Soil Gas	6-6.5													X
SD13-PT3	6963411	2300647	Soil	6.5-8.5	1	X				X							
SD13-PT4	6963414	2300713	Soil Gas	5-5.5													X
SD13-PT4	6963414	2300713	Soil	6.5-8.5	1	X				X							
SD13-PT5	6963464	2300676	Soil Gas	6-6.5													X

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
SD13-PT5	6963464	2300676	Soil	6.5-8.5	1	X				X							
SD13-PT6	6963604	2300738	Soil Gas	6.5-7													X
SD13-PT6	6963604	2300738	Soil	6.5-8.5	1	X				X							
SD13-PT7	6963606	2300803	Soil Gas	6.5-7													X
SD13-PT7	6963606	2300803	Soil	6.5-8.5	1	X				X							
SD13-PT8	6963575	2300770	Soil Gas	7-7.5													X
SD13-PT8	6963575	2300770	Soil	6.5-8.5	1	X				X							
SD13-PT9	6963524	2300721	Soil Gas	7-7.5													X
SD13-PT9	6963524	2300721	Soil	6.5-8.5	1	X				X							
ST14-FLX1	6963725.125	2299102.52	Soil Flux	0-0	2												
ST14-FLX2	6963775.696	2299510.79	Soil Flux	0-0	2												
ST14-FLX3	6963801.035	2299737.41	Soil Flux	0-0	2												
ST14-FLX4	6964063.175	2299893.44	Soil Flux	0-0	2												
ST14-FLX5	6963748.257	2300040.29	Soil Flux	0-0	2												
ST14-FLX6	6963676.961	2300343.58	Soil Flux	0-0	2												
ST14-MPA	6963780.428	2300031.9	Soil Gas	4-4.5	2												X
ST14-MPA	6963780.428	2300031.9	Soil Gas	4.5-5													X
ST14-MPA	6963780.428	2300031.9	Soil	9-10	1					X				X	X		
ST14-MPB	6963790.776	2300029.51	Soil Gas	4-4.5													X
ST14-MPB	6963790.776	2300029.51	Soil Gas	7-7.5													X
ST14-MPB	6963790.776	2300029.51	Soil	9-10	1					X				X	X		
ST14-MPBG2	6964340.572	2300142.42	Soil	10-11	1					X				X	X		
ST14-MPC	6963815.669	2300023.36	Soil Gas	7-7.5	2												X
ST14-MPC	6963815.669	2300023.36	Soil	10-11	1					X				X	X		
ST14-MPC	6963815.669	2300023.36	Soil	6-7	1					X							
ST14-MPD	6963767.917	2299511.99	Soil	3-3.2	1	X				X							
ST14-MPE	6963786.595	2299508.57	Soil	3.5-3.7	1	X				X							
ST14-MW01	6963306.062	2300087.47	Soil Gas	0-0	2												X
ST14-MW01	6963306.062	2300087.47	Soil Gas	4.5-5													X
ST14-MW01	6963306.062	2300087.47	GW	0-0	1	X	X			X	X						
ST14-MW02	6963522.428	2300087.94	Soil Gas	4.5-5													X
ST14-MW02	6963522.428	2300087.94	GW	0-0	1	X					X						
ST14-MW03	6964090.328	2299887.27	GW	0-0	1	X					X						
ST14-MW04	6963653.861	2300341.63	Soil Gas	0-0	2												X
ST14-MW04	6963653.861	2300341.63	Soil Gas	4.5-5													X
ST14-MW04	6963653.861	2300341.63	GW	0-0	1	X					X						
ST14-MW05	6963724.91	2299092.5	Soil	8.4-9.1	1	X	X			X			X	X	X		
ST14-MW05	6963724.91	2299092.5	GW	0-0	1	X	X		X	X	X						

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
ST14-MW06	6963805.152	2299329.6	Soil	10.5-10.7	1	X											
ST14-MW06	6963805.152	2299329.6	GW	0-0	1	X					X						
ST14-MW07	6963613.18	2299392.46	Soil	13.6-14	1	X											
ST14-MW07	6963613.18	2299392.46	GW	0-0	1	X					X						
ST14-MW08	6964322.44	2299478.72	Soil	19.4-19.6	1	X											
ST14-MW08	6964322.44	2299478.72	GW	0-0	1	X			X		X						
ST14-MW09	6963469.438	2299488.62	Soil	9.6-9.8	1	X											
ST14-MW09	6963469.438	2299488.62	GW	0-0	1	X					X						
ST14-MW10	6963951.574	2299579.95	Soil	13.8-14	1	X	X			X							
ST14-MW10	6963951.574	2299579.95	Soil	7.5-7.7	1	X											
ST14-MW10	6963951.574	2299579.95	GW	0-0	1	X					X						
ST14-MW11	6964126.947	2299657	Soil	14.3-14.5	1	X											
ST14-MW11	6964126.947	2299657	GW	0-0	1	X					X						
ST14-MW12	6963947.582	2299728.91	Soil	14.5-14.7	1	X											
ST14-MW12	6963947.582	2299728.91	Soil	9.5-9.7	1	X											
ST14-MW12	6963947.582	2299728.91	GW	0-0	1	X					X						
ST14-MW13	6963693.368	2299775.07	Soil	13.9-14.1	1	X											
ST14-MW13	6963693.368	2299775.07	GW	0-0	1	X					X						
ST14-MW14	6964308.627	2299733.66	Soil	11.5-11.7	1	X											
ST14-MW14	6964308.627	2299733.66	GW	0-0	1	X					X						
ST14-MW15	6963313.701	2299921.45	Soil	11.7-11.7	1	X											
ST14-MW15	6963313.701	2299921.45	GW	0-0	1	X					X						
ST14-MW16	6964062.581	2300127.16	Soil	3-3.2	1	X											
ST14-MW16	6964062.581	2300127.16	Soil	9.3-9.5	1	X											
ST14-MW16	6964062.581	2300127.16	GW	0-0	1	X					X						
ST14-MW17I	6963640.894	2299624.8	Soil Gas	0-0	2												X
ST14-MW17I	6963640.894	2299624.8	Soil Gas	4.5-5													X
ST14-MW17I	6963640.894	2299624.8	GW	0-0	1	X					X						
ST14-MW17J	6963778.287	2299583.37	Soil Gas	4.5-5													X
ST14-MW17J	6963778.287	2299583.37	GW	0-0	1	X	X			X	X						
ST14-MW17K	6963576.581	2299798.14	Soil Gas	4.5-5													X
ST14-MW17K	6963576.581	2299798.14	GW	0-0	1	X					X						
ST14-MW17L	6963810.947	2299739.68	Soil Gas	4.5-5													X
ST14-MW17L	6963810.947	2299739.68	GW	0-0	1	X					X						
ST14-MW17M	6963760.753	2300035.63	LF	0-0						X							
ST14-MW17M	6963760.753	2300035.63	Soil Gas	4.5-5													X
ST14-MW17M	6963760.753	2300035.63	GW	0-0	1	X	X			X	X						
ST14-MW18	6963904.777	2300161.26	Soil	8.8-9	1	X											

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
ST14-MW18	6963904.777	2300161.26	GW	0-0	1	X					X						
ST14-MW19	6963697.747	2300202.37	Soil	13.5-14	1	X	X			X							
ST14-MW19	6963697.747	2300202.37	GW	0-0	1	X					X						
ST14-MW20	6964006.889	2300274.23	Soil	10-10.2	1	X											
ST14-MW20	6964006.889	2300274.23	Soil	7.1-7.3	1	X											
ST14-MW20	6964006.889	2300274.23	GW	0-0	1	X					X						
ST14-MW21	6963415.583	2300240.35	Soil	10.5-10.7	1	X											
ST14-MW21	6963415.583	2300240.35	GW	0-0	1	X					X						
ST14-MW22	6963646.875	2301015.19	Soil	11-11.2	1	X											
ST14-MW22	6963646.875	2301015.19	GW	0-0	1	X			X		X						
ST14-MW23	6962946.551	2300409.83	Soil Gas	0-0	2												X
ST14-MW23	6962946.551	2300409.83	Soil Gas	4.5-5													X
ST14-MW23	6962946.551	2300409.83	Soil	7.5-7.7	1	X	X			X							
ST14-MW23	6962946.551	2300409.83	GW	0-0	1	X			X		X						
ST14-MW24	6964016.606	2299083.12	GW	0-0							X						
ST14-MW25	6964563.004	2299063.94	Soil	5-5.5	1	X	X	X									
ST14-MW25	6964563.004	2299063.94	GW	0-0			X	X	X		X						
ST14-MW26	6964591.613	2299555.16	GW	0-0							X						
ST14-MW27	6964256.503	2300210.28	GW	0-0					X		X						
ST14-MW28	6963727.604	2300493.8	Soil	9.2-9.4	1	X											
ST14-MW28	6963727.604	2300493.8	GW	0-0							X						
ST14-MW29	6963525.41	2300511.33	Soil	9.5-9.7	1	X											
ST14-MW29	6963525.41	2300511.33	GW	0-0							X						
ST14-MW30	6963209.156	2300464.4	Soil	7-7.2	1	X											
ST14-MW30	6963209.156	2300464.4	GW	0-0							X						
ST14-MW31	6963546.733	2300830.78	GW	0-0			X	X			X						
ST14-MW32	6963237.387	2300813.04	GW	0-0			X	X	X		X						
ST14-SB1	6964126.446	2299920.44	Soil	10-11	1					X							
ST14-SB2	6963658.044	2300090.91	Soil	10-11	1					X							
ST14-SB2	6963658.044	2300090.91	Soil	7-8	1					X							
ST14-SB2	6963658.044	2300090.91	Soil	7.6-7.8	1	X											
ST14-SB3	6963538.2	2300108.05	Soil	9-10	1					X							
ST14-SB4	6963371.073	2300200.65	Soil	10-11	1					X							
ST14-SB4	6963371.073	2300200.65	Soil	7-8	1					X							
ST14-SB5	6963414.776	2300064.23	Soil	10-11	1					X							
ST14-SB6	6964108.742	2299846.61	Soil	9-10	1					X							
ST14-SB7	6964184.358	2299910.89	Soil	11-12	1					X							
ST14-SG10B	6963870.177	2299572.72	Soil Gas	4-4.5													X

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
ST14-SG11B	6963768.044	2299586.62	Soil Gas	0-0	2												X
ST14-SG11B	6963768.044	2299586.62	Soil Gas	1-1.5													X
ST14-SG11B	6963768.044	2299586.62	Soil Gas	3-3.5													X
ST14-SG12B	6963701.62	2299610.32	Soil Gas	4-4.5													X
ST14-SG13B	6964056.678	2299680.53	Soil Gas	4-4.5													X
ST14-SG14B	6963937.676	2299685.62	Soil Gas	5-5.5													X
ST14-SG15B	6963879.978	2299698.35	Soil Gas	4-4.5													X
ST14-SG16B	6963841.326	2299650.09	Soil Gas	4-4.5													X
ST14-SG17B	6963763.634	2299723.19	Soil Gas	4-4.5													X
ST14-SG18B	6963674.683	2299685.34	Soil Gas	4-4.5													X
ST14-SG19B	6963626.114	2299762.46	Soil Gas	5-5.5													X
ST14-SG1B	6963855.966	2299385.39	Soil Gas	5-5.5													X
ST14-SG20B	6963540.991	2299813.05	Soil Gas	4-4.5													X
ST14-SG21B	6963804.117	2299326.89	Soil Gas	5-5.5													X
ST14-SG22B	6963583.096	2299370.62	Soil Gas	5-5.5													X
ST14-SG23B	6963613.587	2299485.65	Soil Gas	3-3.5													X
ST14-SG24B	6963708.603	2299759.71	Soil Gas	4-4.5													X
ST14-SG25B	6963692.577	2299236.66	Soil Gas	0-0	2												X
ST14-SG25B	6963692.577	2299236.66	Soil Gas	4-4.5													X
ST14-SG26B	6963944.094	2299578.41	Soil Gas	5-5.5													X
ST14-SG2B	6963763.303	2299396.56	Soil Gas	3-3.5													X
ST14-SG3B	6963732.467	2299426.13	Soil Gas	3-3.5													X
ST14-SG4A	6963480.137	2300007.21	Soil Gas	5-5.5													X
ST14-SG4B	6963639.049	2299430.95	Soil Gas	4-4.5													X
ST14-SG5B	6963855.535	2299487.05	Soil Gas	4-4.5													X
ST14-SG6A	6963640.324	2300338.1	Soil Gas	3-3.5													X
ST14-SG6B	6963805.752	2299498.57	Soil Gas	0-0	2												X
ST14-SG6B	6963805.752	2299498.57	Soil Gas	4-4.5													X
ST14-SG7B	6963700.777	2299521.74	Soil Gas	4-4.5													X
ST14-SG8B	6963655.087	2299484.28	Soil Gas	4-4.5													X
ST14-SG9B	6964085.526	2299567.82	Soil Gas	4-4.5													X
ST14-SW1	6962595.1	2299808.93	SW	0-0	1	X	X			X			X				
ST14-SW2	6962453.772	2300622.78	SW	0-0	1	X	X			X			X				
ST14-SW3	6963163.808	2300929.03	SW	0-0	1	X	X	X		X			X				
ST14-SW4	6963195.751	2301153.97	SW	0-0	1	X	X	X		X			X				
ST14-SW5	6963271.498	2301273.91	SW	0-0	1	X	X			X			X				
ST14-VW1	6963770.564	2300033.63	Soil Gas	5-5.5	2												X
ST14-VW1	6963770.564	2300033.63	Soil	10-11	1					X				X	X		

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
ST14-VW1	6963770.564	2300033.63	Soil	5-6	1					X							
ST14-VW10	6963731.302	2300081.89	Soil Gas	4.5-5													X
ST14-VW10	6963731.302	2300081.89	Soil	10-11	1					X				X	X		
ST14-VW11	6963638.823	2300099.4	Soil Gas	4.5-5													X
ST14-VW12	6964062.993	2299888.98	Soil Gas	4.5-5													X
ST14-VW12	6964062.993	2299888.98	Soil	10-11	1					X				X	X		
ST14-VW13	6963974.016	2299907.61	Soil Gas	4.5-5													X
ST14-VW13	6963974.016	2299907.61	Soil	9-10	1					X				X	X		
ST14-VW14	6963893.372	2299923.48	Soil Gas	4.5-5													X
ST14-VW14	6963893.372	2299923.48	Soil	9-10	1					X				X	X		
ST14-VW15	6963714.935	2299960.55	Soil Gas	4.5-5													X
ST14-VW15	6963714.935	2299960.55	Soil	11-12	1					X				X	X		
ST14-VW16	6963631.483	2299982.88	Soil Gas	4.5-5													X
ST14-VW16	6963631.483	2299982.88	Soil	9-10	1					X				X	X		
ST14-VW17	6963749.828	2299515.41	Soil	1-1.2	1	X											
ST14-VW17	6963749.828	2299515.41	Soil	5.3-5.8	1	X	X			X							
ST14-VW18	6963689.146	2299528.17	Soil	1-1.2	1	X											
ST14-VW18	6963689.146	2299528.17	Soil	5-5.2	1	X											
ST14-VW19	6963678.21	2299422.55	Soil	5.2-5.4	1	X											
ST14-VW2	6963680.418	2300046.11	Soil Gas	4.5-5													X
ST14-VW2	6963680.418	2300046.11	Soil	10-11	1					X				X	X		
ST14-VW20	6963788.916	2299399.37	Soil	5-5.6	1	X				X			X	X	X		
ST14-VW21	6963807.94	2299501.64	Soil	3.4-4.4	1	X	X			X			X	X	X		
ST14-VW22	6963722.532	2299629.38	Soil	1-1.2	1	X	X			X							
ST14-VW22	6963722.532	2299629.38	Soil	5.9-6.5	1	X				X			X	X	X		
ST14-VW23	6963776.039	2299707.49	Soil	1-1.2	1	X											
ST14-VW23	6963776.039	2299707.49	Soil	6.2-6.4	1	X											
ST14-VW24	6963858.522	2299699.98	Soil	6.9-7.1	1	X											
ST14-VW25	6963871.18	2299607.34	Soil	1-1.2	1	X											
ST14-VW25	6963871.18	2299607.34	Soil	6.7-6.9	1	X											
ST14-VW26	6963796.637	2299608.49	Soil	1-1.2	1	X											
ST14-VW26	6963796.637	2299608.49	Soil	5.2-6.1	1	X	X			X			X	X	X		
ST14-VW27	6963692.177	2299694.13	Soil	7.2-7.4	1	X											
ST14-VW28	6963425.659	2300603.18	Soil	5-5.2	1	X											
ST14-VW28	6963425.659	2300603.18	Soil	7.5-8.3	1	X	X	X								X	
ST14-VW29	6963464.014	2300676.97	Soil	4.2-4.5	1	X											
ST14-VW29	6963464.014	2300676.97	Soil	8.6-9.2	1	X	X	X	X							X	
ST14-VW3	6963594.305	2300070.45	Soil Gas	0-0	2												X

TABLE 2.2 (Continued)
SUMMARY OF SAMPLING APPROACH BY SAMPLING LOCATION
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Sampling Location	Northing	Easting	Sample Matrix	Sampling Depth (ft bgs)[k/]	BTEX[a/]	CBZ[b/]	NAPHTH[c/]	BNA[d/]	TCE[e/]	TVH/TEH[f/]	Electron Acceptors	Moisture	TOC[g/]	PHOS[h/]	N[i/]	Fe[j/]	Soil Gas
ST14-VW3	6963594.305	2300070.45	Soil Gas	4.5-5													X
ST14-VW3	6963594.305	2300070.45	Soil	10-11	1					X							
ST14-VW3	6963594.305	2300070.45	Soil	7-8	1					X				X	X		
ST14-VW30	6963386.234	2300718.36	Soil	4.5-4.7	1	X											
ST14-VW30	6963386.234	2300718.36	Soil	8.4-9	1	X	X	X								X	
ST14-VW31	6963524.988	2300721.19	Soil	10.2-10.7	1	X	X	X								X	
ST14-VW31	6963524.988	2300721.19	Soil	4-4.2	1	X											
ST14-VW32	6963530.607	2300634.95	Soil	4.1-4.3	1	X											
ST14-VW32	6963530.607	2300634.95	Soil	9.5-10.5	1	X	X	X								X	
ST14-VW33	6963452.862	2300782.94	Soil	8.7-8.9	1	X											
ST14-VW4	6963859.688	2300014.64	Soil Gas	4.5-5													X
ST14-VW4	6963859.688	2300014.64	Soil	10-11	1					X				X	X		
ST14-VW5	6963944.154	2299996.84	Soil Gas	4.5-5													X
ST14-VW5	6963944.154	2299996.84	Soil	10-11	1					X							
ST14-VW5	6963944.154	2299996.84	Soil	7-8	1					X				X	X		
ST14-VW6	6964035.158	2299977.93	Soil Gas	4.5-5													X
ST14-VW6	6964035.158	2299977.93	Soil	9-10	1					X				X	X		
ST14-VW7	6964123.405	2299960.3	Soil Gas	4.5-5													X
ST14-VW7	6964123.405	2299960.3	Soil	9-10	1					X				X	X		
ST14-VW8	6963901.145	2300044.51	Soil Gas	4.5-5													X
ST14-VW8	6963901.145	2300044.51	Soil	9-10	1					X				X	X		
ST14-VW9	6963819.641	2300062.43	Soil Gas	4.5-5													X
ST14-VW9	6963819.641	2300062.43	Soil	9-10	1					X				X	X		

a/ BTEX - benzene, toluene, ethylbenzene, and xylenes.

b/ CBZ = Chlorobenzene.

c/ NAPHTH = naphthalene.

d/ BNA = base/neutral acids.

e/ TCE = trichloroethene

f/ TVH/TEH = total volatile hydrocarbons/total extractable hydrocarbons.

g/ TOC = total organic carbon.

h/ PHOS = phosphate.

i/ N = nitrate/nitrite as nitrogen.

j/ Fe = ferrous iron.

k/ ft bgs = feet below ground surface (feet below top of casing for groundwater samples in monitoring wells.

Borehole logs, well completion diagrams, well development records, and survey data for all new sampling locations are included in Appendix B. Geological data are presented in Section 3 to characterize the physical setting of the site. Analytical results for soil for Site ST14 and Site SD13 are summarized in Section 4 and Section 5, respectively, to characterize the nature and extent of soil contamination at the site.

2.6 GROUNDWATER INVESTIGATIONS

In March 1994, Law (1994) supervised additional groundwater sampling downgradient from Site ST14. The sampling was completed by Transglobal Environmental Geochemistry using a temporary monitoring probe which was hydraulically driven into the first 18 inches of the groundwater table. Details on the sampling protocol are presented in the RFI report (Law, 1994). Parsons ES also participated in the March 1994 sampling event to collect data necessary to support a preliminary evaluation of the potential effectiveness of natural chemical attenuation processes on organic compounds at the site. Data collected included concentrations of dissolved oxygen, nitrate, nitrite, ferric/ferrous iron, reduction/oxidation (redox) potential, pH, conductivity, and temperature. All sample analysis was performed using field instruments and colormetric (HACH®) methods specified by the draft AFCEE *Technical Protocol for Implementing the Intrinsic Remediation (Natural Attenuation) with Long-Term Monitoring Option for Dissolved Fuel Contamination in Groundwater,* which was prepared by Parsons ES and the EPA's NRMRL Subsurface Protection and Remediation Division (Wiedemeier *et al.*, 1995).

Groundwater samples also were collected in 1994 from the 27 new wells and 16 previously installed wells to define the nature and extent of dissolved hydrocarbon contamination. Geochemical data relevant to documenting the potential for biodegradation of dissolved COPCs and quantitatively investigating chemical fate and transport were collected. Groundwater samples were collected using the procedures described in the work plan (Parsons ES, 1994a). These procedures are in accordance with the general procedures outlined in Section 8.5 of *A Compendium of Superfund Field Methods* (EPA, 1987). Five field duplicates, three equipment rinseate/field blanks, three trip blanks, and one decontamination water blank were collected during 1994 groundwater sampling at Sites ST14 and SD13.

Groundwater samples were collected from the 43 different sampling locations listed in Table 2.2 and shown on Figure 2.6. Both field and laboratory analytical data were collected at each groundwater sampling location, as summarized in Table 2.2. All groundwater samples, including QA/QC samples, were analyzed for the BTEX compounds using EPA Method SW8020. EPA Method SW8270 was used to quantify target PAH compounds. Field and laboratory analytical data were collected to evaluate natural chemical attenuation processes in accordance with the draft AFCEE protocol for implementing intrinsic remediation (Wiedemeier *et al.*, 1995). Table 2.1 summarizes the types of field measurements completed at the sites as part of this investigation. Hydrogeological data are presented in Section 3 to characterize the physical setting of the site. Field and laboratory analytical results for groundwater are used in Section 4 to characterize the nature and extent of groundwater contamination at Site ST14. Analytical results for groundwater samples collected at Site SD13 are presented in Section 5 to characterize the nature and extent of groundwater contamination at this site.

Basewide groundwater monitoring was initiated in 1995. Monitoring wells at both Sites ST14 and SD13 are included in the groundwater monitoring plan and are sampled on a quarterly basis. Four monitoring events were performed from April of 1995 to January of 1996 under the GSAP prepared by LAW Environmental Inc (1994). Under this GSAP, 16 locations at Site ST14 and 9 locations at Site SD13 are sampled. Analyses varied by well, but included analysis for metals using EPA methods SW6010, SW7060 (Arsenic), SW7421 (Lead), SW7470 (Mercury), SW7841(Thallium), analysis for volatile organic compounds using EPA Methods SW8260 or SW8240, analysis for semi-volatile organic compounds using EPA Method SW8270, and analysis for pesticides using EPA Method SW8080. In 1997, a modified groundwater monitoring program was initiated by CH2MHill under a new GSAP. Under the new GSAP, 11 locations at Site ST14 and 8 locations at Site SD13 are sampled on a quarterly basis. Analyses vary by well, but include analysis for metals using EPA Methods SW6010, SW7421 (Lead), SW7470A (Mercury), analysis for volatile organic compounds using EPA Method SW8260, analysis for aromatic volatile organics (the BTEX compounds) using EPA Method SW8020A, analysis for total organic carbon using EPA Method SW9060, and analysis for indicators of natural attenuation and biodegradation using EPA Methods SM6211M (methane), EPA310.1 (alkalinity), and SW9056 (various inorganic parameters). Under both plans, sampling locations were selected to include upgradient, in plume, sentry, and perimeter locations. Sampling locations at Sites ST14 and SD13 included in the current quarterly monitoring program are indicated in Figure 2.6.

2.7 SURFACE WATER INVESTIGATIONS

2.7.1 1994/1995 Sampling Events

As part of the Parsons ES 1994/1995 field investigation, two rounds of surface water grab samples were collected to assess the potential release of contaminated groundwater to Farmers Branch and eventually the West Fork of the Trinity River (stream segment 0806). The french underdrain (SWMU 64) that was constructed across Site SD13 (Figure 2.6) apparently intercepted shallow groundwater and directed it to the oil/water separator (SWMU 67) at the head of the unnamed stream. The majority, if not all, of the unnamed stream flow water came from the oil/water separator (french underdrain outfall).

Five surface water grab samples were collected during low-flow (dry) conditions in Farmers Branch on August 31, 1994. The approximate locations are shown on Figure 2.7. The discrete locations are as follows: SW1 within Farmers Branch, upstream from Site SD13 and the unnamed stream's outfall; SW2 within Farmers Branch, upstream from the unnamed stream's outfall; SW3 at the outfall of the former oil/water separator in the unnamed stream, upstream of its confluence with Farmers Branch; SW4 at the confluence of the unnamed stream and Farmers Branch, and SW5 within Farmers Branch, downstream of its confluence with the unnamed stream and upstream from confluence with West Fork Trinity River.

Two surface water grab samples were collected on April 5, 1995, following a significant overnight rainfall event, to address concerns that greater levels of fuel contaminants were discharged from the oil/water separator after heavy rains. The two

locations were SW3 within the unnamed stream, upstream from Farmers Branch, and SW4 at the confluence of unnamed stream and Farmers Branch.

Surface water samples were collected as described in Appendix A of the work plan (Parsons ES, 1994a). During the first sampling event, one field duplicate, one trip blank, and one field blank were collected for QA/QC. One trip blank was the only QA/QC sample collected during the second sampling event. All of the samples were analyzed for BTEX (SW8020), total organic carbon (TOC) (via EPA Method SW9060), naphthalene (SW8270), and total petroleum hydrocarbons (TPH) (via EPA Method SW8015) during the first round of sampling. The surface water samples collected after the heavy rainfall event were analyzed using EPA Methods SW8020 and SW8270 (full suite).

Two rounds of surface water flow rates were measured at three locations (SW2, SW3, and SW4) to evaluate the contribution of the unnamed stream to Farmers Branch, and eventually to stream segment 0806 of the West Fork Trinity River. These flow measurement locations correspond to the stream sampling locations shown in Figure 2.7. The first round of measurements was performed on August 31, 1994, during low-flow conditions. The second round of surface water flow rates were measured at four locations (SW1 added) on November 10, 1994, following rainfall events that resulted in moderate flow conditions.

Surface water flow measurements and calculations were performed as described in the US Geological Survey Water Supply Paper 2175 titled, *Measurement and Computation of Streamflow: Volume 1, Measurement of Stage and Discharge*. Stream flow was measured at SW4 and SW2 during the low-flow sampling event using the float method due to the low flows. A straight reach of the stream was located, and the cross section across that reach of the stream was measured using measuring tape. The measuring tape was then used to measure the length of the reach and mark the starting and ending points. Once these measurements were made, a float was placed in the creek upstream from the starting point. The float was then allowed to move downstream with the current, and the velocity was measured using a stopwatch. Several velocity measurements were taken and the results were averaged. The calculated flow rate in this reach is presented in Section 3.

The flow was measured at location SW3 during the low-flow sampling event using a graduated bucket. A portion of the creek that flows beneath the road through a culvert was selected for gaging. A graduated bucket was placed so that all flow passing through the culvert was diverted into the bucket. The flow rate was determined by measuring the time it took to fill the bucket. Several measurements were made, and the results were averaged together. The calculated flow rate is presented in Section 3.

Stream flow at locations SW1, SW2, and SW4 were measured during the moderate-flow conditions using a Price "pygmy" current meter. The current meter measures velocity at a point. The discharge measurement at a cross-section requires the determination of mean velocity in each of the selected vertical sections. The current meter was set at a depth of about 60 percent of the total depth at that interval. Once the velocity measurements were collected, the flow through each interval of the cross-section was calculated and the total flow through the cross section was calculated by

adding the flows from each interval. The calculated flow rates are presented in Section 3.

The flow at SW3 was measured again during this sampling event using the graduated bucket. The flow was measured as it flowed directly out of the oil/water separator instead of at the culvert under the road. The short distance between the two locations and the absence of additional influent or effluent streams between the locations made the results from both surveys comparable. Calculation summary sheets are included in Appendix D.

2.7.2 1997 Sampling Event

As part of the current GSAP (CH_2MHill 1996), surface water samples are collected on a quarterly basis at one location above the outlet of the unnamed stream into the Farmers Branch and at one location below the outlet of the unnamed stream. Both samples are analyzed for total and dissolved metals and for TOC. Due to the 1996 removal of portions of the french underdrain system (SWMU 64) and the oil/water separator (SWMU 67) and the subsequent cessation of water flow, it is no longer possible to collect surface water samples from the unnamed stream itself. These data are presented in Section 5 of the RAP to describe the potential for surface water impacts from groundwater discharge.

2.8 AQUIFER TESTING

Slug tests were attempted on September 10-11, 1995, at eight wells located across Sites ST14 and SD13 to provide additional information on the hydrogeologic conditions specific to this area of Carswell AFB/NAS Fort Worth JRB. Groundwater recharge was too rapid at some of these wells to provide reliable measurements for transmissivity calculations. Successful results were obtained from three of the slug tests performed. These field tests were necessary to complement existing hydrogeologic data collected during previous investigations. These types of hydrogeologic data are necessary to support quantitative chemical fate and transport analyses.

Two conservative tracer tests also were conducted in the presumed vicinity of the french underdrain system to evaluate the impact of this subsurface structure on groundwater flow. The tracer test also provided data that enabled determination of groundwater flow velocity and direction at slugged wells. Sodium bromide (NaBr) was selected to be used for the tracer tests because it is not impacted by biological activity and is not significantly sorbed to aquifer materials. Probes for specific conductivity were placed in two wells to monitor for fluctuations in conductivity resulting from the NaBr slug. The first tracer test was performed from November 11, 1994 to December 19, 1994, with conductivity readings recorded on a Hermit® datalogger at 10-minute intervals. The NaBr slug was injected into monitoring well SD13-MW04. Two conductivity probes were also set up for measurements in well SD13-MW06 and in the not-yet-removed oil/water separator outfall from the french underdrain.

The second tracer test was initiated on December 23, 1994, with probes placed in four wells for conductivity measurements. One of the probes was placed in well SD13-MW01 to measure the disappearance rate of the slug from the slug well. The other

three probes were placed into wells believed to be downgradient from well SD13-MW01 and possibly from the then in operation french underdrain system (SD13-MW03, SD13-MW04, and SD13-OT15C). The Hermit® datalogger was set to take hourly measurements for this tracer test. The second tracer test was discontinued on February 8, 1995.

The results of the slug and tracer tests are discussed in Section 3 as part of the hydrogeologic evaluation. The calculation sheets and data summaries for the tracer tests are included in Appendix D.

2.9 INTERIM REMOVAL ACTIONS AT SITE SD13

In 1996, the french underdrain system (SWMU 64) at Site SD13, installed during the mid-1960s with no known documentation, was investigated to determine its location and construction and to determine the source of persistent water flow into the north oil/water separator (SWMU 67), which discharged to a tributary to Farmers Branch Creek referred to as the "unnamed stream". Once a basic understanding of the underdrain system and oil/water separator was achieved, both SWMUs were abandoned in accordance with procedures approved by IHW-TNRCC to eliminate discharges of groundwater into surface drainages by this flow path. Portions of the drain pipe were removed and replaced with low permeability material. These activities halted the flow of groundwater into the north oil/water separator and the unnamed stream. The north oil/water separator was cleaned, then removed. After removing the north oil/water separator (SWMU 67), three soil samples were collected from the resulting pit on 26 June 1996: one sample from the west wall, approximately 4 feet below the top of the former north oil/water separator (in the vicinity of the former inlet pipe); one sample from the south wall, approximately 4 feet below the top of the former north oil water separator (in the vicinity of the outlet pipe); and one sample from the south wall approximately 9 feet below the top of the former north oil water separator and approximately 6 inches above the observed water table. Quality assurance/quality control (QA/QC) samples consisting of one replicate soil sample from the inlet pipe sampling location for use as a matrix spike/matrix spike duplicate (MS/MSD) sample pair, one equipment rinseate blank, and one trip blank also were collected.

The soil, MS/MSD, and rinseate blank samples were analyzed for selected volatile organic compounds (VOCs), a full suite of semivolatile organic compounds (SVOCs), and selected metals. VOCs, including the fuel hydrocarbons benzene, toluene, ethylbenzene, and xylene (BTEX), were analyzed using U.S. Environmental Protection Agency (EPA) Method SW8240/8260. SVOCs were analyzed using EPA Method SW8270. Arsenic and lead were analyzed using EPA Methods SW7061 and SW6010, respectively. The trip blank was analyzed for BTEX constituents only.

Groundwater elevations were measured at monitoring wells in the vicinity of Site SD13 in June and August 1996, both during and following abandonment of the french underdrain system (SWMU 64) and oil water separator (SWMU 67).

2.10 SOURCE REDUCTION FEASIBILITY TESTING

Two potentially appropriate source reduction technologies were evaluated during this field effort: biosparging and bioventing. Biosparging involves the injection of air into

saturated soils with the purpose of increasing dissolved oxygen (DO) concentrations to enhance biodegradation and volatilization of VOCs. A single biosparging test well was constructed at Site ST14A (fuel loading area) as part of the risk-based field program at Carswell AFB/NAS Fort Worth JRB on November 29 through December 1, 1994. The goals of the biosparging test were to measure the increase in the DO concentrations created by sparging and to determine the flow rates required for a full-scale biosparging system in the event that this type of remediation is warranted.

Bioventing is an innovative technology that uses low rates of air injection to supply oxygen to soil bacteria employed in the biodegradation of fuel hydrocarbons in the vadose zone. A bioventing test was completed at Site ST14A near well ST14-MW17M in 1993 to assess whether this low-cost source reduction technology could be used to remediate contaminated soil, if necessary. The biosparging and bioventing pilot test approaches and results are summarized in Section 7.

Due to significant hydrogeological similarities in soils found at Site ST14 and Site SD13, these test results should be useful in predicting the remedial effectiveness of bioventing and biosparging on fuel-contaminated subsurface soil and groundwater at both Sites ST14 and SD13. A full data report of the bioventing pilot test is included in the *Bioventing Pilot Test Final Report for Site ST14, Fuel Loading Area, Carswell AFB* (ES, 1993).

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

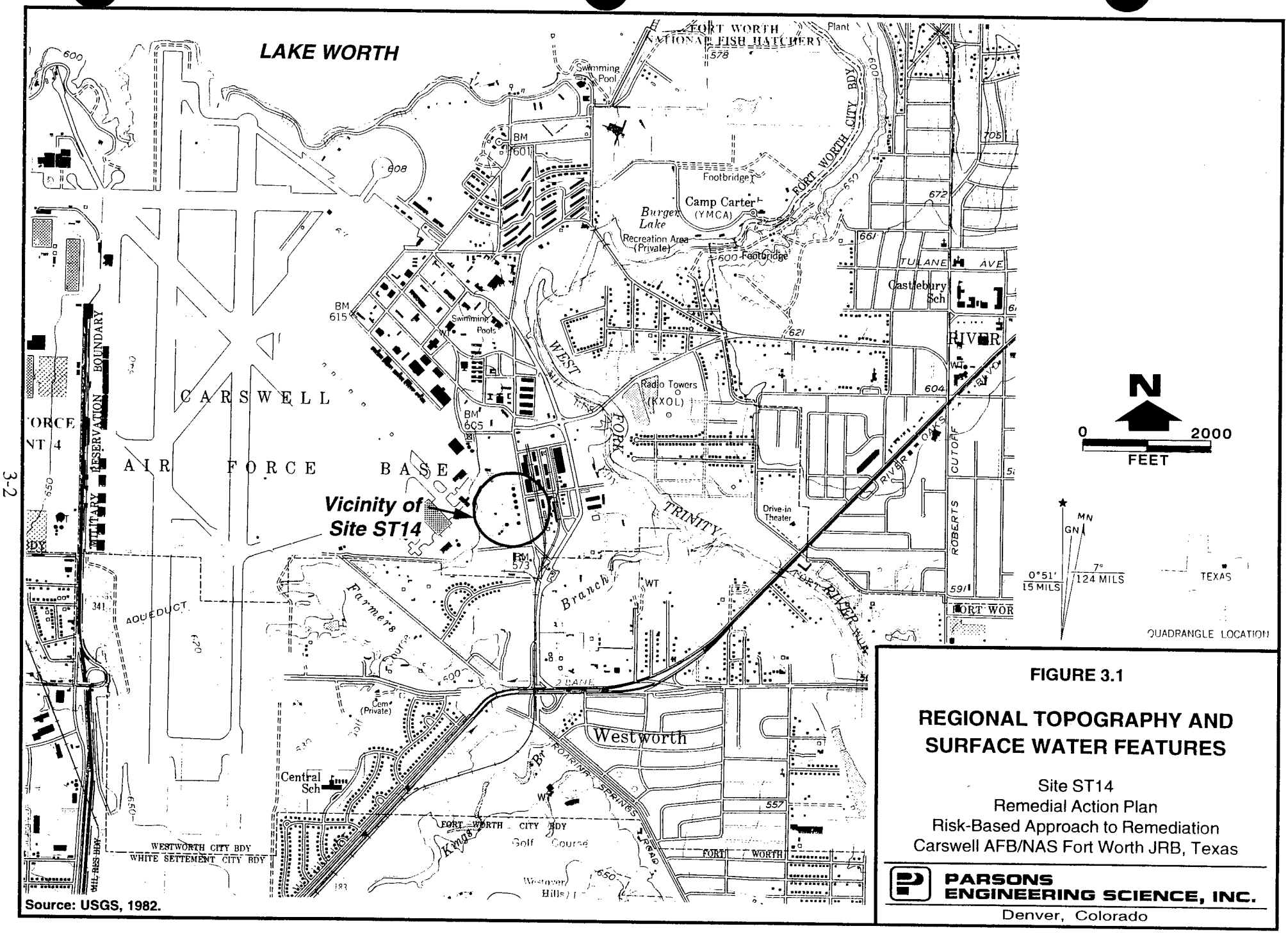
This section describes the physical characteristics of the East Area at Carswell AFB/NAS Fort Worth JRB. Data incorporated into this section from previous investigations were taken from the RI report for the East Area sites (Radian, 1991), the bioventing pilot test and site characterization report for Site ST14 (ES, 1993), the environmental impact study for the Base (US Air Force, 1994), the RFI report for the East Area (Law, 1994), and the quarterly groundwater monitoring performed by both LAW and CH2MHill. A summary of site characterization activities completed by Parsons ES to supplement existing data is presented in Section 2 of this RAP.

3.1 REGIONAL TOPOGRAPHY AND HYDROLOGY

Carswell AFB/NAS Fort Worth JRB is located in the Grand Prairie section of the Central Lowlands Physiographic Province of the Texas Coastal Plain. The Base is underlain by alternating limestones and marls that produce a terrace topography. The Grand Prairie section typically is a broad, gently sloping terrace. Elevations at the Base range from 550 feet above mean sea level (msl) in the east to 690 feet above msl in the southwest (US Air Force, 1994). The topography and major surface water features of the areas near Carswell AFB/NAS Fort Worth JRB are shown on Figure 3.1.

Carswell AFB/NAS Fort Worth JRB is located within the Trinity River watershed. Surface water bodies in the vicinity of the Base include the West Fork, Farmers Branch Creek, and Kings Branch of the Trinity River Basin, Lake Worth, and three ponds located in the on-Base golf course area. The Texas Water Commission (TWC, 1985) has identified the West Fork Trinity River Stream segment adjacent to the Base as segment number 0806.

The amount of water the Trinity River receives is controlled by the watershed runoff from impervious areas during storms, by releases and overflows from a series of man-made reservoirs along the forks and tributaries by natural runoff, and by the discharge of effluent from sewage treatment plants. Lake Worth, a man-made reservoir on the West Fork of the Trinity River, is located immediately north of Carswell AFB/NAS Fort Worth JRB (Figure 3.1) and is owned and operated by the City of Fort Worth. These waters are used for public water supply and recreation (US Air Force, 1994).



Source: USGS, 1982.

FIGURE 3.1

REGIONAL TOPOGRAPHY AND SURFACE WATER FEATURES

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Texas

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Surface water is the main source of potable water in the vicinity of Carswell AFB/NAS Fort Worth JRB. The City of Fort Worth Water Department is the primary supplier to the areas surrounding and including the Base. Water from Farmers Branch is used to irrigate the on-Base golf course. White Settlement and Sansom Park obtain water from 12 and 9 groundwater wells, respectively; but, when required, they purchase surface water from the city of Forth Worth to supplement their water supplies. Carswell AFB/NAS Fort Worth JRB purchased 0.93 million gallons per day (mgd), 0.77 mgd, and 0.76 mgd of water from Fort Worth in 1989, 1990, and 1991, respectively. The availability of surface water was adequate to meet existing demands at the time of Base realignment (US Air Force, 1994).

Surface drainage at Carswell AFB/NAS Fort Worth JRB is collected by the storm drainage system and routed to Farmers Branch and to the West Fork of the Trinity River, or as outfall into Lake Worth. An underground drainage culvert conducts surface runoff generated from areas west of the Base eastward to Farmers Branch. General surface drainage patterns are shown in Figure 3.2 and discussed in Section 3.3.

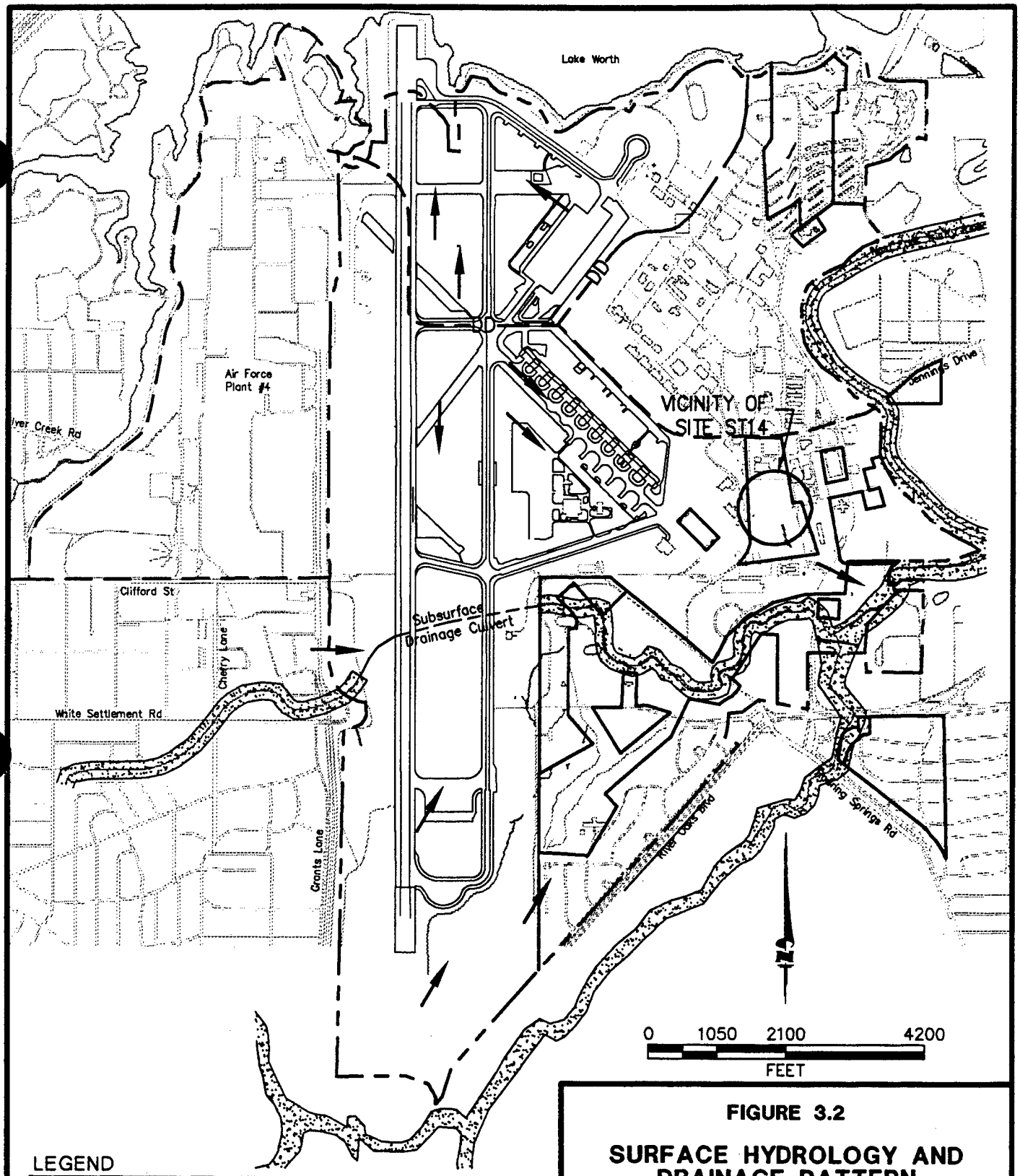
3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

3.2.1 Geology

The surficial geology in the Carswell AFB/NAS Fort Worth JRB vicinity is characterized by lower Cretaceous sedimentary formations underlain by undifferentiated Paleozoic rocks. In river floodplains, the Cretaceous rocks are overlain by younger alluvium and fluvial terrace deposits of the Quaternary age (Bureau of Economic Geology, 1988). These formations lie in more or less parallel bands of outcrops extending across Tarrant County in a north-northeasterly direction (US Department of Agriculture - Soil Conservation Service [USDA-SCS], 1981). Carswell AFB/NAS Fort Worth JRB is underlain by seven geologic formations, from youngest to oldest (and in order of increasing depth): Quaternary alluvium and fluvial terraces, 5 Lower Cretaceous formations (the Goodland Limestone, the Walnut Formation, Paluxy Formation, the Glen Rose Formation, and Twin Mountain Formation), and undifferentiated Paleozoic rocks (US Air Force, 1994).

The Quaternary alluvial deposits and fluvial terrace deposits generally are unconsolidated and consist of poorly to well-sorted clay, silt, sand, and gravel. The alluvium at Carswell AFB/NAS Fort Worth JRB was deposited by the Trinity River during flood stages over the past 3 million years (Baker *et al.*, 1990). The Goodland Limestone and the underlying Walnut Formation are part of the Fredricksburg Group. The Goodland Limestone consists of chalky, fossiliferous, nonresistant limestone. The Walnut Formation is characterized as fossiliferous limestone interbedded with brown sandy clay, thin-bedded fossiliferous clay, fissile shale, and iron-stained earthy limestone. The Fredricksburg Group has a maximum thickness of 250 feet (US Air Force, 1994). The Paluxy, Glen Rose, and Twin Mountains formations have a combined maximum thickness of approximately 2,500 feet. The Paleozoic sequence is 6,000 to 7,000 feet thick.

Soils in the vicinity of Carswell AFB/NAS Fort Worth JRB generally are either clayey soils on nearly level or gently sloping uplands, or are deep, loamy soils on level to sloping stream terraces. The soils are moderately susceptible to erosion by wind and



LEGEND

- 100 Year Floodplain
- Surface Drainage Direction
- —DD— Drainage Divide
- Creeks

Source: US Air Force, 1994

FIGURE 3.2

SURFACE HYDROLOGY AND DRAINAGE PATTERN

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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water (USDA-SCS, 1981). The soils on Base have been described by the USDA-SCS as "urban land." Urban land consists of areas that are 85 to 100 percent built-up with structures, such as office buildings, airfields, aviation support, multiple-unit dwellings, shopping centers, streets, sidewalks, and paved parking lots. The soils that make up urban land have been altered and obscured to the extent that they cannot be classified (USDA-SCS, 1981).

3.2.2 Hydrogeology

Five major hydrogeologic units underlie Carswell AFB/NAS Fort Worth JRB. From shallowest to deepest, the units are (1) an Upper Zone of perched water in alluvial terrace deposits; (2) an aquitard of predominantly dry limestone in the Goodland, Limestone, and Walnut formations; (3) an aquifer in the Paluxy Formation; (4) an aquitard of relatively impermeable limestone in the Glen Rose Formation; and (5) a major sandstone aquifer in the Twin Mountains Formation.

The Upper Zone groundwater occurs under mostly unconfined conditions at a depth of 6 to 16 feet bgs within the alluvial deposits at Carswell AFB/NAS Fort Worth JRB. The alluvium generally has a low permeability because of the large amounts of silt and clay. However, there are zones, such as in the East Area of the Base, with greater permeability in the sands and gravels of former channel deposits that underlie the Base. Groundwater from the alluvium close to the Trinity River is used for irrigation and residential use. It is not economical, however, to develop the alluvium groundwater, because the water's distribution is limited and the water is vulnerable to surface and storm water pollution (US Air Force, 1994).

The groundwater in the alluvium is separated from the aquifers below by the low-permeability limestones and shales of the Goodland, Limestone, and Walnut Formation. The aquitard consists of moist clay and shale layers interbedded with dry limestone beds. The Goodland/Walnut aquitard is estimated to be 30 to 40 feet thick beneath Carswell AFB/NAS Fort Worth JRB (US Air Force, 1994).

The deeper Paluxy aquifer, which is at least 70 feet bgs, is an important source of potable groundwater and has experienced extensive pumping in the Fort Worth area. Communities surrounding Carswell AFB/NAS Fort Worth JRB, especially White Settlement and Sansom Park, rely on the Paluxy aquifer as their primary water source. Of the 12 water wells in White Settlement used to meet water demands, 7 are drilled into the Paluxy aquifer and have a total capacity of 1.2 mgd. The 9 Sansom Park water wells drilled into the Paluxy aquifer have a total capacity of 1.5 mgd. There are no active or open wells on the Base that are used to meet potable water supplies. (US Air Force, 1994).

Recharge to the groundwater in the vicinity of Carswell AFB/NAS Fort Worth JRB is derived from precipitation that falls on the outcrop area of the water-bearing formations. In addition to recharge from precipitation, water enters the formations by seepage from lakes and streams that flow across the areas of outcrop. Groundwater withdrawals in excess of recharge in the Fort Worth area have resulted in a general decline of groundwater levels in the Paluxy aquifer. Adequate supplies of potable water from groundwater sources are not expected to be available to meet forecasted demands. However, the increasing use of surface water is offsetting use of

groundwater in the vicinity of Carswell AFB/NAS Fort Worth JRB (US Air Force, 1994).

3.3 SITE TOPOGRAPHY AND SURFACE WATER HYDROLOGY

The East Area of Carswell AFB/NAS Fort Worth JRB includes four discrete sites, including Sites ST14 and SD13, that may be potential sources of contamination. Site LF01 (landfill 1) and Site BSS (Base service station) are located on the north side of the East Area and are not considered to be contributors to the hydrocarbon contaminant plume originating at Site ST14. Figure 1.2 shows the location of the East Area with respect to the entire Carswell AFB/NAS Fort Worth JRB and the surrounding environs. The East Area has relatively flat topography that slopes gently eastward and southward. No abrupt elevation changes occur within the East Area except close to the Trinity River.

Site ST14 and the surrounding East Area of the Base is generally flat, with a surface elevation of about 580 feet above msl west of Site ST14 to 560 feet above msl on the floodplains of the Trinity River. Surface drainage is primarily toward Farmers Branch, with some drainage into the concrete-lined portion of the Flightline Drainage Ditch (Site SD10). The outfall from this stormwater ditch is located in Farmers Branch several hundred feet south of Site ST14, outside the main Base gate. Although this structure is not expected to significantly impact groundwater flow from Site ST14A, it passes through the middle of the POL Tank Farm (Site ST14B) and may have some effect upon groundwater flow at the site. Other surface features at the site include landscaped areas; concrete, asphalt, and crushed rock driveways and parking areas; three ASTs; and several warehouse structures.

The main surface water bodies located in the East Area are the West Fork of the Trinity River, Farmers Branch, the unnamed stream, and the Flightline Drainage Ditch (Figure 3.1). The West Fork of the Trinity River is located along the eastern boundary of the Base, and Farmers Branch (a tributary of the West Fork of the Trinity River) is located along the southern and southeastern Base boundaries. Farmers Branch discharges into the Trinity River near the southeastern Base boundary. Estimates of flow in Farmers Branch made in April 1990 averaged 6 cubic feet per second (cfs) (Radian, 1991). However, based on previous site data, the flow in Farmers Branch is highly variable and can range from less than 5 cfs to more than 100 cfs, usually after significant precipitation events.

A french underdrain system (SWMU 64) was installed near the now-abandoned gasoline station (Site SD13) to intercept free-phase fuel product leaking from the area and prevent it from advancing toward Farmers Branch and the Trinity River. Groundwater collected by the french underdrain system currently was routed to an underground oil/water separator located south of Building 1337 and immediately south of the fenced civil engineering storage yard. The perennial unnamed stream fed by effluent from this underground oil/water separator flowed into Farmers Branch at an average rate of 0.2 cfs. The primary source water for the perennial unnamed stream was apparently the french underdrain system (Radian, 1991). Additionally, comparison of water level measurements in groundwater monitoring wells near Farmers Branch and staff gauge measurement from Farmers Branch seem to suggest that this stream also is receiving groundwater inflow from adjacent alluvial terrace deposits (Radian, 1991).

The stream flow in the creeks and tributaries associated with surface water in Farmers Branch up- and downstream from the unnamed stream was measured as part of the risk-based field effort. Flow measurements were collected on August 31, 1994, and November 10, 1994. The approximate location of the stream flow measurements are shown on Figure 2.7. During the August 1994 survey, the flow in the creeks was generally very low, and was not measurable in some areas. Stream flow measurements were also taken in November 1994. The calculated flows are presented in Table 3.1.

An analysis of the stream flow data indicates that the flow during the August 1994 survey was considerably lower than during the November 1994 survey. This difference is probably a result of seasonal fluctuations in the rainfall in the area. The increase in flow between SW1 and SW4 may be caused by one or several mechanisms. There could be reaches along the stream where the stream bed is very permeable and the water table is located below the surface of the water in the stream. In addition to the discharge to the groundwater, there can also be a portion of the flow which flows beneath the bottom of the stream bed in areas where the stream bed is more permeable. This means that at least Farmers Branch is a losing stream during low-flow conditions (dry weather) and a gaining stream during high-flow conditions (wet weather).

Although the flow in the November 1994 survey increased significantly along the main creek, the flow from the oil/water separator (SW3) did not change as significantly. This indicates that the flow from the oil/water separator was primarily from groundwater collected by the french drain. Because the groundwater flow in the East Area does not respond as drastically to seasonal changes as surface water, the discharge from the oil/water separator would have remained somewhat constant year around. During periods of low stream flow, such as summer drought conditions, the flow from the oil/water separator would have constituted a significantly higher percentage of the flow into and within the creek than during periods of high flow fed by surface runoff. Therefore, if contamination in the effluent from the oil/water separator was significant, the relative contaminant concentrations contributed to Farmers Branch would have been higher during low-flow conditions.

3.4 SITE GEOLOGY AND HYDROGEOLOGY

The geology of the East Area consists of a thin veneer of alluvial material overlying the Goodland Limestone, Walnut, and Paluxy Formations. The alluvium, called the Upper Zone, consists of unconsolidated Quaternary and Recent alluvial deposits of sand, gravel, silt, and clay, that extend to a depth of approximately 20 feet bgs. Generally, the stratigraphy of the Upper Zone can be described as 5 to 15 feet of gray to black clay overlying 2 to 10 feet of fine-grained sand and up to 5 feet of gravel. The underlying Goodland and Walnut Formations contain fresh and weathered limestone and shale. The Goodland Formation, the shallowest bedrock unit, is usually encountered from 7 to 20 feet bgs in the East Area. In general, the depth to the Goodland Formation increases eastward toward the Trinity River. These geologic units form a basal confining unit of the Upper Zone, the shallowest water-bearing geologic unit. No soil boreholes completed in the East Area as part of previous investigations or during the risk-based remediation investigation penetrate the Goodland/Walnut Formations to the underlying Paluxy Formation.

TABLE 3.1
STREAM FLOW SURVEY DATA
SITES ST14 AND SD13
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

August 1994 Survey		
Measurement Location	Location Description	Flow rate (cubic feet per second)
SW2	In unnamed stream just before it feeds into Farmers Branch	0.17
SW3	Oil/water separator outflow	0.029
SW4	150 feet downstream from confluence of Farmers Branch and unnamed stream	0.09

November 1994 Survey		
Measurement Location	Location Description	Flow rate (cubic feet per second
SW1	Upstream from unnamed stream confluence with Farmers Branch near on-Base golf course	2.30
SW2	In unnamed stream just before it feeds into Farmers Branch	1.65
SW3	Oil/water separator outflow	0.046
SW4	150 downstream from Farmers Branch and unnamed stream confluence	5.03

Figure 3.3 depicts the locations of hydrogeologic cross sections prepared to characterize the stratigraphy of Sites ST14 and SD13. Figures 3.4 and 3.5 show the north-south and east-west hydrogeologic cross sections for Site ST14. Figure 3.6 shows the cross section from the upgradient well, ST14-MW25, to wells located near the former oil/water separator downgradient from Site SD13. At Site ST14, the upper 8 to 20 feet of unconsolidated alluvial deposits consist of highly plastic, olive-gray to black, sandy clay soil with some interbedded gravel and silt, underlain by 3 to 11 feet of sand and gravel. Gravel content of these alluvial materials generally increases with depth. Gravel ranges from pea size to pebbles over 1 inch in diameter.

The shallowest water-bearing zone underlying the East Area sites is known as the Upper Zone aquifer, generally thought to contain groundwater under unconfined conditions. Groundwater in the Upper Zone aquifer at Site ST14 is encountered at depths ranging from approximately 6 to 16 feet bgs, corresponding to a groundwater surface elevation ranging from approximately 560 to 572 feet above msl. Groundwater beneath the site occurs predominantly in the deeper sand and gravel units. In some boreholes, groundwater was first encountered in deeper sands, but the static water level gradually rose to a higher level within the clay, possibly indicating a semi-confined groundwater system.

Figure 3.7 is a map of the approximate groundwater surface at Sites ST14 and SD13 in 1994. Groundwater flow is generally southeastward toward Farmers Branch. Vertical migration of groundwater contamination is prevented by the underlying basal confining unit of the Goodland Formation (estimated at 7 to 20 feet bgs). Horizontal groundwater flow is governed by the variable topography of the Goodland Formation and by intermittent, overlying layers of silty and clayey sands that cause semi-confined flow conditions (Figures 3.4 to 3.6). The physical influence of bedrock topography and semi-confined flow conditions is illustrated in Figure 3.8, which shows the approximate saturated thicknesses at Sites ST14 and SD13. Saturated thickness ranges from approximately 14 feet immediately northwest of the fueling pad at Site ST14 (west of Building 1213) and decreasing to approximately 3 feet toward Site SD13. Bedrock highs to the north and south of Sites ST14 and SD13 create a groundwater channel (approximately 7 feet in thickness) that stretches from Site ST14 to Site SD13. Dissolved contaminants are suspected to preferentially flow along this channel from Site ST14 to Site SD13. Figure 3.8 suggests that groundwater experiences a localized, southerly flow direction near Building 1213, then turns southeastward by the formation channeling toward Site SD13. This flow trend is apparent in the observed migration pathways of total BTEX and benzene from Site ST14 to be discussed in Section 4.

Groundwater level measurements recorded during and after the french underdrain system abandonment suggest that the hydraulic gradient has corrected to the natural southeast direction, and that the localized groundwater table depression observed to the northeast and east of the former french underdrain system is no longer present (Figure 3.9). These measurements, presented in Appendix B, indicate localized changes to the groundwater surface and saturated thickness at Site SD13 as a result of abandonment activities. This increase in groundwater elevation suggests that the removal of the french underdrain system has effectively minimized localized dewatering of the subsurface. The groundwater flow system apparently is no longer

affected by remaining subsurface features. Figure 3.9 presents the approximate groundwater surface at Site SD13 before and after removal actions undertaken in 1996.

The average hydraulic gradient for Site ST14 has been calculated to be about 0.007 foot per foot (ft/ft) (Radian, 1991). Based on recent data obtained from wells installed since the 1990 investigation, the average hydraulic gradient between the POL tanks and the southeastern corner of Site SD13 is approximately 0.011 ft/ft. Before the 1996 removal action completed at Site SD13, the gradient increases an order of magnitude to approximately 0.12 ft/ft, beyond the fenceline at the southeastern corner of the site, near the unnamed stream (Figure 3.7). This correlates with both the surface and bedrock topography.

Six slug tests using groundwater monitoring wells LF01-1D, LF01-1F, ST14-MW17J, ST14-MW17K, ST14-MW17L, and ST14-MW17M were performed in the East Area as part of the 1990 RI to investigate the hydrogeologic characteristics of the Upper Zone Aquifer. The test data yielded estimated hydraulic conductivities ranging from 2×10^{-5} to 2.4×10^{-2} feet per minute (ft/min), which are typical of alluvial deposits containing silt-sand-gravel mixtures (Radian, 1991). In April 1994, Law (1994) performed slug tests on monitoring wells SD13-MW05, SD13-MW06, and SD13-MW07. A hydraulic conductivity of 1.98×10^{-3} ft/min was measured in SD13-MW05, which is screened across the sand and gravel alluvium. Hydraulic conductivities of 1.72×10^{-5} and 5.61×10^{-3} ft/min were observed at monitoring wells SD13-MW06 and SD13-MW07, respectively. These wells are both screened predominantly within the weathered shaley limestone, indicating that the conductivity of the weathered bedrock is highly variable (Law, 1994).

Because of the variability of the reported hydraulic conductivity values for the site, additional slug tests were performed in the Upper Zone aquifer as part of the risk-based field investigation. Rising head slug tests were performed in 1994 on monitoring wells SD13-MW02, ST14-MW05, ST14-MW14, ST14-MW15, ST14-MW20, and ST14-MW23. A falling head slug test was also performed at ST14-MW14. The slug test data were analyzed using the AQTESOLV® software package. The rising head slug tests yielded hydraulic conductivities ranging from 5.25×10^{-4} to 7.73×10^{-3} ft/min, and the falling head test resulted in a conductivity of 4.37×10^{-2} ft/min. All wells tested were screened across saturated alluvial deposits, composed predominately of silty and fine sands. The conductivity observed in 1994 by Law (1994) at well SD13-MW05, which also is screened in saturated alluvial deposits, falls within the range obtained as part of this additional effort.

Assuming an estimated effective porosity of 30 percent, and based on the hydraulic gradient of 0.011 ft/ft and the range of calculated hydraulic conductivities from the most recent rising head tests, the range of calculated groundwater flow velocities is 0.028 to 0.408 foot per day (ft/day). Near the unnamed stream, the gradient increases an order of magnitude to 0.12 and therefore the groundwater flow velocities also would be expected to increase to between 0.3 and 4.41 ft/day.

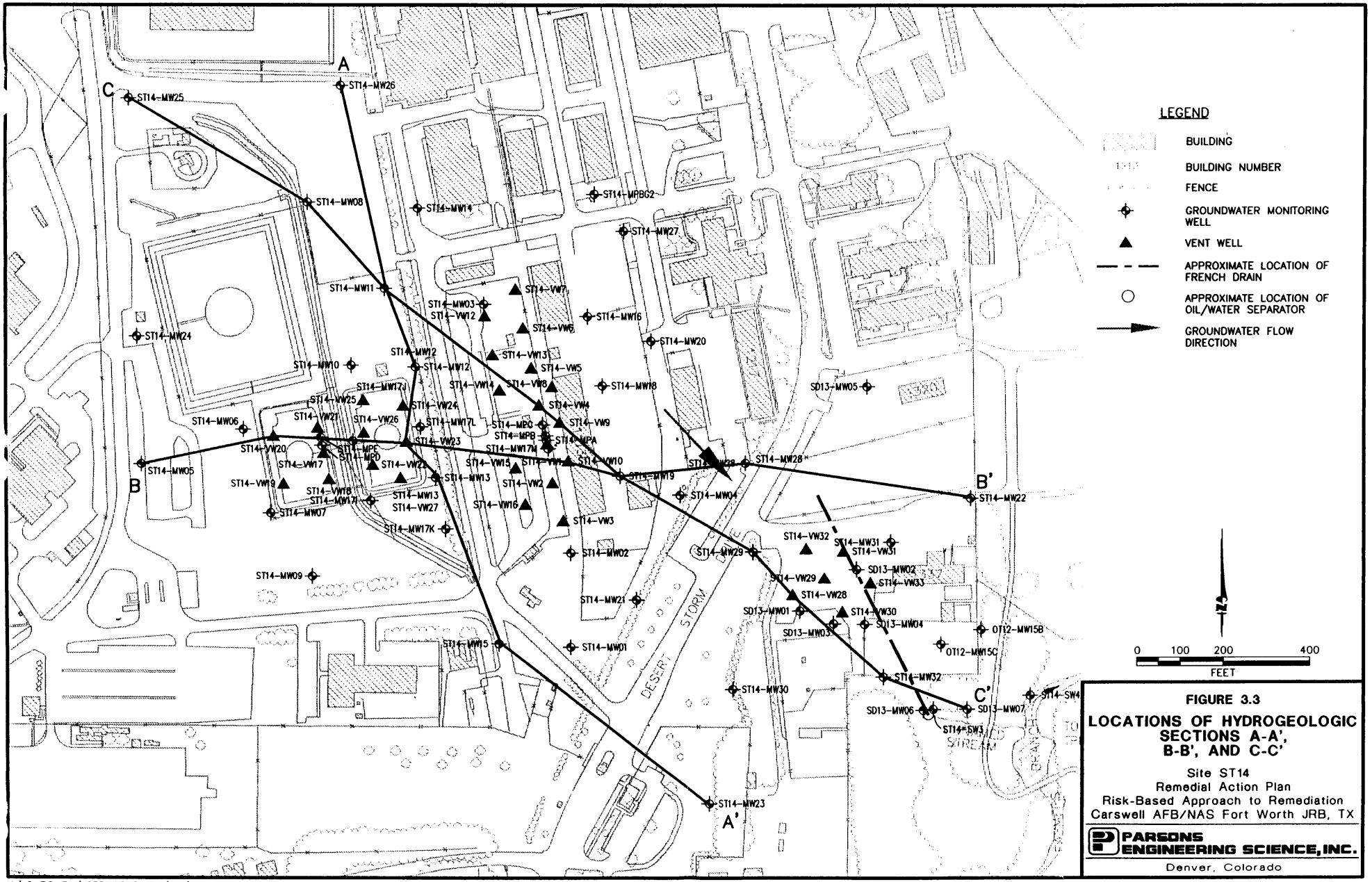


FIGURE 3.3

LOCATIONS OF HYDROGEOLOGIC SECTIONS A-A', B-B', AND C-C'

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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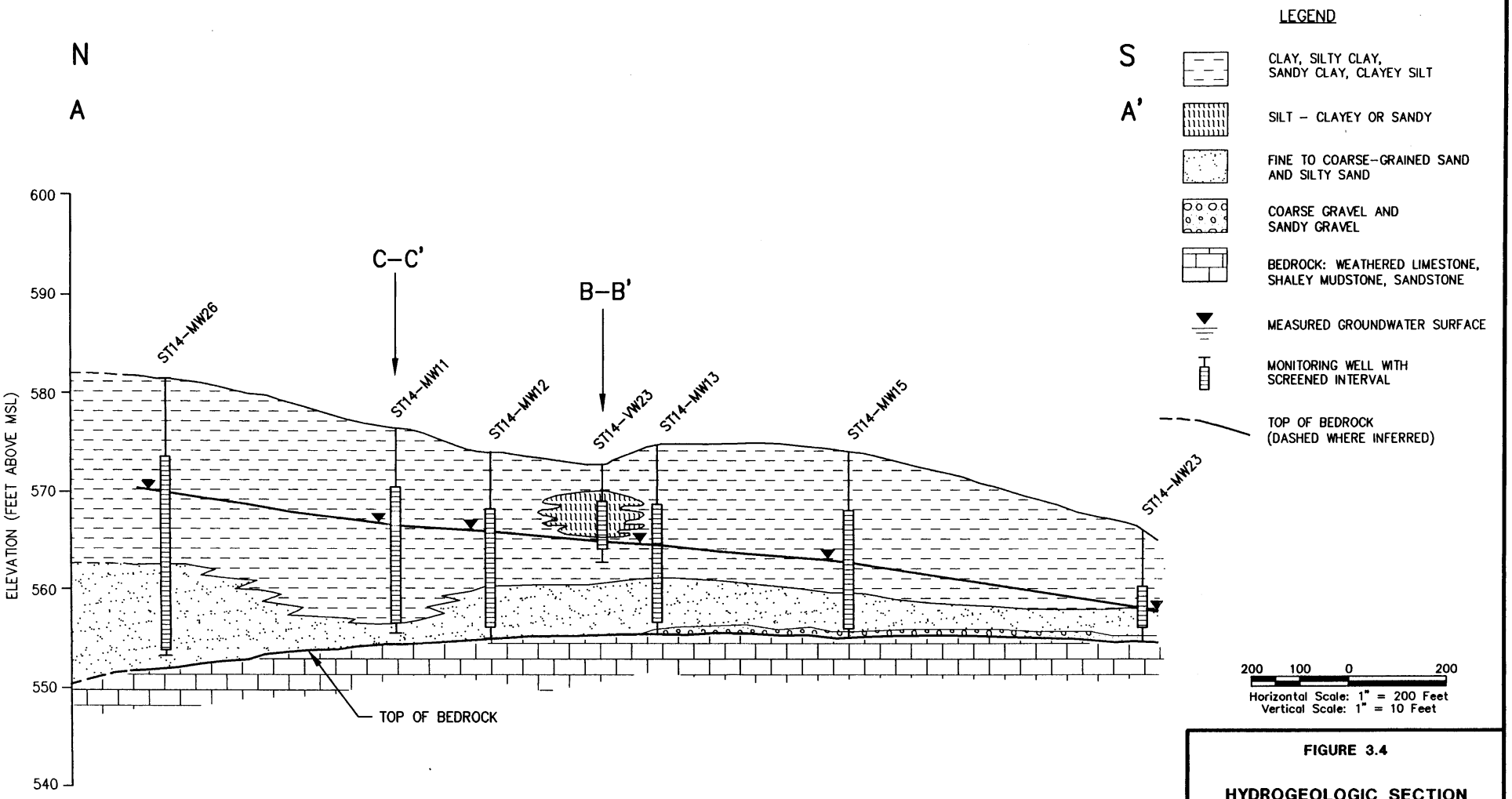


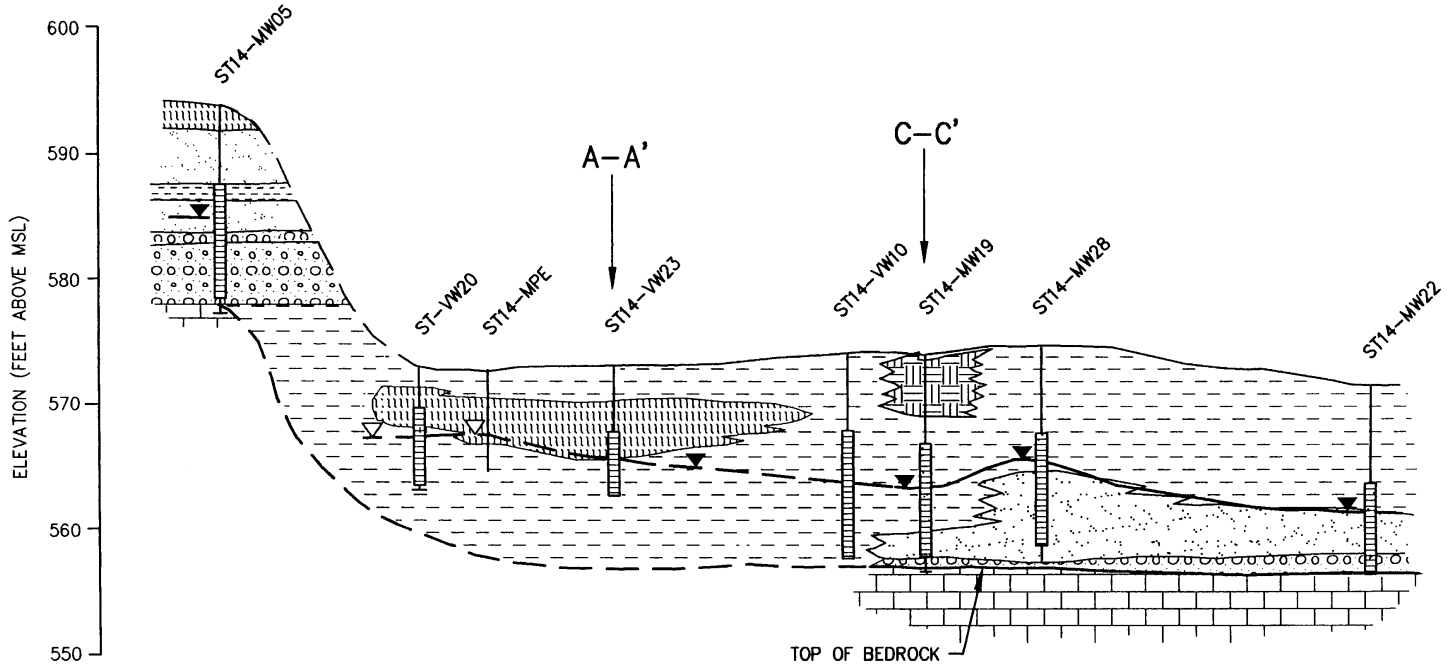
FIGURE 3.4

HYDROGEOLOGIC SECTION A - A'

Sites ST14 and SD13
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell NASJRB, Texas

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LEGEND

- FILL – GRAVEL AND ROCK
- CLAY, SILTY CLAY, SANDY CLAY, CLAYEY SILT
- SILT – CLAYEY OR SANDY
- FINE TO COARSE-GRAINED SAND AND SILTY SAND
- COARSE GRAVEL AND SANDY GRAVEL
- BEDROCK: WEATHERED LIMESTONE, SHALEY MUDSTONE, SANDSTONE
- MEASURED GROUNDWATER SURFACE
- OBSERVED GROUNDWATER SURFACE DURING DRILLING
- MONITORING WELL WITH SCREENED INTERVAL
- TOP OF BEDROCK SURFACE (DASHED WHERE APPROXIMATE)

200 100 0 200

Horizontal Scale: 1" = 200 Feet
Vertical Scale: 1" = 10 Feet

FIGURE 3.5

HYDROGEOLOGIC SECTION B - B'

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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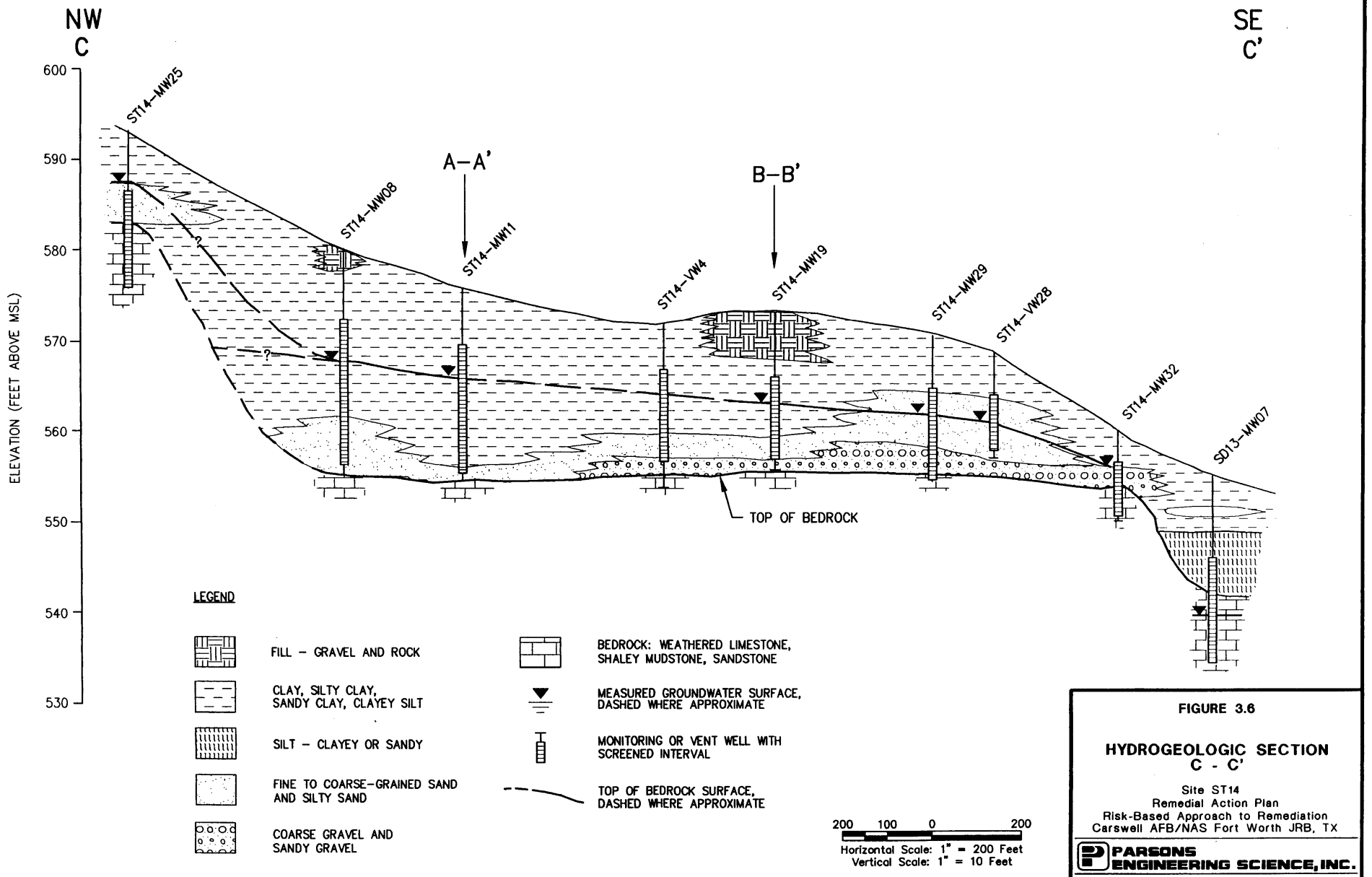


FIGURE 3.6

HYDROGEOLOGIC SECTION C - C'

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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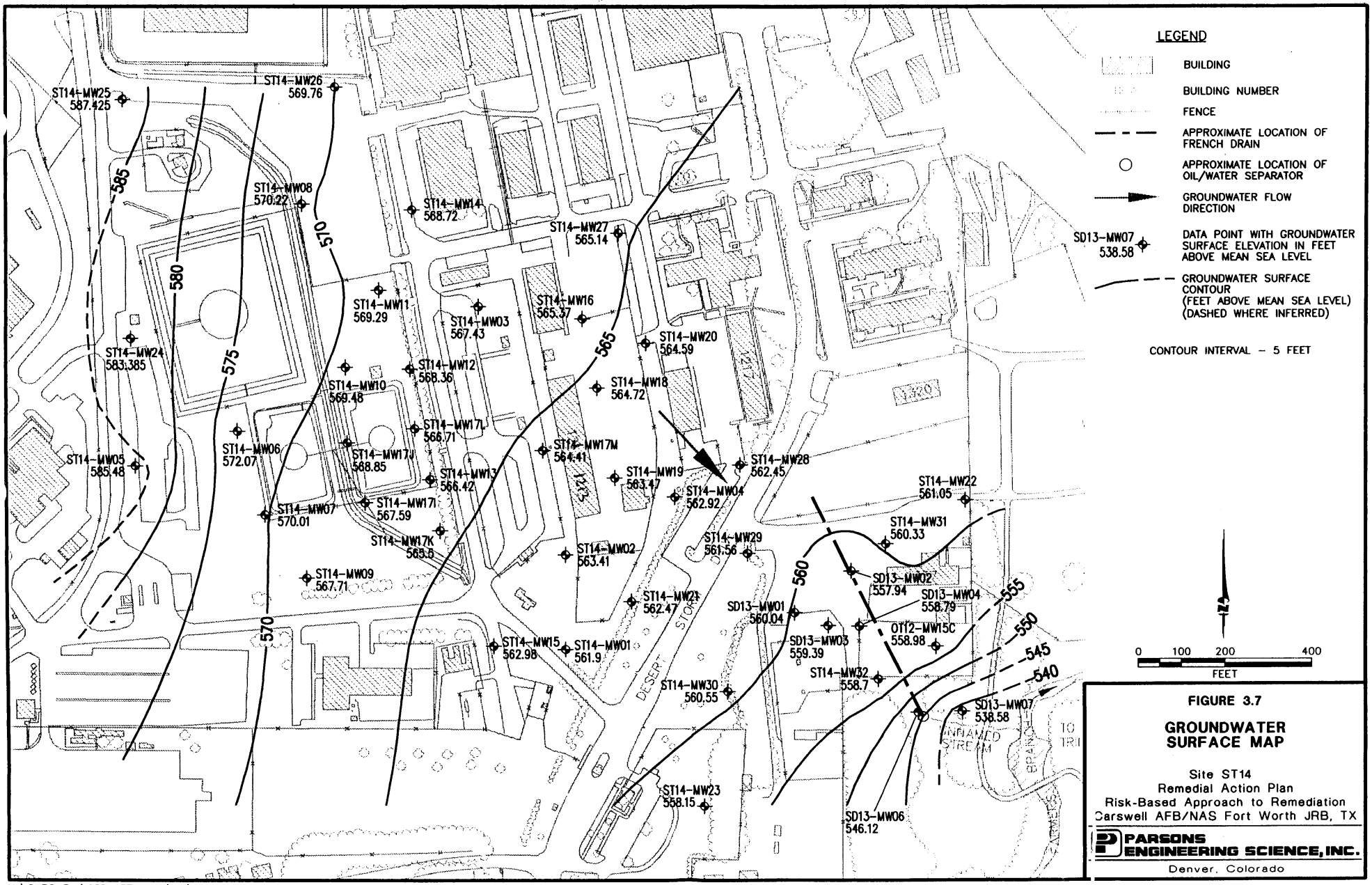


FIGURE 3.7

GROUNDWATER SURFACE MAP

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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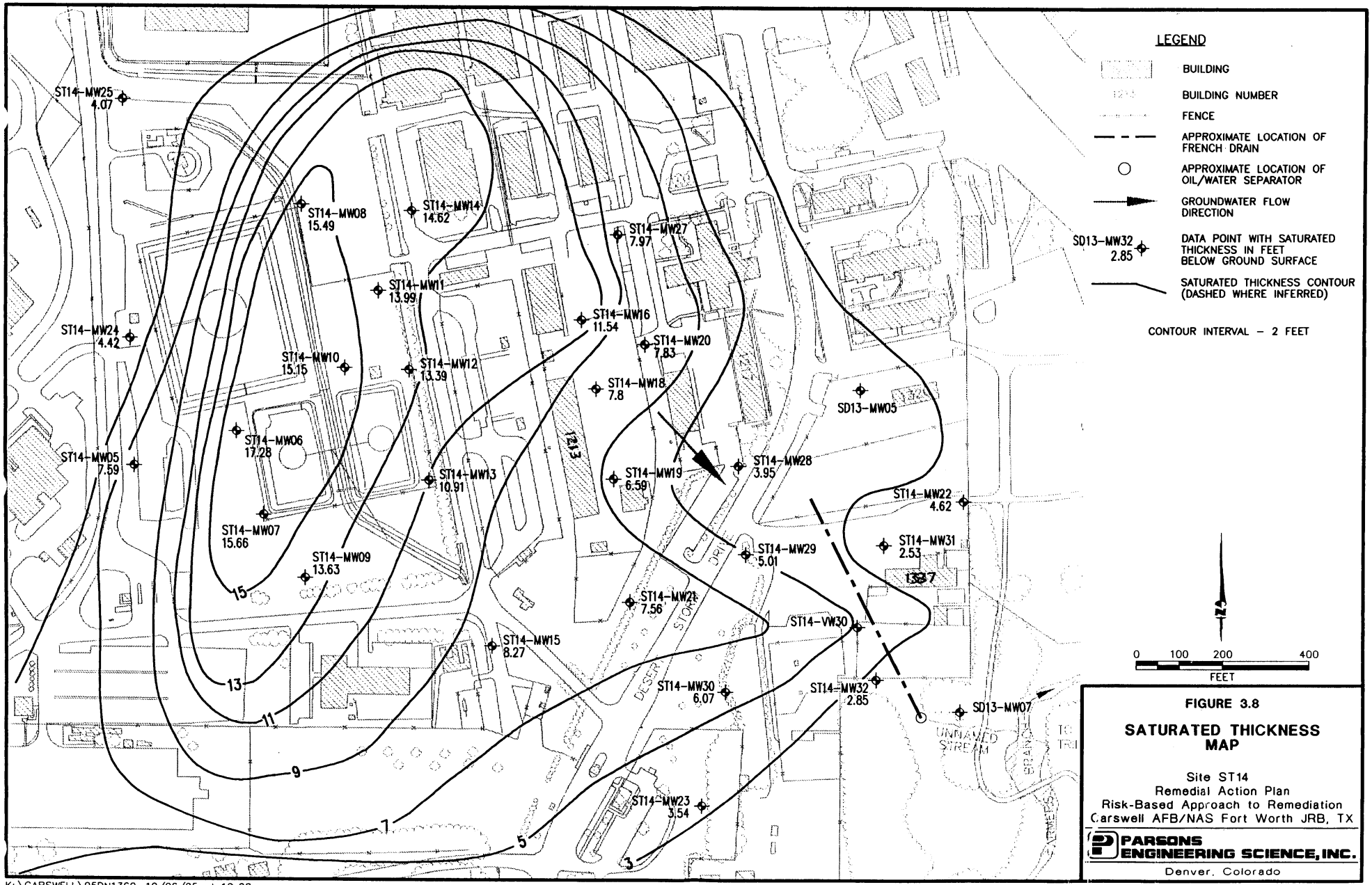


FIGURE 3.8

SATURATED THICKNESS MAP

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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3.5 SUBSURFACE FEATURES

3.5.1 Underdrain System at Site SD13

As discussed previously, a subsurface french underdrain system was installed in the area of Site SD13. Because the construction of the french underdrain system was not documented, the area where groundwater is intercepted by the system ~~ass~~ uncertain. Visible surface evidence of the french underdrain system (a protruding pipe on the north end and the oil/water separator on the south end) have led to the placement of this subsurface feature on figures in this and previous reports. However, it is uncertain if the components identified are the ends of the underdrain system itself or represent a pipe designed to carry the captured water to the former oil/water separator.

Two conservative tracer tests were conducted in 1995 in the presumed vicinity of the french underdrain system as part of the risk-based investigation to assess the impact of the subsurface structure on groundwater flow. These data also may be used to confirm groundwater flow velocity and direction near the slugged wells. A conservative tracer, NaBr, was selected to be used for the tracer tests. Probes to measure conductivity were placed in wells to monitor fluctuations in conductivity resulting from the NaBr slug. The results of tracer tests were inconclusive and could not be used to pinpoint the location of the french underdrain.

Irregular changes in conductivity not attributable to the slug of NaBr were observed in wells SD13-MW01, SD13-MW03, and OT12-MW15C (Figure 3.10). Precipitation data for Carswell AFB/NAS Fort Worth JRB were compared to conductivity data to assess any relationship between groundwater chemistry and rainfall events. The rapid infiltration of precipitation is shown by the timing of the conductivity peaks in relation to rainfall events. The conductivity rises immediately following rainfall events and then rapidly drops back to baseline conditions. These data imply that rainfall is able to infiltrate into the ground through areas of permeable surface materials or cracks in paved surfaces, and to rapidly percolate into the groundwater. The infiltrating water appears to be an effective release and transport mechanism for mineral salts in vadose soils. The release of these constituents causes a rise in the conductivity of the groundwater. These data are significant in that they demonstrate that groundwater quality in the East Area may be significantly impacted by precipitation events, and that constituents in vadose zone soils may be effectively released into the groundwater by infiltrating water. Therefore, contaminant migration from the vadose zone to the groundwater through leaching may be a significant transport mechanism at this site.

In 1996, portions of the french underdrain and all of the north oil/water separator were removed. Approximately 58 feet of the underdrain was removed at three locations along the length of the underdrain. The permeable bedding material surrounding the underdrain was also removed from the excavated locations. The removed material was replaced with low permeability material effectively removing the french underdrain system as a pathway for preferrential movement of groundwater to the oil/water separator and therefore to the unnamed stream. The north oil/water separator was removed in its entirety and the excavation backfilled with low permeability material.

3.5.2 Other Features at Site SD13

Additionally, the 1994 RFI included a geophysical survey of Site SD13 to locate potential buried utilities, and to confirm that no previously unidentified USTs remained at the site. Geophysical anomalies indicative of buried piping, reinforced concrete, and other buried metal were identified. Due to the presence of cultural interferences within the site, including a steel reinforced concrete pad, a chainlink fence, a transformer, and power lines, the survey was not able to conclusively verify the absence of additional, previously unidentified USTs. Cultural interferences are identified metal objects which would create readings on the survey equipment, making it difficult to interpret survey data in the vicinity of the interference. The Air Force has no information to indicate that there are additional USTs at Site SD13.

3.6 CLIMATOLOGICAL CHARACTERISTICS

The climate at Carswell AFB/NAS Fort Worth JRB is subtropical with humid, hot summers. The climate is characterized by a wide range in annual temperature extremes. Winters are generally mild, but occasional cold fronts that result in sudden drops in temperature can occur. Periods of extreme cold temperatures are short-lived such that mild weather typically dominates during the winter months. In an average year, temperatures of 20 degrees Fahrenheit (°F) or below occur on only 6 days. In the winter, the average daily minimum temperature is 37°F. The average daily high temperature in the summer is 94°F. The total annual precipitation is 32.1 inches. The highest monthly precipitation typically occurs in April (3.97 inches) and May (4.57 inches), and the lowest monthly precipitation occurs from December through February (less than 6 inches total for 3 months) (USDA-SCS, 1979). Prevailing winds are primarily southerly from March through November, and northerly from December through February. During the summer and fall months, wind speeds remain fairly constant, averaging 8 knots. During winter and spring months, average wind speeds increase to 9 to 11 knots.

3.7 BIOLOGICAL RESOURCES

Carswell AFB/NAS Fort Worth JRB is located in a transition zone between the Cross Timbers and Prairie vegetational areas of north-central Texas. The vegetation at the Base is predominantly disturbed (mowed) grassland, although there are developed areas, landscaped areas, stands of trees (designated as forested), open water, and areas with hydrophytic vegetation (designated as swamp/marsh) located at the Base. Most of the native species on the Base have been replaced by introduced grasses, forbs, and ornamental trees (US Air Force, 1994).

Human activities in the immediate vicinity of Carswell AFB/NAS Fort Worth JRB have altered the natural environment primarily through urbanization. Carswell AFB/NAS Fort Worth JRB is surrounded by developed land on the east, south, and west sides. Lake Worth borders the northern Base boundary, and the West Fork of the Trinity River separates the eastern boundary of the Base from the developed off-Base land. Approximately 1,100 acres (43 percent) of Carswell AFB/NAS Fort Worth JRB are covered by planted grassland, 750 acres (29 percent) are landscaped, and 680 acres (27 percent) are developed. Landscaped areas of Carswell AFB/NAS Fort Worth JRB consist of lawns, landscape plantings, athletic facilities, cemeteries, and the golf

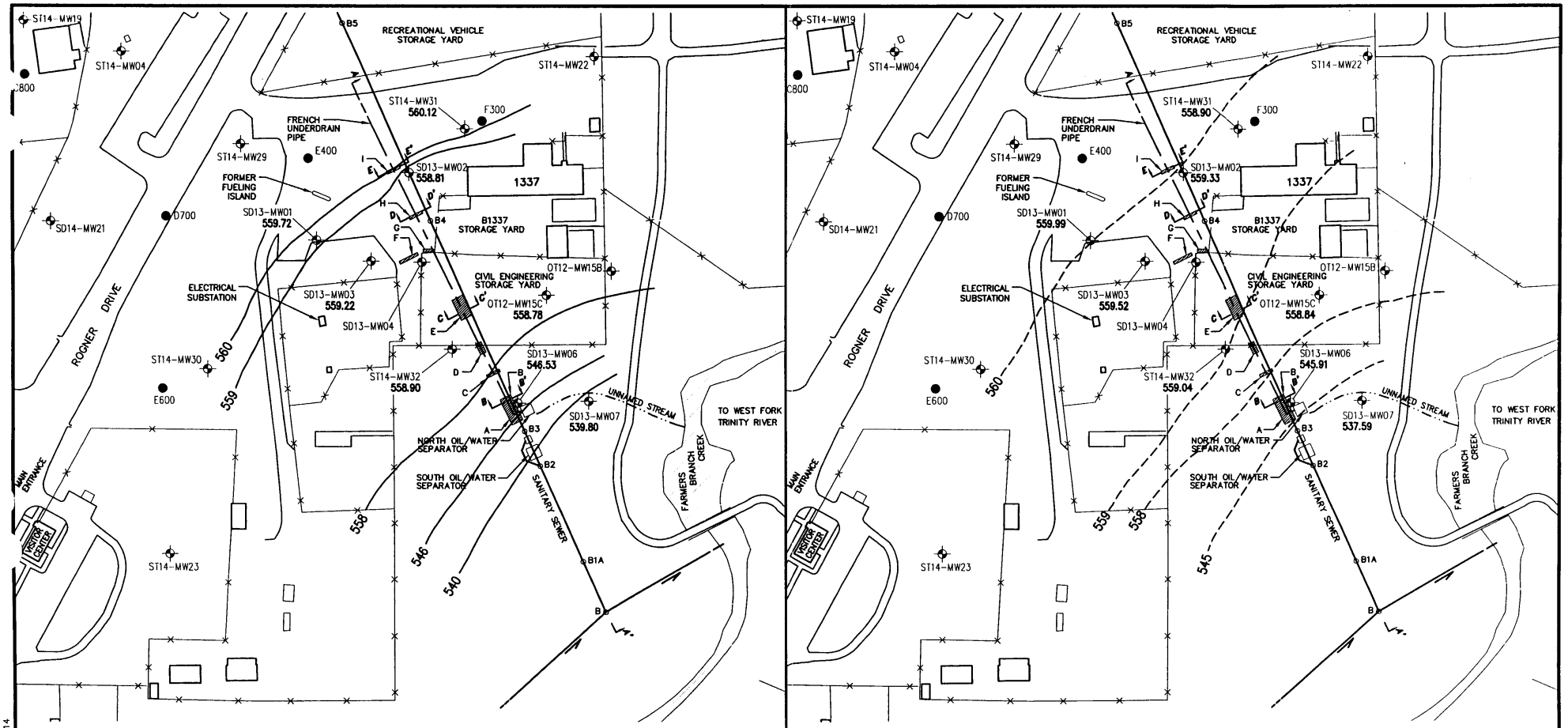


FIGURE 3.9

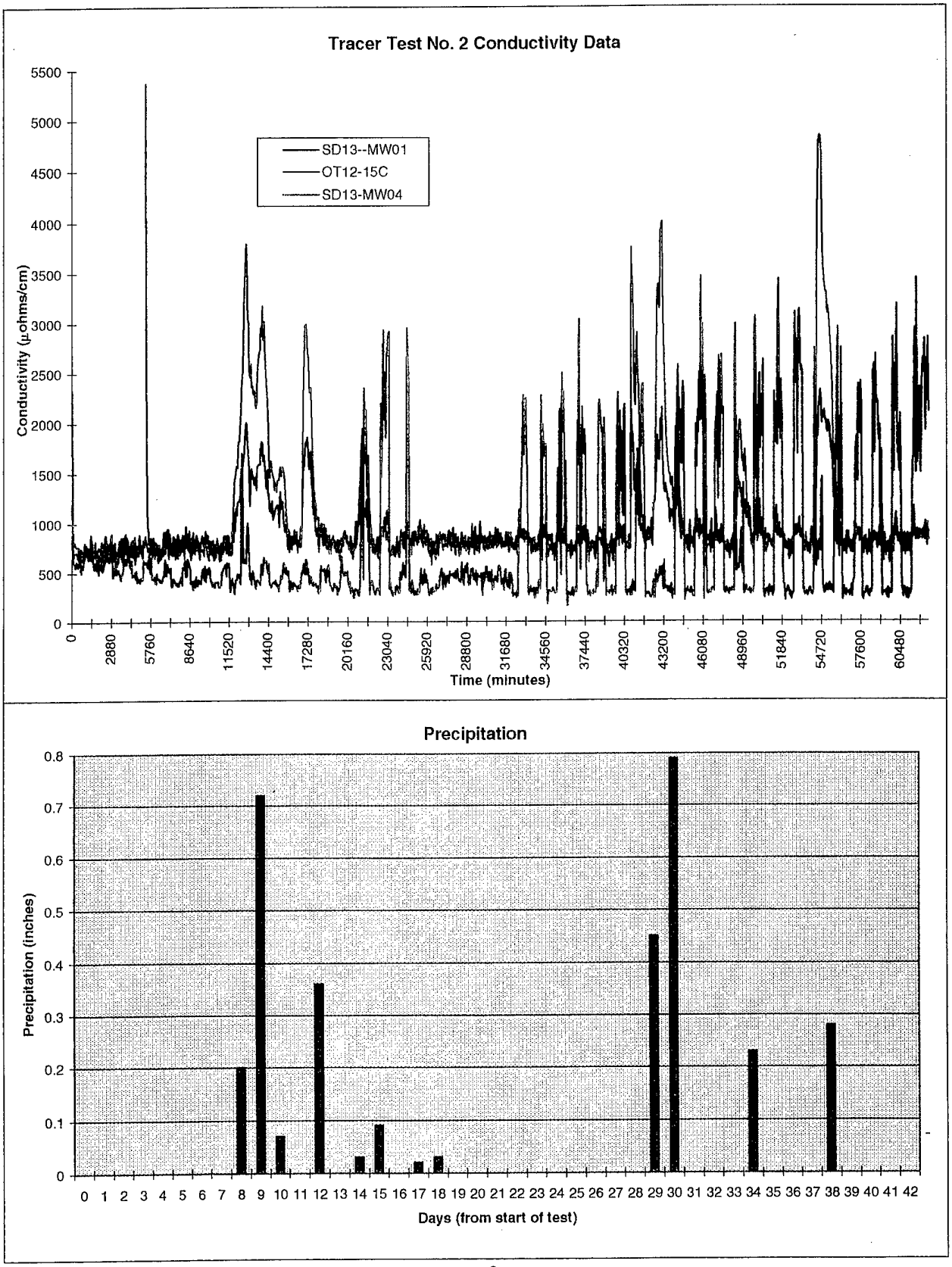
IMPACT OF ABONDONMENT ACTIVITIES ON POTENTIOMETRIC SURFACE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.

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FIGURE 3.10
TEMPORAL CHANGES IN GROUNDWATER CONDUCTIVITY
COMPARED TO PRECIPITATION EVENTS
SITES ST14 AND SD13
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL NASJRB, TEXAS



course. Much of the grassland vegetation is periodically mowed so that only the small fraction near lakes and streams is left undisturbed. Open water in the form of golf course ponds and streams is also found on Carswell AFB/NAS Fort Worth JRB, with both Lake Worth and the West Fork of the Trinity River providing hydrological influences to the Base due to their close proximity. A 0.5-acre swamp/marsh (wetland) area with cattails, rushes, and willows is located on the west side of the Base (US Air Force, 1994).

Wildlife in the vicinity of Carswell AFB/NAS Fort Worth JRB includes numerous birds, reptiles, and small mammals. The wooded lowlands (e.g., Site SD13) are occupied by cottontail rabbit, fox squirrel, and opossum. Other mammals common to the area include raccoon, striped skunk, armadillo, and fox. Hunting and trapping are not permitted on or near Carswell AFB/NAS Fort Worth JRB. The Allen Wildlife Sanctuary, Fort Worth Nature Center, and an abandoned fish hatchery are important nearby wildlife areas.

Nearby bodies of water include Lake Worth and the Trinity River off the Base, and Farmers Branch and three man-made ponds on the Base. Two of the ponds are located between Farmers Branch and the Hush House, and the other is eastern portion of the golf course. The streams and ponds support carp and minnows populations. A soft-shell turtle was identified in the pond northwest of the golf course (US Air Force, 1994).

Compared to the surrounding mowed landscape, the streams on the Base are densely vegetated and provide suitable habitat for native species. The streams have, however, been subject to environmental stress over the years. A fish kill, thought to be caused by an off-Base source, occurred in 1992. Other spills may have occurred in the past due to sanitary wastewater overflows from a sewer line owned by the City of Fort Worth. Fish kills associated with wastewater overflow events have been attributed to the high oxygen demand of the wastewater. This is inferred from the reported rapid recovery of fish populations in Farmers Branch following these episodes (US Air Force, 1994).

The Air Force has conducted informal consultations with the US Fish and Wildlife Service (USFWS) and the Texas Department of Parks and Wildlife (TDPW) concerning threatened and endangered species potentially occurring in the vicinity of Carswell AFB/NAS Fort Worth JRB. These two agencies identified 12 bird, 2 reptile, and 1 plant special-concern species potentially occurring in Tarrant County, although no state or federally listed threatened or endangered species is known to reside permanently on Carswell AFB/NAS Fort Worth JRB. Further details on these consultations are provided in the recent environmental impact statement (US Air Force, 1994).

Sensitive habitats include those areas that can potentially restrict the reuse of the land, such as wetlands under the requirements of Section 404 of the Clean Water Act (CWA), plant communities that are designated as unusual or of limited distribution, and important seasonal use areas for wildlife (e.g., migration routes, breeding areas, or crucial summer/winter habitat that are of agency concern). Wetlands are defined as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a

prevalence of vegetation typically adapted for life in saturated soil conditions" (US Army Corps of Engineers [USACE], 1987). Areas that are periodically wet, but do not meet all three criteria (hydrophytic vegetation, hydric soils, and wetland hydrology), may still be jurisdictional wetlands subject to Section 404 of the federal CWA if they qualify as problem wetlands. Drainage ditches are not considered as "waters of the United States" and are not classified as "jurisdictional" for protection under Section 404 of the CWA by the Fort Worth USACE.

Although water flows through Farmers Branch and is found in various small ponds on the golf course, very little wetland vegetation is associated with these areas. Likewise, wetland vegetation along Lake Worth is infrequent and usually emergent when present. These areas have not been classified as jurisdictional wetlands.

3.8 LAND USE

3.8.1 Site Access

The East Area sites are located near the main entrance to Carswell AFB/NAS Fort Worth JRB at the southeastern portion of the Base. The entire extent of Sites ST14A, ST14B, and SD13 are within the boundaries of the Base, which is surrounded by a chainlink fence. The guard station at the main gate is manned 24 hours per day, 7 days per week. The east gate, located north of the East Area sites, is manned and open only during daylight working hours. There are additional surface restrictions around most of the key site features. Chainlink fences with barbed wire climb barriers surround the POL tank farm (Site ST14B) and the fuel loading area (Site ST14A). Additional fencing located southeast of Site SD13 limits access to the site of the former oil/water separator area. Access to each of these areas is through locked gates. Keys to the locked gates can only be obtained through area supervisors for each of these sites. These restrictions serve to minimize unauthorized on-Base access to the site and to eliminate trespassing.

3.8.2 Current Land Use

Site ST14 (fuel loading area and POL tank farm) has been maintained as an active fuel servicing and storage facility for flight operations at Carswell field. The POL tank farm (Site ST14B) consists of three fuel ASTs. These tanks are connected via underground fuel transfer lines to the fuel loading area located along the eastern side of Desert Storm Drive. The fuel loading area (Site ST14A) services fuel trucks, which receive fuel for transfer to jets on the flightline. Both of these areas are surrounded by chainlink fencing with access through locking gates. Neither of the sites are permanently manned. Fuel personnel work in the POL tank farm only when receiving fuel from an off-site pipeline. These workers are present in the fuel loading area only during tanker truck refueling activities. These activities occur sporadically at the Base.

Site SD13 is an abandoned gasoline station. The abandoned gasoline station is currently a paved lot. All fuel tanks are thought to have been removed and a concrete island for the pumps is the only visible structure of the former gasoline station. Shrubbery, grass, and aircraft on display near the main gates are also located in the vicinity of the former gasoline station. The unnamed stream is a small tributary of Farmers Branch that emerged from the former oil/water separator southeast of Site

SD13. The oil/water separator received groundwater directly from the french underdrain system, which was reportedly constructed to intercept fuel-hydrocarbon-contaminated groundwater. The french underdrain system was partially removed in June/July of 1996, and the portions left in place were filled with a mixture of bentonite and soil to prevent movement of liquids through the drain or along the exterior of the drain. With the removal of the french underdrain system and the oil/water separator, no water is being artificially routed to the unnamed stream, which means that water flow into and through the stream has been effectively minimized/halted. Prior to removal, the oil/water separator was located south of Building 1335 (Whitehouse Communications) and the fenced civil engineering storage yard. Vehicle access to the unnamed stream can be achieved through one of three locking gates, which are controlled by Grounds Maintenance and Civil Engineering units at the Base, or by foot through Farmers Branch. There are no activities associated with the area in the vicinity of the unnamed stream other than routine grounds keeping. Farmers Branch enters the West Fork of the Trinity River approximately 2,000 feet downstream from the unnamed stream confluence. The majority of the stream flow downstream of the confluence is outside the Base boundaries, but access is limited by geographical barriers and dense vegetation.

Most of the area surrounding Carswell AFB/NAS Fort Worth JRB is suburban (residential/ commercial). Various residential areas exist southeast of the Base between the perimeter fence and Interstate 30 (Figure 1.2). Predominant development south of the Base is a commercial area, including a retail center, shopping mall, and convenience center. The on-Base land use maintained at Site ST14 and Site SD13 is industrial (US Air Force, 1994).

3.8.3 Proposed Land Use

Carswell AFB was placed on the 1991 Defense Base Closure and Realignment Commission's list for closure. The Base was officially closed on September 30, 1993. However, in 1993, the Commission recommended realignment of several military reserve and guard units to Carswell, such that portions of Carswell are retained by the DOD, as required to support long-term operations associated with the realigning military units. As part of the proposed land reuse plan, several DOD organizations (Navy Reserve, Marine Reserve, Army Reserve/Guard, and Air National Guard units) are being realigned from NAS Dallas, NAS Memphis, and NAS Glenview to Carswell. The Air Force is required to make a series of interrelated decisions concerning the disposition of Base property determined to be in excess of the needs of the DOD. The US Navy, the US Department of Justice, and the Federal Bureau of Prisons (FBOP) are assisting the Air Force in making decisions regarding Carswell property. The US Navy has assumed command of the Base, and FBOP operates a minimum-security prison in the former Base hospital (renovated for use as a detention facility).

An EIS was prepared by the US Air Force (1994) to provide information on the potential environmental impacts resulting from proposed reuse of Base property in response to realignment actions. The proposed land use plan calls for 1,884 acres of the Base and leased land to be used for military activities related to the realignment, and the remaining 735 acres on Base to be rezoned for residential, commercial, industrial, institutional, and public facilities/recreation uses. Site ST14 (SWMU68) is to be retained for use by DOD, and Site SD13 (including SWMUs 64 and 67 and AOC

7) will be released for public facilities/recreational use. The proposed future military reuse activities have been incorporated as part of the proposed reuse plan for the Base. Realignment and construction activities at Carswell are scheduled to be complete, and the Base fully operational, by 1998.

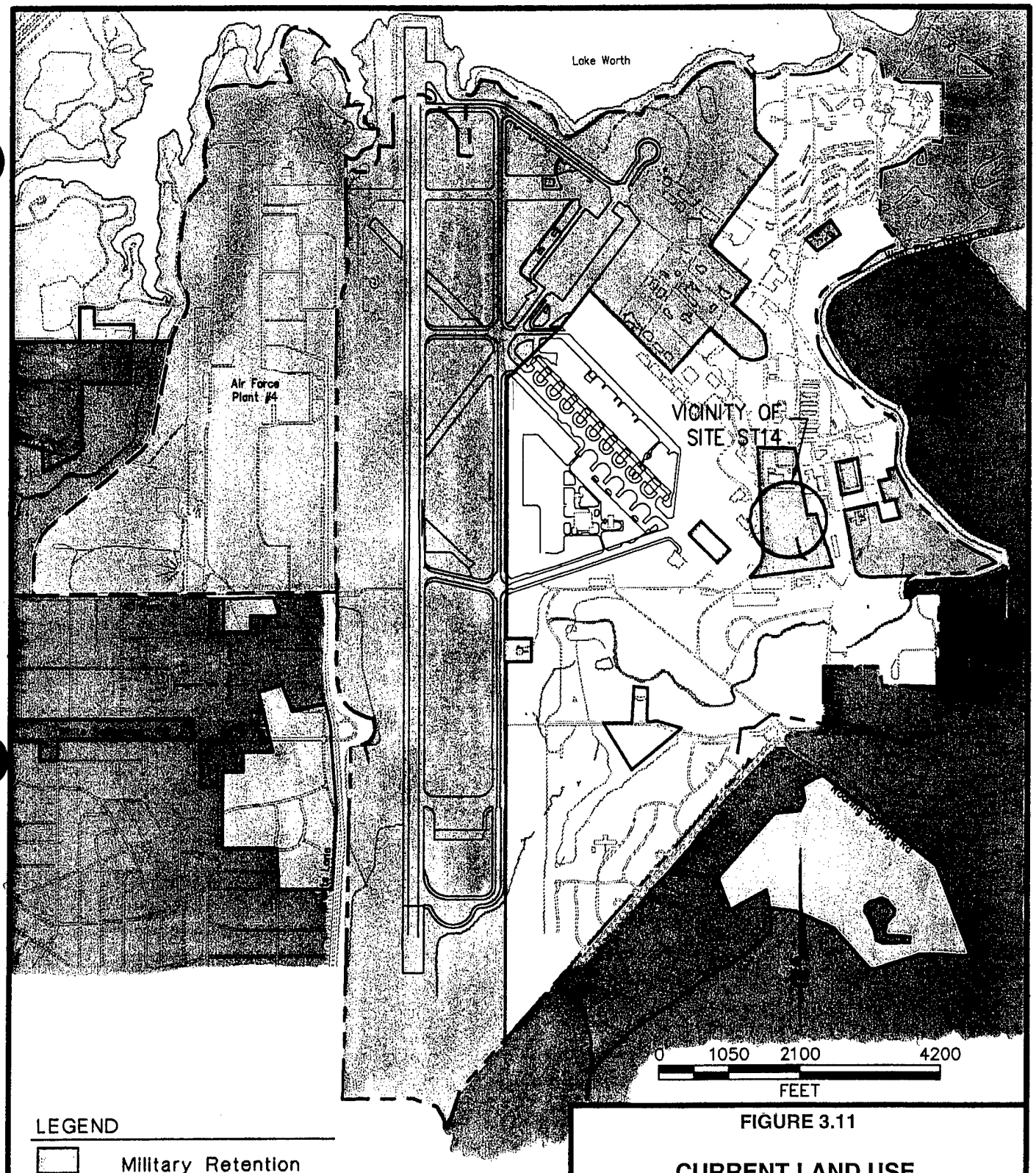
Based on the proposed land reuse plan, Sites ST14A and ST14B will be maintained for Base fueling operations (military). The POL tank farm and the fuel loading area (Site ST14) will continue to maintain security fences and access restrictions to prevent unauthorized access. An area just northeast of Site ST14A is proposed to be converted to an institutional (prison) facility. Building 1231 is proposed to be used as a regional showroom, regional distribution center, and warehouse of products produced by Federal Prison Industries (UNICOR) (US Air Force, 1994).

Site SD13 is a paved lot which is occasionally used as a parking area. Based on the proposed land reuse plan, Site SD13 is designated to be part of an open space area associated with the flood-prone areas along Farmers Branch. The proposed land reuse plan does not call for any new significant construction within the SD13 area. Although a bike path along the Farmers Branch Creek has been discussed, no formal plans have been developed. A small area to the south of Site SD13 may be zoned as a residential area, although no new building construction is planned (US Air Force, 1994). Public access to this site and the unnamed stream will continue to be limited by the perimeter fence at the Base boundary. Access to the unnamed stream is further limited by additional security fences located behind the Whitehouse communication building.

No future permanent human occupation of the East Area sites, or areas along Farmers Branch downstream of the unnamed stream, is anticipated. A large portion of the land south of the East Area sites and outside Base boundaries will continue to serve as public recreational areas in the form of a golf course and creek/river easement property. Areas west of the East Area will be maintained for military aviation support. East Area property and property north and east are proposed for military/industrial reuse. Site workers in these areas could spend the majority of their workdays outside, although most primary duties will be restricted to buildings and paved areas. Workers primarily responsible for grounds maintenance are the only exception. Figures 3.11, 3.12, and 3.13 show the current land uses, the proposed future land uses, and a mixed military/industrial/residential land use, respectively. The proposed reuse alternatives and site environs are described in the EIS (US Air Force, 1994).

3.8.4 Water Resources

Surface water is the main source of drinking water in the vicinity of Carswell AFB/NAS Fort Worth JRB. The City of Fort Worth Water Department is the primary supplier of potable water to the areas surrounding and including the Base. The city obtains its potable water supply from runoff from the West Fork of the Trinity River. This runoff is captured in a series of reservoirs, including Lake Worth, immediately north of Carswell AFB/NAS Fort Worth JRB. Potable water is supplied to the Base through two interconnections with the City of Fort Worth's water system. The current Base water storage system consists of 695,000 gallons of active reserve, and a 225,000-gallon backup capacity. Nonpotable water from Farmers Branch is used to irrigate the



LEGEND

- Military Retention
- Industrial
- Commercial
- Residential
- Public/Recreational
- Vacant Land
- Caretaker Status

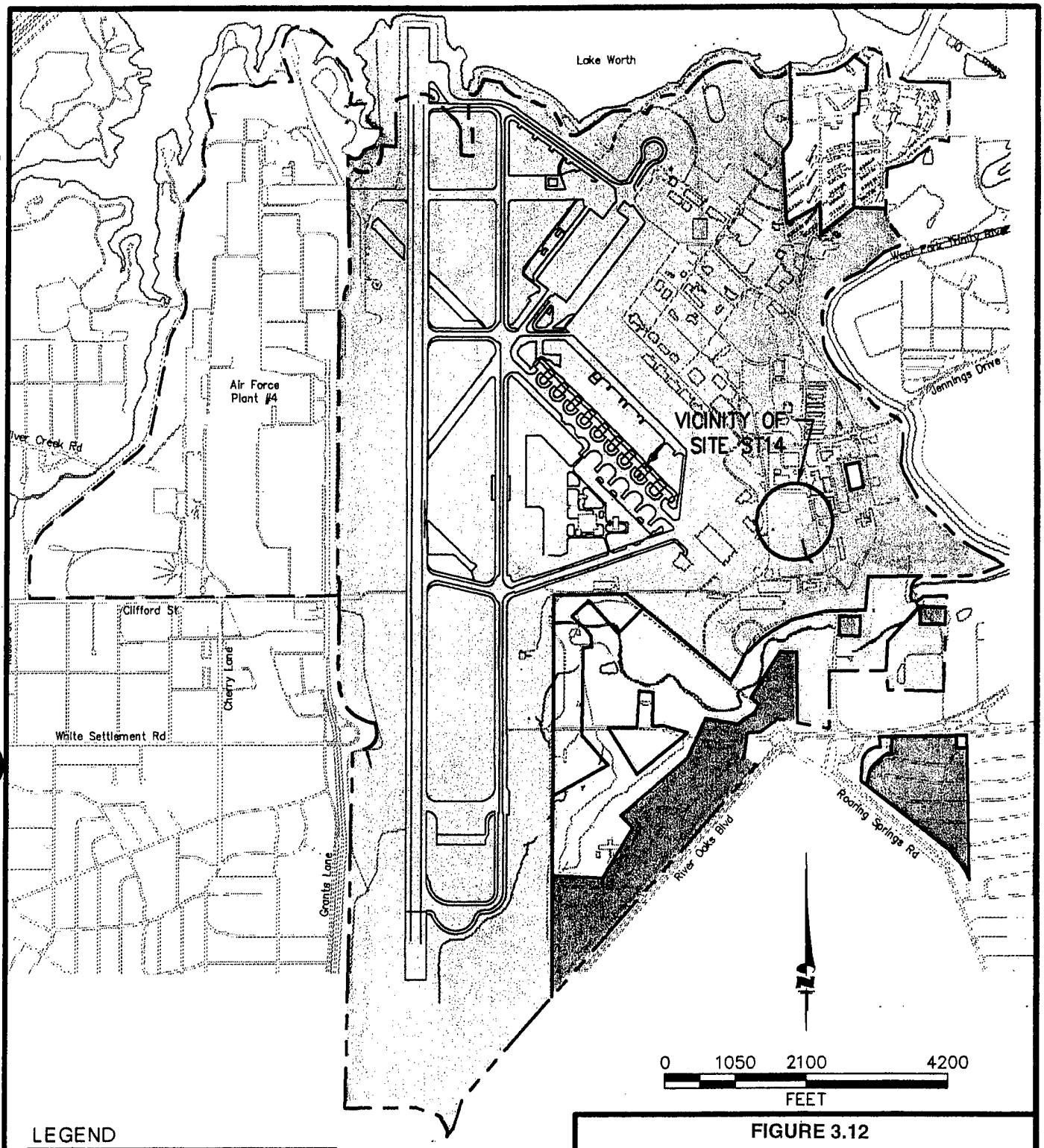
Source: US Air Force, 1994

FIGURE 3.11

CURRENT LAND USE ALTERNATIVE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Texas

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



LEGEND

- Military
- Commercial
- Institutional (Prison)
- Residential
- Public Facilities/Recreational

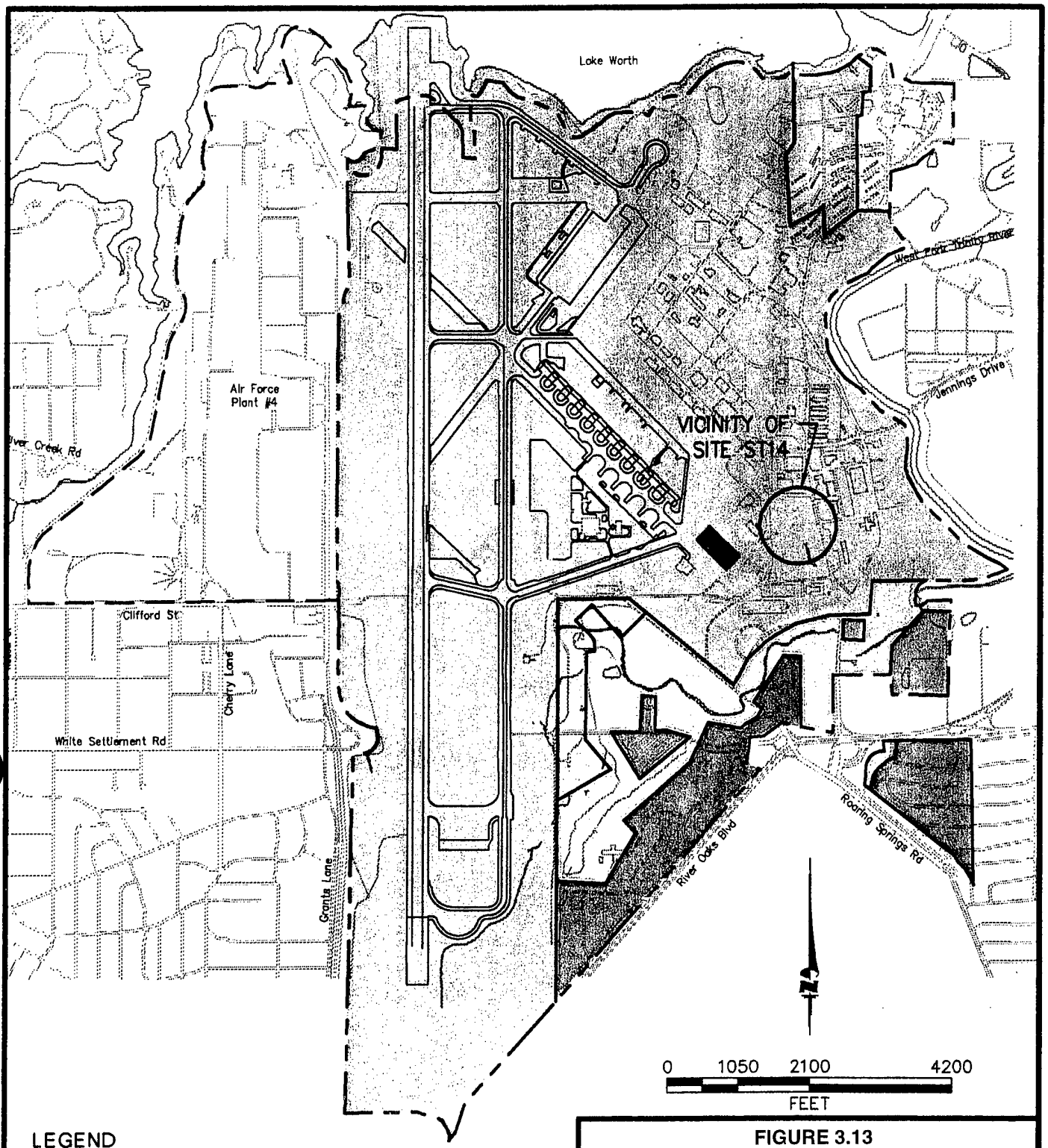
Source: US Air Force, 1994

FIGURE 3.12

PROPOSED LAND USE ALTERNATIVE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Texas

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



LEGEND

- Military
- Commercial
- Office/Industrial
- Institutional
- Aviation Support
- Residential
- Public Facilities/Recreational

Source: US Air Force, 1994

FIGURE 3.13

MIXED LAND USE ALTERNATIVE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Texas

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

on-Base golf course. White Settlement and Sansom Park obtain water from 12 and 9 groundwater wells, respectively; however, they purchase surface water from the City of Forth Worth to supplement their water supplies, as necessary. The availability of surface water to supply the Base and the surrounding communities was determined to be adequate to maintain military operations and land reuse activities following closure and realignment (US Air Force, 1994).

Water supply wells drilled in the vicinity of the Base are completed primarily in the lower sand member of the Paluxy aquifer. The Paluxy Formation occurs beneath the Goodland/Walnut aquitard, which consists of moist clay and shale layers interbedded with dry limestone beds. The aquitard separates the Paluxy Formation from the Upper Zone aquifer located in the younger surface alluvial deposits. Nonpotable water from the alluvium is used for irrigation near the Base on a limited basis. Development of the Upper Zone aquifer is not economically feasible due to limited volume and pumping capabilities, and vulnerability to surface and stormwater pollution (US Air Force, 1994). There are no active or open wells on Base for potable water supplies.

Parsons ES subcontracted with Geosource Incorporated (GI) to provide a water well survey to determine if there are any existing wells within a 0.5-mile radius of Sites ST14 and SD13. GI identified no wells within the area of review. The water well survey is presented in Appendix C.

The potable water demand as a result of the Base realignment is expected to increase slightly over the next 20-year period. The increased water demand anticipated as part of the proposed land reuse plan is a relatively inconsequential amount compared to the Fort Worth water supply capacity. Therefore, overall impacts on the water supply source from the proposed land use changes would be minimal (US Air Force, 1994). Construction of additional supply wells in the Paluxy aquifer is discouraged due to past and ongoing overpumping. Based on the EIS (US Air Force 1994), there are adequate potable surface water supplies to meet projected utility demands. Thus, drilling additional potable supply wells is not necessary.

There is currently no regular flow of water through the unnamed stream; however, any water moving through the unnamed stream would flow into the Farmers Branch river and then into the West Fork Trinity River. Both the Farmers Branch and the West Fork Trinity River are designated "high" aquatic life habitat.

SECTION 4

PLAN A EVALUATION FOR SITE ST14

4.1 OVERVIEW

This section summarizes the nature and extent of soil and groundwater contamination at Site ST14 based on the findings of site characterization activities conducted under the 1990 RI (Radian, 1991), the ES 1993 bioventing pilot test, the Law (1994) RFI, and the 1994/1995 risk-based remediation field investigation (which was conducted in February and March 1994, July through September 1994, and March and April 1995). The TNRCC (1994a) has specified Plan A target concentrations for potential beneficial use II category groundwater and industrial/commercial sites. These target concentrations are used as a screening tool to focus data presentation on those compounds and environmental media that may warrant remediation. The rationale for applying these Plan A target concentrations to Site ST14 is also presented.

4.2 DETERMINING CHEMICALS OF POTENTIAL CONCERN

It is the intention of the Air Force to obtain approval for a remedial action for Site ST14 that will protect human health and the environment from unacceptable exposures to fuel-related chemicals. To accomplish this objective, the fuel-related COPCs that drive potential risks and impact the final remedial requirements at these sites were identified. Previous IRP site investigations (Radian, 1985, 1988, 1989, and 1991), the AFCEE-sponsored bioventing pilot test (ES, 1993), the risk-based work plans (Parsons ES, 1994a and 1995), and the RFI (Law, 1994) identified the fuel-related COPCs for Site ST14 as the volatile BTEX compounds, chlorobenzene, and the semivolatile PAH compounds. These specific chemical constituents were initially defined as COPCs based on existing site characterization data, the chemical nature of the suspected sources (i.e., JP-4 jet fuel), and the analytical requirements specified by the TNRCC (1995a) for petroleum-contaminated soils and groundwater. The COPCs for Site ST14 to be considered in detail in this RAP are based on a comparison of measured site concentrations to TNRCC-specified Plan A target concentrations. These target concentrations are used as a screening level tool. Only those chemicals with site concentrations that exceed the applicable Plan A target concentrations are considered when establishing the risk-reduction requirements for Site ST14. However, pursuant to TNRCC (1994a) guidance, the Plan B limited risk assessment will account for the cumulative effect of all measured organic chemicals, not just the COPCs.

4.2.1 Comparison to Health-Protective Plan A Target Concentrations

According to the final land use plan for Carswell AFB/NAS Fort Worth JRB, Site ST14 is planned to be maintained as a fueling area to support realigned military units (US Air Force, 1994). As described in Section 3.8.2, the site is currently maintained as a military fueling area with limited access. The TNRCC PST risk-based corrective action guidance (1994a) specifies that target cleanup objectives should be based on both current and future land use assumptions. The TNRCC has developed generic Plan A human health-based target concentrations for soil and groundwater appropriate for both unrestricted (i.e., residential) and industrial/commercial use. These generic target concentrations are to be used as a screening tool to assess the need for site remediation based on the current and foreseeable land uses. Site ST14 is currently within and surrounded by industrial/military areas, and is planned to be maintained as an industrial/military area. Consequently, the exposure assumptions used to calculate Plan A target concentrations for residential areas are not representative of the exposure potential at Site ST14 and should not be used to evaluate the need for remediation to protect human health and the environment.

4.2.1.1 Soil Target Concentrations

The health-based Plan A target concentrations for soil for industrial/commercial sites have been developed so that residual concentrations of Class A and B carcinogens do not result in a cumulative risk in excess of 10^{-6}; Class C carcinogens do not result in a cumulative risk in excess of 10^{-5}; and noncarcinogens do not result in a cumulative HI of 1 (TNRCC, 1994a). The routes of exposure included in the health-based Plan A target concentrations for soils provided by TNRCC are incidental direct ingestion of contaminated soil, inhalation of contaminated soil as fugitive dust, and/or inhalation of volatilizing chemicals. Although the potential for volatilization and fugitive dust generation is likely nominal at Site ST14 because the majority of the soil is covered by impermeable materials such as cement and asphalt, the generic health-based Plan A soil target concentrations for industrial/commercial sites include the inhalation pathway. The algorithm specified by TNRCC (1994a) and all default input assumptions were used for this calculation which is presented in Appendix F.

Plan A soil target concentrations that are protective of groundwater quality also have been developed by the TNRCC (1994a). These soil concentrations are "back calculated" to prevent leachate concentrations above the applicable Plan A target concentration for groundwater from being released into underlying groundwater. The algorithm used to develop the Plan A target concentrations that are protective of groundwater is based on equilibrium partitioning and several default input values (TNRCC, 1994a). The derivation of Plan A target soil concentrations is presented in Appendix F.

4.2.1.2 Groundwater Target Concentrations

Health-based Plan A target concentrations for groundwater, which are used to derive the above-mentioned target soil concentrations, were developed to provide the maximum protection required given the suitability of the groundwater for use as a

potential drinking water source (TNRCC, 1994a). Based on conductivity measurements taken at the site in September 1994 and March 1995 (Appendix A), the total dissolved solid (TDS) content of the shallow alluvium groundwater underlying Site ST14 is less than 3,000 mg/L. However, a well survey completed in September 1995 (Appendix C) indicated that no wells within at least 0.5 mile of the site are used for potable water. Additionally, as discussed in Section 3.8.4, it is not economical to develop the Upper Zone alluvium as a potential water supply due to limited volume and pumping capabilities, and its vulnerability to surface and stormwater pollution (US Air Force, 1994). Potable water in the area is derived primarily from surface water sources, although a few wells near the Base, completed primarily in the lower sand unit of the Paluxy aquifer (which is separated from the Upper Zone alluvium by the 30- to 40-foot-thick Goodland/Walnut aquitard), are used. Consequently, pursuant to TNRCC (1994a) definitions, the groundwater underlying Site ST14 should be classified as potential beneficial use II groundwater.

Health-based Plan A target concentrations for beneficial use II groundwater were calculated using the TNRCC (1994a) exposure parameters. Ingestion of groundwater is the only exposure pathway incorporated into these Plan A target concentrations. The Plan A target concentrations are defined so that the individual risk for carcinogens does not exceed 10^{-6}; and the HI for noncarcinogens does not exceed 1. The derivation of the Plan A target groundwater concentrations is presented in Appendix F.

4.2.1.3 Screening to Identify COPCs

The COPCs for Site ST14 were defined by using the health-based Plan A target concentrations as a screening tool. Table 4.1 compares the maximum analytical concentrations for every compound measured in soil and groundwater at Site ST14 during the 1993 bioventing pilot test, the 1994 RFI sampling event, and the 1994/1995 risk-based sampling event to the Plan A target concentrations for the industrial/commercial land use scenario. If the maximum measured site concentration does not exceed the Plan A target concentration, the compound is not identified as a COPC. No additional remediation would be warranted to protect human health and the environment given the current and foreseeable uses of the site. If the maximum measured site concentration exceeds the Plan A target concentration, the compound is identified as a COPC. Table 4.1 also presents the maximum concentrations for fuel hydrocarbons detected at Site ST14 during the 1995/1996 and 1997 groundwater monitoring performed under the Base-wide groundwater sampling and analysis plan (GSAP). Because the 1995-1997 groundwater monitoring data did not exist at the time, risk calculations subsequently performed in this RAP are based on information gathered prior to the 1995-1997 GSAP groundwater monitoring. However, it should be noted that the most recent results for all fuel hydrocarbons at Site ST14 are well below the maximum levels detected in groundwater in the 1994/1995 risk-based sampling event, and therefore risk estimates based on pre-1995-1997 groundwater monitoring data will be a conservative estimator of current conditions.

All analytical results measured below the MDL were identified as not detected (U qualified) and reported at the PQL. This is consistent with EPA (1989) guidance on how to use nondetected values in quantitative risk assessments. All analytical results

TABLE 4.1
COMPARISON TO HEALTH-BASED PLAN A TARGET CONCENTRATIONS

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Max Conc. Bioventing Pilot Test 1993	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	PLAN A TARGET CONCENTRATION		
					Groundwater Protective Soil[c] Concentration	Health-Based Soil Conc.[d] Noncarcinogenic	Health-Based Soil Conc.[e] Carcinogenic
Soil							
Volatile Organic Compounds							
1,2,3,4-Tetramethylbenzene	mg/kg	-	-	19	-	-	-
1,2,3-Trimethylbenzene	mg/kg	-	-	9.6	-	-	-
1,2,4-Trimethylbenzene	mg/kg	-	-	28	-	-	-
1,3,5-Trimethylbenzene	mg/kg	-	-	14	-	-	-
Acetone	mg/kg	-	0.034	-	-	2.04E+05	-
Benzene	mg/kg	67	-	0.0024	7.40E-01	-	7.90E-01
Chlorobenzene	mg/kg	-	-	2.4	9.73E+01	4.47E+02	-
Ethylbenzene	mg/kg	17	-	9.1	8.35E+02	3.36E+03	-
Methylene Chloride	mg/kg	-	0.016	-	-	1.22E+05	7.63E+02
Toluene	mg/kg	54	-	2.5	5.03E+02	3.26E+03	-
Xylenes (Total)	mg/kg	52	-	56	9.68E+02	9.68E+02	-
Semivolatile Organic Compounds							
1,2,4-Trichlorobenzene	mg/kg	-	-	0.053	7.40E+03	1.28E+04	-
1,4-Dichlorobenzene	mg/kg	-	-	0.053	1.23E+02	5.00E+04	6.66E+02
2-Chlorophenol	mg/kg	-	-	0.1	3.00E+02	1.02E+00	-
2-Methylnaphthalene	mg/kg	-	-	0.46	-	-	-
4-Chloro-3-methylphenol	mg/kg	-	-	0.098	-	-	-
Acenaphthene	mg/kg	-	-	0.059	3.14E+02	3.14E+02	-

TABLE 4.1
COMPARISON TO HEALTH-BASED PLAN A TARGET CONCENTRATIONS

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Max Conc. Bioventing Pilot Test 1993	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	PLAN A TARGET CONCENTRATION		
					Groundwater Protective Soil[c/] Concentration	Health-Based Soil Conc.[d/] Noncarcinogenic	Health-Based Soil Conc.[e/] Carcinogenic
Di-n-butylphthalate	mg/kg	-	-	0.068	1.12E+03	2.04E+05	-
Fluorene	mg/kg	-	-	0.025	2.47E+02	2.47E+02	-
Hexachlorobenzene	mg/kg	-	-	0.46	3.14E+03	1.63E+03	3.61E-01
N-Nitroso-di-n-propylamine	mg/kg	-	-	0.054	1.63E+01	-	8.18E-01
Naphthalene	mg/kg	-	-	2.9	3.89E+02	7.82E+02	-
Phenol	mg/kg	-	-	0.12	1.95E+01	1.22E+06	-
Pyrene	mg/kg	-	-	0.049	9.90E+01	9.90E+01	-
Petroleum Hydrocarbons							
Petroleum Hydrocarbons	mg/kg	9300	-	8800	-	-	-
Total Extractable Hydrocarbons	mg/kg	-	-	2200	-	-	-
Other Analyses							
Alkalinity, Carbonate	mg/kg	-	1550	-	-	-	-
Alkalinity, Total (as CACO3)	mg/kg	-	268	-	-	-	-
Nitrogen, Total Kjeldahl	mg/kg	-	714	-	-	-	-
Phosphorus, Total Orthophosphate	mg/kg	-	211	-	-	-	-
Total Organic Carbon	%	-	0.86	-	-	-	-
Total Organic Carbon	mg/kg	-	2800	-	-	-	-
pH	pH	-	9.5	-	-	-	-

TABLE 4.1
COMPARISON TO HEALTH-BASED PLAN A TARGET CONCENTRATIONS

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Max Conc. Bioventing Pilot Test 1993	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Concentration GSAP 1995/1996	Maximum Concentration GSAP 1997	PLAN A TARGET CONCENTRATION	
							Target GW Concentration[a/] Noncarcinogenic	Target GW Concentration[b/] Carcinogenic
Groundwater								
Volatile Organic Compounds								
1,2,3,4-Tetramethylbenzene	mg/L	-	-	0.058	-	-	-	-
1,2,3-Trimethylbenzene	mg/L	-	-	0.062	-	-	-	-
1,2,4-Trimethylbenzene	mg/L	-	-	0.071	-	-	-	-
1,3,5-Trimethylbenzene	mg/L	-	-	0.052	-	-	-	-
Benzene	mg/L	-	-	0.11	0.191	0.06	-	2.94E-03
Bromodichloromethane	mg/L	-	0.0038	-	-	-	7.30E-01	1.37E-03
Chlorobenzene	mg/L	-	-	0.014	-	-	7.30E-01	-
Chloroform	mg/L	-	0.0052	-	-	-	3.65E-01	1.40E-02
Dibromochloromethane	mg/L	-	0.00047	-	-	-	7.30E-01	1.01E-03
Ethylbenzene	mg/L	-	0.409	0.038	0.023	0.0074	3.65E+00	-
Methylene Chloride	mg/L	-	0.012	-	-	-	2.19E+00	1.14E-02
Tetrachloroethene	mg/L	-	0.0091	-	-	-	3.65E-01	-
Toluene	mg/L	-	-	0.069	0.0012	0.0022	7.30E+00	-
Trichloroethene	mg/L	-	-	0.0014	-	-	-	-
Xylenes (Total)	mg/L	-	1.089	0.11	0.0087	0.0098	7.30E+01	-
Semivolatile Organic Compounds					-			
2-Methylnaphthalene	mg/L	-	-	8	-	-	-	-
Dibenzofuran	mg/L	-	-	1	-	-	-	-

TABLE 4.1
COMPARISON TO HEALTH-BASED PLAN A TARGET CONCENTRATIONS

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Max Conc. Bioventing Pilot Test 1993	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Concentration GSAP 1995/1996	Maximum Concentration GSAP 1997	PLAN A TARGET CONCENTRATION	
							Target GW Concentration[a/] Noncarcinogenic	Target GW Concentration[b/] Carcinogenic
Naphthalene	mg/L	-	-	5	-	-	1.46E+00	-
Petroleum Hydrocarbons								
Methane	mg/L	-	5.3	-	-	-	-	-
Petroleum Hydrocarbons	mg/L	-	111,000	5.2	-	-	-	-
Total Extractable Hydrocarbons	mg/L	-	-	25	-	-	-	-
Total Volatile Hydrocarbons	mg/L	-	184,000	-	-	-	-	-

Note: Maximum measured site concentrations that exceed health-based Plan A target concentrations are identified.

Footnotes:

a/ Beneficial use II groundwater concentrations for noncarcinogen.

b/ Beneficial use II groundwater concentration for carcinogens.

c/ Soil concentration that will be protective of underlying beneficial use II groundwater for noncarcinogens.

d/ Health-protective soil concentration for industrial/commercial sites (noncarcinogens).

e/ Health-protective soil concentration for industrial/commercial sites (carcinogens).

f/ Health-protective surface water concentrations (noncarcinogens).

g/ Health-protective surface water concentrations (carcinogens).

measured above the MDL but below the PQL were identified as estimated but usable data (J qualified). All analytical results measured above the PQL were identified as detected concentrations and not qualified. Data also were subject to a usability/acceptability review that included (1) a review of chain-of-custody records, reported holding times, status of instrument calibration, and reported recoveries for laboratory control samples and matrix spike/matrix spike duplicates; (2) analyzing and using laboratory and field blanks to qualify reported sample concentrations; and (3) measuring the reproducibility of sampling techniques and laboratory analytical precision using blind field duplicates/replicates. Appendix A presents the analytical results for all samples collected under this project, organized by environmental medium, and a summary of the data quality evaluation results.

All nondetect analytical results obtained during the 1994/1995 risk-based remediation field test are reported at the PQL and U qualified. Nondetect analytical results obtained during the 1994 RFI are reported at the reporting limit and U qualified. All analytical results obtained during the 1994/1995 risk-based field investigation measured between the MDL and the PQL have been J qualified. All MDLs achieved for the 1994/1995 field investigation are consistent with the TNRCC (1995b) recommendations for analytical sensitivity and are below the most stringent Plan A target concentration (see Table 2.1).

Based on comparison of the maximum detected site chemical concentrations to the health-based Plan A target concentrations, benzene is the only fuel-related COPC in soil at Site ST14. Benzene also is the only fuel-related COPC in groundwater at Site ST14.

4.2.2 Comparison to Plan A Target Concentrations for Environmental Protection

In addition to protection of human health, the need for environmental protection must be considered when identifying COPCs. Generally, protection of surface water and groundwater will be of primary concern (TNRCC, 1994a). It is conceivable assuming no attenuation, that groundwater contamination from Site ST14 could migrate to and impact surface water at the unnamed stream or at Farmers Branch. Although surface water analysis indicates that there is currently no impact, maximum groundwater contaminant concentrations at Site ST14 were compared to the TNRCC surface water criteria as a conservative measure to assess potential future impact to the unnamed stream. The target remedial objective for surface water is to prevent the discharge of any concentration of fuel hydrocarbon into the water body. However, Plan A target concentrations for surface water are based on the Texas Surface Water Quality Standards of Title 30 TAC, Chapter 307 and 319. Freshwater acute and freshwater chronic surface water quality criteria have been defined. In the event that no surface water quality criterion has been identified, the MCL will be the Plan A target concentration for surface water. If no MCL is identified, the health-based Plan A target concentration presented in Table 4.1 is used (TNRCC, 1994a). These target concentrations for surface water are used to identify any compounds present in groundwater at concentrations that could cause unacceptable environmental impacts if an exposure pathway involving surface water is or could be completed at the site.

The only difference between Plan A target concentrations for beneficial use I groundwater and beneficial use II groundwater is that the MCLs, as promulgated pursuant to Section 141 of the federal Safe Drinking Water Act (SDWA), are used for beneficial use I waters instead of health-based concentrations. If no MCL has been defined, the same health-based target concentration derived for beneficial use II groundwater applies to beneficial use I groundwater. Because groundwater underlying Site ST14 will eventually discharge into the unnamed stream and/or Farmers Branch, which in turn discharges into a potable water source (Trinity River), the MCLs were also included in this initial screening of detected compounds to cover potential beneficial use I applicability. This will ensure that any compounds with concentrations that exceed the MCL are retained for more detailed evaluation as part of the Plan B assessment. This conservative approach is warranted because a more stringent remediation may be necessary to protect downgradient environmental resources than would be required to protect potential onsite human receptors (TNRCC, 1994a).

Protection of groundwater resources also must be considered when identifying COPCs and potential remediation requirements for a site. The Groundwater Protection Act (Texas Water Code, Chapter 26.401) specifies that groundwater must be kept reasonably free of contaminants that interfere with the present and potential uses, that the quality of the groundwater should not be degraded, and that the quality of the groundwater should be restored when feasible. The health-based Plan A target concentrations for groundwater are sufficient to identify the maximum nature and extent of site-related contamination that may warrant remediation to protect groundwater resources.

Table 4.2 compares the maximum measured groundwater concentrations to the Plan A environmental protection target concentrations for surface water. Compounds were identified as COPCs for environmental protection concerns if the maximum concentration exceeded the Plan A target concentration for surface water or the health-based Plan A target concentration for beneficial use I groundwater (Table 4.1).

4.2.3 Identified Fuel-Related Chemicals of Potential Concern

Table 4.3 lists the fuel-related COPCs for soil and groundwater for Site ST14. No concentrations of fuel hydrocarbon chemicals measured in surface water exceeded Plan A environmental protection target concentrations for surface water, although several fuel hydrocarbon compounds measured in upgradient groundwater exceeded these surface water criteria. Benzene and hexachlorobenzene are the only compounds identified as fuel-related soil COPCs. No PAH compound was measured at Site ST14 at concentrations above the Plan A target concentrations for soil.

Benzene was the only fuel-related compound to be identified as a groundwater COPC. All other compounds were below the Plan A target concentration for groundwater.

4.2

SCREENING LEVEL EVALUATION OF GROUNDWATER ANALYTES FOR ENVIRONMENTAL PROTECTION

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

ANALYTE	Maximum Concentration [a/]	Units [b/]	MCL [c/]	Water Quality Criteria [d/] Freshwater Acute Criteria [e/]	Water Quality Criteria [d/] Freshwater Chronic Criteria	Does Analyte Exceed Freshwater Criteria ?	Does Analyte Exceed MCL ?
GROUND WATER							
Volatile Organic Compounds							
1,2,3,4-Tetramethylbenzene	0.058	mg/L	--	--	--	--	--
1,2,3-Trimethylbenzene	0.062	mg/L	--	--	--	--	--
1,2,4-Trimethylbenzene	0.071	mg/L	--	--	--	--	--
1,3,5-Trimethylbenzene	0.052	mg/L	--	--	--	--	--
Benzene	0.11	mg/L	0.005	5.3	--	NO	YES
Bromodichloromethane	0.0038	mg/L	0.08	--	--	--	NO
Chlorobenzene	0.014	mg/L	--	--	--	--	--
Chloroform	0.0052	mg/L	0.08	28.9	1.24	NO	NO
Dibromochloromethane	0.00047	mg/L	--	--	--	--	--
Ethylbenzene	0.409	mg/L	0.7	32	--	NO	NO
Methylene Chloride	0.012	mg/L	0.005	--	--	--	YES
Tetrachloroethene	0.0091	mg/L	0.005	5.28	0.84	NO	YES
Toluene	0.069	mg/L	1	17.5	--	NO	NO
Trichloroethene	0.0014	mg/L	0.005	45	21.9	NO	NO
Xylenes (Total)	1.089	mg/L	10	--	--	--	NO
Semivolatile Organic Compounds							
2-Methylnaphthalene	0.008	mg/kg	--	--	--	--	--
Dibenzofuran	0.001	mg/kg	--	--	--	--	--
Naphthalene	0.053	mg/L	--	2.3	0.62	NO	--

E 4.2

SCREENING LEVEL EVALUATION OF GROUNDWATER ANALYTES FOR ENVIRONMENTAL PROTECTION

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

ANALYTE	Maximum Concentration [a/]	Units [b/]	MCL [c/]	Water Quality Criteria [d/] Freshwater Acute Criteria [c/]	Water Quality Criteria [d/] Freshwater Chronic Criteria	Does Analyte Exceed Freshwater Criteria ?	Does Analyte Exceed MCL ?
Petroleum Hydrocarbons							
Methane	5.3	mg/L	--	--	--	--	--
Petroleum Hydrocarbons	111000	mg/L	--	--	--	--	--
Total Extractable Hydrocarbons	25	mg/L	--	--	--	--	--
Total Volatile Hydrocarbons	184000	mg/L	--	--	--	--	--

Note: Shaded chemicals represent those that exceed either one or both of the comparison criteria.

[a/] Maximum concentrations were obtained from both the 1993 RFI and 1994 risk-based investigation sampling events.

[b/] mg/L = milligrams per liter.

[c/] MCL = Maximum Contaminant Level. Maximum permissible level of a contaminant in water which is delivered to any user of a public water system. EPA(1994) Drinking Water Regulations and Health Advisories.

[d/] Freshwater acute and chronic water quality criteria from EPA (1991).

[e/] "--" = reference information not available; unable to make comparison.

TABLE 4.3
LIST OF FUEL-RELATED CHEMICALS OF POTENTIAL CONCERN
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

Fuel-Related COPCs	Rationale[a]
Soil	
Benzene	1993 bioventing maximum concentration > Helath-based Plan A target concentration, Plan A groundwater protection criterion for beneficial use II groundwater
Groundwater	
Benzene	1994 RFI and 1994/1995 risk-based maximum concentration > Plan A target concentration for beneficial use II groundwater

a/ See data ranges presented in Table 4.1.

The two fuel-related COPCs, benzene and hexachlorobenzene, are considered in detail in subsequent sections. Organic compounds measured at the site at concentrations that did not exceed the most stringent Plan A target concentrations will be considered cumulatively with COPCs in the Plan B limited risk assessment, but will not receive detailed assessment as part of the nature and extent and chemical fate discussions. Emphasis has been given to defining the nature and extent of fuel-related contamination at Site ST14 that must be addressed to protect human health and the environment in accordance with the intent of the TNRCC (1994a) risk-based corrective action guidance. Only compounds that may pose a health threat (i.e., a carcinogenic and/or noncarcinogenic risk) to potential receptors or are relevant to conducting remedial technology assessments have been considered as part of this risk-based approach to remediation.

4.3 SOURCES OF CONTAMINATION

Contamination at Site ST14 was likely the result of isolated surface spills and subsurface leaks of JP-4 jet fuel and related fuels from pipelines underlying the fueling area and between the fuel ASTs at Site ST14B and Site ST14A. The site has been maintained as an active military fueling area throughout most of Carswell's operational history (i.e., mid-1942 to the present). Consequently, residual fuel hydrocarbon contamination in soils and groundwater may be the result of low-volume release events that occurred over the last several decades, rather than a single, large-volume release event. An unknown amount of fuel has been released to the subsurface at this site.

4.3.1 LNAPL

Mobile, light nonaqueous-phase liquid (LNAPL) or free product, has been regularly reported in monitoring well ST14-MW17M at Site ST14A. More than 2 feet of free product was observed in this well during the 1990 IRP sampling event (Radian, 1991). A thin film of LNAPL was observed in one bioventing well (VW1) and several vapor monitoring points (MPA, MPB, and MPC) during the May 1993 bioventing pilot test (ES, 1993). All of these sampling locations are located within 40 feet of well ST14-MW17M. Base personnel performed monthly monitoring of LNAPL thickness in monitoring well ST14-MW17M for about 1 year starting in June 1993. The average product thickness encountered in this well from June 1993 until April 1994 was 0.75 inch (Table 4.4). Less than 0.5 inch of LNAPL was measured at this location in September 1994, during the risk-based field investigation. All recoverable LNAPL is hand-bailed from well ST14-MW17M during each monitoring event. Based on reported LNAPL thickness data, only 0.12 gallon of LNAPL has been recovered from this well since mid-1993. No LNAPL was present at this sampling location during the April 1995 sampling event.

Six monthly product removal events were scheduled for February through August 1997 at wells in Sites ST14 and SD13 which had contained free product during previous sampling events. ST14-MW17M was the only well at Site ST14 included in the removal program. Four of the six product removal events have been performed.

0.02 feet of product was detected in ST14-MW17M during the initial removal event in February 1997. No product was detected during the March and June sample removal events or during the April quarterly groundwater monitoring event. Note that ST14-MW17M is included as a sampling location in the GSAP. Well ST14-MW17M will be measured during the remaining events to ensure the continued absence of product.

A sample of LNAPL was collected from well ST14-MW17M during the 1994 risk-based field effort and analyzed for total extractable hydrocarbons (TEH) by EPA Method SW8015 (Appendix A). Assuming JP-4 jet fuel was the source of the subsurface LNAPL, the measured TEH content of 540,000 milligrams per liter (mg/L) of the sampled LNAPL is approximately one-half that expected for relatively "fresh" JP-4 jet fuel, which would have a saturated TEH content of about 1,000,000 mg/L. A comparison of the chromatogram for the LNAPL sample and the chromatogram for the fresh jet fuel standard (Appendix A) illustrates the effect of weathering on TEH content of JP-4. The number and resolution of "peaks" is less pronounced in weathered samples in comparison to the LNAPL collected from ST14-MW17M is depleted in the lower-molecular-weight hydrocarbons, which are more soluble and partition more readily that heavier compounds; fresh product because the more volatile hydrocarbon fraction has been removed by weathering processes. Specifically, this suggests that the LNAPL at the source area at Site ST14A is significantly weathered, implying that the source of contamination is not fresh but the result of years of site use. Compound-specific analytical results are not available for the LNAPL sample.

4.3.2 Residual Source Area Contamination

Elevated concentrations of fuel hydrocarbons have been measured in unsaturated, capillary fringe, and saturated soils at Site ST14 as part of every field investigation conducted to date (Hargis and Montgomery, 1983; Radian, 1985, 1989, and 1991; ES, 1993; Law, 1994). Fuel contamination extends from the surface, or near surface, to a depth of approximately 12 feet bgs. Most detectable concentrations of fuel-related compounds were found between the 8- and 11-feet bgs. Subsequent sections review analytical soil results to delineate the nature and extent of soil contamination at Site ST14, and discuss the potential for these contaminated soils to act as a continuing source of groundwater contamination.

4.4 SOIL GAS SAMPLING RESULTS

Soil gas samples collected at Site ST14 during the 1994/1995 field effort were analyzed for individual BTEX compounds and TVH. Soil gas samples were used for secondary confirmation of the nature and extent of soil contamination at a site. Soil gas samples were used to obtain a better representation of soil contamination because the sample is extracted from a larger volume of soil than discrete soil samples from a splitspoon. Discrete soil samples are usually nonhomogeneous, and analytical results can vary greatly from sampling location to sampling location. Thus, soil gas samples provide a valuable indication of the type and magnitude of VOC contamination in the soil.

TABLE 4.4

1993/1994 FREE PRODUCT THICKNESS MEASUREMENTS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

Date	Free Product Thickness (inches)
6/16/93	Trace
7/1/93	0.18
7/23/93	2.0
8/6/93	2.5
9/10/93	1.0
10/8/93	1.12
11/19/93	0.37
12/30/93	0.63
1/28/94	0.25
2/16/94	0.50
3/10/94	Trace
4/11/94	0.75

Figure 4.1 presents the analytical soil gas results for BTEX by sampling location for samples collected at Site ST14 in 1994. Benzene was detected in only one soil gas sample from ST14-VW3 at ST14A. A benzene concentration of 120 µg/L, which is equivalent to 120 milligrams per cubic meter (mg/m^3), was detected in this soil gas sample. These results correlate well with the initial soil gas data collected in 1987 at Site ST14B (Radian, 1988 and 1991) and the 1993 soil gas screening results for samples taken during the bioventing pilot test at Site ST14A (ES, 1993). The compound-specific soil gas data collected near the two ASTs appear to confirm the presence of at least a soil vapor plume in this general vicinity. Benzene was not detected in any of the soil gas samples collected at Site ST14A as part of the 1993 bioventing pilot test.

The maximum measured soil gas concentration for benzene exceeds the time-weighted-average (TWA) 8-hour permissible exposure limit (PEL) of 3.25 mg/m^3 defined for benzene by the Occupational Safety and Health Administration (OSHA, 1994). Consequently, if future excavation of these soils is necessary to support remedial or construction activities, personnel protective equipment and worker breathing zone air monitoring will be required to prevent adverse exposures. The potential risks associated with inhalation of volatilizing compounds is included in the Plan B limited risk assessment presented in Section 6 of this RAP. All analytical results for soil gas samples collected during the 1994 field effort are presented in Appendix A.

Figure 4.2 presents the TVH soil gas screening results for samples collected upgradient from Site ST14B as part of the 1995 supplemental field work. TVH concentrations measured in soil gas samples collected upgradient of Site ST14B were generally low. These analytical results indicate that no source area exists in the vicinity north of the site near the 1190 Area.

4.5 SOIL FLUX SAMPLING RESULTS

Soil gas flux samples also were collected at Site ST14 in July 1994, and analyzed for the volatile BTEX compounds and TVH (Figure 4.3). Analytical results for the soil gas flux samples were used to estimate the potential for gaseous emissions into the atmosphere. Sampling was completed in accordance with the procedures described in EPA's (1986b) guidance document entitled *Measurement of Gaseous Emission Rates from Land Surfaces Using an Emission Isolation Flux Chamber*. The calculation sheets transforming concentration data into emission-rate data for soil gas flux samples collected at Site ST14 are presented in Appendix A.

Benzene was detected in a flux sample collected at ST14-FLX4 near the suspected source area at Site ST14A. Benzene was not detected in any of the other five flux samples collected at Site ST14. No other BTEX compound was detected in flux samples collected at the site. The calculated emission rate of benzene at flux testing location ST14-FLX4 was 0.58 micrograms per square meter per minute ($\mu g/m^2$-min). Consequently, the maximum concentration of benzene expected in the breathing zone near the source area at Site ST14A over an 8-hour time period, assuming no

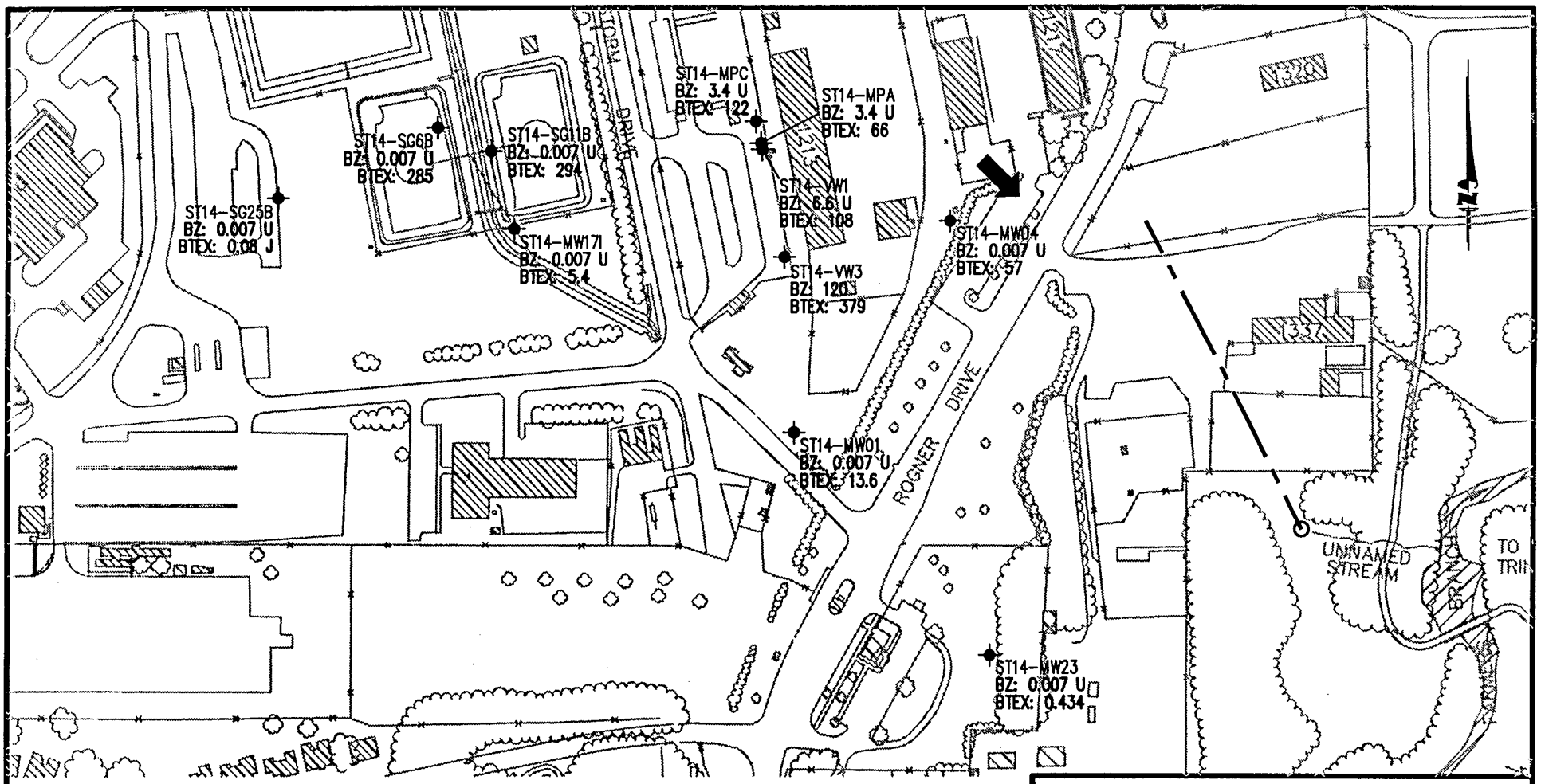


FIGURE 4.1

1994 BENZENE AND BTEX SOIL GAS ANALYTICAL RESULTS AT SITE ST14

Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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Denver, Colorado

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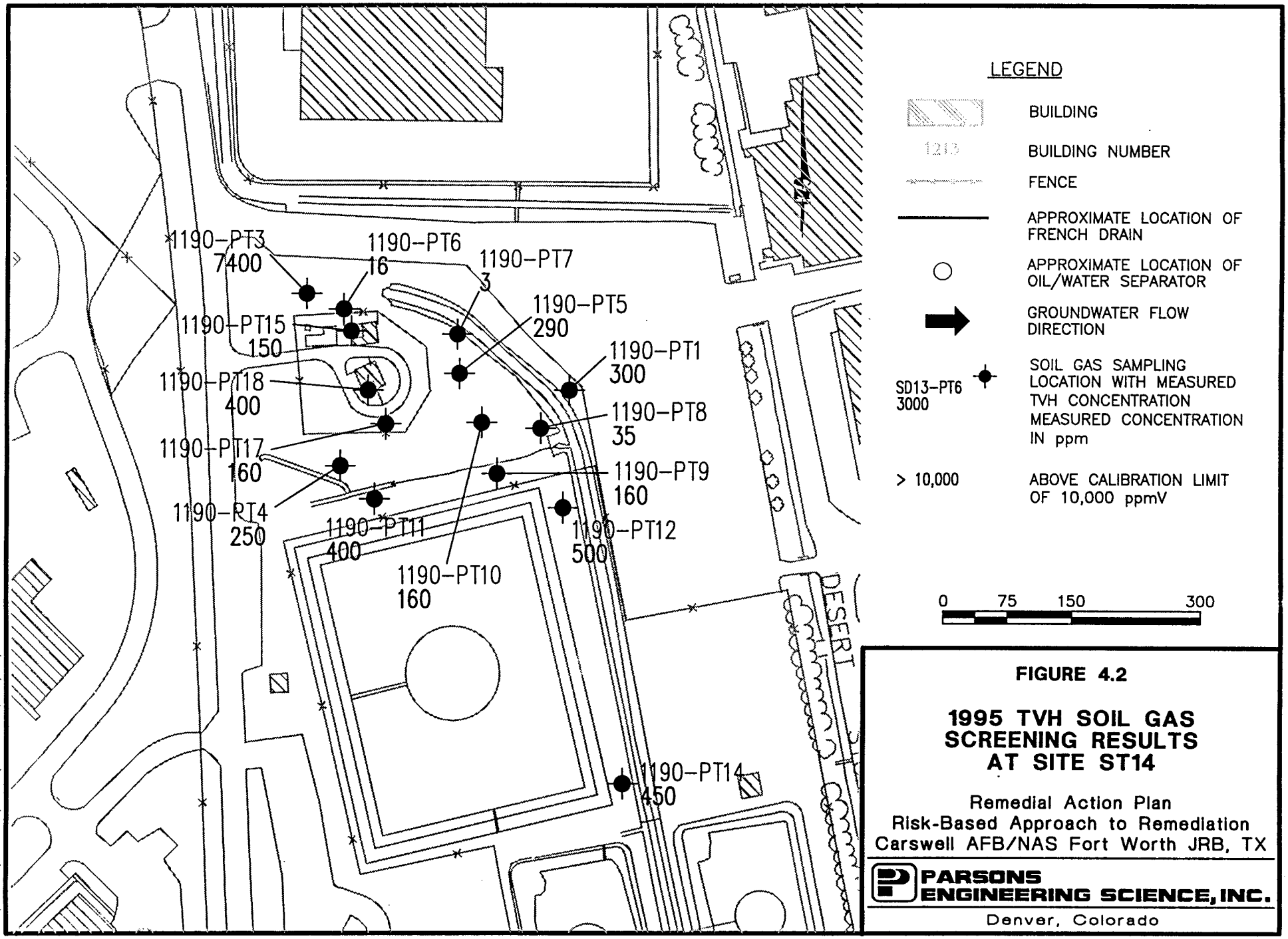


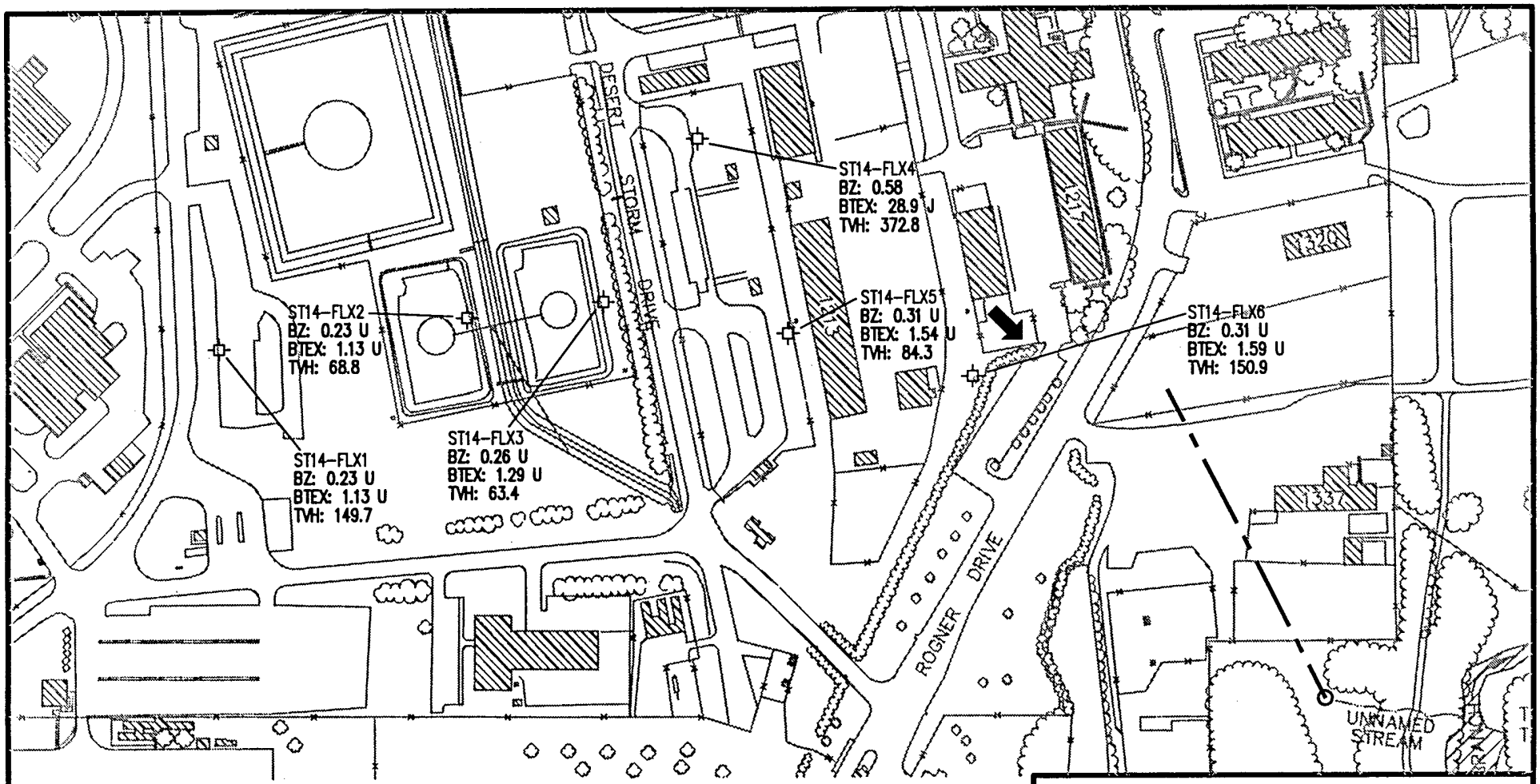
FIGURE 4.2

1995 TVH SOIL GAS SCREENING RESULTS AT SITE ST14

Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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LEGEND

BUILDING

BUILDING NUMBER

FENCE

APPROXIMATE LOCATION OF FRENCH DRAIN

APPROXIMATE LOCATION OF OIL/WATER SEPARATOR

GROUNDWATER FLOW DIRECTION

ST14-FLX1
BZ: 0.23 U
BTEX: 1.13 U
TPH: 149.7

SOIL FLUX SAMPLING LOCATION W/ ACTUAL FLUX IN ?g/min-m 2 (DATA QUALIFIER FLAG WHERE APPLICABLE)

U ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT

J ESTIMATED VALUE

NOTE: RESULTS FOR BENZENE, TOTAL BTEX, AND TOTAL (BZ) VOLATILE HYDROCARBON (TVH) SHOWN

0 125 250
FEET

FIGURE 4.3

1994 SOIL FLUX ANALYTICAL RESULTS AT SITE ST14

Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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Denver, Colorado

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atmospheric dispersion, would be 0.28 mg/m^3. This measured soil gas flux concentration for benzene is well below the OSHA TWA 8-hour PEL of 3.25 mg/m^3. Based on these results, soil gas flux emissions do not represent a source of potential health risk to onsite workers. The low rates of VOC emission suggest that the volatilization pathway and inhalation route are not significant for surface activities at Site ST14.

4.6 SOIL SAMPLING RESULTS

Soil data at Site ST14 were collected during sampling events from March 1984 through December 1987 during installation of 14 permanent groundwater monitoring wells during the Stage 1, Phase II IRP investigation (Radian, 1985 and 1991). Drilling in the unsaturated portion of the Upper Zone yielded visibly stained soils in only a few areas. However, analytical data collected during this investigation indicated fuel hydrocarbon contamination in both vadose zone and saturated soils of the Upper Zone aquifer at Site ST14A. No soil samples were collected at Site ST14B during the earlier IRP investigations for chemical analysis.

An additional 28 soil samples were collected from 24 sampling locations at various depths as part of the 1993 bioventing pilot test. Benzene was detected in all but 6 of the 28 soil samples at concentrations ranging from 160 µg/kg to 67,000 µg/kg (ES, 1993). The maximum concentration of benzene measured in soil at the site was 67,000 µg/kg at ST14-SB1, at a depth of 10 feet bgs. This sampling location is centered on one of the probable source areas at Site ST14A (Figure 4.4). The extent of soil contamination at Site ST14A was defined on the north by ST14-SB7 and the south by ST14-SB4. However, the easterly and westerly extent of soil contamination at this site was not fully defined until the 1994/1995 risk-based investigation.

As part of the 1994/1995 risk-based remediation investigation, 59 soil samples were collected for chemical analysis from 42 new soil boreholes at Sites ST14 and SD13 to define the nature and extent of soil fuel hydrocarbon contamination. All soil samples were analyzed for BTEX and chlorobenzene; and about 25 percent of the most contaminated soil samples were analyzed for PAH compounds. Benzene was detected in more than 30 percent of the new soil samples at concentrations ranging from 0.6 µg/kg to 2,800 µg/kg. The westerly extent of soil contamination at Site ST14A was defined by soil boring ST14-VW24, and the easterly extent by soil borings at ST14-MW20 and ST14-MW28 (Figure 4.4). Three primary areas of measurable soil contamination were identified at Site ST14. All of the analytical soil results from the 1994/1995 risk-based investigation are presented in Appendix A.

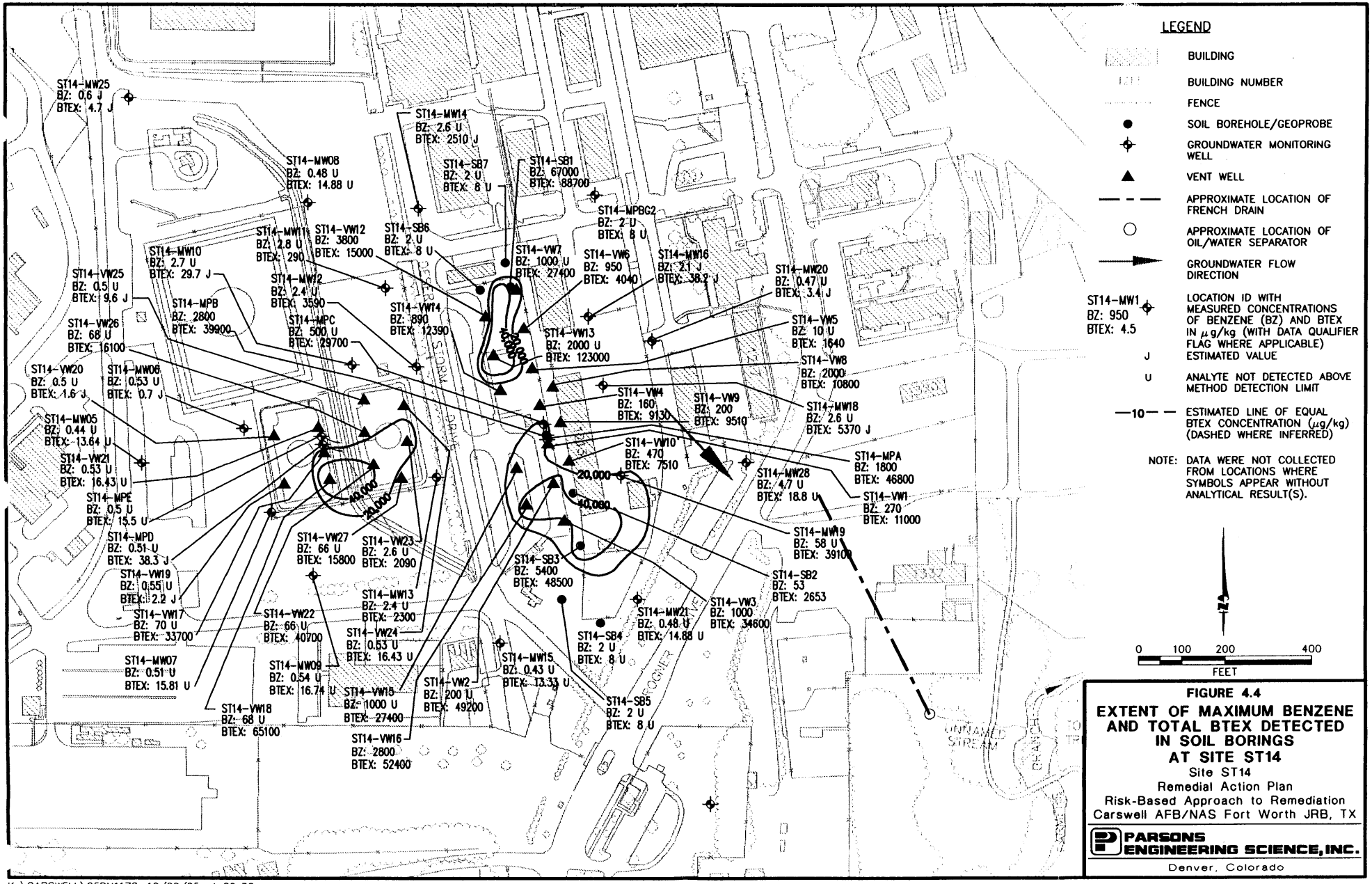


FIGURE 4.4

EXTENT OF MAXIMUM BENZENE AND TOTAL BTEX DETECTED IN SOIL BORINGS AT SITE ST14

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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4.7 GROUNDWATER SAMPLING RESULTS

The following section describes the results of groundwater sampling events conducted during the Law (1994) RFI and the 1994/1995 focused field investigation in support of a risk-based remediation of Site ST14. Benzene was identified as the only fuel-related groundwater COPC. The maximum concentration of other compounds detected in groundwater, but not identified as groundwater COPCs, are presented in Tables 4.1 and 4.2. Analytical results for groundwater from the 1994/1995 focused field investigations are presented in Appendix A.

The saturated thickness of the Upper Zone aquifer, the shallowest water-bearing zone underlying the East Area sites, varies from about 4 to 14 feet (Figure 3.8). Most groundwater monitoring wells at Site ST14 are screened across the upper 4 to 8 feet of the aquifer. Nested well clusters were not required to assess the vertical distribution of chemical contamination in alluvium groundwater at these sites given the thin saturated interval. The underlying Goodland/Walnut bedrock is about 40 feet thick, and likely to be a competent aquitard (Section 3) that prohibits vertical migration to deeper hydrogeologic units. Background groundwater wells ST14-MW24, ST14-MW25, and ST14-MW26 are upgradient from and outside of the zone of contaminant influence originating from Site ST14.

Groundwater samples were collected at Site ST14 and analyzed for the BTEX compounds as part of the various IRP investigations and the 1990 RI sampling event. The maximum reported concentration of benzene measured at the site was 11,000 µg/L, which was measured at well ST14-MW17M in October 1986 (Radian, 1988 and 1991). Benzene was again detected in 4 of the 9 wells sampled during the spring of 1990 as part of the RI, but at significantly lower concentrations than had been measured during the Stage 1, Phase II IRP investigation. The maximum concentration of benzene measured at Site ST14 during 1990 was 16 µg/L at well ST14-MW17M (Radian, 1991). This was the only concentration of benzene measured in groundwater in 1990 at Site ST14 above the most stringent Plan A target concentration of 5 µg/L. This concentration of benzene is below the Plan A target concentration of 29.4 µg/L for beneficial use II groundwater. Other wells in which benzene was detected during the 1990 sampling event include ST14-MW17J (3.8 µg/L), ST14-MW03 (1.3 µg/L), ST14-MW17L (0.65 µg/L), and ST14-MW17K (0.50 µg/L). Based on the 1990 RI data, two distinct regions of dissolved benzene contamination were believed to be present at Site ST14. The first region was associated with Tanks 1156 and 1157 at Site ST14B; the second region was associated with the adjacent fuel loading area (Site ST14A). These two regions were found to be roughly coincident to the regions of fuel hydrocarbon contamination indicated by the Stage 2 soil gas survey (Section 4.4) (Radian, 1988 and 1991).

Groundwater samples were collected at 21 different sampling locations in April 1994 for analytical testing as part of the Law (1994) RFI. Groundwater samples were also collected from 43 permanent groundwater monitoring wells in September 1994 and April 1995 as part of the risk-based investigation. Given the low rate of groundwater flow at Site ST14 (i.e., from 10 feet per year [ft/yr] to 145 ft/yr) and the relatively short period of time between sampling events, all three sets of analytical data from

these sampling events were used to delineate the existing extent of dissolved benzene at the sites depicted on Figure 4.5. The maximum concentration of benzene measured at Site ST14 during these 1994 sampling events was 110 µg/L at ST14-MW16. Dissolved benzene was not detected in any of the permanent monitoring wells where benzene had been measured previously (i.e., ST14-MW17J, ST14-MW17L, ST14-MW17K, ST14-MW17M, and ST14-MW03). Notably, benzene was not detected in well ST14-MW17M where LNAPL has been encountered during previous sampling events. Based on these data, detectable concentrations of dissolved benzene extend about 700 feet downgradient from ST14-MW16 to ST14-MW21. No dissolved benzene was detected at any sampling location underlying Tanks 1157 and 1158.

No benzene was detected in several wells (i.e., ST14-MW21, ST14-MW29, and ST14-MW04) and temporary sampling locations (i.e., C800, D700) located to the northeast (upgradient) and southwest (downgradient) of Rogner Drive, which is immediately downgradient from Site ST14A and upgradient from Site SD13 (Figure 4.5).

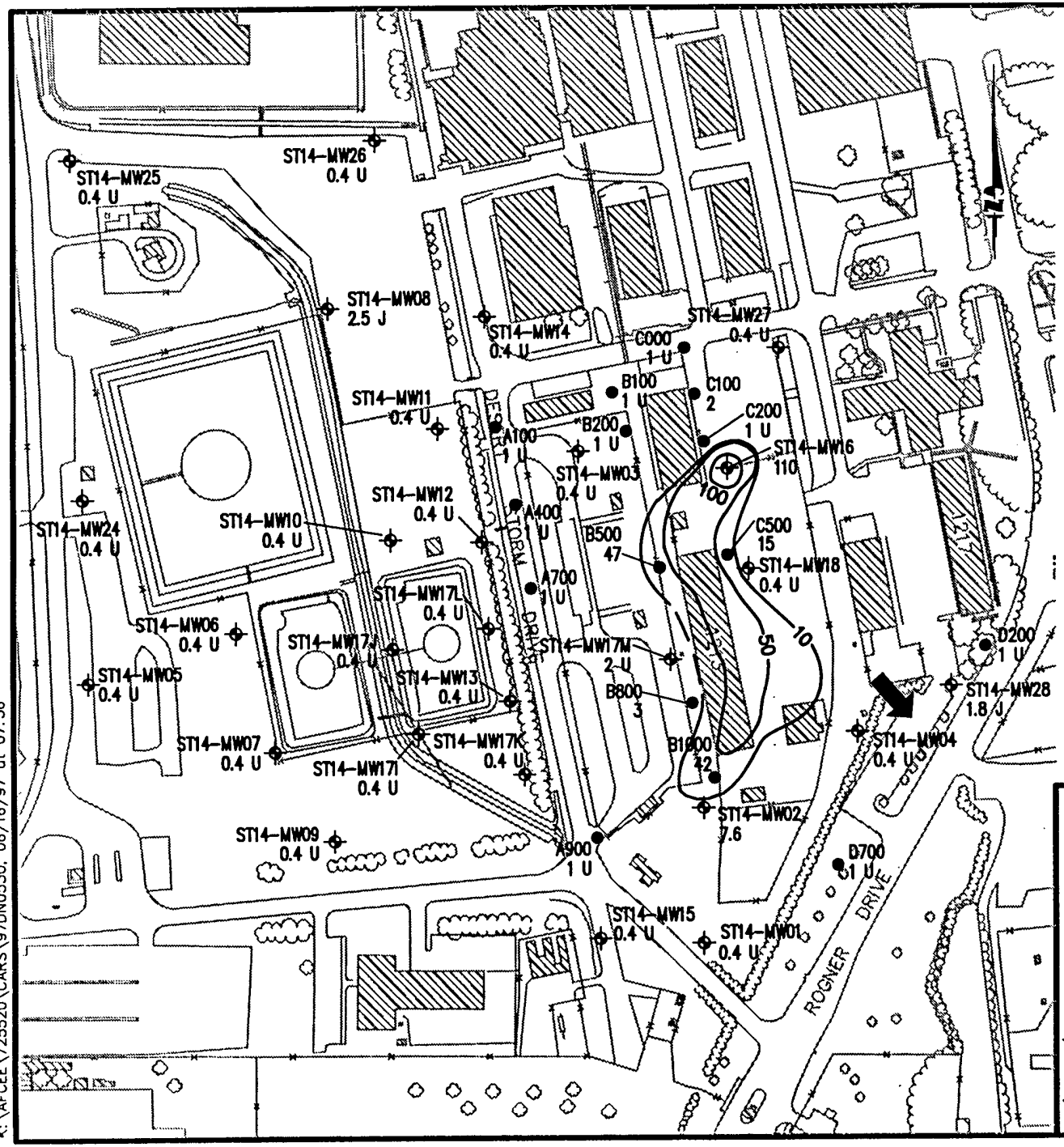
As part of the Basewide groundwater monitoring program, samples were collected from 16 locations at Site ST14 on four occasions in 1995 and 1996. In January of 1997, samples were collected from 10 locations under the revised Basewide groundwater monitoring program. The maximum concentration of benzene detected during the quarterly sampling was 191 µg/L at ST14-MW16 during July 1995. However the concentration of benzene detected at ST14-MW16 has been consistently decreasing since. During the most recent monitoring event (January 1997) 60 µg/L was detected in this location. ST14-MW21 was the only other location sampled during the most recent quarterly sampling event with a detectable level of benzene (20 µg/L).

Figure 4.6 presents the extent of total BTEX in groundwater at Site ST14. Although benzene is the only fuel-related groundwater COPC (Table 4.4), understanding the extent of all dissolved hydrocarbon contamination at the site is important in facilitating predictions about the fate and transport of dissolved benzene over time. Based on the total BTEX data, dissolved contamination from Site ST14 is migrating downgradient toward Site SD13 and the no longer intact french underdrain system. The potential for dissolved contamination in groundwater to discharge into surface water may be an important consideration when establishing appropriate remedial objectives for this site.

4.8 SUMMARY

Soil contamination at Site ST14 is limited to the fueling loading facility. Benzene was measured in soil at Site ST14A at concentrations above the Plan A target soil concentration that is protective of beneficial use II groundwater. These compounds are identified as fuel-related soil COPCs.

Benzene was the only fuel-related chemical compound with concentrations measured in groundwater at Site ST14 that exceed the Plan A target concentration for beneficial use I or II groundwater. Dissolved benzene originating from Site ST14A extends about 700 feet downgradient from the apparent source area near ST14-MW16 (Figure 4.5).



LEGEND

- BUILDING
- 1213 BUILDING NUMBER
- FENCE
- SOIL BOREHOLE/GEOPROBE
- GROUNDWATER MONITORING WELL
- ST14-MW19 45 LOCATION ID WITH MEASURED CONCENTRATION OF BENZENE IN (mg/L) (WITH DATA QUALIFIER FLAG WHERE APPLICABLE)
- J ESTIMATED VALUE
- U ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- –10– – ESTIMATED LINE OF EQUAL ANALYTE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)
- GROUNDWATER FLOW DIRECTION

NOTE: DATA WERE NOT COLLECTED FROM LOCATIONS WHERE SYMBOLS APPEAR WITHOUT ANALYTICAL RESULT(S).

0 125 250
FEET

FIGURE 4.5

1995 EXTENT OF DISSOLVED BENZENE AT SITE ST14

Remedial Action plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Tx

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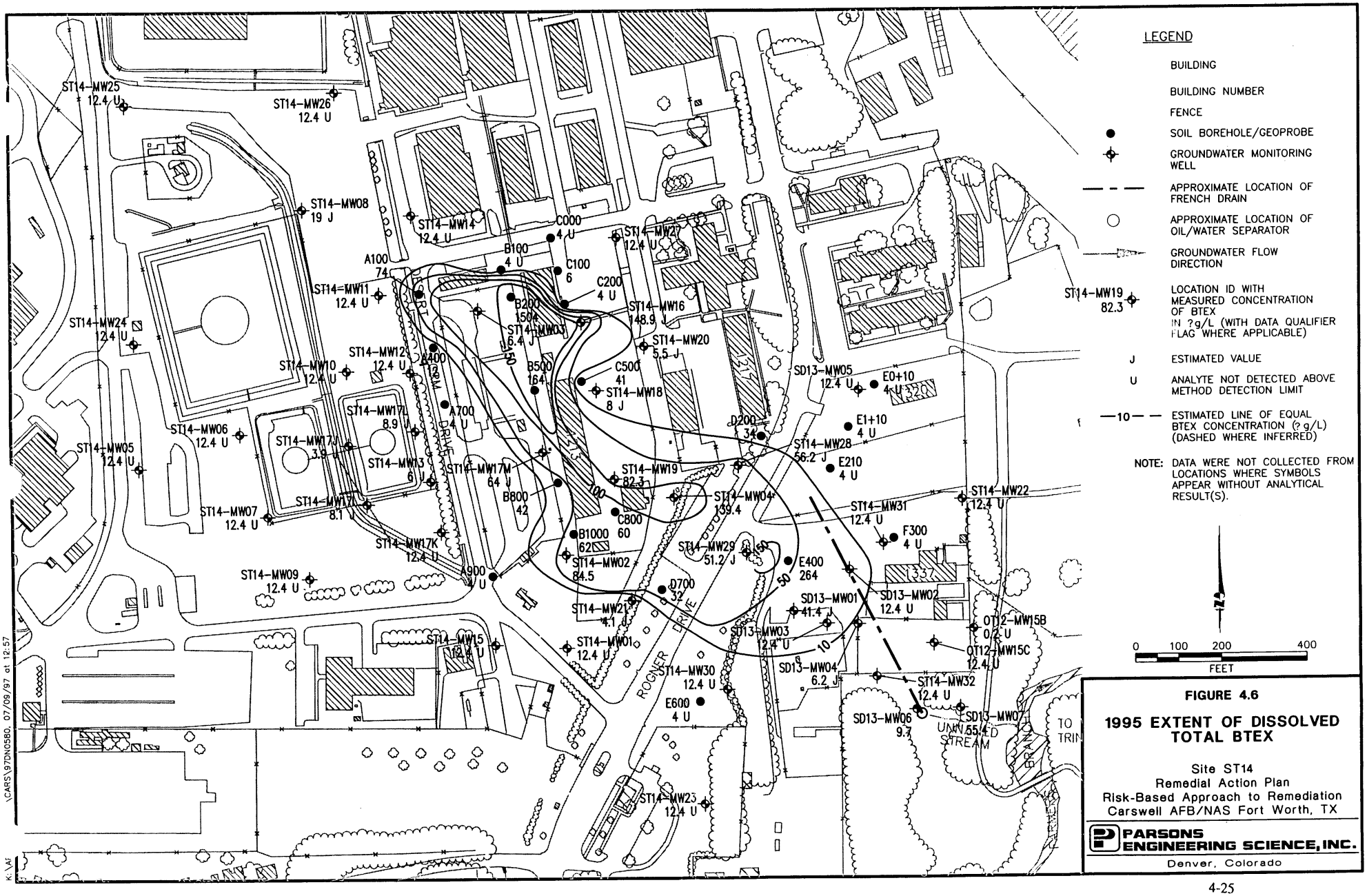


FIGURE 4.6

1995 EXTENT OF DISSOLVED TOTAL BTEX

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth, TX

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No dissolved benzene from Site ST14 has migrated to the southeast of Rogner Drive to Site SD13.

The effect of the chemical characteristics and site-specific characteristics of benzene on its fate and transport is examined in Section 6. Emphasis is placed on documenting the effects of natural physical, chemical, and biological processes on COPC mass, concentration, persistence, toxicity, and mobility.

SECTION 5

COMPARISON OF SITE SD13 CHARACTERIZATION DATA TO RISK REDUCTION STANDARD NUMBER 2 LEVELS

This section summarizes the nature and extent of soil and groundwater contamination at Site SD13, which includes SWMU 64 (the french underdrain system), SWMU 67 (the oil/water separator), and AOC 7 (the former base refueling area), based on the findings of the:

- Site characterization activities conducted under the 1990 RI (Radian, 1991);
- RCRA Facility Investigation (Law, 1994);
- AFCEE-sponsored 1994/1995 risk-based remediation field investigation (which was conducted in February and March 1994, July through September 1994, and March and April 1995); and
- Additional characterization and monitoring activities conducted at the site since 1995 (i.e., the 1996 interim removal action, ongoing quarterly groundwater monitoring as part of the Base-wide GSAP).

This section has been added to the RAP at the request of TNRCC to satisfy the compliance requirements of the industrial/hazardous waste (IHW) program. Unlike remedial planning for Site ST14, which is being conducted pursuant to TNRCC PST program guidance, the remediation and/or closure of Site SD13 is subject to compliance with 30 TAC Chapter 335, Subchapter S. Under this program, TNRCC has established three different types of cleanup levels that, when attained, will assure adequate protection of human health and the environment from potential exposure to contaminants associated with releases from solid waste management facilities or other areas.

In order to document attainment with site-appropriate cleanup levels, the environmental media of concern must first be identified. Then, the nature, extent, and concentration of contaminants in that media can be characterized. Risk Reduction Standard Number 1 and 2 cleanup levels, as defined by the TNRCC, were used in a stepwise-fashion to initially define environmental media of concern and COPCs for Site SD13. These generic cleanup levels are used as a screening tool to focus data presentation on those compounds and environmental media that may warrant remediation. The rationale for applying these generic cleanup levels to Site SD13 is also presented. A site-specific quantitative risk assessment was completed, pursuant to the requirements of Risk Reduction Standard Number 3; the results of this evaluation are presented in Section 8 of this RAP.

5.1 OVERVIEW OF RISK REDUCTION STANDARDS

TNRCC has adopted a three-tiered, risk-based approach for determining the extent and type of closures or remediations at industrial/hazardous waste sites that are necessary to protect human health and the environment. These rules are based on the general premise that protection of human and ecological receptors can be insured while some level of residual contamination remains onsite. Consequently, the principal objective of using the three-tiered cleanup level approach is to distinguish those materials and site conditions that pose a potentially substantial present or future threat to human or ecological receptors. This information is critical to developing and implementing corrective actions to mitigate or eliminate any unacceptable threats.

Compliance with Risk Reduction Standard Number 1 can be demonstrated when all contaminated media, including engineered components of the SWMU, are removed or decontaminated to background concentrations. Background concentrations are defined by the results of analyses of samples taken from media that are unaffected by waste management or industrial activities. In those cases where the practical quantitation limit (PQL) is greater than measured background concentrations, the PQL will be defined as the background concentration for demonstration of attainment of Risk Reduction Standard Number 1. No deed recordation or post-closure care responsibilities will be required for sites remediated and closed in compliance with Risk Reduction Standard Number 1.

Compliance with Risk Reduction Standard Number 2 can be demonstrated when all contaminated media and engineered components of the SWMU are removed or decontaminated to the cleanup levels specified in Section 335.556. In those cases where the established background concentrations are greater than the cleanup levels specified in Section 335.556, attainment of background concentrations shall be deemed adequate to demonstrate compliance with Risk Reduction Standard Number 2. Risk Reduction Standard Number 2 cleanup levels are derived either by conservative, quantitative health-based risk assessment procedures or by directly using other appropriate promulgated standards (e.g., MCLs). The target risk for Risk Reduction Standard Number 2 cleanup levels is 1×10^{-6} for Class A and B carcinogens, 1×10^{-5} for Class C carcinogens, and a hazard quotient (HQ) of 1 for noncarcinogenic chemicals. Different cleanup levels for residential and non-residential properties have been established. Although no post-closure care responsibilities will be required for sites remediated and closed in compliance with Risk Reduction Standard Number 2, a deed certification informing potential future property owners of the level of residual contamination is required.

TNRCC also has established a third performance standard that provides a level of flexibility at sites where closure or remediation strictly by removal or decontamination would not be feasible (or cost-effective). The goal of Risk Reduction Standard Number 3 is to define the type of removal, decontamination, and/or control activities that need to be implemented at a specific site to eliminate, or at least reduce to the maximum extent practicable, any present or potential threat to human health or the environment. A site-specific analysis, which includes a quantitative baseline risk assessment, is required to define appropriate Risk Reduction Standard Number 3 compliance requirements. The target risk range for Risk Reduction Standard Number 3 is 1×10^{-6} to 1×10^{-4} for carcinogens and an HQ of 1 for noncarcinogenic chemicals. Because

compliance with Risk Reduction Standard Number 3 will likely hinge on institutional controls to supplement engineered removal/treatment approaches. Both post-closure care responsibilities and deed certification will be a required element of any site remediation/closure plan.

5.2 SUMMARY OF INTERIM REMOVAL ACTIONS

An interim removal action was completed at Site SD13 in 1996 to partially remove engineered structures associated with SWMU 64 (the french underdrain system) and the north oil/water separator (SWMU 67). The following summarizes the removal actions completed at this site. This information is included at this point in the RAP as a means of defining remaining media of concern that may need to be characterized to determine additional removal or decontamination requirements.

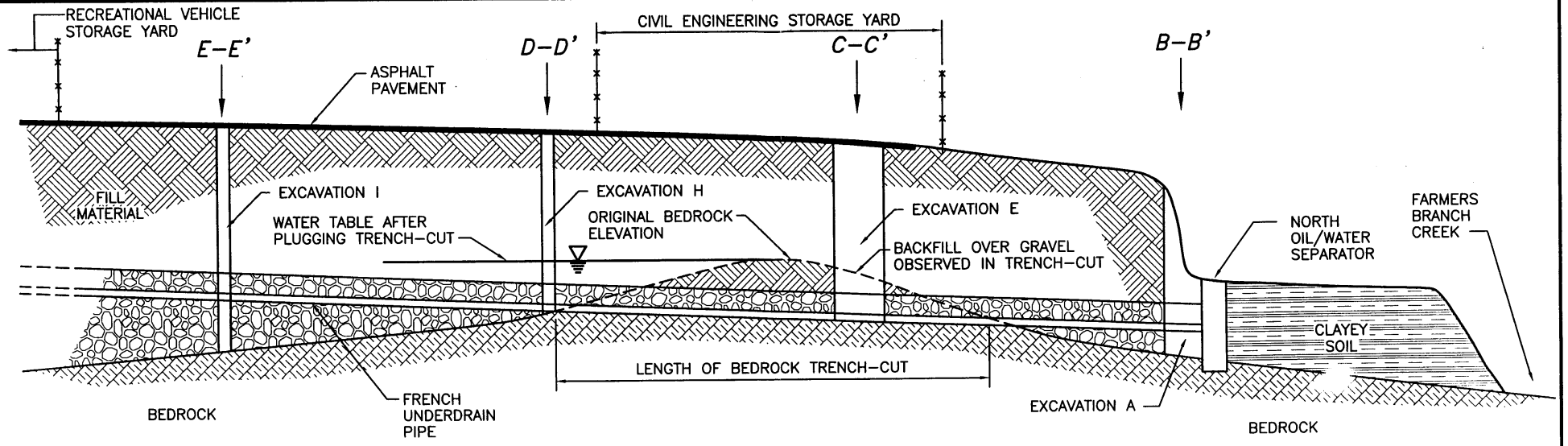
5.2.1 Pre-Removal Investigation Results

In 1996, the french underdrain system at Site SD13 was investigated to determine (1) its location and construction and (2) the source of persistent water flow into the north oil/water separator, which discharged to a tributary to Farmers Branch Creek, referred to as the unnamed stream. Once a basic understanding of the underdrain system and oil/water separator was achieved, both of these SWMUs were abandoned in accordance with procedures approved by TNRCC IHW to eliminate discharges of groundwater into surface drainages by this flow path. Portions of the drain pipe were removed and replaced with low permeability material. Figure 5.1 presents hydrogeologic information on the french underdrain system at the locations of excavations A-A' through E-E'. Figure 5.2 presents the location of the french underdrain system and excavations.

SWMU 64 (the french underdrain system) initially was investigated in March 1996 by non-intrusive means. Florescent dyes and magnetic detection methods were used to identify the source of the persistent water flow into the north oil/water separator (SWMU 67). Dye study results were inconclusive. Magnetic detection could positively locate the drain pipe no more than a few feet from the north oil/water separator.

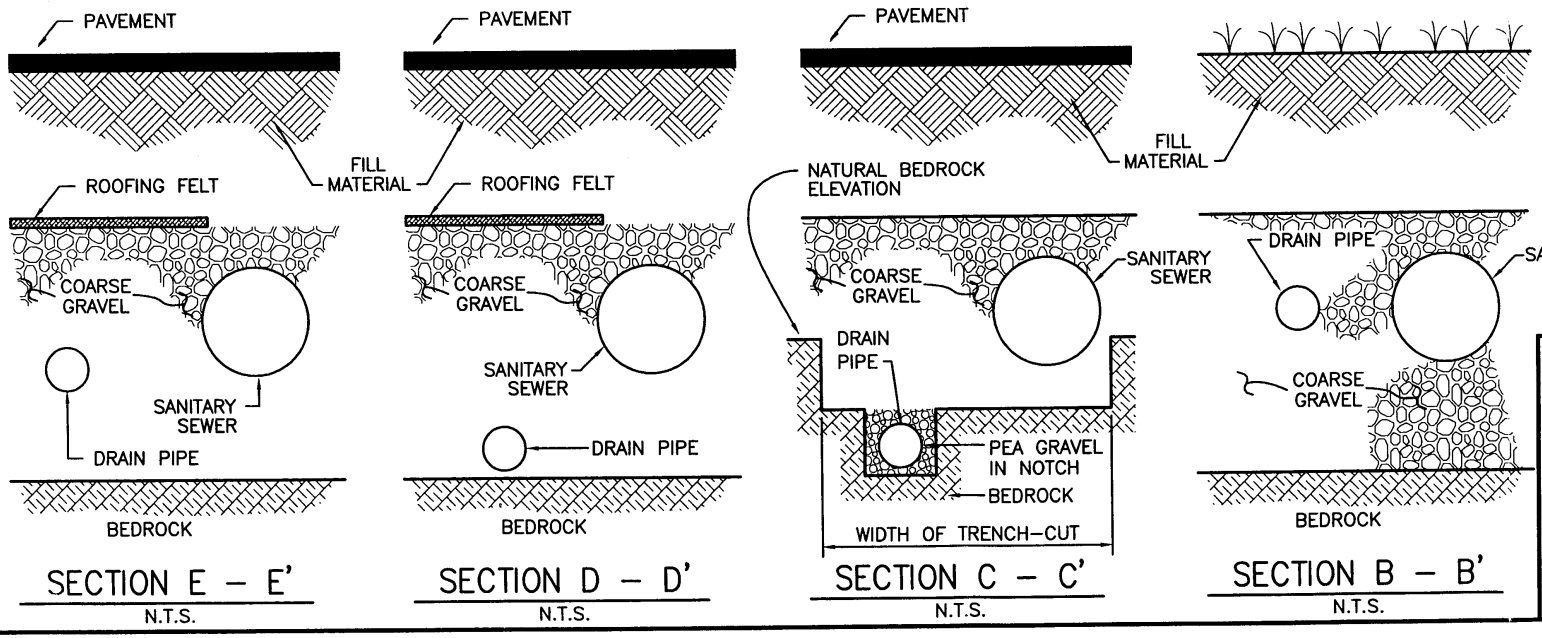
Subsequent intrusive investigations of these two SWMUs were conducted in June 1996 by excavating overlying soils to identify the location and construction of the drain pipe discharging to the north oil/water separator. The general investigation procedure involved excavation along the drain pipe from the north oil/water separator to the first bend in the pipe, determining the pipe's upgradient bearing, then subsequent excavation at functional intervals along the pipe in a perpendicular direction to the anticipated pipe location in order to track the pipe's position and extent. Section A-A' in Figure 5.2 shows a longitudinal section of the site along the french underdrain system.

Excavation "A" revealed a 6-inch-diameter, cast iron drain pipe laid from the north oil/water separator with an upgradient bearing to the west-southwest. Approximately 2 feet from the north oil/water separator the drain pipe crossed under an adjacent reinforced concrete sanitary sewer line and turned 90 degrees to the north-northwest about 6 inches past the sewer, using two consecutive 45-degree elbows. At the upgradient end of this 90-degree bend, the drain pipe transitioned to 6-inch-diameter, galvanized, corrugated



SECTION A – A'

N.T.S.



SECTION E – E'

N.T.S.

SECTION D – D'

N.T.S.

SECTION C – C'

N.T.S.

SECTION B – B'

N.T.S.

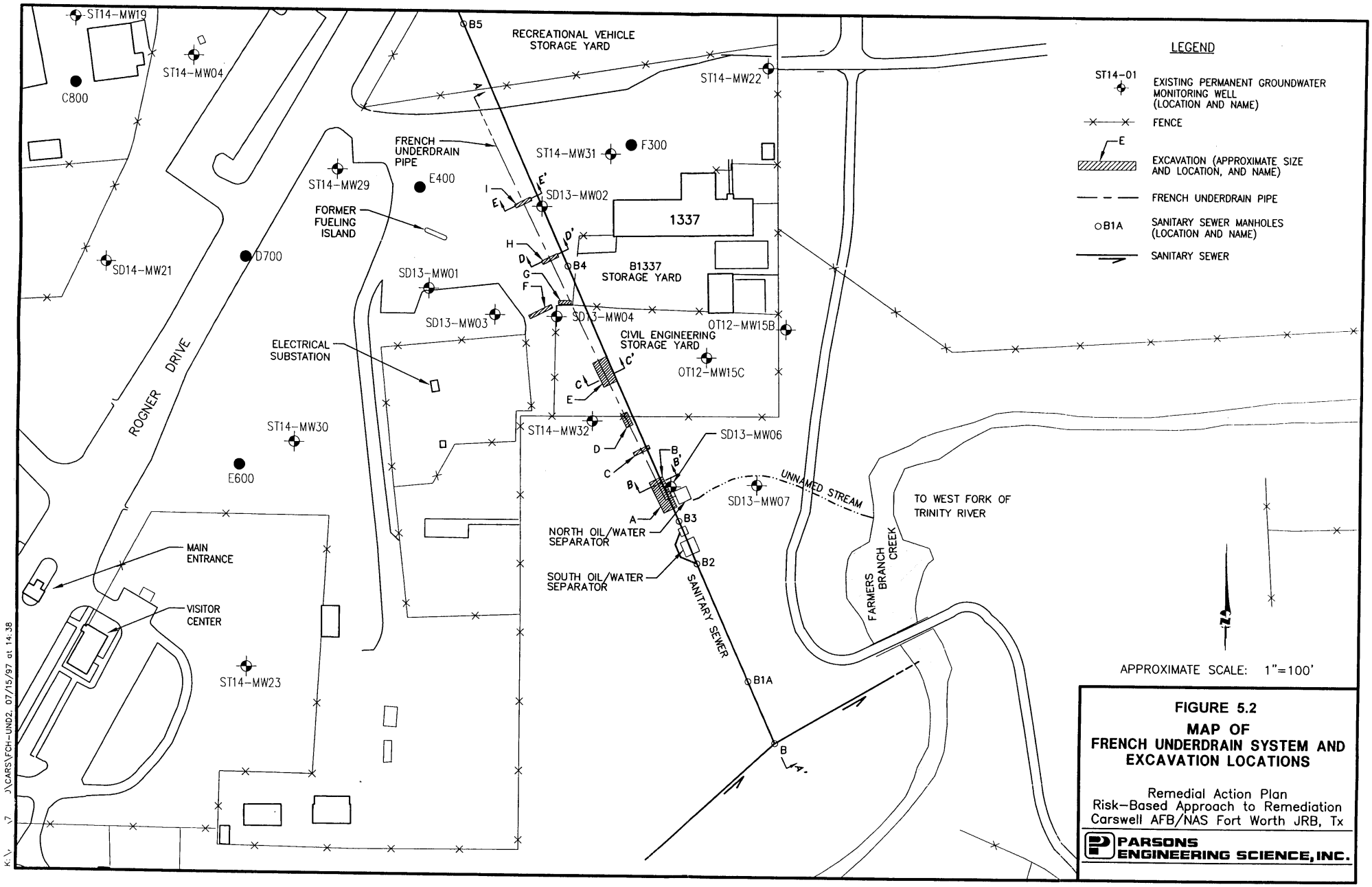
FIGURE 5.1

HYDROGEOLOGIC SECTIONS SHOWING FRENCH UNDERDRAIN SYSTEM

Remedial Action Plan
Risk–Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Tx

PARSONS ENGINEERING SCIENCE, INC.

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ST14-MW19
ST14-MW04
C800
B5
RECREATIONAL VEHICLE STORAGE YARD
ST14-MW22
LEGEND
ST14-01
EXISTING PERMANENT GROUNDWATER MONITORING WELL (LOCATION AND NAME)
FENCE
E
EXCAVATION (APPROXIMATE SIZE AND LOCATION, AND NAME)
FRENCH UNDERDRAIN PIPE
B1A
SANITARY SEWER MANHOLES (LOCATION AND NAME)
SANITARY SEWER
FRENCH UNDERDRAIN PIPE
ST14-MW31
F300
ST14-MW29
E400
SD13-MW02
1337
FORMER FUELING ISLAND
SD14-MW21
D700
SD13-MW01
B4
B1337 STORAGE YARD
SD13-MW03
SD13-MW04
OT12-MW15B
ELECTRICAL SUBSTATION
CIVIL ENGINEERING STORAGE YARD
OT12-MW15C
ROGNER DRIVE
ST14-MW30
ST14-MW32
SD13-MW06
E600
UNNAMED STREAM
SD13-MW07
TO WEST FORK OF TRINITY RIVER
NORTH OIL/WATER SEPARATOR
B3
MAIN ENTRANCE
SOUTH OIL/WATER SEPARATOR
B2
SANITARY SEWER
FARMERS BRANCH CREEK
VISITOR CENTER
ST14-MW23
B1A
B
APPROXIMATE SCALE: 1"=100'
FIGURE 5.2
MAP OF
FRENCH UNDERDRAIN SYSTEM AND EXCAVATION LOCATIONS
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Tx
PARSONS ENGINEERING SCIENCE, INC.
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metal pipe (CMP), perforated with single rows of 0.25-inch diameter holes drilled along the bottom of the pipe at an approximate spacing of 8 holes per foot. The CMP continued upgradient, parallel to the sanitary sewer line, sharing the same trench and gravel bedding material. A conceptual cross-section of the system, perpendicular to the underdrain pipe, at excavation "A" is shown in Section B-B' in Figure 5.1.

At all excavated locations where the CMP was found, it was observed to be perforated and bedded in a layer of uniform, coarse gravel. In excavations "A", "B", and "C", the gravel was overlain by clay soils, while in excavations "D", "E", "H", and "I", the gravel was overlain by loose fill material.

5.2.2 Partial Removal Activities

The engineered components of the french underdrain system (SWMU 64) and the related investigative excavations were partially or fully removed using procedures approved by TNRCC IHW before and/or during implementation. During the course of investigation activities, some excavations were backfilled immediately after determining the presence (or absence) and orientation of the CMP and noting the subsurface lithology. The typical backfilling method involved replacing the excavated soils, unless otherwise specified, in roughly 1-foot lifts and thoroughly compacting it with the backhoe bucket to grade. Other excavations were left open during the investigation to allow subsequent abandonment of the french underdrain system components. After completing abandonment activities, these excavations were backfilled in sequence from downgradient to upgradient position. Where excavations were made in paved areas, asphalt concrete was installed to repair the paved surface. Specific abandonment and backfilling activities for pertinent excavations are described in the following paragraphs.

Observations during the investigation activities suggest that the CMP underdrain was perforated along its entire length. The CMP also was positioned in saturated gravels, particularly the portion upgradient from excavation "E". Therefore, abandoning the pipe in place as initially planned by filling it with cement/bentonite grout was no longer considered a viable option. The alternate approach, which was approved by TNRCC IHW, was to remove several sections of the pipe, totaling 52 linear feet. Several other sections of pipe, totaling 11 feet, were disconnected from service, and the remainder was left in place. To minimize groundwater flow through the remaining sections of pipe and the gravel layer, several excavations were backfilled with impermeable material in the saturated zone. TNRCC IHW personnel were in the field when these changes were made, and concurred with the approach before implementation. TNRCC IHW later concurred by letter (dated 6-18-96 and 7-19-96) with the implemented abandonment procedures.

Approximately 20 linear feet of the underdrain pipe and surrounding gravel bedding material was removed from excavation "A". An equivalent length of bedding also was removed, in 5- to 7-foot sections, from beside the adjacent sanitary sewer line. As each section of bedding material was removed, the excavation was backfilled to a level at least 6 inches above the observed water table with the clay-rich soil obtained from the excavation. The removed gravel material was mixed with the clay soils and replaced above the water table, followed by at least 2 feet of clay soils to grade.

Approximately 18 linear feet of the CMP and surrounding gravel bedding was removed from excavation "D". Bedrock was encountered at an approximate depth of 10 feet bgs, and the water table was observed at a depth of roughly 9 feet bgs. Groundwater entering the excavation was pumped to the inlet port of the north oil/water separator (SWMU 67), in accordance with onsite direction from TNRCC IHW (pers. comm. Tim Sewell). The water from the north oil/water separator discharged to the unnamed stream. The excavation was then filled with bentonite chips to an elevation approximately 6 inches above the observed water table. The removed gravel bedding was mixed with clay soil obtained from a nearby borrow source and replaced above the water table. The remainder of the excavation was backfilled to grade with more than 2 feet of clay soil.

Within excavation "E", a 14-foot length of CMP was successfully removed from the notch-cut in the floor of the trench, but a section of CMP roughly 7 feet long became crushed and shredded and could not be removed. The notch was over-excavated to facilitate removal of the pea gravel bedding within it. All other gravel bedding was removed from the main trench in a zone 12 to 14 feet wide and 21 feet long. Gravel bedding was not removed from the immediate vicinity of the sanitary sewer line that shared the trench with the CMP in order to avoid damage to this active utility. Groundwater entering the excavation ponded roughly 9 feet bgs and flowed in as fast as it could be removed by pumping to the north oil/water separator. The excavation was filled with bentonite chips to an elevation approximately 6 inches above the observed water table. The removed gravel bedding was mixed with clay soil obtained from a nearby borrow source and replaced above the water table. The remainder of the excavation was backfilled to grade with more than 2 feet of clay soil.

After abandoning the french underdrain pipe (SWMU 64) and backfilling the excavations, the north oil/water separator (SWMU 67) was cleaned with a high pressure steam sprayer and the resulting liquids were pumped to the unnamed stream. The north oil/water separator structure measured 14 feet long, 11.6 feet wide, and 8 feet deep. It was constructed of steel-reinforced concrete with 6-inch-thick walls, and it employed a hanging baffle as the oil and water separation device. Inspection of the structure indicated no identifiable cracks, but some portions of the concrete remained stained after cleaning. The north oil/water separator was demolished and removed. The broken pieces of the structure were transported to Big City Concrete Recyclers in Fort Worth, Texas, for disposal on 28 June and 1 July 1996. A Non-Hazardous Waste Manifest for the concrete is on file with Carswell AFBCA. The concrete headwall at the upstream end of the unnamed stream was left in place to control erosion. After soil sampling at SWMU 67 (see subsequent discussion), the oil/water separator excavation pit was backfilled with clay-rich soil to grade.

These removal activities halted the flow of groundwater into the north oil/water separator and the unnamed stream. The remaining engineered components of the SWMU left in place will be considered as media of potential concern in subsequent sections of this RAP.

5.3 DETERMINING MEDIA AND CHEMICALS OF POTENTIAL CONCERN

It is the intention of the Air Force to obtain approval for a remedial action for Site SD13 that will protect human health and the environment from unacceptable exposures

to SWMU-related chemicals. To accomplish this objective, the COPCs that will likely drive potential risks and impact the final remedial requirements at the site were identified. Previous IRP site investigations (Radian, 1985, 1988, 1989, and 1991), the risk-based work plans (Parsons ES, 1994a and 1995), and the RFI (Law, 1994) indicated that COPCs for Site SD13 include petroleum and chlorinated hydrocarbons (i.e., benzene, TCE, PCE, methylene chloride) and possibly a few inorganic metals that may have been mobilized by localized conditions. These specific chemical constituents were initially defined as COPCs based on existing site characterization data, the chemical nature of the suspected sources (i.e., JP-4 jet fuel and gasoline releases that were collected at the french underdrain and oil/water separator), and the analytical requirements specified by the TNRCC for the investigation of IRP sites pursuant to 30 TAC Chapter 335.

The COPCs for Site SD13 to be considered in detail in this RAP are based on a comparison of measured site concentrations to Risk Reduction Standard Number 1 and 2 levels. Analytical results for inorganic compounds in soil and groundwater were first compared to established background concentrations (i.e., Risk Reduction Standard Number 1 levels). Those inorganic compounds that exceeded Risk Reduction Standard Number 1 levels and all detected organic compounds were then compared to chemical-specific Risk Reduction Standard Number 2 levels. Tables 5.1, 5.2, 5.3 present maximum detected concentrations by sampling event and the Risk Reduction Standard Number 2 levels for soil, groundwater, and surface water, respectively. Compounds whose maximum detected concentrations exceed their applicable Risk Reduction Standard Number 2 level are shaded. Media characterized by SWMU-related compounds at concentrations greater than Risk Reduction Standard Number 2 levels will be evaluated in greater detail in the remaining sections of this RAP. The objective of this two-stage comparison is to delineate that media and chemical contamination that may warrant additional removal or decontamination to eventually be closed in accordance with 30 TAC Chapter 335, Section 335.8.

5.3.1 Comparison to Risk Reduction Standard Number 1 Levels

Inorganic compounds detected in soil, alluvium groundwater, and surface water at Site SD13 were first compared to established background levels prior to comparison to the Risk Reduction Standard Number 2 levels. If site concentrations were not above background, the compound was not carried forward in the analysis. Sitewide background data for shallow soil (i.e., 0 to 15 feet bgs), alluvium groundwater, and surface water, as presented in the *Basewide Background Study* (Jacobs, 1997), were used to define single-point numeric estimators of background concentrations. A total of 30 surface and subsurface soil samples, 12 groundwater samples, and 8 surface water samples were used to estimate background concentrations for inorganic compounds. The *Basewide Background Study* (Jacobs, 1997) uses a tolerance interval (TI) method developed by EPA to estimate background concentrations. In summary, the *Basewide Background Study* estimated an upper tolerance limit (UTL) of the distribution of the compound in the background data population using the general methodology set forth by EPA (1992) in its *Addendum to the Interim Final Guidance of Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities.*

A UTL is designed to bound a specific portion of the true but unknown population (i.e., coverage) with a specified degree of confidence. Consequently, a UTL can be

used as a reference value, with a specified level of confidence, to define that concentration below which a specified proportion of the background data distribution will occur. The reference value previously selected as the appropriate background concentration estimator for facilities at Carswell AFB/NAS Fort Worth JRB is the UTL with 95 percent confidence and 95 percent coverage (Jacobs, 1997). This value represents the concentration at which one can say, with 95 percent confidence, that 95 percent of the background data will be equal to or less than this concentration. This means that any discrete sampling result from a site that is above this selected reference value has only a 5 percent probability of being drawn from the background data population. Consequently, exceedances of the selected UTL can be used to infer the presence of site-related constituents. This selected UTL will usually provide reasonable control of false positive and negative rates for large background sample sets.

The media- and chemical-specific UTLs developed as part of the *Basewide Background Study* (Jacobs, 1997) were used without modification as the established background concentrations for Site SD13. It is important to note that a relatively small background data set was used to establish the desired UTLs for groundwater. A background data set with less than 30 samples can result in a degree of coverage that is something less than 95 percent. This means that it is more difficult to distinguish high naturally occurring background values from potentially site-related contamination. Consequently, rather than relying on only one exceedance to imply potential SWMU-related contamination, the expected number of times that the established UTL for background would be exceeded by samples taken from the same population was statistically estimated (by calculating the degree of coverage possible from the sample size). If the number of discrete site samples that fell above the established UTL was equal to or less than this expected number of exceedances, the chemical was determined to be present at background concentrations. Appendix G provides additional summary information on the background study results and the methodology used to compare site-specific concentrations to established background UTLs.

Appendix A presents the analytical results for all samples collected under the 1994/1995 risk based sampling event, organized by environmental medium, and a summary of the data quality evaluation results. All analytical results measured below the MDL were identified as not detected (U qualified) and reported at the PQL. This is consistent with EPA (1989) guidance on how to use nondetected values in quantitative risk assessments. All analytical results measured above the MDL but below the PQL were identified as estimated but usable data (J qualified). All analytical results measured above the PQL were identified as detected concentrations and not qualified. These data also were subject to a usability/acceptability review that included (1) a review of chain-of-custody records, reported holding times, status of instrument calibration, and reported recoveries for laboratory control samples and matrix spike/matrix spike duplicates; (2) analyzing and using laboratory and field blanks to qualify reported sample concentrations; and (3) measuring the reproducibility of sampling techniques and laboratory analytical precision using blind field duplicates/replicates.

Appendix A also presents a summary of all detections for the quarterly groundwater monitoring events for 1995/1996, a summary of all analytical results for detected chemicals measured during the January 1997 groundwater monitoring event, and the results of the 1997 surfacewater sampling. All analytical results obtained during the

1995/1996 groundwater monitoring measured between the MDL and PQL have been F (rather than J) qualified. All analytical results obtained during the 1997 groundwater monitoring measured between the MDL and PQL have been F (rather than J) qualified.

Table 5.1 includes only those inorganic chemicals detected in site soil above established UTLs for background soils. Arsenic, barium, cadmium, lead, manganese, and zinc were measured in site soils at Site SD13 at concentrations above the background UTLs. Table 5.2 includes only those inorganic compounds measured in site groundwater above established background UTLs. Based on a comparison of expected to observed exceedances (see Appendix G), the following inorganic compounds were measured in site groundwater at Site SD13 at concentrations above background: aluminum, arsenic, barium, beryllium, cadmium, calcium, chromium, copper, iron, lead, magnesium, manganese, potassium, sodium, vanadium, and zinc. Finally, Table 5.3 includes only those inorganic compounds measured above established UTLs for background surface water. From this comparison, antimony, arsenic, barium, beryllium, iron, lead, and selenium were detected in site surface water samples at concentrations above background levels. Those inorganic chemicals that have been detected at the site in specific media at concentrations above established background levels are compared next to Risk Reduction Standard Number 2 levels to develop a final summary of media and chemicals of potential concern. No background comparison for organic compounds was completed.

5.3.2 Comparison to Risk Reduction Standard Number 2 Levels

The TNRCC has developed generic Risk Reduction Standard Number 2 levels for both residential and non-residential exposure scenarios. These generic levels can be used directly to ascertain the need for additional removal or decontamination activities at a site to be remediated and/or closed in compliance with Risk Reduction Standard Number 2. According to the final land use plan for Carswell AFB/NAS Fort Worth JRB, Site SD13 is planned to be released for open space/recreational space use by the year 1998 (US Air Force, 1994). As described in Section 3, the site is currently maintained as an abandoned area with limited access. Consequently, under both current and proposed future site conditions, Site SD13 strictly meets the definition of a nonresidential property as defined at 30 TAC Chapter 335, Section 335.552. The property is not now or planned to be used for human habitation. Proposed future uses of the site may meet the Standard Industrial Classification (SIC) major group numbers 7991 (i.e., physical fitness facilities such as a groomed bike trail) and 8422 (i.e., maintained landscape areas). These SIC group numbers are defined by TNRCC to represent non-residential property.

However, at the request of TNRCC IHW, Risk Reduction Standard Number 2 levels based on a residential exposure scenario were used as the initial comparison criteria in this screening-level evaluation for Site SD13. These cleanup levels are generally either (1) Texas or federal promulgated standards (e.g., MCLs), or, when these types of levels are not available or do not provide appropriate protection for human health and the environment, (2) health-based medium-specific concentrations (MSCs) calculated using the algorithms and exposure factors set forth at 30 TAC Chapter 335, Section 335.558. For those sites that are classified as non-residential, the TNRCC still requires compliance with promulgated standards for groundwater or, if not available, compliance with groundwater MSCs that are approximately 3 times greater than the

MSCs based on residential exposure assumptions. Since the objective of this initial evaluation is only to identify the media and chemicals that may warrant further evaluation, the Air Force has agreed to use the residential MSCs at this stage. However, determination of final removal and/or remediation requirements for Site SD13 will be based on exposure assumptions that are more representative of the types of activities that could reasonably occur at this site, both now and in the future. Such a site-specific evaluation is presented in Section 8 of this RAP. The following summarizes the derivation of the residential MSCs used to identify the media and chemicals to consider in greater detail in the remainder of this RAP. Example calculations of MSCs are included in Appendix H.

5.3.2.1 MSCs for Soil

The health-based MSCs for soil have been developed so that residual concentrations of Class A and B carcinogens do not result in a cumulative risk in excess of 10^{-6}; Class C carcinogens do not result in a cumulative risk in excess of 10^{-5}; and noncarcinogens do not result in a cumulative hazard index (HI) of 1. The routes of exposure included in the health-based MSCs for soils provided by TNRCC are incidental direct ingestion of contaminated soil, inhalation of contaminated soil as fugitive dust, and/or inhalation of volatilizing chemicals. Although the potential for volatilization and fugitive dust generation is likely nominal at Site SD13 because the majority of the soil is covered by impermeable materials such as cement and asphalt, the health-based MSCs include the inhalation pathway. The algorithm specified by TNRCC and all default input assumptions were used for this calculation; the Risk Reduction Standard Number 2 levels for soil are presented in Table 5.1.

MSCs that are protective of groundwater quality also have been developed. These soil concentrations are either (1) 100 times the groundwater level, or (2) the concentration in soil that does not produce a leachate in excess of the MCLs or groundwater MSCs when subjected to the Synthetic Precipitation Leaching Procedure. For this screening-level evaluation, the soil-to-groundwater cross-media protection criteria was assumed to be 100 times the identified groundwater level.

5.3.2.2 MSCs for Groundwater

Health-based MSCs for groundwater, which are used to derive the above-mentioned soil-to-groundwater concentrations, were developed to provide the maximum protection required to make the groundwater suitable for use as a potential unrestricted drinking water source. As noted in Section 4, a well survey completed in September 1995 (Appendix C) indicated that no wells within at least 0.5 mile of the site are used for potable water. Additionally, as discussed in Section 3, it is not economical to develop the Upper Zone alluvium as a potential water supply due to limited volume and pumping capabilities, and its vulnerability to surface and stormwater pollution (US Air Force, 1994). Potable water in the area is derived primarily from surface water sources, although a few wells near the Base, completed primarily in the lower sand unit of the Paluxy aquifer (which is separated from the Upper Zone alluvium by the 30- to 40-foot-thick Goodland/Walnut aquitard), are used.

In the absence of Texas or federal promulgated standards, health-based MSCs for groundwater were calculated in accordance with 30 TAC Chapter 335, Section

335.558(b)(1). Ingestion of groundwater is the only exposure pathway incorporated into these MSCs. The groundwater MSCs are defined so that the individual risk for carcinogens does not exceed 10^{-6}; and the HI for noncarcinogens does not exceed 1. The Risk Reduction Standard Number 2 levels for groundwater are presented in Table 5.2; an example derivation of the MSC for groundwater is presented in Appendix H.

5.3.2.3 MSCs for Surface Water

In addition to protection of human health, the need for environmental protection must be considered when identifying COPCs for Site SD13. Generally, protection of surface water and groundwater will be of primary concern. The target remedial objective for surface water is to prevent the discharge of any concentration of contaminant into the water body. Risk Reduction Standard Number 2 levels for surface water are based on the Texas Surface Water Quality Standards of Title 30 TAC, Chapter 307 and 319. Freshwater acute and freshwater chronic surface water quality criteria have been defined. In the event that no surface water quality criterion has been identified, either a Texas or federal promulgated standard or the health-based MSC based on ingestion was identified as the MSC for surface water. The Risk Reduction Standard Number 2 levels for surface water are presented in Table 5.3.

5.3.2.4 Summary of Media and Chemicals of Potential Concern

The COPCs for Site SD13 were identified by comparing the maximum detected concentrations for each chemical detected in soil, groundwater, and surface water during the 1990 sampling event, the 1994 RFI sampling event, the 1994/1995 risk-based sampling event, the 1995/1996 groundwater monitoring sampling events, and the first quarter 1997 groundwater monitoring sampling event to the Risk Reduction Standard Number 2 levels for a residential exposure scenario. This information is presented in Tables 5.1, 5.2 and 5.3 for soils, groundwater, and surface water, respectively. If the maximum site concentration did not exceed the Risk Reduction Standard Number 2 levels, the chemical is not identified as a COPC for Site SD13. Use of the Risk Reduction Standard Number 2 levels based on a residential exposure assumption ensures that no additional removal or remediation would be warranted to protect human health and the environment for chemicals below the target level, regardless of current or future land uses. If the maximum measured site concentration exceeded the Risk Reduction Standard Number 2 target level, the compound is identified as a COPC, and retained for further evaluation.

Table 5.4 summarizes the COPCs for Site SD13. The following compounds were identified as COPCs in soil: hexachlorobenzene, n-nitroso-di-n-propylamine, arsenic, cadmium, lead, and manganese. The following compounds were identified as COPCs in groundwater: benzene, methylene chloride, tetrachloroethylene, benz(a)anthracene, bis(2-ethylhexyl)phthalate, aluminum, arsenic, barium, beryllium, lead, manganese, and zinc. Antimony, arsenic, iron, lead, and selenium were conservatively identified as COPCs for surface water. However, antimony is the only chemical measured recently in surface water at concentrations above the most stringent applicable Risk Reduction Standard Number 2 levels. This concentration of antimony was measured *upstream* of the now-removed oil/water separator and dry unnamed stream.

TABLE 5.1
COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - SOIL
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Groundwater Protective Soil Concentration[a]	Health-Based Soil Conc.[b]	Excceeds Industrial Target Level[c]
Soil						
Volatile Organic Compounds						
1,2,3,4-Tetramethylbenzene	mg/kg	-[d]	19	-	-	N
1,2,3-Trimethylbenzene	mg/kg	-	9.6	-	-	N
1,2,4-Trimethylbenzene	mg/kg	-	28	1.83E+02	1.37E+04	N
1,3,5-Trimethylbenzene	mg/kg	-	14	1.83E+02	1.37E+04	N
Acetone	mg/kg	0.034	-	3.65E+02	3.82E+03	N
Benzene	mg/kg	-	0.0024 J[e]	5.00E-01	1.33E+00	N
Chlorobenzene	mg/kg	-	2.4	1.00E+01	2.56E+02	N
Ethylbenzene	mg/kg	30	30	7.00E+01	1.14E+04	N
Methylene Chloride	mg/kg	0.016	-	5.00E-01	1.07E+01	N
Toluene	mg/kg	-	2.5	1.00E+02	3.58E+03	N
Xylenes (Total)	mg/kg	29	56	1.00E+03	5.47E+03	N
Semivolatile Organic Compounds						
1,2,4-Trichlorobenzene	mg/kg	-	0.053 J	7.00E+00	6.78E+02	N
1,4-Dichlorobenzene	mg/kg	-	0.053 J	7.50E+00	8.64E+01	N
2-Chlorophenol	mg/kg	-	0.1 J	1.83E+01	1.37E+03	N
2-Methylnaphthalene	mg/kg	-	0.46	-	-	N
4-Chloro-3-methylphenol	mg/kg	-	0.098 J	-	-	N
Acenaphthene	mg/kg	-	0.059 J	2.19E+02	1.34E+04	N
Di-n-butylphthalate	mg/kg	-	0.068 J	3.65E+02	2.74E+04	N
Fluorene	mg/kg	-	0.025 J	1.46E+02	9.60E+03	N
Hexachlorobenzene	mg/kg	-	0.46	1.00E-01	4.00E-01	Y
N-Nitroso-di-n-propylamine	mg/kg	-	0.054 J	1.22E-03	9.15E-02	Y
Naphthalene	mg/kg	-	2.9	1.46E+02	4.91E+03	N
Phenol	mg/kg	-	0.12 J	2.19E+03	1.65E+05	N

TABLE 5.1

COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - SOIL

REMEDIAL ACTION PLAN

RISK-BASED APPROACH TO REMEDIATION

CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Groundwater Protective Soil Concentration[/a]	Health-Based Soil Conc.[b/]	Excceeds Industrial Target Level[/c]
Soil						
Pyrene	mg/kg	-	0.049 J	1.10E+02	8.20E+03	N
Metals						
Arsenic	mg/kg	12	-	3.66E-01	3.66E-01	N
Cadmium	mg/kg	1.5	-	5.00E-01	1.37E+02	Y
Copper	mg/kg	66	-	-	-	N
Lead	mg/kg	36	-	1.50E+00	5.00E+02	Y
Manganese	mg/kg	360	-	8.40E+01	6.31E+03	Y
Zinc	mg/kg	33	-	1.10E+03	8.23E+04	N
Petroleum Hydrocarbons						
Petroleum Hydrocarbons	mg/kg	-	8800	-	-	N
Total Extractable Hydrocarbons	mg/kg	-	2200	-	-	N

Note: Maximum measured site concentrations that exceed Risk Reduction Standard Number 2 target levels are identified with shading

Footnotes:

a/ soil concentration that will be protective of groundwater for residential use (100 x residential groundwater target level or health-based soil concentration whichever is lower).

b/ soil concentration that will be protective of human health under residential use (Medium Specific Concentration calculated per 30 TAC 335.559).

c/ maximum contaminant level exceeds Risk Reduction Standard Number 2 target levels for industrial use.

d/ - : compound not analyzed for.

e/ J : compound detected above the Method Detection Limit but below the Practical Quantitation Limit.

TABLE 5.2

COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - GROUNDWATER

REMEDIAL ACTION PLAN

RISK-BASED APPROACH TO REMEDIATION

CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration RFI 1990	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Conc. Groundwater Monitoring 1995/1996	Maximum Conc. Groundwater Monitoring 1997	Target GW Concentration [a]	Excceeds Industrial Target Level[c]
Groundwater								
Volatile Organic Compounds								
1,2,3,4-Tetramethylbenzene	mg/L	- [b]	-	0.058	-	-	-	N
1,2,3-Trimethylbenzene	mg/L	-	-	0.006	-	-	-	N
1,2,4-Trimethylbenzene	mg/L	-	-	0.017	-	ND [c]	1.83E+00 [d]	N
1,3,5-Trimethylbenzene	mg/L	-	-	0.01	-	-	1.83E+00 [d]	N
Benzene	mg/L	0.002 J [e]	-	0.059	0.0008	0.00087 F [f]	5.00E-03 [g]	Y
Bromodichloromethane	mg/L	-	0.0038	-	ND	ND	1.00E-01 [g]	N
Chlorobenzene	mg/L	0.0036	-	.0025J	ND	ND	1.00E-01 [g]	N
Chloroform	mg/L	-	0.0052	-	0.00036 TR [h]	ND	1.00E-01 [g]	N
cis-1,2-Dichloroethylene	mg/L	-	-	-	0.0009	ND	7.00E-02 [g]	N
Dibromochloromethane	mg/L	-	0.00047	-	ND	ND	1.00E-01 [g]	N
Ethylbenzene	mg/L	ND	0.409	0.074	0.00067	0.0074	7.00E-01 [g]	N
Methylene Chloride	mg/L	-	0.012	-	0.014	ND	5.00E-03 [g]	N
Tetrachloroethylene	mg/L	-	0.0091	-	0.0061	ND	5.00E-03 [g]	Y
Toluene	mg/L	0.059	0.0048	0.069	0.00644	0.00075	1.00E+00 [g]	N
Trichloroethene	mg/L	-	-	0.0014	0.0036	ND	5.00E-03 [g]	N
Xylenes (Total)	mg/L	ND	1.089	0.062	0.0036	0.0098	1.00E+01 [g]	N
Semivolatile Organic Compounds								
2-Methylnaphthalene	mg/L	-	-	0.008 J	.049 TR	-	-	N
Acenaphthene	mg/L	-	-	ND	0.0025 TR	-	2.19E+00 [d]	N
Benz(a)anthracene	mg/L	-	-	ND	.0012TR	-	1.17E-04 [d]	Y
Benzyl butyl phthalate	mg/L	-	-	ND	0.053	-	7.30E+00 [d]	N
Bis(2Ethylhexyl)phthalate	mg/L	-	-	ND	.0107 TR	-	6.08E-03 [d]	N
Di-N-Butylphthalate	mg/L	-	-	ND	.00164 TR	-	3.65E+00 [d]	N

TABLE 5.2

COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - GROUNDWATER

REMEDIAL ACTION PLAN

RISK-BASED APPROACH TO REMEDIATION

CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration RFI 1990	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Conc. Groundwater Monitoring 1995/1996	Maximum Conc. Groundwater Monitoring 1997	Target GW Concentration [a]	Excceeds Industrial Target Level[c]
Groundwater								
Dibenzofuran	mg/L	-	-	0.001 J	.00307 TR	-	1.46E-01 [d]	N
Fluorene	mg/L	-	-	ND	.00173 TR	-	1.46E+00 [d]	N
Isophorone	mg/L	-	-	ND	0.013	-	8.96E-02 [d]	N
Naphthalene	mg/L	-	-	0.005 J	.0072 TR	-	1.46E+00 [d]	N
Phenol	mg/L	-	-	ND	.0093 TR	-	2.19E+01 [d]	N
Pyrene	mg/L	-	-	ND	.0011 TR	-	1.10E+00 [d]	N
Metals							-	
Aluminum	mg/L	12	1.5	-	49.6	0.088 F	3.65E+01 [d]	N
Arsenic	mg/L	0.042	0.075	-	0.046	ND	5.00E-02 [g]	Y
Barium	mg/L	0.63	260	-	4.56	0.164	2.00E+00 [g]	Y
Beryllium	mg/L	ND	-		0.004	ND	4.00E-03 [g]	Y
Cadmium	mg/L	ND	0.004	-	ND	ND	5.00E-03 [g]	N
Chromium	mg/L	0.024	0.034	-	0.065	ND	1.00E-01 [g]	N
Cobalt	mg/L	0.017	ND	-	ND	ND	2.19E+00 [g]	N
Copper	mg/L	0.023	5	-	0.07	0.0108 F	1.46E+00 [d]	N
Iron	mg/L	44	17 J	-	63.6	0.12	1.10E+01 [d]	N
Iron, Ferrous	mg/L	-	680	-	-	ND	-	N
Lead	mg/L	0.031	7.3	-	0.161	ND	1.50E-02 [d]	N
Lead (filtered)	mg/L	-	.0049 JB	-	-	ND	-	N
Manganese	mg/L	0.46	220	-	1.86	0.06745	8.40E-01 [d]	Y
Vanadium	mg/L	0.058	-	-	0.102	ND	2.56E-01 [d]	N
Zinc	mg/L	0.13	48	-	0.108	ND	1.10E+01 [d]	Y
Petroleum Hydrocarbons								
Methane	mg/L	-	5.3	-	-	10.8	-	N

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TABLE 5.2
COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - GROUNDWATER
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration RFI 1990	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Conc. Groundwater Monitoring 1995/1996	Maximum Conc. Groundwater Monitoring 1997	Target GW Concentration [a/]	Excceeds Industrial Target Level[/c]
Groundwater								
Petroleum Hydrocarbons	mg/L	-	5.2	1300	-	-	-	N
Total Extractable Hydrocarbons	mg/L	-	-	25	-	-	-	N
Total Volatile Hydrocarbons	mg/L	-	-	1300	-	-	-	N

Note: Maximum measured site concentrations that exceed Risk Reduction Standard Number 2 target levels are identified with shading

Footnotes:

a/ based on MCL per SDWA or MSC per 30 TAC 335.559.

b/ - : compound not analyzed for.

c/ ND : all results below Method Detection Limit.

d/ Target groundwater level based on MSC.

e/ J : compound detected above the Method Detection Limit but below the Practical Quantitation Limit.

f/ F : compound detected above the Method Detection Limit but below the Practical Quantitation Limit.

g/ Target groundwater level based on MCL

h/ TR: compound detected above the Method Detection Limit but below the Practical Quantitation Limit.

TABLE 5.3
COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - SURFACEWATER
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum concentration RFI 1990 [a]	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Concetration GSAP [b] 1997	Target SW Concentration			
						Human Health [c]	Aquatic Chronic [c]	Aquatic Acute [c]	GW Target Level Residential [d]
Surface Water									
Volatile Organic Compounds									
1,2,3,4-Tetramethylbenzene	mg/L	- [e]	-	0.0333	-	-	-	-	-
1,2,4-Trimethylbenzene	mg/L	-	-	0.0021	-	-	-	-	1.83E+00 [f]
1,3,5-Trimethylbenzene	mg/L	-	-	0.0007	-	-	-	-	1.83E+00 [f]
Benzene	mg/L	0.00031	-	ND [g]	-	5.00E-03	-	-	5.00E-03 [h]
Chlorobenzene	mg/L	0.0028	-	0.0009	-	1.31E+00	1.31E+00	-	1.00E-01 [h]
Ethylbenzene	mg/L	0.00097	-	0.0005	-	-	-	3.20E+01	7.00E-01 [h]
Toluene	mg/L	0.00059	-	0.0015	-	-	-	1.75E+01	1.00E+00 [h]
Xylenes (Total)	mg/L	0.00053	-	0.0012	-	-	-	-	1.00E+01 [h]
Semivolatile Organic Compounds									
1,3-Dichlorobenzene	mg/L	0.0012	-	ND	-	-	-	-	3.25E+00 [f]
1,4-Dichlorobenzene	mg/L	0.0017	-	ND	-	7.50E-02	-	-	3.55E-03 [h]
2-Methylnaphthalene	mg/L	-	-	0.004	-	-	-	-	-
Petroleum Hydrocarbons									
Total Extractable Hydrocarbons	mg/L	-	1.2	0.5	-	-	-	-	-
Metals									
Antimony	mg/L	ND	-	-	0.01042	-	-	-	6.00E-03 [h]
Arsenic	mg/L	0.086	-	-	ND	5.00E-02	1.90E-01	3.60E-01	5.00E-02 [h]
Barium	mg/L	0.29	-	-	0.10299	2.00E+00	-	-	2.00E+00 [h]
Beryllium	mg/L	ND	-	-	0.00037	-	-	-	4.00E-03 [h]

TABLE 5.3
COMPARISON TO RISK REDUCTION STANDARD NUMBER 2 CLEANUP LEVELS - SURFACEWATER
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum concentration RFI 1990 [a/]	Maximum Concentration RFI 1994	Maximum Concentration Risk-Based 1994/1995	Maximum Concetration GSAP [b/] 1997	Target SW Concentration			
						Human Health [c/]	Aquatic Chronic [c/]	Aquatic Acute [c/]	GW Target Level Residential [d/]
Surface Water									
Iron	mg/L	26	-	-	0.03041	-	1.00E+00	-	1.10E+01 [f/]
Lead	mg/L	0.066	-	-	ND	-	4.80E-03	1.25E-01	1.50E-02 [h/]
Selenium	mg/L	30	-	-	ND	1.00E-02	5.00E-03	2.00E-02	5.00E-02 [h/]
Other Analyses									
Total Organic Carbon	mg/L	-	-	77.9	ND	-	-	-	-

Note: Maximum measured site concentrations that exceed Risk Reduction Standard Number 2 target levels are identified with shading

Footnotes:

a/ results provided for total metals. All dissolved metals analytical results all below MCLs.

b/ Groundwater Sampling and Analysis Plan.

c/ per Texas Surface Water Quality Standards 30 TAC 307.

d/ based on MCL per SDWA or MSC per 30 TAC 335.559.

e/ - : compound not analyzed for.

f/ Target groundwater level based on MSC.

g/ ND : all results below Method Detection Limit.

h/ Target groundwater level based on MCL

TABLE 5.4
CHEMICALS OF POTENTIAL CONCERN - SITE SD13
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

COPC	Rationale[a]
	Soil
Organics	
Hexachlorobenzene	1994/1995 risk-based maximum concentration > health-based MSC /b and groundwater protective MSC for residential land use
N-Nitroso-di-n-propylamine	1994/1995 risk-based maximum concentration >groundwater protective MSC for residential land use
Metals	
Arsenic	1994 RFI maximum concentration > health-based MSC and groundwater protective MSC for residential land use
Cadmium	1994 RFI maximum concentration >groundwater protective MSC for residential land use
Lead	1994 RFI maximum concentration >groundwater protective MSC for residential land use
Manganese	1994 RFI maximum concentration >groundwater protective MSC for residential land use
	Groundwater
Organics	
Benzene	1994/1995 risk-based maximum concentration > target groundwater concentration (MCL/c)
Methylene chloride	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MCL)
Tetrachloroethylene	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MCL)
Benzo(a)anthracene	1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MSC)
Bis(2-ethylhexyl)phthtalate	1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MSC)
Metals	
Aluminum	1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MSC)
Arsenic	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MCL)
Barium	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MCL)
Berylium	1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MCL)
Lead	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MSC)
Manganese	1994 RFI and 1995/1996 groundwater monitoring maximum concentration > target groundwater concentration (MSC)
Zinc	1994 RFI maximum concentration > target groundwater concentration (MSC)

TABLE 5.4
CHEMICALS OF POTENTIAL CONCERN - SITE SD13
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

COPC	Rationale[a]
Surface Water	
Metals	
Antimony	1997 surface water sampling maximum concentration > target surface water criteria (based on health-based residential groundwater ingestion/d)
Arsenic	1990 RFI maximum concentration/e > target surface water criteria (MCL)
Iron	1990 RFI maximum concentration/e > target surface water criteria (MCL and chronic aquatic criteria)
Lead	1990 RFI maximum concentration/e > target surface water criteria (residetnial groundwater ingestion MSC and chronic aquatic criteria)
Selenium	1990 RFI maximum concentration/e > target surface water criteria (human helath, chronic aquatic, acute aquatic and MCL)

a/ See data presented in Tables 5.1, 5.2, and 5.3
b/ Medium Specific Concentration - calculated per 30 TAC chapter 335
c/ Maximum Contaminant Level - per SDWA
d/ per Texas Water Quality Standards 30 TAC 307.2-307.10
e/ concentration based on totals metal analysis

5.4 SUMMARY OF SWMU-RELATED CONTAMINATION

The remaining discussion in this section of the RAP describes the results of several sampling events with regard to the nature and distribution of the COPCs in site media. Understanding the nature and extent of contamination that may ultimately drive additional removal and/or decontamination activities is an important step in defining the final site remedial/closure plan.

5.4.1 Sources of Contamination

Fuel hydrocarbon contamination at Site SD13 may be the result of small leaks and spills from the now-abandoned gasoline station and related underground storage tanks (USTs). The gasoline station was dismantled and abandoned in the early 1970s. During the 1995 risk-based sampling event, elevated concentrations of fuel hydrocarbons were detected in the soils at the northwestern corner of Site SD13. All other areas where soil samples have been collected during all previous sampling events resulted in low to not detected concentrations of fuel-related compounds. Consequently, soils at Site SD13 are not anticipated to be a significant source of groundwater contamination. The nature and extent of residual soil contamination at Site SD13 is reviewed in subsequent sections.

There is no known source of metals contamination within Site SD13. The 1994 RFI sampling event found detectable concentrations for several metals in soil at Site SD13. Samples were taken at three locations which roughly bounded the site to the north and south (SD13-05, SD13-06 and SD13-07). Soil samples were taken during the 1996 remedial action removal of the oil/water separator (SWMU 67). Analysis of these samples detected elevated concentrations of arsenic and lead. As described in more detail in Section 6 of this RAP, the presence of elevated concentrations of metals in downgradient soils (e.g., near SWMU 67) and in groundwater is likely attributable to localized geochemical conditions caused by organic contamination.

The 1994 RFI, the 1994/1995 risk-based, and the 1996 french underdrain removal sampling events have detected various halogenated compounds in soils at low concentrations. Only hexachlorobenzene has been detected at concentrations which exceed the MSC for soil based on a residential exposure scenario. There is no known source of halogenated chemicals at Site SD13. No hexachlorobenzene has been detected in groundwater at Site SD13.

There is no known source of non-fuel contaminants to groundwater at Site SD13. Groundwater monitoring during the 1990 and 1994 RFI sampling events, the 1994/1995 risk-based sampling, and the 1995-1997 groundwater monitoring events have detected various volatile organic, semi-volatile organic, and inorganic compounds in groundwater at Site SD13. Several halogenated compounds have been detected in groundwater at Site SD13 (Table 5.2). However, only methylene chloride and tetrachloroethylene have been detected above the Risk Reduction Standard Number 2 levels (i.e., in these cases, the promulgated standard of 0.005 mg/L). It should be noted that neither chemical was detected during the January 1997 groundwater monitoring event. The nature and extent of groundwater contamination at Site SD13 is reviewed in subsequent sections.

LNAPL was encountered in well SD13-MW04 at Site SD13 during the 1994 risk-based investigation and the Law (1994) RFI sampling event. Approximately 1 inch of LNAPL was measured in this well in March 1994 as part of the RFI sampling event. A sample of the LNAPL was collected at this time and submitted for TVH/TEH analysis. Analytical data indicate that the LNAPL from this well had a higher diesel fraction (TEH) than gasoline (TVH) fraction (Law, 1995), which is typical of heavier fuels such as JP-4 jet fuel or diesels. The TEH content is significantly less than that expected from a fresh source (i.e., 96,000 mg/L compared to 1,000,000 mg/L). Approximately 0.25 inch of LNAPL was measured at this sampling location during the September 1994 risk-based sampling event. Insufficient volume could be recovered for chemical evaluation. No LNAPL was measured in this well during the 1995 sampling event. In February 1997, a free product removal program was initiated at wells SD13-04 and SD13-07. As of June 1997, well SD13-04 did not contain free product, and well SD13-07 contained about 0.02 feet of product. Two additional removal events are scheduled to insure that all product has been removed from the area surrounding each well. The small quantity of LNAPL at Site SD13 is weathered and is not expected to be a significant source of hydrocarbon contamination.

5.4.2 Soil Gas Sampling Results

Soil gas samples collected at Site SD13 during the 1995 field effort were analyzed for TVH. Soil gas samples were used for secondary confirmation of the nature and extent of soil contamination at the site. Soil gas samples were used to obtain a better representation of soil contamination because the sample is extracted from a larger volume of soil than discrete soil samples from a splitspoon. Discrete soil samples are usually nonhomogeneous, and analytical results can vary greatly from sampling location to sampling location. Thus, soil gas samples provide a valuable indication of the type and magnitude of VOC contamination in the soil.

Figure 5.3 presents the TVH soil gas screening results for samples collected at Site SD13. These results suggest contaminated soils near the concrete pump island. These soil gas results were used to guide the installation of vent wells at the site, should engineered remediation of soils be necessary to achieve the desired level of risk reduction at the site. Section 5.4.3 presents a summary of the analytical soil results for the area defined by elevated TVH soil gas screening results.

5.4.3 Soil Sampling Results

Soil data at Site SD13 were collected during sampling events from March 1984 through December 1987 during installation of 14 permanent groundwater monitoring wells during the Stage 1, Phase II IRP investigation (Radian, 1985 and 1991). Although fuel hydrocarbon contamination was detected at Site SD13, it was not believed to be a significant source of contaminant mass for groundwater (Radian, 1991).

As part of the 1994/1995 risk-based remediation investigation, 59 soil samples were collected for chemical analysis from 42 new soil boreholes at Sites ST14 and SD13 to define the nature and extent of soil fuel hydrocarbon contamination. All soil samples were analyzed for BTEX and chlorobenzene; and about 25 percent of the most contaminated soil samples were analyzed for PAH compounds. Benzene was not

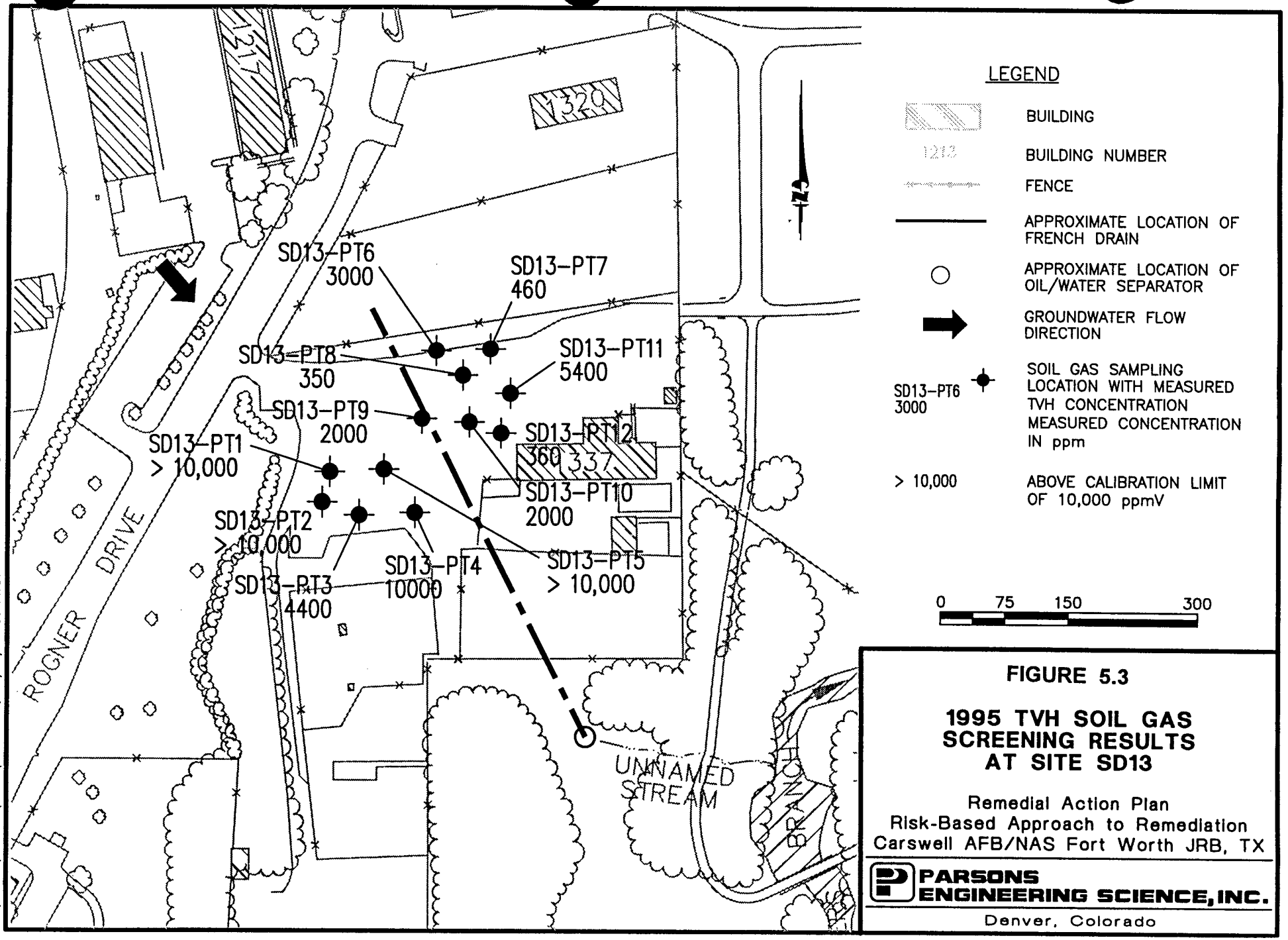


FIGURE 5.3

1995 TVH SOIL GAS SCREENING RESULTS AT SITE SD13

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detected in any of the soil samples collected at Site SD13. This is consistent with the conclusion of the 1990 RI that the soils at the abandoned gasoline station were not likely to be a significant source of groundwater contamination (Radian, 1991). However, elevated concentrations of other BTEX compounds were measured in the soil samples collected at ST14-MW29 at a depth of about 9.5 feet bgs and SD13-MW07 at about 2 to 4 feet bgs. This elevated concentration in shallow soils at SD13-MW07 is likely attributable to past surface water discharges of a fuel sheen from the oil/water separator. This sampling location is near the outfall of the now dismantled french underdrain system, the oil/water separator, and the unnamed stream. Traces of dissolved BTEX that were flushed from the site have apparently sorbed to shallow soils within the surface water flow path. No source area exists at this location. Figure 5.4 presents the extent of benzene and total BTEX detected in soils at Site SD13. The only detected concentration of hexachlorobenzene was measured at sampling location ST14-VW32. The concentration of hexachlorobenzene at this location was 0.46 mg/kg.

During installation of new monitoring wells as part of the 1994 RFI investigation, soil samples taken from locations SD13-MW05, SD13-MW06, and SD13-MW07 were analyzed for inorganic compounds. Arsenic was detected at all three locations with a maximum concentration of 12 mg/kg. Cadmium was also detected at concentrations above the established background UTL at all three locations, with a maximum concentration of 1.5 mg/kg. Lead was detected at all three sampling locations; however it was detected above the background UTL only at SD13-MW06 and SD13-MW07 (at a concentration of 36 and 13 mg/kg, respectively). Manganese was detected at all three locations at concentrations above the background UTL, with a maximum concentrations of 360 mg/kg.

Soil samples collected during the partial removal of the french underdrain system were analyzed for arsenic and lead, as requested by TNRCC IHW. Samples taken near the inlet and outlet pipes detected levels of both metals above their background UTLs. The maximum concentration of arsenic was 37.7 mg/kg, and the maximum concentration of lead was 26.6 mg/kg.

5.4.4 Groundwater Sampling Results

Groundwater samples were collected at Site SD13 as part of the earlier investigations to assess the nature and extent of dissolved contamination at this site. Elevated concentrations of benzene were detected in groundwater grab samples from three soil borings at Site SD13 during the initial IRP assessment activity in late 1985 (Radian, 1988). By 1990, however, benzene was detected at a concentration of only 2 µg/L in one (SD13-MW01) of the three wells sampled during the RI. This concentration of benzene was at the detection limit and is considered approximate (Radian, 1991).

Groundwater samples were collected at 21 different sampling locations in April 1994 for analytical testing as part of the 1994 RFI. Groundwater samples were also collected from 43 permanent groundwater monitoring wells in September 1994 and April 1995 as part of the risk-based investigation. Given the low rate of groundwater flow at Site SD13 (i.e., from 10 feet per year [ft/yr] to 145 ft/yr) and the relatively short period of time between sampling events, all three sets of analytical data from

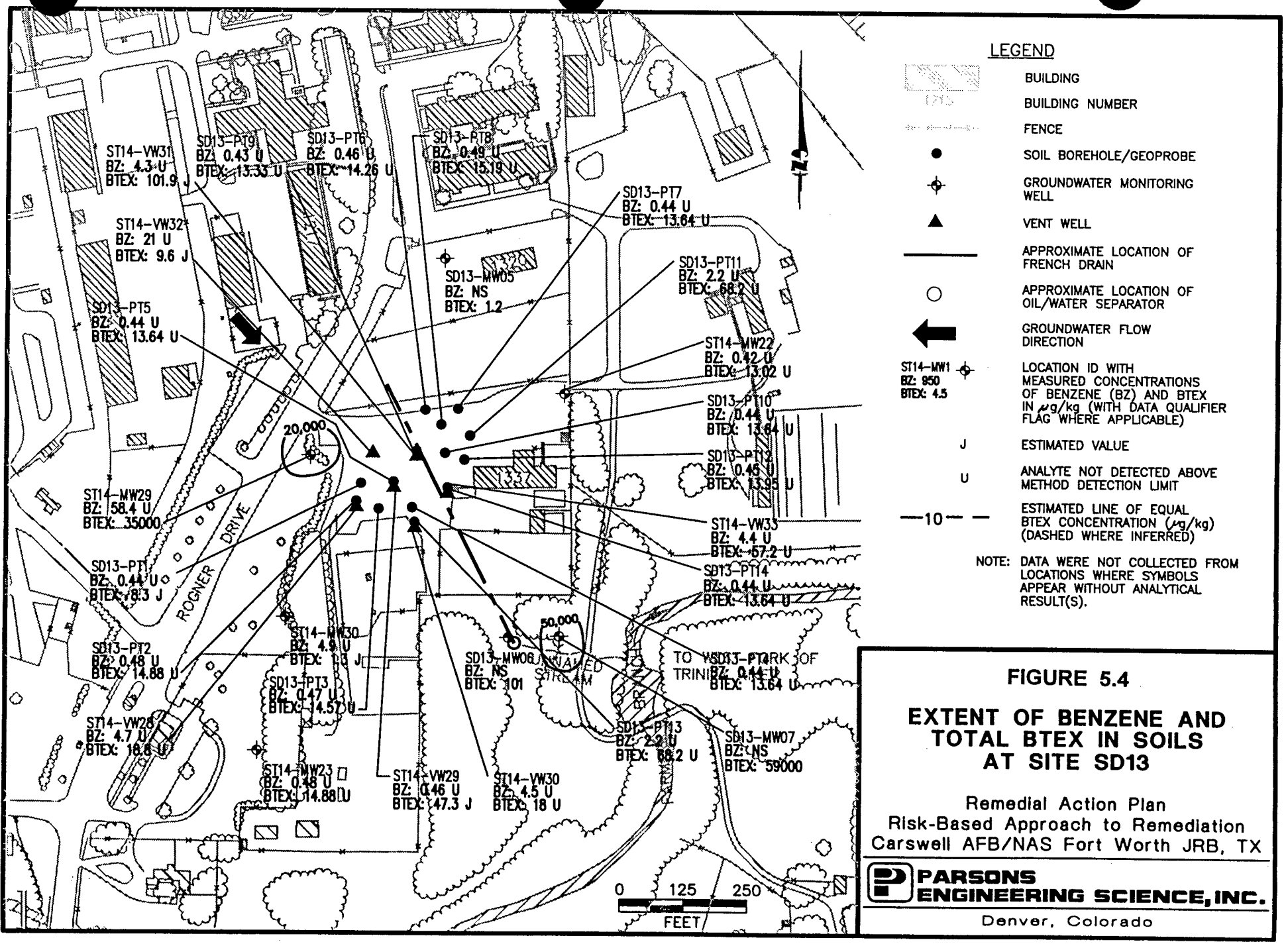


FIGURE 5.4

EXTENT OF BENZENE AND TOTAL BTEX IN SOILS AT SITE SD13

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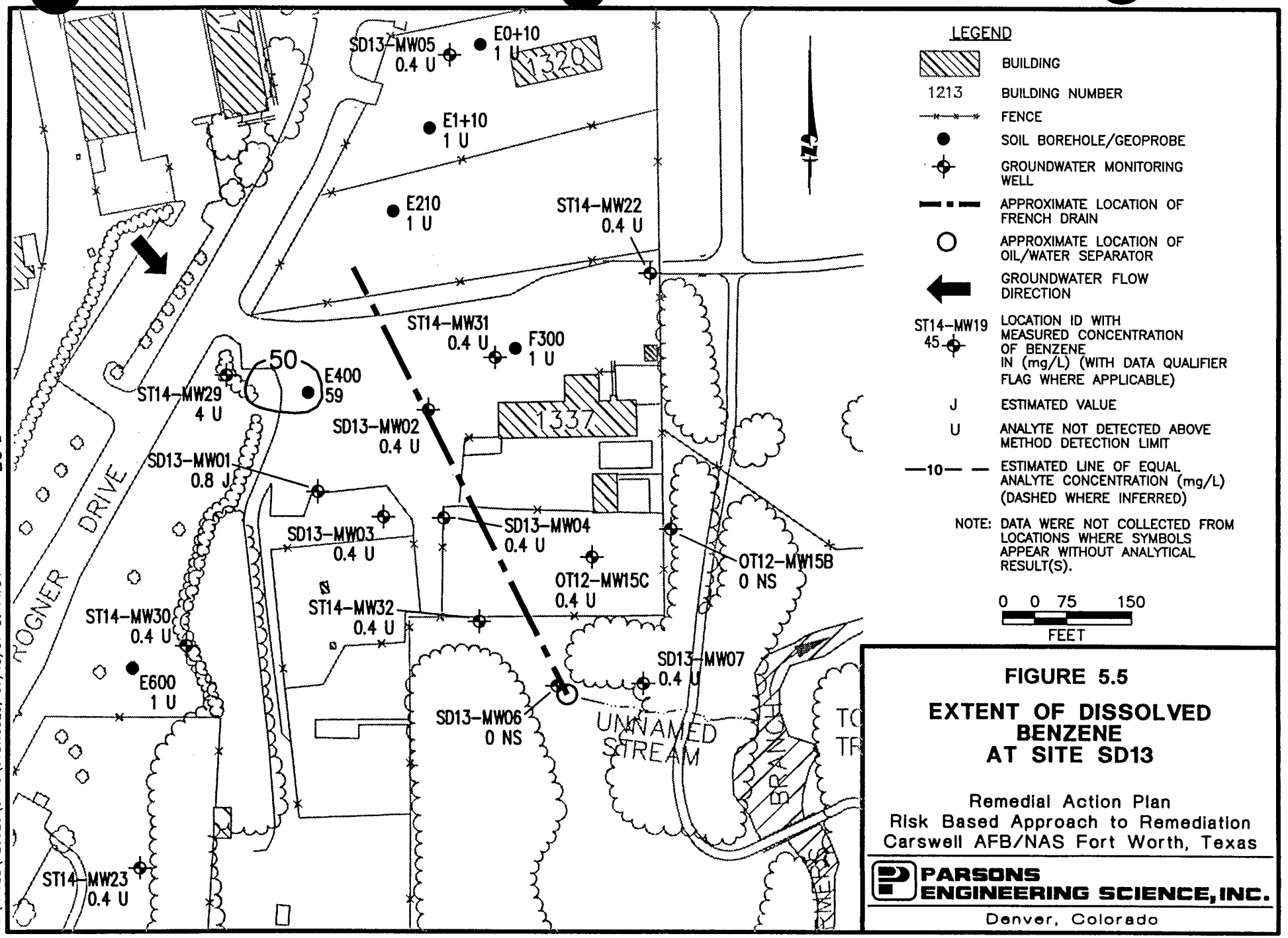


FIGURE 5.5

EXTENT OF DISSOLVED BENZENE AT SITE SD13

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these sampling events were used to delineate the existing extent of dissolved benzene at the sites depicted on Figure 5.5. Benzene was detected at Site SD13 at only one sampling location at a concentration above the Risk Reduction Standard Number 2 level of 0.005 mg/L. Benzene was detected during the 1994 RFI at a concentration of 0.059 mg/L at temporary sampling location E400. No benzene was detected in well ST14-MW29, which is about 50 feet west of E400 (Figure 5.5). This concentration of dissolved benzene is distinctly separate from the dissolved benzene plume originating at Site ST14A. No benzene was detected in several wells (i.e., ST14-MW21, ST14-MW29, and ST14-MW04) and temporary sampling locations (i.e., C800, D700) located to the northeast (upgradient) and southwest (downgradient) of Rogner Drive, which is immediately downgradient from Site ST14A and upgradient from Site SD13 (Figure 4.7). Benzene was not detected in well SD13-MW04 where LNAPL has been encountered during previous sampling events. Groundwater monitoring at Site SD13 performed during 1995-1997 has detected benzene at wells OT15C and SD13-06 at levels slightly above the PQL but below the Risk Reduction Standard Number 2 level of 0.005 mg/L.

Sampling performed as part of the 1994 RFI and the 1995/1996 groundwater monitoring events detected levels of methylene chloride and tetrachloroethylene at levels above the Risk Reduction Standard Number 2 level of 0.005 mg/L. The 1994 sampling found methylene chloride in low levels in wells SD13-01, SD13-02, SD13-03, SD13-05, SD13-06, SD13-07, SD13-06, OT15B, and OT15C. The maximum concentration of methylene chloride detected in 1994 was an estimated value of 0.012 mg/L at SD13-06. Methylene chloride was detected in blanks associated with the June and September 1994 sampling events. All detects for methylene chloride in 1994 were obtained during these two sampling events. The 1995 groundwater monitoring found low levels of methylene chloride in most wells sampled, with a maximum level of 0.006 mg/L in well SD13-02. It should be noted that the 1996 and 1997 groundwater monitoring did not detect methylene chloride in any samples. Methylene chloride was detected in a number of background samples taken as part of the *Basewide Background Study* (Jacobs, 1997).

Tetrachloroethylene was detected in wells OT15B and OT15C in 1994 at maximum concentrations of 0.0091 mg/L and 0.00096 mg/L, respectively. Tetrachloroethylene was detected in well OT15B during each of the three 1994 sampling events, but was detected in OT15C in only one sampling event. Tetrachloroethylene was detected in well OT15C during the 1995/1996 groundwater sampling at a maximum level of 0.0024 mg/L in April 1995 and at a concentration of 0.0007 mg/L in July 1995. Tetrachloroethylene has been below the detection limit at this location for all three subsequent sampling events. Tetrachloroethylene was also detected at sampling location ST14-W22 during the 1995/1996 groundwater monitoring event at a maximum concentration of 0.0061 mg/L.

Trichloroethylene also has been detected in wells OT15B and OT15C, although never above its MCL of 5 µg/L. Trichloroethylene was detected in well OT15B in June and September of 1994 at a maximum concentration of 0.0014 mg/L. It was detected in OT15C in July of 1995 at a concentration of 0.0036 mg/L. However, it has not been detected in any of the three subsequent groundwater monitoring events at this well.

Benzo(a)anthracene and bis(2-ethylhexyl)phthalate were detected during the 1995/1996 groundwater sampling. Benzo(a)anthracene was detected in a single well (SD13-05) and during a single sampling event (January 1996), at a concentration of 0.0012 mg/L. This result was below the PQL and is an estimated value. Bis(2-ethylhexyl)phthalate was detected during the 1995/1996 groundwater sampling events at several wells (SD13-05, SD13-07, ST14-W22, and ST14-W23). All detects were estimated results below the PQL, with a maximum detected concentration of 0.0107 mg/L in well SD13-05. Bis(2-ethylhexyl) phthalate was detected in a number of background samples taken as part of the *Basewide Background Study* (Jacobs, 1997).

Analytical results for inorganics in groundwater were taken during the 1990 and 1994 RFI, and as part of the 1995/1996 and 1997 groundwater monitoring events. No metals were detected above the Risk Reduction Standard Number 2 levels during the 1990 RFI or during the 1997 groundwater monitoring events. Analytical results for metals detected during the 1994 RFI and the 1995/1996 groundwater monitoring events above Risk Reduction Standard Number 2 levels are summarized by analyte below.

- Aluminum was detected in well OT15C at 49.6 milligrams per liter (mg/L) in 1996. This was the only detection above the Risk Reduction Standard Number 2 level of 36.5 mg/L.

- Arsenic was detected only once above the Risk Reduction Standard Number 2 level of 0.05 mg/L. The sample taken from well SD13-01 as part of the 1994 RFI contained 0.075 mg/L arsenic.

- Samples taken in 1994 from wells OT15B and OT15C contained 230 and 260 mg/L of barium, respectively. In January of 1996, 4.56 mg/L of barium was detected in well OT15C. It should be noted that the September 1994 results for OT15B and OT15C were approximately three orders of magnitude higher than other results for barium taken during the 1994 RFI sampling events.

- Beryllium was detected in a single sample from a single well (OT15C) at a concentration of 0.004 mg/L. This is equivalent to the Risk Reduction Standard Number 2 level of 0.004 mg/L (MCL).

- Lead has been detected in a number of wells above the Risk Reduction Standard Number 2 level of 0.015 mg/L. During the 1994 RFI, lead was detected at a concentration of 7.3 mg/L at sampling location SD13-03. In 1995/996, lead was detected above the Risk Reduction Standard Number 2 level in wells SD13-07, SD13-03, and SD13-01, with a maximum contamination of 0.161 mg/L.

- Manganese was detected in 1994 and 1996 above the Risk Reduction Standard Number 2 level of 0.84 mg/L. It was detected in wells OT15B and OT15C during the September 1994 RFI sampling event at concentrations of 70 and 220 mg/L, respectively. Manganese was also detected at 1.86 mg/L in well OT15C in January of 1996. It should be noted that the September 1994 results for OT15B and OT15C were approximately three orders of magnitude higher than other results for manganense taken during the 1994 RFI sampling event.

- Zinc was detected at concentrations above the Risk Reduction Standard Number 2 level of 11 mg/L during a single sampling event (September 1994) at wells OT15B and OT15C (at a concentration of 37 and 48 mg/L, respectively). It should be noted that the September 1994 results for wells OT15B and OT15C were approximately three orders of magnitude higher than any other results for zinc, including samples taken previously and since from the same wells.

It should be noted that the most recent groundwater sampling event (January 1997) detected no concentrations of metals above the Risk Reduction Standard Number 2 levels. Figure 5.6 illustrates the distribution of arsenic and manganese in groundwater.

5.4.5 Surface Water Sampling Events

The potential adverse impacts of dissolved groundwater contamination at Site SD13 on receiving surface water bodies has been a primary concern of previous investigations (Radian, 1985, 1988, 1989 and 1991; Law, 1994) and recent TNRCC INW comments. Surface water samples were collected in the unnamed stream and Farmers Branch as part of the Stage 2, Phase II IRP investigation (Radian, 1988). Elevated concentrations of dissolved benzene were measured in all of the surface water samples collected during the initial round of sampling during Stage 2, which was initiated in September 1987. A maximum concentration of 0.12 mg/L of dissolved benzene was detected in surface water. No benzene was detected in any of the surface water samples collected during the second round of sampling of Stage 2 (Radian, 1989). Only low concentrations of benzene were detected in the surface water samples collected as part of the 1990 RI (Radian, 1991). Benzene was detected in 3 of the 4 surface water samples collected in the spring of 1990, with a maximum concentration of 0.00031 mg/L.

Surface water samples also were collected as part of the 1994 RFI and the 1994/1995 risk-based remediation investigation. Benzene was not detected in the surface water samples collected during the 1994 RFI (Law, 1994). Neither was benzene detected in either the 5 surface water samples collected under low-flow conditions in September 1994, or the 2 surface water samples collected under a moderate-flow condition in April 1995 during this investigation. Recent sampling data suggest that dissolved fuel hydrocarbon contamination in groundwater is not having a measurable impact on surface water quality at either the unnamed stream or Farmers Branch at this time. Significant decreases in the concentration of dissolved benzene in surface water over time may be an indication that the groundwater upgradient from the french underdrain system is no longer a significant source of hydrocarbon contamination. The potential for groundwater underlying Site SD13 to impact surface water has been further minimized by the partial removal of the french underdrain system in 1996.

Surface water samples taken as part of the 1990 RFI and during the first quarterly sampling event of 1997 have been analyzed for inorganics. Antimony, arsenic, barium, beryllium, iron, lead, and selenium were detected at least once in surface water at concentrations above their respective background UTLs. Of these only antimony was detected above its Risk Reduction Standard Number 2 level during the most recent sampling event. Sampling in 1997 involved taking one sample from Farmers Branch at a location above the outlet of the unnamed stream and one sample below the outlet of the unnamed stream. This sampling strategy was required because the removal of the

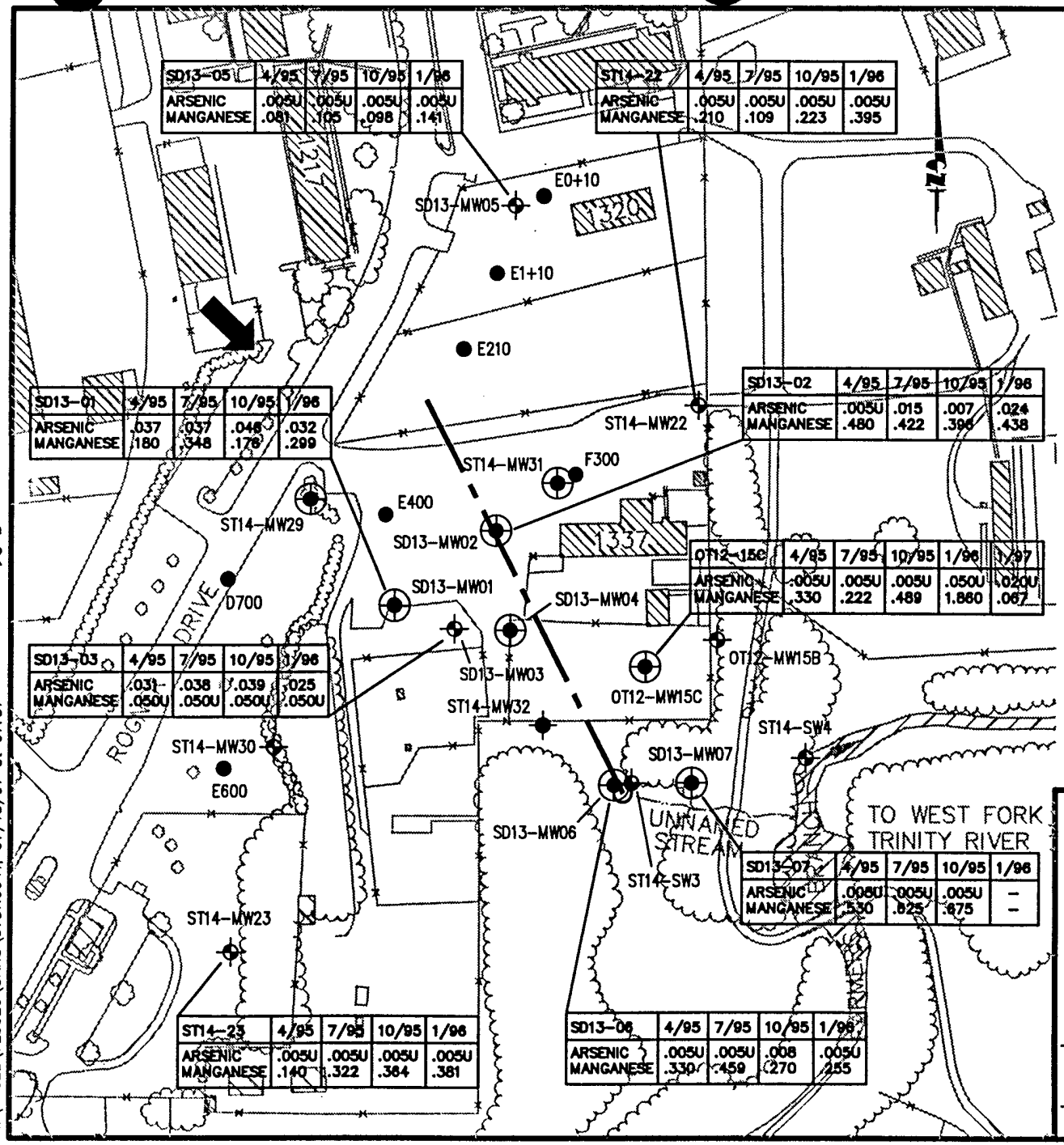


FIGURE 5.6

ARSENIC AND MANGANESE CONCENTRATION GROUNDWATER

Site SD13
Remedial Action Plan
Risk-BAsed Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

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french underdrain system and the oil/water separator has resulted in the cessation of water flow in the unnamed stream. Results from the 1997 sampling event indicated that antimony and beryllium were present above background levels, with only antimony (0.0104 mg/L) above its Risk Reduction Number 2 level of 0.006 mg/L. However, it should be noted that both metals were detected at concentrations above background in the ***upstream samples only***. **No detections of dissolved metals were above the background levels for the sample taken below the unnamed stream's outfall.** Analytical results for these recent surface water sampling activities are presented in Appendix A.

As part of the 1990 RFI sampling event, surface water samples were analyzed for both total and dissolved metals. The RFI reports quantitative results for only total metals. However, the document states that no analytes exceeded their MCL for dissolved metals.

5.5 SAMPLE RESULTS SUMMARY

Hexachlorobezene and arsenic were the only chemicals detected at Site SD13 above the Risk Reduction Standard Number 2 health-based soil MSCs for residential land use. Hexachlorobezene, arsenic, n-nitroso-di-n-propylamine, cadmium, lead, and manganese were detected at maximum concentrations which exceeded the soil-to-groundwater MSCs. These compounds have been identified at this stage as soil COPCs.

Benzene, methylene chloride, tetrachloroethylene, benzo(a)anthracene, bis(2-ethylhexyl)phthalate, aluminum, arsenic, barium, beryllium, lead, manganese, and zinc were chemicals detected at a maximum concentration above the Risk Reduction Standard Number 2 levels based on residential land use. It should be noted that current and future land use does not include use of Site SD13 for residential purposes. The residential-based Risk Reduction Standard Number 2 levels were used as a conservative screen for COPCs, at the request of TNRCC IHW.

Antimony, arsenic, barium, beryllium, iron, lead, and selenium were chemicals detected, at least during one sampling event, at maximum concentrations above the surface water Risk Reduction Standard Number 2 levels. However, all surface water COPCs except antimony exceed these target surface water criteria based on sample results from the 1990 RFI. Based on more recent sampling events, which are representative of current site conditions, these chemicals are below surface water criteria. The recent surface water sampling results for antimony in Farmers Branch detected higher levels of contamination upstream of the SD13 discharge area than were detected downstream of SD13. These data indicate that the groundwater underlying these SWMUs are not contributing inorganic metal mass at significant levels to downgradient surface water.

SECTION 6

QUANTITATIVE CHEMICAL FATE ASSESSMENT

6.1 INTRODUCTION

Section 3 of this RAP is devoted to describing the physical site conditions. Section 4 identifies the fuel-related COPCs for Site ST14 that would have to be addressed by remedial activities if remedial goals are to be established under Plan A. Section 5 identifies the organic and inorganic compounds detected at Site SD13 at concentrations above background that are present above Risk Reduction Standard Number 2 levels developed for unrestricted use. Yet Plan A or Risk Reduction Standard Number 2 does not allow for a site-specific determination of the type, magnitude, and timing of remediation needed to minimize or eliminate potential risks to current and future receptors, accounting for the short- and long-term fate of COPCs. As part of both the PST risk-based corrective action program and the Risk Reduction Standards program, the TNRCC has provided the responsible party with the option to undertake more rigorous, site-specific risk assessments to better make these determinations. A quantitative risk assessment, which must consider the transport and fate of COPCs in air, soil, and water must be prepared to identify site-specific risk reduction requirements. This section estimates the effects natural chemical attenuation processes have had and will have on the extent of migration, mass, concentration, persistence, and toxicity of various COPCs in soils and of benzene in groundwater. Emphasis is given to the fuel hydrocarbons, which originate from the known sources of contamination at both sites. However, other chemical classes, such as halogenated organics and inorganic metals, are also considered.

As discussed in Section 1, one of the primary objectives of this RAP was to evaluate the effectiveness of remedial options that could be implemented at Site ST14 to protect human health and the environment. Site SD13 was originally incorporated into this RAP only because of the potential for fuel-related contamination originating at Site ST14 to migrate to and commingle with fuel-related contamination originating from Site SD13. However, the Air Force recognizes that the target remedial goals and the timing of remedial activities may be affected by upcoming land use changes. Site SD13 is scheduled to become an open space/recreational area in 1998 as part of the proposed land reuse plans (US Air Force, 1994). Consequently, the RAP has been expanded to address all fuel- and nonfuel-related contamination at Site SD13 that should be considered in the remedial evaluation process. Additionally, the need to protect downgradient surface water resources from any upgradient source of contaminant mass over time could drive risk reduction requirements at both Sites ST14 and SD13. This section summarizes and interprets site characterization data used to document the effectiveness of natural chemical, physical, and biological processes that are minimizing COPC migration and reducing concentration, mass, and toxicity over time.

6.2 OPERATIVE MECHANISMS OF CONTAMINANT ATTENUATION

Understanding the fate of COPCs in environmental media is critical to evaluating and predicting contaminant distribution patterns. There are several physical, chemical, and biological processes that influence how a chemical behaves in soil and groundwater. The following sections present a brief overview of the major chemical characteristics that define the fate of certain COPCs in soils and groundwater at Sites ST14 and SD13. These chemical characteristics ultimately determine if the mass of contaminants in the environment can be eliminated or rendered immobile by natural processes. The positive effects of these natural processes on reducing the actual mass of COPCs and/or minimizing leaching or the extent of migration in groundwater is termed intrinsic remediation.

6.2.1 Chemical Characteristics and Mass Transport Mechanisms

The relative solubility, sorptive nature, and volatility of a chemical can govern the effectiveness of nondestructive chemical attenuation processes at Site ST14 and Site SD13. Nondestructive attenuation processes can be described as those physical and chemical processes that may prohibit significant contaminant migration but may not result in a permanent reduction in contaminant mass. Examples of nondestructive attenuation processes include volatilization, sorption, advection, and dispersion. These processes must be evaluated when determining whether a compound poses or has the potential to pose, an actual risk to human health and the environment. If the contaminant is not likely to reach a potential receptor, the contaminant poses no risk.

6.2.1.1 Solubility

The water solubility of a chemical species defines how that particular chemical could partition (leach) from a contaminant source and dissolve into and migrate with groundwater. Although benzene is fairly water soluble, other COPCs such as several of the heavier organics and inorganics are not. For example, the water solubility of benzene is above 1,700 mg/L, whereas the water solubility of of the fuel-related compound hexachlorobenzene is between 0.005 and 0.11 mg/L (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Verschueren, 1983; Isnard and Lambert, 1988; Howard, 1990). Consequently, even though benzene may make up a low mass fraction of the initial source of contamination, this compound should preferentially leach from residual LNAPL in soil and from mobile LNAPL into groundwater and migrate as dissolved contamination (Lyman *et al.*, 1992).

In contrast, the differences in solubility between benzene and other fuel-related compounds is the cause of the disproportionate effect that benzene can have on groundwater quality in comparison to other hydrocarbons commonly found in fuel. Usually the less soluble compounds become adsorbed or occluded in the soils and have relatively low mobility.

For inorganic compounds such as arsenic and manganese, the relative solubility can also be a function of environmental conditions. The solubility of these types of compounds can change as the groundwater becomes more or less reducing, more or less acidic, or more or less saturated with other compounds. For example, under highly reducing conditions, such as those found when organic contamination is present,

compounds such as arsenic, manganese, and iron persist as species with low oxidizing potential (e.g., Masscheleyn *et al.*, 1991a, 1991b). These reduced species are generally more soluble, which means that the compounds desorb from the solid soil matrix and are available to be transported as dissolved constituents. pH also can play a large role in determining a compound's relative solubility. Adsorption-desorption behavior for many inorganics (e.g., selenium) can be controlled by pH. As an example, the solubility of selenium is almost 5 times greater under slightly alkaline conditions (e.g., pH of 7.5) than more acidic conditions (e.g., pH of 5). Consequently, localized changes in environmental conditions can dramatically affected the solubility (and therefore the concentration of a contaminant in solution) of certain inorganic compounds. This phenomenon has been tracked by a number of researchers interested in the fate of inorganics in the environment, particularly with regard to developing cost-effective remediation strategies. Subsequent sections explore how several chemical interactions could mobilize inorganic compounds at concentrations that appear to be above established background levels.

6.2.1.2 Sorption

Another chemical characteristic that can govern how a compound is attenuated in soil and groundwater is its sorptive properties. Most of the COPCs at Sites ST14 and SD13 sorb to that portion of the soil matrix that is composed of organic carbon and fine clay particles. If a contaminant can be strongly sorbed to organic carbon and/or clay particles in the aquifer matrix, the compound will be less mobile and less likely to be transported great distances from the source area. Benzene does not sorb readily to soil and is considered the most mobile of the BTEX compounds (Abdul *et al.*, 1987). In comparison, hexachlorobenzene sorbs much more strongly to the soil matrix, and migration is limited in both soil and groundwater (Verschueren, 1983).

Increases in dissolved inorganic concentrations also can be linked to the reductive dissolution of iron oxyhydroxides. For example, arsenic chemistry in soils is believed to be controlled by adsorption-desorption mechanisms (Livesey and Huang, 1981). Soil pH (Goldbert and Glaubig, 1988), the amount and type of clay (Bar-Yosef and Meek, 1987), and iron oxides (Livesey and Huang, 1981; Pierce and Moore, 1982) are factors that are important in controlling the sorption behavior of arsenic. Therefore, if iron oxyhydroxides are released (such as can happen under reducing conditions), previously adsorbed arsenic would be released into solution. This type of behavior can be inferred by correlating elevated concentrations of dissolved arsenic and iron (as ferrous iron). The presence of elevated ferrous iron suggests highly reducing conditions. This more mobile iron species can then compete with the iron oxyhydroxides that are part of the solid soil matrix. Arsenic may desorb from soil and sorb to the now-mobile ferrous iron. This pattern is clearly indicated at Site SD13, as will be described in subsequent sections.

6.2.1.3 Volatility

The volatility of COPCs also can affect how they behave in the environment. Benzene is a volatile compound, with a vapor pressure of about 95 millimeters of mercury (mm Hg). Methylene chloride and tetrachloroethylene also are very volatile compounds. In contrast, hexachlorobenzene is significantly less volatile at soil temperatures, with a vapor pressure of 1.089×10^{-5} mm Hg (Isensee *et al.*, 1976).

Benzo(a)anthracene and bis(2-ethylhexyl)phthalate are not significantly volatile. None of the inorganic COPCs are considered volatile compounds.

Volatilization from contaminated media was field-investigated as a mass transport mechanism at Site ST14. The soil flux concentrations of the volatile BTEX compounds, specifically benzene, were measured at the site (Figure 4.3; Appendix A). These analytical data imply that the urbanization of the site surface and the clayey nature of the soils at Site ST14 minimize the importance of volatilization at the site. Benzene was detected in only one soil flux sample taken from within the source area at Site ST14A. Even assuming no atmospheric dispersion (i.e., assuming daily accumulation in the breathing zone above the source area), the measured emission rate would result in an ambient air concentration significantly below the OSHA TWA 8-hour PEL. Because no significant soil flux was measured at the surface of the site, the volatilization pathway is not likely to be a major risk element or significantly involved in chemical fate at the site. However, both quantitative site-specific risk assessments (Sections 7 and 8) include volatilization to provide a conservative estimate of potential site risks.

6.2.1.4 Discussion

The preceding discussion shows that solubility and sorptive characteristics are important chemical characteristics to consider when assessing whether COPC contamination in soil and groundwater may present an unacceptable risk to human health and the environment. Site contaminants characterized by relatively high water solubility can and low sorptive properties readily partition from soils or mobile LNAPL and be transported with groundwater. Less soluble and more sorptive compounds are likely to be persistent in source area soils. In fact, heavier fuel hydrocarbons such as hexachlorobenzene and inorganics are rarely found in groundwater or surface water because of their strong affinity for soils. Consequently, more mobile compounds such as benzene or tetrachloroethylene may drive the type and magnitude of remediation necessary to isolate the contamination and protect downgradient receptors from potential risks due to exposure to these types of chemicals.

6.2.2 Biodegradation of COPCs in Soil and Groundwater

Biodegradation may also act as a chemical attenuation process. In comparison to nondestructive chemical attenuation processes, destructive chemical attenuation processes result in the permanent removal of contaminant mass from the environment and may reduce the length of time required to attain site-specific cleanup goals. Documenting and distinguishing the effects of destructive attenuation processes, such as biodegradation, from nondestructive attenuation processes is critical to evaluating the potential for intrinsic remediation to bring about a reduction in contaminant mass over time. The effectiveness of destructive attenuation processes at reducing contaminant mass at a site depends on how amenable the chemical is to biodegradation and whether the site is characterized by physical, chemical, and biological conditions favorable to such processes.

Numerous laboratory and field studies have shown that hydrocarbon-degrading bacteria can participate in the degradation of many of the chemical components of JP-4 jet fuel, gasoline, and diesel fuel under both aerobic and anaerobic conditions (e.g., Jobson *et al.*, 1972; Perry, 1977; Atlas, 1981, 1984, and 1988; Gibson, 1984; Reinhard

et al., 1984; Young, 1984; Bartha, 1986; Wilson *et al.*, 1986, 1987, and 1990; Baedecker *et al.*, 1988; Lee, 1988; Chiang *et al.*, 1989; Grbic-Galic, 1989, and 1990; Leahy and Colwell, 1990; Parker *et al.*, 1990; Stieber *et al.*, 1990, 1994; Altenschmidt and Fuchs, 1991; Alvarez and Vogel, 1991; Baedecker and Cozzarelli, 1991; Bauman, 1991; Borden, 1991; Brown *et al.*, 1991a; Haag *et al.*, 1991; Hutchins and Wilson, 1991; Beller *et al.*, 1992; Bouwer, 1992; Edwards and Grbic-Galic, 1992; Thierrin *et al.*, 1992; Malone *et al.*, 1993; Davis *et al.*, 1994). Biodegradation of fuel hydrocarbons will occur when an indigenous population of hydrocarbon-degrading microorganisms is present in the soil and groundwater, and sufficient concentrations of electron acceptors and nutrients, including fuel hydrocarbons, are available to these organisms. Soils and groundwater with a history of exposure to fuel hydrocarbon compounds generally contain microbial populations capable of facilitating biodegradation reactions (Zobell, 1946; Litchfield and Clark, 1973; Borden, 1994; Seech *et al.*, 1994; Simpkin and Giesbrecht, 1994). The chemical basis for the biodegradation of fuel hydrocarbons is described in more detail in subsequent sections, where geochemical data relevant to documenting biodegradation at the field scale at Site ST14 and Site SD13 are presented.

6.3 EVIDENCE OF FUEL HYDROCARBON BIODEGRADATION OVER TIME AND DISTANCE

The first step in determining whether site data indicate that fuel-related COPCs are biodegrading in soils and groundwater at Site ST14 (and Site SD13) was to compare analytical data on the nature and extent of site contamination collected during previous IRP investigations to analytical data on the nature and extent of site contamination collected in April and September 1994 and April 1995 as part of the RFI and the risk-based investigation. The purpose of this comparison was to assess the evidence of field-scale contaminant mass loss. Changes in the nature and extent of contamination at a site over time that cannot be explained by physical processes (e.g., leaching from soils, transport in groundwater) may be an indication that contaminants are biodegrading at the site.

6.3.1 Evidence of Leaching from Soils

Hexachlorobenzene was detected in a single soil sample collected at ST14-VW32 at Site SD13 at a concentration slightly above the health-based Risk Reduction Standard Number 2 soil concentration of 400 µg/kg for industrial sites, and above the Risk Reduction Standard Number 2 target soil concentration of 100 µg/kg that is protective of underlying groundwater. No hexachlorobenzene was detected in groundwater during any sampling event conducted at either Site ST14 or Site SD13.

Benzene was the only BTEX compound measured in soil samples collected at Site ST14A at concentrations (up to 67,000 µg/kg) above the Plan A target soil concentration of 740 µg/kg for beneficial use II groundwater. Elevated concentrations of benzene were not measured in soil samples from Site ST14B or Site SD13 (see Figure 4.3). During the 1993 bioventing pilot test, benzene also was measured at concentrations above the Plan A target soil concentration that is protective of underlying groundwater quality at Site ST14A. However, because no soil samples were collected at Site ST14A as part of the 1994 RFI or the 1994/1995 risk-based investigation, it was not possible to observe any trends in soil contaminant concentrations over time.

However, the presence of benzene in groundwater underlying contaminated soils at Site ST14A indicates that it is being effectively leached from soils. Elevated dissolved benzene concentrations were measured at sampling locations where soil samples collected within the capillary fringe were depleted in benzene. For example, although no benzene was detected in the soil sample collected from the capillary fringe at ST14-MW16 in 1994, the maximum dissolved benzene concentration of 110 µg/L was measured at this same location in 1994. Additionally, site characterization data indicate that the small amount of remaining mobile LNAPL is probably not a significant source of dissolved benzene. The LNAPL is weathered (Section 4.3), and most of the lower-molecular-weight hydrocarbons such as benzene have already partitioned from the LNAPL into underlying soils. The absence of dissolved benzene in the two wells where product thicknesses have been repeatedly reported (i.e., ST14-MW17M and SD13-MW03) shows that the remaining LNAPL is no longer a significant source of groundwater contamination at either site.

Finally, the changes in conductivity after precipitation events observed during the tracer test (Section 3.5) imply that rainfall is able to infiltrate into the ground through areas of permeable surface materials or cracks in paved surfaces and rapidly percolate into the groundwater. The infiltrating water could be a release mechanism for both mineral salts and soluble organics such as benzene, which are sorbed to the soils within the source area. The degree to which these chemicals could partition from the source area vadose soils and leach into underlying groundwater depends on solubility and sorptive characteristics of the chemicals and the amount of infiltrating water that passes through the soil column. As discussed previously, benzene is a fairly soluble organic with a low affinity for binding to soils.

6.3.2 Observed Contaminant Loss from Groundwater

Analytical data from several permanent groundwater monitoring wells that were sampled and analyzed for benzene during all field investigations were compared to assess whether dissolved contaminant concentrations appeared to be decreasing over time. These data indicate a significant reduction in dissolved benzene from 1986 until the present. During the previous IRP investigations (Hargis and Montgomery, 1983; Radian, 1985, 1988, and 989) and the 1990 RI (Radian, 1991), the maximum concentration of dissolved benzene detected in groundwater was 11,000 µg/L at ST14-MW17M. This concentration of benzene was detected during the October 1986 sampling event as part of the Stage 1, Phase II investigation. By 1990, however, the dissolved concentration of benzene at well ST14-MW17M had decreased to 16 µg/L. Less than 0.2 percent of the initial dissolved benzene concentration was measured near the source area after 4 years. Benzene was not detected in ST14-MW17M during the 1994/1995 risk-based remediation investigation. The maximum concentration of dissolved benzene measured at Site ST14A during the Law (1994) RFI and this investigation was 110 µg/L at ST14-MW16 (detected in September 1994), which is 1 percent of the maximum dissolved benzene found at the site about 8 years earlier (October 1986). In January 1997, the maximum benzene concentration detected at Site ST14 was measured at sampling location ST14-MW16 at a concentration of 59.9 µg/L.

Additionally, dissolved benzene was measured in several of the other permanent wells at both Site ST14 and Site SD13 as part of the pre-1994 investigations. During the March/April 1990 RI, dissolved benzene was also detected at Site ST14 in wells

ST14-MW17J (3.8 µg/L), ST14-MW17L (0.65 µg/L), ST14-MW17K (0.50 µg/L), and ST14-MW03 (1.3 µg/L), and at Site SD13 in well SD13-MW01 (2 µg/L). By September 1994, however, no detectable concentration of benzene was measured at any of these sampling locations.

6.3.3 Discussion of Field-Scale Contaminant Mass Losses

The first line of evidence for natural attenuation of fuel hydrocarbons at Site ST14 is the decreasing concentrations of benzene measured at the same groundwater sampling locations over time. Comparison of early IRP sampling data and the 1994/1995 site data indicate that dissolved benzene, the only fuel-related groundwater COPC at Site ST14, is being attenuated. Maximum benzene concentrations decreased by at least 98 percent in approximately 8 years (i.e., about 96 months).

The second line of evidence of natural attenuation of dissolved benzene is the lack of significant migration in comparison to other BTEX compounds over time. Benzene is the most soluble of all the BTEX compounds, and has the lowest affinity for soils. This means that benzene is one of the most mobile fuel hydrocarbon compounds likely to be present in either JP-4 jet fuel (Site ST14) or gasoline or diesel (Site SD13). Yet, comparison of the current extent of dissolved benzene found at Site ST14 to the extent of the other BTEX compounds show that benzene has not migrated as far downgradient as some of the higher-molecular-weight, less-mobile compounds such as ethylbenzene and xylenes (Figure 6.1). The benzene plume is attenuated relative to the other BTEX compounds. This attenuation cannot be the result of the effects of nondestructive attenuation processes since similar or even stronger processes would affect the migration of the other BTEX compounds. However, benzene is chemically the most simple and bioavailable BTEX compound, which can facilitate degradation processes.

Field data on groundwater velocity and TOC content was combined with the chemical-specific octanol-carbon partition coefficient (K_{oc}) for benzene to estimate contaminant velocity and expected travel distance from October 1986 to September 1994. Significantly elevated concentrations of dissolved benzene should have migrated from well ST14-MW17M approximately 260 feet downgradient toward well ST14-MW19 and temporary sampling point C800 (Figure 6.1). The pathway of migration that the mass of benzene should be expected to take can be inferred from the migration path of the other BTEX compounds. Yet, no significant benzene concentrations (i.e., in comparison to the 11,000 µg/L concentration measured at well ST14-MW17M in 1986) were measured downgradient in 1994. The reduction in benzene concentrations and the lack of forward migration of significant concentrations of benzene indicates that dissolved benzene is being effectively attenuated in saturated media. This field-scale evidence suggests that mass removal processes such as biodegradation are operating at the site. In fact, in the absence of contaminant mass removal processes, the dissolved benzene plume could not decrease in concentration without increasing in size over time.

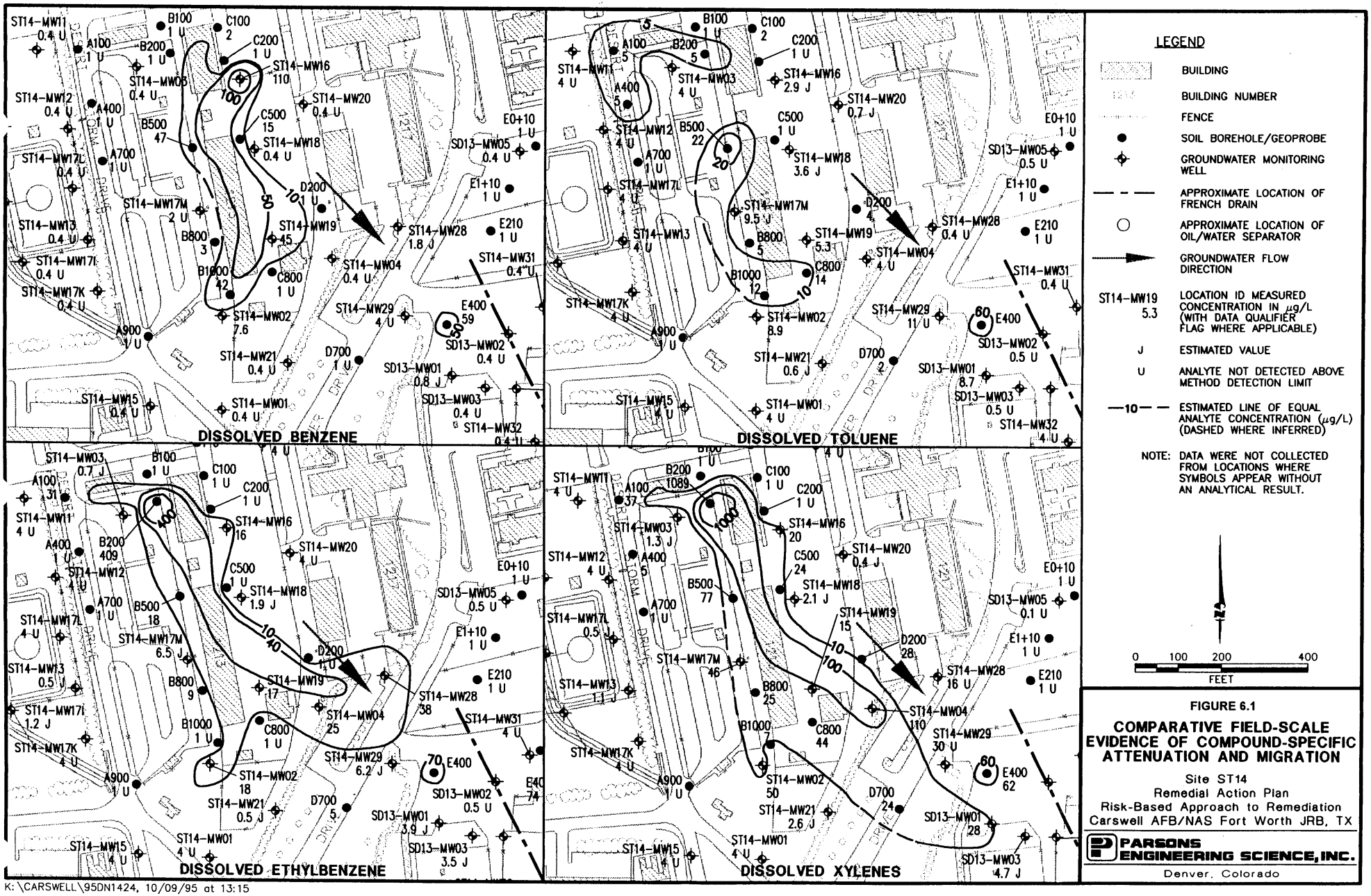


FIGURE 6.1

COMPARATIVE FIELD-SCALE EVIDENCE OF COMPOUND-SPECIFIC ATTENUATION AND MIGRATION

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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6.3.4 Estimating Site-Specific Contaminant Biodegradation Rates

It is important to distinguish between the effects of nondestructive attenuation processes (i.e., advection, dispersion, and sorption) and the effects of destructive attenuation processes (i.e., biodegradation) on the mass of dissolved benzene in the groundwater at Site ST14. Note that no benzene has been detected at Site SD13 since the 1994 RFI. Comparison of analytical data from several sampling events suggest that benzene is being removed from saturated soils and groundwater by mechanisms other than dispersion, advection, and sorption. To quantify these effects, a spatial regression technique (Buscheck and Alcantar, 1995) was used to estimate the site-specific biodegradation rates of each of the BTEX compounds in saturated soil and groundwater based on analytical data.

It is commonly assumed that biodegradation rates for fuel hydrocarbons such as benzene in saturated media can be approximated by a first-order decay constant (Chapelle, 1993). A spatial regression analysis of contaminant concentration data is presented in Appendix E. The slope of the best-fit regression line through measured benzene concentrations versus distance is used to estimate the amount of distance that benzene was attenuated that cannot be explained by advection, dispersion, and sorption (Buscheck and Alcantar, 1995). This spatial regression technique is more fully described in Appendix E.

Table 6.1 summarizes the calculated biodegradation rates for total BTEX, benzene, toluene, ethylbenzene, and total xylenes based on analytical data collected at Site ST14. These rates express how much of the contaminant mass is being removed from the saturated media that cannot be explained by nondestructive attenuation processes such as dispersion and adsorption. The effects of both aerobic and anaerobic destructive attenuation processes within the established plume are included in these site-specific biodegradation rate-constant estimates. The potential for additional mass to leach from overlying soils into groundwater, which will add additional mass to the groundwater, was not factored into the rate estimates. As a result, the estimated rates will likely underestimate the effectiveness of biodegradation processes at the site.

The calculated biodegradation rate for benzene is 0.0014 day^{-1}, significantly greater than that for ethylbenzene (0.0006 day^{-1}). This is consistent with the differences in the spatial distributions of dissolved benzene and ethylbenzene at the site (Figure 6.1). The biodegradation rates reported in literature for benzene in saturated soils and groundwater range from 0.0009 day^{-1} to 0.069 day^{-1} (Howard *et al.*, 1991). Based on these values, the site-specific half-life of benzene in saturated soil and groundwater at Site ST14 is 495 days.

6.4 EVIDENCE OF HYDROCARBON BIODEGRADATION VIA MICROBIALLY CATALYZED REDOX REACTIONS

Available site data suggest that the BTEX compounds, specifically benzene, are biodegrading in saturated soils and groundwater at Site ST14. There were measurable decreases in the concentrations of each BTEX compound in groundwater between the 1986 Stage 1, Phase II sampling event, the 1990 RI sampling event, and the September 1994 risk-based sampling event. Spatial regression techniques were applied to calculate

TABLE 6.1
COMPOUND-SPECIFIC BIODEGRADATION RATES
SITE ST14, REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

Compound	Contaminant Velocity (ft/day)	Attenuation Distance (f^{t-1})	Site-specific Biodegradation Rate (day^{-1})[a/]	Literature-reported Biodegradation Rates (day^{-1})[b/]
Total BTEX	0.047	0.0062	0.00045	0.0009 - 0.23
Benzene	0.068	0.0106	0.00141	0.0009 - 0.059
Toluene	0.047	0.0038	0.00024	0.025 - 0.098
Ethylbenzene	0.041	0.0083	0.00059	0.003 - 0.1
Total xylenes	0.028	0.0075	0.00035	0.002 - 0.05

[a/] Rate calculated using the spatial regression method described in Appendix E.

[b/] Based on biodegradation rates reported by Howard *et al* (1991)

site-specific biodegradation rates for each BTEX compound. On the basis of this evaluation, it can be inferred that the BTEX compounds, including benzene, are biodegrading at Site ST14 at rates consistent with those reported in the technical literature.

There is also another line of evidence that can be used to show that these contaminants are biodegrading in saturated soil and groundwater at Site ST14. Analytical data on potential electron acceptors can be used as geochemical indicators of biodegradation (Salanitro, 1993; McCallister and Chiang, 1994; Wiedemeier *et al.*, 1995; Borden *et al.*, 1995). Reductions in the concentrations of oxidized chemical species that are used by microorganisms to facilitate the oxidation of BTEX compounds within contaminated media is another indication that contaminants are biodegrading. The amount of potential electron acceptors available to participate in contaminant biodegradation reactions can be used to estimate the total contaminant mass that can be biodegraded over time at this site. Coupled with the biodegradation rates described earlier, this information can be used to predict how much and how quickly benzene can be permanently removed from saturated soils and groundwater at Site ST14 by natural processes.

6.4.1 Relevance of Redox Couples in Biodegradation

Microorganisms obtain energy to replenish enzymatic systems and to reproduce by oxidizing organic matter. Biodegradation of the BTEX compounds is the result of a series of redox reactions that maintain the charge balance within the natural environment. Microorganisms facilitate the degradation of the BTEX compounds by transferring electrons from the contaminant (electron donor) to available electron acceptors. Electron acceptors are elements or compounds that occur in relatively oxidized states and can participate in redox reactions involving the BTEX compounds. Common electron acceptors known to be present in saturated soil and groundwater at Site ST14 and Site SD13 are oxygen, manganese, nitrate, sulfate, ferric iron, and carbon dioxide. Electron acceptors also can be other compounds that occur in relatively oxidized states, including highly chlorinated solvents [e.g., PCE, TCE, and trichloroethane (TCA)].

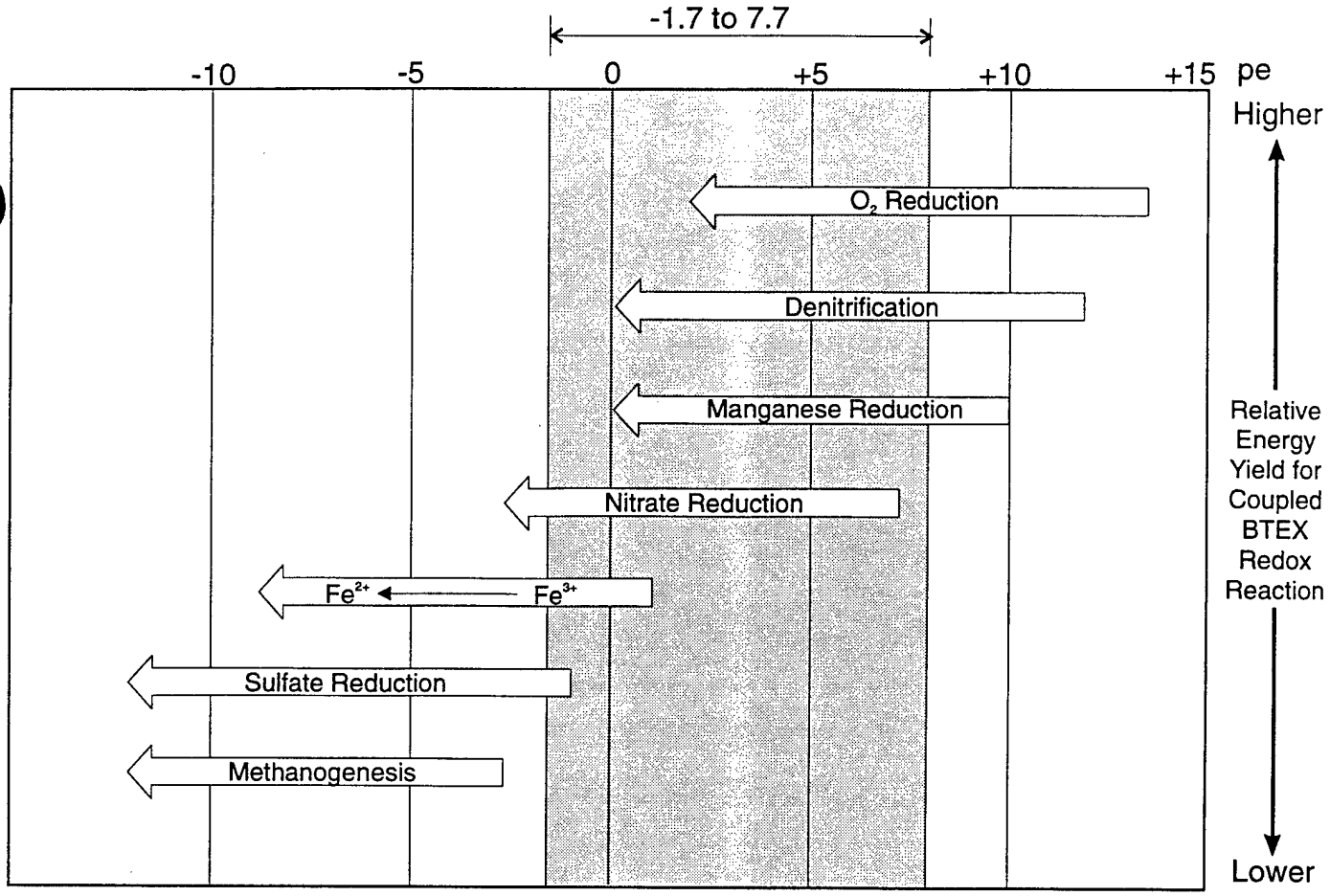
Microorganisms facilitate BTEX biodegradation to produce energy for their use. The amount of energy that can be released when a reaction occurs or is required to drive the reaction to completion is quantified by the free energy of the reaction (Stumm and Morgan, 1981; Bouwer, 1994; Chapelle, 1993; Godsey, 1994; Mueller *et al.*, 1994; Berg *et al.*, 1994). Microorganisms will facilitate only those redox reactions that will yield energy. Microorganisms are able to utilize electron transport systems and chemiosmosis to combine energetically favorable and unfavorable reactions to produce energy for life processes (i.e., cell production and maintenance). By coupling the oxidation of BTEX compounds, which requires energy, to the reduction of other compounds (e.g., oxygen, nitrate, ferric iron, sulfate, and carbon dioxide), which yields energy, the overall reaction will yield energy. Electron donors may be natural organic carbon, fuel hydrocarbon compounds, and less-chlorinated solvents [e.g., vinyl chloride (VC), dichloroethene (DCE), or dichloroethane (DCA)]. Fuel hydrocarbons and chlorinated solvents can be completely degraded or detoxified if they are utilized as the primary electron donor (i.e., as a primary substrate or carbon source) for microbial

metabolism (Bouwer, 1992). Detailed information on the redox reactions required to biodegrade each of the BTEX compounds, especially benzene, is included in Appendix E. The reader is encouraged to review this information to more fully understand the chemical basis of biodegradation.

Figure 6.2 illustrates the sequence of microbially mediated redox processes based on the amount of free energy released for microbial use. In general, reactions yielding more energy tend to take precedence over processes that yield less energy (Stumm and Morgan, 1981; Godsey, 1994; Reinhard, 1994). As 6.2 shows, oxygen reduction would be expected to occur in an aerobic environment with microorganisms capable of aerobic respiration because oxygen reduction yields significant energy (Bouwer, 1992; Chapelle, 1993). However, once the available oxygen is depleted and anaerobic conditions dominate the interior regions of the contaminant plume, anaerobic microorganisms can utilize other electron acceptors in the following order of preference: nitrate, ferric iron, sulfate, and finally carbon dioxide. Chlorinated solvents are generally used as electron acceptors when aquifer conditions are such that sulfate or carbon dioxide are preferred electron acceptors. Each successive redox reaction provides less energy to the system, and each step down in redox energy yield would have to be paralleled by an ecological succession of microorganisms capable of facilitating the pertinent redox reactions.

The expected sequence of redox processes is also a function of the oxidizing potential (Eh) of the groundwater. The oxidizing potential measures the relative tendency of a solution or chemical reaction to accept or transfer electrons. The oxidizing potential of the groundwater can be measured in the field. This measurement can be used as a crude indicator of which redox reactions may be operating at a site. This field measurement can then be expressed as pe, which is the hypothetical measure of the electron activity associated with a specific Eh. High pe means that the solution or redox couple has a relatively high oxidizing potential. As noted earlier, the oxidizing potential of the aquifer can also dramatically affect the mobility of compounds that are not amenable to biodegradation per se: the inorganic metals.

Microorganisms can only facilitate the biodegradation (oxidation) of the BTEX compounds using redox couples that have a higher oxidizing potential than the contaminants. Appendix E includes tables that show that redox couples including common electron acceptors all have higher oxidizing potentials than the redox couples including the BTEX compounds. This is why these electron acceptors can be used to oxidize the BTEX compounds. The reduction of highly oxidized species results in an overall decrease in the oxidizing potential of the groundwater. As shown in Figure 6.2, the reduction of oxygen and nitrate will reduce the oxidizing potential to levels at which ferric iron (Fe^{3+}) reduction can occur. Interestingly, the reduction of ferric iron results in the production of ferrous iron, which is more soluble. Elevated concentrations of dissolved iron would be expected to be produced in areas where microorganisms are facilitating the oxidation of organic compounds such as fuel hydrocarbons. As each chemical species that can be used to oxidize the contaminants is exhausted, the microorganisms are forced to use other available electron acceptors with lower oxidizing capacity. When sufficiently negative pe levels have been developed as a result of these redox reactions, sulfate reduction and methanogenesis can occur almost simultaneously (Stumm and Morgan, 1981).



Notes

Range of pe measured at Site ST14 and Site SD13

1. These reactions would be expected to occur in sequence if the system is moving toward equilibrium.

2. These redox processes occur in order of their energy-yielding potential (provided microorganisms are available to mediate a specific reaction). Reduction of a highly oxidized species decreases the pe of the system.

3. The pe of the system determines which electron acceptors are available for COPC oxidation.

4. Redox sequence is paralleled by an ecological succession of biological mediators.

Adapted from Stumm and Morgan, 1981.

FIGURE 6.2

SEQUENCE OF MICROBIALLY MEDIATED REDOX PROCESSES

Site ST14 Remedial Action Plan
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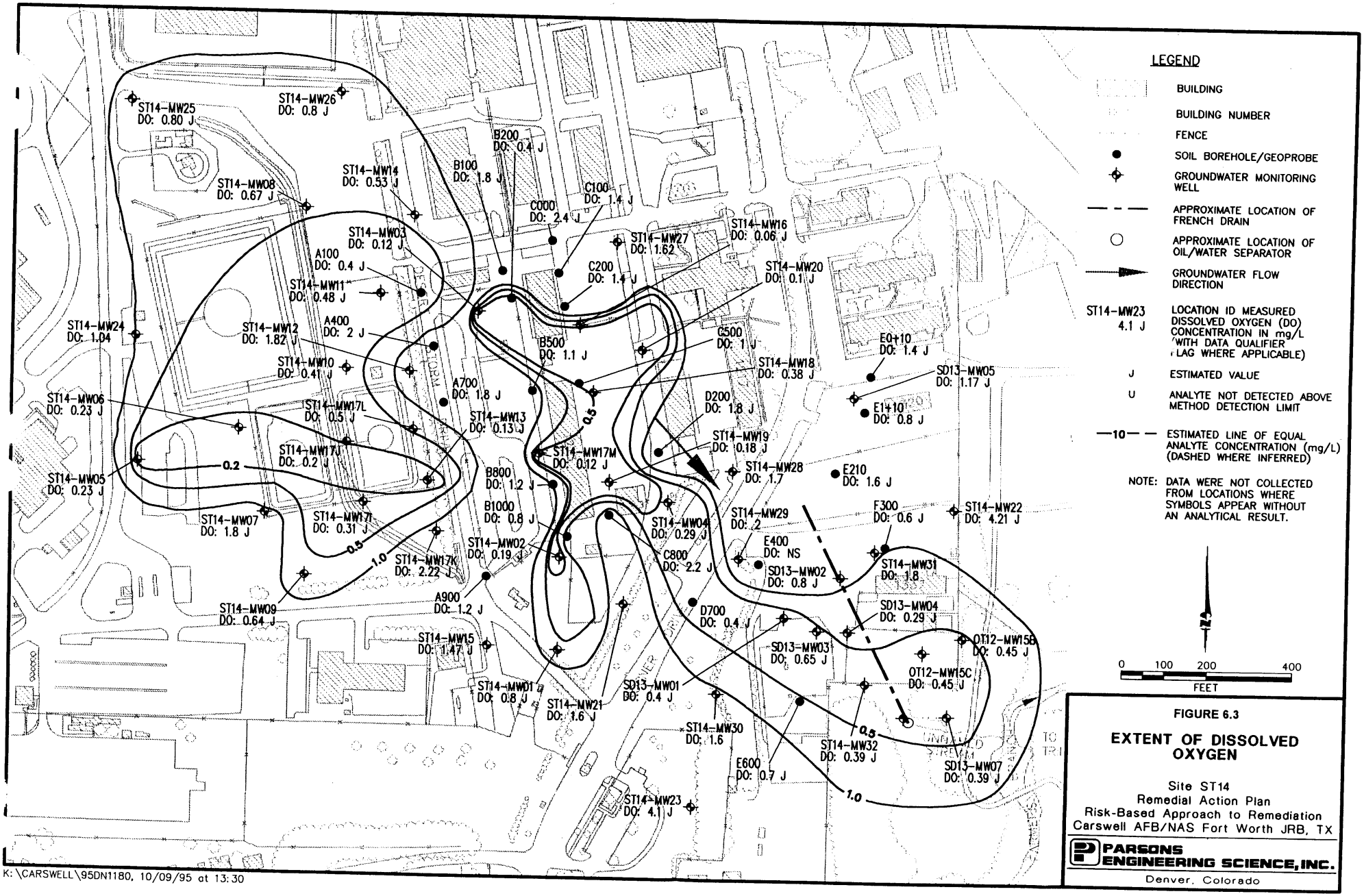
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Figure 6.2 shows the range of pe in the groundwater at Site ST14 and Site SD13, based on Eh measurements. These data imply that oxygen, nitrate, ferric iron, and sulfate may be used to biodegrade fuel hydrocarbon contaminants at these sites. Analytical data on oxidized and reduced species are presented in the next sections to verify which electron acceptors are actually being used to biodegrade the BTEX compounds, specifically benzene, in saturated soil and groundwater at Site ST14 and Site SD13. The Eh measurements also indicate that the groundwater is sufficiently reducing that less oxidized forms of arsenic, cadmium, and manganese will predominate. These reduced forms of inorganics are generally more soluble than oxidized species, which means that these inorganics will desorb from solid soil matrix and be available to be transported with groundwater. For example, arsenic solubility can be expected to increase by almost 25 times once the groundwater has been reduced to a Eh of about -200 millivolts (mV) (Massacheleyn *et al.*, 1991a, 1991b), In contrast, the reduced Cr(III) species is less mobile than the more toxic, oxidized Cr(VI) (Palmer and Puls, 1994).

6.4.2 Dissolved Oxygen Concentrations

Almost all types of fuel hydrocarbons can be biodegraded under aerobic conditions (Borden, 1994). Mineralization of fuel hydrocarbons to carbon dioxide and water under aerobic conditions involves the use of oxygen as a cosubstrate during the initial stages of metabolism, and as a terminal electron acceptor during the later stages of metabolism for energy production (Higgins and Gilbert, 1978; Gibson and Subramanian, 1984; Young, 1984). The reduction of molecular oxygen during the oxidation of the BTEX compounds yields a significant amount of free energy to the system that the microorganisms could utilize.

DO concentrations were measured at ST14 and SD13 groundwater sampling locations in September 1994/April 1995. Figure 6.3 presents analytical results for DO by sampling location. The isoconcentration contours show that there is a strong correlation between areas that have been or are currently contaminated with fuel hydrocarbons and areas depleted of DO relative to measured background levels (compare Figure 6.3 to Figure 6.1). DO concentrations from sampling locations within and immediately downgradient from the suspected source areas at Site ST14A ranged from about 1.4 mg/L to below the detection limit. These analytical data show that the alluvium groundwater at Site ST14 has fairly low DO concentrations, which may be a function of other geochemical or biological oxygen demands in shallow soils (Appendix A). Although the low concentrations of DO in contaminated groundwater indicate that oxygen may function as an electron acceptor during microbially mediated degradation of fuel hydrocarbons at these sites, such degradation is limited by the naturally depleted oxygen levels. This means that oxygen is probably not a major electron acceptor during microbial degradation of the BTEX compounds. The anaerobic nature of the groundwater underlying these sites is consistent with the measured Eh (pe) levels at the site (Figure 6.2 and Appendix E). DO measurements collected in January 1997 confirm that anaerobic conditions still prevail at Sites ST14 and SD13.



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FIGURE 6.3

EXTENT OF DISSOLVED OXYGEN

Site ST14
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6.4.3 Dissolved Nitrate and Nitrite Concentrations

Because near-anaerobic conditions generally prevail in the site groundwater, nitrate can be used as an electron acceptor by indigenous facultative anaerobic microorganisms to mineralize BTEX compounds via either denitrification or nitrate reduction processes. Nitrate can only function as an electron acceptor in microbially facilitated fuel hydrocarbon degradation reactions if the groundwater system has been depleted of oxygen (i.e., the groundwater must be functionally anaerobic). Oxygen is toxic to the enzyme systems used for electron transfer and energy production of nitrate-reducing microorganisms (McCarty, 1972). Denitrification is the most energetically favorable of the redox reactions likely to be involved in the oxidation of benzene (Appendix E). Although the oxidation of benzene by nitrate reduction also will yield significant amounts of free energy for microbial use, nitrate reduction is not as energetically favorable as other potential redox reactions. However, nitrate reduction may take precedence over denitrification at Site ST14 and Site SD13 as the groundwater becomes more reducing.

Concentrations of both nitrate and nitrite were measured at groundwater sampling locations in October 1994. Figure 6.4 presents the analytical data for the oxidized nitrate. Figure 6.4 shows that nitrate is slightly depleted near the suspected source areas at Site ST14A and Site SD13 (see Figure 6.1). Dissolved nitrate concentrations also are depleted in groundwater underlying Site ST14B, further indicating that the fuel hydrocarbon contamination that existed in this area during earlier sampling events have been degraded. Figure 6.5 shows that detected slightly elevated concentrations of nitrite, which is produced as nitrate is reduced during the oxidation of fuel hydrocarbons, were measured near the source area at Site ST14A and north of Site SD13. The measured Eh (pe) levels at the site were an early indication that the oxidizing potential of the groundwater had been reduced sufficiently so that denitrification and nitrate reduction can occur (Figure 6.2).

6.4.4 Total Iron and Ferrous Iron Concentrations

Although relatively little is known about the anaerobic metabolic pathways involving the reduction of ferric iron (Fe^{3+}), this process has been shown to be a major metabolic pathway for some microorganisms (Lovley and Phillips, 1988; Chapelle, 1993). Elevated concentrations of ferrous iron (Fe^{2+}) often are found in anaerobic, fuel-contaminated groundwater systems. Concentrations of dissolved ferrous iron once were attributed to the spontaneous and reversible reduction of ferric oxyhydroxides, which are thermodynamically unstable in the presence of organic compounds such as benzene. However, recent evidence suggests that the reduction of ferric 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 mediation by microorganisms with the appropriate enzymatic capabilities. The reduction of ferric iron results in the formation of ferrous iron.

To determine if ferric iron is being used as an electron acceptor for fuel biodegradation at Sites ST14 and SD13, ferrous iron concentrations were measured at

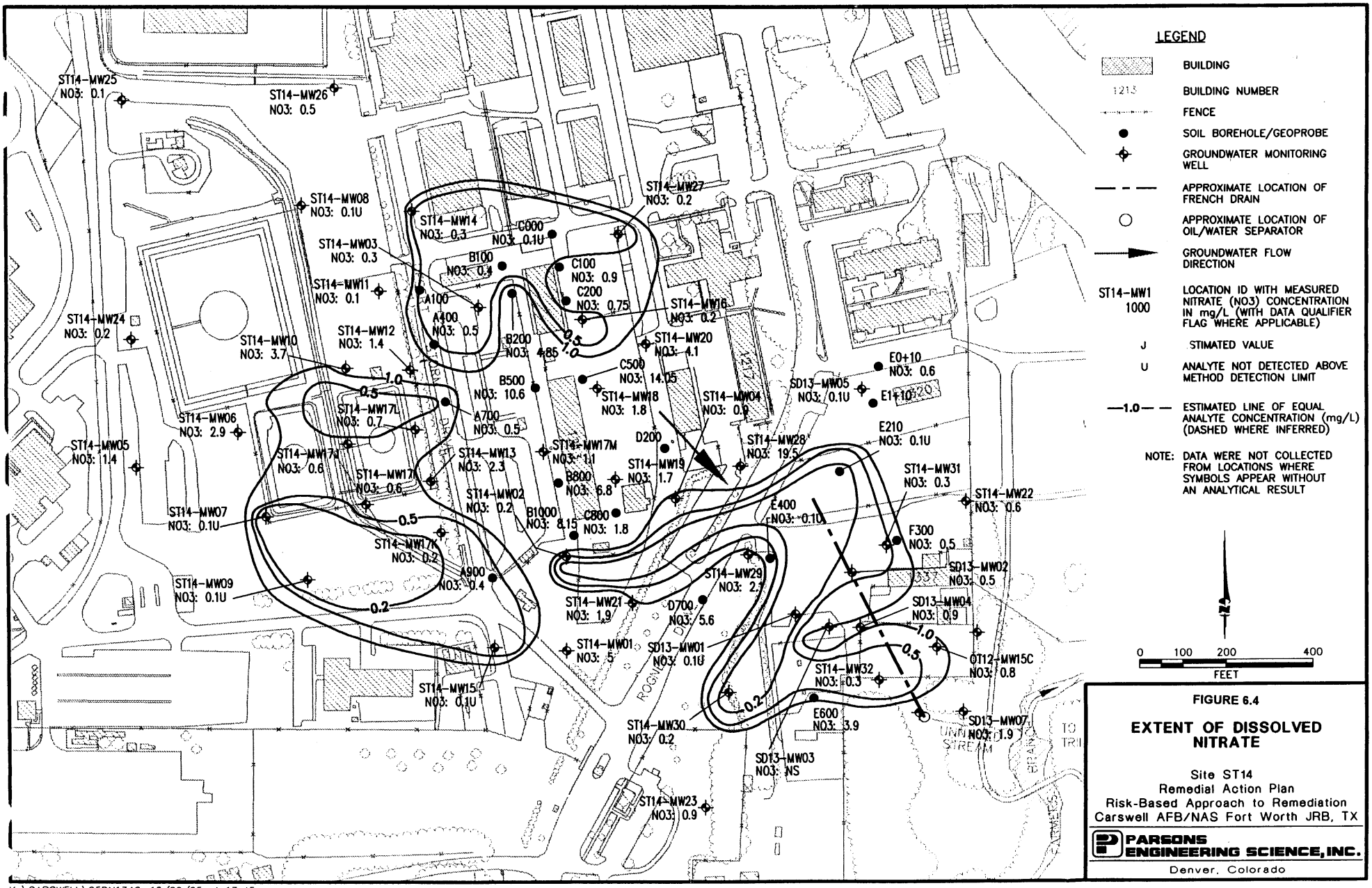


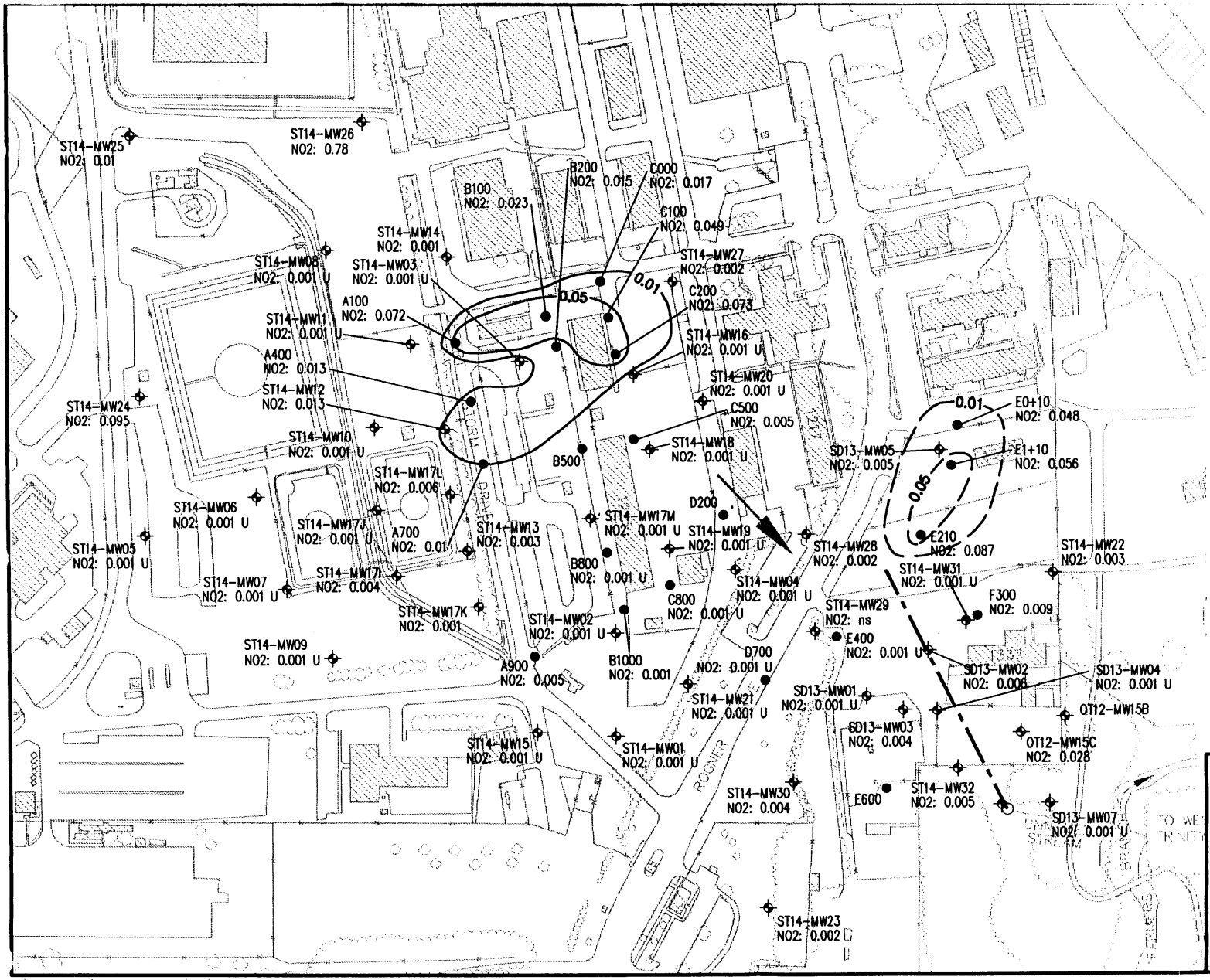
FIGURE 6.4

EXTENT OF DISSOLVED NITRATE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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LEGEND

- BUILDING
- BUILDING NUMBER
- FENCE
- SOIL BOREHOLE/GEOPROBE
- GROUNDWATER MONITORING WELL
- APPROXIMATE LOCATION OF FRENCH DRAIN
- APPROXIMATE LOCATION OF OIL/WATER SEPARATOR
- GROUNDWATER FLOW DIRECTION
- ST14-MW23 0.002 — LOCATION ID WITH MEASURED NITRITE (NO_2) CONCENTRATION IN mg/L (WITH DATA QUALIFIER FLAG WHERE APPLICABLE)
- J — ESTIMATED VALUE
- U — ANALYTE NOT DETECTED ABOVE METHOD DETECTION LIMIT
- —10— — ESTIMATED LINE OF EQUAL ANALYTE CONCENTRATION (mg/L) (DASHED WHERE INFERRED)

NOTE: DATA WERE NOT COLLECTED FROM LOCATIONS WHERE SYMBOLS APPEAR WITHOUT AN ANALYTICAL RESULT.

FIGURE 6.5

EXTENT OF DISSOLVED NITRITE

Site ST14
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Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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groundwater sampling locations. Figure 6.6 presents the 1994 analytical results for ferrous iron in groundwater at these sites. Areas characterized by elevated concentrations of dissolved benzene and other fuel hydrocarbons (Figure 6.1) correspond well with areas of elevated concentrations of ferrous iron relative to measured background concentrations. Ferrous iron was measured at or below the detection limit in background wells and most wells located outside the areas affected by fuel contamination. However, the concentrations of ferrous iron at sampling locations where elevated concentrations of benzene and other BTEX compounds were measured were as high as 680 mg/L.

The correlation between elevated dissolved hydrocarbon contamination and elevated ferrous iron concentrations suggests that the iron-reducing microorganisms are using ferric iron to oxidize the contaminants. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in contaminated groundwater underlying Site ST14 and Site SD13 are strong indicators of microbial activity. These geochemical data suggest that iron-reducing microorganisms are present in the groundwater at the site, and that these microorganisms are using ferric iron to energize BTEX metabolism. Elevated levels of ferrous iron in groundwater also account for the orange-colored coating of sediments previously observed at the unnamed stream. Ferrous iron is re-oxidized to ferric iron when the anaerobic groundwater was discharged to the unnamed stream via the french underdrain and oil/water separator. Ferric iron precipitates are responsible for the iron-orange colors noted at the outfall. Note that iron has not been measured in surface water samples since the 1994 RFI at concentrations above Risk Reduction Standard Number 2 levels protective of surface water quality (see Section 5).

More recent 1997 data indicate that, although ferrous iron is still being produced in areas characterized by elevated hydrocarbon contamination, less ferrous iron mass is present in groundwater. This may be an indication that the dissolution of ferric iron oxyhydroxides is slowing, which may eventually cause several inorganic compounds such as aluminum, arsenic, and zinc to be less mobile. These compounds have been shown to desorb from the solid soil matrix and sorb to the mobile ferrous iron particles (Masscheleyn *et al.*, 1991a, 1991b; Forstner *et al.*, 1989). A reduction in the amount of ferrous iron in groundwater can serve to reduce the mobilization of the inorganic groundwater COPCs. Additionally, the partial removal of the french underdrain system and complete abandonment of the oil/water separator has eliminated the preferential flow of water to the unnamed stream. Any mobilized inorganics are more likely to be oxidized prior to natural seepage into surface water bodies (i.e., at the sediment interface).

6.4.5 Sulfate Concentrations

Sulfate also may be used as an electron acceptor during microbial degradation of benzene and other fuel hydrocarbons under anaerobic conditions (Grbic-Galic, 1990). This redox reaction is commonly called sulfate reduction. Sulfate is reduced to sulfide during the oxidation of the BTEX compounds. The presence of decreased concentrations of sulfate in the source area relative to background concentrations indicates that sulfate may be participating in redox reactions at these sites. To

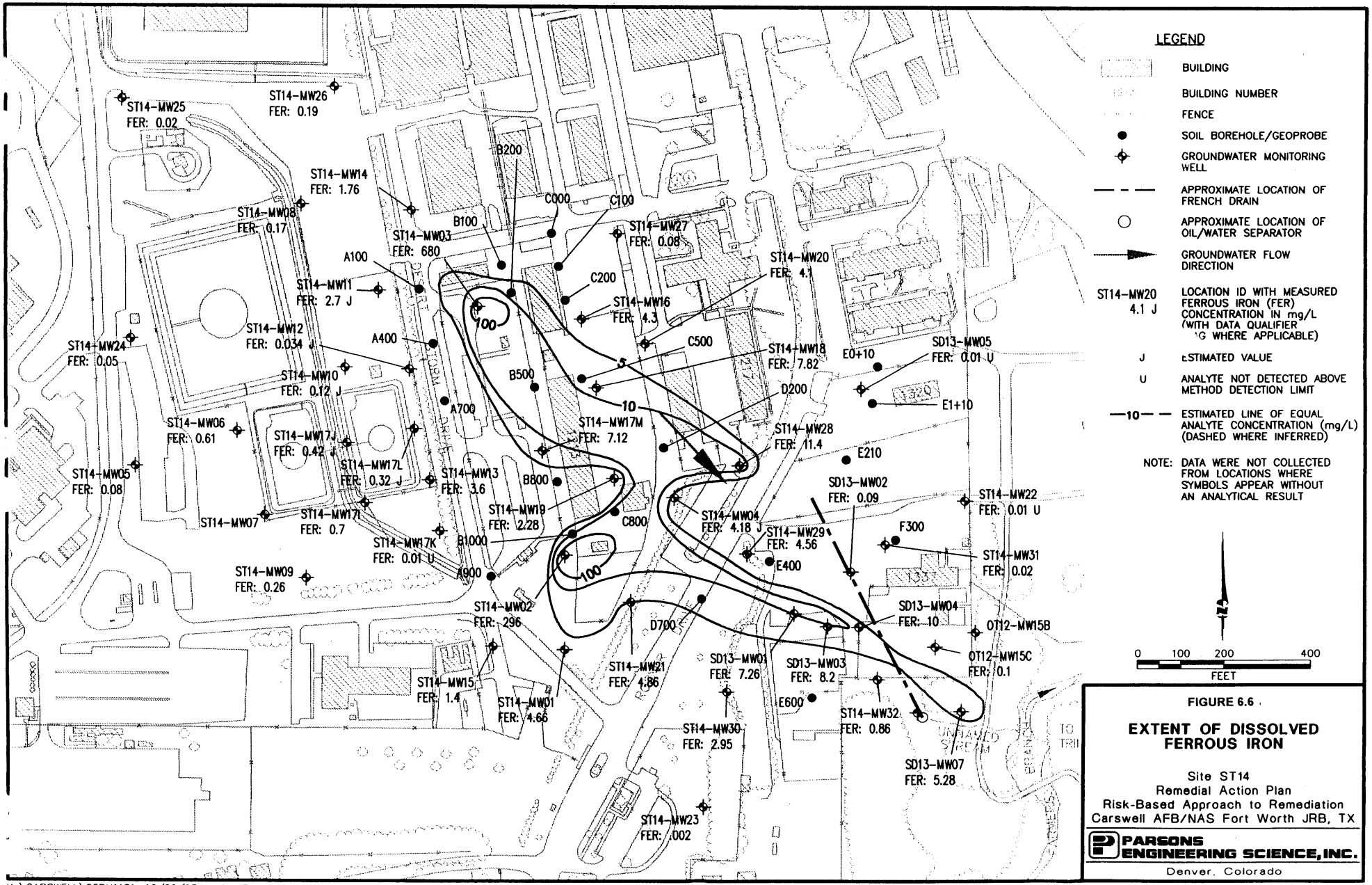


FIGURE 6.6

EXTENT OF DISSOLVED FERROUS IRON

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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investigate the potential for sulfate reduction at Site ST14 and Site SD13, total sulfate and sulfide concentrations were measured at groundwater sampling locations.

Figure 6.7 shows the analytical results for sulfate in groundwater. In general, areas characterized by elevated concentrations of dissolved benzene and other fuel hydrocarbon compounds (Figure 6.1) are depleted in sulfate concentrations relative to measured background concentrations. Background concentrations of sulfate at these sites ranged from 48.47 mg/L at ST14-MW24 to 120.6 mg/L at ST14-MW11. Sulfate concentrations measured at sampling locations with elevated fuel hydrocarbon concentrations ranged from 2.56 mg/L at the eastern edge of the dissolved plume originating from Site ST14A to 0.57 mg/L at ST14-MW29, which is about 60 feet from the elevated benzene concentration measured at Site SD13. Similar sulfate data was obtained during the January 1997 sampling event. This depletion of sulfate within the contaminated areas suggests that this compound is also acting as an electron acceptor.

Figure 6.8 shows that elevated concentrations of sulfide, which are produced when sulfate is reduced during benzene oxidation, was only measured slightly upgradient from Site ST14B. The absence of inorganic sulfide production in the other suspected source areas does not mean that sulfate reduction is not occurring. Rather, it is an indication that sulfate reduction at this site results in the production of another reduced form such as inorganic sulfur. The distinctive odor of sulfur was present during recent sampling activities at ST14-MW17J and ST14-MW16.

The measured Eh of the groundwater at Site ST14 and Site SD13 also was an early indicator that sulfate reduction could be occurring at these sites. Measured Eh levels at Site ST14 were sufficiently negative to suggest that sulfate reduction can occur at the site (Figure 6.2).

6.4.6 Dissolved Methane Concentrations

On the basis of free energy yield and the oxidizing potential of the site groundwater, the carbon dioxide-methane (CO_2-CH_4) redox couple also could be used to oxidize fuel hydrocarbon compounds to carbon dioxide and water once the groundwater is sufficiently reducing. To attain these reducing levels, other highly oxidizing chemical species such as oxygen, nitrate, and sulfate must be reduced. This redox reaction is called methanogenesis or methane fermentation. Methanogenesis yields the least free energy to the system in comparison to other chemical species (Figure 6.2 and Appendix E). The presence of methane in groundwater at elevated concentrations relative to background concentrations is a good indicator of methane fermentation.

Dissolved methane was measured at several groundwater monitoring wells as part of recent field sampling events. Figure 6.9 presents the analytical data for methane by sampling location. Methane was detected at several sampling locations at substantially elevated concentrations (relative to background levels) ranging from 2 mg/L to 5.3 mg/L. The presence of methane in groundwater at Sites ST14 and SD13 indicates that biodegradation processes have occurred via methanogenesis. The production of significant concentrations of methane is likely attributable to the anaerobic nature of the groundwater in the core of the BTEX plume (Figure 6.1), the slow contaminant

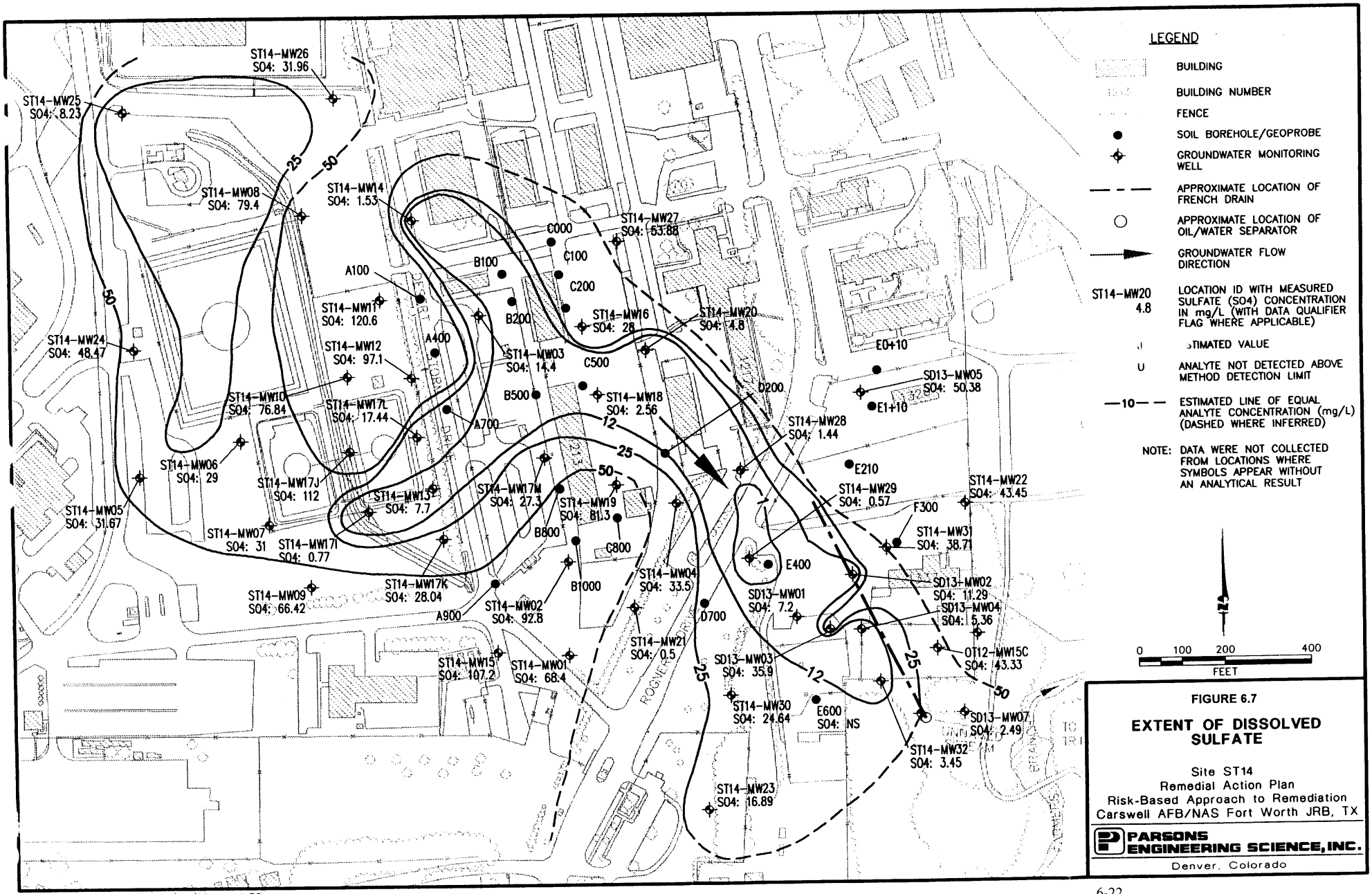


FIGURE 6.7

EXTENT OF DISSOLVED SULFATE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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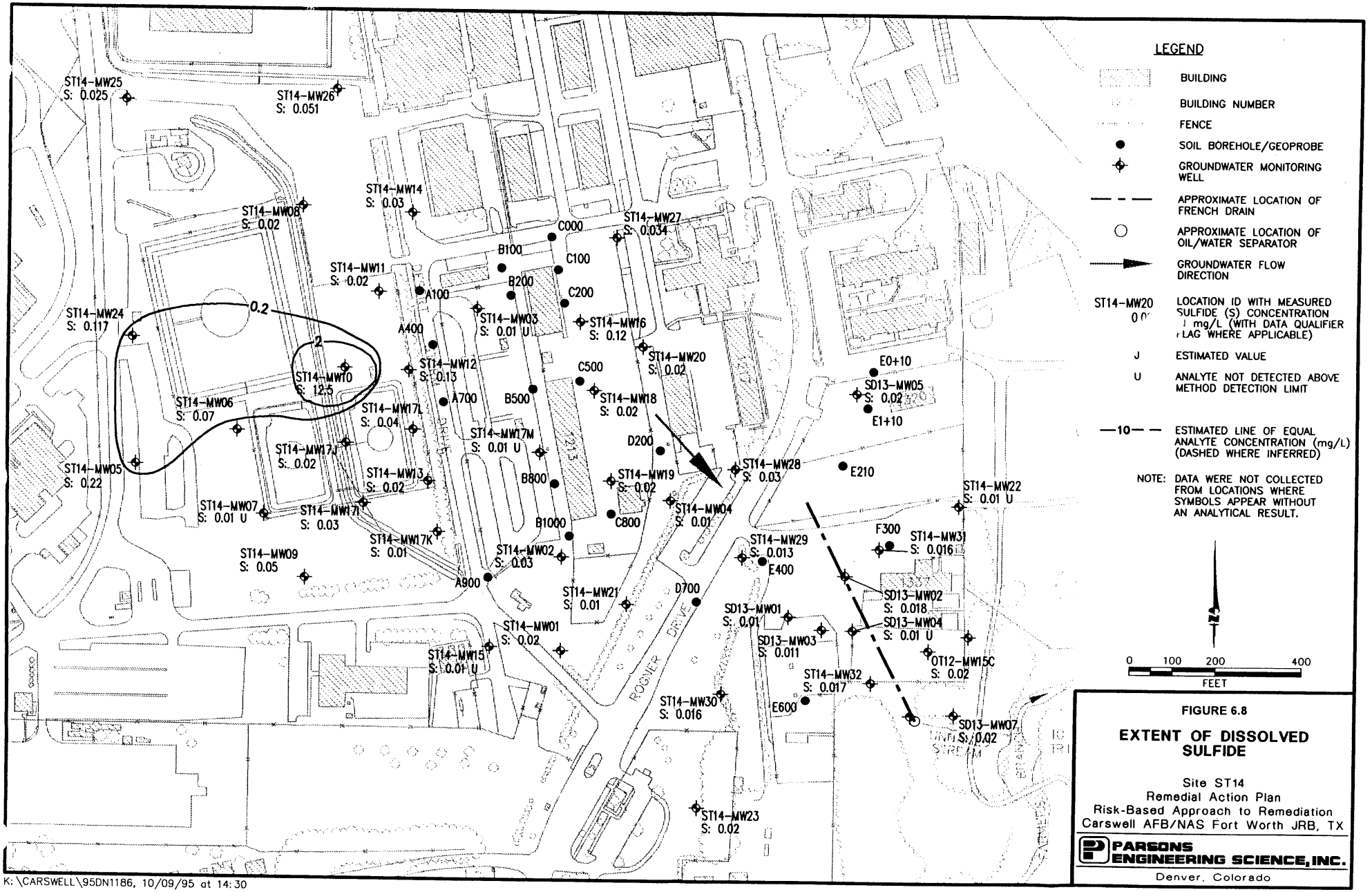


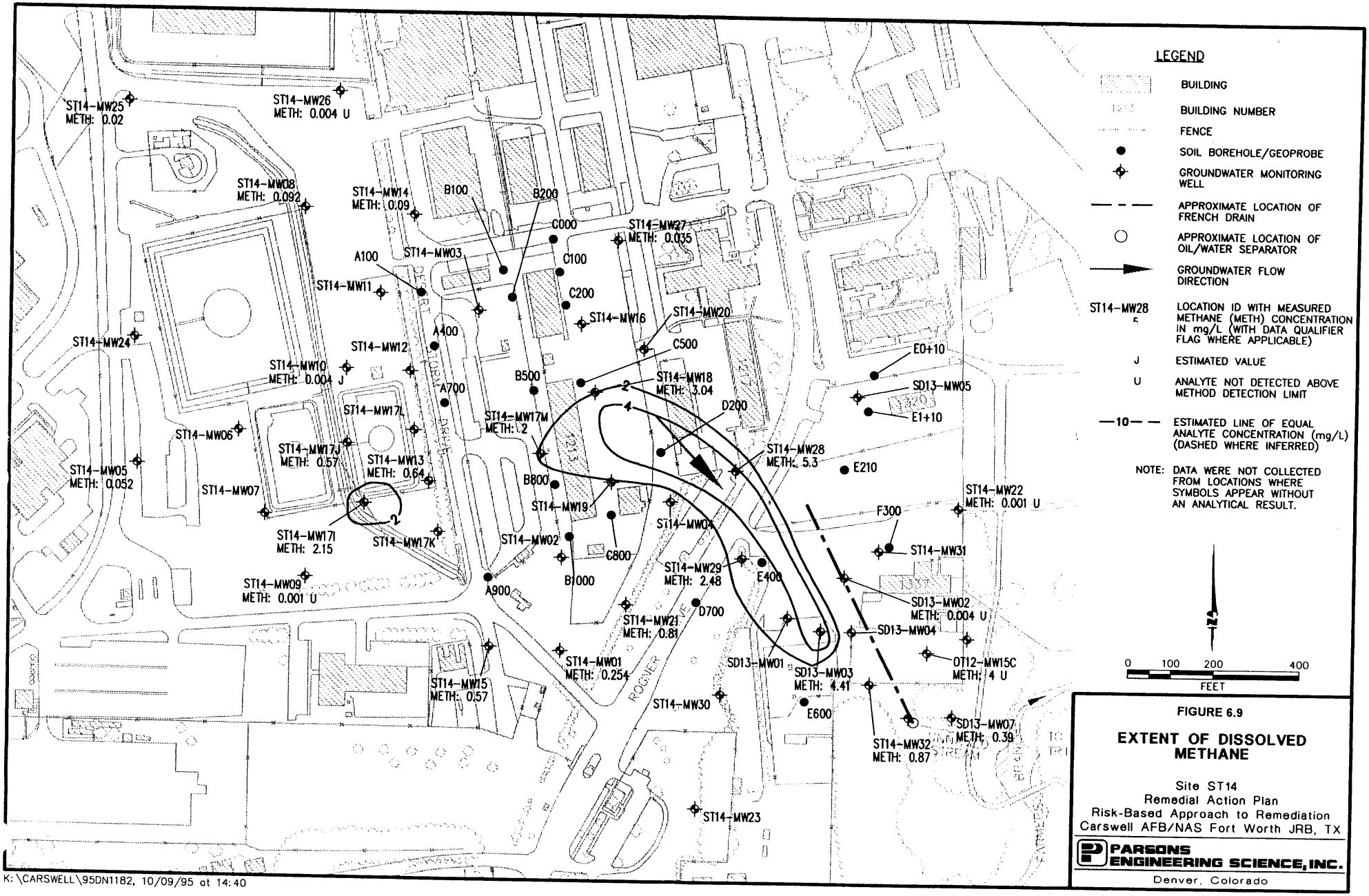
FIGURE 6.8

EXTENT OF DISSOLVED SULFIDE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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FIGURE 6.9

EXTENT OF DISSOLVED METHANE

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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Denver, Colorado

transport velocities, and the age of the dissolved hydrocarbon contamination at these sites. Methane has been produced and is accumulating in groundwater underlying and immediately downgradient from the suspected Sites ST14A and SD13 sources. As of 1997, similar concentrations of methane were measured in these source areas.

6.5 THEORETICAL ASSIMILATIVE CAPACITY ESTIMATES

The preceding discussions have been devoted to determining if fuel hydrocarbons, benzene in particular, are biodegrading in saturated soils and groundwater at Sites ST14 and SD13. Analytical data on reduced and oxidized chemical species indicate that indigenous microorganisms are facilitating the oxidation of fuel hydrocarbons, including benzene, and the reduction of electron acceptors to generate free energy for cell maintenance and production. The question of how much contaminant mass can be biodegraded must be addressed to assess the full potential for long-term intrinsic remediation of the site.

Mass balance relationships can be used to determine how much contaminant mass can be degraded by each of the redox reactions that the microorganisms might use to make free energy available for cell maintenance and production. The stoichiometric relationship between the contaminant and the electron acceptor can be used to estimate the assimilative capacity of the groundwater. Now that the redox reactions operating at these sites have been defined, it is possible to estimate how much contaminant mass can be assimilated or oxidized by available electron acceptors. This analysis, when coupled with the biodegradation rate information discussed earlier (Table 6.1), will provide the basis for determining the potential for continued removal of benzene mass from saturated soils and groundwater at the site.

Appendix E presents the coupled redox reactions that represent the biodegradation of each of the BTEX compounds. These tables also present the stoichiometric mass ratio of electron acceptors needed to oxidize each of the BTEX compounds. These stoichiometric mass ratios can be used to estimate the assimilative capacity of the groundwater at Site ST14 and Site SD13. This is accomplished by first determining the initial mass of each electron acceptor available in the groundwater. Data on these chemical species were collected at sample locations upgradient from and outside of the plume of fuel hydrocarbon contamination. As groundwater migrates into the source area, electron acceptors are brought into contact with hydrocarbon-degrading microorganisms and site contamination. The reduction of electron acceptors that occurs within the dissolved plume represents the utilized oxidizing capacity of the groundwater. This utilized capacity is then divided by the mass of electron acceptors required to mineralize each of the fuel hydrocarbon compounds to estimate the expressed intrinsic capacity of the groundwater to biodegrade these compounds.

Conservative estimates of the utilized concentrations of all of the electron acceptors that appear to be operating at the site to biodegrade fuel hydrocarbon compounds are listed in Table 6.2. These concentrations are used to calculate the theoretical expressed assimilative capacity of each electron acceptor for total BTEX and benzene based on the mass stoichiometric relationships presented in detail in Appendix E. Table 6.2 also presents the highest concentration of ferrous iron and methane measured at the site. These concentrations are used to "back-calculate" the expressed assimilative capacity

TABLE 6.2
ESTIMATE OF EXPRESSED ASSIMILATIVE CAPACITY OF SATURATED SOIL AND GROUNDWATER
SITE ST14, REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

Electron Acceptor	Background Concentration (µg/L)	Utilized Electron Acceptor Mass (µg/L)	Initial BTEX Assimilative Capacity[a/] (µg/L)	Initial Benzene Assimilative Capacity[a/] (µg/L)
Oxygen	1000	500	159.5	162.9
Nitrate	1400	1000	205.5	209.6
Ferric iron[b/]	680000	300000[c/]	13736.3	13953.5
Sulfate	48470	36470	7755.4	7911.1
Methane[b/]	5300	3000	3833.9	3846.2
		Total	25690.6	26083.2
		1986 Maximum	11,000+	11,000
		1994 Maximum	1503	110

[a/] Calculated based on the ratio of the total mass of electron acceptor required to oxidize a given mass of total BTEX or benzene, assuming no other source of oxidizing demand (Appendix E).

[b/] This represents the reduced form of the electron acceptor. Assimilative capacity is expressed only as an estimate. Does not represent actual total reservoir of electron acceptor to be exhausted.

[c/] Average utilized electron mass rather than maximum expressed level.

that is attributable to ferric iron reduction and methanogenesis. On the basis of these calculations, the groundwater at Site ST14 and Site SD13 has demonstrated the intrinsic capacity to eventually oxidize up to 25,700 µg/L of total BTEX or 26,100 µg/L of benzene. The analytical data collected in January 1997 confirm that the groundwater still has the intrinsic capacity to biodegrade a similar mass of hydrocarbon compounds.

Although the maximum measured BTEX or benzene concentrations apparently do not exceed the theoretical assimilative capacity of the groundwater at Site ST14, some contaminant mass remains in the groundwater at this site. It is important to note that the expressed assimilative capacity estimate derived in Table 6.2 is an upper-bound estimate of the expressed assimilative capacity because it assumes perfect mixing of the fuel-related COPCs and available electron acceptors, instantaneous reaction rates, and complete mineralization. Actually, the total reservoir of electron acceptors will not be available to the microorganisms because of mass transfer, kinetic, and other biological and chemical limitations. Additionally, the mass of electron acceptors reduced within the plume may be the result of other oxidizing demand sources, such as residual TPH, incomplete degradation products of BTEX, and other organic carbon species.

6.6 DEGRADATION OF CHLORINATED SOLVENTS

Chlorinated solvents also can be transformed, directly or indirectly, by biological processes (e.g., Bouwer *et al.*, 1981; Miller and Guengerich, 1982; Wilson and Wilson, 1985; Nelson *et al.*, 1986; Bouwer and Wright, 1988; Little *et al.*, 1988; Mayer *et al.*, 1988; Arciero *et al.*, 1989; Cline and Delfino, 1989; Freedman and Gossett, 1989; Folsom *et al.*, 1990; Harker and Kim, 1990; Alvarez-Cohen and McCarty, 1991a, 1991b; DeStefano *et al.*, 1991; Henry, 1991; McCarty *et al.*, 1992; Hartmans and de Bont, 1992; McCarty and Semprini, 1994; Vogel, 1994; Bradley and Chapelle, 1996; Klier *et al.*, 1996). Chlorinated aliphatic hydrocarbons (CAHs) such as PCE may act as both a substrate (electron donor) and an electron acceptor.

CAHs may undergo several types of biodegradation involving several steps. CAHs may undergo biodegradation through three different pathways: (1) use as an electron acceptor; (2) use as an electron donor; or (3) cometabolism, which is degradation resulting from exposure to a catalytic enzyme fortuitously produced during an unrelated process. At a given site, one or all of these processes may be operating, although the use of CAHs as electron acceptors appears to be the most likely.

In a pristine aquifer, native organic carbon is utilized as an electron donor and DO is utilized first as the prime electron acceptor. Where anthropogenic carbon (e.g., fuel hydrocarbons or less-chlorinated CAHs) is present, it also will be utilized as an electron donor. After the DO is consumed, anaerobic microorganisms typically use native electron acceptors (as available) in the following order of preference: nitrate, ferric iron oxyhydroxide, sulfate, and finally carbon dioxide. If present, CAHs will be used as electron acceptors as well, but in competition with the other compounds. Evaluation of the distribution of these electron acceptors can provide evidence of where and how CAH biodegradation is occurring.

6.6.1 Electron Acceptor Reactions (Reductive Dehalogenation)

Under anaerobic conditions, biodegradation of chlorinated solvents usually proceeds through a process called reductive dehalogenation. During this process, the halogenated hydrocarbon is used as an electron acceptor, not as a source of carbon, and a halogen atom is removed and replaced with a hydrogen atom. In general, reductive dehalogenation of chlorinated ethenes occurs by sequential dehalogenation from PCE to TCE to DCE to VC to ethene. Depending upon environmental conditions, this sequence may be interrupted, with other processes then acting upon the products. During reductive dehalogenation, all three isomers of DCE can theoretically be produced; however, Bouwer (1994) reports that under the influence of biodegradation, *cis*-1,2-DCE is a more common intermediate than *trans*-1,2-DCE, and that 1,1-DCE is the least prevalent intermediate of the three DCE isomers produced via microbially mediated reductive dehalogenation. At Site SD13, *cis*-1,2-DCE is present in the vicinity of PCE, but not at concentrations that exceed Risk Reduction Standard Number 2 levels. The presence of this daughter product suggest that the low concentrations of PCE at this site are being reductively dehalogenated.

Reductive dehalogenation of chlorinated solvent compounds is associated with the accumulation of daughter products and an increase in chloride. Reductive dehalogenation affects chlorinated compounds differently. Of the chlorinated compounds, those with the greatest number of chlorine atoms (e.g., PCE, TCE, PCA, or TCA) are the most susceptible to reductive dehalogenation because they are the most oxidized. Conversely, less-chlorinated compounds like VC are the least susceptible to reductive dehalogenation because they are the least oxidized of these compounds. The rate of reductive dehalogenation also has been observed to decrease as the degree of chlorination decreases (Vogel and McCarty, 1985; Bouwer, 1994). Murray and Richardson (1993) have postulated that this rate decrease may explain the accumulation of VC in PCE and TCE plumes that are undergoing reductive dehalogenation.

In addition to being affected by the degree of chlorination of the CAH, reductive dehalogenation can also be controlled by the redox conditions of the site groundwater system. In general, reductive dehalogenation has been demonstrated under anaerobic nitrate- and sulfate-reducing conditions, but the most rapid dehalogenation rates, affecting the widest range of CAHs, occur under methanogenic conditions (Bouwer, 1994). Dehalogenation of PCE and TCE to DCE can proceed under mildly reducing conditions such as nitrate reduction or ferric iron reduction (Vogel *et al.*, 1987), while the transformation of DCE to VC, or the transformation from VC to ethene requires more strongly reducing conditions (Freedman and Gossett, 1989; DeStefano *et al.*, 1991; De Bruin *et al.*, 1992). Because CAH compounds are used as electron acceptors, there must be an appropriate and available source of carbon for microbial growth in order for reductive dehalogenation to occur (Bouwer, 1994). Potential carbon sources can include low-molecular-weight compounds (e.g., lactate, acetate, methanol, or glucose) present in natural organic matter, fuel hydrocarbons, or less-chlorinated solvents (as discussed below). The oxidizing conditions of the groundwater underlying Site SD13 are sufficiently low to promote reductive dehalogenation reactions, particularly in the presence of residual hydrocarbon contamination.

6.6.2 Electron Donor Reactions

Under aerobic conditions some CAH compounds can be utilized as the primary substrate (i.e., electron donor) in biologically mediated redox reactions (McCarty and Semprini, 1994). In this type of reaction, the facilitating microorganism obtains energy and organic carbon from the degraded CAH. In contrast to reactions in which the CAH is used as an electron acceptor, only the least oxidized CAHs (e.g., VC, DCE, and DCA) may be utilized as electron donors in biologically mediated redox reactions.

For example, while Murray and Richardson (1993) write that microorganisms are generally believed to be incapable of growth using TCE and PCE, other less chlorinated CAHs have been shown to be used as substrates. Davis and Carpenter (1990) describe the aerobic oxidation of VC in groundwater. McCarty and Semprini (1994) describe investigations in which VC and 1,2-DCA were shown to serve as primary substrates. These authors also document that dichloromethane has the potential to function as a primary substrate under either aerobic or anaerobic environments. Klier *et al.* (1996) describe aerobic mineralization of all three isomers of DCE. In addition, Bradley and Chapelle (1996) show evidence of oxidation of VC under iron-reducing conditions so long as there is sufficient bioavailable ferric iron. Aerobic metabolism of VC may be characterized by a loss of VC mass, a decreasing molar ratio of VC to other CAH compounds, and, rarely, the presence of chloromethane. Use of chlorinated compounds as an electron donor is not a likely biodegradation pathway at Site SD13.

6.6.3 Cometabolism

When a CAH is biodegraded through cometabolism, it serves as neither an electron acceptor nor a primary substrate in a biologically mediated redox reaction. Instead, the degradation of the CAH is catalyzed by an enzyme or cofactor that is fortuitously produced by organisms for other purposes. The organism receives no known benefit from the degradation of the CAH; rather, the cometabolic degradation of the CAH may in fact be harmful to the microorganism responsible for the production of the enzyme or cofactor (McCarty and Semprini, 1994).

Cometabolism is best documented in aerobic environments, although it potentially could occur under anaerobic conditions. It has been reported that under aerobic conditions chlorinated ethenes, with the exception of PCE, are susceptible to cometabolic degradation (Murray and Richardson, 1993; Vogel, 1994; McCarty and Semprini, 1994). Vogel (1994) further elaborates that the cometabolism rate increases as the degree of halogenation decreases.

In the cometabolic process, TCE is indirectly transformed by bacteria as they use fuel hydrocarbons or another substrate to meet their energy requirements. Therefore, TCE does not enhance the degradation of other carbon sources, nor will its cometabolism interfere with the use of electron acceptors involved in the oxidation of those carbon sources. Given this relationship, it would follow that depletion of suitable substrates (i.e., other organic carbon sources) likely limits cometabolism of CAHs. At Site SD13, PCE is probably not susceptible to cometabolism, but TCE (particular in the presence of elevated methane concentrations) may be degraded via cometabolism. Note that TCE has not been detected recently at Site SD13 at concentrations above the residential Risk Reduction Standard Number 2 levels.

6.6.4 Abiotic Degradation Mechanisms

Chlorinated solvents dissolved in groundwater may also be degraded by abiotic mechanisms, although the reactions may not be complete and often result in the formation of a toxic intermediate. The most common abiotic reactions affecting chlorinated solvents are hydrolysis and dehydrohalogenation. Hydrolysis is a substitution reaction in which a halogen substituent is replaced with a hydroxyl (OH^-) group from a water molecule. Dehydrohalogenation is an elimination reaction in which a halogen is removed from a carbon atom, followed by removal of a hydrogen atom from an adjacent carbon atom, with a double bond between the carbon atoms being produced. Other possible reactions include oxidation and reduction, although Butler and Barker (1996) note that no abiotic oxidation reactions involving common halogenated solvents have been reported in the literature. They also note that reduction reactions are most commonly microbially mediated.

Hydrolysis of chlorinated methanes and ethanes has been well-demonstrated in the literature (e.g., Vogel *et al.*, 1987; Jeffers *et al.*, 1989; Vogel, 1994; Butler and Barker, 1996). The likelihood that a solvent will hydrolyze is partly dependent upon the number of halogen substituents, typically with fewer halogens resulting in more rapid hydrolysis. Dehydrohalogenation, on the other hand, is more likely to take place as the number of halogen substituents increases.

Butler and Barker (1996) note that attributing changes in the presence, absence, or concentration of halogenated solvents to abiotic processes is usually difficult, particularly on the field scale. Solvents may undergo both biotic and abiotic degradation, and discerning the effects of each mechanism (on the field scale), if possible, would be very difficult. Also, as Butler and Barker (1996) note, the breakdown products of some reactions such as hydrolysis (e.g., acids and alcohols) may be more easily degraded (biotically or abiotically); these products also require additional analyses that may not be feasible for a field investigation. This makes collection of field evidence to demonstrate hydrolysis very difficult to collect and interpret, and Butler and Barker (1996) note that such evidence has not been successfully collected and presented

6.7 EFFECTS OF REDOX CONDITIONS ON METALS MOBILITY

The reduction-oxidation potential (ORP) and pH of a groundwater system can greatly affect both the speciation and solubility of several inorganic compounds, particularly the inorganic COPCs for Site SD13 (e.,g. aluminum, arsenic, manganese, and zinc). Under oxidized conditions, the solubility of these compounds is generally low. The predominant oxidized species of these compounds are relatively immobile and sorb strongly to the solid soil matrix. However, as the groundwater conditions become reducing, reduced species of these inorganic compounds predominant. These reduced species are generally characterized by increased solubility. For example, total arsenic measured in solution has been shown to increase approximately 25 times when the solution is sufficiently reduced to support methanogenesis (Masscheleyn et al., 1991a, 1991b).

The large increases in aluminum, arsenic, and zinc observed upon reduction is probably linked to the reductive dissolution of iron oxyhydroxides. Arsenic chemistry

in soils and sediments is believed to be controlled by adsorption-desportion mechanisms (Livesey and Huang, 1981). Soil pH (Goldbert and Glaubig, 1988), the amount and type of clay (Bar-Yosef and Meek, 1987), and iron oxides (Livesey and Huang, 1981; Pierce and Moore, 1982; Forstner *et al.*, 1989; Chuan *et al.*, 1996) are factors that are important in controlling the sorption of these inorganic compounds. For example, dissolution of iron oxyhydroxides upon reduction and subsequent release of adsorbed arsenic (or any other of these inorganic COPCs) would lead to increased dissolved arsenic concentrations. Total water-soluble arsenic and iron (as ferrous iron) are highly correlated at this and other sites, suggesting the importance of iron oxyhydroxides in controlling arsenic adsorption-desorption reactions.

The transformation of oxidized forms of inorganic metals to reduced species could be an additional mechanism leading to increased concentrations in groundwater. Upon reduction, many of these compounds will be present predominantly as uncharged species (e.g., Ferguson and Gavis, 1972), thus enhancing desorption from positively charged amorphous iron oxyhydroxide surfaces associated with the solid soil matrix. pH also controls the concentrations of water-soluble species. In most cases, the solubility of these compounds were as much as 5 times higher under slightly alkaline conditions (e.g., pH of 7.5) than more acidic conditions (e.g., pH of 5). Consequently, under oxidized conditions, compound solubility is controlled by adsorption-desorption reactions. Yet adsorption can decrease with increasing pH in the range of 4 to 9. A pH increase leads to greater dissolved inorganic compound concentrations.

As described previously, the groundwater underlying Sites ST14 and SD13 are strongly reducing, and methane is produced in significant concentrations in areas characterized by fuel hydrocarbon contamination. Similar to the production of methane, the distribution of several of these inorganic compounds in groundwater at Site SD13 appears to be directly tied to the localized ORP. Section 5 includes a map of the distribution of arsenic in groundwater at Site SD13. Elevated concentrations of arsenic coincide with elevated concentrations of manganese, which is being reduced (and therefore is more soluble) by microorganisms facilitating the oxidation of fuel hydrocarbons.

6.8 PREDICTING FUEL HYDROCARBON TRANSPORT AND FATE

Understanding the effects of natural physical, chemical, and biological processes on chemicals is an important step in determining potential long-term risks associated with chemical migration in the environment. The behavior of benzene under the influence of these processes must be quantified to estimate the likelihood and nature of a future release, to predict the extent that benzene (and possibly the more highly retarded hexachlorobenzene detected at Site SD13) could leach from soils and migrate in groundwater, and to assess the effects on benzene persistence, mass, concentration, and toxicity over time at the site. If destructive and nondestructive attenuation processes can minimize or eliminate the concentration of benzene to which a receptor could be exposed, remedial action may not be warranted because no reasonable exposure pathway exists or completion of the exposure pathway would not result in significant risks. The focus of this final section is to predict how benzene (the fuel-related COPC for Site ST14) will be transported and transformed over time in soil and groundwater based on site data and site-specific transport and fate models assuming no engineered remedial action is undertaken.

6.8.1 Source Contribution from Contaminated Soils

The Seasonal Soil Compartment Model (SESOIL) was used to estimate the potential impacts to groundwater quality due to contaminants leaching from unsaturated soils, per TNRCC (1994b) recommendations. SESOIL is a one-dimensional vertical transport model for the unsaturated soil zone. The model was originally developed for the EPA (Arthur D. Little, Inc., 1981), and modified by the Oak Ridge National Laboratory and the Wisconsin Department of Natural Resources (Hetrick and Scott, 1993). SESOIL is based on mass balance and equilibrium partitioning the chemicals between different phases (i.e., dissolved, sorbed, vapor, and pure). This model can be used to simulate the transport of chemical contamination to the atmosphere and groundwater. SESOIL is essentially a screening level model, because it uses less soil, chemical, and meteorological data than other similar models. SESOIL is coupled with the Summers model (Summers *et al.*, 1980) to compute contaminant concentrations in the saturated zone below the unsaturated column. The model was applied as part of this evaluation to simulate chemical releases from unsaturated soil to groundwater.

The model requires several types of chemical- and site-specific data to estimate the concentration of a chemical in the soil, its rate of leaching toward groundwater, and the impact of other environmental pathways. SESOIL was operated in a monthly option mode to provide a better estimate of chemical movement through the unsaturated soil at Sites ST14 and SD13. Monthly meteorological data for Carswell was obtained from the Naval Training Meteorology and Oceanography Detachment (Appendix E). The unsaturated soil column was conceptualized as 10 feet thick. This depth represents an average depth to groundwater at the site, as the thickness of the vadose zone varies from about 6 feet bgs to more than 16 feet bgs. This depth was selected to allow infiltrating precipitation to pass through a representative soil column to impact underlying groundwater. An average source area concentration of 96 mg/kg of benzene in source area soils was used in the SESOIL simulations. This concentration is approximately the average between the site maximum and the calculated 95-percent upper confidence limit (UCL) of the mean of measured concentrations at Site ST14A (see Section 6). Appendix E presents the SESOIL model input data.

The climate at Carswell is classified as subtropical with humid, hot summers (Section 3.6). Groundwater is recharged from infiltrating precipitation (US Air Force, 1994), so an annual groundwater yield rate is expected. The SESOIL model results predicted that at least 30 centimeters of precipitation would infiltrate through soils and discharge into underlying groundwater (Appendix E). Based on the air-filled soil porosity observed during the 1993 bioventing pilot test, about 1.5 years is required to complete one full flush of the representative soil column. This results in a benzene mass transfer of about 25 µg/L-day from Site ST14A soils to the underlying groundwater. No detectable concentrations of benzene were measured in soils at Site SD13 during recent sampling events. Consequently, the source term for this area was developed during calibration of the groundwater flow and contaminant transport model (Section 5.6.2).

The flux of contaminant mass that was estimated to leach from Site ST14A soils (based on the SESOIL model) was used as an initial mass loading rate in the groundwater flow and contaminant transport model described in the next sections. The cumulative impact of leaching soil contaminants from these soils was factored into the source term calculations over time. As contaminant mass leaches from these soils, the

residual contamination in the soils gradually decreases. The Appendix E model simulation shows how the source area soils are slowly depleted of contaminant mass due to leaching. The SESOIL model results indicate that soils could contribute significant contaminant mass to groundwater for about 10 more years. The reduction in leachate concentration over time was included in the fate and transport modeling to simulate the impacts of natural weathering on groundwater quality.

6.8.2 Bioplume II Model Overview

A numerical modeling approach was selected to investigate the transport and fate of dissolved benzene in groundwater at Sites ST14 and SD13. It was not possible to simulate the behavior of other groundwater COPCs given the limited distribution of contamination (e.g., PCE) or the complexity of release and transport properties involved in groundwater migration (e.g., inorganic metals). Consequently, the mathematical model Bioplume II was used to simulate the behavior of benzene in groundwater at the sites over time. The two primary objectives of this modeling effort were to determine the maximum extent of benzene migration and to characterize the anticipated concentrations of benzene in groundwater as a function of distance and time at the site. Because dissolved contamination exists in saturated media at both Site ST14 and SD13, which are hydrologically connected to each other, dissolved benzene from the small source area at Site SD13 was included in the fate and transport modeling. Therefore, the mathematical model developed for this effort accounts for the natural physical, chemical, and biological processes documented to be occurring at both Sites ST14 and SD13. This type of model is useful in defining and understanding the various factors that may contribute most to potential future exposure to fuel-related contamination (EPA, 1992a). The model results also may be used to assess the potential for migration of other compounds, particularly those whose fate and transport behavior is directly tied to the fate of fuel hydrocarbons (e.g., PCE as an alternate electron acceptor; inorganic compounds that have been mobilized as a result of localized [microbially mediated] changes in geochemical conditions).

6.8.2.1 Model Overview

The Bioplume II model code incorporates advection, dispersion, adsorption, and biodegradation to simulate benzene plume migration and degradation. The computer code used to simulate these processes is based upon the US Geological Survey Method of Characteristics (USGS MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The USGS MOC model accounts for advective, dispersive, and adsorptive mechanisms only. The model was modified by researchers at Rice University for the EPA to include a biodegradation component based on the work of Borden and Bedient (1986). The model was configured to simulate benzene loss from biodegradation using the conservative site-specific biodegradation rates derived in Section 6.3.4. The site-specific biodegradation rate constant for benzene presented in Table 6.1 (i.e., 0.00141 day^{-1}) was used to simulate the effects of biological processes on contaminant fate over time. This is an important element of this model, because it ensures that biodegradation effects as calculated from actual field-scale evidence are incorporated into the quantitative chemical fate assessment. A complete description of the Bioplume II model developed for this site is included in Appendix E.

The Bioplume II model developed for Site ST14 and Site SD13 used site-specific data

and conservative assumptions about governing physical, chemical, and biological processes. The use of a 2-D model is appropriate at these sites because the saturated interval is relatively thin, and the local flow system, as defined by groundwater elevation data and the underlying basal confining unit of the Goodland Formation (estimated at 7 to 20 feet bgs), will likely prevent significant downward vertical migration of dissolved contamination. Based on the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as an unconfined aquifer of variable saturated thickness and composed of fine sand and gravel with intermittent zones of silty and clayey sands. Saturated thickness at the site ranges from approximately 3 to 14 feet, depending on the variable topography of the Goodland Formation. Saturated thickness is approximately 14 feet to the northwest of Site ST14, and decreases to as low as 3 feet southeast of Site ST14, toward Site SD13 (Figure 3.8). Layers of silty and clayey sands residing above the water table are suspected of causing localized, semiconfined flow conditions, specifically near the southern part of Site SD13 in the proximity of wells ST14-MW30 and ST14-MW23. In addition, groundwater flow is largely controlled by a wide paleochannel formed by the Goodland Formation, which is not immediately evident from constructed groundwater isocontours (Section 3). Topographic highs of the Goodland Formation north and south of Site ST14 and Site SD13 appear to channel groundwater through the southeastern directed path of the paleochannel. The combined effect of paleochanneling and localized, semiconfined-flow conditions influences groundwater to flow more southerly at Site ST14 (west of building 1213), and eventually turn to the southeast, predominantly as a result of paelochanneling, to proceed toward Site SD13. This flow trend is apparent in the observed migration path of dissolved contamination from Site ST14A (Section 4).

Other model assumptions focused on defining the effects of remaining contaminant sources on groundwater quality over time at the site. As described in Section 4, mobile LNAPL has been regularly reported in monitoring well ST14-MW17M, (Radian, 1991). Sheens of LNAPL were also observed in a bioventing well and several vapor MPs in May 1993 (ES, 1993). Although not confirmed, it is probable that mobile LNAPL exists along the water table in thin layers that vary in thickness based on water table fluctuations. These thin layers of fuel contamination are most likely found near the fueling area at Site ST14A and between the ASTs at Site ST14B. Mobile LNAPL also has been recently observed at SD13-MW07, which is directly downgradient from the location of the former oil/water separator. This LNAPL is likely the result of past releases from this SWMU. The small quantity of mobile LNAPL at both sites appear highly weathered and is unlikely to be a significant future source of benzene to groundwater. The absence of detectable benzene in wells where LNAPL has been measured supports this conclusion.

Consequently, residual benzene concentrations in the unsaturated and capillary fringe soils at Site ST14 and Site SD13 were considered as the most significant remaining source of dissolved contamination. The mass of benzene that could partition from these contaminated soils, and dissolve into and migrate with groundwater over time was based on the source term estimates derived in Section 6.8.1. A significant contaminant source term was estimated to persist at the sites for an additional 10 years, assuming no additional contaminant mass or LNAPL is released at the site (Appendix E). After this time, the bulk of benzene mass will have been effectively weathered from the contaminated soils.

The Bioplume II model also was used to simulate the effects of soil remediation using remedial technologies such as bioventing. The reduction in the amount of benzene mass that could partition from residual soil contamination into groundwater over time after bioventing source area soils was based on the pilot test results presented in Section 9.1. Approximately 98 percent of the benzene mass could be removed from source area soils at Site ST14A as a result of one to two years of bioventing. This decreasing source term rapidly reduces the amount of benzene mass that would otherwise leach from soils and dissolve into underlying groundwater. These specific model results are presented and discussed in Section 10. The model results presented in this section only account for the effects of nonengineered processes on contaminant transport and fate.

6.8.2.2 Model Calibration

Part of the modeling strategy for this site was to identify and develop a groundwater flow and contaminant transport model that can be used to reasonably simulate observed site conditions. The ideal situation would be to have a limitless supply of site data to use in the creation of a groundwater model that would then generate output that was absolutely representative of site conditions. However, the economics and logistics of collecting enough site data to satisfy each model input parameter would be enormous. Sites with incomplete site data are usually modeled by performing a model calibration rather than returning to the field for additional data to check model predictions. Model calibration is the process of systematically adjusting specific model input parameters within an expected range until the resulting model output is a reasonably good match to observed field conditions. Model calibration is an essential step toward developing an appropriate and defensible mathematical tool to predict contaminant behavior in a complex system (Freeze and Cherry, 1979; National Research Council, 1990).

Site data collected during March 1994, July through September 1994, and March and April 1995 as part of the risk-based remediation field investigation were used to calibrate the Bioplume II model for Site ST14 and Site SD13. The groundwater model was calibrated by directly adjusting and calculating a select range of model parameters until good agreement between model predictions and observed site conditions was achieved. Only trasmissivity was adjusted in a trial-and-error fashion as part of the calibration of the Bioplume II model for this site. The Bioplume II model developed for this site was calibrated using the highest transmissivity values observed at the site based on available hydraulic conductivity and saturated thickness data. Calibrated groundwater flow velocities were within the estimated groundwater velocities at the site of 0.2 to 0.3 ft/day (Section 3). Site-specific data on a benzene biodegradation coefficient, chemical retardation, dispersivity, and source term loading rates were used directly and were not varied during model calibration.

The calibration of the Bioplume II model developed for Sites ST14 and SD13 can be evaluated by comparing how closely model predictions match recorded site conditions in terms of groundwater hydraulics and contaminant plume shape and migration. The final calibrated model resulted in a reasonable representation of groundwater flow patterns. The root-mean-square error between actual and observed groundwater elevation heads was 2.22 feet, which translates to a model error of approximately 5.5 percent given a total head drop of 34 feet over the model domain (see Appendix E for more details). This error value suggests that model errors associated with the flow hydraulics are only a small part of the overall model response. Additionally, a good agreement between the simulated benzene

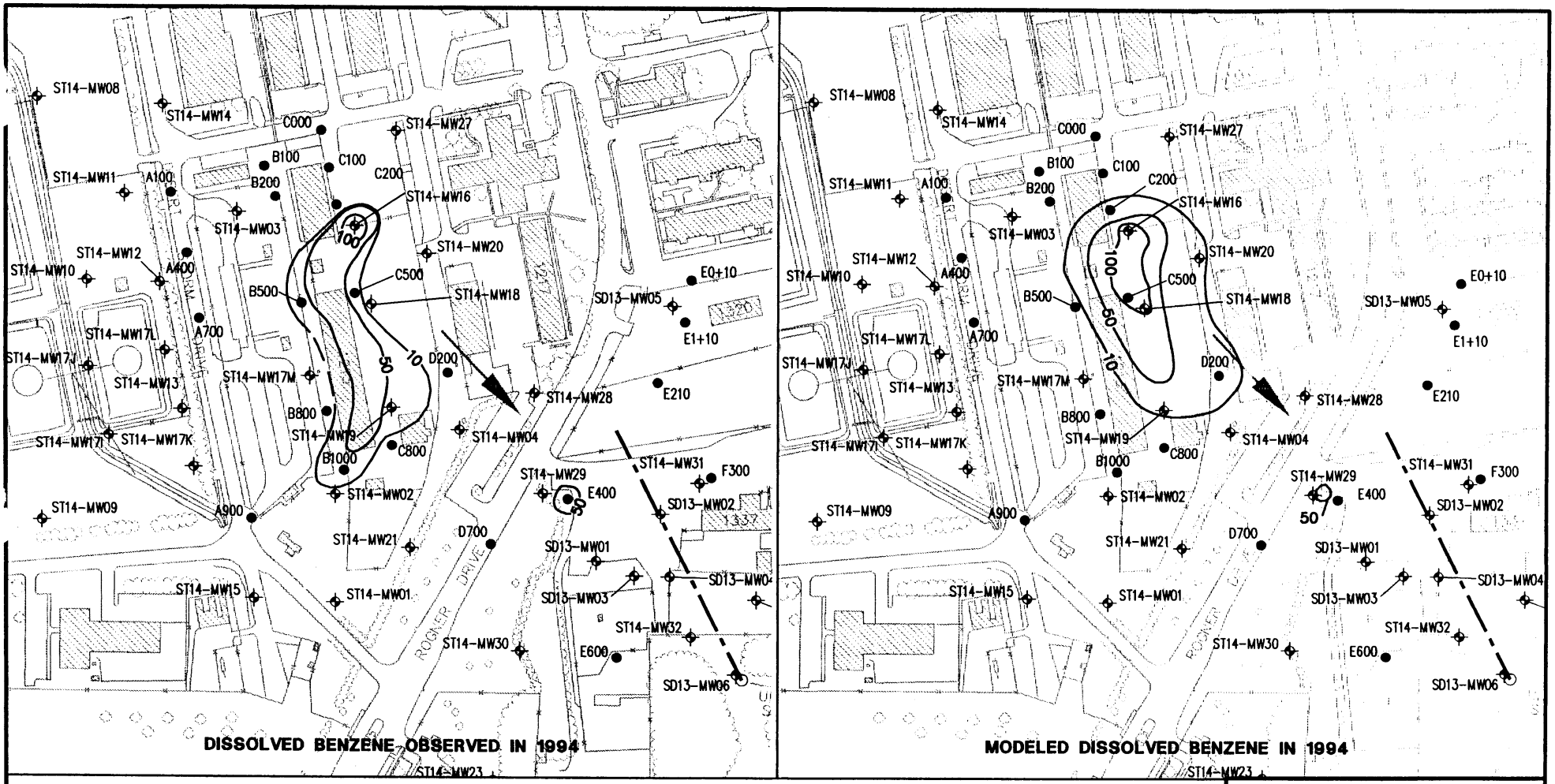
plumes and the observed benzene plumes was achieved. Figure 6.10 compares the modeled benzene plumes for March-April 1995 to the benzene plumes observed in March-April 1995. Although the simulated benzene concentrations in the center of the plume were slightly more than observed at the site, the general geometry of the calibrated benzene plume was a good representation of 1994/1995 site conditions. The calibrated Bioplume II model was determined to be a reasonable and conservative estimate of actual field conditions, and sufficient to be used to develop predictive chemical fate estimates.

6.8.2.3 Sensitivity Analysis

The Bioplume II model calibration described in Section 6.8.2.2 is a non-unique solution for conditions at Sites ST14 and SD13. Nearly every groundwater model can have more than one plausible solution because of the number of variable model input parameters and the complex interactions between them (Anderson and Woessner, 1992). Because a model calibration does not quantify the uncertainty or reliability of the calibrated results, a model calibration should always be followed by a sensitivity analysis. A sensitivity analysis helps quantify the uncertainty in a model calibration by observing changes in modeled output produced by specific changes in model input parameters.

Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of anaerobic decay (which was set equal to the site-specific degradation coefficient in this model to simulate biodegradation), and the hydraulic conductivity of the aquifer media. The Bioplume II model is typically less sensitive to changes in the retardation factor, porosity, and dispersivity. However, as part of the sensitivity analysis for this model, hydraulic conductivity (and therefore transmissivity), the coefficient of reaeration (i.e., site-specific biodegradation rate constant), the retardation factor, the dispersivity, and the effective porosity were varied. A detailed discussion of the sensitivity values used and the sensitivity results is presented in Appendix E.

The results of the sensitivity analysis suggest that the calibrated Bioplume II model is a good representation of site conditions. With respect to contaminant migration, transmissivity and the biodegradation rate constant (Table 6.1) are the parameters to which the model is most sensitive. Variations in either of these parameters produced substantial changes in how far benzene migrates and affected the maximum concentrations of benzene predicted to be present in the groundwater at the site at any time. The retardation coefficient follows the hydraulic conductivity and the biodegradation rate constant in terms of how much these input parameters can affect model results. The retardation coefficient had a modest effect on either benzene concentrations or migration distance when specific input values were varied up to 20 percent from the calibrated input values. Dispersivity had a similar effect as retardation coefficient when varied up to 20 percent, with the exception of migration distance which was not noticeably changed in the model. Variations in effective porosity by up to 15 percent had negligible effects on the fate and transport of benzene.



LEGEND

- BUILDING
- 1213 BUILDING NUMBER
- FENCE
- SOIL BOREHOLE/GEOPROBE
- GROUNDWATER MONITORING WELL
- APPROXIMATE LOCATION OF FRENCH DRAIN
- APPROXIMATE LOCATION OF OIL/WATER SEPARATOR
- GROUNDWATER FLOW DIRECTION
- —10— ESTIMATED LINE OF EQUAL ANALYTE CONCENTRATION (µg/L) (DASHED WHERE INFERRED)

0 100 200 400
FEET

FIGURE 6.10

COMPARISON OF MODELED VS OBSERVED GROUNDWATER BENZENE PLUMES

Site ST14
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6.8.2.4 Model Results

The attenuation of benzene by both nondestructive and destructive contaminant attenuation processes will affect the concentration of benzene in the affected media over time and distance at the site. In addition to the effects of nondestructive attenuation processes, site characterization data indicate benzene is slowly biodegrading in saturated soils and groundwater at Sites ST14 and SD13. Destructive contaminant attenuation processes will continue to minimize total dissolved contaminant mass and limit benzene concentrations and migration over time. The expressed assimilative capacity of the saturated soils and groundwater at Sites ST14 and SD13 was shown to be sufficient to promote mainly anaerobic biodegradation rates (Table 6.2). Anaerobic processes have a significant impact on chemical mass, concentration, mobility, persistence, and toxicity over time at Sites ST14 and SD13.

The Bioplume II model was employed to quantitatively investigate whether existing concentrations of benzene may migrate from Site ST14 to Site SD13, or from Site SD13 to the french drain at concentrations above the most stringent site-applicable target concentration of 5 µg/L. Model predictions also provide quantitative estimates of how contaminant mass is reduced until this target concentration can be achieved at every point in the shallow aquifer at the sites. The calibrated Bioplume II model was run under three scenarios to predict benzene migration and persistence. The first model simulated a natural attenuation scenario and was run for a period of 20 years to predict benzene migration and persistence in groundwater. The second model was used to simulate future benzene concentrations, as influenced by bioventing/biosparging at Site ST14A, and also was run for 20 years. Bioventing in the second scenario was simulated in the source area near monitoring well ST14-MW16. The third model was used to simulate biosparging near the second identified benzene source at Site SD13. All models were initiated after a 20-year calibration period under non-diminishing source term conditions. This calibration period was used to simulate the approximate concentrations and extent of the benzene plumes to those conditions observed in 1994. Therefore, the dissolved benzene present in groundwater at the start of the model simulation closely matched observed conditions. The mass of benzene that could partition into the groundwater over time was calculated as part of the SESOIL modeling effort.

Figure 6.11 shows the expected extent of benzene migration in the shallow aquifer at Sites ST14 and Site SD13 in 3 years (model year 1998) and 10 years (model year 2005) if no engineered source reduction is implemented at either site. By the year 2005, the maximum concentration of benzene near the ST14 fueling area is expected to decrease below 30 µg/L, which is the Plan A target concentration for beneficial use II groundwater. The Bioplume II model predicts that the benzene plume at Site ST14A is currently at its maximum downgradient extent as long as future spills are avoided. Groundwater benzene concentrations are predicted to naturally decrease to below 5 µg/L at Site ST14 in 16 years, or by the year 2011.

Because the site-applicable target concentration for benzene at Site SD13 is 5 µg/L, the model simulation was run until concentrations in this area decreased below this

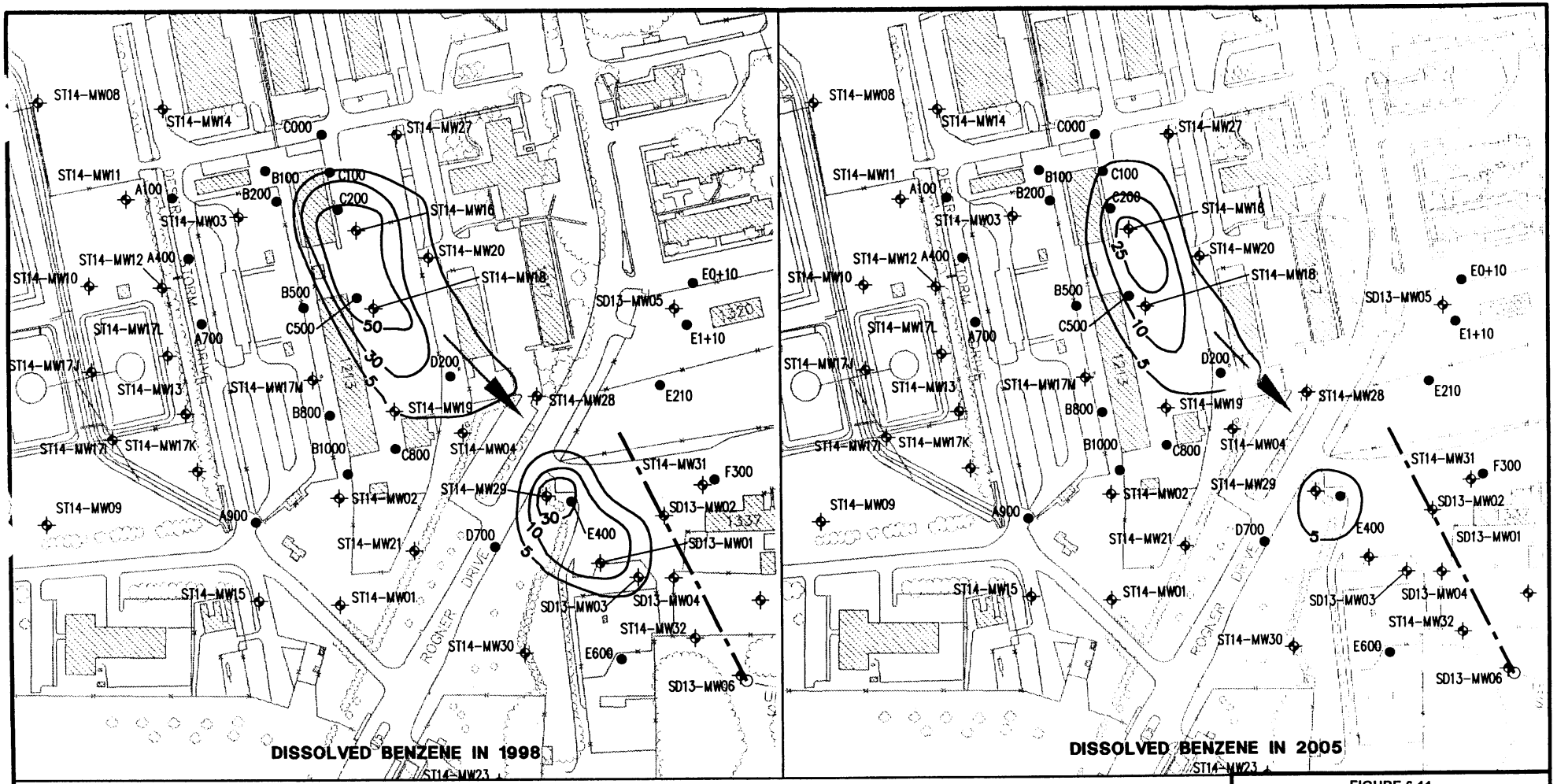


FIGURE 6.11

MODELED FUTURE GROUNDWATER BENZENE CONCENTRATIONS INFLUENCED BY NATURAL ATTENUATION ONLY

Site ST14
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level. The Bioplume II model conservatively predicts that dissolved benzene will not be reduced to 5 µg/L at every point at Site SD13 until the year 2007. The Bioplume II model predicts that dissolved benzene at concentrations above 5 µg/L could migrate to the french underdrain system area. However, since the french underdrain system has been partially removed, the potential for accelerated transport of benzene to surface groundwater is low. Further, no benzene has been detected in any surface water samples collected recently at and downgradient from the past release areas. These data suggest that this pathway may have already been eliminated.

On the basis of these simulations, it appears that natural hydrodynamic and chemical attenuation processes are sufficient to inhibit further benzene migration from Site ST14A without engineered remediation.

6.9 CONCLUSIONS

This section has focused on explaining how and why certain COPCs, particularly benzene, in saturated soil and groundwater at Sites ST14 and SD13 can be effectively attenuated by natural nondestructive and destructive processes. The important findings of this section are summarized as follows:

- Benzene is biodegrading in saturated soils and groundwater at Site ST14 and Site SD13 via oxygen reduction, nitrate reduction, ferric iron reduction, sulfate reduction, and methanogenesis at rates similar to those reported in the technical literature;

- Site-specific biodegradation rate estimates and site-specific theoretical expressed assimilative capacity estimates confirm that measured concentrations of benzene in saturated soil and groundwater eventually could be completely biodegraded by natural processes;

- Chlorinated hydrocarbons such as PCE may be biodegraded at Site SD13 through its use as an alternate electron acceptor;

- Elevated concentrations of several inorganic compounds appears to be attributable to the localized changes in reduction-oxidation conditions brought about the microbially mediated reactions involving organic contamination. Available site data implies that once suffficient organic mass has been biodegraded, groundwater conditions will soon be restored to pre-release characteristics. Consequently, the attenuation of inorganic compounds is directly tied to the short- and long-term fate of the hydrocarbon compounds that are driving these biogeochemical changes in groundwater conditions.

- The SESOIL model code was used to estimate the mass partitioning of benzene from unsaturated soils to groundwater, because leaching is likely to be a significant source of groundwater contamination;

- The calibrated Bioplume II model suggests that natural attenuation processes are sufficient to limit additional downgradient migration of benzene from Site ST14A; and

- Model simulations suggest that benzene concentrations at Site ST14 will decrease below the Plan A target concentration for beneficial use II groundwater of 30 µg/L by the year 2005. Dissolved benzene concentrations originating from Site SD13 are conservatively not expected to be reduced below 5 µg/L until the year 2007 (although no concentrations of benzene have been detected at this site since 1995).

This quantitative chemical fate assessment demonstrates that COPC concentrations at both sites are not expected to increase over time and will eventually be reduced below the most stringent site-applicable target concentrations. However, it may be necessary to implement some level of source reduction at these sites to ensure that dissolved contamination does not discharge to surface water and/or to attain the desirable level of protectiveness given the current and planned uses of the sites. Because measured site concentrations currently exceed Plan A or Risk Reduction Standard Number 2 target concentrations, a site-specific risk assessment for each site was prepared. The purpose of these risk assessments was to evaluate whether current levels of site contamination pose an unacceptable risk to human health given the current and proposed use of the impacted resources. Sections 7 and 8 document the potential risks to human receptors based on the actual site concentrations and the types of exposures that could occur at Site ST14 and Site SD13, respectively, under current conditions and in the foreseeable future if any exposure pathway should be completed. The conclusions of the risk assessments can be used to evaluate the type, magnitude, and timing of remediation required to protect human health and the environment, and establish appropriate remedial objectives.

SECTION 7

PLAN B LIMITED RISK ASSESSMENT FOR SITE ST14

A Plan B limited risk assessment has been prepared to quantitatively evaluate potential site risks based on site-specific assumptions regarding potential human exposure and short- and long-term fate of benzene (and possibly hexachlorobenzene), the only COPCs at Site ST14 (NRCC, 1994a). The Air Force believes that a Plan B evaluation is necessary to demonstrate that no imminent threat to human health or the environment exists even though site-related COPCs are present above TNRCC-specified Plan A target concentrations. This Plan B limited risk assessment takes into account all detected organic chemicals and the short- and long-term fate of the COPCs, as predicted by the modeling results presented in Section 6. The Plan B limited risk assessment shows that existing concentrations of organic contaminants may result in unacceptable carcinogenic risks to onsite current intrusive receptors, although cumulative risk estimates for hypothetical nonintrusive workers are below TNRCC-established thresholds. However, some type of engineered remediation is warranted at Site ST14A, both to reduce the cumulative risk estimate for onsite intrusive workers below the TNRCC threshold of 1×10^{-6} (which is the defined target for receptor groups where actual exposure may or has occurred) and to achieve site-specific Plan B target concentrations. Remediation also may be warranted to provide the desired level of health protection for nonintrusive workers should actual exposure occur. The Plan B limited risk assessment is the basis for developing Plan B target concentrations for affected environmental media at Site ST14.

7.1 EXPOSURE PATHWAYS ANALYSIS

An exposure pathways analysis describes the migration paths a chemical takes from the source of contamination to a potentially exposed individual (EPA, 1989). A completed exposure pathway must consist of a source, a release mechanism (e.g., leaching or volatilization), a transport medium (e.g., groundwater or air), a potential human or ecological receptor (e.g., current and future onsite workers, current and future offsite receptors, or terrestrial plants), a potential exposure point (i.e., locations where receptors could come into contact with site-related contamination), and potential routes of exposure (i.e., ingestion, dermal contact, or inhalation). Each of these elements must be present before a particular exposure pathway can be considered complete. If any one of these elements is missing, the exposure pathway is considered incomplete, and there is no risk. Site-related contamination can present a potential risk to receptors only if exposure pathways are completed.

A site-specific exposure pathways analysis was completed for Site ST14 to determine the likelihood of human or ecological contact with site-related contamination. The objective of this assessment is to determine which, if any, exposure pathways are

complete (EPA, 1992a). Emphasis was given to identifying those pathways where released contaminants may migrate within the environment, but through which potential receptors currently do not come into contact with these chemicals and are not likely to do so in the future. These incomplete exposure pathways were eliminated from further consideration.

Those exposure pathways that were considered complete and significant as a result of this assessment were retained for quantitative evaluation. The potential cumulative risks to human receptors due to exposure to each detected organic contaminant was then quantitatively characterized. The total cancer risk and total hazard index (HI) for each receptor group involved in potentially complete exposure pathways were characterized. Both reasonable maximum exposure (RME) and central tendency (CT) risk estimates are presented to support the remedial evaluation process. This Plan B limited risk assessment was prepared in accordance with EPA *Risk Assessment Guidance for Superfund* (RAGS) documents (EPA, 1989, 1991a-c, 1991e, 1992a-c) and TNRCC PST (1994a) guidance.

7.1.1 Conceptual Site Model

A conceptual site model (CSM) is used to qualitatively define the type of potential exposures to contaminants at and migrating from a site (i.e., to systematically evaluate the impact of chemicals in relevant media to potential receptors). The CSM describes onsite release points, the affected physical media, the types of contaminant transport and fate mechanisms that may be involved at the site, each group of potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. The CSM is used to summarize existing site characterization data, including assumptions about land and groundwater use, and to complete the qualitative exposure pathway screening assessment. A preliminary CSM for Site ST14, which was used to identify data gaps and guide data collection activities, is included in the work plan (Parsons ES, 1994a and 1995). The revised CSM for this site (Figure 7.1), which is briefly explained in the following sections, identifies only those exposure pathways that may be involved in actual exposures or hypothetical future exposures.

7.1.1.1 Source and Release Mechanisms

The likelihood of release from a source, the nature of the contaminants involved, and the probable magnitude of their release all must be included in the CSM (EPA, 1989a and 1992a). As described in Section 4, the most likely sources of fuel hydrocarbon contamination include surface spills and subsurface releases of JP-4 from fuel transfer lines at Site ST14. No significant volatilization of fuel-related compounds was measured during soil flux sampling at Site ST14, even in areas with elevated soil and groundwater contamination (Figure 4.3). Volatilization from surface media is not considered to be a significant release mechanism. Volatilization of chemicals from undisturbed contaminated media into the atmosphere is a possible release/transport mechanism at the site. Therefore, elevated concentrations of benzene vapors could be present if excavation of the soils at Site ST14A is required. Future remedial and/or maintenance activities would require that appropriate personnel protective measures are taken. The maximum concentration of benzene measured in a soil gas sample collected at 3 feet bgs at Site ST14A exceeded the OSHA 8-hour TWA PEL. Therefore,

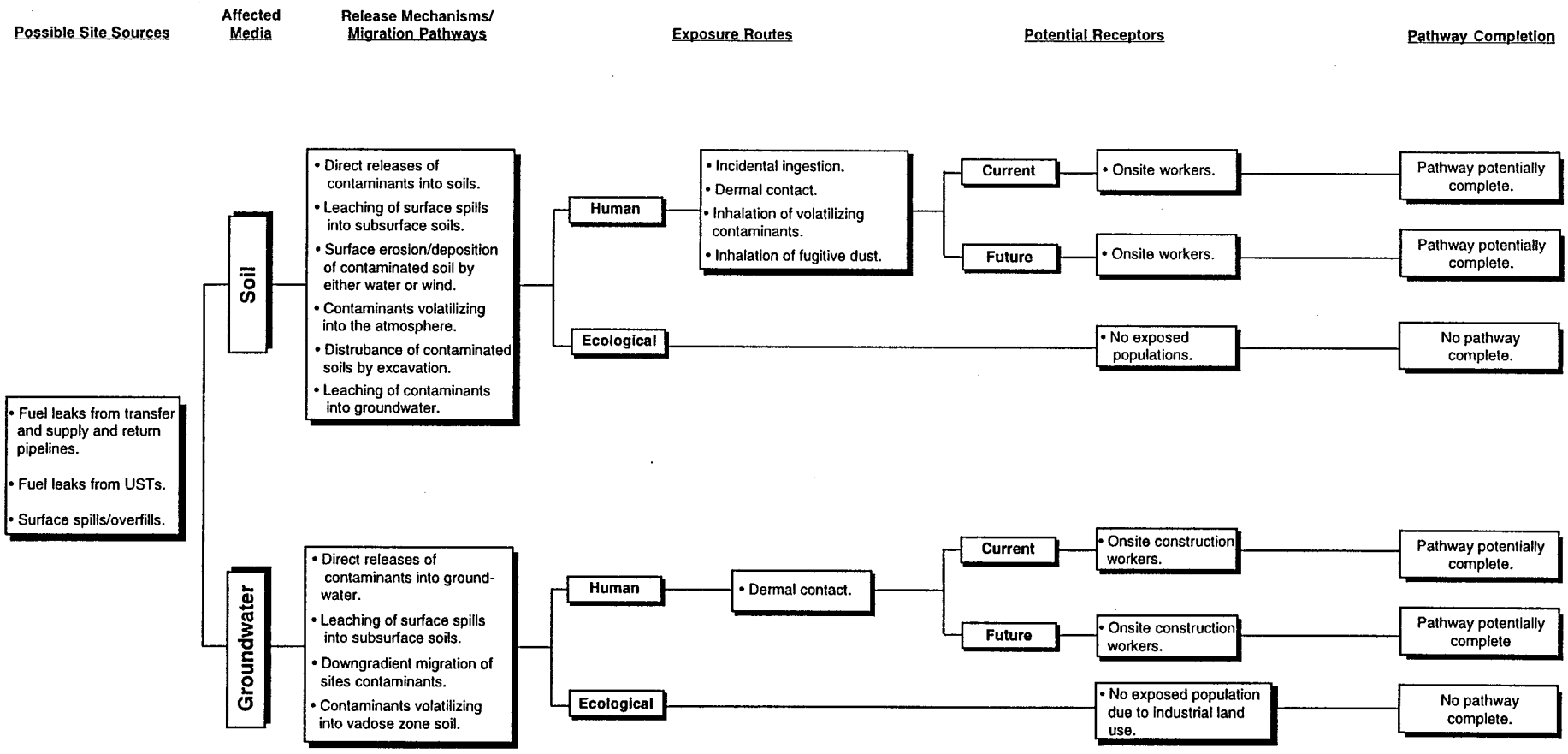


FIGURE 7.1

FINAL CONCEPTUAL SITE MODEL

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
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volatilization of contaminants from disturbed subsurface soils and transport into the atmosphere could be a potentially significant exposure pathway in source areas for intrusive onsite workers. This release/transport mechanism is evaluated in the Plan B limited risk assessment.

The majority of Site ST14 is covered by impermeable materials such as cement and asphalt. The remaining land surface at the site is gravel or grass, both of which will minimize fugitive dust generation. The potential for generation of contaminated fugitive dust is further reduced because the measured soil contamination is most concentrated at the 8- to 11-foot bgs interval. However, intrusive excavation activities in these areas could expose these subsurface soils. Consequently, fugitive dust emission was retained as a potential release mechanism only for exposure pathways for receptors engaged in site intrusive activities (i.e., deep excavation).

Although small quantities of LNAPL has been measured at Site ST14, data indicate it is sufficiently weathered that it no longer is likely to be a significant source of benzene to soils or groundwater. However, benzene was measured at Site ST14A at concentrations above the Plan A target concentration for beneficial use II groundwater (Table 4.1). The SESOIL model results predict that contaminated unsaturated and capillary fringe soils will continue to be significant sources of groundwater contamination for at least another 10 years if not remediated (Section 6).

7.1.1.2 Contaminant Environmental Transport

Contaminant transport, transformation, and fate in the environment following release is important to consider when assessing the potential for exposure. Benzene was the only fuel-related compound measured in groundwater at concentrations above the Plan A target concentrations (Table 4.1). An in-depth, quantitative evaluation of the transport, transformation, and fate of benzene in groundwater over time and distance at this site is presented in Section 6. In summary, dissolved benzene originating from Site ST14A should not migrate any further southeast toward Desert Storm Drive (and Site SD13). Concentrations of benzene are expected to decrease gradually as a result of natural biodegradation processes until benzene is reduced to below 30 µg/L (Plan A beneficial use II target concentration) by the year 2005 and below 5 µg/L (Plan A beneficial use I concentration) by the year 2011.

7.1.1.3 Potentially Exposed Populations and Exposure Routes

The third major component of the CSM for this site is the identification of potentially exposed populations and exposure routes. The objective of this step is to determine the likelihood and extent of human or ecological receptor contact with site-related contaminants (EPA, 1989a and 1992a). Land use assumptions are critical to defining the types of receptors that are now present or may be reasonably expected to be present in the foreseeable future at this site, or in immediately adjacent areas that could potentially be impacted by site-related contamination.

Current Onsite Conditions

As described in Section 3.6.2, Site ST14 is an active military fueling area. Potential human receptor groups are limited to onsite workers (both intrusive and nonintrusive).

Site ST14 is still used as a fueling area, so nonintrusive workers are regularly present at the site. However, most normal activities conducted at the fueling area are confined to the paved surfaces of the site, and incidental contact with environmental media is unlikely. Consequently, no actual exposure of onsite nonintrusive workers to contaminated site media is occurring. However, excavation activities have been conducted at Site ST14 in the past, so actual human exposure under intrusive conditions is possible.

Trespassing by potential residential or recreational receptors is not expected to be a significant concern at this site due to access restrictions and habitat constraints (Section 3.6.1). Institutional access controls prohibit access of potential trespassers to the site and make trespassing unlikely. Further, no shallow groundwater is withdrawn from areas within at least 0.5 mile from this site to meet potable or nonpotable water requirements (Appendix C).

For the purposes of this Plan B limited risk assessment:

- Nonintrusive workers could potentially be exposed to mixed soils (0-12 feet bgs) via incidental ingestion and possibly dermal contact.

- Intrusive workers could be exposed to mixed soils (0-12 feet bgs) via incidental ingestion of and dermal contact with soil, inhalation of fugitive dusts and volatilizing chemicals from exposed soils, and dermal contact with alluvium groundwater. Because alluvium groundwater can be encountered at about 6 feet bgs (Section 3.4), workers engaged in deep excavations could hypothetically come into contact with groundwater and saturated soils.

The industrial nature of the site, which includes concrete, asphalt and crushed rock driveways and parking areas, warehouse structures, and chain link fencing to limit access, precludes the existence of suitable wildlife habitat. No resident ecological receptors were identified for which soils and/or groundwater are likely contaminant exposure media. In addition, the concentrations of inorganic compounds measured at the site as part of the Law (1994) RFI are well below the EPA (1983) guidelines for the protection of plants.

Current Offsite Conditions

Site ST14 is located on a military facility currently undergoing realignment. The site is surrounded on all sides except to the southeast by operating military/industrial facilities (Figure 3.10). The unnamed stream and Farmers Branch lie downgradient (southeast) from this site. Dissolved benzene originating from Site ST14A has not and is not expected to migrate more than 700 feet beyond the suspected source area. The benzene plume from Site ST14A should not commingle with the dissolved benzene plume detected at Site SD13. No offsite impacts from Site ST14 are anticipated. No exposure pathway involving offsite human receptors is considered complete.

Future Conditions

As described in Section 3.6.3, no changes in onsite land use at Site ST14 are planned. The site is to be maintained as a military fueling area. This means that the

exposure assumptions developed for current conditions also apply to future conditions at Site ST14.

7.1.2 Summary of Potentially Completed Exposure Pathways

Figure 7.1 presents the CSM for Site ST14. Incidental exposure to onsite contamination in soil and surface water is possible during nonintrusive (i.e., maintenance) activities. Additionally, incidental exposure to contaminated subsurface soils and shallow groundwater is possible only if deep excavation/construction activities are conducted in and immediately downgradient from the source areas at this site. Onsite workers are the only group of receptors that would be likely to come into incidental contact with site-related contamination under both current and future land use scenarios. For potential ecological receptors, the exposure pathways from contaminated soils and groundwater are not complete.

7.2 ESTIMATING EXPOSURE-POINT CONCENTRATIONS

The representative exposure-point concentration is defined as the concentration that represents the highest exposure that could reasonably be expected to occur for a given exposure pathway. This value is intended to account for both the uncertainty in environmental data and the variability in exposure parameters (EPA, 1992b). Simple statistics and model results were employed to compute the exposure-point concentrations for each of the compounds detected during the Law (1994) RFI and the 1994/1995 risk-based sampling events for each exposure pathway considered in this risk assessment. Concentrations of compounds detected at sampling locations at Site ST14 since the 1994 risk-based sampling event are not used to quantitatively estimate risks. Rather, these decreasing concentrations are used to confirm contaminant distribution trends over time as predicted by the model results (see Section 6). All detected compounds (not just the two COPCs) were used to characterize potential risks, pursuant to TNRCC (1994a) guidance.

7.2.1 Statistical Evaluation of Measured Site Data

The EPA (1992a) has provided recommendations and guidance on what would result in an estimate of the exposure concentration appropriate for use in RME risk estimates. The EPA has defined the concentration term as the 95-percent upper confidence limit (UCL) of the arithmetic mean for data sets that are not small. If data for a site is limited (i.e., less than 5 values), it may be more appropriate to use the maximum value as the concentration term in risk calculations. In general, the data sets for soil, groundwater, and surface water for Site ST14 were sufficient in number to compute the normal concentration term, as prescribed by EPA (1992a) and the TNRCC (1994a). The EPA finds that the 95-percent UCL provides reasonable confidence that the true site average will not be underestimated and increases the consistency and comparability of risk assessments. In those instances where the assumption of normality of the data caused the calculated 95-percent UCL to approach or exceed the maximum value, the maximum measured site concentration was used instead. The exposure-point concentrations for each compound are presented in Appendix F.

7.2.2 Modeled Exposure-Point Concentrations

7.2.2.1 Fugitive Dust

Current and future fugitive dust concentrations were based on modeled results. Fugitive dust in outdoor air may contain semivolatile fuel hydrocarbons measured in soils at Site ST14. Although the potential for fugitive dust emissions is low under nondisruptive conditions, intrusive workers could generate fugitive dusts during deep excavation activities. The Integrated Risk Information System (IRIS) (Micromedex, Inc., 1995) states, "Particle size determines the site of deposition in the respiratory tract. Generally in humans, fine mode particles (<2.5 microns) preferentially deposit in the pulmonary region and coarse mode particles (>2.5 microns) deposit in the tracheobronchial and extrathoracic regions." EPA's (1989b) *Interim Methods for Development of Inhalation Reference Doses* guidance supports this by stating, "Impaction remains a significant deposition mechanisms for particles larger than 2.5-μm aerodynamic diameter (D_{ae}) in the larger airways of the tracheobronchial region and competes with sedimentation..." Therefore, when evaluating the inhalation exposure route for fugitive dusts, modeling was adjusted to consider only particulates less than 2.5 microns in diameter. [In fact, particles greater than 2.5 microns are predicted (by the adjusted model) to be trapped in the lower pulmonary regions, but the fraction is much lower than for the particulates of 2.5 microns or less.] Refer to Appendix F for further discussion of fugitive dust modeling.

Three different models were used to estimate the concentration of fugitive dust that receptors could be exposed to under high-disturbance exposure scenarios at the site. The Gillette (EPA, 1985) model was used to simulate the emission rate of fugitive dust from highly disturbed, unvegetated soils at the site. This model was then coupled with a dispersion model, the Near-Field Box model (EPA, 1985; Gas Research Institute, 1988), to estimate the concentration of fugitive dust in the breathing zone immediately above the source area. No significant atmospheric dispersion that would account for dilution of suspended particulates was considered in these calculations. Section 7.6 (Uncertainty Analysis) contains a discussion of the conservative nature of the applied model assumptions.

The fugitive dust concentrations in the atmosphere under high disturbance scenarios were derived using a probabilistic modeling (Monte Carlo) approach. A software program called *Crystal Ball*, by Decisioneering, Inc. (1993), was used to generate a range of model input parameters for both the Gilette and the Near-Field Box models based on their statistical characteristics. Assumptions about data characteristics were based on available site-specific information such as the Base-specific meteorological/weather data to the maximum extent practicable. Best professional judgment and single-point values were used to supplement existing site-specific data. This range of input parameters was used in this model to calculate the likelihood or probability that a single, exposure-point concentration term would be representative of the exposure potential at the site. Consequently, this probabilistic approach yields data useful for directly calculating the risks to potential receptors caused by inhalation of fugitive dusts, and data on the likelihood that such exposure could occur at the site.

The models and subsequent inputs, assumptions, and calculations used to estimate fugitive dust concentrations are provided in Appendix F. The fugitive dust to which

the current or future intrusive worker will be exposed via inhalation is assumed to originate from representative soils at the site (i.e., the statistically-derived exposure-point concentration for soil).

7.2.2.2 Future Soil and Groundwater Concentrations

The coupled SESOIL and Bioplume II models were used to predict the future exposure-point concentrations of benzene in soil and groundwater at Site ST14. The natural weathering of benzene (and hexchlorobenzene) from soil was considered when identifying future exposure-point concentrations for these compounds if no engineered remediation was implemented at the site. A second potential future exposure-point concentration for benzene (and hexachlorobenzene) in soils was determined by accounting for the beneficial impacts of bioventing/biosparging (Section 9.1). This second exposure-point concentration was used to estimate the residual risk reduction that could be achieved by implementing some type of engineered source reduction at the site. The relative reduction of potential site risks is presented in Section 10 as part of the comparative analysis of remedial alternatives. Modeled exposure-point concentrations are presented in Section 7.7 and Appendix F.

The maximum concentration of dissolved benzene projected to be present in groundwater by the year 1998 was used as the future exposure-point concentration instead of the current measured site concentration. By 1998, the maximum dissolved benzene concentration at Site ST14 was projected to be naturally reduced from 110 µg/L to 101 µg/L (Figure 6.11). No other fuel-related compounds measured in groundwater were included in the modeling effort since all other chemicals were detected below their respective Plan A target concentrations (Tables 4.1). The incremental reduction in potential site risks as a result of the natural attenuation of COPCs over time was considered in this Plan B limited risk assessment.

A second potential future exposure-point concentration for dissolved benzene was determined by accounting for the beneficial impacts of bioventing/biosparging at Site ST14 (Sections 9.1 and 9.2). This exposure-point concentration was used to estimate the residual risk reduction that could be achieved by implementing some type of engineered source reduction and limited groundwater treatment at the sites. The relative reduction of potential site risks is presented in Section 10 as part of the comparative analysis of remedial alternatives. Modeled exposure-point concentrations are presented in Appendix F.

7.3 QUANTIFICATION OF EXPOSURE: CHEMICAL INTAKES

Once the exposure pathways are described qualitatively and the exposure concentrations are defined quantitatively, the amount of any one chemical to which a receptor may be exposed during a specified time is estimated. Calculating chemical intakes hinges on reasonable, yet conservative, assumptions about how each group of potential receptors at a particular site may be exposed to site-related contamination. This step in the risk assessment process is called quantification of exposure. The risks to potential receptors exposed to site-related contamination are then calculated quantitatively by coupling toxicity data and quantified exposure data.

Intake estimates are normally expressed as the amount of chemical at the exchange boundary in milligrams per kilogram of body weight per day (mg/kg-day), which represents an intake normalized for body weight over time. The total exposure is then divided by the time period of interest to obtain an average exposure over time. The time used to average exposure is a function of the toxic endpoint: for noncarcinogenic effects it is the exposure time, and for carcinogenic effects it is a lifetime (70 years).

The emphasis in this risk assessment is on chronic exposure to measured compounds. Long-term exposure to relatively low chemical concentrations (i.e., chronic exposure) is the primary concern. Short-term (i.e., subchronic) and acute exposures are not evaluated in this Plan B limited risk assessment. Although the intrusive construction workers were assumed to have subchronic exposure, they were evaluated with chronic toxicity values to be more conservative (health-protective). As required by the EPA (1992c) and the TNRCC (1994a), two types of exposure scenarios are evaluated for this risk assessment: average (CT) and RME. CT and RME exposure factors were combined with corresponding exposure-point concentrations to give a range of CT and RME intake values. When coupled with the appropriate toxicity information, intakes calculated using both the average and RME exposure parameters result in arithmetic mean (or median, if appropriate) and RME risk estimates, respectively. Both the CT and RME intakes (and therefore risk estimates) use the 95-percent UCL (or maximum concentration) of the arithmetic mean as an exposure-point concentration (EPA, 1994). In accordance with EPA (1992d) guidance, RME is used to estimate risk for decision-making purposes; whereas, CT exposure-based results are used for comparison purposes only.

Both the current and future receptor exposure factors used for the evaluation of potential risks are presented in Appendix F. Standard default intake variables as defined by the EPA (1991e) were used exclusively in quantifying exposure of the nonintrusive industrial workers. In addition, an absorption fraction of 25 percent was assumed for volatile contaminants in the soil, and 10 percent was assumed for semi-volatile contaminants based on studies done on absorption from soil (Ryan *et al.*, 1983). The intake variables, resulting exposure factors, and the formulas used to calculate intake for nonintrusive industrial workers are shown in Appendix F.

Intake variables defining onsite intrusive construction workers' exposure were different than those used for the nonintrusive industrial worker. For example, the intrusive industrial worker was assumed to remain at the job for an equivalent of only 1 year (instead of the 25 years assumed for the nonintrusive industrial worker). This assumption is based on best professional judgment, as most construction-related/remediation activities at the site would likely not last more than the equivalent of 1 year of continuous exposure. Any necessary remediation activities at the site will not require workers to be constantly present after initial installation activities are complete. The intake variables, resulting exposure factors, and the formulas used to calculate intake for intrusive industrial workers are shown in Appendix F.

The exposure factors for dermal contact with contaminants in shallow groundwater used a combination of standard default exposure variables and best professional judgment if the EPA had not defined standard default variables. A chemical-specific permeability constant (Kp) value was determined to calculate dermal intakes. All Kp

values were taken from *Dermal Exposure Assessment: Principles and Applications* (EPA, 1992c).

7.4 TOXICITY ASSESSMENT

The objective of the toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. For humans, EPA has conducted numerous toxicity assessments that have undergone extensive review within the scientific community.

The types of EPA toxicity values used in this risk assessment include oral reference doses (RfDs) inhalation reference concentrations (RfCs), oral carcinogenic slope factors (SFs), and inhalation unit risk factors (URFs). RfDs and RfCs are used to evaluate noncarcinogenic effects. SFs and URFs are used to evaluate carcinogenic effects. Toxicity values for the noncarcinogens and carcinogens evaluated in this risk assessment are presented in Appendix F. The toxicity information used in this Plan B limited risk assessment was obtained from IRIS (Micromedex, Inc., 1995). If values were not available from IRIS, Health Effects Assessment Summary Tables (HEAST) values (EPA, 1994a), or EPA's Superfund Technical Support Center were used.

EPA has not derived toxicity values for all routes of exposure. Most of the available toxicity values are for oral exposure, and many inhalation values are available. No values are currently available for dermal exposure. Dermal toxicity values were developed by modifying oral toxicity values with dermal absorption factors (Appendix F). For those chemicals for which toxicity values are not available for any route of exposure, it may be appropriate to use toxicity values derived for similar chemicals (i.e., surrogates). This is appropriate for chemicals where the toxicity values for one isomer may be used for another isomer. For most chemicals, however, there is no chemical that is similar enough to justify the use of toxicity information for a surrogate, therefore, these chemicals cannot be quantitatively evaluated in the risk assessment.

7.5 RISK CHARACTERIZATION

To characterize risk, toxicity and exposure assessments were summarized and integrated into quantitative expressions of risk. To characterize potential noncarcinogenic effects, comparisons were made between projected intakes of chemicals and chronic toxicity values. To characterize potential carcinogenic effects, probabilities that an individual would develop cancer over a lifetime of exposure were estimated from projected intakes and chemical-specific dose-response information. Major assumptions, scientific judgments, and, to the extent possible, estimates of the uncertainties embodied in the assessment are also presented. CT and RME risk estimates for the receptors and pathways of concern are quantified in this risk characterization section.

The current and future land uses at Site ST14 are assumed to consist of predominantly nonintrusive industrial and intrusive construction activities. The RME and CT chemical-specific hazard quotients (HQs), total HIs, and cancer risk estimates

for the aforementioned exposure routes are presented in Appendix F. Table 7.1 summarizes the RME and CT risk estimates developed for the current receptors that could be exposed to existing levels of site contamination at Site ST14. Table 7.2 summarizes the RME and CT risk estimates developed for hypothetical future receptors that could be exposed to the residual levels of site contamination that may persist in 1998 at Site ST14 assuming no engineered remediation is undertaken at the sites.

7.5.1 Risk Estimates for Hypothetical Current Receptors

The TNRCC (1994a) states that "a cumulative hazard index greater than 1 or a cumulative carcinogenic risk greater than 1×10^{-4} is unacceptable and necessitates remediation and/or appropriate control measures to protect human health. If there is actual human exposure, then the target risk shall not be less stringent than 1×10^{-6}." Although no actual exposures to current nonintrusive workers at Site ST14 are expected, the cumulative HIs for this receptor are 0.031 for RME and 0.0056 for CT, well below the threshold value of 1 that could trigger remedial action. Cumulative cancer risk estimates for this receptor are 2.22×10^{-5} and 1.60×10^{-6} for RME and CT, respectively. Because the potential for actual exposure for this receptor is believed to be low at this site, both the cumulative RME and CT cancer risk totals are below the TNRCC target of 1×10^{-4}, indicating an acceptable risk level. However, if actual exposure could occur, as defined by the Plan B limited risk assessment, some type of remediation may be warranted to provide the desired level of health protection for this group of receptors.

Exposure of current intrusive workers, particularly at Site ST14, has occurred and could exist in the future. This means that the target risk level is 1×10^{-6} (TNRCC, 1994a). The cumulative HIs for this receptor are 0.011 for RME and 0.063 for CT. Cumulative cancer risk estimates for this receptor are 1.63×10^{-6} and 5.82×10^{-7} for RME and CT, respectively. The cumulative RME cancer risk total is slightly above the TNRCC-specified target of 1×10^{-6}, indicating that some type of remediation or more stringent institutional control measures that prohibit excavation without adequate personal protection equipment may be necessary to minimize potential health risks to this receptor group due to exposure to primarily benzene.

7.5.2 Risk Estimates for Hypothetical Future Receptors

The projected reduction of benzene (and hexachlorobenzene) in soils and benzene in groundwater at Site ST14 by the year 1998 as a result of natural weathering and attenuation (Section 6) will further reduce the potential risks posed by measured compounds. The projected reduction of COPCs in soils and groundwater by the year 1998 reduces the cumulative carcinogenic risk estimate by 3.7×10^{-7} for RME and by 6.1×10^{-8} for CT for intrusive workers. Consequently, the cumulative risk for intrusive workers in 1998 effectively decreases to 1.26×10^{-6} for RME and 5.21×10^{-7} for CT when the effects of natural chemical attenuation of the COPCs are considered in the future quantitative risk estimates. However, the projected RME cumulative risk estimate is still slightly above the TNRCC (1994a) target risk of 1×10^{-6} for receptors where exposure may actually exist.

TABLE 7.1
QUANTITATIVE RISK ESTIMATES FOR CURRENT SITE WORKERS
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

Exposure Pathway	RME[a/]		Central Tendency[d/]	
	HQ[b/]	Risk Level[c/]	HQ[b/]	Risk Level[c/]
Maintenance Worker (Nonintrusive)				
Incidental ingestion of soil	5.92E-04	5.34E-07	5.54E-04	2.00E-07
Dermal contact with soil	3.02E-02	2.17E-05	4.88E-03	1.40E-06
Incidental ingestion of surface water	5.17E-05	--	1.92E-05	--
Dermal contact with surface water	1.48E-04	--	1.15E-04	--
TOTAL	**3.10E-02**	**2.22E-05**	**5.57E-03**	**1.60E-06**
Construction Worker (Intrusive)				
Incidental ingestion of soil	5.69E-03	2.05E-07	5.54E-04	2.00E-08
Dermal contact with soil	3.02E-02	8.66E-07	4.88E-03	1.40E-07
Inhalation of fugitive dusts	1.13E-05	9.41E-08	5.92E-06	4.93E-08
Dermal contact with groundwater	7.11E-02	4.63E-07	5.73E-02	3.73E-07
TOTAL	**1.07E-01**	**1.63E-06**	**6.27E-02**	**5.82E-07**

[a/] RME = reasonable maximum exposure

[b/] HQ = chemical-specific hazard quotients; summed across all pathways for each receptor group to obtain cumulative HI (target is cumulative < 1).

[c/] Carcinogenic risk level; expressed as probability; summed across all pathways for each receptor group to obtain cumulative risk level (target is cumulative 1E-4 for potential exposure, scenarios and 1E-6 where actual exposure is or may occur).

[d/] Central tendency = average expression of exposure potential; used to compare to RME.

TABLE 7.2
REDUCTION IN RISK ESTIMATES BY 1998 - NATURAL ATTENUATION ONLY
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14, CARSWELL AFB/NAS FORT WORTH JRB, TX

Exposure Pathway	RME[a/]		Central Tendency[d/]	
	HQ[b/]	Risk Level[c/]	HQ[b/]	Risk Level[c/]
Construction Worker (Intrusive)				
Incidental ingestion of soil	4.39E-03	1.48E-07	4.28E-04	1.44E-08
Dermal contact with soil	2.23E-02	6.15E-07	2.30E-03	1.26E-07
Inhalation of fugitive dusts	1.13E-05	7.16E-08	5.92E-06	3.75E-08
Dermal contact with groundwater	7.11E-02	4.26E-07	5.73E-02	3.43E-07
TOTAL	**9.78E-02**	**1.26E-06**	**6.00E-02**	**5.21E-07**

[a/] RME = reasonable maximum exposure

[b/] HQ = chemical-specific hazard quotients; summed across all pathways for each receptor group to obtain cumulative HI (target is cumulative < 1).

[c/] Carcinogenic risk level; expressed as probability; summed across all pathways for each receptor group to obtain cumulative risk level (target is cumulative 1E-4 for potential exposure, scenarios and 1E-6 where actual exposure is or may occur).

[d/] Central tendency = average expression of exposure potential; used to compare to RME.

7.5.2 Summary/Discussion of Results

This Plan B limited risk assessment demonstrated that existing concentrations of all measured compounds in mixed soils and groundwater at Site ST14 do not result in HQs or HIs greater than the noncarcinogenic threshold limit of 1 for all receptor groups considered. No current or future nonintrusive worker risk estimate exceeds the carcinogenic threshold of 1×10^{-4} for potentially completed exposure pathways. However, the cumulative carcinogenic risk estimate for this receptor group is above the TNRCC threshold established for actual exposure situations. If exposure of nonintrusive workers occurs in the future, this receptor group may not be afforded the desired level of protection (i.e., 1×10^{-6}). Although no current or future intrusive worker pathway-specific carcinogenic risk estimate exceeds the threshold of 1×10^{-6} (Appendix F), the RME cumulative risk estimates are just slightly greater than this threshold. This cumulative risk level has been identified as the target risk level by TNRCC for receptor groups where actual exposure has occurred or may occur. Note that the CT cumulative risk level for this receptor group is below the 1×10^{-6} target threshold. The natural chemical attenuation of the COPCs by the year 1998 reduces the RME carcinogenic risks to the receptor groups to levels almost (but not exactly) equivalent to the 1×10^{-6} target risk level.

7.6 UNCERTAINTY CHARACTERIZATION AND ANALYSIS

All risk assessments involve the use of assumptions, judgments, and imperfect data to varying degrees. That results in uncertainty in the final estimates of hazard and risk. This section describes the likelihood that the approaches incorporated into this Plan B limited risk assessment overestimate or underestimate of the actual risks associated with exposure to site-related organic chemical concentrations, pursuant to TNRCC (1994a) guidance. Risk assessment in general, as it is currently practiced, is highly conservative and often based on extremely conservative assumptions and scenarios. This risk assessment characterizes high-end risk as an RME, and also provides risk estimates based on average values to characterize CT (average risk).

There are several categories of uncertainty associated with risk assessment. One is the initial selection of substances for analyses; this selection drives which chemical data are available to characterize risk from exposure. A second category is the selection of exposure scenarios that are conservative and therefore protective of human health, and yet are probable. Additional uncertainties are inherent in the exposure assessment for individual substances and individual exposures. Those uncertainties are driven by the degree of reliability of the chemical monitoring data, the models used to estimate exposure-point concentrations in the absence of monitoring data, and the receptor intake parameters (e.g., exposure factors). A third category is the availability of toxicity information for the COPCs at the site to address all routes of potential exposure. Finally, additional uncertainties are incorporated into the risk assessment when exposures to several substances are summed.

7.6.1 Data Uncertainties

Inorganic chemicals were eliminated from this Plan B risk assessment. The impact of inorganic chemicals present above background levels on risk estimate 7 for Site

SD13 is presented in Section 8. It is possible that some of the chemicals not retained for risk analysis may be present as a result of anthropogenic activities. It is possible, although unlikely, that the elimination of the anthropogenic fraction of these inorganic chemicals present at this site could lead to an underestimation of risk. Organic chemicals were not eliminated from the quantitative risk assessment based on any detection-frequency analysis, and this approach possibly resulted in an overestimation of risks. For example, hexachlorobenzene, one of the two soil COPCs for this site, was only measured near the detection limit in one saturated soil sample. The likelihood that this chemical is involved in significant exposures that could occur at this site is extremely low. To calculate the 95-percent UCL, chemicals detected in at least one sample were assumed to be present in all nondetect samples. Statistical analyses (mean, standard deviation, 95-percent UCL, etc.) were then performed on all data by evaluating detects in combination with nondetects at half the practical quantitation limit (PQL). Especially for these types of scenarios, use of the 95-percent UCL or the maximum measured concentration as the concentration term may overestimate the overall amount of chemical present in the exposure medium and, consequently, the risk posed by the chemical exposure-point concentration.

7.6.2 Exposure Uncertainties

A large part of the risk assessment is the estimation of risks that are based on receptor exposure; if exposure of receptors does not occur, no risks are present. Although this assessment does qualitatively identify the probability of the exposure pathway occurring, the quantitative risk estimates for those receptor groups where exposure is possible but unlikely will be overestimated. Additionally, in the risk assessment, it is assumed that each unique receptor is exposed to the same contaminant concentrations and exposure durations (i.e., the nonintrusive worker scenario encompasses all potential nonintrusive workers). This assumption tends to overestimate risk because each individual receptor will not realistically be exposed to precisely the same contaminant concentrations for the same length of time.

7.6.3 Uncertainty in Exposure-Point Concentration and Intake Values

This section discusses the uncertainty associated with estimating exposure-point concentrations and the matrix-specific intake factors, including uncertainty associated with intake values and their respective default values for the RME and average CT exposure scenarios. Uncertainty arises in the assumption that current and future nonintrusive receptors will be exposed to a mixed soils stratum. By not evaluating the soil strata on an individual basis, and assuming all strata are combined, an underestimation or potential overestimation of risks may occur. The result of the mixing assumption tends to skew the strata-specific soil concentrations that are averaged with the over- and underlying soil strata.

Calculated and modeled exposure-point concentrations approximate the actual conditions to which receptors will be exposed at a given site. There always will be some concern regarding how well an exposure model approximates the actual conditions to which receptors will be exposed. Whenever models are used to estimate risk, uncertainty is involved. The uncertainty lies within the models, which are used as simplified representations of reality (i.e., the assumption that the model will generate results that closely resemble the real situation). Each model has different variable

inputs and modeling scenarios that also lead to uncertainty. This factor is recognized by EPA (1992d), which states, "The degree to which release or transport models are representative of physical reality may overestimate or underestimate risk." Key assumptions in estimating exposure-point concentrations are presented in Appendix E.

Standard assumptions regarding body weight, duration of exposure, life expectancy, receptor population characteristics, and lifestyle were made to reflect the RME and CT exposure to individuals for each pathway evaluated. The assumption for RME reflects a conservative (health-protective) approach. CT exposure values represent a less conservative approach. The CT exposure values and the subsequent intake factor calculations potentially may underestimate risk to certain sensitive subpopulations. However, CT risk is used only to provide a comparison to the RME risk estimates. Because of the conservative approach, the RME assumption most likely will overestimate actual risk, whereas the CT risk estimates may underestimate the risk for any hypersensitive subpopulations (which are not expected to be present at this site).

Exposure variables for this Plan B limited risk assessment were taken from current EPA guidance, when available. However, some exposure scenario intake values are location-specific and reflect best professional judgment. For example, the duration and frequency of exposure to soils via several exposure routes for the current and future intrusive worker are unknown, and professional judgment was used. Best professional judgment was applied with the intention of overestimating, rather than underestimating the upper-bound risk estimate.

7.6.4 Uncertainty in the Toxicity Assessment

Some uncertainty is inherent in the toxicity values used for the assumed duration of exposure assessed. These uncertainties are compounded under the assumption of dose additivity for multiple substance exposure. That assumption ignores possible synergisms or antagonisms among chemicals, and assumes similarity in mechanisms of action and metabolism. Another assumption is that all the toxicity values used have an equal degree of reliability, which in reality is not the case. Overall, those assumptions would tend to overestimate hazards and risks. Because toxicity constants for cancer generally are based on the 95-percent UCL limit, risks tend to be overestimated.

However, it must be emphasized that not all organic chemicals detected could be evaluated quantitatively for health effects because toxicity values do not exist for all chemicals. The lack of toxicity data tends to underestimate risk, therefore, the more chemicals that lack toxicity data, the greater the tendency is for risk underestimation.

The use of dermal absorption factors poses uncertainty when used to convert oral toxicity values to dermal toxicity values. Whenever multiple absorption factors existed for a particular chemical, the most stringent factor for the various chemical forms was selected. This may lead to an overestimation of risk.

Regarding noncarcinogenic health, the application of uncertainty factors to no-observed-adverse-effect level (NOAEL) for a chemical in an animal study for animal-to-human extrapolation adds additional uncertainty to the toxicity assessment. The application of scaling or uncertainty factors may result in an overestimation of risk.

7.6.5 Uncertainty in Risk Characterization

Uncertainties in the risk characterization reflect the cumulative effects of uncertainties in all preceding risk analysis steps. Overall, the assumptions tend to overestimate risk. The results of the Plan B limited risk assessment are supported by the risk screening evaluation for all analytes at Site ST14 performed independently of this assessment presented in Section 4. The "risk-driving" organic chemicals prove to be benzene and hexachlorobenzene, which were identified as site-related COPCs based on the Plan A target concentration screening.

7.7 PROPOSED PLAN B TARGET CONCENTRATIONS

The Air Force intends to implement a risk-based remedial action at Site ST14 that is sufficient to minimize contaminant migration and eliminate potential risks to human and ecological receptors. The Plan B limited risk assessment indicates that potential RME cumulative risks to intrusive workers due to prolonged exposure to all detected organic chemicals may be slightly above the TNRCC acceptable target risk range of 1×10^{-6} for receptor groups where an actual exposure has or may occur. The risk calculations indicate that the major chemical contributors to the cumulative risk are benzene and hexachlorobenzene in soils and benzene in groundwater (Appendix F). However, the individual estimated risk due to exposure to either benzene or hexachlorobenzene for each route of exposure considered in the Plan B limited risk assessment except dermal contact with contaminated soil by nonintrusive workers is less than 1×10^{-6}. This means that residual concentrations of COPCs in both soil and groundwater are not at sufficient concentrations to cause unacceptable carcinogenic health risks unless dermal contact with contaminated soil, as represented in the Plan B limited risk assessment, occurs.

The Plan B limited risk assessment is used as the basis for developing Plan B target concentrations for COPCs in impacted media at Site ST14. Although the chemical fate and transport analysis presented in Section 6 illustrates that natural chemical attenuation processes are expected to reduce COPC concentrations to applicable Plan A target concentrations within a reasonable timeframe (i.e., by the year 2003 in source soils at Site ST14A, by the year 2005 in groundwater underlying Site ST14), Plan B target concentrations were developed to identify the time required to achieve the desired level of health protection for potential receptor groups at this site, given the types of exposure that could occur and the mass reducing effects of natural chemical attenuation processes over time. The objective of Plan B target concentrations is to define the concentration for each COPC that can persist in onsite environmental media and not result in an individual risk greater than 1×10^{-6} for carcinogenic chemicals (benzene and hexachlorobenzene) or an HQ of 1 for noncarcinogenic chemicals (hexachlorobenzene) for each receptor group given the site-specific exposure assumptions incorporated into the Plan B limited risk assessment. The need to provide this level of health protection for receptor groups that are not involved in actual completed exposure pathways can be re-evaluated if the Plan B target concentrations prompt apparently excessive remedial requirements.

The exposure assumptions used in the Plan B limited risk assessment were used to derive Plan B target concentrations. The only two differences between the Plan B limited risk assessment and the Plan B target concentration calculations was how

exposure to fugitive dusts was incorporated into algorithms and how cross-media impacts were considered. As discussed previously, fugitive dust generation was modeled for the Plan B limited risk assessment using several coupled chemical fate models and a Monte Carlo approach (Section 6). It is not possible to incorporate such model results into a Plan B target concentration calculation. Consequently, the particulate emission factor (PEF) algorithm presented in TNRCC (1994a) guidance was modified to include site-specific conditions. Cross-media impacts were not quantitatively considered in the Plan B limited risk assessment, since groundwater was not identified as a target receptor. A quantitative chemical fate assessment of the long-term potential of soils to act as a source of groundwater contamination is presented in Section 6. This analysis indicated that source soils at Site ST14A are expected to act as a continuing but diminishing source of groundwater contamination for about 10 years. This potential source was included in the Bioplume II model developed for this site. Plan B target concentrations that are protective of underlying groundwater quality were developed by modifying the cross-media algorithm developed by the TNRCC (1994a) with site-specific data. The exposure assumptions, algorithms, and derivation of the Plan B target concentrations for benzene and hexachlorobenzene are presented in Appendix F.

Table 7.3 presents the Plan B target concentrations that are protective of both onsite intrusive and nonintrusive workers and underlying groundwater quality. The maximum measured concentration of benzene in groundwater, the only groundwater COPC, is well below the Plan B target concentration of 241 μg/L for dermal exposure. Natural chemical attenuation process that have been documented to be operating at this site are expected to further reduce benzene concentrations by the year 1998 (i.e., when the site is planned to be transferred and used in accordance with the final land use plan). The chemical fate assessment in Section 6 indicated that benzene in groundwater would be reduced to the Plan A beneficial use II target concentration of about 30 μg/L at Site ST14A by the year 2005. This Plan B target concentration for groundwater reiterates the findings of the Plan B limited risk assessment: exposure pathways involving groundwater, given the type of exposure that is likely to occur at this site, do not result in significant human health threats.

However, Table 7.3 does indicate that residual concentrations of benzene (and possibly hexachlorobenzene) in soils may pose an unacceptable risk to both nonintrusive workers (should actual exposure occur as described in the Plan B target concentration algorithms) and underlying groundwater quality. These results are consistent with the Plan B limited risk assessment. The cumulative carcinogenic risk estimate for nonintrusive workers was within the 10^{-5} risk range (Table 7.1). This is below the TNRCC target risk range of 1×10^{-4} for receptor groups that are not actually or likely to be exposed at a site. However, because the target risk for the Plan B target concentrations is 1×10^{-6}, the resultant Plan B concentrations are below measured residual concentrations at the sites. This means that contaminated soils, particularly at Site ST14A, may pose an unacceptable risk to nonintrusive workers should they come into direct contact with impacted soil on a regular basis. The exposure pathways analysis, which is summarized in Figure 7.1, indicates that these receptors are not likely to be involved in complete exposure pathways including direct contact with impacted site media. However, appropriate exposure controls or some type of similar low-cost remediation strategy may be considered a prudent "insurance" measure to prevent unacceptable risks to this potential receptor group.

TABLE 7.3
COMPARISON TO HEALTH-BASED PLAN B TARGET CONCENTRATIONS

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Compound	Units	Maximum Concentration From 1993-1995	1998 Projected Concentration[a]		Plan B Groundwater Protective Soil Concentration[d]		Plan B Health-Based Concentration[g]			
			Natural Attenuation[b]	Natural Attenuation with Bioventing[c]	Intrusive Workers		Intrusive[h]		Nonintrusive[i]	
					RME[e]	CT[f]	RME[e]	CT[f]	RME[e]	CT[f]
Soil										
Benzene	mg/kg	67	49.6	BDL[j]	10.8	13.4	101	469	6.27	84.2
Hexachlorobenzene	mg/kg	0.46	0.239	BDL[j]	0.021	0.026	0.497	1.29	0.061	0.869
Groundwater										
Benzene	mg/L	0.11	0.1	0.0604	NA	NA	0.241	0.298	NA	NA

Note: Measured and projected site concentrations that exceed Plan B target concentrations are identified by shading.

Footnotes:

[a] Modeled residual concentration that will be present in affected environmental media in 1998 (Section 5).

[b] Modeled residual concentration in soil and groundwater in 1998 as a result of natural chemical attenuation processes only.

[c] Modeled residual concentration in soil and groundwater in 1998 as a result of bioventing source soils and natural chemical attenuation processes.

[d] Derived soil concentrations that prevent leachate generation above Plan B target groundwater concentrations.

[e] RME = reasonable maximum exposure; used RME assumptions to derive Plan B target concentration.

[f] CT = central tendency; used CT assumptions to derive Plan B target concentration.

[g] Calculated health-based soil concentration to prevent carcinogenic and/or systemic toxic impacts to onsite workers.

[h] Intrusive worker assumed to be exposed to soils via dermal contact, incidental ingestion of soil, and inhalation of volatilizing chemicals and suspended contaminated soil particulates and exposed to groundwater via dermal contact only (Appendix F).

[i] Nonintrusive worker assumed to be exposed to soils via dermal contact and incidental ingestion only (Appendix F).

[j] BDL = below detection limit.

Cross-media contamination of groundwater from contaminated soil also was factored into the development of the Plan B target concentrations for soil. The SESOIL model developed for this site (Section 6) indicated that soils at Site ST14A will act as a continuing but diminishing source of groundwater contamination for about 10 years. The Plan B target concentrations are consistent with these earlier model results, although the Plan B levels may overestimate the degree to which contaminants may leach from and dissolve into underlying groundwater at the sites. The target groundwater concentration used in the Plan B derivations was the Plan B target groundwater concentration. Benzene has not been measured in groundwater at concentrations above its Plan B target concentration. No hexachlorobenzene has been detected in groundwater. These site analytical data suggest that soils are <u>not</u> causing Plan B target groundwater exceedances. However, on the basis of both the SESOIL model results and the Plan B target concentrations for soil that are protective of underlying groundwater quality, some type of soil remediation may be warranted to prevent exceedances of Plan B target groundwater concentrations or at least minimize the addition of contaminant mass to groundwater to ensure that existing plumes stabilize. The latter objective is important to ensure that dissolved contamination does not unexpectedly migrate downgradient toward areas under different exposure controls (e.g., Site SD13) and/or the unnamed stream and Farmers Branch.

SECTION 8

HUMAN HEALTH RISK ASSESSMENT FOR SITE SD13

A human health risk assessment has been performed to quantitatively evaluate the potential risks based on site-specific conditions and assumptions regarding potential human exposure to the COPCs identified in Section 5 for Site SD13. This human health risk assessment takes into account all detected organics and all inorganics detected above background levels, not just those chemicals detected above the Risk Reduction Standard 2 levels. The Air Force believes that this risk assessment is necessary to demonstrate that no imminent threat to human health or the environment exists even though several chemicals were detected at Site SD13 above the Risk Reduction Standard 2 levels. This quantitative risk assessment has been prepared to partially satisfy the compliance requirements of Risk Reduction Standard Number 3, 30 TAC Chapter 335, Sections 335.561 through 335.563.

This risk assessment shows that existing concentrations of organic and inorganic chemicals at Site SD13 do not pose an unacceptable level of carcinogenic risk to current or future receptors. The risk assessment also demonstrates that the risk due to exposure to non-carcinogenic chemicals is below unacceptable levels. Under the current proposed land use plan, portions of Site SD13 are scheduled to become open space/recreational areas in 1998. This planned change in land use has been incorporated into the risk assessment. It should be noted that natural chemical attenuation processes, which have been documented to be occurring at this site, will continue to reduce the risk presented by organic compounds. These processes are not accounted for in the final risk estimates. This risk assessment serves to document that existing residual concentrations in site media and in-place engineered components provide the level of protection afforded by Risk Reduction Standard Number 3 levels.

8.1 EXPOSURE PATHWAYS ANALYSIS

An exposure pathways analysis describes the migration path a chemical takes from the source of contamination to a potentially exposed individual (EPA, 1992a). A completed exposure pathway must consist of a source, a release mechanism (e.g., leaching or volatilization), a transport medium (e.g., groundwater or air), a potential human or ecological receptor (e.g., current and future onsite workers, current and future offsite receptors, or terrestrial plants), a potential exposure point (i.e., locations where receptors could come into contact with site-related contamination), and potential routes of exposure (i.e., ingestion, dermal contact, or inhalation). Each of these elements must be present before a particular exposure pathway can be considered complete. If any one of these elements is missing, the exposure pathway is considered

incomplete, and there is no risk. Site-related contamination can present a potential risk to receptors only if exposure pathways are completed.

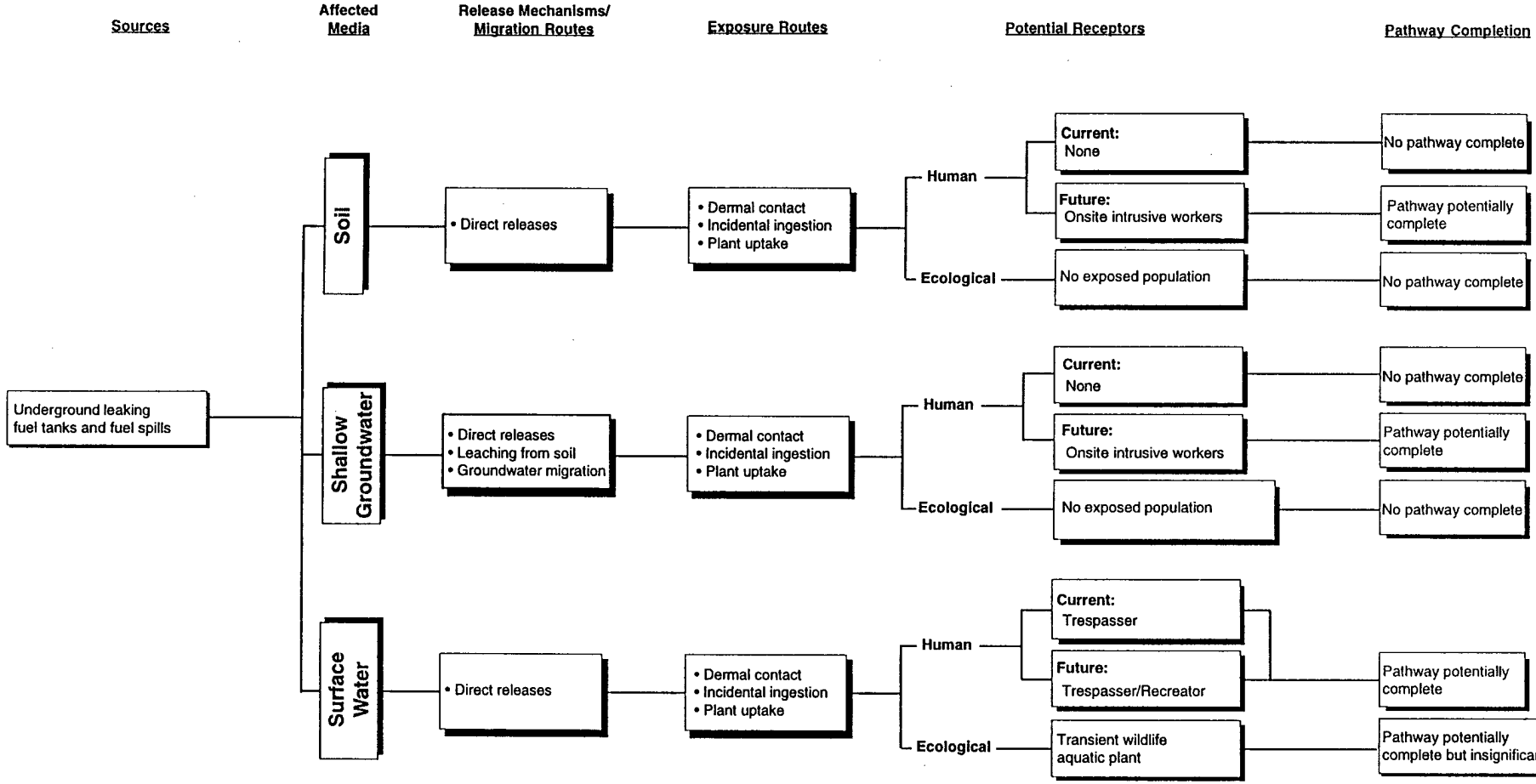
A site-specific exposure pathways analysis was completed for Site SD13 to determine the nature and likelihood of human or ecological contact with site-related contamination. The objective of this assessment is to determine which, if any, exposure pathways are complete (EPA, 1992a). Incomplete exposure pathways were eliminated from further consideration. Those exposure pathways that were considered complete and significant as a result of this assessment were retained for quantitative evaluation. The potential cumulative risks to human receptors due to exposure to each contaminant detected above background was then quantitatively characterized. For non-carcinogenic effects, the potential risk presented by all chemicals affecting the same target organ were summed for all pathways for each receptor type. Cancer risk was summed for all chemicals and across all exposure pathways for each potential receptor. Consequently, the final risk estimates account for the presence of multiple chemicals in exposure media, as well as exposure to multiple media. Both reasonable maximum exposure (RME) and central tendency (CT) risk estimates are presented. Only the RME estimates were used in determining the need for additional removal and/or remediation. The CT estimates are presented as reference information only. This risk assessment was prepared in accordance with EPA *Risk Assessment Guidance for Superfund* (RAGS) documents (EPA, 1989, 1991a-c, 1991e, 1992a-c) and 30 TAC Chapter 335, sections 335.561 through 335.566.

8.1.1 Conceptual Site Model

A conceptual site model (CSM) is used to qualitatively define the type of potential exposures to contaminants at and migrating from a site (i.e., to systematically evaluate the impact of chemicals in relevant media to potential receptors). The CSM describes onsite release points, the affected physical media, the types of contaminant transport and fate mechanisms that may be involved at the site, each group of potentially exposed populations or receptors, and how each receptor group could come into contact with site-related contamination. The CSM is used to summarize existing site characterization data, including assumptions about land and groundwater use, and to complete the qualitative exposure pathway screening assessment. The final CSM identifies those exposure pathways that may be involved in actual current exposures or hypothetical future exposures at Site SD13, and is presented in Figure 8.1.

8.1.1.1 Source and Release Mechanisms

The likelihood of release from a source, the nature of the contaminants involved, and the probable magnitude of their release all must be included in the CSM (EPA, 1989a and 1992a). As described in Section 6, the most likely past sources of fuel hydrocarbon contamination include leaking gasoline from USTs at Site SD13. Although small quantities of LNAPL has been measured at Site SD13, data indicate it is sufficiently weathered that it no longer is likely to be a significant source of hydrocarbon mass to soils or groundwater.



* No site related concentrations above risk reduction standard number 2 levels.

FIGURE 8.1

FINAL CONCEPTUAL SITE MODEL

Site SD 13
Remedial Action Plan
Risk Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, Texas

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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As described in Section 6, measured metal contamination in groundwater is due to the reducing conditions present at the site brought about by the biodegradation of fuel hyrdrocarbons. This reducing environment has the potential to effect the speciation of the inorganics present in the soil at the site. This change in speciation can greatly effect the solubility of the particular inorganic (see Section 6). At Site SD13, it is thought that the change in the oxidation-reduction status of the subsurface has resulted in the release of previously insoluble inorganics from the soil into the groundwater. There are no known anthropogenic sources of metal contamination at the site.

Volatilization from undisturbed surface media is not considered to be a significant release mechanism. Volatilization of chemicals from *disturbed* subsurface media into the atmosphere is a possible release/transport mechanism at the site. Elevated concentrations of organic contaminant vapors could be present if excavation of the soils at Site SD13 is required. This release/transport mechanism is evaluated in the risk assessment for future construction worker receptors.

The majority of Site SD13 is covered by impermeable materials such as cement and asphalt. The remaining land surface at the site is gravel or grass, both of which will minimize fugitive dust generation. The potential for generation of contaminated fugitive dust is further reduced because the measured soil contamination is most concentrated below 2 feet bgs. However, intrusive excavation activities in these areas could expose these subsurface soils. Consequently, fugitive dust emission was retained as a potential release mechanism only for exposure pathways for receptors engaged in on-site intrusive activities (i.e., deep excavation).

8.1.1.2 Contaminant Environmental Transport

Contaminant transport, transformation and fate in the environment is important to consider when assessing the potential for exposure. The french underdrain system (SWMU 64) is thought to have been an important transport mechanism for movement of soluble contaminants at Site SD13. This system was designed to intercept groundwater moving through Site SD13 and route it to the oil/water separator (SWMU 67) at the south end of the drain. Historical site data suggest that dissolved benzene had previously discharged into the french underdrain and unnamed stream, because elevated concentrations were measured in Farmers Branch during previous sampling events (Radian, 1985 and 1988). In 1996, portions of the french underdrain and the north oil/water separator were removed (see Section 5). This has removed the french underdrain system as a potential transport mechanism for rapid movement of chemicals from portions of the site to the unnamed stream. Therefore, the potential for contaminants at Site SD13 to impact surface water, either within the unnamed stream or in Farmer's Branch is greatly reduced. The impact of this removal action as well as natural processes, on reducing or eliminating discharge of measurable concentration of soil/groundwater contaminants to surface water is described in Section 6 of this RAP. No elevated concentrations of organics or inorganics have been measured in surface water recently.

Due to the reducing environment of the subsurface soil and groundwater, inorganics sorbed to the soil matrix may be subject to transport via groundwater flow. As groundwater containing mobilized inorganics moves out of the area impacted by the

presence of fuel hydrocarbons and the ORP returns to a more oxidizing environment, the speciation of the inorganics should return to a less soluble form and the inorganics should be removed from solution. Thus transport of mobilized inorganics should only take place in the reducing environment of the area immediately downgradient from the organic contamination. As presented in Section 6, the extent of the hydrocarbon contamination is expected to decrease due to natural attenuation processes. Therefore, the transport of inorganics via groundwater should also be a transient process and the extent of transport via this mechanism is thought to be limited and is not expected to have off-site impacts. Although the effects of this phenomenon are thought to be transitory, current groundwater sampling results are used in the quantitative risk evaluation for future receptors.

8.1.1.3 Potentially Exposed Populations and Exposure Routes

The third major component of the CSM for this site is the identification of potentially exposed populations and exposure routes. The objective of this step is to determine the likelihood and extent of human or ecological receptor contact with site-related contaminants (EPA, 1989a and 1992a). Land use assumptions are critical to defining the types of receptors that are now present or may be reasonably expected to be present in the foreseeable future at these sites, or in immediately adjacent areas that could potentially be impacted by site-related contamination.

8.1.1.4 Current On-Site Conditions

As described in Section 3.6.2, Site SD13 is maintained as an abandoned industrial area. Potential human receptor groups are limited to onsite workers The potential exposure of workers at Site SD13 should be classified as reasonable but hypothetical. The site is abandoned, so nonintrusive workers are not regularly present. No intrusive activities have been recently conducted or are planned at this site as part of normal site maintenance. Limited construction activities may be undertaken as part of the conversion of a portion of Site SD13 to open space/recreation area, as planned in the current land use plan. Trespassing by potential residential or recreational receptors is not expected to be a significant concern at these sites due to access restrictions and habitat constraints (Section 3.6.1). Institutional access controls prohibit access of potential trespassers to the site and make trespassing unlikely. Further, no shallow groundwater is withdrawn from areas within at least 0.5 mile from this site to meet potable or nonpotable water requirements (Appendix C).

Based on the above current land use information, on-site intrusive construction workers are the only on-site receptors involved in a potentially completed exposure pathway. Intrusive workers could be exposed to mixed soils (0-12 feet bgs) via incidental ingestion of and dermal contact with soil, inhalation of fugitive dusts, and volatilizing chemicals from exposed deeper soils and dermal contact with alluvium groundwater. Because alluvium groundwater can be encountered at about 6 feet bgs (Section 3.4), workers engaged in deep excavations could hypothetically come into contact with groundwater and saturated soils.

Although the potential for exposure to off-site trespassers is highly unlikely, this exposure scenario has been retained for quantitative analysis, because the unnamed

stream is outside of the Base's perimeter fence. Trespassers could be exposed to surface water via incidental ingestion of and dermal contact with surface water while wading in Farmers Branch Creek. The depth of Farmers Branch Creek does not allow swimming.

The industrial nature of the site, which includes concrete, asphalt and crushed rock driveways and parking areas, warehouse structures, and chain link fencing to limit access, precludes the existence of suitable wildlife habitat. No resident ecological receptors were identified for which soils and/or groundwater are likely contaminant exposure media. In addition, the concentrations of inorganic compounds measured at the site as part of the Law (1994) RFI are well below the EPA (1983) guidelines for the protection of plants. Removal of the oil/water separator and portions of the french underdrain have minimized the potential surface water source for current aquatic organisms in and around the unnamed stream and Farmers Branch. No compound recently detected in surface water exceeded the toxicity-based benchmarks for ecological receptors (Section 5).

8.1.1.5 Current Off-Site Conditions

Site SD13 is located on a military facility undergoing realignment. The site is surrounded on all sides except the southeast by operating military/industrial facilities (Section 3). The unnamed stream and Farmers Branch lie downgradient from the site. Removal of the north oil/water separator and portions of the french underdrain system in 1996 has greatly diminished the potential impact of Site SD13 on the unnamed stream and Farmers Branch. Based on surface water sampling results collected during the Law (1994) RFI and the 1994 risk-based sampling event, the impact of Site SD13 contaminants on surface water quality was minimal prior to partial removal of the french underdrain system. No benzene was detected in surface water during these sampling events, and concentrations of other contaminants were below the Risk Reduction Standard 2 levels (Table 5.1).

Although a potential exposure pathway involving surface water may be complete, neither on-site or off-site ecological receptors in surface water are exposed to concentrations of other volatile contaminants above the toxicity-based ecological benchmarks (Section 5).

8.1.1.6 Future Conditions

As described in Section 3.6.3, portions of Site SD13 are scheduled to be converted to an open space/recreational area in 1998 as part of the realignment efforts (US Air Force, 1994). Because the area is adjacent to the 100-year flood plain and within the 500-year flood plain of Farmers Branch, no construction of new facilities is likely. The site will likely be maintained as open space. No permanent residents will be allowed. Although surface water recreators are unlikely due to variable low flow conditions that persist at Farmers Branch for much of the year (Section 3), as a conservative measure of potential future exposure, this pathway has been retained for quantitative analysis. The exposure assumptions used to evaluate potential current risks also will be used to characterize potential future risks except the exposure media will be mixed soils and surface water only. No exposure to groundwater by onsite recreators is

believed to be reasonable, given it's depth and the absence of intentional extraction for use. Recreators will most likely confine their activities to the nearby golf course, which is upstream from and not impacted by potential contamination from Site SD13.

Hypothetical future intrusive construction workers could come into contact with impacted environmental media at Site SD13. However, as under the current land use scenario, the likelihood of exposure is low. This pathway has been retained for quantitative analysis, although no actual exposure pathway is likely to be completed. The assumptions used to evaluate potential current risks also will be used to characterize potential future risks for this receptor group.

With reclamation of Site SD13 as an open space/recreational area, limited increased use of the site by songbirds and possibly small rodents may occur if habitat potential is enhanced by lawns and landscape planting to replace current paved areas. However, such reclamation activities likely will involve grading the site and covering it with imported topsoil to support cultivated plantings. Such a layer of soil and sod will effectively create a barrier between any near-surface site soil contaminants and transient ecological receptors.

8.1.2 Summary of Potentially Completed Exposure Pathways

Figure 8.1 presents the CSM for Site SD13. Incidental exposure to contaminated subsurface soils and shallow groundwater is possible only if deep excavation/construction activities are conducted in and immediately downgradient from the source areas at this site. Also, exposure to surface water is possible only during recreational/trespasser activities. These two exposure scenarios are the only ones believed to be potentially complete and significant under both current and future land uses. The exposure pathway involving surface water may have been complete in the past, but recent sampling data suggest that this pathway is now incomplete or at least insignificant. For potential ecological receptors, the exposure pathway from contaminated soil and groundwater is not complete.

8.2 ESTIMATING EXPOSURE-POINT CONCENTRATIONS

The representative exposure-point concentration is defined as the concentration that represents the highest exposure that could reasonably be expected to occur for a given exposure pathway. This value is intended to account for both the uncertainty in environmental data and the variability in exposure parameters (EPA, 1992b). All compounds detected above background (not just those chemicals identified as COPCs) were used to characterize potential risks.

8.2.1 Evaluation of Measured Site Data

For evaluation of soil contamination, the exposure-point concentration was taken to be the maximum value detected during any of the soil sampling episodes. However, analytical results from the three soil samples taken during the 1996 removal of the oil/water separator were not incorporated into the risk assessment. The north oil/water separator (SWMU 67) received groundwater collected in the french underdrain system and discharged this water into the unnamed stream. During the 1996 removal

activities, confirmatory soil samples were taken from the sides of the excavation near the inlet and outlet pipes of the oil/water separator. Since the oil/water separator acted as a focus point for much of the groundwater moving through Site SD13, it is expected that the area immediately surrounding the oil/water separator will have uncharacteristically high concentrations of contaminants. The area immediately surrounding the oil/water separator is not representative of the site and therefore is not included in the risk calculations. It should be noted that the excavation was backfilled with clay-rich soils to grade. All samples were collected several feet bgs. Therefore, re-excavation of this area will be required to contact any potential contamination remaining in the area immediately surrounding the oil/water separator. Given the current and future uses of this site, completion of an exposure pathway involving deeper soils for the area immediately surrounding the oil/water separator is highly unlikely.

For evaluation of groundwater contamination, the exposure-point concentration was taken to be the maximum value detected during the 1995/1996 and 1997 groundwater monitoring events. These data incorporate 5 sampling events at 9 locations at Site SD13. The sampling performed under the ongoing GSAP is the most recent information available for groundwater and therefore will be most representative of current site conditions. Analytical results from the 1994/1995 risk-based sampling indicated that concentrations of BTEX compounds were slightly above the levels found during the 1995-1997 groundwater sampling events. These results were not incorporated into the risk calculations because it is believed that natural attenuation, which has been documented to be ongoing at the site, is causing the observed reduction in concentrations. Additionally, 1994 data is less representative of current site conditions. Analytical results from the 1994 RFI were not incorporated into the risk calculations because it is believed that the more recent results provide a more accurate assessment of current site conditions.

It should be noted that the groundwater sampling results for the September 1994 sampling event for wells OT12-15B and OT12-15C, which were part of the RFI sampling, appear to be anomalous results. The results for all inorganic analytes for these two wells are approximately three orders of magnitude higher than results observed at these two wells during the April or June 1994 groundwater sampling as part of the RFI. These results are three orders of magnitude higher for all analytes than results for other wells sampled in September 1994, when results from these wells had roughly correlated with the results from the other wells sampled in previous sampling events. This suggests that the results may have been reported in the wrong units. Regardless of the reason for these anomalous results, the more recent analysis performed under the GSAP should be more representative of current site conditions. Groundwater sampling performed under the GSAPs (1995/1996 and 1997 sampling events) include continued sampling of wells which had relatively high concentrations of contaminants detected during the 1994 RFI or the 1994/1995 risk-based groundwater sampling events (i.e., well OT12-15C), and/or wells which are immediately downgradient from 1994/1995 sampling locations. For example, the maximum concentrations detected during the 1994 RFI for the BTEX compounds was at location E400 (a temporary sampling location). This temporary sampling location could not be included in either the 1994/1995 risk-based or subsequent GSAP sampling events.

However, wells SD13-01, SD13-04, and SD13-02 are immediately downgradient from location E400 and are included in the ongoing groundwater monitoring program.

For surface water contamination, exposure-point concentrations for organics are based on the maximum result detected during the 1994/1995 risk-based sampling event. This is the most recent surface water sampling performed which analyzed for specific organic chemicals. Exposure-point concentrations for inorganics are based on analytical results from sampling done as part of the 1997 groundwater monitoring event, the most recent analysis performed for inorganics in surface water. It should be noted that due to removal of portions of the french underdrain there is no longer surface water in the unnamed stream. Therefore, the 1997 surface water samples were taken in Farmers Branch Creek. Based on the 1997 surface water sampling, no dissolved inorganics were detected at concentrations above the background levels established in the *Basewide Background Study* (Jacobs, 1997) at locations downstream from the unnamed stream's outfall. Antimony was detected upstream of Site SD13 at concentrations greater than background and above the Risk Reduction Standard Number 2 level of 6 µg/L. However, since this concentration was detected upstream of the site, it cannot be site related and is not included in the risk assessment.

The exposure-point concentrations for each compound are presented as part of the risk calculation tables in Appendix H.

8.2.2.1 Fugitive Dust

Fugitive dust in outdoor air may contain semivolatile organic compounds and metals found in the soil at Site SD13. Although the potential for fugitive dust emissions is low under nondisruptive conditions, intrusive workers could generate fugitive dusts during deep excavation activities. Concentrations of fugitive dust were developed using the model provided in the *Soil Screening Guidance: Technical Background Document* (USEPA, 1996). This model allows development of estimated concentrations to which receptors will be exposed via inhalation of contaminated dust due to wind erosion. To more accurately simulate intrusive construction conditions, it was assumed that there was no vegetative cover present at the site. Due to the potentially invasive nature of construction activities, it was also assumed that intrusive construction receptors could be exposed to fugitive dust from subsurface soil as well as from surface soils. The model, inputs, assumptions, and calculations used to estimate fugitive dust emissions are provided in Appendix H.

8.3 QUANTIFICATION OF EXPOSURE: CHEMICAL INTAKES

Once the exposure pathways are described qualitatively and the exposure concentrations are defined quantitatively, the amount of any one chemical to which a receptor may be exposed during a specified time is estimated. Calculating chemical intakes hinges on reasonable, yet conservative, assumptions about how each group of potential receptors at a particular site may be exposed to site-related contamination. This step in the risk assessment process is called quantification of exposure. The risks to potential receptors exposed to site-related contamination are then calculated quantitatively by coupling toxicity data and quantified exposure data.

Intake estimates are normally expressed as the amount of chemical at the exchange boundary in milligrams per kilogram of body weight per day (mg/kg-day), which represents an intake normalized for body weight over time. The total exposure is then divided by the time period of interest to obtain an average exposure over time. The time used to average exposure is a function of the toxic endpoint: for noncarcinogenic effects it is the exposure time, and for carcinogenic effects it is a lifetime (70 years).

The emphasis in this risk assessment is on chronic exposure to measured compounds. Short-term (i.e., subchronic) and acute exposures are not evaluated in this risk assessment. Although the intrusive construction workers were assumed to have subchronic exposure, they were evaluated with chronic toxicity values to be more conservative (health-protective). As required by the EPA (1992c), two types of exposure scenarios are evaluated for this risk assessment: average (CT) and reasonable maximum exposure (RME). CT and RME exposure factors were combined with corresponding exposure-point concentrations to give a range of CT and RME intake values. When coupled with the appropriate toxicity information, intakes calculated using both the CT and RME exposure parameters result in arithmetic mean (or median, if appropriate) and RME risk estimates, respectively. Both the CT and RME intakes (and therefore risk estimates) use the maximum concentration, as described in Section 8.2, as an exposure-point concentration. In accordance with EPA (1992d) guidance, RME is used to estimate risk for decision-making purposes; whereas, CT exposure-based results are used for comparison purposes only.

Where appropriate, standard default intake variables as defined by EPA (1991e) were used in quantifying exposure for the intrusive construction worker (i.e., body weight, breathing rate, lifetime). Some intake variables were based on best professional judgment. For example, the intrusive construction worker was assumed to remain at the job for an equivalent of only 1 year . This assumption is based on best professional judgment, as most construction-related/remediation activities at the site would likely not last more than the equivalent of 1 year of continuous exposure. Any necessary remediation activities at the site will not require workers to be constantly present after initial installation activities are complete. Calculation of dermal exposure to groundwater also required development of several intake variables. An exposed surface area of 5,800 cm^2 was developed based on the assumption that an individual's hands, arms and head would not be covered by clothing and therefore were exposed to contaminated groundwater. Consistent with the development of other generic criteria, the exposure assumption for dermal contact with groundwater was developed to characterize a reasonable maximum exposure (RME). Dermal contact with groundwater by a construction worker is not likely to be continuous over an 8-hour work day. It is reasonably assumed that a construction worker will be in contact with groundwater for 50 percent of the 8 hour work day (i.e., ET = 4 hrs). Dermal absorption factors were developed based on studies of absorption from soil (Ryan *et al.*, 1983, DTSC, 1994). Twenty-five percent of volatile organics, 10 percent of semi-volatile organics, and 1 percent of inorganics were assumed to be absorbed dermally, unless chemical-specific absorption factors were available. A chemical-specific permeability constant (Kp) value was determined to calculate dermal intakes from groundwater. All Kp values were based on the *Dermal Exposure Assessment: Principles and Applications* (EPA, 1992c). The intake variables, resulting exposure

factors, and the formulas used to calculate intake for intrusive construction workers are shown in Appendix H.

Where appropriate, default intake variables were used to quantify both child and adult recreator/trespasser exposure to surface water via dermal exposure and incidental ingestion. If EPA has not defined standard default variables, best professional judgment was used in determining reasonable values for intake variables. Values for surface area were developed from mean values for specific body parts, provided in the *Exposure Factors Handbook* (EPA, 1996), assuming that a receptors feet, lower legs, thighs, and hands are exposed to surface water. Due to variable low flow conditions which persist at Farmers Branch for much of the year, exposure was based on an assumption that the trespasser/recreator would be wading in the river. Given that access to Farmers Branch is limited by geographical barriers and dense vegetation, the intake variables for exposure time (2.6 hrs/day) and exposure frequency (90 days/yr) are thought to represent a reasonable maximum exposure (RME). A chemical-specific permeability constant (Kp) value was determined to calculate dermal intakes. All Kp values were taken from *Dermal Exposure Assessment: Principles and Applications* (EPA, 1992c).

8.4 TOXICITY ASSESSMENT

The objective of the toxicity assessment is to weigh available evidence regarding the potential for particular contaminants to cause adverse effects in exposed individuals and to provide, where possible, an estimate of the relationship between the extent of exposure to a contaminant and the increased likelihood and/or severity of adverse effects. For humans, EPA has conducted numerous toxicity assessments that have undergone extensive review within the scientific community.

The types of EPA toxicity values used in this risk assessment include oral reference doses (RfD), inhalation reference doses (RfD_i), oral carcinogenic slope factors (SF), and inhalation slope factors (SF_i). RfDs and RfD_is are used to evaluate noncarcinogenic effects. SFs and SF_is are used to evaluate carcinogenic effects. Toxicity values for the noncarcinogens and carcinogens evaluated in this risk assessment are presented in Appendix H. The toxicity information used in this risk assessment was obtained from IRIS (Micromedex, Inc., 1995). If values were not available from IRIS, the *Health Effects Assessment Summary Tables* (HEAST) values (EPA, 1994a) were used.

EPA has not derived toxicity values for all routes of exposure. Most of the available toxicity values are for oral exposure, although many inhalation values are available. No values are currently available for dermal exposure. Dermal toxicity values were developed by modifying oral toxicity values with dermal absorption factors. For those chemicals for which toxicity values are not available for any route of exposure, it may be appropriate to use toxicity values derived for similar chemicals (i.e., surrogates). This is appropriate for chemicals where the toxicity values for one isomer may be used for another isomer. For most chemicals, however, there is no chemical that is similar enough to justify the use of toxicity information for a surrogate, therefore, these chemicals cannot be quantitatively evaluated in the risk assessment.

8.5 RISK CHARACTERIZATION

To characterize risk, toxicity and exposure assessments were summarized and integrated into quantitative expressions of risk. To characterize potential noncarcinogenic effects, comparisons were made between projected intakes of chemicals and chronic toxicity values. To characterize potential carcinogenic effects, probabilities that an individual would develop cancer over a lifetime of exposure were estimated from projected intakes and chemical-specific dose-response information. Major assumptions, scientific judgments, and, to the extent possible, estimates of the uncertainties embodied in the assessment are also presented. CT and RME risk estimates for the receptors and pathways of concern are quantified in this risk characterization section.

The current and future land uses at Site SD13 are assumed to consist of intrusive construction activities and trespasser/recreator activities. The RME and CT chemical-specific hazard quotients (HQs), total HIs, and cancer risk estimates for these exposure routes are presented in Appendix H. HIs were calculated by summing all HQs for a particular target organ across all exposure pathways for each receptor. Table 8.1 summarizes the RME and CT risk estimates developed for the current and future receptors that could be exposed to existing levels of site contamination at Site SD13. For the intrusive construction worker, the HIs are presented by target organ.

8.5.1 Risk Estimates for Hypothetical Current Receptors

The excess upper bound lifetime risk equivalent to a cumulative hazard index greater than 1 or a cumulative carcinogenic risk greater than 1×10^{-4} is unacceptable pursuant to 30 TAC Chapter 335, Section 335.563, and necessitates remediation and/or removal to protect human health. Although no actual exposures to current intrusive workers at Site SD13 are expected, the cumulative carcinogenic risk estimate for this receptor is 8.9×10^{-6} and 9.29×10^{-7} for RME and CT respectively. Exposure pathway-specific risks and receptor totals are presented in Table 8.1. The cumulative RME cancer risk is well below the upper bound limit of 1×10^{-4} specified as the desired risk goal for compliance with Risk Reduction Standard Number 3. Since Site SD13 is currently unused, and there are no current plans to undertake intrusive construction activities, the likelihood of actual current exposure under this scenario is considered low.

Hazard Quotients (HQs) were summed for all chemicals which affect the same target organ or act by the same method of toxicity; HQs also were summed across all completed exposure pathways for a given receptor. For intrusive construction workers, no HIs exceeded the target level of unity (1). However, the HIs for central nervous system toxicants approached 1. HIs for specific target organs are presented in Table 8.1. Table 8.2 presents the chemicals whose HQ are summed to develop the organ specific HIs. The target organ or mode of toxicity for each chemical detected is presented in table 8.3. Although these levels are below the target level of 1, some type of institutional control that prohibits excavation without adequate personal protection equipment may be warranted.

TABLE 8.1
SUMMARY OF QUANTITATIVE RISK ESTIMATES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE SD13, CARSWELL AFB/NAS FORT WORTH JRB, TX

Exposure Pathway	RME[a/]		Central Tendency[d/]	
	HQ[b/]	Risk Level[c/]	HQ[b/]	Risk Level[c/]
Trespasser/Recreator Child				
Dermal contact and incidental ingestion of surface water	3.89E-03	-	9.37E-04	-
TOTAL	**3.89E-03**	**0.00E+00**	**9.37E-04**	**0.00E+00**
Trespasser/Recreator Adult				
Dermal contact and incidental ingestion of surface water	1.44E-03	-	3.47E-04	-
TOTAL	**1.44E-03**	**0.00E+00**	**3.47E-04**	**0.00E+00**
Construction Worker (Intrusive)				
Incidental ingestion of soil		1.28E-06		1.25E-07
Dermal contact with soil		9.99E-07		1.61E-07
Inhalation of fugitive dusts		9.32E-10		4.89E-10
Dermal contact with groundwater		6.62E-06		6.42E-07
Inhalation of volatiles from soil		2.22E-09		1.16E-09
TOTAL		**8.90E-06**		**9.29E-07**

TABLE 8.1
SUMMARY OF QUANTITATIVE RISK ESTIMATES
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE SD13, CARSWELL AFB/NAS FORT WORTH JRB, TX

Construction Worker - RME (Intrusive)	HQ by Target Organ						
	Liver	Kidney	CNS	Blood	Skin	Increased Blood Pressure	Other
Incidental ingestion of soil	4.74E-03	1.48E-03	7.35E-02	5.20E-04	1.88E-01	8.72E-03	2.54E-04
Dermal contact with soil	2.72E-02	1.38E-02	2.96E-01	1.77E-05	8.51E-02	2.11E-02	1.16E-03
Inhalation of fugitive dusts	-	8.96E-06	8.58E-03	-	-	3.10E-04	5.85E-09
Dermal contact with groundwater	2.10E-01	4.28E-02	6.12E-01	1.04E-02	4.35E-02	2.96E-01	3.55E-01
Inhalation of volatiles from soil	6.11E-03	2.20E-03	-	-	-	-	4.34E-05
TOTAL	**2.48E-01**	**6.02E-02**	**9.90E-01**	**1.09E-02**	**3.17E-01**	**3.26E-01**	**3.56E-01**

[a] RME = reasonable maximum exposure

[b] HQ = chemical-specific hazard quotients; summed across all pathways for each receptor group to obtain cumulative HI (target is cumulative < 1).

[c] Carcinogenic risk level; expressed as probability; summed across all pathways for each receptor group to obtain cumulative risk level (target is cumulative 1E-4 for potential exposure, scenarios and 1E-6 where actual exposure is or may occur).

[d] Central tendency = average expression of exposure potential; used to compare to RME.

TABLE 8.2
CHEMICALS SUMMED BY TARGET ORGAN/MODE OF TOXICITY

Liver
Chlorobenzene
Chloroform
Dibromochloromethane
Ethylbenzene[a]
Methylene chloride
Tetrachlorethylene
Toluene[a]
Acenaphthene
Benzylbutlyphthalate
Bis(2-ethylhexyl)phthtalate
Acetone[a]
Hexachlorobenzene
Kidney
Bromodichloromethane
Ethylbenzene[a]
Toluene[a]
Isophorone
Pyrene
Cadmium
Acetone[a]
CNS
Manganese
Blood
1,2-Dichloroethylene (cis)
Fluorene
Zinc
Skin
Arsenic
Increased Blood Pressure
Barium
Other
all remaining chemicals

a/ toxic to liver and kidney

TABLE 8.3
TARGET ORGAN/MODE OF TOXICITY
ALL DETECTED COMPOUNDS

Compound	Target Organ / Mode of Toxicity
1,2,3,4-Tetramethylbenzene	- [a]
1,2,3-Trimethylbenzene	-
1,2,4-Trichlorobenzene	Adrenal effects/rats
1,2,4-Trimethylbenzene	-
1,2-Dichloroethylene (cis)	Effects on the blood/rats
1,3,5-Trimethylbenzene	-
1,4-Dichlorobenzene	-
2-Chlorophenol	Reproduction effects/rats
2-Methylnaphthalene	-
4-Bromofluorobenzene	-
4-Chloro-3-methylphenol	-
Acenaphthene	Hepatotoxicity/mice
Acetone	Liver and kidney effects/rats
Aluminum	-
Arsenic	Skin and vascular effects/humans
Barium	Increased blood pressure/humans
Benz[a]anthracene	-
Benzene	-
Benzyl butyl phthalate	Increased liver weight/rats
Beryllium	No adverse effects/rats
Bis(2-ethylhexyl)phthalate	Increased liver weight/guinea pigs
Bromodichloromethane	Renal cytomegaly/mice
Bromofluorobenzene	-
Cadmium	Significant proteinuria/humans
Calcium	-
Chlorobenzene	Liver changes/dogs
Chloroform	Fatty cysts in liver/dogs
Chromium	No observed effects/rats
Cobalt	-
Copper	Gastrointestinal irritation/humans
Di-N-Butylphthalate	Increased mortality/rats
Dibenzofuran	-
Dibromochloromethane	Liver lesions/rats
Ethylbenzene	Liver and kidney tox/rats
Fluorene	Hematological effects/mice
Hexachlorobenzene	Liver effects/rats
Iron	-
Iron, Ferrous	-

TABLE 8.3 (Continued)
TARGET ORGAN/MODE OF TOXICITY
ALL DETECTED COMPOUNDS

Compound	Target Organ / Mode of Toxicity
Isophorone	No effects/dogs, kidney effects/rats
Lead	-
Manganese	CNS effects/humans
Methylene Chloride	Liver toxicity/rats
N-Nitroso-di-n-propylamine	-
Naphthalene	-
Nickel	Decreased body and organ wt/rats
Phenol	Reduced fetal body weight/rats
Pyrene	Kidney effects/mice
Silver	Argyria (skin discoloration)/humans
Tetrachloroethylene	Liver tox/mice; weight gain/rats
Toluene	Liver and kidney effects/rats
Trichloroethene	-
Vanadium	No observed effects/rats
Xylenes (Total)	Hyperactivity, incr mortality/rats
Zinc	RBC effects/humans

(a) no systemic toxicity or no information available

The HIs for the child trespasser are 3.89×10^{-3} and 9.37×10^{-4} for RME and CT, respectively. The HIs for the adult trespasser are 1.44×10^{-3} and 3.47×10^{-4} for RME and CT respectively. These levels are below the target level of 1 for non-carcinogenic effects. For ease of presentation, HIs for trespasser/recreators were summed for all target organs and across all exposure pathways. There were no chemicals with carcinogenic effects to assess in the risk calculation for surface water pathways, and are presented in table 8.1. None of the organics detected in surface water during the 1994/1995 risk-based sampling event had carcinogenic effects, and no inorganics were detected above background levels for surface water during the 1997 sampling event. It should be noted that the calculations used to assess the trespasser scenario used input variables developed for recreators. It is believed that the use of recreator-based variables will act as an upper bound on exposure for trespassers, since occasional use by recreators, once the site is converted to open space/recreational land use, would likely be more frequent than use by trespassers.

8.5.2 Risk Estimates for Hypothetical Future Receptors

Based on the final conceptual site model (CSM), potentially completed future exposure pathways exist for intrusive construction workers and for recreational users of the planned open space. Input variables and exposure point concentrations were assumed to be the same for future receptors as for current receptors under these scenarios. Therefore, the estimated risk of carcinogenic effect and the HIs for non-carcinogenic effects will be identical to those calculated for current receptors. Use of current exposure-point concentrations to calculate future risk acts as a conservative upperbound on future exposures, and thus on risk, particularly for a site where natural bioattenuation has been documented.

8.6 UNCERTAINTY CHARACTERIZATION AND ANALYSIS

All risk assessments involve the use of assumptions, judgments, and imperfect data to varying degrees. This results in uncertainty in the final estimates of hazard and risk. This section describes the likelihood that the approaches incorporated into this risk assessment overestimate or underestimate the actual risks associated with exposure to site-related chemical concentrations. Risk assessment in general, as it is currently practiced, is highly conservative and often based on extremely conservative assumptions and scenarios. This risk assessment characterizes high-end risk as an RME, and also provides risk estimates based on average values to characterize CT (average risk).

There are several categories of uncertainty associated with risk assessment. One is the initial selection of substances for analyses and, therefore, used to characterize risk from exposure. A second category is the selection of exposure scenarios that are conservative and therefore protective of human health, and yet are probable. Additional uncertainties are inherent in the exposure assessment for individual substances and individual exposures. Those uncertainties are driven by the degree of reliability of the chemical monitoring data, the models used to estimate exposure-point concentrations in the absence of monitoring data, and the receptor intake parameters (e.g., exposure factors). A third category is the availability of toxicity information for the COPCs at the site to address all routes of potential exposure. Finally, additional

uncertainties are incorporated into the risk assessment when exposures to several substances are summed.

8.6.1 Data Uncertainties

Inorganic chemicals were compared to background levels, as described in Section 5, and eliminated if site concentrations did not exceed background levels. It is possible that some of the chemicals not retained for risk analysis may be present as a result of anthropogenic activities. It is possible, although unlikely, that the elimination of the anthropogenic fraction of these inorganic chemicals present at these sites could lead to an underestimation of risk. Chemicals were not eliminated from the quantitative risk assessment based on any detection-frequency analysis, and this approach possibly resulted in an overestimation of risks. Use of the maximum measured concentration as the concentration term may overestimate the overall amount of chemical present in the exposure medium and, consequently, the risk posed by the chemical exposure-point concentration.

8.6.2 Exposure Uncertainties

A large part of the risk assessment is the estimation of risks that are based on receptor exposure; if exposure of receptors does not occur, no risks are present. Although this assessment does qualitatively identify the probability of the exposure pathway occurring, the quantitative risk estimates for those receptor groups where exposure is possible but unlikely will be overestimated. Additionally, in the risk assessment, it is assumed that each unique receptor is exposed to the same contaminant concentrations and exposure duration (i.e., the intrusive construction worker scenario encompasses all potential intrusive construction workers). This assumption tends to overestimate risk because each individual receptor will not realistically be exposed to precisely the same contaminant concentrations for the same length of time.

8.6.3 Uncertainty in Exposure-Point Concentration and Intake Values

This section discusses the uncertainty associated with estimating exposure-point concentrations and the matrix-specific intake factors, including uncertainty associated with intake values and their respective default values for the RME and average CT exposure scenarios. Uncertainty arises in the assumption that current and future nonintrusive receptors will be exposed to a mixed soils stratum. Assuming that a receptor will be exposed to the maximum concentration detected, regardless of the soil strata from which the detection occurred could result in an overestimation of risk.

Calculated and modeled exposure-point concentrations approximate the actual conditions to which receptors will be exposed at a given site. There always will be some concern regarding how well an exposure model approximates the actual conditions to which receptors will be exposed. Whenever models are used to estimate risk, uncertainty is involved. The uncertainty lies within the models, which are used as simplified representations of reality (i.e., the assumption that the model will generate results that closely resemble the real situation). Each model has different variable inputs and modeling scenarios that also lead to uncertainty. This factor is recognized

by EPA (1992d), which states, "The degree to which release or transport models are representative of physical reality may overestimate or underestimate risk."

The models used to estimate exposure via a particular route can introduce a considerable amount of uncertainty. In particular the calculations of dose for dermal exposure to groundwater or soil introduce relatively large amounts of uncertainty. The exposure estimates incorporate several factors for which there is little chemical-specific experimental information available (i.e., permeation rates through skin, availability of chemicals bound in soil, or length of time soil remains in contact with skin). Without specific information it is necessary to make assumptions about the behavior of chemicals and soils. Uncertainty will be introduced into the risk assessment to the degree that the assumptions used in these models are not accurate. In general assumptions are made which will tend to make the model results conservative (health protective). For example the non-steady state model recommended by EPA in *Dermal Exposure Assessment: Principles and Applications* was used to calculate the dose of organic contaminant absorbed dermally from groundwater. EPA states that this approach provides a more conservative total absorbed dose over the traditional steady-state equation. An examination of the calculated amount of ethyl benzene absorbed dermally through contact with groundwater indicates that 0.19 mg/day are absorbed under the RME assumptions ((3.32 x 10^{-5} mg/cm^2-day) x 5,800 cm^2 exposed = 0.19 mg/day). This is equivalent to drinking 26 liters of groundwater per day (7.4 x 10^{-3} mg/L ethylbenzene in groundwater / 0.19 mg = 26 L). EPA suggests that a maximum of 50 percent absorption of contaminant from water be used as a guide in assessing the reasonableness of the model (EPA 1992). Using this 50 percent maximum absorption guideline it would be necessary for the industrial worker to contact 51 liters of groundwater per day to receive the calculated dose (0.19 mg/day / (7.4 x 10^{-3} mg/L x 0.5) = 51L). This suggests that the dermal absorption model (used in both the intrusive construction worker and the trespasser/recreator scenarios) will likely overestimate risk.

Standard assumptions regarding body weight, duration of exposure, life expectancy, receptor population characteristics, and lifestyle were made to reflect the RME and CT exposure to individuals for each pathway evaluated. The assumption for RME reflects a conservative (health-protective) approach. CT exposure values represent a less conservative approach. The CT exposure values and the subsequent intake factor calculations potentially may underestimate risk to certain sensitive subpopulations. However, CT risk is used only to provide a comparison to the RME risk estimates. Because of the conservative approach, the RME assumption most likely will overestimate actual risk, whereas the CT risk estimates may underestimate the risk for any hypersensitive subpopulations (which are not expected to be present at these sites).

Exposure variables for this risk assessment were taken from current EPA guidance, when available. However, some exposure scenario intake values are location-specific and reflect best professional judgment. For example, the duration and frequency of exposure to soils via several exposure routes for the current and future intrusive worker are unknown, and professional judgment was used. Best professional judgment was applied with the intention of overestimating, rather than underestimating the upper-bound risk estimate.

8.6.4 Uncertainty in the Toxicity Assessment

Some uncertainty is inherent in the toxicity values used for the assumed duration of exposure assessed. These uncertainties are compounded under the assumption of dose additivity for multiple substance exposure. That assumption ignores possible synergisms or antagonisms among chemicals, and assumes similarity in mechanisms of action and metabolism. Another assumption is that all the toxicity values used have an equal degree of reliability, which in reality is not the case. Overall, those assumptions would tend to overestimate hazards and risks. Because toxicity constants for cancer generally are based on the 95-percent upper confidence limit (UCL), risks tend to be overestimated.

However, it must be emphasized that not all organic chemicals detected could be evaluated quantitatively for health effects because toxicity values do not exist for all chemicals. The lack of toxicity data tends to underestimate risk, therefore, the more chemicals that lack toxicity data, the greater the tendency is for risk underestimation.

The use of oral absorption factors poses uncertainty when used to convert oral toxicity values to dermal toxicity values. Whenever multiple absorption factors existed for a particular chemical, the most stringent factor for the various chemical forms was selected. This may lead to an overestimation of risk. Use of dermal toxicity values based on converted oral toxicity values introduces uncertainty due to potential differences in point-of-entry effects and potential differences in metabolic activation/deactivation in dermally absorbed doses. This could tend to either overestimate or underestimate risk.

Regarding noncarcinogenic health, the application of uncertainty factors to no-observed-adverse-effect level (NOAEL) for a chemical in an animal study for animal-to-human extrapolation adds additional uncertainty to the toxicity assessment. The application of scaling or uncertainty factors may result in an overestimation of risk.

8.6.5 Uncertainty in Risk Characterization

Uncertainties in the risk characterization reflect the cumulative effects of uncertainties in all preceding risk analysis steps. Overall, the assumptions tend to overestimate risk. The results of the risk assessment are supported by the risk screening evaluation for all analytes performed independently of this assessment presented in Section 5. The "risk-driving" chemicals prove to be arsenic, manganese, vanadium and barium, which were identified as compounds which exceeded the Risk Reduction Standard 2 levels.

SECTION 9

PILOT TESTING OF SOURCE REDUCTION TECHNOLOGIES AT SITE ST14

Section 6 of this RAP shows that both destructive and nondestructive attenuation processes should be effective at minimizing contaminant migration and reducing contaminant mass over time. Comparison of maximum detected concentrations of soil COPCs for Site ST14 to proposed Plan B target concentrations (Table 7.3) indicates that residual concentrations of contaminants in soils could continue to leach from soils and adversely impact underlying groundwater quality. The quantitative SESOIL model results imply that benzene could persist in soils at concentrations above proposed Plant B target soil concentrations that are protective of underlying groundwater for about 8 years (or until the year 2003). The anticipated natural reduction in contaminant mass and concentration in both soils and incidentally groundwater may be expedited by implementing some type of source reduction in the source area at Site ST14. Several low-cost source reduction technologies were evaluated at Site ST14 as part of the field efforts in the event that engineered source reduction was required to protect human health and the environment or to reduce the total time and cost of remediation.

A bioventing pilot test was completed by ES (1993) at Site ST14A in May 1993 to determine the feasibility of using this technology for reducing BTEX and TPH in contaminated soils. Based on the positive results of this test, Parsons ES completed a conceptual design for a full-scale bioventing system at Site ST14A (fuel loading area) and constructed 16 bioventing wells in contaminated soils during initial site characterization activities. Because the surface soils and subsurface hydrogeologic conditions at Sites ST14A, ST14B, and SD13 are similar, additional bioventing wells were constructed during the risk-based investigation in soils that appeared to contain significant fuel-related contamination. A total of 11 vent wells were constructed at Site ST14B (POL tank farm), and 6 vent wells were constructed at Site SD13 (abandoned gasoline station). Spacing between vent wells was based on the radius of oxygen influence and air permeability data generated from the Site ST14A pilot test. Soil gas measurements indicate fully depleted oxygen in vadose zone soil gas exhibiting hydrocarbon contamination in the identified source areas. Results of the bioventing pilot test are detailed in the final report for Site ST14A (ES, 1993), a summary is provided in Section 9.1 of this RAP.

A biosparging test was performed as part of the field activities at Site ST14A (fuel loading area) from November 28, to December 1, 1994. Biosparging is a groundwater remediation process that reduces the total mass of dissolved hydrocarbons through volatilization and by enhancing biodegradation. Biodegradation is enhanced by

introducing oxygen into the subsurface thereby stimulating aerobic biodegradation. DO concentrations in the groundwater are often used as an indicator of the applicability of biosparging. Very low DO levels were reported for Upper Zone groundwater throughout the East Area (Figure 6.3). DO readings were 0.4 mg/L or less in 15 contaminated monitoring wells throughout the East Area prior to air injection (biosparging) into the groundwater. Generally, DO levels are less than 2 mg/L throughout the groundwater BTEX plume. The low DO concentrations in the source area indicate aerobic biodegradation processes are oxygen limited. Biosparging may enhance biodegradation of hydrocarbons in saturated media by providing DO to the microbial populations to use as an electron acceptor during fuel hydrocarbon oxidation. A summary of the biosparging test procedures and results is provided in Section 9.2.

9.1 BIOVENTING PILOT TEST AT SITE ST14A

Bioventing pilot testing was conducted at Site ST14A in 1993. All field procedures and data analysis followed methodologies specified in the AFCEE bioventing protocol document (Hinchee *et al.*, 1992).

9.1.1 Bioventing Well and Vapor Monitoring Point Installation

One 4-inch-diameter air injection vent well (VW1) and three vapor monitoring points (MPA, MPB, and MPC) were installed at Site ST14A near monitoring well ST14-MW17M in May 1993 (Figure 9.1). VW1 was screened throughout the contaminated interval from approximately 5 to 15 feet bgs. The shallow soils are primarily silty clays, with the sand content increasing with depth. Saturated sand with trace clay and gravel was encountered at 11 feet bgs. Groundwater levels were measured at 8.5 to 9.0 feet bgs in VW1 following completion. The VW was screened several feet into groundwater to allow for seasonal fluctuations and to monitor groundwater level and chemistry.

The three monitoring points (MPs) were constructed in contaminated vadose and capillary fringe soils approximately 10, 20, and 45 feet north of VW1 (Figure 9.1). A background MP was constructed in clean soils approximately 500 feet north of VW1. A 6-inch-long screened interval was installed in each MP at 4-, 7-, and 10-foot depths to allow soil gas sampling of discrete intervals within the vadose zone. The 10-foot interval was saturated in each MP at the time of pilot testing. These MPs were constructed at 10-foot depths so future measurements can be made if the static water level drops during seasonal fluctuations. The MPs were designed to allow collection and measurement of soil gas to evaluate the performance of air injection at the site. Thermocouples were installed at 5 and 10 foot depths at MPA (10 feet north of VW1) to measure soil temperatures.

9.1.2 *In Situ* Respiration Test Procedures and Test Results

Following installation of the VW and MPs, soil gas samples were collected from all nonsaturated intervals and were analyzed with field instruments for oxygen, carbon dioxide, and TVH. Generally, the results indicated that all intervals with elevated TVH concentrations were depleted of oxygen and had elevated concentrations of carbon

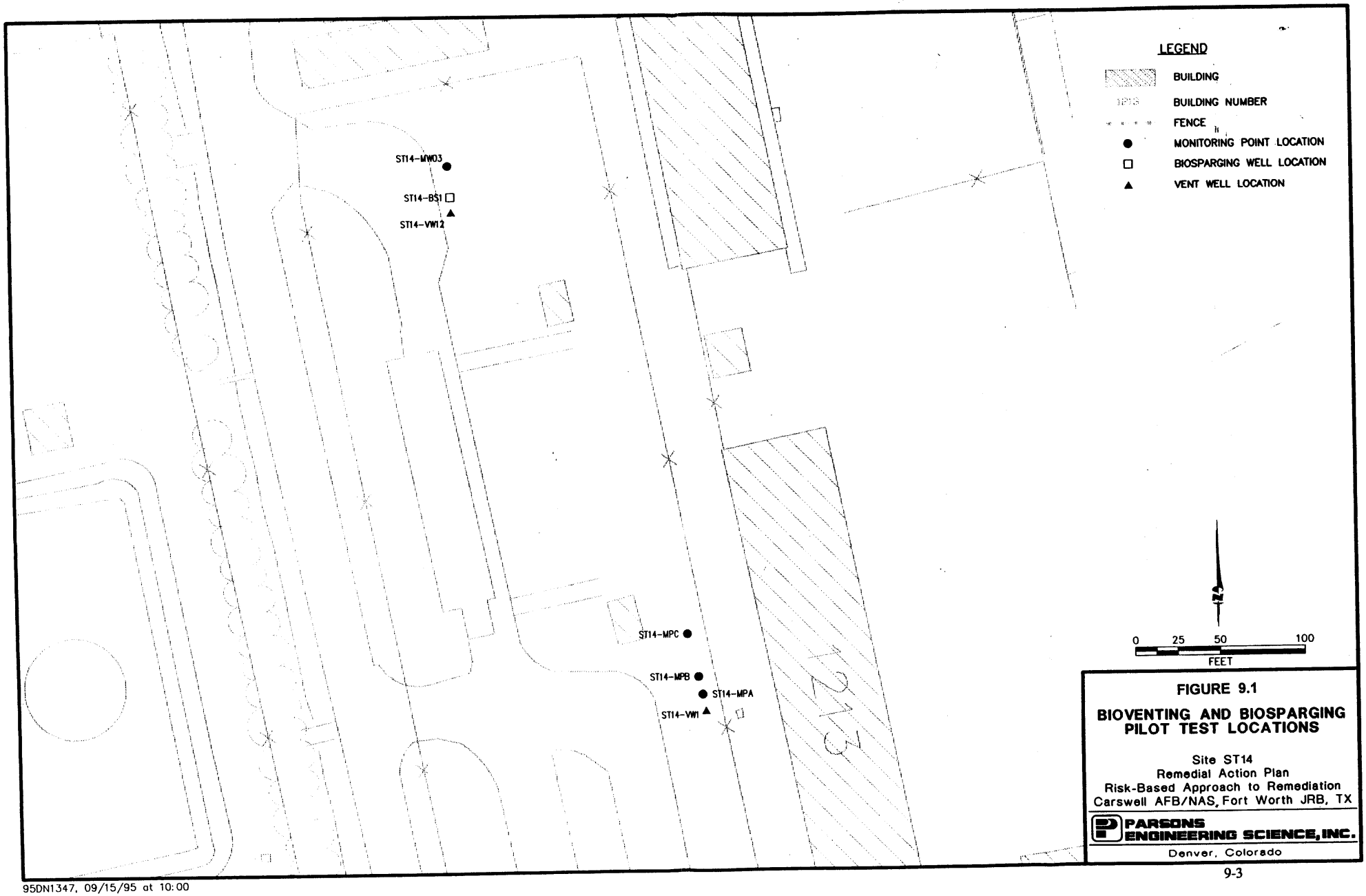


FIGURE 9.1

BIOVENTING AND BIOSPARGING PILOT TEST LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

95DN1347, 09/15/95 at 10:00

dioxide. Soil gas samples collected from the background MP had higher oxygen and lower carbon dioxide concentrations. These results suggest that biodegradation of fuel hydrocarbons is occurring in the vadose zone, but that natural biodegradation is now oxygen limited.

An *in situ* respiration test was performed to determine the rate at which soil bacteria will degrade fuel hydrocarbons under aerobic conditions in subsurface soils at Site ST14A. The test was completed using procedures described in the AFCEE bioventing protocol document (Hinchee *et al.*, 1992). Air was injected into VW1 and four discrete MP screened intervals for 16 hours to deliver oxygen to the contaminated soils. At the end of the 16-hour injection period, the air supply was cut off, and oxygen, carbon dioxide, and hydrocarbon levels were measured over a period of 72 hours. Oxygen loss was rapid and linear at every sampling point during approximately the initial 500 minutes of the *in situ* respiration test. The observed rates of oxygen utilization then were used to calculate the estimated aerobic fuel degradation rates at Site ST14A.

Calculations based on the initial respiration test results indicate that, at Site ST14A, an estimated 1,800 to 14,000 mg of fuel per kg of soil can be degraded each year. These values were calculated as described in the protocol document (Hinchee *et al.*, 1992) using air-filled porosities ranging from 0.06 to 0.15 L of air per kg of soil. Point-specific fuel consumption rates were calculated using observed oxygen utilization rates, estimated air-filled porosities, and a conservative ratio of 3.5 mg of oxygen consumed for every 1 mg of fuel biodegraded. It should be noted that initial respiration tests often yield higher biodegradation rates than subsequent respiration tests. This is because during the initial months of bioventing the more biodegradable hydrocarbons are degraded, such as the BTEX compounds, leaving the more biologically recalcitrant hydrocarbons for long-term biodegradation (Miller, 1993).

Bioventing test results from Site FSA1 and Site FSA3 at Air Force Plant 4, located immediately west of Carswell AFB/NAS Fort Worth JRB (Figure 1.1), are useful in illustrating how biodegradation rates change over time (Parsons ES, 1994b). During the initial pilot test at Site FSA1, calculated biodegradation rates ranged from 300 mg of fuel per kg of soil to 1,600 mg of fuel per kg of soil per year. After 6 months of bioventing, however, the biodegradation rate for residual hydrocarbons had decreased to an average of 110 mg of fuel per kg of soil per year. Similar changes in biodegradation rates were observed at Site FSA3 over time. During the first pilot test, estimated biodegradation rates ranged from between 380 mg of fuel per kg of soil to 2,800 mg of fuel per kg of soil per year. Within 6 months, the observed rates had dropped to an average of 265 mg of fuel per kg of soil per year. The average BTEX reduction at the Air Force Plant 4 sites was greater than 98 percent during the first year of bioventing. These results, which were obtained from sites with physical and chemical characteristics similar to those at Site ST14, suggest that expected biodegradation rates will decrease over time as the more readily biodegradable fuel fraction is reduced.

9.1.3 Air Permeability Test Procedures and Results

An air permeability test was also performed to determine the ability to move air through subsurface soils at Site ST14A. The test was conducted according to technical protocol document procedures (Hinchee *et al.*, 1992). Air was injected into VW1 with a 3-horsepower (hp) blower for approximately 3.5 hours at a rate of approximately 28 actual cubic feet per minute (acfm) and an average pressure of approximately 7 pounds per square inch (psi). The pressure response measured at all MPs achieved steady-state conditions within 45 minutes. The dynamic method of determining soil gas permeability that is coded in the HyperVentilate model was used to calculate the air permeability of Site ST14A soils. Air permeabilities were calculated for two depths from both MPA (10 feet from the injection point, VW1) and MPC (45 feet from VW1). No initial pressure response was observed in the 4-foot-bgs interval of MPB (20 feet from injection point, VW1) because the interval was constructed in moist, highly plastic, tightly consolidated clayey soil.

The calculated soil gas permeabilities at the injection flow rate of 28 afcm and a screened interval thickness of 3.5 feet (5 feet bgs at the top of screen to 8.5 feet bgs at the water level in vent well) were 26 and 31 darcys for the 10-foot radial distance at 4 and 7 feet bgs, respectively. The soil gas permeabilities for the 45-foot radial distance at 4 and 7 feet bgs is 94 and 93 darcys, respectively. The average permeability calculated for this site was 61 darcys. This value is approximately one order of magnitude higher than would be expected for the clayey sands at the site; however, the presence of gravel throughout the soil profile and the increasing sand content with depth may be responsible for the increased average permeability measured at this site. A radius of pressure influence of at least 45 feet was observed at all depths.

9.1.4 Oxygen Influence Testing and Results

The depth and radius of oxygen influence in the subsurface soils resulting from air injection into VW1 during pilot testing constitute the primary design parameters for the full-scale bioventing system partially constructed at Site ST14A. Several soil gas measurements were made following different air injection periods and flow rates to assess the radius of soils that can be oxygenated by the pilot system. These air injection periods consisted of: (1) the 3.5-hour air permeability test at 28 acfm; (2) an extended 17-hour air injection period immediately following the air permeability test at a lower flow rate of 24 acfm; and (3) a 12-hour air injection period at 15 acfm following installation of the 1-hp extended pilot test blower.

The relatively brief (3.5 hours) air injection period at 28 acfm produced significant changes in soil gas oxygen levels at both monitored depth intervals in MPA and MPC and at the one monitored depth interval in MPB. This indicated a radius of oxygen influence of at least 45 feet from the central VW. A blower was manifolded to the VW for continuous air injection to monitor long-term performance of a bioventing system at the site. Oxygen increases were observed at all unsaturated MP intervals, including the upper 4 feet of clayey soil, after injecting air for 12 hours at 15 acfm. Considering these results and the measured pressure response during the air permeability test, it is anticipated that the radius of influence for a long-term bioventing system at this site

will exceed 45 feet at all depths. These results also indicate that air injection at low flow rates is an effective way to oxygenate contaminated soils at all unsaturated depths at the site.

9.1.5 Technology Assessment

Analytical results from soil sampling indicate that significant hydrocarbon contamination is present in vadose soils in three general areas at Site ST14 (Figure 4.4). Soil gas screening results also reveal that these vadose soils are depleted of oxygen. Because the soils are relatively uniform, bioventing is a potentially useful technology for reducing source area hydrocarbon contamination. Reduction of contamination may be important to minimize the potential release of contaminants via the following mechanisms: (1) volatilization to the atmosphere; (2) partitioning from soil or mobile LNAPL into groundwater; (3) direct release into surface water from the french drain and oil/water separator system; and/or (4) indirect release to surface water via groundwater inflow. Based on the source release assessment in Section 6 of this RAP, partitioning from soil to underlying groundwater is anticipated to be the primary release mechanism operating at the site.

Bioventing pilot test results indicate that a low rate of air injection is an effective method of stimulating aerobic fuel biodegradation and BTEX reduction in Site ST14A soils. The effective radius of oxygen influence for air injection bioventing exceeds 45 feet from each air injection well. For full-scale design a radius of influence of 45 feet was recommended, and VWs installed to date have been spaced based on this radius. A design air flow rate of 15 acfm per VW is recommended at a pressure of approximately 1.8 psi.

9.2 BIOSPARGING TEST AT SITE ST14

Biosparging was evaluated at Carswell AFB/NAS Fort Worth JRB as a remediation technology for removing fuel hydrocarbons from the saturated soil zone. Injecting air into the source area groundwater serves two potential purposes: volatilizing VOCs, including the BTEX compounds, from the groundwater, and supplying oxygen to the groundwater to enhance biodegradation.

The depth and radius of DO increase in the groundwater resulting from air injection into the sparging point during pilot testing, and the air injection pressure and flow rate, are the primary design parameters for full-scale biosparging systems. Optimization of full-scale, multiple sparging point systems requires pilot testing to determine the areal extent of groundwater that can be oxygenated at a given flow rate and sparging point screen configuration. The following sections summarize the biosparging test procedures and results for the biosparging test conducted at Site ST14A. An assessment of the general applicability of this technology for source reduction at the East Area sites is also provided.

9.2.1 Biosparging Well Installation

A 2-inch-diameter polyvinyl chloride (PVC) air sparging well (BS1) was installed at the site as shown on Figure 9.1. BS1 was screened from 14 to 16 feet bgs to inject air into the groundwater at the depth interval extending from 6 to 8 feet below the groundwater surface, just above the limestone bedrock beneath the site. One VW (VW12), located 9 feet from BS1, and one monitoring well (ST14-MW03), located 18 feet from BS-1, were used to measure changes in groundwater DO concentrations (Figure 9.1). VW12 was constructed as part of the 1993 bioventing pilot test (ES, 1993), and well ST14-MW03 was constructed as part of the RI (Radian, 1991). Figure 9.1 shows the locations of VW12 and ST14-MW03 in relation to BS1. A construction log for BS-1 is included in Appendix B. Construction details for the other test wells are discussed in the referenced reports (ES, 1993; Radian, 1991).

9.2.2 Biosparging Test Procedures

A biosparging pilot test was performed at Site ST14A during the period from November 28 to December 1, 1994. Initial DO concentrations were measured prior to injecting air into BS1. Then air was injected into BS1 at varying flow rates and pressures for approximately 3 days. Air injection pressures ranged from 5.5 to 8.5 psi, with an average injection pressure of about 7.5 psi and a flow rate of approximately 40-50 scfm.

During the period of air injection, DO concentrations and injection pressures were periodically measured and recorded. These parameters were measured at VW12 and ST14-MW03. After air injection was discontinued, DO levels in BS1, VW12, and ST14-MW03 were monitored for an additional 4 hours to estimate the temporal influence of oxygen and the DO consumption in the groundwater. All readings were measured by slowly agitating the DO meter probe in the groundwater at a depth of 10 feet below the top of the well casing, which put the probe near the groundwater surface.

9.2.3 Biosparging Test Results

Changes in groundwater DO concentrations were used to determine the effective radius of influence of the single sparging point. The biosparging test results are summarized in Table 9.1. The maximum DO increase was measured at VW12, which is located 9 feet from BS1. At VW12, the DO concentration increased from 0.4 to 5.5 mg/L at approximately 8 to 10 feet bgs. Negligible or nonexistent DO increases were obtained in ST14-MW03, which is located 18 feet from the sparging point.

No increases in DO were observed at VW12 when air was injected at an injection pressure of 5.5 psi over a period of 5 hours. An instantaneous increase in DO at VW12 was observed when the injection pressure was increased to 8.5 psi; however no significant increase in DO was observed at ST14-MW03 throughout the pilot test. On the basis of erratic increases in DO concentrations, the effective treatment radius cannot be interpreted from these data. Although the uniformity of oxygen distribution cannot reliably be determined, pilot testing clearly indicates that sparging is capable of

TABLE 9.1
SITE ST14 BIOSPARGING TREATABILITY RESULTS FOR DISSOLVED OXYGEN
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TX

Date and Time of Measurement	Elapsed Time (hours)	Pressure (psi)	Location, dissolved oxygen in mg/L		
			BS1	VW12	MW03
11/29/94 at 1100 hours	Pretest	-[a/]	0.4	0.4	0.4
11/29/94 at 1700 hours	Start test	6.5	-	-	-
11/29/94 at 1800 hours	1	6.5	-	0.4	0.6
11/29/94 at 2000 hours	3	6.5	-	0.4	0.4
11/29/94 at 2210 hours	5	6.5	-	0.4	0.4
11/30/94 at 0730 hours[b/]	14.5	6.5	-	0.4	0.4
11/30/94 at 0830 hours	15.5	8.5	-	4.8	0.4
11/30/94 at 0925 hours	16.42	8.5	-	4.8	0.4
11/30/94 at 1150 hours	18.83	8.5	-	5.3	0.4
11/30/94 at 1515 hours	22.25	8.5	-	5.4	0.4
11/30/94 at 1710 hours	24.17	8.5	-	5.5	0.4
12/01/94 at 0800 hours	39	8.5	-	5.4	0.4
12/01/94 at 0805 hours	0[c/]	-	6.4	5.0	0.8
12/01/94 at 0905 hours	1	-	6.0	4.2	0.4
12/01/94 at 1005 hours	2	-	5.3	4.3	0.4
12/01/94 at 1105 hours	3	-	5.6	3.2	0.4
12/01/94 at 1205 hours	4	-	6.0	3.0	0.4

a/ - = not applicable.

b/ Injection pressure increased to 8.5 psi after measurement taken at 0730 hours.

c/ Air injection stopped at 0805 hours.

increasing DO concentrations, thus promoting *in situ* biodegradation of fuel hydrocarbons. The immediate response to the increased air injection pressure suggests that channelized flow predominates in the subsurface at the biosparging test site. This further suggests that the increase in DO could be the result of as few as one air channel intersecting the well, creating an *in situ* air stripping column. While this would have the effect of increasing the DO in the monitoring well, it does not support the effectiveness of biosparging in increasing the DO of the aquifer as a whole. In a channelized flow regime, DO distribution and stripping of VOCs both would be diffusion-limited processes. Channelization could be reduced by pulsing air injection and using lower injection pressures and flow rates.

Following shutdown of the pilot testing blower system, DO concentrations were monitored in VW12 for 4 hours. DO declined from 5 to 3 mg/L during this period. This may be an indication of consumption of oxygen through aerobic biodegradation of fuel hydrocarbons. However, assuming the increase in DO measured in VW12 was the result of an intersected air channel, the decrease in DO could have resulted from diffusion to and mixing with low DO groundwater in the formation surrounding VW12.

9.2.4 Potential Air Emissions

The long-term potential for air emissions into the atmosphere from full-scale bioventing or biosparging operations at this site is low. Emissions would be minimal because of the low air injection rates and because vapors released into the vadose zone would move slowly upward from the bioventing or biosparging wells and would be biodegraded as they move through the oxygenated vadose soil. The biodegradation of BTEX vapors in soil gas was clearly demonstrated during the bioventing pilot test performed at Site ST14A (ES, 1993). Soil flux measurements taken before and during the first 24 hour period after initiation of air injection for the biosparging test at Site ST14A confirm that the BTEX and TVH vapor flux to the atmosphere did not measurably increase as a result of biosparging (see Section 4). Emission flux testing was performed using the procedures described in Section 2. Similar tests could be conducted if full-scale biosparging was employed for source reduction. Additionally, site-specific testing could be conducted to ensure that horizontal migration of VOCs did not result in unacceptable exposures.

9.2.5 Technology Assessment

The value of air sparging as a remediation tool is one of the most controversial topics in the remediation industry. Advocates of this technology cite case studies where VOCs are removed and dissolved oxygen is transferred to the groundwater in relatively short time frames (Brown *et al.*, 1991b; Marley *et al.*, 1990). Despite many apparently successful applications of this technology, a number of independent researchers have concluded that the use of fully-screened monitoring wells for monitoring sparging efficiency has significantly biased groundwater DO and VOC data. They point out that the monitoring wells may intersect a single channel of air, which essentially turns the well into an *in situ* air stripping column, adding DO to the water and stripping VOCs from the well. Independent researchers also have conducted large pilot tests have shown that injected air generally follows preferential channels and is not

uniformly distributed, even in sandy aquifer material (Johnson, 1993). Studies on DO distribution have yielded similar results, with uneven DO distribution measured over long-term pilot testing (Johnson, 1994). In these pilot tests, DO initially increased and then gradually declined over a 110-day test. This decline was likely the result of increased channeling, which reduces mass transfer of oxygen as smaller channels combine into larger, less efficient channels. Pulsing of air sparging systems has been suggested as a method of maintaining smaller channels and maximizing mass transfer (Johnson, 1994).

The biosparging pilot test results indicate that DO can be increased in a well 10 feet from the sparging well. However, it is likely that channelized flow is occurring at this site. On the basis of the pilot test data gathered at Site ST14A, and on other air sparging research to date, the pulsed operation of air sparging systems may serve to increase DO near the sparge points and provide oxygen to the capillary fringe and vadose zone to enhance natural biodegradation. However, it is doubtful that air sparging can remove large quantities of VOCs from the groundwater, given mass transfer limitations. This fact and the demonstrated biodegradation of hydrocarbons in the vadose zone support the premise that a soil vapor extraction (SVE) system would not be necessary if biosparging is selected as part of the remedial action for Site ST14, or possibly for Site SD13. The application of biosparging to the relatively uniform sandy soils in the Upper Zone aquifer of the East Area site is possible, although the long-term benefits of sparging remain in question.

SECTION 10

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

Sections 6 and 9 provided scientific documentation of natural chemical attenuation processes and the potential benefits of various low-cost source reduction technologies, respectively, in accelerating the remediation of the source area at Site ST14A, the potential secondary source area at Site SD13, and the resulting dissolved organic contaminant plumes. An initial screening of remedial approaches and technologies was completed, and several technologies were identified for possible use at these sites. A complete review of the initial screening process is included in Appendix G. Three remedial alternatives were developed using various combinations of natural chemical attenuation, land and groundwater use controls, long-term monitoring, engineered source reduction, and groundwater extraction and treatment. The objectives of Section 10 are to summarize the alternatives developed from candidate approaches and technologies selected in Appendix G, to review the primary evaluation criteria used to compare these alternatives, to complete a more detailed comparative analysis of each alternative, and to identify the most logical approach for remediating to achieve Plan B target concentrations and TNRCC target cumulative risk thresholds at Site ST14 and to demonstrate attainment of Risk Reduction Standard Number 3 at Site SD13 in a reasonable timeframe (i.e., by the 1998 land transfer date). Each alternative is more fully explained in terms of its effectiveness, technical and administrative implementability, and cost. Following this evaluation, an implementation plan for the recommended alternative is summarized in Section 11.

10.1 SUMMARY OF CANDIDATE REMEDIAL ALTERNATIVES

Based on the initial remedial screening process, which is summarized in Appendix G, several remedial approaches and technologies were retained for the development of remedial alternatives. These technologies were selected to provide a range of passive to more active response actions, all of which will minimize contaminant migration, minimize increases in contaminant concentrations, prevent receptor exposure to hazardous concentrations of chemical contamination, and protect environmental resources. The primary goals of all of the proposed alternatives are to reduce soil and groundwater contaminant concentrations to levels that meet the site-applicable target concentrations appropriate for proposed future land uses and reduce the RME cumulative risk estimate for the intrusive worker receptor at Site ST14 group to below the TNRCC threshold of 1×10^{-6}. As secondary goals, all remedial alternatives may also provide sufficient protection for onsite nonintrusive workers and onsite recreators/trespassers, should they come into direct contact with contaminated media. The target concentrations/risk thresholds would be met in different time frames and at

different costs under each alternative. The following remedial approaches and technologies were retained for evaluation:

- Groundwater monitoring;
- Limited land use controls (including deed recordation);
- Groundwater use controls (including deed recordation);
- Public education;
- Intrinsic remediation (bio-decontamination) of soil and groundwater contamination;
- Groundwater extraction via vacuum extraction;
- Extracted groundwater treatment with an oil/water separator and air stripping unit;
- Treated groundwater discharge to surface water; and
- Air injection bioventing and biosparging in source areas.

The primary objective of source reduction technologies would be to more rapidly remove COPCs from unsaturated and saturated soils (and incidentally shallow groundwater) at the suspected source areas at these sites. Accelerating the reduction of source contamination will meet the stated risk reduction requirements of the TNRCC and may actually decrease the length of time that would be required to demonstrate attainment of Plan B and eventually Plan A target concentrations in both soils and groundwater at Site ST14 and of Risk Reduction Standard Number 3 and eventually Number 2 levels at Site SD13.

Site ST14 is to be maintained as a military fueling area. No change in exposure potential as a result of Base realignment is anticipated at Site ST14. However, Site SD13, downgradient from Site ST14A, is proposed to become part of an open space/recreational area in 1998 as part of the Base realignment initiative. To ensure that contamination originating from Site ST14 does not impact this potential future use of Site SD13, the fate of chemical contamination under various remedial alternatives was evaluated. All remedial alternatives developed for Site ST14 will be evaluated in terms of how the alternative can reduce contaminant migration, concentration, and/or exposure potential at both Sites ST14 and SD13.

The maximum concentrations of COPCs in both vadose zone and phreatic soils and groundwater were measured at Site ST14A. Results from the soil sampling event in the source area of Site ST14 indicate that benzene was measured above health-based Plan B target soil concentrations for nonintrusive workers. Additionally, measured benzene concentrations in soil exceeded the Plan B target soil concentration for protection of groundwater. This comparison is consistent with, the soil modeling results presented in

Section 6, which indicated that soil contamination is anticipated to be a significant source of downgradient groundwater contamination through leaching and dissolution.

Because natural chemical attenuation processes have been effectively reducing the mass and toxicity of organic COPC compounds in soils and groundwater and limiting downgradient migration (Section 6), these processes can best be enhanced through a reduction of the continuing source of contamination at Site ST14A. One candidate source-reduction technology, *in situ* bioventing/biosparging, was retained for additional analysis. Three candidate remedial alternatives were developed and are described in the following sections.

10.1.1 Alternative 1 - Natural Chemical Attenuation, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 1: Attainment of Plan B soil target concentrations at every point in the impacted area at Site ST14A in approximately 8 years. Attainment of Risk Reduction Standard Number 2 levels for unrestricted use sites at Site SD13 in approximately 10 years. Demonstration of plume stability in about 5 years.

Section 6 presents evidence that organic groundwater contaminants are being remediated by natural physical, chemical, and biological processes. On the basis of soil sampling results presented in Section 4 and evaluated in Section 6, contaminant concentrations in soils at Site ST14A are above levels that are protective of human health (i.e., health-based Plan B target concentrations for nonintrusive worker assuming direct contact with soils) and underlying groundwater quality. Based on the soil contaminant attenuation observed in the past at Site ST14A, it will take approximately 8 years for soils to attenuate to below Plan B target concentrations if no engineered remedial techniques are employed at the site. Because site soil contaminants are present at concentrations that exceed Plan B target concentrations and may pose a risk to human health if an exposure were to occur as defined by the Plan B limited risk assessment and algorithms (Section 7), appropriate exposure controls (i.e., restriction on site activities) will need to be implemented at the site.

Section 6 provides a thorough evaluation of the natural chemical attenuation processes operating at the site. Several chemical fate and transport models were coupled to simulate the effects of these processes on contaminant mass and mobility over time. The model for this alternative predicted that no significant additional downgradient migration of benzene should occur, and that the existing plume should stabilize within 3 years. No COPCs have been detected in groundwater at concentrations in excess of the Plan B target concentrations for groundwater. Additionally, dissolved benzene originating from the secondary source area at Site SD13 should be reduced to below the Risk Reduction Standard Number 2 level for groundwater of 5 mg/L by the year 2007. Dissolved benzene concentrations should be reduced to the Plan A beneficial use II target concentration of 29.4 mg/L at Site ST14 by the year 2005. Appropriate (i.e., restrictions on use as potable source; deed recordation) groundwater use restrictions should be put in place until all groundwater impacted by Sites ST14 and SD13 meets applicable TNRCC target concentrations.

These proposed limitations on groundwater use would not pose additional restrictions on current or planned use in the uninhabited industrial area at Site ST14 or SD13.

The partial removal of the french underdrain system at Site SD13 minimized the potential for benzene and other COPCs in groundwater to be discharged to surface water. Previous surface water sampling events conducted as part of early IRP investigations and the 1990 RI reported elevated concentrations of benzene in the unnamed stream and Farmers Branch (Radian, 1991). Concentrations of benzene in surface water have been decreasing, and no benzene has been detected since the 1994 risk-based sampling event. Additionally, no elevated concentrations of dissolved inorganic COPCs have been recently measured in downgradient surface water samples. In fact, concentrations of metals detected at surface water sampling locations upstream of the discharge area for Site SD13 are greater than the concentrations measured at near downstream sampling locations. These data indicate that although the pathway to surface water has been complete in the past, diminishing concentrations in groundwater and the partial removal of the french underdrain system (SWMU 64) have resulted in diminishing surface water impacts. However, the conservative Bioplume II results presented in Section 6 demonstrated that dissolved benzene measured at E400 at Site SD13 could have migrated to the suspected vicinity of the french underdrain at concentrations greater than 10 mg/L by the year 1998. Consequently, the french underdrain system at Site SD13 was partially removed. The goal of this activity was to eliminate the potential migration pathway to surface waters. The oil/water separator (SWMU 67) at Site SD13 also was completely removed as part of this action.

This alternative would include about 5 years quarterly monitoring of groundwater at Site ST14 to verify and document that natural chemical attenuation is sufficient alone to minimize contaminant mass and mobility. Although Plan B groundwater target levels have been attained at Site ST14, an additional 3 years of sampling are proposed to verify the plume is stable despite the presence of residual soil concentrations at Site ST14A above Plan B groundwater protective levels. Natural processes have been removing and should continue to remove contaminant mass and limit contaminant migration. The progress of natural chemical attenuation at minimizing impacts above Plan B levels in groundwater would be monitored using the existing network of monitoring wells. Sentry wells located along Rogner Drive will be used to document the concentrations of contaminants migrating from Site ST14 toward Site SD13. Point-of-Compliance (POC) wells would be used to ensure that no contaminant concentrations above Risk Reduction Standard Number 2 levels migrate beyond the area of established exposure controls (i.e., past Site SD13 and into Farmers Branch). Additional details on the frequency and types of groundwater analysis recommended to confirm natural chemical attenuation and to verify the eligibility of the site for risk-based closure are presented in the long-term monitoring plan included in Section 12.

This alternative also would include 10 years of quarterly monitoring at Site SD13 to verify and document eventual attainment of Risk Reduction Standard Number 2 levels for every COPC. Natural processes have been removing and will continue to remove organic contaminant mass and limit migration. The destruction of organic contaminant mass will allow the localized geochemical conditions to be restored to pre-release conditions, which should cause mobilized inorganics to adsorb to solid soil matrix (i.e.,

remove dissolved metals from solution). No continued free product recovery actions are proposed under this alternative, either for Site ST14 or Site SD13. Several POC wells, that are upgradient from Farmers Branch, also will be monitored to confirm that no compound in excess of residential Risk Reduction Standard Number 2 levels is approaching or released at the facility boundary.

Under Alternative 1, land use controls would be implemented at Site ST14 to ensure continued industrial land use without groundwater extraction from the shallow aquifer. Land use controls would also be implemented to prevent onsite workers from exposure to soils contaminated in excess of Plan B health-based target levels without adequate personal protective equipment. Additional land use controls and deed recordation will be required at Site SD13 when the site is to be used as an open/recreational area. For example, shallow groundwater could not be used for unrestricted potable uses until residential Risk Reduction Standard Number 2 levels were achieved.

10.1.2 Alternative 2 - Natural Chemical Attenuation, Continued Low-cost Free Product Recovery, *In Situ* Bioventing and Biosparging at Site ST14A, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 2: Attainment of Plan B target concentrations at every point in the impacted area at Site ST14 in approximately 1 year (i.e., by the year 1998). Compliance with provisions of risk Reduction Standard Number 3, and eventual attainment (i.e., 10 years) of Risk Reduction Standard Number 2 levels for unrestricted use at Site SD13. Demonstration of dissolved plume stability 2 years following source reduction at Site ST14.

Alternative 2 is similar to Alternative 1 except for the addition of *in situ* bioventing/biosparging at Site ST14A and continuing recovery of all separate-phase liquids (LNAPL) at both sites. Bioventing would be employed at Site ST14 to lower contaminant concentrations in unsaturated soils. Biosparging would be employed to increase DO concentrations in saturated soils and groundwater and promote contaminant biodegradation. Both of these treatment processes would be accomplished with a dual-purpose well design described in Section 11.

Continued remediation of groundwater is not required to protect human health under current and proposed future land use assumptions for Site ST14. However, bioventing/biosparging would more rapidly reduce contaminant mass in both soil and groundwater the site, reduce cumulative risk to onsite workers, and ensure attainment of at least Plan B target concentrations for all media before land transfers occur.

Bioventing would be used to remediate fuel-related contamination in unsaturated soils at Site ST14A. *In situ* pilot-scale bioventing tests were performed by ES at Site ST14A in 1993 and at adjoining Air Force Plant 4 in 1993 and 1994. The results of these tests are summarized in Section 9.1. As the pilot test results indicate, bioventing should effectively remove benzene from unsaturated soils at Site ST14A. Several 4-inch-diameter air injection wells were installed at Site ST14A during the 1993 bioventing pilot test and the risk-based field investigation in 1994. Air supply lines were installed and the system began operation in April 1996. Air flow to the wells has

been optimized to maximize subsurface biodegradation while minimizing contaminant volatilization. Figure 10.1 presents the locations of existing bioventing air injection wells that are being used for full-scale bioventing at Site ST14A. Details of this recent field activity have been presented separately to the TNRCC PST in a Field Activity Report (FAR) (Form TNRCC-0017).

Simultaneous bioventing of unsaturated soils and biosparging (oxygenation) of saturated soils and groundwater is being performed at each of the air injection vent wells (VWs) shown at Site ST14A on Figure 10.1. Air is being supplied to each VW through a 1-inch-diameter PVC air injection pipe placed inside a 4-inch-diameter well. When the groundwater level in the injection well is above the bottom of the air injection pipe, the air first bubbles through the water (increasing the DO concentration), then exits through the well screen into the unsaturated soils. When the water level in the VW is near or above the top of the screen, the air is vented from the injection well through a small-diameter stopcock. This venting allows air to continue bubbling through the water even though there is little or no flow through the well screen. The pressure in the injection wells forces air into the surrounding unsaturated soils as the water level drops or as a result of pressure-induced groundwater level depression. As the length of screen above the water level increases, air flow to the injection well and into the soil increases proportionately.

The Bioplume II model developed for Site ST14 (and Site SD13) was used to simulate the positive effects of bioventing/biosparging (details are presented in Appendix E). The anticipated impact of bioventing/biosparging for 2 years was incorporated into the Bioplume II model by reducing the estimated source area soil contaminant concentrations by about 100 mg of total BTEX per kg of soil each year. Soil concentrations would be reduced below Plan B target concentrations within 2 years (i.e., by the year 1998). This approach conservatively assumes that a degradation rate significantly less than was observed during pilot testing at Site ST14A can be maintained by only the *in situ* bioventing technology. The impacts of increasing DO in groundwater underlying Site ST14A were conservatively not considered in the model. Figure 10.2 presents the projected minimal impact of bioventing/biosparging at Site ST14A on dissolved benzene concentrations and the extent of migration at year 1998 and year 2001.

Incidentally, the Bioplume II model for this alternative predicts that the maximum dissolved concentration of benzene at Site ST14 would be 24 percent less than expected in 3 years if no source reduction activity is initiated (i.e., 85 mg/L compared to 101 mg/L). Hence, if source reduction is implemented, the dissolved contaminant plume originating from Site ST14A would stabilize and start to decrease in size after approximately 5 to 6 years. The elevated organic contamination measured in wells at Site SD13 would not be actively remediated under this alternative. However, the abandonment of the french underdrain and oil/water separator was still required to interrupt the potential exposure pathway to surface water.

Although no engineered remediation of residual contamination associated with Site SD13 media or remaining engineered SWMU components is proposed as part of this alternative, natural decontamination processes will continue to effect contaminant mass,

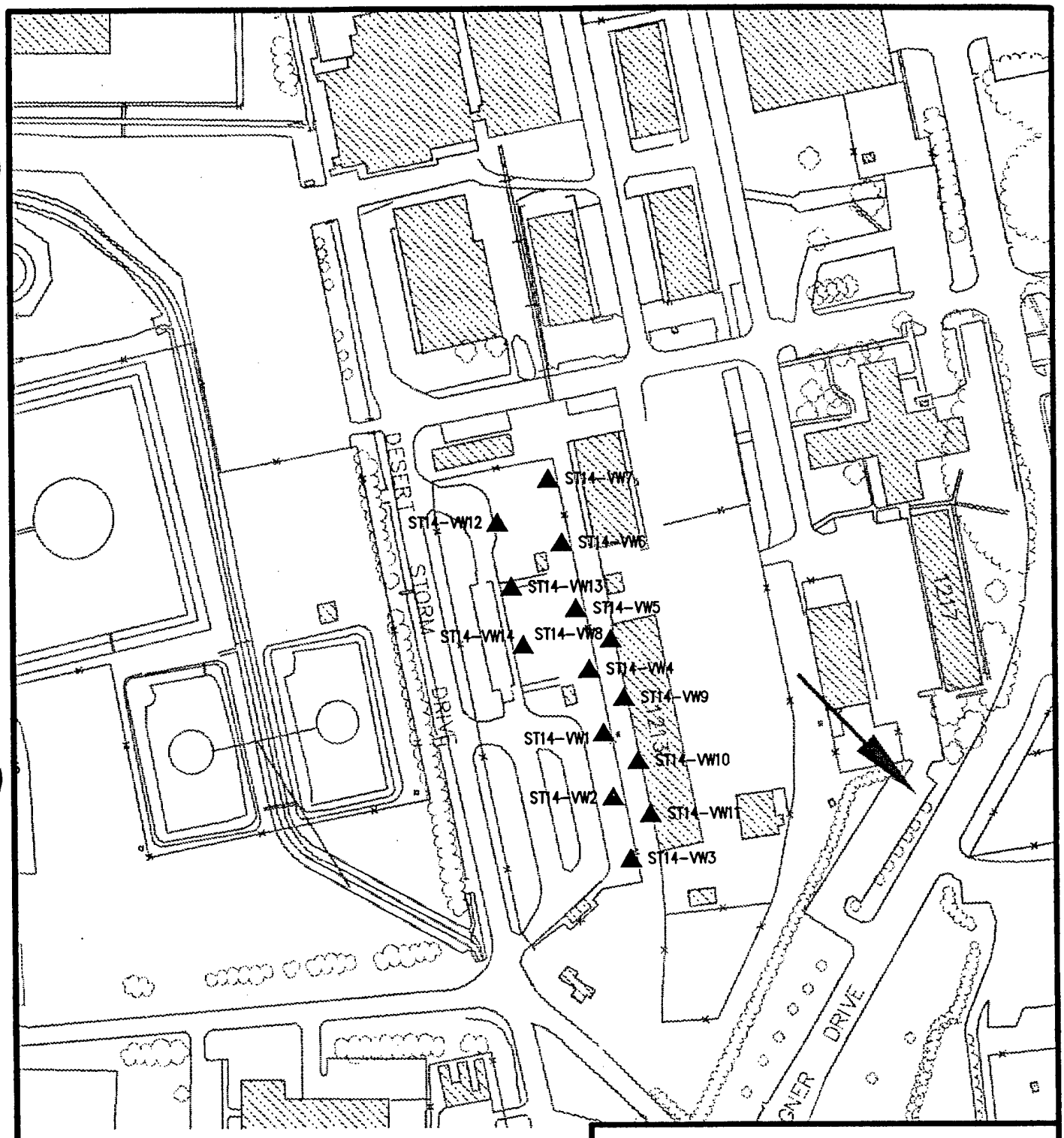


FIGURE 10.1

SITE ST14A BIOVENTING/BIOSPARGING WELL LOCATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

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mobility, and toxicity. As described in Section 6 of this RAP, natural chemical attenuation processes are ongoing at these sites, and should effectively reduce at least residual fuel hydrocarbon mass. The low concentrations of halogenated organic compounds measured at Site SD13 also may be susceptible to reductive dehalogenation, given the low reducing conditions that prevail in this area of the Base. Additional analytical data downgradient from monitoring well OT12-MW15C would be collected to investigate the potential for natural decontamination processes at minimizing contaminant migration toward the facility boundary. Also, as discussed in Section 6, the reduction in organic contaminant mass will eventually cause localized geochemical conditions to be restored to pre-release conditions. Consequently, inorganics mobilized by the low oxidation-reduction potential of the groundwater will re-adsorb to the solid soil matrix. Section 6 provides a more detailed evaluation of these expected chemical interactions.

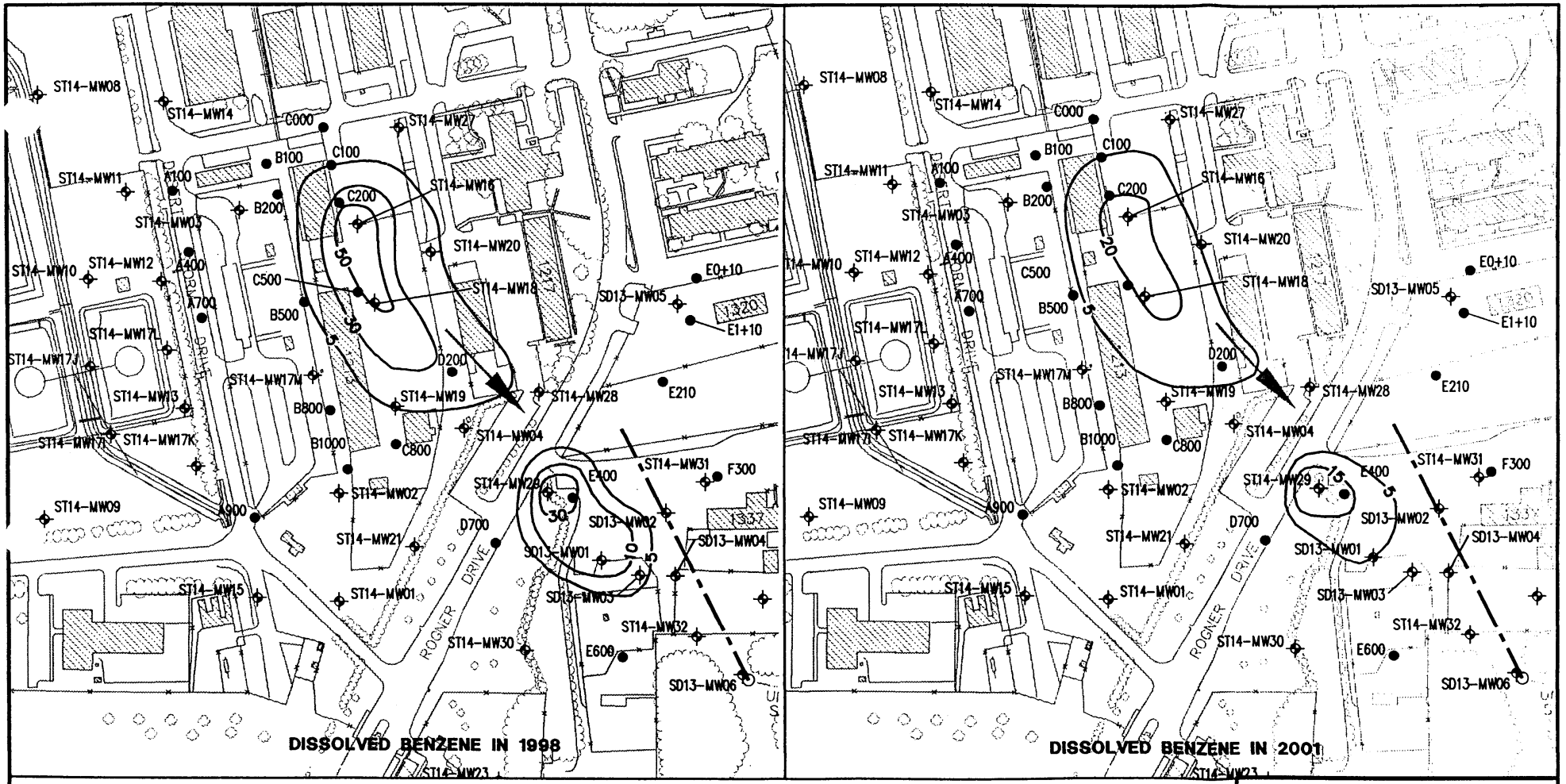
Finally, although no engineered soil or groundwater remediation is proposed as part of this alternative, low-cost free product recovery techniques would continue to be employed to remove all recoverable LNAPL observed in existing site wells. Passive skimmers (or socks) would be placed in all wells where LNAPL has been or is still measured. The effectiveness of these low-cost recovery units would be checked at least quarterly, during sampling activities, and replaced as necessary. Active free product recovery, in terms of forced extraction, is not proposed.

Land use and groundwater use controls for Alternative 2 would be identical to Alternative 1. Additional site access for site ST14A will be required to maintain the bioventing/biosparging system. Long-term groundwater monitoring also would be the same as Alternative 1. Additional long-term soil gas and respiration testing also would be required for the full-scale bioventing/biosparging system to document progress toward attainment of Plan B target levels for soil and to ensure optimal system performance. Soil samples would be collected at the conclusion of source reduction to confirm attainment of at least Plan B target concentrations.

10.1.3 Alternative 3 - Natural Chemical Attenuation, *In Situ* Bioventing/ Biosparging at Site ST14A, Continued Low-Cost Free Product Recovery, Groundwater Removal/Treatment and Soil Vapor Extraction at Site SD13, Long-Term Monitoring, and Land and Groundwater Use Controls

Goal of Alternative 3: Attainment of Plan B target concentrations at every point in Site ST14 in approximately 1 year. Additional remediation would be conducted at Site SD13, rather than relying only on exposure controls and natural decontamination processes to interrupt potential exposure pathways and/or achieve Risk Reduction Standard Number 2 levels.

The preceding two remedial alternatives were developed to show that natural chemical attenuation mechanisms, low-cost source reduction technologies, exposure controls, and rational risk management decisions would be sufficient to protect human health and the environment at Sites ST14 and SD13. To provide an additional measure of protection at Site SD13, it would be necessary to implement additional and/or different types of



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FIGURE 10.2

MODELED FUTURE GROUNDWATER BENZENE CONCENTRATIONS INFLUENCED BY BIOVENTING AND BIOSPARGING OPERATIONS

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

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remedial technologies than previously considered. If some level of engineered groundwater remediation is employed, no exposure controls will be required to protect downgradient surface water and hypothetical onsite human receptors.

This alternative combines active groundwater collection and treatment with the source reduction actions found in Alternative 2. Under this alternative, groundwater extraction wells would be installed at Site SD13, and groundwater would be extracted and then treated with an oil/water separator and a low-profile air stripper or sparging tank. After treatment, water would be discharged directly to the unnamed stream under the Base-wide NPDES permit. Air stripper effluent sampling would be performed to assure that treated water released from the site meets applicable federal and state regulations.

Long-term monitoring requirements would be essentially the same as described for Alternative 2 except for the additional monitoring and maintenance required by the groundwater treatment system. Land and groundwater use controls similar to those described under Alternative 1 are recommended until groundwater contaminants are reduced to concentrations below site-applicable target concentrations at all points in the impacted area. During groundwater extraction, long-term groundwater monitoring would continue. Additional monitoring of extracted and treated groundwater would be required to ensure contaminant removal prior to release to the unnamed stream.

It is anticipated that this alternative of groundwater extraction and source reduction could meet Risk Reduction Standard Number 2 levels for groundwater at Site SD13 in 1 year. It should be noted that this alternative would not reduce the amount of time required to attain Plan B target concentrations at ST14 because no additional actions (i.e., different than Alternative 2) are proposed for Site ST14. The only benefit of Alternative 3 over Alternative 2 is faster attainment of the site-applicable target concentrations at Site SD13, with the resulting shorter monitoring time.

10.2 REVIEW OF SCREENING AND EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives for soil and groundwater contamination at Sites ST14 and SD13 were adapted from those recommended by the EPA (1988) for selecting remedial actions for Superfund sites (OSWER Directive 9355.3-01). These criteria are consistent with those required for initial screening and detailed evaluation of remedial alternatives by the TNRCC PST (1994a) and Risk Reduction Standard Number 3 (30 TAC Chapter 335, Section 335.562). These criteria include (1) anticipated effectiveness in meeting target cleanup criteria, (2) technical and administrative implementability, and (3) relative cost. An initial screening of remedial technologies was conducted using the three broad evaluation criteria (Appendix G). The following sections briefly describe the scope and purpose of each criterion.

10.2.1 Effectiveness

Each remedial approach/technology or remedial alternative (which can be a combination of remedial approaches and technologies) was evaluated to determine how effectively it can attain the desired degree of cleanup. Remedial technologies and approaches that could not cost-effectively attain the desired level of remediation were eliminated from further consideration. The remedial actions proposed for these sites are designed to provide risk-reduction compatible with current and future proposed land uses at the sites. Sections 7 and 8 estimate the potential noncarcinogenic and carcinogenic risks to current receptors at Sites ST14 and SD13, respectively. Anticipated reductions in contaminant mass by natural processes and/or engineered activities will reduce potential risks until site-applicable target concentrations are achieved.

Remedial technologies retained for detailed evaluation are compared in terms of the expected effectiveness of each technology to attain the desired degree of risk reduction at the sites, based on site-specific data supplemented with actual treatability tests performed at the site. The ability to minimize potentially adverse impacts on surrounding facilities and operations and other environmental resources is considered. Time to implementation and time until protection is achieved are described. Potentially adverse impacts that could be realized during implementation and the cost of necessary mitigation measures also are qualitatively considered.

The potential risk, if any, that is expected to remain in the year 1998 after the implementation of each alternative is qualitatively described and compared. This year was chosen because this is when proposed changes in land use will be implemented. The residual risk of all three of the alternatives proposed in this RAP will be the same once remedial goals are met (i.e., all three alternatives will eventually meet the same target concentrations). Specifically, the Base land use at Site SD13 will change from industrial to open space/industrial. Contaminant concentrations remaining at Site SD13 in 1998 must not pose an unacceptable risk when the land conversion takes place. To adequately evaluate each remedial alternative in this RAP, the potential risks to human health risk from contamination expected to be present in 1998 will be evaluated.

10.2.2 Implementability

The technical feasibility, applicability, and reliability of each remedial technology were initially used as broad criteria to narrow the list of potentially applicable remedial approaches for the site. Technologies retained for detailed evaluation were evaluated in terms of engineering implementation, reliability, constructability, and technical feasibility. Potential effects due to unanticipated site conditions or significant changes in site conditions are considered. The ability to monitor performance and public perception are discussed. Any prohibition of onsite activities that would be required to ensure successful implementation is described.

10.2.3 Cost

Relative cost of various remedial technologies was used as an initial screening tool (Appendix G). More detailed cost estimates were prepared for each remedial alternative retained for comparative analysis. The cost includes operation and maintenance costs, over the time required for implementation. Present-worth cost estimates were prepared in accordance with OSWER Directive 9355.3-01 using a 7 percent annual adjustment (discount) factor (EPA, 1988).

10.3 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES

In this section, each of the candidate alternatives is evaluated using the more detailed criteria described in the previous section. Each alternative is more fully described in terms of its effectiveness, technical and administrative implementability, and cost.

10.3.1 Alternative 1 - Natural Chemical Attenuation of Site Media and Engineered Components, Long-Term Monitoring, and Land and Groundwater Use Controls

10.3.1.1 Effectiveness

Recent soil sampling performed at Sites ST14 and SD13 indicates that residual soil concentrations exceed levels that are protective of residents, and in some cases workers assuming direct contact with soils. Plan B target levels for groundwater were not exceeded at Site ST14. Plan B target concentrations for groundwater are appropriate for Site ST14 because the site will be maintained as an industrial area and no additional dissolved benzene is anticipated to migrate downgradient to Site SD13. However, residential Risk Reduction Standard Number 2 levels for groundwater, which are recommended as appropriate for Site SD13 because the site will no longer be maintained as an industrial area are exceeded for several compounds. Additionally, the site is believed to be the source of past dissolved benzene discharges to surface water. The assimilative capacity of the saturated media and the site-specific biodegradation rates (Section 6) will be sufficient to eventually transform fuel hydrocarbon compounds into carbon dioxide and water and to limit forward migration of the plumes. These same processes may eventually limit or eliminate the mass, concentration, mobility, and toxicity of other COPCs, but for other related reasons (see Section 6).

The relative reduction in carcinogenic and noncarcinogenic health risks to expected receptors in 1998, should any potential exposure pathways actually be completed at either Site ST14 and Site SD13, was estimated given the outcome of the chemical fate and transport models. The coupled SESOIL and Bioplume II models predict that the maximum concentrations of dissolved benzene in the year 1998 will be about 101 mg/L at Site ST14 and approximately 18 mg/L at Site SD13. The potential for dissolved benzene (and other COPC) concentrations above residential Risk Reduction Standard Number 2 levels to migrate from Site SD13 toward the facility boundary may still exist under this alternative.

To eliminate the potential expedited pathway to surface water, the french underdrain was partially abandoned. The oil/water separator also was completely removed. Measurable thicknesses of LNAPL may still persist in onsite wells, depending on the outcome of the six-month product recovery program.

Long-term groundwater monitoring is recommended under Alternative 1 as a method of measuring the effectiveness of natural chemical attenuation. The groundwater monitoring network would consist of 18 existing and 4 proposed groundwater monitoring wells. All long-term groundwater monitoring wells would be sampled quarterly for at least the COPCs and chemical indicators of natural decontamination processes. For cost estimation purposes, 10 years of groundwater sampling have been assumed necessary to document plume stability in the absence of engineered source reduction. This type of monitoring was deemed necessary since residual COPC concentrations are expected to persist above Risk Reduction Standard Number 2 levels at Site SD13 at least until the year 2007.

A complete long-term monitoring plan for the recommended remedy is provided in Section 12 to assist the Base in implementing long-term groundwater monitoring. Every year, groundwater data would be compared to model predictions to ensure that natural chemical attenuation processes are preventing the contaminant plumes from spreading further than predicted by the conservative models. In the event that natural biodegradation is not progressing as expected and/or the dissolved plume is migrating further or faster than expected, the following contingency actions could be implemented:

- Resample all downgradient sentry and POC wells to confirm initial results;
- Evaluate the results of the most recent groundwater sampling event to determine if there is a trend indicating more rapid contaminant migration due to a lack of natural chemical attenuation;
- Complete a risk evaluation to determine if the levels of groundwater contamination present a risk given actual site and downgradient land use at the time of sampling; and
- If a significant risk exists, reevaluate more active methods of remediation and implement the most effective risk-reduction method (e.g., the active remediation methods described for Alternatives 2 or 3).

Land and groundwater use controls are an important component of this alternative. The current restrictions to access (Base perimeter fencing and restricted-area status) provide an effective measure of protection against unauthorized site access and soil and groundwater contact at Site ST14. Site ST14 will remain a military fuels operation and access will continue to be strictly controlled by site perimeter fencing. Base perimeter fencing currently provides a limited access restriction at Site SD13. Upon land transfer, however, deed recordation and any other form of applicable exposure controls will be necessary to prevent exposure of onsite recreators/trespassers. The risk

estimate for this exposure scenario (see Section 8) indicates that no unacceptable risk due to exposure to existing maximum concentrations should occur.

The present and proposed land use and nonuse of groundwater have effectively eliminated potential current exposure pathways involving groundwater at both Site ST14 and Site SD13. However, exposure pathways involving soil are or may be complete. As part of this RAP, the Air Force proposes excavation and well permit restrictions to prevent direct contact with source soils and withdrawal of groundwater from the shallow aquifer within 1,000 feet of the leading edge of the current dissolved plumes until such time as the COPCs decrease below at least site-applicable target concentrations. Groundwater use restrictions should be a component of any future land use change or property exchange (i.e., restrictions on use as potable source). This includes the planned change in land use of Site SD13 from industrial to recreational/open space. This strategy will not interfere with the current and intended use of Site ST14 as a fueling facility. In the unlikely event that Site ST14 is released from government ownership and rezoned for unrestricted residential use within the next 10 years, groundwater use restrictions must be kept in place and enforced until such time as COPCs have been reduced to concentrations equal to or below the most stringent Plan A target concentrations at every point.

10.3.1.2 Technical and Administrative Implementability

Alternative 1 is technically simple and easy to implement. Two additional groundwater monitoring wells would be required to monitor the source area and area downgradient from the current plumes. These wells would be typical groundwater monitoring wells constructed using a typical hollow-stem auger drill rig. Several existing wells also are far enough downgradient to serve as sentry and POC wells. Long-term groundwater sampling is a standard procedure involving minimal worker exposure to contaminated media. Equipment reliability and maintainability are not issues under Alternative 1 because no remediation equipment will be used at the site. The reliability of natural chemical attenuation and processes to reduce contaminant concentrations in soils and limit plume migration would be reevaluated each year after the long-term monitoring event.

Administrative implementation of this alternative would require the Base realignment group responsible for the reallocation of government real estate at Carswell to communicate any plans regarding future use of the Base and Sites ST14 and SD13 to the public and the TNRCC. Any change in activities or land use that differs from the proposed uses or any proposed groundwater pumping within 1,000 feet of the leading edge of the current plumes should be carefully evaluated. The existing controlled-access status of Site ST14 also should be maintained to prevent unauthorized access. Activities conducted at Site SD13 after it is converted to an open space/recreational area will likely be limited to nonintrusive activities. Although site access will not be strictly controlled, exposure to subsurface soils and groundwater is unlikely. Any future construction or maintenance activities in these areas should be planned to protect the network of long-term monitoring wells. Wells should remain locked and protected against tampering or vandalism.

Public perception of Alternative 1 could be somewhat negative. Although this alternative would be protective of human health, contaminants that exceed Plan B and Risk Reduction Standard Number 2 target concentrations would remain onsite for a lengthy period of time. Additionally, no form of free product recovery would continue, which is not in keeping with the requirements of 30 TAC Chapter 335, Subchapter S. To counteract potentially negative public opinion, public education on the findings of the risk assessment would be a prominent part of this alternative. Discussions would need to focus on the site-specific risk assessment and cost savings. COPC reductions that are compatible with existing and future land use with appropriate exposure controls would be achieved at minimum taxpayer expense. Consistent long-term monitoring would provide verification of the effectiveness of natural chemical attenuation processes to minimize COPC concentrations and stabilize dissolved plumes and ensure that site conditions (i.e., exposure potential) do not change unexpectedly over time.

10.3.1.3 Cost

The costs associated with Alternative 1 are presented in Table 10.1. Detailed cost calculations are presented in Appendix G. There would be no remediation equipment operated or maintained under this alternative. Annual costs would include quarterly groundwater monitoring and site management (to be provided by the Carswell realignment committee), which would include evaluation of quarterly monitoring data, continued liaison with the TNRCC and the public, and participation in future land use planning. Based on the assumption that 10 years of long-term monitoring would be required to document attainment of site-applicable levels and contaminant stability, the present-worth cost of Alternative 1 is estimated to be $812,775.

10.3.2 Alternative 2 - Natural Chemical Attenuation, Continued Low-Cost Free Product Recovery, *In Situ* Bioventing/Biosparging at Site ST14A, Long-Term Monitoring, and Land and Groundwater Use Controls

10.3.2.1 Effectiveness

The effectiveness of Alternative 2 in minimizing plume migration and reducing contaminant concentrations at Sites ST14 and SD13 would rely primarily on the mass removal effects of natural biodegradation processes and engineered source-reduction actions. Bioventing/biosparging would be performed at Site ST14A to promote *in situ* biodegradation in soils and groundwater and to reduce the amount of time residual COPCs are present in source area soils above Plan B levels. The major benefit derived from implementing source-reduction activities at Site ST14A would be attainment of Plan B target concentrations by the year 1998, when land transfers are planned. Reduction of volatile organics in source area soils would also reduce any potential risks due to dermal contact during deep soil excavation or even nonintrusive activities.

TABLE 10.1
COST ESTIMATE FOR ALTERNATIVE 1
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Tasks	Capital Costs
Drilling and Installation of Four Groundwater Monitoring Wells	$36,356
Abandonment of French Underdrain and Oil/Water Separator [a/]	$50,000
Source Area Soil Sampling (in 1998)	$33,200
Site Management and Monitoring Tasks	**Annual Costs**
Conduct Quarterly Groundwater Sampling at 22 Groundwater Monitoring Wells in Accordance with the Long-Term Monitoring Plan (10 years)	$87,610
Site Management/Maintain Institutional Controls (10 years)	$11,280
Present Worth of Alternative 1[b/]	$812.775

[a/] Already completed by Parsons ES in 1996.

[b/] Based on an annual discount/adjustment factor of 7 percent, calculated in accordance with recent EPA guidance.

Benzene in soils at Site ST14 should be eliminated by 2 years of bioventing/biosparging. The Bioplume II model also predicts that the residual concentration of benzene in groundwater underlying Site ST14 will be about 60 mg/L. The cumulative potential carcinogenic risk to hypothetical intrusive workers at Site ST14 would be reduced below the target risk level of 1×10^{-6}. Bioventing/biosparging would be employed at Site ST14A under this alternative to remediate unsaturated contaminated soils and increase DO concentrations in saturated soils and groundwater. Based on the results of the pilot-scale bioventing tests performed at Site ST14A and Air Force Plant 4, bioventing will efficiently and cost-effectively remediate fuel-related contamination in unsaturated soils. An average BTEX removal efficiency of more than 98 percent was documented at Air Force Plant 4 based on initial and 12-month soil sampling. Slower removal rates would be expected for heavier hydrocarbons.

Groundwater oxygenation also would be performed at Site ST14A in concert with bioventing to increase DO concentrations in groundwater. DO is one of the primary

electron acceptors used by microorganisms to biodegrade hydrocarbon compounds. Increasing DO concentrations in groundwater at Site ST14A will increase the assimilative capacity of the groundwater and increase biodegradation rates. Oxygenation will be accomplished by injecting air below the groundwater surface via 1-inch-diameter injection pipes placed inside existing 4-inch diameter bioventing vent wells. Air will bubble through groundwater to oxygenate it and then flow into unsaturated soils through the well screen placed above the groundwater surface.

Continued use of low-cost free product recovery materials at wells at Site ST14 and Site SD13 is a component of this alternative. These passive skimming products will be placed in all wells characterized by measurable LNAPL thicknesses. The mass of free product recovered between each monitoring event will be documented; the Air Force will conduct a bail-down test to verify if collected data indicate that a more active form of product recovery is technically feasible. No engineered remediation of residual contamination in site media or remaining SWMU components at Site SD13 is proposed. Decontamination will be brought about by natural attenuation processes only. Concentrations of site-related COPCs may persist in site media above Risk Reduction Standard Number 2 levels until the year 2007. However, natural processes and the partial removal of the french underdrain system/complete abandonment of the oil/water separator are believed to be sufficient to minimize discharges to surface water and/or migration of contaminants off-site.

The groundwater use controls for this alternative would be identical to those described for Alternative 1. The installation and operation of the bioventing/biosparging system would require additional site access. The long-term groundwater monitoring proposed for Alternative 2 would be similar to Alternative 1, except that the bioventing/biosparging system would require at least monthly system maintenance checks and annual respiration testing to estimate rates of biodegradation. Compliance with Plan A target concentrations at Site ST14 is expected within 5 years, while attainment of Risk Reduction Standard Number 2 levels at Site SD13 is expected within 10 years. Compliance soil sampling also would be performed at the end of 2 years to ensure that the bioventing/biosparging system adequately reduced soil contaminant concentrations to at least Plan B levels.

10.3.2.2 Technical and Administrative Implementability

Alternative 2 would require installation of four groundwater monitoring wells as described for Alternative 1. Air lines were installed in April 1996 to supply atmospheric oxygen to 14 existing bioventing/biosparging VWs at Site ST14A. Two air injection blowers have also been installed at Site ST14A to supply air to the wells.

The general reliability and maintainability of bioventing/biosparging systems are good. These are simple mechanical systems; motors are sealed and do not require lubrication. Air filters provide protection for the air pumps. Filters generally require replacement every 90 to 180 days. Weekly system checks are recommended, and operating data such as injection pressure, temperature, and flow rates would be manually recorded. It is estimated that the bioventing/biosparging system would be operational for 2 years to remediate the source area at Site ST14A to the maximum

extent possible. Compliance soil sampling would be performed at Site ST14A at the end of the 2-year period to confirm that soil contaminants have been reduced to acceptable levels.

As described for Alternative 1, additional drilling would be required for four new groundwater monitoring wells. These new wells and the existing groundwater monitoring well network would be used to verify plume stability. Installation of these wells would involve typical hollow-stem auger drilling and traditional groundwater monitoring well installation techniques.

Administrative implementation of this alternative would be similar to that described for Alternative 1, and would require that Base realignment group personnel communicate with the public and the TNRCC regarding the future use of the sites (i.e., continued industrial use or a switch to open space/recreational use). Appropriate land use restrictions must be upheld to prevent unnecessary exposure of humans to contaminated subsurface soils and groundwater. Access to Site ST14 should continue to be restricted by the perimeter fence and strict access controls. Any future site development plans should protect the bioventing/biosparging system, the underground piping associated with the system, and the network of long-term monitoring wells. Wells should remain locked and protected against damage.

The public perception of Alternative 2 would be expected to be positive. This alternative would be protective of human health and the environment, and could achieve COPC reductions to the site-applicable target levels at a relatively low expense. Bioventing/biosparging would be expected to more rapidly reduce COPC concentrations in the source area at Site ST14A and would influence how quickly dissolved contamination downgradient from the source area is eliminated. The primary advantages of Alternative 2 are that it would (1) speed the reduction of cumulative risk to onsite worker; (2) result in attainment of Plan B levels at Site ST14; and (3) provide an extra measure of protection for onsite nonintrusive workers in a short timeframe. Additionally, this alternative provides a mechanism for removing recoverable free product at Sites ST14 and SD13. Attainment of Risk Reduction Standard Number 2 levels at Site SD13 would not be expedited by implementation of this alternative. Long-term monitoring would provide verification that the implemented remedy is effective and that site conditions do not change over time.

10.3.2.3 Cost

The costs associated with Alternative 2 are presented in Table 10.2. Detailed cost calculations are presented in Appendix I. Capital costs include the cost of drilling and installation of additional wells and acquisition/installation of bioventing injection blowers and associated piping, abandonment of the french underdrain, and confirmation soil sampling after 2 years of bioventing/biosparging. For cost estimating purposes, 2 years of bioventing/biosparging operation and monitoring have been included as a annual cost. Annual costs also would include groundwater monitoring by contractors and site management (provided by Carswell personnel), which would include public education, continued liaison with the TNRCC, and participation in future land use planning. Sampling and well maintenance costs associated with quarterly monitoring

TABLE 10.2
COST ESTIMATE FOR ALTERNATIVE 2
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Tasks	Capital Costs
Drilling and Installation of Four Groundwater Monitoring Wells	$36,356
Installation of Bioventing/Biosparging System at ST14A[a/]	$61,957
Abandonment of oil/water separator and of French Underdrain[a/]	$50,000
Confirmation Soil Sampling (after 2 years)	$33,200
Site Management and Monitoring Costs	**Annual Costs**
Conduct Quarterly Groundwater Sampling at 13 Groundwater Monitoring Wells at Site ST14 in Accordance with the Long-Term Monitoring Plan (5 years)	$51,770
Conduct Quarterly Sampling at 9 Groundwater Monitoring Wells at Site SD13 in Accordance with the Long-Term Groundwater Monitoring Plan (10 years)	$35,840
Site Management/Maintain Institutional Controls (10 years)	$11,280
Present Worth of Alternative 2 [b/]	$278,900

a / Already completed by Parsons ES in 1996.

b/ Based on an annual discount/adjustment factor of 7 percent, calculated in accordance with recent EPA guidance.

until compliance with the appropriate target concentrations has been achieved are included in the cost estimate. Using these assumptions, the present-worth cost of Alternative 2 is $724,600.

10.3.3 Alternative 3 - Natural Chemical Attenuation, *In Situ* Bioventing/ Biosparging at Site ST14A, Continued Low-Cost Free Product Recovery, Groundwater Removal/Treatment and Soil Vapor Extraction at Site SD13, Long-Term Monitoring, and Land and Groundwater Use Controls

10.3.3.1 Effectiveness

The effectiveness of Alternative 3 in reducing site contaminants to levels below appropriate target concentrations would depend upon a combination of source-reduction activities, bioventing/biosparging, free product recovery, groundwater and vapor extraction and treatment, and long-term natural chemical attenuation. A bioventing/biosparging system would be installed for source removal at Site ST14A, as described for Alternative 2. Under Alternative 3, however, bioventing wells would also be installed at Site SD13 and reconfigured for groundwater extraction and SVE. This system would employ a liquid-ring vacuum pump to remove both liquid and vapor from the bioventing wells. Vapor removal would cause oxygenated soil gas to migrate toward the extraction well, promoting biodegradation (bioventing). Limited groundwater (at approximately 20 gallons per minute) would be extracted and treated with an aboveground air stripping system. Such a system would reduce the period of time required for Site SD13 to achieve Risk Reduction Standard Number 2 levels for unrestricted use. The residual risk estimates for this alternative are identical to Alternative 2, as the same amounts of contaminant mass reduction are expected.

Two additional 4-inch-diameter pumping wells would be installed at Site SD13 for the active extraction of groundwater and vapor at the site. Groundwater extracted from Site SD13 will be treated using the existing oil/water separator and a low-profile air stripper or sparging tank. It is anticipated that the system would have to operate for only 1 year to remediate the limited contamination remaining at Site SD13. Because groundwater is actively extracted and removed as part of this alternative, it is anticipated that Alternative 3 would be the most effective in remediating contamination in the short-term. This gain is, however, offset by a large increase in cost.

The primary drawback to the effectiveness of this alternative would be the expected lead time and administrative effort required to design, permit, and construct the additional groundwater extraction/air stripper treatment system. The installation and operation of a groundwater extraction and treatment system also would require additional site access. The groundwater/vapor extraction system would require biweekly system checks, and, at a minimum, monthly monitoring of groundwater influent and treated effluent. Bioventing/biosparging monitoring would be limited to weekly system checks and annual respiration testing to determine the effectiveness *in situ* biodegradation in the contaminated soil. Finally, compliance soil sampling would be required at both sites to verify that soils have been remediated to acceptable levels.

The groundwater use controls for this alternative would be identical to those described for Alternative 1 until Site SD13 was remediated to residential Risk Reduction Standard Number 2 levels. The installation and operation of the bioventing and groundwater extraction and treatment systems would require additional site access. The long-term groundwater monitoring proposed for Alternative 3 would be similar to

that described for Alternative 2, except that the groundwater extraction and treatment system would require additional monitoring, maintenance, and sampling.

10.3.3.2 Technical and Administrative Implementability

Alternative 3 would require additional below-grade piping for the groundwater/vapor extraction and treatment system. Cutting and trenching of asphalt will be necessary for the installation of vacuum lines at Site SD13. The groundwater treatment system, including five dewatering wells, a liquid-ring pump, an oil/water separator, and air stripper, would be composed of common remedial equipment that could easily be installed at Site SD13. Electrical power for the pumps and stripper is available at Building 1337. Transmission would involve the installation of several power poles or an underground cable. For this engineering estimate, it was assumed that this treatment system would be installed inside a prefabricated building, which would be heated during winter operations.

Liquid ring-vacuum pumps and air stripping systems generally are highly reliable when they are properly maintained. Weekly monitoring of the system would be required to assure proper operation. The most significant maintenance requirement for this system would be regular monitoring of the stripper effluent to ensure that air emission standards are attained. The analytical requirements and documentation associated with meeting surface water discharge specifications could add appreciably to the monthly operation and maintenance costs.

A bioventing/biosparging system that has been installed at Site ST14A would be operated for 2 years, as described for Alternative 2. Periodic maintenance would be required for the system, as described in Alternative 2.

The same groundwater monitoring well network described in Alternatives 1 and 2 would be necessary to monitor the natural attenuation feature of Alternative 3. POC wells would be installed near Farmers Branch to ensure that the groundwater pump-and-treat system is effectively capturing all contaminated groundwater flowing through Site SD13. The annual sampling requirements would also be the same under this remedial alternative.

Administrative implementation of this alternative would require that the Carswell realignment committee continue to communicate with the TNRCC and the public regarding the future use of Sites ST14 and SD13. The perimeter fence and controlled site status should be maintained at Site ST14 to prevent unauthorized entrance. Any future land use plans should protect the groundwater/vapor extraction and treatment system, bioventing system, and network of long-term monitoring wells. Wells should remain locked and protected against tampering.

Public perception of Alternative 3 would be expected to be positive. However, most experienced remediation professionals would view this level of treatment as excessive, given that the risks of offsite contaminant migration and receptor exposure are very low (see Sections 7 and 8). This alternative would be protective of human health and the environment, and would achieve COPC reductions that are compatible with current and

foreseeable industrial land use at Site ST14 and the proposed future recreational/open space use at Site SD13. However, the benefits of more rapid chemical mass removal may not be justified, given the additional cost.

10.3.3.3 Cost

The costs associated with Alternative 3 are presented in Table 10.3. Detailed cost calculations are included in Appendix G. Capital costs include the cost of design and construction of the groundwater extraction and treatment system and the bioventing/biosparging system at Site ST14A. The 1-year cost of operation and monitoring of the Site SD13 groundwater extraction and SVE systems is included in the capital costs. Annual costs include 2 years of bioventing/biosparging operation and monitoring at Site ST14A and 5 years of groundwater monitoring and site management to demonstrate plume stability. Based on these assumptions, the present worth cost of Alternative 3 is $840,180. Alternative 3 costs are most sensitive to additional years of bioventing/biosparging and groundwater/vapor extraction system operation and maintenance.

10.4 RECOMMENDED ALTERNATIVE

Alternative 2 (Natural Chemical Attenuation, French Drain Continued Low-Cost Free Product Recovery, *In Situ* Bioventing/Biosparging at Site ST14A, Long-Term Monitoring, and Land and Groundwater Use Controls) is recommended for remediation of Sites ST14 and SD13 based on its expected effectiveness in reducing cumulative risk to onsite workers and attaining target concentrations, its relative simplicity with respect to technical and administrative implementation, and its relatively low overall cost. Table 10.4 provides a summary of the evaluation process for each alternative.

The conservative Bioplume II model suggests that the addition of bioventing/biosparging at Site ST14A would speed attainment of Plan B levels and reduce the total mass of contaminants that could be introduced into and remain in the groundwater over time at the sites. As discussed in Section 9, there is considerable evidence that bioventing will effectively reduce fuel-related contamination in unsaturated soils in the vicinity of the source area at Sites ST14A. Accordingly, bioventing/biosparging will be implemented in 14 existing air injection VWs at Site ST14A to remediate contaminated soils and groundwater to the maximum extent possible.

Significant evidence exists that natural physical, chemical, and biological conditions at Sites ST14 and SD13 will limit the migration of the dissolved contaminants. Currently, the dissolved benzene plume originating at Site ST14A extends approximately 700 feet downgradient from the source area at Site ST14. Based on the conservative Bioplume II model, no appreciable forward migration is expected before it begins to recede. Groundwater contaminant concentrations at Site ST14 do not exceed Plan B target concentrations. As a result, Site ST14 is currently eligible for Plan B closure. However, quarterly groundwater sampling is recommended for 2 years during bioventing/biosparging to determine the effect of this engineered remedial technique on groundwater contaminant concentrations. Verification monitoring is also recommended

TABLE 10.3
COST ESTIMATE FOR ALTERNATIVE 3
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Tasks	Capital Cost
Drilling and Installation of Four Groundwater Monitoring Wells	$36,356
Design and Construction of a Groundwater Extraction/Treatment System at SD13	$140,225
Design and Installation of ST14 Bioventing/ Biosparging System[a/]	$61,957
Abandon Oil/Separator and French Drain[a/]	$50,000
Confirmation Soil Sampling (after 2 years)	$33,200
Site Management and Monitoring Costs	**Annual Costs**
Conduct Quarterly Groundwater Sampling at 22 Groundwater Monitoring Wells in Accordance with the Long-Term Monitoring Plan (5 years)	$87,610
Operation of Extraction/Treatment System at Site SD13	$112,000
Site Management/Maintain Institutional Controls (5 years)	$11,280
Present Worth of Alternative 3 [b/]	$840,180

[a/] Already completed by Parsons ES in 1996.
[b/] Based on an annual discount/adjustment factor of 7 percent, calculated in accordance with recent EPA guidance.

for 2 years after attainment of Plan B soil target levels. A total of 5 years (1996 - 2000) of annual groundwater sampling is recommended for Site ST14.

TABLE 10.4
SUMMARY OF REMEDIAL ALTERNATIVE EVALUATION
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Remedial Alternative	Effectiveness	Implementability	Present Worth Cost Estimate
Alternative 1[a/]			$812,775
-Natural Chemical Attenuation -Long-Term Monitoring -Land and Groundwater Use Controls	Contaminant mass, volume, and toxicity will gradually be reduced by intrinsic remediation alone. Plan B target levels attained at Site ST14by year 2005; Risk Reduction Standard Number 2 level attained at Site SD13 by 2007.	Technically simple and easy to implement. Long-term groundwater monitoring for about 10 years is required. Groundwater use restrictions need to be implemented. Requires public education.	
Alternative 2[a/]			$724,600
-Natural Chemical Attenuation -*In Situ* Bioventing/Biosparging at Site ST14A -Continued Low-Cost Free Product Recovery -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 1, with the addition of bioventing for 2 years to increase source soils contaminant removal and degradation. Pilot testing indicates bioventing will significantly remove benzene from unsaturated soils. Plan B target levels attained at Site ST14 in approximately 2 years.	Long-term groundwater monitoring for 5 years at Site ST14 and 10 years at Site SD13 is expected. The bioventing system is expected to operate for 2 years. This system will require weekly monitoring. Groundwater and land use restrictions would be the same as Alternative 1. Positive public perception. Requires public education.	
Alternative 3			$840,180
-Natural Chemical Attenuation -*In Situ* Bioventing at Site ST14A -Groundwater Removal/Treatment and SVE at Site SD13. -Continued Low-Cost Free Product Recovery -Long-Term Monitoring -Land and Groundwater Use Controls	Similar to Alternative 2, with additional groundwater removal and treatment. Expedites attainment of Risk Reduction Standard Number 2 levels at site SD13. Plan B target levels attained at Site ST14 in approximately 2 years.	Long-term groundwater monitoring for 5 years is expected. Operation of the treatment system will require weekly monitoring. Lengthy lead time required for design and installation of extraction/treatment system. Positive public perception.	

a/ Partial removal and complete abandonment of the french underdrain system and oil/water separator, respectively, are common elements of each alternative. These were completed in 1996.

Given the current and projected industrial land use at Site ST14 and in surrounding areas, no active remediation is required at this site to protect human health; bioventing and biosparging are proposed only to reduce cumulative risk, attain Plan B levels, and reduce contaminant loading to groundwater. Conservative Bioplume II modeling predicted limited plume migration, with virtually no chance of off-site migration. Long-term groundwater monitoring will be used to verify the effectiveness of natural chemical attenuation and to assure that COPCs do not migrate beyond the area under reliable exposure controls. Limitations on groundwater pumping at this site should not affect future land use or operations. Abandonment of the french underdrain and oil/water separator appears to have eliminated a potential pathway to surface water.

Alternative 2 relies on natural decontamination processes to address residual contamination associated with subsurface media and remaining engineered SWMU components. The quantitative site-specific risk assessment prepared for Site SD13 (Section 8) indicates that existing concentrations of measured contaminants will not pose an unacceptable risk to both current and potential future receptors, assuming the land is made available for open space/recreational uses. However, deed recordation as well as post-closure care monitoring will be a required element of the alternative to be implemented at Site SD13. The Air Force is currently considering the language to include in the deed recordation to accompany any change in land use at Site SD13. Free product recovery activities will continue at this site, to ensure that no residual free product is available to discharge to and impact surface water quality in the vicinity of these sites.

Although Alternative 3 could speed attainment of Risk Reduction Standard Number 2 levels at Site SD13, the cost of constructing and maintaining a groundwater/vapor extraction system and aboveground treatment system at this site is not justified given that no current risk exists, no future risk is expected if sufficient groundwater use controls are implemented, and the potential for substantial surface water impacts is low.

On the basis of this evaluation, Alternative 2 provides the best combination of risk reduction and low cost without imposing additional land use restrictions. Section 11 provides additional details on the recommended implementation of this alternative.

SECTION 11

IMPLEMENTATION OF RECOMMENDED REMEDIAL ACTION

This section provides an implementation plan for the recommended remedial action (Alternative 2: natural chemical attenuation of residual contamination and engineered components, *in situ* bioventing/biosparging at Site ST14A, monitoring of groundwater to verify plume stability, and land and groundwater use controls) for Sites ST14 and SD13. This section reviews the scope and schedule of remediation activities; discusses possible contingencies if this remedial approach does not achieve target concentrations, prevent downgradient migration into areas under different exposure controls, or eliminate discharges to surface water; and summarizes costs by fiscal year.

11.1 SCOPE OF REMEDIAL ACTIVITIES

The recommended remedial action alternative will be implemented over a 5-year period to ensure that Sites ST14A and SD13 will attain and maintain the site-applicable target concentrations. The following sequence of events is proposed to fully implement this remedial action.

11.1.1 Review and Approval of Remedial Action Plan

Approval of this draft final second version RAP is within the authority of Carswell AFB/NAS Fort Worth JRB personnel, the TNRCC, and the AFCEE. This group of environmental professionals is responsible for review of this draft final RAP and eventual implementation of the approved remedial actions. Copies of this document will be distributed to each of the above organizations for review and comment. Approximately 30 days has been designated in the implementation schedule for document review and approval.

Following the 30-day review period, a teleconference can be conducted to describe the changes to the RAP as a result of TNRCC and Base comments on an earlier version, to answer any questions, and to receive feedback and discuss any unresolved issues that may surface during document review. This direct interface between the document preparers and the group charged with RAP implementation is essential for RAP approval and a smooth transition into remedial actions.

11.1.2 Optimization of the Full-Scale Bioventing/Biosparging System at Site ST14A

Fourteen existing bioventing/biosparging wells at Site ST14A were plumbed and connected to two Gast® R6 regenerative blowers located in sheds adjacent to Buildings

1213 and 1189 in March and April 1996. Seven wells were supplied by each air supply blower. Well locations, blower locations, and air supply line locations are shown on Figure 11.1. Wells were placed to allow for maximum oxygenation of the subsurface based on pilot test results and an effective radius of influence of 40 feet (Section 9). The 4-inch diameter vent wells are screened across the interval of unsaturated soil contamination and into groundwater in the source area at Site ST14A, generally from 5 to 15 feet bgs. Air is being injected into the wells through 1-inch injection tubes placed inside the 4-inch diameter wells. The injection tubes were placed so that air is first bubbled through groundwater before flowing into unsaturated soils. The bottom of the 1-inch injection tubes were placed near the bottom of the 4-inch wells to oxygenate the maximum amount of groundwater. Figure 11.2 shows a typical biosparging/bioventing well as constructed at Site ST14A.

Air is being supplied to each well by individual lengths of 1-inch-diameter high-density polyethylene (HDPE) tubing. The tubing was bedded in sand in a 18-inch-deep trench and covered with native soil. Shallow burial should avoid other buried utilities on the sites. All trenching at Site ST14A was through topsoil. No cutting or trenching of asphalt or concrete was required. Excavated soils were placed back in the trenches as backfill. Individual air supply lines run to control panels located at the blower that allow the control of air flow into each well. During April and May 1996, air injection rates and injection pressures will be optimized for each individual well to maximize biodegradation potential while minimizing contaminant volatilization.

After system startup and optimization, periodic monitoring of the system has been and will continue to be performed. The system will be monitored every week to assure proper operation. Blower temperatures, injection pressures, and flow rates will be recorded, and the inlet air filter will be changed as necessary. Additionally, DO concentrations in adjacent groundwater monitoring wells will be monitored every 6 months. Every 6 months during system operation, *in situ* respiration testing will be performed to assess soil contaminant biodegradation rates at Site ST14A. Results of testing activities will be provided to Carswell, TNRCC, and AFCEE to update all parties involved on remediation progress (e.g., November 1996 Field Activity Report).

At the conclusion of approximately 2 years of operation, compliance soil samples will be collected at Site ST14 to determine the degree of contaminant reduction. If contaminant levels have been reduced to acceptable levels (i.e., below the most stringent Plan B target concentrations), the bioventing/biosparging system will be deactivated. Based on results from the pilot tests performed at Site ST14A and Air Force Plant 4 (Section 9.1), 2 years should be adequate to reduce COPC concentrations in contaminated soils at Site ST14A to at least Plan B levels. Additional details on system operation and maintenance, compliance sampling, and abandonment procedures can be found in Section 12, the long-term monitoring plan for Sites ST14 and SD13, and Appendix J, the SAP.

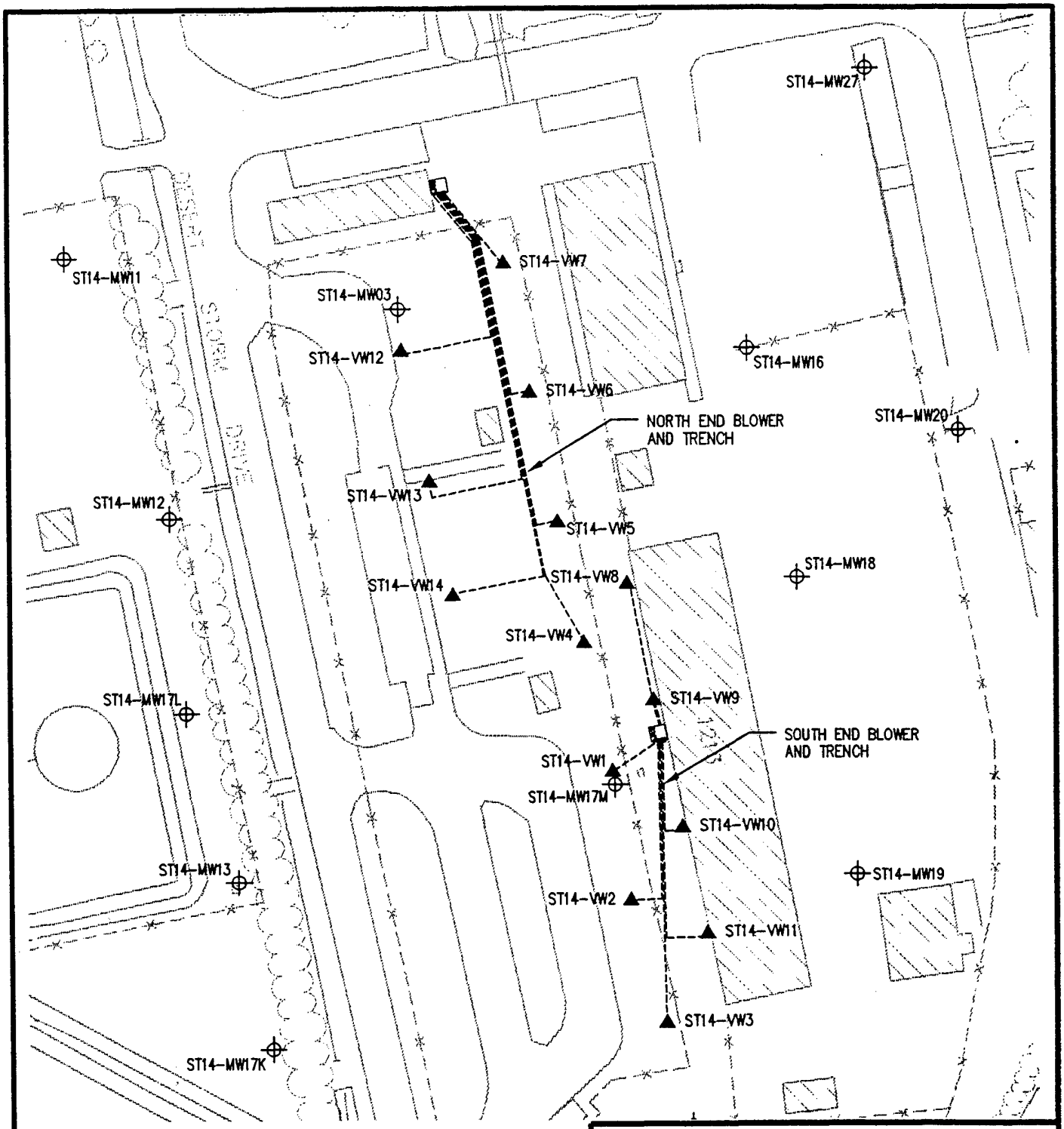
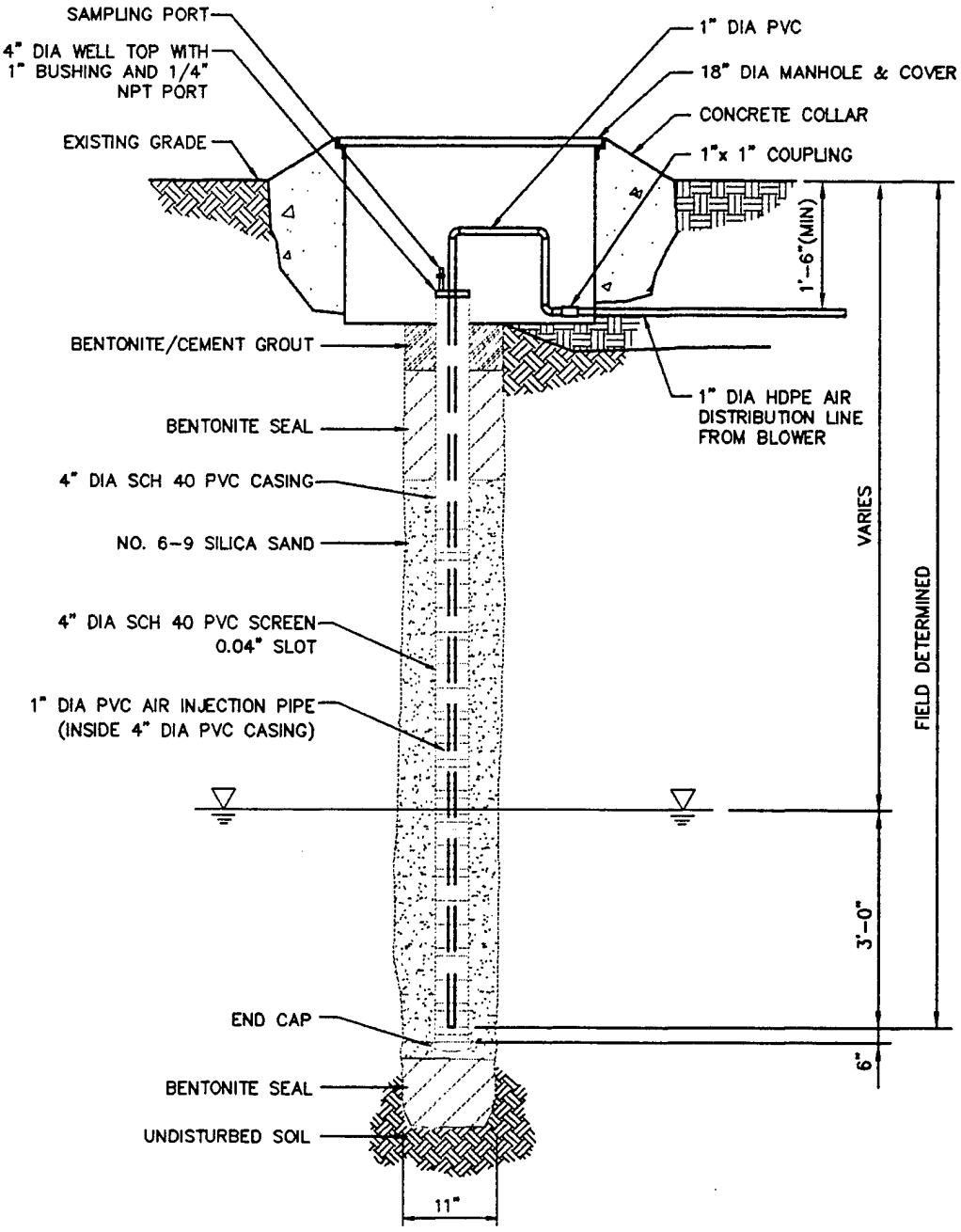


FIGURE 11.1

LAYOUT OF BIOVENTING/BIOSPARGING SYSTEM AT SITE ST14A

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado



NOT TO SCALE

FIGURE 11.2

BIOVENTING/ BIOSPARGING WELL CONSTRUCTION DETAIL

Site ST14
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

11.1.3 Implementation of Long-Term Groundwater Monitoring

Section 12 of this RAP provides a complete long-term monitoring plan (LTMP) for Sites ST14 and SD13. Long-term groundwater monitoring is being proposed to verify that soil remediation and natural chemical attenuation processes are sufficient to prevent groundwater concentrations from exceeding target concentrations and retard the migration of COPCs at the sites. Prior to implementation of long-term monitoring, four additional groundwater monitoring wells will be installed at the sites. One of the wells will be installed within the existing benzene plume at Site ST14A to monitor the continued biodegradation of benzene. Two of the other wells will be located south of the now-removed oil/water separator and west of SD13-MW02, respectively, to serve as additional POC wells. The final well to be installed is proposed to be downgradient of OT12-MW15C. Additional details on proposed well locations and the long-term monitoring well network are presented in Section 12. No other additional wells will be required at either of the two sites to facilitate the monitoring of plume stability at the sites.

Careful implementation of the LTMP is a key component of this RAP. The proposed remedial alternative for these sites calls for quarterly sampling until the appropriate target concentrations are attained. Additionally, 2 years of verification sampling will be performed after the sites attain the appropriate target concentrations to ensure plume stability and ongoing compliance. Wells will be purged in accordance with the GSAP, and then sampled for several specific chemicals and indicator compounds. Additional details for the proposed annual sampling can be found in the LTMP in Section 12.

Quarterly groundwater monitoring is recommended to begin in January 1997 upon approval of the RAP. Annual monitoring is considered appropriate given the limited contaminant migration observed to date and low groundwater velocities at the sites. Results of groundwater monitoring will be provided to Carswell, TNRCC, and AFCEE to update all parties involved on remediation progress and to provide new information for pending land use decisions, as necessary.

11.1.4 Verification of Current and Future Land and Groundwater Use Controls

An important element of the recommended remedial action at Sites ST14 and SD13 is land use controls. On the basis of the exposure pathways analysis (Sections 4 and 7), Site ST14 is and will continue to be acceptable for continued industrial use provided noninstrusive workers do not come into direct contact with impacted media on a regular basis and intrusive workers do not engage in excavation activities without appropriate personal protective equipment until soil remediation is completed. The target cleanup objectives are also based on the assumption that future land use will not require extraction of shallow site groundwater for potable uses. It is recommended that access to the site continue to be restricted. This action will prohibit unauthorized site access and unplanned ground disturbance. Additionally, any future lease or new land use of this land must stipulate that shallow groundwater will not be extracted within 1,000 feet of the plume centerline for potable use until benzene concentrations have been reduced below applicable target concentrations based on ingestion. Excavation in the impacted

area also should only be performed by workers who have been briefed on the nature of onsite contamination and trained in proper use of personal protective equipment. These minor restrictions will eliminate potential unprotected exposure of onsite workers to contaminated soil and groundwater at Site ST14.

Site SD13 currently is acceptable for industrial use because subsurface soils are covered by asphalt and no pathway to contaminated soils or groundwater at the site exists. However, the site is scheduled to be converted to an open space/recreational area in 1998. It should be verified that no exposure pathway to impacted soil and groundwater is complete or that COPC concentrations have been reduced to acceptable levels before the land use conversion takes place. Adequate groundwater and land use restrictions must be maintained until such time as the appropriate target concentrations are attained. The Air Force is currently developing model deed certification language for Site SDB.

11.2 IMPLEMENTATION SCHEDULE

Figure 11.3 is a proposed schedule for implementation of the RAP at Sites ST14 and SD13. The schedule is provided for planning purposes only, and is subject to timely approval of the RAP by Carswell AFB/NAS Fort Worth JRB, TNRCC, and AFCEE.

11.3 CONTINGENCY PLAN

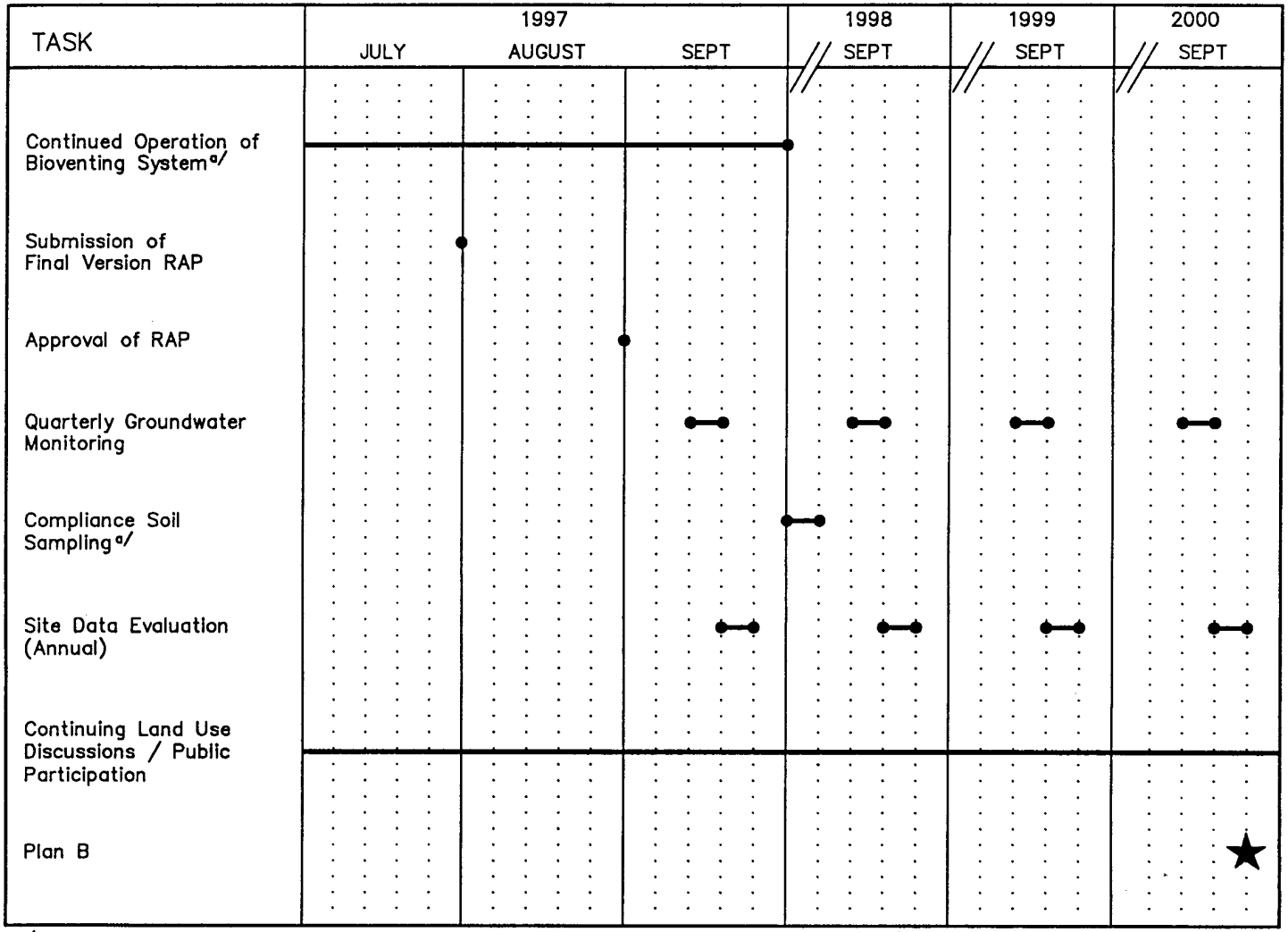
Should engineered remediation and natural chemical attenuation processes fail to achieve and maintain target concentrations and retard plume migration, there should be no significant impact on the land use plans for Site ST14. No new land use has been proposed for Site ST14. For the foreseeable future, Site ST14 will continue to be used as a military fueling area.

The Plan B limited risk assessment for Site ST14 indicates that existing concentrations of all organic chemicals detected at the sites result in a cumulative risk estimate only slightly above the 1×10^{-6} target risk range for the receptor group that may be actually exposed (i.e., intrusive workers). No individual chemical resulted in a carcinogenic or noncarcinogenic risk above the 1×10^{-6} target. This was confirmed by the Plan B target concentrations; no COPCs were detected in soil or groundwater at concentrations above health-protective Plan B target concentrations for intrusive workers. Exposure controls may have to be maintained if Plan B levels are not achieved to prevent nonintrusive workers from coming into direct contract with impacted media on a regular basis.

However, Site SD13 is planned to be released for open space/recreational use in 1998. The Risk Reduction Standard Number 3 risk assessment indicates that no unacceptable exposure will occure if appropriate land and groundwater use controls are maintained. No intrusive activities are expected at the site once land use is converted so no receptor exposure pathway will be complete for contaminants in subsurface soil and groundwater. Consequently, the site will still be suitable for nonintrusive open space/recreational activities.

FIGURE 11.3

IMPLEMENTATION OF PROPOSED ACTIONS CARSWELL AFB/NAS FORT WORTH JRB, TEXAS



a/ Performed or to be performed by Parsons Engineering Science.

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Groundwater extraction is not anticipated at either site so long as alternate water supplies exist. In the unlikely event that shallow groundwater from either site must be extracted for potable uses, and applicable target concentrations for groundwater have not yet been achieved, the following contingency actions are available:

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6.

- If significant risk exists due to changing land use or groundwater use patterns, more active methods of remediation will be evaluated. These could include possible initiation of more aggressive groundwater extraction methods.

Once again, failure of the proposed soil remediation and ongoing natural chemical attenuation to achieve risk-based target levels will not impact the current or proposed uses of these sites, unless groundwater must be extracted for long-term potable industrial uses or soils must be excavated (without appropriate personal protective equipment) before the appropriate target concentrations have been met.

Finally, a total of three POC wells have been or will be installed downgradient from the partially removed french underdrain and upgradient from Farmers Branch. These wells will be used to monitor for COPCs that may migrate past the abandoned french underdrain and discharge directly into the Farmers Branch. Because groundwater velocity at the site is low, and natural chemical attenuation processes have been shown to be effective in minimizing migration, no detectable levels of benzene are predicted to migrate to within approximately 160 feet upgradient from the POC wells. If COPCs are detected in any of the POC wells, the following contingency actions are available:

- All downgradient POC wells will be resampled to determine the extent of migration and to locate the center of highest concentrations.

- The results of the most recent groundwater sampling event will be evaluated to determine if there is a trend indicating that natural chemical attenuation is not proceeding at the rates predicted in Section 6.

- The risk assessments will be reviewed/recalculated to determine if COPCs concentrations approaching the POC well present a risk based on the actual intended use of the groundwater.

- Surface water sampling of Farmers Branch will be performed to determine if surface water is being adversely impacted (available data indicate no adverse impacts at this time).

- If significant risk exists, more active methods of remediation such as groundwater extraction and treatment at Site SD13, as described in Alternative 3, will be evaluated.

11.4 COST OF IMPLEMENTATION

A summary of the estimated present-worth cost of implementing the recommended remedial alternative is provided in Section 10. Table 11.1 provides a cost estimate, based on estimated expenditures during the next 5 fiscal years, to assist the Air Force and Navy in budgeting for implementation of the recommended Site ST14 and Site SD13 remedial actions.

TABLE 11.1

ESTIMATED COST BY FISCAL YEAR

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Task	FY96	FY97	FY98	FY99	FY00
Quarterly Groundwater Monitoring	$71.680	$76,696[a/]	$82,064	$87,808	$93,952
Annual Site Mgt/Institutional Controls	$11,280	$11,844	$12,436	$13,058	$75,760
Source Areas Soil Sampling	$0.00	$0.00	$33,200		
Drill/Install LTM Wells	$36,356				
French Underdrain and Oil/Water Separator Abandonment (Computed FY96)	$50,000[b/]				
Design/Install Bioventing/Sparging System (Computed FY96)	$61,957[b/]				
FISCAL YEAR TOTALS	**$231,273**	**$88,540**	**$127,700**	**$100,866**	**$169,712**

a/ Assumes a 7 percent annual inflation rate.
b/ Currently funded under Parsons ES contract with AFCEE.

It is estimated that it will take 4 to 5 years to attain Plan B target levels under Alternative 2 at Site ST14. In contrast, it is estimated that it would take 12 years to attain Plan A target levels under Alternative 2 at Site ST14. The added cost of additional monitoring and site management required to document attainment of Plan A target concentrations at Site ST14 would raise the present worth costs by about 30 percent.

SECTION 12

LONG-TERM MONITORING PLAN

12.1 OVERVIEW

In keeping with the requirements of the recommended remedial action for Site ST14 and Site SD13 (i.e., natural chemical attenuation of residual contamination and engineered components, *in situ* bioventing/biosparging at Site ST14A, groundwater monitoring for plume stability, and land and groundwater use controls), a site monitoring and compliance sampling program has been developed. This plan includes a proposed groundwater monitoring network, sampling and analysis strategies for groundwater and soils, and an evaluation of land use controls. A schedule for implementation of the actions described in the plan is presented in Figure 11.3. The purpose of this plan is to confirm the effectiveness of proposed engineered remediation and natural processes over time. This plan also will provide the mechanism to assess site conditions over time and the need for additional remediation.

As part of this monitoring and compliance plan, contaminant behavior in groundwater over time will be monitored to verify that the proposed remedial action is sufficient to protect groundwater quality underlying the source area at Site ST14 and to prevent downgradient migration especially into surface water at Site SD13. The areal extent of contamination will be monitored for increases in concentration and spatial distribution of COPCs during the course of the proposed remediation. In the event that data collected under this program indicate that natural chemical attenuation processes are insufficient to maintain dissolved contamination at levels below Plan B target concentrations at site ST14 or prevent plume stability at Site SD13, contingency actions will be implemented to augment the effects of the proposed remedial action.

12.2 MONITORING BIOVENTING/BIOSPARGING SYSTEM PERFORMANCE AT SITE ST14A

The proposed full-scale bioventing/biosparging system was installed at Site ST14A in April 1996. Currently, the system has been in long-term operation since summer of 1996. An operation and maintenance (O&M) manual was prepared and presented to Carswell AFB/NAS Fort Worth JRB personnel prior to the beginning of long-term operation. Parsons ES prepared the manual as part of system installation and optimization. Contents of the O&M plan for bioventing/biosparging include system as-built drawings, vendor specifications, maintenance schedules, and a list of emergency contacts.

System checkups should be performed every other week by Carswell AFB/NAS Fort Worth JRB personnel. The following activities will typically be performed during a system check:

- Record air injection pressures and flow rates for each of the injection wells;
- Measure injection blower operating temperature and inlet vacuum;
- Assess the condition of the air inlet filter element and replace as necessary;
- Measure DO content in specified monitoring points; and
- Note any unusual operating characteristics (e.g., clogged lines or tripped breakers).

All maintenance activities will be recorded on an O&M checklist and will become part of the site record.

In addition to the monitoring described above, *in situ* respiration and radius of influence tests should be performed annually at all injection vent wells (VWs) and at the discrete vapor monitoring points (MPs) at the site. Soil gas samples collected from these locations will be analyzed for BTEX and TVH. This testing and sampling will be used to assess remedial progress and to assure that biodegradation is continuing in accordance with the bioventing technical protocol (Hinchee *et al.*, 1992). If, at the end of 2 years of operation, it appears that the majority of the benzene contamination at the site has been biodegraded based on respiration rates and soil gas samples, compliance soil samples will be collected. Samples will be analyzed for BTEX by USEPA Method SW8020 and for hexachlorobenzene by USEPA Method SW8270. Additional sample collection and analysis details for soil and soil gas are presented in the next subsection. Soil samples will be compared to initial samples collected during VW and MP installation and used to determine if contaminant levels at Site ST14 have been remediated to at least Plan B target concentrations. Soil gas samples will be used in the same manner. Based on the results of the pilot test performed at Site ST14A, 2 years of operation should be adequate to reduce soil COPCs to levels approaching analytical method PQLs. When compliance soil samples indicate that source soils have been remediated to at least Plan B levels, the system will be deactivated. All VWs will be abandoned in place with bentonite.

12.3 SUBSURFACE SOIL COMPLIANCE SAMPLING AT SITE ST14A

Two years of bioventing/biosparging has been proposed as part of the recommended remedial alternative for Site ST14A. Sample data from vadose zone soils in the source area at Site ST14A indicate that benzene may pose a threat to underlying groundwater quality (i.e., exceed Plan B target concentration) and may pose a threat to onsite nonintrusive and intrusive workers if assumed exposure pathways were complete. Although hexachlorobenzene was detected once in saturated soils at Site SD13, no active remediation is proposed for this area (except the now completed partial removal of the subsurface french underdrain and abandonment of the north oil/water separator).

After 2 years of bioventing/biosparging operation, approximately 28 subsurface compliance soil samples will be collected within the source area at Site ST14A to assure that contaminant concentrations and mass have been reduced to at least Plan B target concentrations. Approximately 15 samples will be collected at Site SD13 to verify that soil COPCs are not present in sufficient mass or concentration to pose unacceptable risk to potential receptors or downgradient surface water. Samples will be taken at 120-degree angles around the VWs at Site ST14A at a radius of approximately 20 feet. Samples will be collected near VW-32 and ST14-MW29 at Site SD13. Some sample locations may be moved or excluded as required by utility constraints. Samples will be collected using a Geoprobe® hydraulic push sampler. Soil samples will be collected from the smear zone just above the groundwater surface. Additional sampling and analysis information can be found in Appendix J, the SAP.

12.3.1 Implementation Requirements

All soil samples will be collected in accordance with the site-specific SAP presented in Appendix J and analyzed as specified in Table 12.1. QA/QC procedures will be applied as described in the SAP.

12.3.2 Sampling Frequency

Soil samples will be collected after 2 years of bioventing/biosparging operation. This is the amount of time conservatively estimated to be required to remediate soils at Site ST14A to at least Plan B target concentrations. Sampling activities are shown on the schedule presented in Figure 11.3. If the data collected at this time indicate the need for additional remedial activities at the site, contingency activities such as described in Alternative 3 will be considered.

12.3.3 System Abandonment Procedures

If compliance sampling indicates that soils have been remediated to at least Plan B target concentrations, the bioventing/biosparging system at Site ST14A will be dismantled and abandoned. Abandonment procedures will include the following:

- Removal of the air injection blowers, including associated sheds and electrical conduit/wiring;
- Abandonment of the 1-inch HDPE air supply lines by capping below grade at the blower and the wellheads (i.e., tubing will remain in place); and
- Abandonment of all VWs and MPs.

12.4 GROUNDWATER MONITORING NETWORK

A total of 22 wells will be used to monitor the nature, extent, and distribution of dissolved COPCs at both sites over time. The purpose of these monitoring events is to confirm that source soils are not causing increases in groundwater concentrations and that no unanticipated downgradient migration is occurring. These wells are located within, upgradient from, downgradient from, and at the leading edge of the

TABLE 12.1

COMPLIANCE SOIL SAMPLING ANALYTICAL PROTOCOL

REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14 CARSWELL AFB/NAS FORT WORTH JRB

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site-Specific Water MDL	Water Reporting Limit	Field or Fixed-Base Laboratory
Hexachloro-benzene	SW8270	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	Hexachlorobenzene has been identified as a soil COPC at Site SD13	After 2 years of bioventing at Site ST14A	Collect 4 grams of soil in a glass container with a Teflon® lined lid	See Table 2.1	See Table 2.1	Fixed-base
Aromatic hydrocarbons (Benzene)	SW8020 (Gas Chromatography/ Mass Spectrometry Method	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	Benzene has been identified as a soil contaminant at both Sites ST14A and SD13.	After 2 years of bioventing	Collect 4 grams of soil in a glass container with a Teflon® lined lid	See Table 2.1	See Table 2.1	Fixed-base

characterized dissolved plumes to ensure that implemented remedial actions and natural chemical attenuation processes are sufficient to prevent increases in COPC concentrations and minimize COPC transport in groundwater. The locations of all wells to be used for long-term monitoring are illustrated in Figure 12.1.

12.4.1 Upgradient and Plume Wells - Site ST14

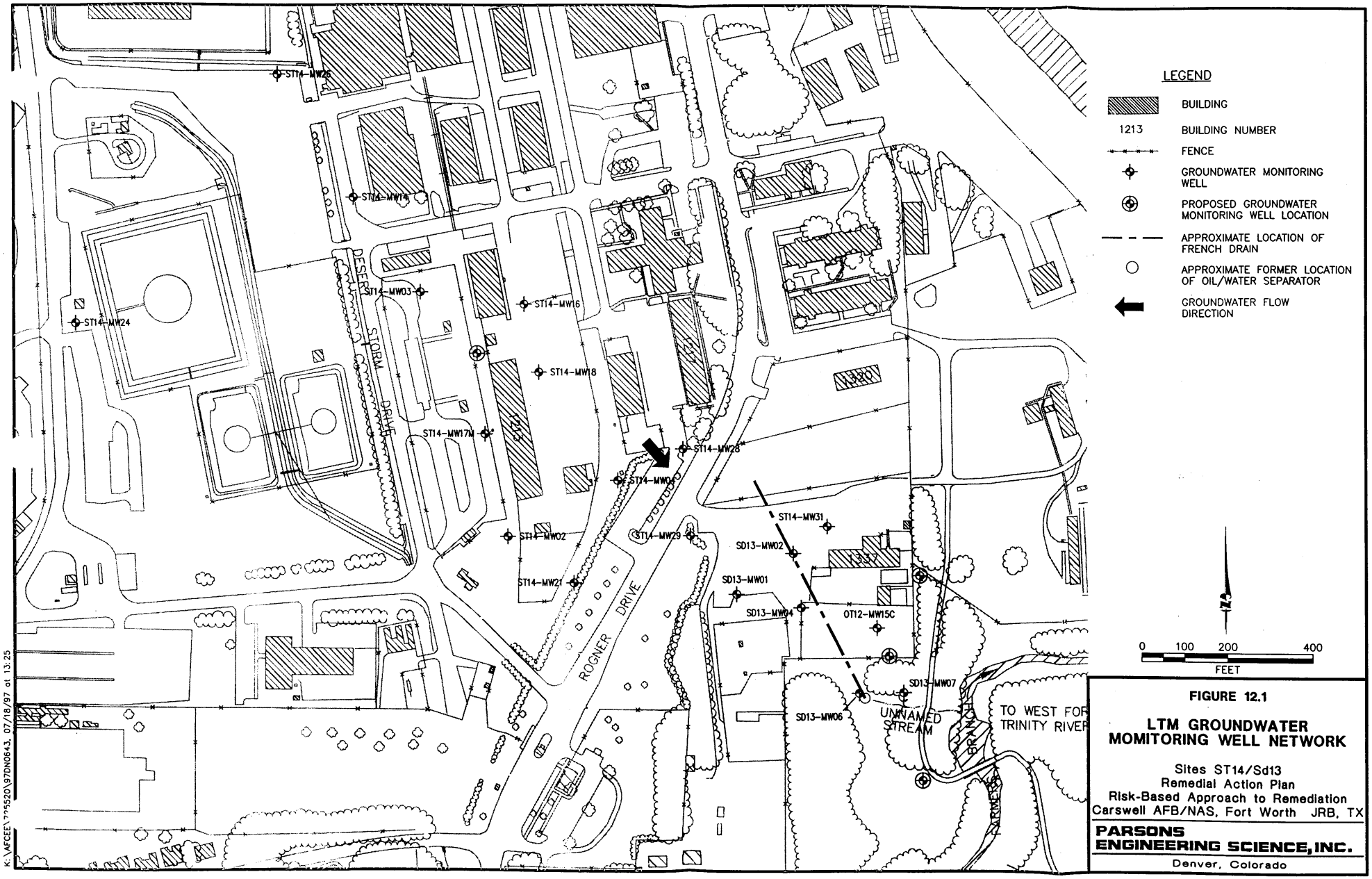
Three existing wells (ST14-MW14, ST14-MW24, and ST14-MW26) are located upgradient from and outside the influence of the potential Site ST14 and Site SD13 contaminant sources, and will be monitored to evaluate background conditions. Nine existing wells (ST14-MW03, ST14-MW16, ST14-MW18, ST14-MW17M, ST14-MW02, ST14-MW29, ST14-MW21, ST14-MW04, and ST14-MW28) located within or at the lateral edges of the dissolved benzene plume originating at Site ST14 will be monitored to evaluate the stability of the contamination and possibly the rates of COPC removal as a result of engineered remediation of source soils and natural chemical attenuation. One new well will be installed near the center of the benzene plume at Site ST14A to supplement the existing nine plume wells. Upgradient and plume wells will be sampled and analyzed for the parameters listed in Table 12.2 to verify the effectiveness of the proposed remedial action.

12.4.2 Upgradient and Plume Wells - Site SD13

Six wells, including one new well, will be used to verify limited downgradient migration of COPCs at Site SD13. The existing wells include SD13-MW01, SD13-MW02, ST14-MW31, SDB-MW04, and SD-MW06. The new proposed well is to be installed about 50 feet south of existing well OT12-MW15C. Because Site SD13 is downgradient from Site ST14, these wells also can be used to monitor benzene from Site ST14. However, it will not be possible to ascertain from which source area any detected benzene originated, since the only detection of benzene at Site SD13 was upgradient of all these wells at temporary sampling location E400. Conservative model simulations predict that benzene could migrate to wells downgradient of E400 at a concentration of 10 mg/L, which is in excess of the Risk Reduction Standard Number 2 Level of 5 mg/L. If benzene concentrations are detected in any of these wells at concentrations in excess of those predicted by the Bioplume II model, the contingency actions described in Section 10.3 would be enacted. These wells will be monitored for parameters listed in Table 12.2.

12.4.3 Point-of-Compliance Wells

One existing well (SD13-MW07) and two new wells that will be installed downgradient from the abandoned french underdrain and northeast of well OT12-MW15B will be used as POC wells. These wells also will be monitored to ensure that concentrations of COPCs above Risk Reduction Standard Number 2 levels will migrate beyond or around the abandoned french underdrain and into Farmers Branch. The POC wells will be monitored for parameters listed in Table 12.2. Based on an assessment of hydrogeology and natural chemical attenuation processes occurring at the sites, it is unlikely that site-related COPCs in excess of residential Risk Reduction Standard Number 2 levels will ever be measured at the POC wells. The detection of any organic



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FIGURE 12.1

LTM GROUNDWATER MOMITORING WELL NETWORK

Sites ST14/Sd13
Remedial Action Plan
Risk-Based Approach to Remediation
Carswell AFB/NAS, Fort Worth JRB, TX

PARSONS ENGINEERING SCIENCE, INC.
Denver, Colorado

TABLE 12.2
GROUNDWATER MONITORING ANALYTICAL PROTOCOL
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14 CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Recommended Sampling Locations	Field or Fixed-Base Laboratory
Aromatic hydrocarbons (Benzene)	SW8020 (Gas Chromatography/ Mass Spectrometry method)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	To verify that source soils do not cause site applicable exceedances and to verify plume stability	Quarterly	Collect water samples in a 40-milliliter (mL) volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤2 standard units.	ST14-03, ST14-04, ST14-02, ST14-16, ST14-17M, ST14-18, ST14-21, ST14-28, ST14-29, SD13-01, SD13-02, SD13-04, proposed wells.	Fixed-base
TCE	SW8260 (Volatile Organic Hydrocarbons)	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	Monitoring will be performed to ensure that chlorinated solvents are not migrating into Site ST14 from upgradient sources and to verify that Base known compounds do not migrate through Site SD13.	Quarterly	Collect water samples in a 40-milliliter (mL) volatile organic analysis vial with zero headspace; cool to 4°C; add hydrochloric acid to pH ≤2 standard units.	ST14-14, ST14-26, ST14-24, SD13-06, SD13-07, OT15C, and proposed wells.	Fixed-base
Metals	SW6010A	As described in latest version of *Test Methods for Evaluating Solid Waste* (EPA SW-846)	Monitoring will be performed to ensure that metals are not migrating into Site ST14 from upgradient sources and to verify that metals do not migrate to Point-of- Compliance wells at Site SD13.	Quarterly	Collect water samples in a 40-milliliter (mL) volatile organic analysis vial; cool to 4°C; add hydrochloric acid to pH ≤2 standard units.	ST14-02, ST14-14, ST14-18, ST14-21, ST14-24, ST14-26, SD13-06, SD13-07, OT15C, and proposed wells.	Fixed-base
Redox potential	Direct-reading meter (Orion Model 290A with Orion Combination Redox 9678BN probe)	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: can be used as an indicator of the terminal electron acceptor process involved in fuel hyrocarbon biodegradation	Quarterly	Measure directly using a flow-through cell with probe portals. Probe should be standardized against Zobel solution.	All plume related wells.	Field
Dissolved oxygen	Direct-reading meter (YSI Model 50B with YSI 5739 probe)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Reduced concentrations of dissolved oxygen indicate that microorganisms are facilitating oxygen reduction to biodegrade fuel hyrocarbons.	Quarterly	Measure directly using flow-through cell with probe portals. Probe should be calibrated with zero dissolved oxygen solution.	All plume related wells.	Field

TABLE 12.2 (Continued)
GROUNDWATER MONITORING ANALYTICAL PROTOCOL
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14 CARSWELL AFB/NAS FORT WORTH JRB, TEXAS

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Recommended Sampling Locations	Field or Fixed-Base Laboratory
Nitrate (NO_3^{-1})	SW9056	Field only	Depleted nitrate concentrations indicate that microorganisms are facilitating nitrate reduction to biodegrade fuel hyrocarbons	Quarterly	Collect 100 mL of water in a glass container; filter and use 10-mL aliquot for analysis.	All plume related wells.	Fixed-base
Ferrous iron (Fe^{2+})	Colorimetric HACH 8146	Field only	Elevated ferrous iron concentrations indicate that microorganisms are facilitating ferric iron reduction to biodegrade fuel hydrocarbons	Quarterly	Collect 100 mL of water in a glass container; filter and use 10-mL aliquot for analysis.	All plume related wells.	Field
Sulfate (SO_4^{2-})	SW9056	Field only	Reduced concentrations of sulfate indicate that microorganisms are facilitating sulfate reduction to biodegrade fuel hydrocarbons	Quarterly	Collect 100 mL of water in a glass container; filter and use 10 mL aliquot for analysis	All plume related wells.	Fixed-base
Methane	SM6211M	Field only	Increased concentrations of methane indicate that microorganisms are facilitatine biodegradation of fuel hydrocarbons.	Quarterly	per SM6211M.	All plume related wells.	Field
Alkalinity (as $CaCO_3$)	E310.1	Field only	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Quarterly	Collect 100 mL of water in a glass container; filter and use 10-mL aliquot for analysis.	All plume related wells.	Field
pH	Direct-reading meter (Orion Model 140)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	Aerobic and anaerobic processes are pH-sensitive	Quarterly	Measure directly using a contained flow-through cell with probe portals. Probe should be calibrated using at least three pH standards.	All plume related wells.	Field

TABLE 12.2 (Concluded)
GROUNDWATER MONITORING ANALYTICAL PROTOCOL
REMEDIAL ACTION PLAN
RISK-BASED APPROACH TO REMEDIATION
SITE ST14 CARSWELL AFB/NAS FORT WORTH JRB, TEXT

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Site -Specific Water MDL	Field or Fixed-Base Laboratory
Temperature	Direct-reading meter	Field only	Metabolism rates for microorganisms depend on temperature	Quarterly	Measure directly using a contained flow-through cell with probe portals.	All plume related wells.	Field
Conductivity	Direct-reading meter (Orion Model 140 with Conductivity Cell 014050)	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	General water quality parameter used as a marker to verify that site samples are obtained from the same ground water system	Quarterly	Measure directly using a contained flow-through cell with probe portals. Probe is factory calibrated.	All plume related wells.	Field

contamination at any of the POC wells above the Risk Reduction Standard Number 2 levels will trigger the need to evaluate contingency actions. The exact scope of contingency actions will be determined at such time as concentrations of site-related COPCs appear in collected samples from any of the POC wells. These actions could include, but may not be limited to, the following:

- Resampling of POC wells to confirm presence of contaminants in excess of the target concentrations;
- Reevaluation of stream flows and the effects of dilution and volatilization to determine if concentrations of COPCs entering Farms Branch will pose a human or ecological risk; and
- Additional engineering evaluations to determine if more aggressive remedial efforts, such as groundwater extraction, are necessary and/or feasible.

12.5 GROUNDWATER SAMPLING

This plan includes a comprehensive groundwater SAP which is to be used to supplement the GSAP (CH2M Hill, 1997) as necessary. The monitoring plan, when implemented in accordance with the SAP, will verify that no contaminant concentrations above Plan B target concentrations are present at or migrating from Site ST14 and that no contaminants above the residential Risk Reduction Standard Number 2 levels are migrating downgradient from any of the POC wells. The SAP for all sampling related to this plan is provided in Appendix J. All wells will be sampled and analyzed quarterly as described above to verify that engineered remediation and natural processes are sufficient to minimize/eliminate downgradient migration and eventually COPC mass, volume, and toxicity.

12.5.1 Implementation Requirements

All groundwater monitoring wells included in the proposed network will be sampled and analyzed in accordance with Table 12.2 to verify no increases in maximum site concentrations, plume stability over time, and possibly progress toward and compliance with the applicable target concentrations for Sites ST14 and SD13. All samples will be collected in accordance with the GSAP, as supplemented by the SAP presented in Appendix J. Additionally, QA/QC samples and procedures will be implemented as described in the GSAP.

12.5.2 Sampling Frequency

Each of the groundwater sampling points will be sampled quarterly. Sampling results will be evaluated after each event to document observed changes in concentrations and plume stability (and possibly reduction). Monitoring of all 22 wells in the network will continue until both sites have attained the applicable target concentrations. Two years of sampling will be performed following attainment of the target levels in soils or plume stability (whichever comes first) to ensure that compliance with the approved target concentrations can be maintained. The long-term

goal of this sampling effort is to track attainment of Plan A and Plan B target concentrations at Site ST14 and eventually Risk Reduction Standard Number 2 levels at Site SD13. Early sampling results can be used to support the land use transfer decisions to be made in 1998.

12.6 LAND USE CONTROLS VERIFICATION

Site management responsibilities during the proposed corrective action period will include verification that any proposed land uses are consistent with the target cleanup objectives. Any planned or unplanned changes in activities conducted in areas impacted by Site ST14 and Site SD13 contamination will be documented. Additionally, the Air Force is currently developing model deed recordation language for Site SD13 in anticipation of the proposed 1998 transfer in land use.

Any future uses of the sites will preclude use of impacted shallow groundwater as a source of potable water until such time that the applicable target concentrations for groundwater have been attained at every monitoring point. The Plan B target concentrations for Site ST14 were developed to protect against risks due to incidental dermal contact; they are not sufficient to prevent unacceptable risks due to exposure via regular ingestion of contaminated groundwater. The quantitative risk assessment developed for Site SD13 includes only dermal contact with groundwater for intrusive workers and dermal contact and incidental ingestion of surface waters for future recreators/trespassers. These exposure assumptions do not include regular ingestion of contaminated water.

In addition to land use reviews, interim confirmation of land and groundwater use controls are proposed to include documenting land zoning, types of potential onsite receptors, and the kinds of activities in which these potential receptors may engage at the sites. For example, this RAP recommends that extensive soil excavation in the source area at Site ST14A (and Site SD13) without adequate personal protective equipment should be restricted to prevent worker contact with contaminated soil and groundwater. Additionally, fueling personnel and other nonintrusive workers should be warned/prevented against coming into direct contact with impacted site media for extended periods of time. This confirmation step will be formally documented when the results of quarterly analytical sampling events are prepared for review and assessment. Any significant changes in land use will be identified, and any modification of the recommended remedial alternative that may be required to protect human health and the environment will be identified and proposed for review and implementation, as necessary. Final requirements for deed recordation will be established as part of the land transfer activities to be completed in 1998.

SECTION 13

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