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Feasibility Study

FFTA-MAAF
at
Fort Riley, Kansas

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Prepared for

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Prepared by

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LIST OF ACRONYMS AND ABBREVIATIONS

ACLs	Alternate Concentration Limits
ARAR	Applicable or Relevant and Appropriate Requirement
BER	Bureau of Environmental Remediation
bgs	below ground surface
BMcD	Burns & McDonnell Engineering Company, Inc.
BMPO	Base Master Plan Overlay
BNP	Bimetallic Nanoscale Particles
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
CENWK	United States Army Corps of Engineers, Kansas City District
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
COPC	Chemical of Potential Concern
CSGWPP	Comprehensive State Groundwater Protection Program
CWA	Clean Water Act
DA	Department of the Army
DAA	Detailed Analysis of Alternatives
DCE	Dichloroethene
DDC	Density Driven Convection
DERP	Department of Defense Environmental Restoration Program
DES	Directorate of Environment and Safety
DO	Dissolved Oxygen
DOE	Department of Energy
DOT	Department of Transportation
DPRA	Development Planning Resource Associates
DRO	Diesel Range Organics
DSR	Data Summary Report
DUS	Dynamic Underground Stripping
EBLRA	Ecological Baseline Risk Assessment
EE/CA	Engineering Evaluation/Cost Analysis
EPA	Environmental Protection Agency
ETI	Environmental Technologies, Inc.
Fe^0	Zero-Valent Iron
Fe^{+2}	Ferrous Iron
Fe^{+3}	Ferric Iron
FFA	Federal Facility Agreement
FFTA	Former Fire Training Area
FS	Feasibility Study
GCW	Groundwater Circulation Wells

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

GMS	Groundwater Modeling System
gpm	gallons per minute
GRA	General Response Action
GRO	Gasoline Range Organics
HAP	Hazardous Air Pollutant
HEAST	Health Effects Assessment Summary Tables
HHBLRA	Human Health Baseline Risk Assessment
HMTA	Hazardous Materials Transportation Act
HWIR	Hazardous Remediation Waste Management Requirements
IAG	Interagency Agreement
ICUZ	Installation Compatibility Use Zone
IDW	Investigative Derived Waste
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
ISRM	In-Situ Redox Manipulation
IWSA	Installation Wide Site Assessment
KSA	Kansas Statutes Annotated
KDHE	Kansas Department of Health and Environment
LBA	Louis Berger & Associates
lbs	Pounds
MAAF	Marshall Army Airfield
MCL	Maximum Contaminant Level
MCLGs	Maximum Contaminant Level Goals
mg/kg	Milligrams per Kilogram
µg/kg	Micrograms per Kilogram
µg/L	Micrograms per Liter
MNA	Monitored Natural Attenuation
msl	Mean Sea Level
NAAQS	National Ambient Air Quality Standards
NAP	National Academy Press
NAPLs	Non-aqueous Phase Liquids
NESHAPs	National Emission Standards for Hazardous Air Pollutants
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NSPS	New Source Performance Standards
O&M	Operation and Maintenance
ORP	Oxidation Reduction Potential
OSHA	Occupation Health and Safety Administration
OSWER	Office of Solid Waste and Emergency Response

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

PCBs	Polychlorinated Biphenyls
PCE	Tetrachloroethene
POTWs	Publicly Owned Treatment Works
PNNL	Pacific Northwest National Laboratory
PP	Proposed Plan
ppb	parts per billion
PRB	Permeable Reactive Barrier
PRGs	Preliminary Remedial Goals
PSD	Prevention of Significant Deterioration
RACER	Remediation Action Cost Engineering and Requirements
RAGS	Risk Assessment Guidance for Superfund
RAOs	Remedial Action Objectives
RCRA	Resource Conservation and Recovery Act
RD/RA	Remedial Design/Remedial Action
RI	Remedial Investigation
RME	Reasonable Maximum Exposure
ROD	Record of Decision
RSK	Risk-Based Standards for Kansas
RT3D	Reactive Multi-species Transport in 3-Dimensional Groundwater Aquifers
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
Site	Former Fire Training Area – Marshall Army Airfield, Fort Riley, Kansas
SIPs	State Implementation Plans
SMCL	Secondary Maximum Contaminant Level
SPSH	Six-phase Soil Heating
SSL	Soil Screening Level
SVE	Soil Vapor Extraction
SVOCs	Semi-Volatile Organic Compounds
SWMU	Solid Waste Management Unit
TBCs	To Be Considered Standards
TCE	Trichloroethene
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbon
TSD	Treatment, Storage, and Disposal
TVPH	Total Volatile Petroleum Hydrocarbon
UCLs	Upper Concentration Limits
UIC	Underground Injection Control
USAEHA	United States Army Environmental Hygiene Agency
USACE	United States Army Corps of Engineers
USATHMA	United States Army Toxic and Hazardous Materials Agency
USGS	United States Geological Survey
VC	Vinyl Chloride
VOCs	Volatile Organic Compounds

* * * *

1.0 INTRODUCTION

1.1. PURPOSE

The purpose of this Feasibility Study Report (*FS Report*) is to develop and evaluate remedial alternatives to allow selection of an appropriate remedy for contamination associated with the Former Fire Training Area (FFTA) at Marshall Army Airfield (MAAF), Fort Riley, Kansas (Site). This report was developed in support of the Fort Riley, Kansas, Directorate of Environment and Safety (DES), Installation Restoration Program (IRP). This report was also developed to satisfy the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986; the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) [40 CFR 300]; the Department of Defense Environmental Restoration Program (DERP), established by Section 211 of SARA; and the Army Regulation 200-1, Environmental Protection Enhancement. This report was prepared by Burns & McDonnell Engineering Company, Inc. (BMcD) under contract DACA41-96-D-8010 with the United States Army Corps of Engineers, Kansas City District (CENWK) and represents Fort Riley's ongoing fulfillment of obligations to investigate and take appropriate actions at sites posing a potential threat to human health and the environment.

Prior to the submittal of this report, the following were submitted as secondary documents, as per the Federal Facilities Agreement (FFA) [EPA, 1991]:

- Applicable or Relevant and Appropriate Requirements, To Be Considered Information, and Remedial Action Objectives Evaluation for Former Fire Training Area Marshall Army Airfield at Fort Riley, Kansas. (*ARARs Report*) [BMcD, 2002]. Submitted January 16, 2002.
- Identification/Screening of Technologies and Development of Remedial Alternatives for the Former Fire Training Area at Marshall Army Airfield, Fort Riley, Kansas. (*Tech ID*) [BMcD, 2002a]. Submitted May 17, 2002.
- Detailed Analysis of Alternatives, FFTA-MAAF at Fort Riley, Kansas. (*DAA*) [BMcD, 2002b]. Submitted November 11, 2002.

The purpose of these submittals was to provide necessary information so the EPA and the KDHE could provide guidance to Fort Riley during the production of the FS Report. These documents were communication milestones between the lead agency (Fort Riley) and the support agencies (EPA and KDHE) to obtain input and agreement on the requirements, technologies/processes, and alternatives considered for implementation at the Site. In addition to the submittal of these reports (including review and comments), on-going discussions at Line Item Review/Project Manager Meetings facilitated open communication between the lead agency, support agencies, and their contractors, and opportunities for feedback.

These efforts have served to streamline and expedite the development of the FS Report. In addition, since essentially there is very little new information presented in this report that has not already been reviewed and commented on by the EPA and the KDHE, the review of this report should be fairly straightforward.

Specific objectives for this *FS Report* are:

- Develop remedial action objectives and preliminary remediation goals that are protective of human health and the environment;
- Identify treatment technologies relevant to the nature and extent of contamination present at the Site;
- Screen and assemble appropriate technologies into remedial action alternatives; and
- Define, evaluate, and compare alternatives based on the criteria defined by relevant EPA guidance documents.

1.2. REPORT ORGANIZATION

This *FS Report* is organized as follows:

- **Section 1.0 – Introduction.** This section provides a brief description of the Site, a summary of aquifer characteristics, a description of the nature and extent of contamination, an evaluation of fate and transport processes, and a summary of the baseline risk assessment performed in the Remedial Investigation Report for the Former Fire Training Area at Marshall Army Airfield, Fort Riley, Kansas (*RI Report*) [BMcD, 2001]. Most of the information presented in this section is verbatim from the *RI Report*, and has been updated where appropriate.
- **Section 2.0 – Applicable or Relevant and Appropriate Requirements and To Be Considered Information.** This section discusses federal, state, and other statutes, regulations, and guidance documents that may be applicable or relevant and appropriate to the Site.
- **Section 3.0 – Remedial Action Objectives and Preliminary Remedial Goals.** This section is from Section 6.0 of the *ARARs Report* (BMcD, 2002), and describes the media of interest, contaminants of interest, remedial action objectives, and preliminary remedial goals. General response actions for the media of interest are also identified.

- **Section 4.0 – Identification and Screening of Remedial Technologies.** This section was initially presented in the *Tech ID* (BMcD, 2002a), but has been expanded in this report to provide a more detailed description of the technologies originally presented in the *Tech ID*. The technology screening results presented in this section (Section 4.0) are identical to the results from the *Tech ID*. The alternatives that were developed from the technology screening, and are presented in Section 4.4 of this *FS Report*, are also identical to the alternatives of the Tech ID; with the exception of two additional alternatives (Alternatives 7 and 8) that have been added at the request of the KDHE and the EPA.
- **Section 5.0 – Detailed Analysis of Alternatives.** This section is from the *DAA* (BMcD, 2002b), and evaluates the remedial alternatives with respect to the CERCLA screening criteria, including the estimated cost associated with each alternative.
- **Section 6.0 – Comparative Analysis of Alternatives.** This section is from Sections 1.3 and 1.4 of the *DAA* (BMcD, 2002b), and provides comparative analyses of remedial alternatives and ranks the most feasible and effective alternative for the Site.
- **Section 7.0 – References.**

1.3. BACKGROUND INFORMATION

1.3.1. Site Description

Fort Riley is located along the Republican and Kansas Rivers in Geary and Riley Counties. MAAF is in the southern region of Fort Riley, south of the Kansas River. The FFTA is located at the north end of MAAF, approximately 300 ft. southwest of the Fort Riley reservation boundary (Figure 1-1). The term Site is used in this report to refer to the general area extending from the FFTA north to the Kansas River.

1.3.2. Site History

The FFTA was operated from the mid-1960s through 1984 to conduct fire-training exercises (U.S. Army Environmental Hygiene Agency [USAEHA], 1979; U.S. Army Toxic and Hazardous Materials Agency [USATHMA], 1984). During this period, the former fire-training area consisted of a crushed stone pad (approximately 200 ft. by 200 ft.) with no subsurface liner. Flammable liquids were temporarily stored in drums near the FFTA for use during training exercises. During fire training exercises, flammable liquids were poured into the FFTA, ignited, and then extinguished.

The predominant fuels used for the fire training exercises were petroleum hydrocarbons, including JP-4, diesel, and MOGAS (a generic term for motor gasoline often used to refer to gasolines with lead alkyls, and gasoline). In August 1982, reportedly 55 gallons of tetrachloroethene (PCE) were inadvertently poured into the FFTA. The next day it was pumped out of the area and contained in 55-gallon drums. Hay was spread over any remaining liquid in the area, and subsequently removed and placed in drums. The drums were then properly disposed of. No fire fighting training has been conducted at the FFTA since 1984.

An overview of historic Site features is provided in Figure 1-2 (based on a 1984 aerial photograph). Notable historic features previously at the Site include the drum storage area to the east and southeast of the former fire-training area, and the areas near the perimeter of the FFTA used for storage of miscellaneous debris. Prominent drainage features at the Site include the drainage ditch that formerly directed surface runoff from the area northwest of the FFTA to a culvert located to the west of the Site that passed through the levee. The levee was designed and built by the United States Army Corps of Engineers (USACE) to prevent flooding from the Kansas River. Another culvert through the levee was located east of the FFTA. Remnants of this culvert are still visible along the levee, and the vegetation and topography north of the levee provide discernible traces of this former drainage from the airfield.

1.3.3. Current and Future Land Uses

The Site is located in the southeastern part of the Fort Riley reservation and is governed by the Geary County zoning as well as the Fort Riley Installation Compatibility Use Zone (ICUZ), as part of the Noise Management Program. Fort Riley is in possession of a Base Master Plan Overlay (BMPO). The BMPO is used prior to any future construction or subsurface related activities. Land use on MAAF is related to the operation of an active military airfield. The level of activity at MAAF has decreased significantly over the past several years due to reassignment of aviation units to other bases. However, land use for MAAF in the short and long-term is anticipated to continue to be military.

The FFTA is situated between the levee road of MAAF and within a few feet of the levee described above. Typically, construction activities within 500 feet to the landward side of the toe of a levee are restricted, although each construction activity is evaluated for its own merit (Pers. Comm., 1996). It is extremely unlikely that land use will change at the FFTA in the future.

A small triangular tract of property north of the levee and the racetrack road is owned by the Fort Riley reservation, but is leased as a safety zone to Plaza Speedway (referred to as Junction City Raceway on the property lease) [see cross-hatched area on Figure 1-1]. The lease agreement restricts construction of any permanent structure on the subject property.

The actual racetrack north of the FFTA is zoned commercial by Geary County. Commercial zoning does allow the use of a mobile home for commercial use, but not for residence. Because it is in the 100-year floodplain, future development of this property for other commercial uses is unlikely. Geary County zoning regulations impose building restrictions within the 100-year floodplain that require the bottom finished floor of the structure to be a minimum of one foot above flood level, i.e., 1,067 feet above mean sea level (msl) [Pers. Comm., 1996a]. Ground surface elevation near the Site ranges from 1,050 to 1,060 feet above msl.

Properties located to the north, east, and west of the racetrack are zoned by Geary County for agricultural use. Single-family dwellings are allowed; however the county does impose building restrictions within the 100-year floodplain (1,067 feet above msl). There is an occupied mobile home located beyond the racetrack, approximately 1,000 feet north of the FFTA. Given the building restriction associated with the floodplain, it is unlikely that future residences will be built or that other land uses besides agricultural will occur in this area.

Of the seven private wells identified in this area, six of these are located within approximately one-half mile north of the Fort Riley installation boundary (Figure 1-1). Well B-1 is located approximately one mile north of the Fort Riley installation boundary. All of these wells are located outside (cross-gradient) of the area impacted by the chlorinated solvent plume at the Site. The use of these wells is described below:

- Well N-1 reportedly supplies water to residences for domestic use.
- Well M02-02 is located northwest of the racetrack (Figure 1-1). This well was installed in August 2002 to serve as a replacement water supply for former well M-1. Well M02-02 is located outside of the area impacted by the chlorinated solvent plume at the Site. Well M-1 was abandoned in August 2002 (Bay West, 2003).
- Wells F-1 and F-2 are located at an abandoned trailer house. One of these wells is reported to supply water for livestock.
- Well R02-02 is located southeast of the racetrack (Figure 1-1). This well was installed in August 2002 to serve as a replacement water supply for former wells R-1, R-2, R-3, and R-4. Well R02-02 is located outside of the area impacted by the chlorinated solvent plume at the Site. Wells R-1, R-2, R-3, and R-4 were abandoned in August 2002 (Bay West, 2003).
- Well I-1 is an irrigation well placed into service in the spring of 1994.
- Well B-1 is a domestic well located at a residence approximately 6,000 feet northeast of the FFTA near the eastern margin of the Kansas River valley.

1.3.4. Regulatory History

Fort Riley was established in 1853 and has been owned and operated by the Department of the Army (DA) since that time. Environmental investigations and sampling events were performed at Fort Riley during the 1970s and 1980s. These investigations identified activities and facilities where hazardous substances had been released or had the potential to be released to the environment. On July 14, 1989, the EPA proposed inclusion of Fort Riley on the National Priorities List (NPL) pursuant to CERCLA. The EPA included the Site on the NPL, promulgated in August 1990. Fort Riley is identified by the EPA as Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) Site KS6214020756.

Effective June 1991, the DA entered into a FFA, Docket No. VII-90-F-0015, with the KDHE and the EPA Region VII to address environmental pollution subject to the Resource Conservation and Recovery Act (RCRA) and/or CERCLA (EPA, 1991). This agreement is typically referred to as the Interagency Agreement (IAG). Pursuant to the IAG, Fort Riley conducted an Installation Wide Site Assessment for Fort Riley, Kansas (*IWSA*) [LBA, 1992] to identify sites having the potential to release hazardous substances to the environment. The *IWSA* identified the FFTA-MAAF as one of the sites where releases of hazardous substances to the environment either have occurred or were likely to have occurred. Results of the investigation indicated that concentrations of organic compounds had been released to groundwater at concentrations exceeding federal and state drinking water standards. Also, similar contaminants were found in off-Site private wells at levels above drinking water standards. These results indicated that additional investigation at the Site was necessary (LBA, 1992).

In 1996, Fort Riley began the process of implementing an interim action at the Site to control human exposure to the groundwater containing Site-related compounds. The resulting Exposure Control Action Engineering Evaluation/Cost Analysis for the Former Fire Training Area, Marshall Army Airfield, Fort Riley, Kansas (LBA, 1997) recommended the installation of two new supply wells in areas that have not been influenced by the groundwater plume.

Two alternate water supply wells (M02-02 and R02-02) were installed in August 2002 on private property to replace wells impacted by the chlorinated solvent plume at the Site (Bay West, 2003). Well M02-02 replaced Well M-1, and Well R02-02 replaced Wells R-1, R-2, R-3, and R-4. Wells M-1, R-1, R-2, R-3, and R-4 were abandoned in August 2002. With the removal of these wells, there are no longer any private wells impacted by the chlorinated solvent plume at the Site.

An additional Engineering Evaluation/Cost Analysis (EE/CA) was undertaken beginning in 1997 to provide a reasonable reduction of off-Site "hot-spot" contamination. The resulting Groundwater Engineering Evaluation/Cost Analysis for the Former Fire Training Area at Marshall Army Airfield, Fort Riley, Kansas (*FFTA EE/CA*) [BMcD, 1998] was never completed because plume characterization activities identified a larger plume than anticipated, therefore addressing "hot-spot" contamination was no longer the immediate concern. It was agreed by Fort Riley, CENWK, EPA, and KDHE to abandon the *FFTA EE/CA* process and proceed with the *RI/FS Reports*.

The *RI Report* (BMcD, 2001) identified the nature and extent of contamination, evaluated the fate and transport of chemicals of potential concern (COPCs), and assessed the risk to human health and the environment. The *RI Report* is pending approval by the KDHE and the EPA until additional items requested by the KDHE are completed. These items, outlined in an April 23, 2001 letter from the KDHE, are as follows:

- Further evaluation of data ranges in the groundwater model;
- Installation of one nested pair of groundwater monitoring wells (intermediate and deep) on the north side of the Kansas River opposite the groundwater contamination plume; and
- Completion of a surface water sampling transect where the groundwater contamination plume contacts the Kansas River.

Fort Riley has made substantial efforts to fulfill each of the contingencies in a diligent and timely manner. Twenty surface water samples were collected along two cross-sections in July 2001 by the United States Geological Survey (USGS). These samples were collected both upstream and downstream of the point where the groundwater plume enters the river. Volatile organic compounds (VOCs) were not detected in any samples. A memo discussing the data ranges in the groundwater model was submitted to the KDHE and the EPA December 4, 2002. Landowner negotiations are underway for permission to install the nested pair of groundwater monitoring wells (intermediate and deep) on the north side of the Kansas River opposite the groundwater contamination plume.

Prior to the development of this *FS Report*, three secondary reports were submitted as per the FFA (EPA, 1991). These reports include the *ARARs Report* (BMcD, 2002), the *Tech ID* (BMcD, 2002a), and the *DAA* (BMcD, 2002b).

1.3.5. Aquifer Characteristics

1.3.5.1. Geology

The Site is located on the alluvial floodplain of the Kansas River. The material beneath the Site consists primarily of unconsolidated alluvial sand and gravel deposits (with minor discontinuous lenses of silt and clay) that tend to coarsen downward to the bedrock surface. The top of bedrock is at a depth of approximately 60 to 70 feet below ground surface (bgs), and is composed of limestone and shale units that dip gently (less than ten degrees) to the west-northwest. A more detailed description of the Site geology is presented in the *RI Report* (BMcD, 2001).

1.3.5.2. Hydrogeology

The Site is underlain by the alluvial aquifer of the Kansas River valley. This aquifer is unconfined and connected hydraulically to the Kansas River. Underlying the alluvial sediments is bedrock composed of limestone and shale units that are considered relatively impermeable, compared to the highly permeable alluvial sediments.

Water table elevations at the Site generally have ranged between 1,036 and 1,043 feet above msl, or approximately 20 to 25 feet bgs. Groundwater flow within the alluvium is generally toward the north-northeast and parallel to the alluvial valley. For any one sampling event, the horizontal component of the hydraulic gradient has typically been in the range of 0.0006 to 0.0009 feet per foot (ft/ft). A series of potentiometric contour maps illustrating the predominant groundwater flow direction for each screened interval at the Site is presented in Figures 1-3, 1-4, and 1-5.

Horizontal hydraulic conductivity ranges from 600 ft/day to 900 ft/day and increases with depth. Effective porosity (excluding shallow clay samples) ranges from 0.31 to 0.40, with a mean of 0.35. A more detailed description of the Site hydrogeology is presented in Section 2.5 of the *RI Report* (BMcD, 2001).

1.3.6. Source Removal

A pilot test study was performed November 1994 through May 1995 to evaluate the feasibility of two technologies for soil remediation at the FFTA (LBA, 1999). In the FFTA, a soil vapor extraction (SVE)/bioventing system was evaluated for its effectiveness on petroleum hydrocarbon and low level VOCs contamination. In the former drum storage area, an SVE system was evaluated for its effectiveness on PCE contamination. The primary goal of the bioventing system was to enhance in-situ biodegradation of petroleum hydrocarbons in the soil. The primary goal of the SVE system was focused on the removal of VOCs.

During the initial three-day SVE/bioventing test in the FFTA, unexpectedly high loading of the vapor phase carbon adsorption units by petroleum hydrocarbons was experienced. This resulted in complete consumption of the activated carbon within the first 48-hours of operation, and required termination of the SVE portion of the pilot system. However during this period, the SVE/bioventing system removed an estimated 776 lbs. of VOCs, primarily Total Petroleum Hydrocarbons (TPH), from the FFTA (LBA, 1999).

The bioventing portion of the pilot system was operated in two phases, an initial 45-day period and a six-month extended period. During the initial 45-day test period, approximately 320 lbs. of TPH contaminants were removed from the FFTA. During the extended phase pilot test, an additional 800 lbs. of TPH contaminants were removed from this area. The total mass of TPH contaminants removed from the FFTA is estimated at 1,120 lbs (LBA, 1999).

The SVE pilot study in the former drum storage area was conducted in two phases; an initial 30-day period (December 15, 1994 to January 16, 1995) and a 79-day extended test (March 3 to May 23, 1995). During the initial 30-day test period, approximately 252 lbs. of VOCs (primarily PCE) were removed from this area. During the extended phase pilot test, an additional 220 lbs. of VOCs (primarily PCE) were removed from the area. The total mass of PCE removed from the former drum storage area is estimated at 472 lbs.

1.3.7. Nature and Extent of Contamination

The following contaminants were determined to be soil and groundwater COPCs at the Site in the *RI Report* (BMcD, 2001):

- PCE;
- trichloroethene (TCE);
- 1,2-dichloroethene [1,2-DCE (cis and trans isomers)];
- vinyl chloride (VC);
- 1,1-dichloroethene (1,1-DCE);
- benzene;
- toluene;
- ethylbenzene;
- xylenes (total);

- 2-methylnaphthalene; and
- naphthalene.

COPCs identified for the *FS Report* are presented in Section 3.3.

1.3.7.1. Soil

1.3.7.1.1. Metals

Metals were detected above background levels in a limited number of soil samples located at or near the FFTA during the April 1996 post-pilot study soil sampling (LBA, 1996). Due to limited detections, metals in soil are not considered COPCs at this Site. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.1.2. Semi-Volatile Organic Compounds

Semi-volatile organic compounds (SVOCs), including naphthalene and 2-methylnaphthalene, were detected in soil samples located at or near the FFTA during the April 1996 post-pilot study soil sampling (LBA, 1996). Positive detections ranged from 680 µg/kg to 18,000 µg/kg for naphthalene and from 740 µg/kg to 46,000 µg/kg for 2-methylnaphthalene. SVOCs were not analyzed for during the June 1999 soil sampling. Naphthalene and 2-methylnaphthalene are considered COPCs for soil at this Site. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.1.3. Chlorinated Solvents

Chlorinated solvents including, PCE, TCE, and cis-1,2-DCE, have been detected in soil samples located at or near the former drum storage area. Positive detections in June 1999 ranged from 15 µg/kg to 170 µg/kg for PCE, from 14 µg/kg to 19 µg/kg for TCE, and from 55 µg/kg to 800 µg/kg for cis-1,2-DCE (BMcD, 1999). VC was not detected in soil samples at the FFTA. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.1.4. Petroleum Products

Petroleum products, including total volatile petroleum hydrocarbons (TVPH), TPH as diesel fuel, and TPH in the $C_{19} - C_{40}$ range (Note: This range is typically referred to as motor oil) were detected in soil samples located at or near the FFTA in June 1999 (BMcD, 1999). Positive detections ranged from 39,000 µg/kg to 1,800,000 µg/kg for TVPH, from 120 mg/kg to 11,700 mg/kg for TPH as diesel fuel, and from 5.9 mg/kg to 15,000 mg/kg for TPH in the $C_{19} - C_{40}$ range.

Petroleum VOCs including ethylbenzene, toluene, and xylenes were also detected in soil samples located at or near the FFTA in June 1999 (BMcD, 1999). Positive detections ranged from 690 µg/kg to 14,000 µg/kg for ethylbenzene, from 3,700 µg/kg to 39,000 µg/kg for toluene, and from 2,380 µg/kg to 77,000 µg/kg for xylenes. Benzene was not detected in soil samples at the FFTA. For additional information, refer to the *RI Report* (BMcD, 2001).

Since BTEX (benzene, toluene, ethylbenzene, and xylenes) constituents are among the most hazardous components of TPH and are highly volatile and mobile, evaluating the human health risks associated with exposure to BTEX serves as an appropriate means of evaluating TPH. Therefore, TPH *per se* was not considered a COPC, but the BTEX constituents were retained as COPCs.

1.3.7.1.5. Leaching to Groundwater Potential

Remediation of contaminated soil at the FFTA was performed during the pilot study completed in May 1995 (see Section 1.3.6). An evaluation of the potential for remaining contaminants in soil to leach to groundwater was performed as part of the *RI Report* (BMcD, 2001). The maximum contaminant concentrations for contaminants detected in soil during the June 1999 soil sampling event were used to perform the screening in accordance with Risk-Based Standards for Kansas (RSK Manual) [KDHE, 2003]. Screening levels are set such that soil contaminant concentrations below these levels are not anticipated to contribute contaminant concentrations to the groundwater that are above drinking water Maximum Contaminant Levels (MCLs).

TPH is the only contaminant that exceeded the screening levels for soil to groundwater pathway for residential scenarios (KDHE, 2003). TPH in soil exceeded the residential screening level presented in the RSK Manual for samples collected at or near the former fire-training area. TPH in soil is contained on Site and does not present a risk to either on-Site or off-Site receptors. TPH detections above the residential groundwater screening level in off-Site wells occurred in December 1995 in Monitoring Well FP-94-11 and in May and August 1997 in Monitoring Well FP-96-09b. TPH has not exceeded the residential groundwater screening level presented in the RSK Manual for any off-Site wells since August 1997. This data suggest that TPH in groundwater at concentrations above the residential screening levels is not currently migrating off Site. TPH in off-Site groundwater is anticipated to remain below the residential screening levels, since groundwater TPH concentrations have historically decreased in all off-Site wells, no new known TPH sources have be introduced to the aquifer, and the 1995 Pilot Test removed an estimated 1,896 lbs. of TPH from the FFTA source area (see Section 1.3.6). All other contaminant concentrations detected in soil during the June 1999 soil sampling event are at or below screening levels. Therefore, leaching of contaminants from soil is not anticipated to contribute contaminant concentrations to the groundwater that exceed the MCL. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.2. Groundwater

The aquifer at the Site is a continuous alluvial aquifer. However, based on the screened interval of monitoring wells at the Site, groundwater contamination is divided into three vertical zones. These zones are referred to as the shallow, intermediate, and deep zones. The screened interval of the shallow zone averages from 10 to 25 feet bgs, the screened interval of the intermediate zone averages from 40 to 50 feet bgs, and the screened interval of the deep zone averages from 60 to 70 feet bgs. The division into zones is strictly to collect information on the vertical extent of contamination at this Site. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.2.1. Metals

Metals at this Site were all detected at levels below the MCL, in diverse locations, and are not known to be associated with activities conducted at the Site. Therefore, metals in groundwater are not considered COPCs at this Site. For additional information, refer to the *RI Report* (BMcD, 2001).

1.3.7.2.2. Chlorinated Solvents

Chlorinated solvents including PCE, TCE, cis-1,2-DCE, and VC were detected in groundwater samples at the Site in 2002. However, only TCE and cis-1,2-DCE were detected at concentrations exceeding the MCL. Historical groundwater data suggests that the chlorinated solvent plume has migrated downgradient from the FFTA toward the Kansas River. Historical groundwater data prior to and including August 1999 is available in the *RI Report* (BMcD, 2001). More recent groundwater data are available in the following Data Summary Reports (DSRs): February 2000 (BMcD, 2000), August 2000 (BMcD, 2000a), February 2001 (BMcD, 2001a), August 2001 (BMcD, 2001b), March 2002 (BMcD, 2002c), and August 2002 (BMcD, 2002d). The historical extent of chlorinated solvents is displayed in monitoring wells along the centerline of the plume in Figure 1-6.

Groundwater concentrations of chlorinated solvents have generally been decreasing in the plume since 1995, when soil remediation at the FFTA was completed (Section 1.3.6). Current (August 2002) groundwater concentration data indicate that PCE positive detections range from 1.2 μg/L to 3.3 μg/L, TCE positive detections range from 0.7 μg/L to 10.7 μg/L, and cis-1,2-DCE positive detections range from 0.5 μg/L to 134 μg/L (BMcD, 2002d). VC has been detected six times at the Site (from over 700 groundwater samples), but only twice above the MCL, and all detections occurred in the shallow zone (wells FP-94-09 and FP-94-11). There is no trend to these detections, they are low level and sporadic.

The MCLs for PCE, TCE, cis-1,2-DCE, and VC in groundwater are 5 µg/L, 5 µg/L, 70 µg/L, and 2 µg/L, respectively.

Generally, the chlorinated solvent plume has moved deeper into the aquifer as it continues to migrate downgradient from the FFTA. The historical extent of chlorinated solvents is displayed in monitoring wells along the centerline of the plume in Figure 1-6. Current (August, 2002) concentrations of PCE, TCE and cis-1,2-DCE are displayed for each aquifer zone in Figures 1-7 through 1-13. VC is not displayed in these figures due to limited detections.

1.3.7.2.3. Petroleum Products

Petroleum products including benzene, ethylbenzene, xylene (total), and naphthalene were detected in groundwater samples at the Site in 2002. Historical groundwater data prior to August 1999 is available in the *RI Report* (BMcD, 2001). More recent groundwater data are available in the DSR Reports referenced above in Section 1.3.7.2.2. Groundwater concentrations of petroleum products have generally been decreasing in the plume since 1995, when soil remediation at the FFTA was completed (Section 1.3.6). Current (August 2002) groundwater concentration data indicates that benzene (a Class A carcinogen) positive detections range from 0.7 µg/L to 1.3 µg/L and have been decreasing with time, ethylbenzene had only one positive detection of 17.5 µg/L, xylene (total) had only one positive detection of 30.7 µg/L, and naphthalene had only one positive detection of 6.5 µg/L. The MCLs for benzene, ethylbenzene, xylene (total), and naphthalene in groundwater are 5 µg/L, 700 µg/L, 10,000 µg/L, and 100 µg/L [no MCL available for naphthalene, 100 µg/L is the residential value from the RSK Manual (KDHE, 2003)], respectively.

TPH-Diesel Range Organics (DRO) and TPH-Gasoline Range Organics (GRO) were also detected in groundwater samples at the Site in 2002. There are no MCLs available for TPH-DRO and TPH-GRO; however, 500 µg/L is the residential value from the RSK Manual for both TPH-DRO and TPH-GRO (KDHE, 2003). Current (August 2002) groundwater concentration data indicates that TPH-DRO had only one positive detection of 410 µg/L and TPH-GRO had only one positive detection of 790 µg/L. Both detections were from the on-Site Monitoring Well FP-93-04. TPH-DRO and TPH-GRO have not exceeded the residential groundwater screening level for any off-Site wells since August 1997.

1.3.7.3. Surface Water

Fifty-five surface water samples were collected along five cross-sections of the Kansas River in July 1999 (BMcD, 1999a) and twenty samples were collected along two cross-sections in March 2000 by the USGS (BMcD, 2000b). These samples were collected both upstream and downstream of the point where the groundwater plume enters the river. The samples were analyzed for VOCs. VOCs were not detected in any samples.

1.3.8. Contaminant Fate and Transport in Groundwater

Several processes including advection, dispersion, diffusion, sorption, volatilization, and degradation affect the fate and transport of contaminants in groundwater. These natural processes, typically referred to as natural attenuation processes, combine to reduce and disperse contaminant concentrations in groundwater.

The fate and transport of contaminants in groundwater was evaluated in the *RI Report* (BMcD, 2001) through contaminant transport modeling and by evaluating geochemical indicator parameters. This evaluation, along with updated information where appropriate, is summarized in the following subsections.

1.3.8.1. Conceptual Site Model

Refer to Section 6.0 of the *RI Report* (BMcD, 2001) for more detailed information on the conceptual model for this Site. The only documented release of a chlorinated solvent at the Site was PCE. TCE and cis-1,2-DCE in groundwater at the Site are typical daughter products from the breakdown of PCE.

Aquifer geochemical parameters indicate that two major geochemical zones exist. The first is an iron-reducing anaerobic zone that is comprised of the intermediate and deep aquifer zone and the shallow aquifer zone from the source area (i.e., the FFTA) to approximately Monitoring Well FP-96-23. The second zone is an aerobic zone comprised of the shallow aquifer zone that extends from Monitoring Well FP-98-27 to the Kansas River. The iron-reducing conditions in the anaerobic portion of the aquifer zone allow for relatively rapid reductive dehalogenation of PCE and TCE but relatively slow reductive dehalogenation of the cis-1,2-DCE. This is supported by the relative accumulation of cis-1,2-DCE in the aquifer, particularly in the intermediate and deep zones downgradient of the source area (see Figure 1-6). This is also one explanation for the relative low occurrence of VC (the reductive dehalogenation daughter product of cis-1,2-DCE), which has been detected at low concentrations in only two locations in the plume (Monitoring Wells FP-94-09 and FP-94-11). VC has been detected six times at the Site (from over 700 groundwater samples), but only twice above the MCL of 2 µg/L (2.1 µg/L in 1/99 and 2.8 µg/L in 8/99; both detections were from FP-94-11). Refer to Section 6.0 of the *RI Report* for more detailed information on the geochemical zones at this Site.

Another reason for the few VC detections is the potential for VC to aerobically degrade at a rate equivalent to or greater than the rate of VC formation from cis-1,2-DCE. Higher aerobic VC degradation rates compared to cis-1,2-DCE degradation have been documented by Aronson and Howard, 1997. Finally, the lack of VC and cis-1,2-DCE in the shallow plume (lack of VC beyond Monitoring Well FP-94-09, and cis-1,2-DCE beyond Monitoring Well FP-98-27) may be due to the presence of aerobic conditions that support the direct oxidation of cis-1,2-DCE and VC to innocuous, non-chlorinated transformation products.

In addition to reductive dehalogenation and oxidation, reduction of chlorinated solvent concentrations can also occur through physical processes, including dilution, dispersion, and sorption. These processes are anticipated to reduce chlorinated solvent concentrations independent of the reduction through degradation processes. For a more detailed description of these processes, refer to the *RI Report* (BMcD, 2001).

The conceptual model for the Site includes the following:

1. Sequential reductive dechlorination of PCE to the daughter products TCE, cis-1,2-DCE, and VC is occurring and is anticipated to continue at the Site. Historical data shows a decrease in PCE and TCE concentrations which correspond to an increase in cis-1,2-DCE concentrations (see Figure 1-6).

   The EPA screening protocol for reductive dechlorination (EPA, 1998) indicates there is strong evidence for reductive dechlorination at this Site (refer to Section 6.3.4.2.1 of the *RI Report*).

2. Geochemical and concentration data suggest that reducing conditions are inadequate for significant dechlorination of cis-1,2-DCE, and thus production of VC. This is supported by the infrequent low-level detections of VC (only six detections in over 700 groundwater samples), as well as the presence of iron reducing conditions, rather than the sulfate or methanogenic reducing conditions that are ideal for complete dechlorination of cis-1,2-DCE (refer to Section 6.0 of the *RI Report*). These six VC detections are not indicative of a growing trend.

3. Natural attenuation indicator parameters evaluated at this Site provide strong evidence that anaerobic degradation of chlorinated solvents is occurring in all three aquifer zones at the Site. However, in the shallow zone approximately 3,000 feet downgradient from the FFTA, the degradation conditions change to aerobic. As a result, increased degradation (i.e., direct mineralization) of cis-1,2-DCE and VC appears to be occurring, and is anticipated to continue in this area of the plume.

1.3.8.2. Contaminant Transport Modeling

Contaminant transport modeling was performed for the Site, during the *RI Report* (BMcD, 2001), to predict future concentrations at potential receptor locations, and to evaluate the potential for natural attenuation processes to reduce contaminant concentrations. The last round of data input into the model was from the August 1999 sampling event. Therefore, a little more than three years have elapsed since the model predictions. Major conclusions from the transport modeling are as follows (dates are relative to August 1999):

- Maximum concentrations of PCE, TCE, and cis-1,2-DCE in the plume have already been reached in all three zones at the Site.
- cis-1,2-DCE in groundwater is not predicted to discharge to the Kansas River at concentrations above the MCL.
- Maximum concentrations of VC in the plume have already been reached in the shallow zone, but are predicted to peak at 0.9 µg/L in approximately six years (i.e., August 2005) for both the intermediate and deep zones. VC in groundwater is not predicted to discharge to the Kansas River at concentrations above the MCL.
- Benzene, the only petroleum hydrocarbon that initially exceeded its MCL of 5 µg/L, is predicted to have a concentration of less than 5 µg/L in 10 years (i.e., August 2011).

Thus far, the model has been accurate in predicting the concentrations at the Site. Below is a summary of the model predictions and the August 2002 groundwater sampling results. The results from this comparison provide strong support to the model's credibility and conservative (in terms of risk and transport) nature. The model predictions presented below represent the worst case scenario from each of the three zones.

RI Model Predictions (August 1999)	**Groundwater Results from the August 2002 Sampling Event**
PCE will be below the MCL (5 µg/L) in 1.5 years. (i.e., February 2001)	PCE has been below the MCL at the Site for the past two rounds (i.e., March 2002 and August 2002).
TCE will be below the MCL (5 µg/L) in 3.5 years. (i.e., February 2003)	There are only four wells where TCE remains above the MCL, compared to eight in August 1999. TCE has decreased from 25.8 µg/L in August 1999 to 10.7 µg/L in August 2002.
cis-1,2-DCE will be below the MCL (70 µg/L) in 10 years. (i.e., August 2009)	cis-1,2-DCE has decreased from 496 µg/L in August 1999 to 134 µg/L in August 2002.
VC will be below the MCL (2 µg/L) in 0.5 years. (i.e., February 2000)	VC has only been detected one time since August 1999, and that was in March 2002 at a concentration of 1.1 µg/L.

A detailed description of the input parameters, assumptions, and limitations of the contaminant transport modeling performed for this Site is provided in Section 6.5 of the *RI Report* (BMcD, 2001).

1.4. RISK ASSESSMENT SUMMARIES

1.4.1. Summary of Health Risk

The following is a summary of the Human Health Baseline Risk Assessment (HHBLRA) that was performed in the *RI Report* (BMcD, 2001). For a more detailed description, refer to Section 7.0 of the *RI Report* (BMcD, 2001). The potential for human health risk due to exposure to chemicals at the Site was considered for soil, water, and air media. Based on observed Site conditions, it was concluded that chemical exposure was possible to on-Site populations through contact with subsurface soil and/or vapors from soil and to off-Site populations through contact with groundwater and vapors.

The results of the risk characterization indicated that risks posed by COPCs are at, or less than, EPA thresholds for acceptable risk. Most of the potential for risk was posed by VC.

For the future scenarios, the highest risk for adverse health effects was for the off-Site child resident, at a hazard index of 1 (non-carcinogenic risk). The EPA level of concern is a hazard index greater than 1 (non-carcinogenic risk). Most of the potential for risk in this scenario was posed by cis-1,2-DCE. The highest excess cancer risk was for the off-Site future resident farmer at 4×10^{-05}, still within the EPA acceptable excess cancer risk range of 1×10^{-04} to 1×10^{-06}. Most of the potential for carcinogenic risk was posed by VC.

Uncertainties associated with the risk characterization were evaluated. The potential risk (i.e., hazard index of 1) posed by cis-1,2-DCE for the future child resident is likely overestimated as a result of conservative assumptions in the exposure and toxicity assessments. In developing the exposure concentrations, it was assumed that the predicted yearly maximum concentrations (from the *RI Report* model) for all chemicals occur at the same location in the aquifer zone (which is not the predicted case), and that the receptor well "floats" with time so that it is always screened in the maximum chemical concentrations. Additionally, the provisional reference dose for cis-1,2-DCE, provided in Health Effects Assessment Summary Tables (HEAST) [EPA, 1997], was developed by the EPA using a 3,000-fold uncertainty factor. This means that the hazard index of 1 may be overestimated by a factor of 3,000. The provisional reference dose for cis-1,2-DCE is considered by the EPA as non-verifiable and subject to change. Verified reference doses once placed in the Integrated Risk Information System (IRIS) [EPA, 1999] still have uncertainty spanning an order of magnitude and, according to the EPA, should not be viewed as a strict scientific demarcation between toxic and non-toxic levels (EPA, 1989).

1.4.2. Summary of Health Risk, Alternative Evaluation

An alternative method of estimating exposure concentrations was also performed (BMcD, 2001), at the request of the KDHE and the EPA, to address risk management issues. Risk was evaluated for each well along the center-line of the plume (FP-93/96-04 cluster, FP-94/96-09 cluster, FP-94-11, FP-96-23 cluster, FP-96-25 cluster, FP-98-27 cluster, FP-98-29 cluster, FP-98-31 cluster, and FP-99-32 cluster) using the methodology described in the remainder of this paragraph. Chemical concentrations in these wells were assumed to remain constant at their present concentrations for the duration of the residential exposure (i.e., 30 years for an adult and 6 years for a child). Data from July 1998 through August 2000 from the shallow, intermediate, and deep sampling intervals at each well location were combined to determine the COPC 95 percent Upper Concentration Limits (UCLs). The exception was at location FP-94-11, where there is only a shallow well. If the 95 percent UCL was greater than the maximum concentration detected, then the maximum concentration was considered representative of exposure concentration. For chemicals that have not been detected during sampling rounds, one-half the chemical detection limit was used as a proxy concentration. For more information, refer to Section 7.7.2 of the *RI Report* (BMcD, 2001).

The results of that risk characterization indicated hazard indices for a future child resident were above 1 at three well locations (FP-94/96-09 cluster, FP-94-11, and FP-98-27 cluster). The largest hazard index was 4. Ingestion of cis-1,2-DCE in tap water produced all of the significant non-carcinogenic risk at these well locations. The exposure concentrations for cis-1,2-DCE at well locations were based on the lesser of the maximum concentrations or the calculated 95 percent UCLs. The hazard indices for a future resident/farmer were above one at several well locations (FP-93/96-04 cluster, FP-94/96-09 cluster, and FP-94-11). Inhalation of naphthalene produced the significant risk at the on-Site well location (FP-93/96-04 cluster). Ingestion of cis-1,2-DCE in tap water produced the significant non-carcinogenic risk at the other locations. Carcinogenic risk was within the 1 x 10^{-04} to 1 x 10^{-06} (one in 10,000 to one in a million) acceptable risk range at all well locations.

The uncertainty associated with the alternative risk characterization may be great, ranging from an overestimation to an underestimation of potential risk. This may serve to underestimate exposure and risk in the case of chlorinated solvents. This can result if there is an accumulation over time of daughter products of PCE-TCE degradation, which are more potent carcinogens than the parent compounds. However, by comparison to historical trends of contaminant concentrations and the predictions of the fate and transport model, the results of this risk characterization are likely an overestimate of exposure and risk.

Additionally, the provisional reference dose for cis-1,2-DCE, provided in HEAST (EPA, 1997), was developed by the EPA using a 3,000-fold uncertainty factor. This means that the hazard index of 1 may be overestimated by a factor of 3,000. The provisional reference dose for cis-1,2-DCE is considered by the EPA as non-verifiable and subject to change. Verified reference doses once placed in the IRIS (EPA, 1999) still have uncertainty spanning an order of magnitude and, according to the EPA, should not be viewed as a strict scientific demarcation between toxic and non-toxic levels (EPA, 1989).

The alternative evaluation of risk at this Site was performed strictly to address risk management issues, as requested by the KDHE and the EPA. The HHBLRA risk assessment performed in the *RI Report* more accurately reflects Site conditions than the alternative evaluation, and therefore will be used throughout the *FS Report* to evaluate the remedial alternatives. In addition, the current risk potential at this Site has likely changed since an alternative water supply has been provided at this Site to replace private wells impacted by the chlorinated solvent plume (see Section 1.3.3).

In the event that groundwater conditions and land use at the Site, which includes FFTA-MAAF and the general area extending north to the Kansas River (not currently under operational control of the US Army), change to demonstrate potentially significant risk (as defined by the standard EPA protocols) to human health different than previously determined in the *RI Report* (BMcD, 2001), Fort Riley will conduct a comprehensive review of all factors related to the potential risk to ensure adequate protection of human receptors at the Site into the future.

1.4.3. Summary of Ecological Risk

The following is a summary of the Ecological Baseline Risk Assessment (EBLRA) that was performed in the *RI Report* (BMcD, 2001). For a more detailed description, refer to Section 8.0 of the *RI Report* (BMcD, 2001). The FFTA was also evaluated for the presence of ecological receptors and completed ecological exposure pathways. Although a completed exposure pathway from soil to small mammals may be present, the habitat provided by the FFTA was marginal for these receptors. All other receptors, including plants and soil organisms, were qualitatively determined to have no observable adverse effects.

Migration of TCE, PCE, DCE, and VC were modeled and compared to aquatic life benchmarks to evaluate ecological risk to macroinvertebrate receptors in the Kansas River. The estimated maximum present and future concentrations for each chemical were below all available aquatic life benchmarks.

In the event conditions change as described in Section 1.4.2, ecological risk will be reviewed similarly to that conducted for human health risk.

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2.0 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS AND TO BE CONSIDERED INFORMATION

2.1. DEFINITIONS AND METHODOLOGY FOR IDENTIFYING ARARS AND TBCS

2.1.1. INTRODUCTION

CERCLA requires the lead agency for a site to select remedial actions that are protective of human health and the environment, are cost-effective, and utilize permanent solutions and alternative technologies or resource recovery technologies to the maximum extent practicable. CERCLA itself does not contain any cleanup standards; however, one of the requirements of the FS process is to identify the federal and state environmental regulations associated with the remedial alternatives being considered. Specifically, Section 121(d) of CERCLA (42 U.S.C. § 9601 et. Seq.) and the NCP (40 CFR 300), require that the selected remedial action for a site meet the following requirements:

1. The remedial action must be protective of human health and the environment.
2. The remedial action must comply with all federal and state ARARs, unless grounds for invoking a waiver of ARARs are provided. These ARARs are used in combination with the Remedial Action Objectives (RAOs) to assess remedial alternatives for the site.

These requirements make certain that remedial actions performed under CERCLA comply with all pertinent federal and Kansas environmental requirements. Effectively, the CERCLA process requires the lead and support agencies to use ARARs to select remedial standards.

2.1.2. DEFINITION OF ARARs

Section 121 (d) of CERCLA requires that at a minimum, remedial actions must meet federal, or more stringent state, ARARs. ARARs are derived from both federal and state laws. Under Section 121 (d)(2), the federal ARARs for a site may include requirements from any of the federal environmental laws. State ARARs include any promulgated requirements under the state's environmental or facility siting laws that are more stringent than federal requirements. ARARs are identified by applying a two-tier test to first determine if the requirement is applicable, and then if it is not applicable, to determine if it is both relevant and appropriate.

Applicable requirements are those legal standards, criteria, protective requirements, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site (see NCP [40 CFR

300.5]). It is important to note that if a state is authorized to implement a program in lieu of a federal agency, state laws arising out of that program constitute the ARAR instead of the federal authorizing legislation (EPA, 1988).

If a requirement is not applicable, it still may be relevant and appropriate. A requirement may be relevant if it regulates or addresses problems or situations sufficiently similar to the circumstances of the release or remedial action contemplated for the site, and it may also be appropriate if it is well suited to the site in question. If it is not both relevant and appropriate, it is not adopted as an ARAR. However, it is possible for a portion of a requirement to be relevant and appropriate, while other parts are not appropriate for site-specific circumstances. In evaluating the relevance and appropriateness of a requirement, the NCP provides eight factors, as discussed in Section 2.1.7, for comparison against potential ARARs.

2.1.3. State ARARs

Under the NCP, remedial actions must comply with ARARs, which include state promulgated environmental regulations, if any, that are more stringent than federal environmental requirements. State ARARs are also used in the absence of a federal ARAR, or where a state ARAR is broader in scope than the federal ARAR. In order to qualify as an ARAR, state requirements must be promulgated and identified in a timely manner. Furthermore, for a state requirement to be a potential ARAR it must be applicable to all remedial situations described in the requirement, not just at CERCLA sites.

With respect to potential state ARARs, the term "promulgated" is defined to mean regulations of "general applicability [and] legally enforceable." The March 8, 1990 NCP Preamble (55 CFR 46) defines the term "legally enforceable" to mean state regulations issued in accordance with pertinent state procedures and that "contain specific enforcement provisions or [are] otherwise enforceable under state law." A statute or regulation need only contain presumptively valid enforcement "provisions" to be satisfactorily enforceable for ARAR identification. This can occur whether or not such provisions are valid in general or as applied to a specific remedial action.

An applicable state requirement applies as a matter of law to a given situation. A relevant and appropriate requirement does not apply as a matter of law but addresses sufficiently similar situations (See 40 CFR 300.5). The criteria for identifying a state requirement as relevant and appropriate can be construed to mean that, even though there may be no legal (jurisdictional) authority to impose a given regulation for a remedial action taken under CERCLA, the requirement could nonetheless qualify as relevant and appropriate by virtue of its subject matter alone.

The state of Kansas and the implementing Agency, the KDHE, have respectively adopted statutes and administrative regulations which are ARARs.

2.1.4. Types of ARARS

The ARARs which are identified for a specific site are based upon accumulated site contaminant data, specific site conditions, and the identified remedial action alternatives. Consequently, under CERCLA guidance, ARARs are categorized into three broad categories of ARARs, based on the manner in which they are applied at a site. These categories are as follows:

- **Chemical-Specific ARARs** define acceptable exposure levels for a specific chemical in an environmental medium and are used in establishing preliminary remediation goals (PRGs). They may be actual concentration based cleanup levels, or they may provide the basis for calculating such levels. Examples of chemical-specific ARARs are MCLs in drinking water or ambient air quality standards.

- **Location-Specific ARARs** are restrictions imposed when remedial activities are performed in an environmentally sensitive area or special location, such as wetlands or floodplains.

- **Action-Specific ARARs** set controls or restrictions on specific treatment or disposal technologies, such as management of site-excavation remediation waste.

The different categories of ARARs are considered at various stages of the FS process. For example, preliminary chemical-specific ARARs are considered early in the FS process and are generally used to develop remedial goals or cleanup standards for the medium of concern presented in the FS. Location-specific and action-specific ARARs are considered in the evaluation of remedial alternatives, but not defined until further in the CERCLA process [i.e. Proposed Plan (PP) and Record of Decision (ROD)] because the action alternative and the specific location of the response activity have not yet been selected.

2.1.5. To Be Considered Standards

In addition to ARARs, the lead and support agencies for a site may identify federal or state advisories, criteria, or To Be Considered Standards (TBCs) for a specific release that may be useful in developing remedies. Other information that does not qualify as an ARAR may be needed during the development of remedies. This information, referred to as TBCs, consists of non-promulgated advisories, criteria, or guidance issued by federal, state, or local governmental agencies. TBCs are typically issued by federal or state governments, are not legally binding, and do not have the status as potential ARARs. However, TBCs can be used in determining the necessary level of cleanup for the protection of human health and the environment. The NCP Preamble indicates that the use of TBCs is discretionary rather than mandatory; however, their incorporation is recommended. TBC information generally falls within three categories:

- Health effects information with a high degree of credibility;
- Technical information on how to perform or evaluate site investigations or response actions; and
- Policy of administrative agencies.

While they do not carry the weight of ARARs in the determination of remediation goals, TBCs are considered in conjunction with ARARs during a site evaluation and may be used as guidance in determining remediation goals and/or in developing remedies.

2.1.6. Permit Requirements

Section 121(e) of CERCLA codifies the EPA policy that on-site response actions may proceed without obtaining permits. This permit exemption allows the response action to proceed in an expeditious manner, free from potentially lengthy delays of approval by administrative bodies. This permit exemption applies to all administrative requirements, whether or not they are actually styled as "permits." Thus, in determining the extent to which on-site CERCLA response actions must comply with other environmental and public health laws, one should distinguish between substantive requirements, which may be applicable or relevant and appropriate, and administrative and procedural requirements, which are not.

Substantive and administrative requirements are explained as follows:

- Substantive requirements are those requirements that pertain directly to actions or conditions in the environment.
- Administrative requirements are those mechanisms that facilitate the implementation of the substantive requirements of a statute or regulation.

This distinction is important because cleanup activities on a CERCLA site are statutorily exempted by CERCLA Section 121(e) from obtaining permits. While CERCLA cleanups must comply with all the substantive requirements that permits enforce, on-site CERCLA cleanups are not required to obtain the actual permit papers, or to obtain the approval of state or local administrative boards.

For permitting, “on-site” is defined as the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action (EPA, 1989a and EPA, 1989b).

The CERCLA program has its own set of administrative procedures, which facilitate proper implementation of CERCLA. The FS Report, the PP, the ROD, the Community Relations Plan, and the Administrative Record document that the substantive requirements of other federal and state laws have been identified and are complied with.

The classification of a requirement as substantive or administrative is based on whether the provision relates primarily to program administration or primarily to environmental and human health goals. In this case CERCLA guidance provides the following considerations for determining whether the requirement is substantive or administrative:

- The basic purpose of the requirement;
- Any adverse effect on the ability of the action to be protective of human health and the environment if the requirement were not met;
- The existence of other requirements (e.g., CERCLA procedures) at the Site that would provide functionally equivalent compliance; and
- Classification of similar or identical requirements as substantive or administrative in other CERCLA situations.

2.1.7. ARAR IDENTIFICATION PROCESS

The process of identifying ARARs and TBCs is specified in CERCLA Section 121 and the NCP. In addition to the above-mentioned statutory and regulatory requirements, the EPA has published numerous guidance documents for identification of ARARs and TBCs (see ARAR and TBC Guidance Documents in Section 7.0).

The process of identification of ARARs is described and graphically depicted in Section 1.2.4 of the CERCLA Compliance with Other Laws Manual: Interim Final (EPA, 1989a). In general, the identification process involves a two-part evaluation to determine if the promulgated environmental requirement is applicable or, if not applicable, relevant and appropriate. An ARAR may be either "applicable" or "relevant and appropriate."

An applicable requirement directly and fully addresses or regulates the hazardous substance, pollutant, contaminant, action being taken, or other circumstances at the site. To determine if the particular requirement is legally applicable, it is necessary to refer to the terms, definitions, and jurisdictional prerequisites of the statute or regulation. All pertinent jurisdictional prerequisites must be met for the requirement to be applicable. These jurisdictional prerequisites include:

- Who, as specified as in the statute or regulation, is subject to its authority;
- The types of substances or activities listed as falling under the authority of the statute or regulations;
- The time period for which the statute or regulation is in effect; and
- The types of activities the statute or regulations requires, limits, or prohibits.

These statutory or regulatory provisions must then be compared to the pertinent facts about the CERCLA site and the CERCLA response actions being considered. Many of these facts, such as the chemicals present, special characteristics of the location of a site, persons affected, and the type of action under consideration are presented in the *RI Report* (BMcD, 2001) and summarized in Section 3.0 of this report. Other facts, such as the approximate date when substances were placed at a Site, may also be needed to determine if the requirement applies. Different categories of information will be necessary to determine the jurisdictional prerequisites of different requirements, and not all categories will be pertinent in all cases.

If the requirement is not applicable, the next step is to decide if it is both relevant and appropriate. This is essentially a two-step process:

1. Determine if the requirement regulates or address problems or situations sufficiently similar to those at the site, and
2. Determine if the requirement is appropriate to the circumstances of the release or threatened release such that its use is well suited to the site.

The first step focuses on whether a requirement is relevant based on a comparison between the action, location, or chemicals covered by the requirement and related conditions of a site, the release, or the potential remedy. This step should be a screen which will determine the relevance to the potentially relevant and appropriate requirement under consideration. The second step determines whether the requirement is appropriate by further refining the comparison, focusing on the nature/characteristics of the substance(s), the characteristics of a site, the circumstances of the substance(s), the circumstances of the release, and the proposed remedial action. Determining if requirements are relevant and appropriate is site-specific and must be based on best professional judgment considering the characteristics of the remedial action, the hazardous substance(s) present at a site, and the physical circumstances of a site and of the release, as compared to the statutory or regulatory requirement.

The site-specific conditions must be compared to the statutory or regulatory requirements. The EPA further clarifies that requirements determined to be relevant and appropriate do not need to be legally enforceable. This was clarified in the NCP Preamble which states, "EPA disagrees [with the comment regarding changing the definition of relevant and appropriate to include 'while not applicable, sufficiently satisfies the jurisdictional prerequisites for legal enforceability'], because the jurisdictional prerequisites, while the key in the applicability determination, are not the basis for relevance and appropriateness."

The following eight factors, as identified in the NCP, are generally considered in determining if a requirement is relevant and appropriate:

- Purpose of requirement and purpose of CERCLA action;
- Medium regulated or affected by requirement and the medium contaminated or affected at the CERCLA site;
- Substances regulated by requirement and substances found at the CERCLA site;
- Actions or activities regulated by requirement and remedial actions contemplated at the CERCLA site;
- Variances, waivers, or exemptions of requirement and their availability for the circumstances at the CERCLA site;
- Type of place regulated and type of place affected by release or CERCLA action;
- Type and size of structure or facility affected by release or contemplated by the CERCLA action; and
- Consideration of use or potential use of affected resources in requirement and use or potential use of affected resource at the CERCLA site.

The pertinence of each of these factors depends in part on whether a requirement addresses a chemical-, location-, or action-specific ARAR.

The regulations and the EPA guidelines state that the identification of ARARs is conducted on a site-specific basis for each remedial alternative under consideration. The rationale as to why a particular statutory or regulatory requirement is determined to be an ARAR should be documented for each remedial alternative being considered during the detailed analysis of alternatives. Since the preliminary chemical-specific ARARs will generally be the same for all alternatives, a single list is sufficient and does not need to be repeated for each alternative.

2.1.8. TBC IDENTIFICATION PROCESS

TBCs may be used as guidance in determining remediation goals and/or developing remedies. TBCs can be used in determining the necessary level of cleanup for the protection of human health and the environment. Chemical-specific TBC values should be used in the absence of ARARs or where ARARs are not sufficiently protective. Other TBC materials such as guidance or policy documents developed to implement regulations may be considered and used as appropriate. The basic criterion to determine when a TBC should be used is to determine whether use of the TBC is necessary to be protective of human health and the environment at the site. Those TBCs that may be useful in developing CERCLA remedies should be identified.

2.1.9. ARARS Waivers

Occasionally, ARARs may be waived. The NCP identifies six circumstances under which ARARs may be waived:

- The alternative is an interim measure and will become part of a total remedial action that will attain the ARAR;
- Compliance with the ARAR will result in a greater risk to human health and the environment than other alternatives;
- Compliance with the ARAR is technically impracticable from an engineering perspective;
- The alternative will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, or limitation through use of another method or approach;
- With respect to a state requirement, the state has not consistently applied, or demonstrated the intent to consistently apply, the promulgated requirement in similar circumstances at other remedial actions within the state; or,

- For CERCLA-financed response actions only, an alternative that attains the ARAR will not provide a balance between the need for protection of human health and the environment at the site and the availability of CERCLA monies to respond to other sites that may present a threat to human health and the environment.

2.2. PRELIMINARY ARAR/TBC IDENTIFICATION

2.2.1. INTRODUCTION

In accordance with the FFA, the KDHE identified all potential ARARs for the Site early in the remedial process. ARAR identification is an iterative process and possible ARARs are re-examined throughout the RI/FS process. The most recent list of potential ARARs was provided to Fort Riley by the KDHE in August 2001.

2.2.2. EVALUATION OF POTENTIAL ARARs

The KDHE list of potential ARARs was evaluated according to each statutory program and the regulations specific to each program, by considering the COPCs at the Site. The ARAR evaluation was conducted in accordance with <u>CERCLA Compliance with Other Laws Manual, Parts I and II</u> (EPA, 1989a and EPA, 1989b).

Following the ARAR evaluation process, preliminary chemical-specific ARARs for the Site were identified and are summarized in the following section. The term "preliminary" is used at this stage of the FS process, until the final ARAR list is developed further in the CERCLA process (i.e. PP and ROD). Because the action alternative and the specific location of the response activity have not yet been selected, action-specific and location-specific ARARs will be identified further in the CERCLA process (i.e. PP and ROD). Possible location-specific and action-specific ARARs were considered in the evaluation of remedial alternates. The list of ARARs for this Site will be updated as may be necessary throughout the CERCLA process.

2.2.2.1. Preliminary Chemical-Specific ARARs

The preliminary chemical-specific ARARs for this Site are:

- Kansas Surface Water Quality Standards (KAR § 28.16.28b)
- Kansas Water Pollution Control, Antidegradation Policy (KAR § 28.16.28c(a))
- SDWA, National Primary Drinking Water Regulations (40 CFR § 141 and 142)
- Kansas Drinking Water Standards (KAR § 28.15)

2.2.3. OVERVIEW OF GUIDANCES AND POLICIES

Guidances and policies (i.e., TBCs) do not carry the weight of statutory or regulatory requirements but are considered during site evaluations and may be used as guidance in determining remediation goals and/or in developing remedies. The following text provides a brief overview of major guidance materials considered during the preparation of the FS and the evaluation of remedial alternatives.

2.2.3.1. TBC Information

TBCs identified for this Site are:

- SSLs Guidance [EPA, 1996]
- Risk-Based Standards for Kansas (RSK Manual – 3rd Version) [KDHE, 2003]
- Land Use in the CERCLA Remedy Selection Process [EPA, 1995]
- Groundwater Protection Strategy (EPA, 1984)
- Guidelines for Groundwater Classification under the EPA Groundwater Protection Strategy, Final Draft (EPA, 1986)
- 1990 NCP Preamble at 55 CFR 8732
- Corrective Action for SWMUs at Hazardous Waste Management Facilities [61 CFR 18780, April 1996]
- Proposed Rule for Management of Hazardous Contaminated Media (EPA, 1996)
- National Secondary Drinking Water Standards [40 CFR 143]
- Consideration for Hydraulic Containment, Bureau of Environmental Remediation/Remedial Section, BER Policy # BER-RS-028 (KDHE, 1994)
- Monitored Natural Attenuation, Bureau of Environmental Remediation Policy, BER Policy # BER-RS-042 (KDHE, 2001)
- Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. EPA-540-R-99-009 (EPA, 1999a)

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3.0 REMEDIAL ACTION OBJECTIVES AND PRELIMINARY REMEDIAL GOALS

3.1. INTRODUCTION

RAOs consist of medium-specific goals to address risks to human health and the environment posed by a site. RAOs should specify media of interest, contaminants of interest, and PRGs that permit a range of treatment and containment alternatives to be developed and evaluated. Acceptable contaminant levels or ranges of levels for each exposure route should be identified. RAOs are developed on the basis of preliminary chemical-specific ARARs and site-specific risk-related factors. RAOs should also consider current and anticipated future land and groundwater use.

3.2. MEDIA OF INTEREST AND EXPOSURE PATHWAYS

3.2.1. Soil

Potential exposure pathways from soil contamination at this Site include direct exposure (from vapors and direct contact) and leaching to groundwater. However, results from the human and ecological risk assessments performed in the *RI Report* (BMcD, 2001) concluded that concentrations of COPCs at the Site were found to be at, or less than, EPA thresholds for acceptable risk.

In addition, results from a leaching to groundwater evaluation performed in the *RI Report* (BMcD, 2001), concluded that the maximum contaminant concentrations for the COPCs detected in soils were at or below the screening levels for soil to groundwater pathway for residential scenarios (KDHE, 2003). The maximum contaminant concentrations for all of the COPCs detected during the June 1999 soil investigation were at or below the screening levels for soil to groundwater pathway for residential scenarios (KDHE, 2003). Therefore, leaching of contaminants from soil is not anticipated to contribute contaminant concentrations to the groundwater that exceed the MCL. Results from this evaluation are presented in the *RI Report* (BMcD, 2001).

In addition, the pilot test study performed at the FFTA, was successful in removing an estimated 1,896 lbs. of TPH from the FFTA and an estimated 472 lbs. of PCE from the former drum storage area (see Section 1.3.6).

Based on these evaluations, it does not appear that contaminants detected in soil are a significant contributor to groundwater contamination at the Site, and these soil contaminants do not pose an unacceptable risk to human health or ecological receptors at this Site. Therefore, soil is not a medium of interest at this Site.

3.2.2. Groundwater

Results from the HHBLRA and EBLRA, performed in the *RI Report* (BMcD, 2001) concluded that concentrations of COPCs at the Site were found to be at, or less than, EPA thresholds for acceptable risk. However, because the chlorinated solvent plume may potentially be reaching the Kansas River and exists below private property, groundwater is the primary medium of interest at this Site.

3.2.3. Other Media

Surface water is not present at the Site, except immediately following large precipitation events. Five sediment samples collected from the drainage ditch during early investigations, and were non-detect for VOCs (BMcD, 2001). Therefore, surface water and sediment at the Site are not considered media of interest.

In addition, 55 surface water samples were collected by the USGS along five cross-sections of the Kansas River in 1999 and 20 samples were collected along two cross-sections in 2001. These samples were collected both upstream and downstream of the point where the groundwater plume enters the river. The samples were analyzed for VOCs, and all results were reported as non-detect.

Air is also not considered a medium of concern at this Site. Contaminants have never been detected in the breathing zone during any air monitoring activities performed at the Site.

3.3. CHEMICALS OF CONCERN

The EPA screening methodology described in Risk Assessment Guidance for Superfund (RAGS) Part A (EPA, 1989) was used to select COPCs during the HHBLRA performed in the *RI Report* (BMcD, 2001). During this selection process, consideration was given to detection frequency, impacted media, chemical mobility and toxicity, availability of toxicological information, and chemical family. Concentrations of metals detected in soil and groundwater were compared to background levels, and it was determined that, with the exception of isolated and minimal occurrences, metals at the Site are within their respective background ranges and are not considered as COPCs.

Based on the preliminary COPC screening performed in the *RI Report* (see Section 1.3.7), the results of the HHBLRA, the ARAR analysis, and the COPCs currently present at concentrations above MCLs (see Section 1.3.7.2), the following are considered COPCs in groundwater for this Site:

- TCE
- cis-1,2-DCE

3.4. REMEDIAL ACTION OBJECTIVES

As identified in the EPA guidance Rules of Thumb for Superfund Remedy Selection (EPA, 1997a), a remedial action is generally warranted if one or more of the following conditions apply:

1) Cumulative excess carcinogenic risk to an individual exceeds 10^{-4}.

2) Non-carcinogenic hazard index is greater than one.

3) Site contaminants cause adverse environmental impacts.

4) Chemical-specific standards (i.e., ARARs) or other measures that define acceptable levels are exceeded and exposure to contaminants above these levels is predicted for the reasonable maximum exposure (RME) identified in the risk assessment.

For this Site, only item number (4) above applies. Item (4) is applicable at this Site because there are exceedances of chemical-specific standards. For example, drinking water standards (i.e., MCLs) are exceeded in the groundwater, which could potentially be used as a future drinking water source.

RAOs provide a general description of what remedial action is anticipated to accomplish. RAOs are developed based on protection of human health and the environment including consideration of the goals of the CERCLA program. The current goal for long-term groundwater cleanup is summarized in the NCP: "EPA expects to return usable groundwaters to their beneficial uses wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not technically practicable, EPA expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction".

RAOs are developed in this section considering the 1) current and future use at the Site; 2) beneficial use of groundwater at the Site; 3) results of risk assessment; and 4) anticipated fate and transport of contaminants beneath the Site. Current land use, risk assessment (including media of interest, COPCs, and exposure pathways), and anticipated fate and transport are summarized in previous sections of this report with more details provided in the *RI Report* (BMcD, 2001). The following sections provide additional discussion of anticipated future land use and beneficial groundwater use at the Site.

3.4.1. Land Use

3.4.1.1. General

Land use assumptions are an integral factor in the development of RAOs. These assumptions affect the exposure pathways that are evaluated and future land use is important in estimating potential future exposure and associated risks, if any. Realistic land use assumptions allow the FS to be focused on developing practicable and cost effective remedial alternatives.

The EPA's directive on land use in the CERCLA remedy selection process (EPA, 1995) supports the formulation of realistic assumptions regarding future land use and clarifies how these assumptions influence the development of alternatives and the process of remedy selection. The key points of this directive which are relevant to the FS process are the following:

- Remedial action objectives should reflect the reasonably anticipated future land use or uses.
- Future land use assumptions allow the baseline risk assessment and the feasibility study to be focused on developing practicable and cost effective remedial alternatives. These alternatives should lead to site activities that are consistent with the reasonably anticipated future land use.
- Land uses that will be available following completion of remedial action are determined as part of the FS process. During this process, the goal of realizing reasonably anticipated future land uses is considered along with other factors. Any combination of unrestricted uses, restricted uses, or use for long-term waste management may result.

Consistent with the EPA guidance, an assessment of current and future land uses for the Site was conducted, which considered the following factors:

- Current site conditions, such as acreage, zoning, and current land use;
- The zoning and character of the surrounding properties; and
- Potential future land uses for the Site, including residential, recreational, conservation, commercial, and agricultural.

The intent of this land use evaluation is to ascertain feasible options for the development of the Site as it pertains to the FS. A discussion of current and anticipated future land use is identified in Section 1.3.3.

3.4.1.2. Anticipated Future Land Use

Based on the *RI Report* (BMcD, 2001), the anticipated future land use consists of:

- Active military airfield.
- Commercial use including the operation of a racetrack. Future development is anticipated to be minimal due to floodplain zoning regulations.

- A few isolated single family residential dwellings (a few residential homes are currently using groundwater as their primary water supply and are assumed to continue this use into the future). An increase in the number of homes, from current conditions, is not anticipated due to floodplain zoning regulations.
- Agricultural use.

These anticipated land uses will be considered in defining RAOs and evaluating remedial alternatives.

3.4.2. Groundwater Beneficial Use

RAOs and PRGs should reflect current and potential future groundwater uses and exposure scenarios that are consistent with those uses. As identified in the risk assessment, COPCs in groundwater at the Site were found to be at, or less than, EPA thresholds for acceptable risk. Additionally, the evaluation of environmental risk concluded that there is no detrimental exposure to environmental receptors at the Site.

Currently, the following guidance is provided regarding CERCLA program policy for determination of potential future groundwater use:

- Guidelines for Groundwater Classification under the EPA Groundwater Protection Strategy, Final Draft (EPA, 1986)
- A Groundwater Protection Strategy for the Environmental Protection Agency (EPA, 1984)
- 1990 NCP Preamble (55 FR 46)
- Office of Solid Waste and Emergency Response (OSWER) Directive 9283.1-09: The Role of CSGWPPs in EPA Remediation Programs (EPA, 1997b)

The Comprehensive State Groundwater Protection Program (CSGWPP) Directive indicates that, where available, potential future groundwater use should be determined from a CSGWPP that has been endorsed by the EPA and has provisions for site-specific use determinations. Kansas has not developed a CSGWPP. For states that do not have an EPA-endorsed CSGWPP, such as Kansas, the CERCLA program continues to follow the guidance provided in the NCP Preamble. To adhere to the NCP Preamble, groundwater is generally assumed to be a future source of drinking water if designated as such by the state or if considered to be a potential source of drinking water under the 1986 Classification Guidelines, and the remedy must be protective of human health and the environment.

Through the classification guidelines, groundwater resources are separated into hierarchical categories on the basis of their value to society, use, and vulnerability to contamination. The guidelines indicate that the groundwater classification will be a factor in determining the level of protection or remediation.

The EPA classification system is based on drinking water as the highest beneficial use of the resource within a classification review area. The classification review area is delineated based on a two-mile radius from the boundaries of the facility or the activity. The groundwater beneficial use classification classes are:

Class I – Special groundwater

Class II – Groundwater currently and potentially a source for drinking water.

A) Current sources of drinking water

B) Potential sources of drinking water

Class III – Groundwater not a source of drinking water.

A) High degree of interconnection with surface waters or adjacent groundwater units containing groundwater of a higher class.

B) Low degree of interconnection with surface waters or adjacent groundwater units containing groundwater of a higher class.

It is assumed that any groundwater which is currently used for drinking water will fall in Subclass IIA, unless Class I criteria apply (EPA, 1986). Groundwater at this Site is not considered Class I since it does not meet the criteria of irreplaceable or ecologically vital, as defined in the Groundwater Classification Guidelines (EPA, 1986). Since the groundwater is currently used for drinking water at Private Well M02-02, groundwater at this Site is classified as Class IIA.

3.4.3. Defined RAOs

Based on the HHBLRA and EBLRA, the preliminary ARARs identified in Section 2.0, the media of interest, the COPCs in groundwater at this Site, and the anticipated land and beneficial groundwater use, the following groundwater RAOs are presented:

- Prevent ingestion and inhalation (through showering) of groundwater and dermal contact with groundwater containing COPCs exceeding ARARs or risk-based levels.

- Reduce contaminant levels, to the extent practicable and appropriate, through natural and/or active remedial processes.

The RAOs are listed in the general sequence in which they should be addressed (EPA, 1996). These RAOs will be used in the development and evaluation of remedial alternatives in the Feasibility Study.

3.5. PRELIMINARY REMEDIAL GOALS

PRGs are the desired end point concentrations or risk levels, for each exposure route, that are believed to provide adequate protection of human health and the environment. PRGs are usually quantitative chemical-specific concentration targets for each individual COPC for each reasonable exposure scenario. When chemical-specific ARARs are not available or appropriate, risk-based PRG concentrations are often back-calculated using the results of the RME risk estimates. In essence, PRGs are the quantification of the RAOs.

PRGs should reflect current and potential future uses of groundwater and exposure scenarios that are consistent with those uses. Generally, drinking water standards are relevant and appropriate as PRGs for groundwater that is determined to be a current or potential future source of drinking water. As indicated in Section 3.4.2, groundwater at this Site is classified as Class IIA groundwater. The NCP Preamble states that for Class I and II groundwaters, preliminary remediation goals are generally set at MCLs promulgated under the Safe Drinking Water Act, or more stringent state standards.

CERCLA Alternate Concentration Limits (ACLs) may also be used if the requirements of CERCLA section 121 (d) (2) (B) (ii) are met. ACLs may be established in lieu of cleanup levels that would otherwise be ARARs (i.e. MCLs). ACLs may be established where cleanup is not practicable or cost-effective (EPA, 1989a) and where the circumstances fulfill the following conditions as identified in the NCP:

1) Contaminated groundwater discharges to surface water;
2) Such groundwater discharge does not lead to statistically significant increases of contaminants in surface water; and
3) Enforceable measures can be implemented to prevent human consumption of the contaminated groundwater.

In general, ACLs may be used where the preceding conditions are satisfied (as at this Site), and where restoration of groundwater to beneficial use is found to be impracticable. In the context of determining whether ACLs could or should be used for a given site, practicability refers to an overall finding of the appropriateness of groundwater restoration. This is based on the analysis of remedial alternatives using the remedy selection criteria, especially the balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; and cost) and modifying criteria (state and community acceptance). This is distinct from a finding of "technical impracticability from an engineering perspective", which refers specifically to an ARAR waiver and is based on the narrower grounds of engineering feasibility and reliability (with cost generally not a factor). When establishing an ACL, a detailed site-specific justification should be provided in the Administrative Record, which documents that the above three conditions for use of ACLs are met, and that restoration to ARAR or risk-based levels is not practicable.

Based on current and potential future use, the beneficial use of groundwater at this Site is a drinking water source, and the PRGs are defined as the MCLs. The PRGs for this Site are as follows:

- TCE 5 µg/L
- cis-1,2-DCE 70 µg/L

The final remedial goals will be established during remedy selection. These goals can be changed at a later time if more appropriate standards are adopted by the regulatory community, if it is found that technical limitations preclude achieving the goals, if it is found that aquifer restoration is not practicable, or if ACLs are appropriate.

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4.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

4.1. INTRODUCTION

The information presented in this section is a revised version of the document titled Identification/Screening of Technologies and Development of Remedial Alternatives for the Former Fire Training Area at Marshall Army Airfield, Fort Riley, Kansas. (BMcD, 2002a). This document was submitted to the EPA and the KDHE May 17, 2002.

The purpose of this section is to identify and evaluate potential remedial technologies for this Site. The selection of potentially feasible technologies for the Site comprises two steps:

1) Identification and initial screening of potential remedial technologies and process options.
2) Evaluation of remedial technologies and process options.

Remedial technologies refer to general categories of technologies within each general response action (GRA) group. For example, biological treatment and physical/chemical treatment are technologies within the in-situ treatment GRA. Process options refer to specific processes within each technology type. For example, air sparging and in-situ chemical oxidation are process options under physical/chemical technologies. In subsequent chapters, selected technologies and process options are assembled into remedial alternatives capable of achieving the established RAOs. The GRAs selected for this Site are presented below:

- No Action;
- Institutional Controls;
- Other Controls;
- MNA;
- Containment;
- Extraction, Ex-Situ Treatment, and Discharge; and
- In-Situ Treatment.

4.2. IDENTIFICATION AND INITIAL SCREENING OF POTENTIAL TECHNOLOGIES AND PROCESS OPTIONS

4.2.1. Identification of Potential Technologies and Process Options

The initial step taken in the technology evaluation process consists of the identification of potentially applicable technologies and process options, which may be utilized for the management, containment, treatment, and/or disposal of contaminated groundwater. Technologies selected for preliminary screening represent a wide range of responses commonly used to address groundwater contamination. Both fully-developed and emerging process options have been considered. A list of technologies and process options is presented in Table 4-1. Technologies are grouped into seven distinct subsets that correspond to the identified GRAs.

4.2.2. Initial Screening of Technologies and Process Options

Identified technologies are initially screened to eliminate technologies that cannot be effectively implemented at this Site. Technologies are removed from further consideration if they are not technically feasible based on Site-specific conditions such as the aquifer characteristics, the volume of impacted groundwater, and the chemical characteristics of compounds of interest. A summary of this initial screening of technologies is presented, along with a brief description of each technology and the rationale for eliminating process options from further consideration, in Table 4-2.

4.3. EVALUATION OF TECHNOLOGIES

4.3.1. General

Following the initial technology screening, remaining potentially applicable technologies and process options are further evaluated to determine which are potentially feasible for implementation at the Site. This section describes the evaluation and screening procedures and criteria which result in the selection of feasible remedial technology options.

Following EPA guidelines (EPA, 1988), the technology screening evaluation process considers the relative effectiveness, implementability, and cost of each process option for achieving RAOs. Specific technology processes are evaluated based on these three criteria as to whether they are effective (or have a low cost), have no advantage or disadvantage, or are ineffective (or have a high cost) relative to other processes within the same technology type.

The effectiveness of the process option focuses on: (1) the applicability of the process option for the given Site characteristics and estimated areas and/or volumes of contaminated medium and its ability to meet the PRGs identified in the RAOs; (2) the potential impacts to human health and the environment during implementation of the process option; and (3) how proven and reliable the process option is for the given contaminants and Site conditions.

Implementability considers the technical and administrative feasibility of using the technology at the Site. Technical considerations include the ability to construct, maintain, and operate the technology and the ability to comply with regulations. Administrative considerations include the ability to obtain necessary approvals and the availability of equipment, materials, and services.

The relative cost evaluation of each process option focuses on a qualitative evaluation of the capital and operation and maintenance (O&M) costs to implement the technology as compared to other options in the same technology group. These costs will vary significantly from site to site and are used only as a preliminary indication of financial resources required to implement each technology. At this stage of the FS process, effectiveness, and technical implementability evaluations of process options are more important than administrative implementability and cost analyses.

The evaluation of technologies and general comments regarding potential benefits or limitations of each process option are provided in Table 4-3 as part of the screening process. From the technology screening process, several process options are identified as potentially feasible options for groundwater remediation at the Site based on relative potential effectiveness, implementability, and cost. The following sections evaluate process options, identify technologies selected for development of potential remedial alternatives, and provide the rationale for eliminating process options from further consideration. Technologies and process options are discussed by GRA, as identified above. Only technology and process options retained from the initial screening (Table 4-2) are discussed in the following sections.

4.3.2. No Action

Pursuant to Section 300.430(e)(6) of the revised NCP (March, 8 1990) and the EPA's current guidance for conducting *RI/FS* investigations, the "no action" option must be developed and examined as a potential remedial action for all sites. Pursuant to the NCP, this action is retained for further consideration as a baseline for comparison with other remedial actions.

4.3.3. Institutional Controls

Institutional controls such as water use restrictions and alternative water supplies can be used to prevent or reduce exposure to groundwater contaminants. Institutional controls are generally divided into two categories: governmental controls and proprietary controls. Governmental controls are usually implemented and enforced by state or local government and can include zoning restrictions, ordinances, statutes, building permits, or other provisions that restrict land or resource use at a site. Local governments have a variety of land use control measures available from simple use restrictions to more sophisticated measures such as planned unit development zoning districts and overlay zones (EPA, 2000). While government control of property also falls under state or local law, it does not present the same enforcement issues as private controls. Governmental controls remain effective so long as they are not repealed and are enforced (DPRA, 2000).

Proprietary controls include private land use restrictions that typically result by agreement with the landowner and an enforcing party which may be a neighboring landowner, a state environmental agency, or a local civic association. These controls are generally referred to as deed restrictions, since the restriction typically becomes placed within the chain-of-title to the restricted property (DPRA, 2000). The benefit of these types of controls is that they can be binding on subsequent purchasers of the property (successors in title) and transferable, which may make them more reliable in the long-term than other types of institutional controls (EPA, 2000).

4.3.3.1. Government Controls

4.3.3.1.1. Zoning Ordinance Amendment

An amendment to the Geary County zoning ordinance that would create a groundwater restriction overlay district may be applied to the entire county, including the Site, or just only to the Site. However, one of the limitations of applying the new overlay to the entire county is that state law requires zoning districts to contain fixed boundaries. Since this new amendment would restrict contaminated groundwater use anywhere it occurred in the county, it may not be possible to fix boundaries for this overlay district. Therefore, this would qualify as a "floating zone" district, and state law does not allow counties to establish floating zone districts (DPRA, 2000).

The other option for creating a groundwater restriction overlay district is to target only the Site. This scheme may not raise the fixed boundary issue, because a fixed boundary could easily be drawn around the Site, but may be viewed as an unlawful attempt to spot zone. Spot zoning refers to zoning ordinances that unfairly benefit a single person rather than the public. Landowners at the Site may contend that the new zoning is only to Fort Riley's advantage and does not provide any real public benefit. Therefore, targeting only the Site may fail as an illegal attempt to spot zone (DPRA, 2000).

Zoning ordinance amendment is retained for inclusion as a potential component of remedial alternatives.

4.3.3.1.2. County Resolution

An alternative to amending the zoning ordinance is to pass a resolution or new law to restrict contaminated groundwater use. This resolution would serve the same purpose as a zoning ordinance amendment; but, would likely assume the form of a health or environmental resolution, because Kansas state law allows counties to issue such a regulation. This resolution would likely be applied to the entire county because there are no boundary constraints associated with this type of regulation (DPRA, 2000).

Both the zoning ordinance and the environmental and health resolution may face regulatory takings issues; although, the resolution would probably not qualify as a taking. Recent United States Supreme Court decisions and Kansas case law suggest that a taking occurs only if a government regulation denies all economically viable use for land. A groundwater use restriction is unlikely to result in a complete economic loss to impacted properties (DPRA, 2000).

County resolution is retained for inclusion as a potential component of remedial alternatives.

4.3.3.2. Proprietary Controls

4.3.3.2.1. Negative Easements and Restrictive Covenants

Potential proprietary controls at this Site include the use of negative easements, affirmative (access) easements, or restrictive covenants. Restrictive covenants have had greater success in Kansas, and are generally more enforceable against existing and subsequent landowners than negative easements. Landowners are not obliged to grant easements or restrictive covenants. Thus, they may request monetary consideration in exchange for their promise to refrain from groundwater use (DPRA, 2000).

An easement is a property right conveyed by a landowner to another party that gives the second party rights with regard to the first party's land. Easements generally fall into two categories, affirmative or negative. An affirmative easement allows the holder of the easement to enter upon or use another's property for a particular purpose (i.e., an access easement). A negative easement acts as a land use restriction and imposes limits on how the landowner can use his or her property. At this Site, a negative easement could be issued to EPA, KDHE, Fort Riley, or all three. If this easement is issued to prohibit landowners from using contaminated groundwater, the easement owners (EPA, KDHE, or Fort Riley) are allowed to enter and inspect the impacted lands for compliance with the easement. Historically, common law has discouraged the enforcement of negative easements. Whether Kansas courts would allow the enforcement of a negative easement is unclear because Kansas case law is completely void of decisions concerning negative easements (DPRA, 2000).

Restrictive covenants simply provide promises concerning the use of land and act as a contract between the parties who originally enter into it; and as such, its terms may be enforced under contract law. In addition, restrictive covenants generally "run with the land". That is, they apply to and are enforceable on subsequent landowners.

Negative easements and restrictive covenants are retained for inclusion as a potential component of remedial alternatives.

4.3.3.2.2. Affirmative Easements

Affirmative (access) easements would likely be required at the Site to monitor conditions and verify compliance with institutional controls. Additionally, access easements will likely be required if any remedial equipment or active remediation systems are implemented on impacted lands. However, landowners are not obliged to grant easements and may request monetary consideration in exchange for the easement (DPRA, 2000).

Affirmative easements are retained for inclusion as a potential component of remedial alternatives.

4.3.4. Other Controls

4.3.4.1. Monitoring

Groundwater monitoring can be used to evaluate contaminant concentration and migration, monitor natural attenuation, and evaluate remedial system performance. Monitoring results can indicate the need to take appropriate measures, and/or modify the operation of the remedial system, should contaminant levels be found to be migrating off the Site. A network of groundwater monitoring wells is currently in place at the Site. If necessary, additional monitoring wells can be installed to evaluate specific remedial system requirements. Groundwater monitoring is an effective means of evaluating Site conditions and is readily implemented at this Site.

Groundwater monitoring is retained for inclusion as a potential component of remedial alternatives, since this option may be used in combination with other remedial technologies.

4.3.4.2. Alternative Water Supply

4.3.4.2.1. Rural Water Supply

Currently, there are no known users of groundwater at levels greater than MCLs in the vicinity of the contaminant plume. A rural water district supply would consist of extending the municipal water distribution system to serve residents in the area of influence at this Site. City water could be supplied by either extending rural water lines, adding service connections to existing lines, or extending city water lines depending on location(s) and required capacities.

Rural water supply is removed from further consideration as a potential component of remedial alternatives, because new water supply wells were installed at this Site in August 2002, and additional water supply is no longer an issue.

4.3.4.2.2. New Supply Wells

Two alternate water supply wells (M02-02 and R02-02) were installed in August 2002 on private property to replace wells impacted by the chlorinated solvent plume at the Site. Well M02-02 replaces Well M-1, and Well R02-02 replaces Wells R-1, R-2, R-3, and R-4. Wells M-1, R-1, R-2, R-3, and R-4 were abandoned in August 2002 in accordance with KDHE regulations. With the removal of these wells, there are no longer any private wells impacted by the chlorinated solvent plume at the Site.

New supply wells are removed from further consideration as a potential component of remedial alternatives, because new water supply wells were installed at this Site in August 2002, and water supply is no longer an issue.

4.3.4.3. Individual Well Treatment

Readily available and commonly used "point of use" treatment systems include activated carbon adsorption, low-profile air stripping, and oxidation by ultraviolet light. Monitoring of treatment system effluent would be applicable to "point of use" treatment systems to evaluate performance. Implementation of this option requires approval and cooperation of individual landowners.

Individual well treatment is removed from further consideration as a potential component of remedial alternatives, because new water supply wells were installed at this Site in August 2002, and there are no longer any private wells impacted by the plume.

4.3.5. Monitored Natural Attenuation

The term MNA refers to the reliance on natural attenuation processes (within the context of a controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to those timeframes offered by other more active methods (KDHE, 2001). MNA relies on natural subsurface processes to reduce contaminant concentrations. Some of these natural processes may be dilution, dispersion, volatilization, biodegradation, sorption, and chemical reactions with subsurface materials.

Monitored natural attenuation is an active research topic and is becoming increasingly accepted as a remedial alternative. Mechanisms which result in natural attenuation are either destructive or nondestructive. Nondestructive mechanisms include dispersion, diffusion, dilution, volatilization, and sorption.

Dispersion, typically referred to as mechanical dispersion, is the process by which a contaminant plume spreads or disperses as it moves downgradient. Contaminated groundwater mixes with uncontaminated groundwater and produce a dilution of the plume along the leading edge (Fetter, 1993).

Diffusion is the process by which contaminants move from an area of greater concentration toward an area of lesser concentration (Fetter, 1993). Diffusion processes are more pronounced in groundwater systems with very slow flow velocities. The faster the flow velocity, the less likely there will be a noticeable effect due to diffusion processes.

Dilution is the process by which contaminant levels are reduced by introducing clean water into an area of contaminated groundwater. The clean water mixes with the contaminated water and reduces the contaminant concentrations through dilution.

Volatilization is the process by which groundwater concentrations of chlorinated solvents are reduced through mass transfer between liquid and gaseous phases. Contaminants that come in contact with air molecules may transfer from a liquid to gaseous phase and enter the air, thus decreasing the concentration in groundwater.

Adsorption is the process by which contaminants adhere to the solid surface of minerals or organic carbon present in the aquifer. These contaminants may later desorb from the solid surface and continue to flow along with the moving groundwater. This process of adsorption and desorption is generally referred to as sorption and is responsible for slowing the transport of contaminants relative to the transport of groundwater. Rebound of contaminant concentrations is often related to the adsorption and desorption process (EPA, 1996a). The effect of the desorption process also results in a tailing effect in groundwater concentrations. The sorption process is a reason why an ex-situ treatment technology such as pump and treat is less effective at a timely reduction in contaminant levels when compared to a technology that effectively treats the sorbed phase more directly.

Destructive mechanisms include abiotic and biotic degradation processes. Abiotic degradation includes processes such as dechlorination of chlorinated aliphatic hydrocarbons through chemical reactions with ferrous iron. Biotic degradation includes degradation through mechanisms such as electron acceptor reactions, electron donor reactions, and co-metabolism. An important process of natural biodegradation of chlorinated solvents in groundwater is through reductive dechlorination (an electron acceptor reaction) (Wiedemeier et al, 1999). The reductive dechlorination pathway for PCE is as follows: PCE → TCE → cis or trans-1,2-DCE → VC → Ethene → $CO_2 + H_2O$.

Natural attenuation is sometimes perceived as equivalent to "no action". However, MNA differs from the "no action" alternative in that the site is actively monitored and evaluated to reduce the risk of exposure and to evaluate potential further degradation of the aquifer. Typical performance parameters monitored for natural attenuation include: temperature, pH, methane, ethene/ethane, alkalinity, nitrate, sulfate/sulfide, chloride, total organic carbon (TOC), dissolved oxygen (DO), oxygen reduction potential (ORP), iron, and contaminant concentrations. System components of MNA are usually groundwater wells, soil borings, and/or soil vapor probes.

Consideration of this option as a sole remedy requires collection of groundwater quality information and evaluation of contaminant degradation rates and pathways. Modeling can be used to demonstrate that natural processes may reduce contaminant concentrations below regulatory standards before potential exposure pathways are completed. A risk assessment can also be used to evaluate whether monitored natural attenuation is likely to be protective of human health and the environment.

For MNA to be a considered a stand-alone remedial alternative for this Site, the criteria outlined in the following guidance documents must be met: Monitored Natural Attenuation, Bureau of Environmental Remediation/Remedial Section Policy, BER Policy # BER-RS-042 (KDHE, 2001); and Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (EPA, 1999a).

Site geochemical and contaminant concentrations, results from contaminant fate and transport modeling, and results from EPA reductive dechlorination screening protocol (EPA, 1998) performed in the *RI*, indicate there is strong evidence for reductive dechlorination (and thus natural attenuation) of chlorinated solvents at this Site. Therefore, MNA is retained for inclusion as a potential component of remedial alternatives.

4.3.6. Containment

Vertical barriers are typically used as containment walls or to fully surround an area of contamination to arrest migration of contaminants. Barriers can also be used as a means of focusing contaminant migration toward a zone of treatment via extraction and ex-situ treatment, or via in-situ treatment by reactants or amendments. Methods of constructing barrier walls include: slurry walls, sheet piling, and deep soil-mixed walls.

Slurry walls are low permeability vertical cutoff walls which are constructed by installing a vertical barrier into the subsurface using the slurry trench method of construction. The resulting vertical barrier has a lower hydraulic conductivity than the associated formation. Slurries typically consist of lime, bentonite, cement, and/or a proprietary mixture.

Sheet piling consists of steel sheets that are driven into the ground using vibratory or impact equipment to form a continuous cutoff wall.

Deep soil mixing cutoff walls are installed using a crane-supported series of mixing paddles and augers that lift and mix the soil with a low permeability slurry as they penetrate through the subsurface.

Since vertical barriers may be used as a means of focusing contaminants toward a treatment zone (i.e., funnel and gate), they are retained for inclusion as a component of remedial alternatives.

4.3.7. Extraction, Ex-Situ Treatment, and Discharge

4.3.7.1. Collection/Extraction

Vertical wells equipped with pumps are typically used to extract contaminated groundwater for treatment and disposal. The design of recovery wells depends on the type of aquifer that has been contaminated and the recovery rate that is required. The recovery rate determines the size and type of pump and, consequently, determines the diameter of the casing and screen.

Vertical pumping wells are a proven technology for hydraulic containment of groundwater plumes, however the limitations of this technology in reducing contaminant concentrations to MCL (within a reasonable duration) have been well documented (EPA, 1996a). Typically, pumping well systems (generally referred to as "pump and treat" systems) have been successful in reducing high (mg/L) concentrations to much lower levels (i.e., µg/L), but not to MCLs. Reduction to concentrations below MCLs are usually achieved by "polishing" using an additional alternative more appropriate to low level concentrations.

The primary advantage of "pump and treat" systems is to provide hydraulic control of the groundwater and minimize the potential for off-site migration of contaminants. Therefore, collection/extraction (i.e., pump and treat) is retained for inclusion as a potential component of remedial alternatives.

4.3.7.2. Biological Treatment

In the aerobic biological reactor process contaminated water is pumped to a susped growth or attached growth-type reactor where microbial populations aerobically oxidize the organics. Cometabolic aerobic biological reactors are a another biological treatment option. In this option chlorinated VOCs, are transformed as a secondary substrate by methanogenic bacteria (methane degraders). The process requires the addition of methane and oxygen. These treatment processes are removed from further evaluation because they are not as effective and are more difficult to implement than competing technologies.

4.3.7.3. Physical/Chemical Treatment

4.3.7.3.1. Air Stripping

In the air stripping process, volatile organics (chlorinated solvents) are partitioned from groundwater by greatly increasing the surface area of the water exposed to air. The groundwater may be aerated through a variety of methods, including packed towers, diffused aeration, tray aeration, and spray aeration. Air strippers can be permanent or mobile, and can be operated continuously or in a batch mode. Air stripping is used for VOC contamination in groundwater; however, it is ineffective for inorganic contaminants.

To properly select equipment size and type for use, the following information must be known: range of feed water flow rates, range of air and water temperatures, type of operation (continuous or intermittent), type of tower feed and discharge systems, tower height restrictions, influent type and concentration of contamination, mineral content, pH, effluent water contaminant concentrations, and restrictions on air discharge. Technical and administrative considerations do not significantly limit the implementability of this technology. However, iron fouling may be an issue due to the relatively high level of naturally occurring iron at this Site.

Air stripping is retained for inclusion as a potential component of remedial alternatives.

4.3.7.3.2. Carbon Adsorption

Activated carbon is a widely used process for the removal of organic contaminants from liquid waste streams. Groundwater is pumped through a series of vessels containing the activated carbon. The dissolved contaminants adsorb to the carbon and are removed from the water. As the carbon surface areas become saturated with the contaminants, the column's active adsorption zone moves from the influent to effluent end of the vessel. Eventually contaminant breakthrough occurs when all the adsorbing capacity of the carbon is exhausted. Upon exhaustion, the carbon is removed, replaced or regenerated, and disposed of.

Activated carbon is particularly effective for the removal of hydrophobic, high molecular weight organic compounds, such as most of the halogenated organic contaminants of concern. However, VC, a by-product of the dechlorination of PCE, is usually not well adsorbed by carbon; and carbon replacement may be frequent if fouling/plugging is a potential at a site. Technical and administrative considerations do not significantly limit the implementability of this technology.

Carbon adsorption is removed from further consideration as a potential component of remedial alternatives, because the anticipated high flow rates and low concentrations at this Site would limit its effectiveness.

4.3.7.3.3. Organoclay Adsorption

Organically modified clays, which are hydrophobic and organophilic, have shown to be very competitive adsorbing materials when compared to activated carbon. The adsorbing capacity of these clays may be several times as much as that of an equivalent amount of activated carbon. However, these adsorbents are usually more expensive products to manufacture than activated carbon. Another negative aspect of organically modified clays is that it cannot be regenerated on-site.

The disposal options for this process are bioremediation (regeneration), landfill disposal, or incineration. Since this technology has not been used at a scale similar to this project, there are some technical concerns in constructing and operating a larger scale system. Administrative considerations in implementing this technology are the availability of materials and services to operate a system of this scale.

Organoclay adsorption is removed from further consideration as a potential component of remedial alternatives, since it is more applicable to high concentration waste streams and this Site has relatively low contaminant concentrations.

4.3.7.3.4. Oxidation/Reduction

Oxidation/reduction reactions are those in which electrons are transferred so that the oxidation state of at least one reactant is raised while that of another is lowered. In chemical oxidation, the oxidation state of the treated compound(s) is raised. Common oxidants include potassium permanganate, hydrogen peroxide, ozone, calcium or sodium hypochlorite, and chlorine gas. Some of these processes can be enhanced by application of ultraviolet light.

Chemical reduction involves addition of a reducing agent that lowers the oxidation state of a substance in order to reduce toxicity or solubility or to transform it to a form that can be more easily handled. For example, in the reduction of hexavalent chromium to trivalent chromium using sulfur dioxide, the oxidation state of chromium changes from 6+ to 3+ (chromium is reduced) and the oxidation state of sulfur increases from 2+ to 3+ (sulfur is oxidized). Commonly used reducing agents include sulfite salts (e.g., sodium bisulfite, sodium metabisulfite, and sodium hydrosulfite), sulfur dioxide, and the base metals (e.g., iron, aluminum, and zinc).

Chemical oxidation has been used primarily for detoxification of cyanide and oxidation of the chlorinated hydrocarbons and for treatment of waste streams containing oxidizable organics. Organics that have been treated by chemical oxidation are aldehydes, mercaptans, phenols, benzidine, unsaturated acids, and certain pesticides. An oxidant like potassium permanganate can be decomposed in the presence of high concentrations of alcohols and organic solvents. Oxidation/reduction has not been widely used to treat hazardous waste streams. Chemical oxidation can be an effective way of pretreating wastes prior to biological treatment. Compounds that are refractory to biological treatment can be partially oxidized, making them more amenable to biological oxidation.

Chemical oxidation/reduction is removed from further consideration as a potential component of remedial alternatives, because it is more applicable to high concentration waste streams and this Site has relatively low contaminant concentrations.

4.3.7.4. Disposal (Treated or Untreated)

4.3.7.4.1. Discharge to Fort Riley Wastewater Treatment Plant

Groundwater removed from the aquifer can be treated and disposed of by the Fort Riley Wastewater Treatment Plant. Extracted water would require transport to the nearest intake, located at MAAF (approximately 8,000 ft).

Discharge to Fort Riley Wastewater Treatment Plant is removed from further consideration due to the anticipated excessively high costs associated with this discharge option, relevant to other discharge options.

4.3.7.4.2. Discharge to Kansas River

Once groundwater is treated, it can be disposed of to surface water. The nearest surface water body to the Site is the Kansas River. Discharge to this river will not require obtaining a National Pollutant Discharge Elimination System (NPDES) discharge permit, since CERCLA sites are exempt.

Discharge to Kansas River is retained for inclusion as a potential component of remedial alternatives.

4.3.7.4.3. Spray/Sprinkler Irrigation

Sprinkler irrigation is a relatively innovative approach to the treatment/disposal of water contaminated with volatile constituents. This process does not require a separate treatment step prior to disposal as the water is treated during the disposal process. By spraying the water in a fine mist over the area to be irrigated, the surface area available for mass transfer from the water to the air is increased dramatically, and the volatile constituents are transferred to the atmosphere. This process is very similar to air stripping; however, it does not require air blowers or transfer media. Spray irrigation is applicable for volatile compounds only.

Though there are no significant technical concerns in constructing a spray irrigator system, technical considerations in operating a spray irrigation system include maintaining the irrigator system components to eliminate leaks and coordination with farmers to maximize operation of the system without over watering. Administrative issues include the need for sufficient land area to apply the water, and agreements would need to be made or land purchased to allow application by spray irrigation.

Spray irrigation is removed from further consideration, because it could only operate when temperatures are above freezing.

4.3.7.4.4. Groundwater Recharge

An additional option for discharge of treated groundwater is to re-inject the water back to the aquifer. This can be done with the use of injection wells, recharge trenches, or recharge basins. For recharge well options, groundwater is pumped back to the aquifer through permeable zones in the alluvial aquifer. For recharge trench and recharge basin options, shallow, less permeable materials are removed and replaced with a trench or basin. Treated groundwater is discharged to the recharge trench or basin and allowed to percolate by gravity drainage back through permeable unsaturated zone soils and/or directly to the saturated zone. Typically, recharge systems are designed such that an excess capacity is available to account for potential biological and precipitation buildup that might eventually diminish the recharge rate. Required design parameters include subsurface stratigraphy, soil grain-size distribution, infiltration rates, groundwater quality, and groundwater elevations.

Groundwater recharge is removed from further consideration, because it is not needed for an aquifer with such high groundwater velocities and cost relative to surface discharge.

4.3.7.4.5. Discharge to Atmosphere

Discharge of vapors to the atmosphere becomes an issue if technologies such as SVE or air stripping are retained as remedial options. These technologies will produce VOC vapors that may require treatment before discharging to the atmosphere. However, it is extremely unlikely that vapor concentrations would exceed the state limit of 25 tons per year, given the low VOC concentrations in groundwater. Therefore, discharge of vapors to the atmosphere without treatment is anticipated to be permissible at this Site because loading rates are anticipated to be much lower than the state limit. However, discharge to the atmosphere will not require obtaining a permit, since CERCLA sites are exempt.

Discharge of vapors to the atmosphere is retained for inclusion as a potential component in remedial alternatives, because the possibility of producing VOC vapors, as a byproduct of other remedial technologies, exists at this Site.

4.3.8. In-Situ Treatment

4.3.8.1. Enhanced Anaerobic Bioremediation (EAB)

Common electron acceptors used by microorganisms to degrade organic compounds under aerobic (O_2) or anoxic (NO_3^{2-}, SO_4^{2-}) conditions become depleted in anaerobic environments. Therefore, under these conditions, chlorinated solvents have been shown to serve as terminal electron acceptors through reduction reactions. Reduction reactions may be of an abiotic or a biotic nature. Through reduction reactions, chlorinated solvents are dehalogenated (i.e., chlorine atoms are replaced by protons) and the carbon atoms are reduced to a lower oxidation state.

Anaerobic conditions can be produced or enhanced in the subsurface by introducing a primary carbon source, such as glucose, molasses, acetate, organic oils, or lactate; and/or mineral nutrients, such as nitrogen and phosphorous. When proper anaerobic conditions are attained, the introduced carbon source acts as an electron donor and the target contaminants are reduced. For example, PCE is dechlorinated to TCE, and TCE is dechlorinated to DCE and VC. Since the carbon atoms in the resulting intermediate products of the dehalogenation process (e.g., DCE) have a lower oxidation state, these intermediates are more susceptible to subsequent aerobic biological oxidation.

EAB systems can be designed to function as an injection/recovery well system, or injection only well system. Systems consisting of horizontal and/or vertical wells have been used to inject gaseous or liquid additions into groundwater aquifers. EAB systems are generally more applicable to medium to coarse-grained aquifers where compounds and nutrients can be easily delivered to the aquifer. EAB is very site-specific and typically requires extensive pilot testing to determine which system design and/or nutrient requirement is the most applicable to the site.

Vegetable oil has been used recently by the US Air Force for EAB. One of the benefits of organic oils is the partitioning of the contaminants in the oil rather that on the subsurface structure or groundwater. This partitioning results in a containment and treatment technology.

A common carbon source compound is a polylactate ester specially formulated for slow release of lactic acid upon hydration, however similar other compounds use sodium lactate to obtain similar results as lactic acid. These compounds are referred hereinafter as lactate. The lactate is applied to the subsurface via direct-push injection or within dedicated wells. The lactate is then left in place where it passively works to stimulate contaminant degradation (Regenesis, 2001). The process by which lactate operates is a complex series of chemical and biologically mediated reactions. Initially, when in contact with subsurface moisture, the lactate slowly releases lactic acid. Indigenous anaerobic microbes (such as acetogens) metabolize the lactic acid, producing low concentrations of dissolved hydrogen. The resulting hydrogen is then used by other subsurface microbes (reductive dehalogenators) to replace the atoms with hydrogen atoms and allow for further biological degradation. When in the subsurface, the lactate continues to operate for a period of approximately one year, degrading a wide range of chlorinated aliphatic hydrocarbons including PCE and TCE, as well as their daughter products (Regenesis, 2001).

The lactate formulation includes a time-release mechanism to facilitate controlled hydrogen production, to help optimize reductive dechlorination. This controlled release of hydrogen from lactate has been documented in field applications to generate the desired conditions for dechlorination (2-8 nmolar) resulting in contaminant degradation and site restoration (Regenesis, 2001).

EAB is retained for inclusion as a potential component in remedial alternatives due to the potential for enhancing reductive dechlorination of chlorinated solvents at this Site.

4.3.8.2. In-Situ Biofilters

In-situ biofilters are a type of permeable reactive barrier (PRB) in which non-indigenous methanotrophic bacteria are placed within a sand-filled trench that is positioned to intercept a contaminant plume. The bacteria attach to the sand particles to create a sand biofilter. As the ground water flows through the trench, the bacteria metabolize the contaminants. The advantage of using this approach is that by containing the bacteria in a permeable trench, instead of distributing them throughout the aquifer, it is easier to maintain and monitor the required bacteria levels. The disadvantage of this approach is that non-indigenous bacteria are susceptible to rapid die-off. Thus requiring periodic re-injection of bacteria, as well as other nutrient requirements.

In-situ biofilters are removed from further consideration because they are more applicable to low permeability aquifers, rather than the high permeability aquifer at this Site, and because the longevity of non-indigenous bacteria is questionable and difficult to sustain.

4.3.8.3. Air Sparging

Air sparging is an in-situ physical treatment process used to remove volatile chemicals from groundwater. During air sparging, air is discharged into the aquifer through sparging wells, creating a flow of air horizontally and vertically through the saturated soil column. The air flow enhances chemical volatilization. The air bubbles carry the volatilized contaminants to the unsaturated soil layer where they may require removal by vacuum wells. Air sparging is applicable to the treatment of chlorinated and non-chlorinated VOCs and fuels.

At this Site, the aquifer is relatively uniform and permeable, which would enhance the effectiveness of an air sparging system, because aquifer heterogeneties significantly reduce the effectiveness of this technology. An effective remediation system requires that contaminated vapors be collected and removed in the vadose zone to avoid the accumulation of vapors in buildings, and/or to minimize vapor discharge to the atmosphere. At this Site however, because there are no buildings located above the contaminated groundwater plume, and vapor concentrations are anticipated to be well below the State limit of 25 tons per year, collection of vapors (i.e., SVE) is not necessary.

Air sparging systems have traditionally been designed and implemented using a series of vertical injection wells. One of the major disadvantages of this method is that a close spacing of wells, and thus large number of wells, is typically required. More recently, horizontal wells have been successfully used in air sparging systems. This method has been shown to be effective and requires fewer wells than a typical vertical well system.

Depending on the aerial extent of groundwater contamination at the areas where this technology is applied, the overall effectiveness of this technology may be limited. Additionally, because air flow has been shown to be primarily in discrete air channels, only a limited amount of the saturated zone is contacted by the air and there is only minimal mixing, which makes aqueous-phase diffusion limited and therefore relatively slow. Technical considerations do not significantly limit the implementability of this technology. However, current land use and land access needs may limit implementation of this technology.

At the request of the KDHE and the EPA, air sparging is retained for inclusion as a potential component in remedial alternatives.

4.3.8.4. C-Sparger™

C-Sparger™ systems are patented systems that combine in-situ air stripping with in-situ chemical oxidation to remove and destroy chlorinated solvents in the subsurface. In this system, an air/ozone mixture is injected below and into the VOC plume in the form of fine bubbles with a high surface to volume ratio. The gas bubbles extract the volatile contaminants from the contaminated groundwater and the ozone contained within the bubbles reacts in the gaseous phase to decompose the solvents into CO_2, H_2O, and HCl.

The system consists of a two-screen well, two air/ozone points of injection, one below the well casing and the other at the bottom screen, and a submersible pump. Pulsed injection of air/ozone through the bottom diffuser introduces bubbles near the bottom of the plume region, which move upward through the contaminated water. Within the central core area of the plume, a second air/ozone diffusion point, combined with the intermittent operation of a submersible pump at the bottom screen of the well, displaces the vertically-moving bubbles laterally to maximize dispersion and contact. By pulsing the pump operation, groundwater enters the well through the top screen and is forced into the aquifer through the bottom screen. Therefore, groundwater is externally circulated from the bottom to the top of the well, causing circulation of groundwater in the aquifer adjacent to the well and improving the treatment area of the VOC impacted saturated zone.

With this technology, a vapor recovery system in the vadose zone is not necessary because by the time the gas bubbles reach the unsaturated zone, the contaminants are oxidized by the ozone. One potential concern with this approach may be the ozone, which is an air pollutant itself. The quantity of ozone fed to the system needs to be carefully evaluated based on contaminant concentrations in the groundwater. In theory, the amount of ozone needed could be calculated from the chemical oxidation reaction by stoichiometry; however, there may be other organic materials competing with the contaminants of concern, which would increase the required dose.

C-Sparging™ is removed from further consideration because it is has no distinct advantage over competing technologies, is not very effective on low concentration VOC plumes, and has similar limitations to pump and treat systems.

4.3.8.5. Groundwater Circulation Wells

The technology of groundwater circulation wells (GCW) provides volatilization of VOCs within the well casing. In this system, the well has two screened intervals within the same saturated zone. The lower screen is placed at or near the bottom of the contaminated aquifer and the upper screen is installed across or above the water table. By introducing compressed air into the well casing through an open-ended bubbler pipe, groundwater is lifted within the well casing due to the density gradient created between the aerated water and the non-aerated water. As groundwater moves upward and is discharged through the upper screened interval, contaminated groundwater enters the well from the aquifer through the lower casing creating a circulation cell around the well. A mass transfer of VOCs occurs within the well as the air and water mixture rises to the surface.

The three main types of GCW systems that have been used for in-situ VOCs removal are:

- NoVOCs™ patented by Stanford University and purchased in 1994 by EG&G Environmental;
- UVB or "vacuum vaporizer well" system developed in Germany and patented by IEG Technologies Corp.; and,
- Density Driven Convection (DDC) system, developed and patented by Wasatch Environmental, Inc.

With all of the systems, the treatment of VOCs is enhanced by using a vacuum system to transfer the vapor to a VOC treatment system. In the UVB system, the upper and lower screens of the well casing are separated by a packer or divider and a support pump is used to improve water circulation.

The main criteria that need to be considered in designing an GCW system are vapor pressures of the contaminants and subsurface geologic conditions. Optimum conditions for this technology are high contaminant vapor pressures and coarse and homogeneous media. For deep aquifers (> 50 ft), the use of a submersible pump (i.e., UVB) may be necessary to assist the air-lift effect. Potential problems associated with GCW systems may be excessive biological growth and precipitation of soluble metals around injection points. Furthermore, calcium may precipitate as insoluble calcium carbonate ($CaCO_3$) in the presence of carbon dioxide (or highly alkaline waters).

Chlorinated VOCs, the main contaminants at the Site, have high vapor pressures and are likely to be effectively volatilized by this technology. This aquifer presents good geologic conditions, because it mainly consists of coarse materials (sand and gravel). However, depth limitations noted for this type of system may restrict its use at the Site to shallow portions of the aquifer without the assistance of a submersible pump.

GCW are removed from further consideration because it has no distinct advantage over competing technologies, is not very effective on low concentration VOC plumes, and has similar limitations to pump and treat systems.

4.3.8.6. Soil Vapor Extraction

Soil vapor extraction is an in-situ unsaturated (vadose) zone soil remediation technology in which a vacuum is applied to the soil to induce the controlled flow of air and remove volatile and some semivolatile contaminants from the soil. The gas leaving the soil may be treated to recover or destroy the contaminants, depending on local and state air discharge regulations. Vertical extraction vents are typically used at depths of 1.5 meters (5 feet) or greater and have been successfully applied as deep as 91 meters (300 feet). Horizontal extraction vents (installed in trenches or horizontal borings) can be used as warranted by contaminant zone geometry, drill rig access, or other site-specific factors.

For the soil surface, geomembrane covers are often placed over the soil surface to limit or prevent short-circuiting and to increase the radius of influence of the wells.

Ground water depression pumps may be used to reduce ground water upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection, combined with SVE, is effective for facilitating extraction of deep contamination, contamination in low permeability soils, and contamination in the saturated zone.

At the request of the KDHE and the EPA, SVE is retained for inclusion as a potential component in remedial alternatives.

4.3.8.7. In-Situ Chemical Oxidation

Chemical oxidants, such as hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), or ozone (O_3) can be used to oxidize organic contaminants in-situ. This approach may be used to address groundwater and/or soil contamination and non-aqueous phase liquids (NAPLs). An injection method is designed for the specific site and can be either an injection well array, direct-push points, or groundwater injection galleries. A concentrated oxidant solution is injected into the wells or galleries and reacts with organic material present, yielding mainly carbon dioxide and water, both of which are inert and nontoxic. Larger quantities of oxidants may be required if a high organic carbon content is present in aquifer materials. An array of groundwater recovery wells may also be installed downstream of the contaminated plume to provide hydraulic containment. In this latter case, recovered groundwater would be mixed with the oxidant and reinjected into the aquifer creating a circulation cell.

When hydrogen peroxide is used as the oxidant in the process, ferrous iron may also be added as a catalyst. The combination of H_2O_2 with Fe^{2+}, known as Fenton's reagent, has been successfully used for chemical oxidation of contaminants. Ferrous iron enhances the production of hydroxyl radicals which are very strong oxidants. Hydrogen peroxide addition may also increase dissolved oxygen levels in the aquifer which may promote aerobic degradation. Highly chlorinated VOCs are not readily biodegraded aerobically, but some of the transformation products, such as DCE, DCA, or VC have been shown to be metabolized under aerobic conditions.

This technology works better in coarse and homogeneous soils, so that uniform distribution of the oxidant throughout the soil matrix can be achieved. However, large quantities of oxidants may be required to effectively reduce contaminant concentrations. In low-permeability or highly heterogeneous soils, non-uniform distribution of the reagents may result in poor cleanup results. Technical considerations do not significantly limit the implementability of this technology.

In-situ chemical oxidation is eliminated from further consideration due to the anticipated large quantities of oxidants that would be required to reduce contaminant concentrations. At this Site, due to the high permeability, the large area of contamination, and the high organic carbon content of aquifer sediments, in-situ chemical oxidation is not anticipated to be economically feasible.

4.3.8.8. Permeable Reactive Barrier: Zero-Valent-Iron

PRBs involve the construction of a permeable wall across the flow path of the contaminant plume. As the contaminated groundwater moves passively through the treatment wall, the contaminants are removed by physical, chemical and/or biological processes. PRB containing zero-valent iron (Fe^0) chemically reacts with chlorinated solvents usually yielding non-toxic and non-chlorinated by-products. In this process, iron and chlorinated organics undergo an oxidation/reduction reaction, which results in the dehalogenation of the contaminants. Fe^0 acts as an electron donor being oxidized into ferrous/ferric iron, while carbon atoms act as electron acceptors being reduced to lower oxidation states. In this reduction process, the carbon atoms release chlorine atoms, which are replaced by hydrogen. As a result, the reductive elimination process usually renders non-toxic chlorine-free organic compounds.

Main parameters considered in the design of Fe^0 PRBs are the residence time in the reaction zone and the reaction zone size to provide an appropriate life span. Residence time in the PRB is of special importance in completing degradation of highly chlorinated solvents, such as TCE. If contaminants are not completely dehalogenated, intermediates, such as DCE and VC, may still be present in the effluent. The latter is more toxic than TCE itself. Fe^0 PRB design and residence time calculations are available from Environmental Technologies Inc., who owns the patent on this technology.

This technology has several potential advantages over other technologies. A major advantage is that PRBs do not require a continuous input of energy. However, periodic replacement or rejuvenation of the reactive iron medium may be required if its capacity is exhausted. The life of the iron medium mainly depends on contaminant concentrations and groundwater quality in the aquifer. Other advantages are that groundwater is conserved, contaminants are destroyed (not just transferred to other media), and no above-ground structures are required. Therefore, the land surface can be returned to other useful purposes.

Technical implementability issues with this technology are mainly construction related. The depth to bedrock (>60 ft.) makes installation of a fully penetrating PRB difficult, but feasible. Administrative considerations do not significantly limit the implementability of this technology.

Fe^0 PRB is retained for inclusion as a potential component in remedial alternatives due to its applicability in reducing contaminant concentrations at this Site.

4.3.8.9. Permeable Reactive Barrier: In-Situ Air Stripping

VOCs can be stripped from groundwater by discharging air into gravel-filled trenches as groundwater passes through the stripping zone. The freely rising bubbles of air then strip volatile compounds from groundwater that is flowing through the sparge zone. Depending on the situation, VOCs in the air generated by sparging may need treatment prior to release to the atmosphere.

This approach can be advantageous for certain applications compared to in-situ air sparging. In-situ air sparging may be more cost-effective in treating contamination in permeable aquifers, but in-trench sparging may be better suited for low permeability aquifers, where the effectiveness of distributing air into low permeability sediments is greatly reduced. Air stripping PRBs at this Site would encounter construction difficulties similar to those described for Fe^0 PRBs. Administrative considerations do not significantly limit the implementability of this technology.

In-situ air stripping PRB is removed from further consideration because this technology is more applicable to low conductivity materials where traditional aquifer air sparging is limited.

4.3.8.10. In-Situ Redox Manipulation

In-Situ Redox Manipulation (ISRM) is a technology based upon the in-situ manipulation of natural processes to change the mobility or form of contaminants in the subsurface. ISRM was developed to remediate groundwater that contains chemically reducible metallic and organic contaminants. ISRM creates a permeable treatment zone by injection of chemical reagents and/or microbial nutrients into the subsurface. The type of reagent is selected according to its ability to alter the oxidation/reduction state of the groundwater, thereby destroying or immobilizing specific contaminants. Because unconfined aquifers are usually oxidizing environments and many of the contaminants in these aquifers are mobile under oxidizing conditions, appropriate manipulation of the redox potential can result in the immobilization of redox-sensitive inorganic contaminants and the destruction of organic contaminants. This concept requires the presence of natural iron (i.e., Fe^{+3} state), which can be reduced from its oxidized state in the aquifer sediments to serve as a long-term reducing agent (DOE, 2000).

A chemical reducing agent such as sodium dithionite is injected into the aquifer through a conventional groundwater well. The reducing agent reacts with iron (i.e., Fe^{+3} state) naturally present in the aquifer sediments in the form of various minerals (clays, oxides, etc.). During the injection phase, the reagent is injected into the aquifer through injection/withdrawal wells at the rate and duration required to treat the desired volume of aquifer sediments. This treatment volume plus the quantity of available iron in the sediments determines the amount of reductive capacity generated in the barrier and, ultimately, the barrier's duration. During the residence phase (24 to 36 hours), the reagent is allowed to react with the aquifer sediments. The reductant reacts with the iron in the sediments by the following reaction: $SO_2^- + Fe^{+3} + H_2O = SO_3^{-2} + Fe^{+2} + 2H^+$. Buffers are added to balance the groundwater pH, which decreases with the addition of sodium dithionite.

During the withdrawal phase, unreacted reagent, buffers, reaction products, and mobilized trace metals are withdrawn through the injection/withdrawal wells and disposed. Once Fe^{+3} in the aquifer has been reduced to Fe^{+2}, reductive degradation of chlorinated solvents is initiated. Redox sensitive contaminants that migrate through the reduced zone in the aquifer become immobilized (metals) or destroyed (organic solvents). The major pathway for reductive degradation of chlorinated solvents is by reductive elimination. TCE, for example, is reduced to chloroacetylene, then to acetylene, and finally to ethene by reductive elimination. The minor pathway, hydrogenolysis, is also possible within the reactive zone, but less likely than reductive elimination. In this pathway, TCE is reductively reduced to cis-1,2-DCE, then to VC, and finally to ethene. Potential contaminants for treatment with ISRM include: chromate, uranium, technetium, and chlorinated solvents.

ISRM is a passive barrier technique, with no pumping or above-ground treatment required once the treatment zone is installed. For this reason, the operation and maintenance costs after installation are very low. The treatment zone remains active in the subsurface, where it is available to treat contaminants that seep slowly from less permeable zones. The barrier is renewable if the original emplacement does not meet performance standards.

ISRM has been demonstrated to treat TCE contamination at a Fort Lewis, Washington site in 1998. Battelle Pacific Northwest National Laboratory is currently working with commercial partners to deploy the technology.

ISRM is retained for inclusion as a potential component in remedial alternatives due to its applicability in reducing contaminant concentrations at this Site. However, because ISRM is a relatively new innovative technology, extensive pilot testing would likely be required before a full-scale system is implemented.

4.3.8.11. Bimetallic Nanoscale Particles

Bimetallic Nanoscale Particles (BNP) are submicron ($<10^{-6}$ meters) particles of Fe^0 that are small enough to migrate along with the groundwater flow. When injected into an aquifer contaminated with chlorinated solvents, the BNP and chlorinated organics undergo an abiotic oxidation/reduction reaction, which results in the reductive elimination of the contaminants. Fe^0 acts as an electron donor being oxidized into ferrous/ferric iron, while carbon atoms act as electron acceptors being reduced to lower valance states. In this reduction process, the carbon atoms release chlorine atoms, which are replaced by hydrogen. As a result, the reductive elimination process yields non-toxic, chlorine-free organic compounds. The minor pathway, sequential hydrogenolysis (see Section 4.3.8.11), is also possible but is 100 to 400 times less prevalent (Szecsody et al., 2000; Vermeul et al., 2000). Sequential hydrogenolysis is also referred to as the reductive dechlorination of PCE to VC. The BNP technology has been used at nine groundwater remediation sites (PARS, 2002).

The microscopic size of BNP provides a large surface area that is available to react with chlorinated solvents, thus resulting in a much lower iron-contaminant ratio than required by a Fe^0 PRB. Some fraction of the injected nanoparticle mass remains relatively immobile, functioning as a semi-permeable in-situ PRB. The remainder will travel to some degree with the groundwater flow. The proportion varies with the hydrogeologic conditions at the site and could be better assessed during a pilot study (Elliot, 2002). No extraction or recovery is necessary with BNP. The particles will be completely consumed by the contaminants or the other reduction processes present in the aquifer. The concentration and application rate of BNP can be designed to limit or prevent the BNP from moving too far downgradient before they are consumed by the aquifer, if necessary.

BNP technology is retained for inclusion as a potential component in remedial alternatives due to its applicability in reducing contaminant concentrations at this Site. However, because BNP is a relatively new innovative technology, extensive pilot testing would likely be required before a full-scale system is implemented.

4.3.8.12. Dynamic Underground Stripping

Dynamic underground stripping (DUS) is a process that uses steam injection to heat permeable aquifer layers, electric current to heat impermeable or less permeable layers, and underground imaging to delineate the heated areas and facilitate cleanup. The heat produced from this process volatilizes VOCs and SVOCs in the subsurface. These vapors are then removed from the soil through SVE systems.

Typical DUS systems consist of a series of steam injection wells and vacuum extraction wells. A heated front is created as the steam/electric heat moves from the injection to the extraction wells. Underground imaging, primarily electrical resistance tomography is used to monitor the heated front and ensure that all of the anticipated areas are heated. Although DUS has been field-tested in limited settings, results indicate this technology is very effective in removing VOCs and SVOCs. One of the limitations of this technology is it is an energy-intensive process and is typically only used for shallow and/or small "hot spot" contamination areas due to the very high operating costs. Therefore, DUS is removed from further consideration because the high concentration area at this Site is beyond the economical feasibility of this technology.

4.3.8.13. Six-Phase Soil Heating

Six-phase soil heating (SPSH) was developed to rapidly remediate soil contaminated with VOCs, SVOCs, and heavy hydrocarbons such as diesel, jet fuel and coal tar. SPSH is designed to enhance the removal of contaminants from the soil and groundwater with a recovery system such as SVE or dual phase vapor extraction. The SHSH, developed by the Battelle's Pacific Northwest National Laboratories in 1992 and being demonstrated first full-scale system in 1998, is an innovative technology using multiphase electric technique that is powered by readily available 60 hertz electricity to resistively heat soil and groundwater to enhance the removal of the contaminants from the subsurface.

The SPSH operates under the principal that electric current passing through a resistive component, such as soil, will generate Joule heat. The amount of current that can be made to flow through a given soil type is a function of the voltage applied and the resistance of that soil. Several factors govern the resistance between adjacent SPSH electrodes. Since distance and soil types are fixed components for a given site, current flow and associated generated heat across the site can be controlled by regulating soil moisture content and applied voltage. As voltage is applied to the electrodes, the current flows via the pathway of least electrical resistance, causing the soil including groundwater in those areas to heat first. As subsurface temperatures rise to the boiling point of water, contaminants with low boiling points are volatilized and soil moisture is vaporized into steam. The induced contaminant vapors and steam are then withdrawn by the SVE and/or a dual phase vapor extraction system. During operation of the SPSH system, the subsurface with less electric resistance begins to dry out first. This drying reduces the electric conductivity of the soil in these areas, causing an increase in soil resistance. As the resistance of the soil increases, other pathways become preferential for current flow, effectively increasing the heating to the remaining impacted areas. This self-regulating mechanism provides for uniform heating of even heterogeneous lithologies.

SPSH uses conventional single-phase transformers to convert standard three-phase electricity into six-phase electricity. This power is then delivered to an electrode array consisting of six steel electrodes arranged in a hexagonal pattern, with one neutral electrode placed in the center. The electrodes are surrounded with granular graphite to improve electrical conductivity to the soil matrix. The center electrode functions not only as the electrical neutral, but also as a soil vapor extraction well, dual phase vapor extraction well, or oil recovery well.

One of the limitations of this technology is it is an energy-intensive process and is typically only used for shallow and/or small "hot spot" contamination areas due to the very high operating costs. Therefore, SPSH is removed from further consideration since the high concentration area at this Site is beyond the economical feasibility of this technology.

4.3.8.14. Fluid Delivery Systems

Fluids such as nutrients, oxidants, and other chemical compounds can be added to the subsurface through vertical or horizontal wells/borings. Vertical wells have typically been used to disperse chemicals and additives into groundwater aquifers. The advantage of this method is that chemicals can be continuously applied or reapplied as necessary.

Recently, direct-push technology has been utilized to disperse chemicals and additives into groundwater aquifers. This method has been used in bioremediation to apply lactate, and in chemical oxidation to apply oxidants to the subsurface. The advantage of this method is that multiple injection points at various depths can be utilized at a cost much less than that of conventional wells.

Horizontal wells have also been used to disperse chemicals and additives into the subsurface. The advantage of this method is that fewer wells are typically required to achieve the desired coverage, compared to vertical wells. In addition, fluids can be dispersed at specific depths if required, and applied continuously or reapplied as necessary.

Technical considerations do not significantly limit the implementability of these delivery systems. However, current land use and land access needs may limit implementation.

Vertical and horizontal fluid delivery systems are retained for inclusion as a potential component in remedial alternatives because these systems may be used in conjunction with other remedial technologies.

4.4. REMEDIAL ALTERNATIVES

Based on the results from the screening procedure presented above, eight remedial alternatives are identified for this Site. The first six alternatives were originally identified in the *Tech ID* (BMcD, 2002a) submitted to the KDHE and the EPA on May 17, 2002. Two additional alternatives (Alternatives 7 and 8) have been added at the request of the KDHE and the EPA. The remedial alternatives assembled for this Site are as follows:

Alternative 1	No Action
Alternative 2	Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action
Alternative 3	Enhanced Anaerobic Bioremediation with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action
Alternative 4	Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring
Alternative 5	In-Situ Redox Manipulation with Institutional Controls and Monitoring
Alternative 6	Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action
Alternative 7	Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring
Alternative 8	Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

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5.0 DETAILED ANALYSIS OF ALTERNATIVES

5.1. INTRODUCTION

The information presented in this section is a revised version of the document <u>Detailed Analysis of Alternatives, FFTA-MAAF at Fort Riley, Kansas.</u> (BMcD, 2002b). This document was submitted to the EPA and the KDHE November 11, 2002.

This detailed analysis of alternatives consists of the analysis and comparison of remedial alternatives, and allows decision-makers to select a site remedy. During the detailed analysis, each alternative is assessed against the evaluation criteria described in Section 5.2. The results of this assessment are arrayed to compare the alternatives and identify the key tradeoffs among them. This approach to analyzing alternatives is designed to provide decision-makers with sufficient information to adequately compare the alternatives, select an appropriate remedy for a site, and demonstrate satisfaction of the CERCLA remedy selection requirements in the ROD (EPA, 1988).

5.2. EVALUATION CRITERIA

To address the CERCLA requirements adequately, nine evaluation criteria have been developed by the EPA (EPA, 1988). The first two criteria are the "threshold" factors. Any alternative that does not satisfy both of the following criteria is dropped from further consideration in the remedy selection process:

1. Protection of human health and the environment, and
2. Compliance with ARARs.

Five "primary balancing" criteria are then used to make comparisons and to identify the major trade-offs between the remedial alternatives. Alternatives that satisfy the threshold criteria are therefore evaluated using the following balancing criteria:

3. Long-term effectiveness and permanence,
4. Reduction of toxicity, mobility, or volume,
5. Short-term effectiveness,
6. Implementability, and
7. Cost.

The remaining two criteria are "modifying" factors and are to be evaluated in the ROD. The evaluation of these two factors can only be complete after the CERCLA PP is published for comment and the public comment period is completed. These modifying factors are:

8. State (or support agency) acceptance, and
9. Community acceptance.

A more detailed discussion of the nine evaluation criteria is presented below. Each remedial alternative is evaluated in Section 5.3 with respect to the first seven criteria.

5.2.1. Protection of Human Health and the Environment

Remedial actions must be protective of human health and the environment. If the alternative is not considered to be protective of human health and the environment, then it cannot be selected. This analysis is a final check to assess whether each alternative provides adequate protection of human health and the environment. Each alternative is evaluated on its potential to limit exposure risk to humans and the environment during and after implementation of the remedial action. Alternatives posing the least short- and long-term risk to human health and the environment are the most desirable. Risks associated with construction and management of wastes generated during remedial actions are also considered in the evaluation.

5.2.2. Compliance with ARARs

The NCP indicates that the lead agency will identify ARARs based upon an objective determination of whether the requirement specifically addresses a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site (40 CFR 300.400(g)). The identification and selection of potential ARARs and TBCs is intended to assist in evaluation of potential remedial alternatives. Alternatives must be compliant with ARARs or they cannot be considered for remedy selection unless an ARAR waiver is justifiable (as defined under 40 CFR 300.430 (f)). Preliminary ARARs and TBCs potentially applicable at this Site are presented in Section 2.0 of this report.

5.2.3. Long-Term Effectiveness and Permanence

The long-term effectiveness and permanence criterion evaluates the ability of an alternative to prevent or minimize substantial danger to public health and the environment after RAOs have been met. Components considered when evaluating the long-term effectiveness and permanence of an alternative include examining the magnitude of residual risk and the adequacy and long-term reliability of controls that may be required to manage this residual risk (EPA, 1988). Residual risk, for example, may be the risk posed by treatment residuals and/or untreated wastes or areas. The demonstrated long-term effectiveness and permanence of equivalent alternatives(s) (under similar site conditions) at other sites is considered in evaluating whether the alternative can be used effectively.

5.2.4. Reduction of Toxicity, Mobility, or Volume

This evaluation criterion addresses the statutory preference for selecting remedial actions that employ treatment technologies that permanently and significantly reduce toxicity, mobility, or volume of the hazardous substances as their principal element (EPA, 1988). The fundamental objective of reducing the toxicity of a hazardous chemical is the protection of human health and the environment. This can be accomplished by reducing the contamination levels (thus, the risk of human exposure) and by limiting or preventing contaminants from reaching unimpacted areas. Mobility refers to the contaminant's ability to migrate to unimpacted areas or media. Volume reduction can be evaluated by assessing the amount of hazardous material destroyed or treated, the proportion of the contaminant plume that is remediated, and the amount remaining on site. In addition, the degree to which the treatment is reversible needs to be evaluated. Thus, based on these considerations, the effectiveness of each alternative in reducing toxicity, mobility, and volume is evaluated in this document by assessing its ability to: (1) reduce risk for human exposure, (2) prevent further degradation of the aquifer or migration of contaminants to unimpacted zones, and (3) reduce volume of impacted aquifer.

5.2.5. Short-Term Effectiveness

Short-term effectiveness evaluates alternatives with respect to their effects on human health and the environment during implementation of the remedial action. The estimated time frame required to achieve the RAOs, the short-term reliability of the technology, and protection of the community and workers during remediation also are considered under this criterion. Furthermore, the ability of an alternative to be protective of potential receptors during the failure of any one technology or uncontrollable changes at the Site are considered.

5.2.6. Implementability

Implementability is used as a measure of both the technical and administrative feasibility of constructing, operating, and maintaining a remedial action alternative (EPA, 1988). Technical feasibility refers to the following factors:

- Ability to reliably construct, operate, and maintain the components of the alternative during remediation and after completion, as well as the ability to meet applicable technical regulatory requirements;

- Likelihood that technical problems associated with implementation will lead to schedule delays;
- Ability of remedial equipment to undertake additional remedial actions (e.g., increased flows or volumes), and/or phase in other interim remedial actions, if necessary; and
- Ability to monitor the effectiveness of the implemented remedies.

Administrative feasibility includes the following criteria:

- Ability to get permits and approvals from the appropriate agencies to implement the alternative;
- Availability of support services for the treatment, storage and disposal of generated wastes; and,
- Availability of specialized equipment or technical experts to support the remedial actions.

5.2.7. Cost

O&M costs are evaluated for each alternative. Capital costs include design costs, equipment costs, construction costs, and other relevant short-term expenditures associated with the installation of the remedial action components. O&M costs include the expenses associated with equipment maintenance and repair, site and equipment monitoring, power, chemicals, disposal of residues, and any other periodic costs associated with the remedial action operation throughout the project life.

Cost is mainly used to eliminate alternatives that are significantly more expensive than others without proportional benefits or to choose among several alternatives offering similar protection to human health and the environment. The main components of each alternative were preliminary sized prior to developing the cost estimates. Sizing was based on general guidelines found in technical literature, past experience, and general professional judgment. For the cost estimation process, data were gathered from cost estimation software (RACER, 2000), vendor quotations, prior expenses, and professional judgement. The level of detail was kept very similar in all of the alternatives to avoid comparing estimates having different levels of accuracies.

For comparison purposes, capital costs are assumed to be expended in year zero (0), even though some alternatives may take longer to implement than others. Since expenditures occur over different periods of time in some of the alternatives, O&M and periodic costs are discounted to a common base year (i.e., year zero) and added to the capital costs to obtain the total present worth of each alternative. With present worth analysis, alternatives can be compared on the basis of a single value. Following EPA guidelines (EPA, 1993; and EPA, 2000a), a discount rate of 3.2 percent is appropriate to use for federal facilities.

In accordance with 40 CFR 300.430 (f)(1)(ii)(D), cost-effectiveness is determined by first evaluating overall effectiveness based on the three balancing criteria of long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; and short-term effectiveness. Overall effectiveness of an alternative is then compared to its cost to determine if its costs are proportional to its overall effectiveness. Cost estimates are intended to provide a basis for alternative evaluation and comparison purposes only and should not be used for future budgeting, bidding, or construction purposes. Detailed cost analysis tables are presented in Appendix A.

5.2.8. State Acceptance

This assessment is to be performed as part of the ROD development and public comment process and incorporates the state's technical and administrative agencies input regarding each of the remedial alternatives. At this Site, the state is represented by KDHE and EPA Region VII, along with the lead agency (the United States DA). The factors to be evaluated include features of the actions that the state supports, has reservations about, or opposes.

5.2.9. Community Acceptance

This assessment is to be performed as part of the ROD development and public comment process, and incorporates public input into the analysis of the remedial alternatives. Factors of community acceptance to be discussed include features of the support, reservations, and opposition of the community. Fort Riley has an existing community relations plan (per the Fort Riley Restoration Advisory Board) and conformance with this plan will be a component of the assessment of this criterion.

5.3. ANALYSIS OF REMEDIAL ALTERNATIVES

In this section, the six remedial alternatives identified in the *Tech ID* (BMcD, 2002a), plus two additional alternatives added at the request of the KDHE and the EPA, are evaluated using the first seven criteria described above in Section 5.2. Evaluation of the last two criteria (i.e., state and community Acceptance) are deferred to the ROD following receipt of state and public comments. The eight remedial alternatives are as follows:

Alternative 1	No Action
Alternative 2	Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action

Alternative 3	Enhanced Anaerobic Bioremediation with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action
Alternative 4	Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring
Alternative 5	In-Situ Redox Manipulation with Institutional Controls and Monitoring
Alternative 6	Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action
Alternative 7	Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring
Alternative 8	Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

In addition to the screening criteria evaluation, this detailed analysis of alternatives presents advantages and disadvantages of each alternative. These are included to provide critical information that may influence the selection of a remedial alternative. This list includes information obtained from technology vendors, technology reports and articles, and other related publications.

To assess the effectiveness and help determine relative cleanup times for each technology, the contaminant transport model developed as part of the *RI Report* (BMcD, 2001) was used to analyze remedial alternatives. This model was used by incorporating the technology outlined in each alternative into the model. The cleanup times predicted by the model represent the length of time required for concentrations to decrease below MCLs. However, the cleanup times predicted by the model are for comparison purposes only and may not represent actual dates. The actual cleanup times may vary significantly due to a number of factors (e.g., detailed final design, effectiveness of alternatives at low concentrations, system down time, concentration rebound, etc.). A sensitivity analysis of the model is provided in Section 6.5.3.5.2 of the *RI Report* (BMcD, 2001).

The modeling scenario used to evaluate Alternatives 1 and 2 is identical to the model developed in the *RI Report* (Section 6.5.3.5.1), because this is a simulation of the natural processes occurring at the Site. The model for this Site is consistent with the recent data collected and appears to simulate Site conditions (see Section 1.3.8.2). For the remaining alternatives, each active remedial technology was incorporated into the model using the preliminary design developed for each alternative. A detailed description of the modeling performed for each remedial alternative is provided in Appendix B.

A preliminary design of the remedial technologies was developed for each alternative. All of the designs are based on an estimated treatment area of 4,500-ft. (L) x 250-ft. (W) x 45-ft. (D), essentially the area of the plume with concentrations greater than MCL (based on results from the March 2002 sampling event; BMcD, 2002b). This area extends from the FFTA to Monitoring Well FP-98-31 (see Figure 5-1). Downgradient of Monitoring Well FP-98-31, the concentrations of all contaminants are below MCLs (based on results from the March 2002 sampling event; BMcD, 2002c). The preliminary design was based on results from the March 2002 sampling event (BMcD, 2002c) and may change, if necessary, during the final design phase of this project.

5.3.1. Alternative 1 – No Action

5.3.1.1. Description

This alternative is the "no action" alternative, a requirement of the NCP, which provides a baseline for comparison of active remedial alternatives developed for the Site. Under the no action alternative, institutional controls are not implemented and remediation and monitoring of the groundwater contamination are not conducted. Two alternate water supply wells (M02-02 and R02-02) were installed in August 2002 on private property to replace wells impacted by the chlorinated solvent plume at the Site (see Figure 1-1). Well M02-02 replaces Well M-1, and Well R02-02 replaces Wells R-1, R-2, R-3, and R-4. Wells M-1, R-1, R-2, R-3, and R-4 were abandoned in August 2002. With the removal of these wells, there are no longer any private wells impacted by the chlorinated solvent plume at the Site.

By definition, this alternative requires that the current monitoring program be discontinued. At a minimum, CERCLA requires administrative reassessments every five years, if the Site is not open for unrestricted use, whenever contaminants are left in place.

5.3.1.2. Evaluation

5.3.1.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. However, since this alternative does not include institutional controls, there is no control of future use. Therefore, an atypical exposure scenario (not characterized in the *RI Report* baseline risk assessment) is possible.

5.3.1.2.2. Compliance with ARARs

Groundwater sampling results, up to and including the March 2002 sampling round, indicate that preliminary chemical-specific ARARs (i.e., MCLs) were exceeded for two of the COPCs at the Site (TCE and cis-1,2-DCE). Based on the natural attenuation modeling performed in the *RI Report* (BMcD, 2001), all COPCs at the Site are predicted to be reduced below MCLs in ten years, thus meeting the preliminary chemical-specific ARARs for this Site. VC has only been detected in six of over 700 groundwater samples collected at this Site. There is no trend to these detections, they are low level and sporadic. This provides strong evidence that it is not accumulating in the aquifer as a result of dechlorination of cis-1,2-DCE. For this alternative, there are no location- or action-specific ARARs. A list of preliminary ARARs for this Site is presented in the Section 2.2.2.1.

5.3.1.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, until closure to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). Institutional controls are not included with this alternative.

5.3.1.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that natural attenuation processes will reduce COPC concentrations at the Site to below MCLs in ten years, and that it is unlikely that the contaminant plume will migrate to unimpacted areas of the aquifer. This prediction is to be used only for comparative purposes with other alternatives. Since the contaminant plume has terminated at the Kansas River, there are no downgradient unimpacted areas of the aquifer, with the exception of the shallow aquifer zone downgradient of Monitoring Well FP-96-23. This shallow area of the aquifer is currently uncontaminated, and is anticipated to remain unimpacted from COPCs. This is likely due to aerobic degradation of contaminants in the shallow zone (*RI Report*, Section 6.5.3.5.1).

The modeling scenario used to evaluate this alternative is identical to the model developed in the *RI Report* (Section 6.5.3.5.1), because this is essentially a simulation of the natural processes occurring at the Site. Thus far, the model has been accurate in predicting the concentrations at the Site. Below is a summary of the model predictions and the August 2002 groundwater sampling results. The last round of data input into the model was from the August 1999 sampling event. Therefore, three years have elapsed since the model predictions. The results from this comparison provide strong support to the model's credibility.

RI Model Prediction	Groundwater Results from the August 2002 Sampling Event
PCE will be below the MCL (5 µg/L) in 1.5 years. (i.e., February 2001)	PCE has been below the MCL at the Site for the past two rounds (i.e., March 2002 and August 2002).
TCE will be below the MCL (5 µg/L) in 3.5 years. (i.e., February 2001)	There are only four wells where TCE remains above the MCL, compared to eight in August 1999. TCE has decreased from 25.8 µg/L in August 1999 to 10.7 µg/L in August 2002.
cis-1,2-DCE will be below the MCL (70 µg/L) in 10 years. (i.e., August 2009)	cis-1,2-DCE has decreased from 496 µg/L in August 1999 to 134 µg/L in August 2002.
VC will be below the MCL (2 µg/L) in 0.5 years. (i.e., February 2000)	VC has only been detected one time since August 1999, and that was in March 2002 at a concentration of 1.1 µg/L.

Reduction in contaminant volume is anticipated to be achieved with this alternative through biodegradation. Biodegradation is the dominant natural attenuation process at this Site acting to destroy contaminant mass in groundwater. VC has only been detected in six of over 700 groundwater samples collected at this Site. There is no trend to these detections, they are low level and sporadic. This provides strong evidence that it is not accumulating in the aquifer as a result of dechlorination of cis-1,2-DCE. In addition to biological processes, dispersion and diffusion processes also serve to reduce contaminant concentrations.

5.3.1.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative predicts that all COPCs at the Site will be reduced below MCLs in ten years (see Appendix B). There would be no additional detrimental effects posed on the community, the workers, or the environment as a result of implementing the "no action" alternative.

5.3.1.2.6. Implementability

There are no implementability concerns posed by this remedy because no action would be taken.

5.3.1.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $370,000, with a capital cost of $0, total O&M cost of $0, periodic costs totaling $490,000, and a total project cost of $490,000. The only costs are for five-year reviews, groundwater monitoring for the reviews, and the closure report. Detailed cost analysis tables are presented in Appendix A.

5.3.1.3. Additional Criteria

5.3.1.3.1. Advantages

- Low cost.
- No additional risk to the community or environment.

5.3.1.3.2. Limitations and Considerations

- Will not reduce the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Without an annual groundwater monitoring program, changes in site and/or contaminant conditions would only be assessed during the five-year reviews.
- Contaminants are predicted to remain above MCLs for ten years.

5.3.2. Alternative 2 – Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action

5.3.2.1. Description

Natural attenuation is the process by which contaminant concentrations are reduced through mechanisms such as advection, dispersion, diffusion, volatilization, sorption, and degradation. Site data indicates that biodegradation and other natural attenuation processes capable of reducing contaminant concentrations below MCLs are occurring within the area of impacted groundwater at this Site (see Section 1.3.8).

MNA refers to the periodic sampling and monitoring of geochemical and contaminant conditions at the Site. Contaminant concentrations and natural attenuation parameters will be monitored periodically to evaluate if the natural attenuation processes are reducing contaminant concentrations to MCLs in the time frame predicted by MNA modeling at the Site (see *RI Report* for modeling details). Natural attenuation parameters may include the following: temperature, pH, conductivity, methane, ethane, ethene, alkalinity, nitrate, sulfate, sulfide, chloride, TOC, DO, ORP, and ferrous iron. These parameters were used in the *RI Report* to demonstrate that natural attenuation is occurring at this Site, however not all of these parameters are needed to demonstrate that natural attenuation is continuing during MNA. MNA will be performed using the currently available monitoring wells to assess ongoing natural attenuation at the Site.

The inclusion of institutional controls, such as groundwater restrictions, reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site. The EPA guidance on institutional controls suggests that controls should be "layered" to enhance the effectiveness and protectiveness of the remedy (EPA, 2000). Layering refers to using different types of institutional controls together or in series to enhance their effect. Examples at this Site may include the enactment of a county environmental and health resolution designed to restrict contaminated groundwater use or restrictive covenants with private landowners. Other institutional controls, such as an amendment to the county zoning ordinance that would create a groundwater restriction overlay district, and negative easements on private lands are other possibilities at the Site. The purpose of these institutional controls is to limit exposure to contaminants in the groundwater. Details of the institutional controls to be implemented under this alternative and how their implementation affects contaminant pathways will be provided as part of the Proposed Plan. Other controls, including alternate supply (replacement) wells, community awareness, and groundwater monitoring, are also components of this alternative. Groundwater monitoring is intended to provide a level of protection to ensure that risk levels are adequate at the Site during the remediation period. Two alternate water supply wells (M02-02 and R02-02) were installed in August 2002 to replace Private Wells R-1, R-2, R-3, R-4, and M-1 (see Section 1.3.4).

The contingency for future action provides for the designing and implementation of more aggressive remediation, should conditions change from those anticipated. At a minimum, CERCLA requires administrative reassessments every five years, if the Site is not open for unrestricted use, whenever contaminants are left in place. If justified by this review, additional remedial actions could be implemented if unexpected monitoring results (e.g., increases in contaminant levels) or land use changes indicate that such action is warranted. Under the NCP, all potentially appropriate process options would be considered during the development of the contingency action should future changes in site and/or contaminant conditions show institutional controls and monitoring under this alternative are no longer adequately protective of human health and the environment. The specific response activities and process options that might be part of the contingency action would depend on the future changes in conditions that ultimately triggered the contingency (e.g., changes in land use, identification of a new and/or imminently threatened receptor, monitoring data suggesting an unexpected change in the nature and/or extent of contamination).

MNA is an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a time frame that is reasonable compared to other alternatives (EPA, 1999a).

5.3.2.2. Evaluation

5.3.2.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and natural degradation of contaminants will further reduce concentrations. In addition, this alternative includes a contingency for future action in the event that unexpected changes in the nature or extent of the contamination occur.

5.3.2.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in ten years, as predicted by natural attenuation modeling (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Since there are no major construction activities associated with this alternative, there are no anticipated issues with location- or action-specific ARARs. Compliance with endangered and/or threatened species ARARs are anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs are anticipated to be met because remedial activities will not result in any permanent structures or surface improvements. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined. All location-specific RCRA-related ARARs are anticipated to be met. A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

In addition to ARARs, this alternative is anticipated to comply with the TBCs <u>Monitored Natural Attenuation, Bureau of Environmental Remediation/Remedial Section Policy, BER Policy # BER-RS-042</u> (KDHE, 2001); and <u>Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites</u> (EPA, 1999a). MNA is not anticipated to pose an unacceptable risk to human health because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. MNA is not anticipated to allow continued degradation of groundwater quality, because the contaminant levels at this Site are continuing to decrease (see Figure 1-6). Samples collected from the Kansas River do not indicate that the plume is impacting the river. VC has only been detected in six of over 700 groundwater samples collected at this Site. There is no trend to these detections, they are low level and sporadic. This provides strong evidence that it is not accumulating in the aquifer as a result of dechlorination of cis-1,2-DCE.

Based on the results from the ecological risk assessment performed in the *RI Report* (BMcD, 2001), MNA is not anticipated to increase the potential for risk to environmental receptors at this Site. The EPA expects MNA to be an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a timeframe that is reasonable compared to other alternatives (EPA, 1999a). This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in ten years, as predicted by natural attenuation modeling.

Institutional controls are anticipated to control the contaminated property and/or obtain agreement from landowners to use MNA, if this alternative is selected as the final remedy. A contingency for future action is included with MNA in this alternative in the event that the MNA remedy proves ineffective.

5.3.2.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.2.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that natural attenuation processes will reduce COPC concentrations at the Site to below MCLs in ten years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. The modeling scenario used to evaluate this alternative is identical to the model developed in the *RI Report* (Section 6.5.3.5.1), since this is essentially a simulation of the natural processes occurring at the Site. Thus far, the model has been accurate in predicting the concentrations at the Site (see Section 5.3.1.2.4 above). Reduction in contaminant volume is achieved with this alternative primarily through biodegradation. Biodegradation is the dominant natural attenuation process at this Site acting to destroy contaminant mass in groundwater. VC has only been detected in six of over 700 groundwater samples collected at this Site. There is no trend to these detections, they are low level and sporadic. This provides strong evidence that it is not accumulating in the aquifer as a result of dechlorination of cis-1,2-DCE. Dispersion also acts to dilute the plume such that the volume of groundwater with contaminant levels above MCL will decrease.

5.3.2.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative predicts that all COPCs at the Site will be reduced below MCLs in ten years (see Appendix B). The inclusion of a groundwater monitoring program, institutional controls, and contingency for future action addresses short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.2.2.6. Implementability

There are no anticipated technical difficulties implementing this alternative. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements and/or groundwater use restrictions.

5.3.2.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $2,000,000, with a capital cost of $48,000, total O&M cost of $2,200,000, periodic costs totaling $108,000, and a total project cost of $2,300,000. Detailed cost analysis tables are presented in Appendix A.

5.3.2.3. Additional Criteria

5.3.2.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- No additional risk to the community or environment.

- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.
- Includes contingency for active remediation in the event that MNA does not function as anticipated.

5.3.2.3.2. Limitations and Considerations

- Contaminants are predicted to remain above MCLs for ten years.
- More extensive education and outreach efforts may be required in order to gain public acceptance of MNA.

5.3.3. Alternative 3 – Enhanced Anaerobic Bioremediation with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

5.3.3.1. Description

This alternative consists of installing an in-situ treatment system in the higher concentration areas within all the aquifer zones of the plume to remediate the most contaminated area(s) of the plume. Carbon sources such as lactate, vegetable oil, molasses, and others can be added to aquifer materials to enhance anaerobic bioremediation via reductive dechlorination. Lactate is a compound that slowly releases lactic acid, which breaks down to release hydrogen, and stimulates degradation of chlorinated solvents. Vegetable oil and molasses are other potential carbon additions for promoting increased degradation. When applied at a slow continuous rate, these products provide a constant carbon source for anaerobic degrading microbes. Various combinations of methane, nitrogen, and phosphorous have also been used to promote increased biodegradation. A system of vertical or horizontal wells could deliver these nutrients to selected aquifer zones.

Although several biodegradation options are available, for conceptual design, cost estimation, and applicability evaluation, the lactate technology is a representative option. Specifically, the sodium lactate option (slow release) will be used for cost estimation purposes. Other carbon source options may be evaluated in detail in the PP. The lactate technology has been used at over 400 groundwater remediation sites (Regenesis, 2002).

To remediate the chlorinated solvent plume at this Site, a multi-curtain approach is anticipated to provide the most effective and efficient design. Conceptual design of this alternative uses nine curtains spaced approximately 500 feet apart (Figure 5-1). Each curtain consists of one row of 25 injection points spaced on ten-foot centers and extending 250 feet across the plume. Curtain numbers 1 and 2, at the south end of the plume, will be injected into the shallow and intermediate zones only (i.e., from 20 to 50 ft. bgs); curtain numbers 3, 4, and 5 will be injected into the intermediate zone only (i.e., from 35 to 50 ft. bgs); and the remaining four curtains (numbers 6 through 9) will be injected into the intermediate and deep zones only (i.e., from 35 to 65 ft. bgs) [see Figure 5-1]. This design is consistent with the horizontal and vertical extent of the contaminant plume at the Site (for addition information, refer to the *RI Report* and/or March 2002 DSR). Lactate is typically applied at a rate of 15 pounds per vertical foot and is injected into the aquifer using direct-push equipment. The number of wells, spacing, and application rate was estimated using software and specifications provided by a lactate vendor, but should be verified through a pilot test, should this alternative be selected.

The 500-foot curtain spacing will allow one pore volume of groundwater to flow through the treatment curtains in approximately one year. This estimate assumes a conservative groundwater velocity of 1.4 ft/day, based on a conservative hydraulic conductivity of 600 ft/day, and average effective porosity of 0.30, and an average gradient of 6.92×10^{-4} (refer to Section 6.5 of the *RI Report* for details on hydrogeologic parameters for this Site). This configuration was selected because typical lactate is designed to remain active for approximately one year. Any contaminants remaining above MCLs following the lactate treatment are anticipated to be remediated through MNA.

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan. The contingency for future action provides for the design and implementation of more aggressive remediation, should conditions change from those anticipated. At a minimum, CERCLA requires administrative reassessments every five years, if the Site is not open for unrestricted use, whenever contaminants are left in place. If justified by this review, additional remedial actions could be implemented if unexpected monitoring results (e.g., unexplainable increases in contaminant levels) or land use changes indicate that such action is warranted. As dictated by the NCP, all potentially appropriate process options would be considered during the development of the contingency action should future changes in Site and/or contaminant conditions show institutional controls and monitoring under this alternative are no longer adequately protective of human health and the environment.

5.3.3.2. Evaluation

5.3.3.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

5.3.3.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in eight years, as predicted by contaminant transport modeling of this alternative (see Appendix B).

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs are anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs is anticipated to be met because remedial construction activities will not result in any permanent structures or surface improvements. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined. A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. An underground injection permit will not likely be required to inject lactate into the subsurface, since CERCLA sites are exempt. OSHA requirements are anticipated to be met during implementation of this alternative. All action-specific RCRA-related ARARs are anticipated to be met.

5.3.3.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.3.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in eight years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the treatment curtains shown on Figure 5-1 were entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through enhanced anaerobic biodegradation. Accumulation of VC is unlikely due to low level concentrations of contaminants at this Site and the reported effectiveness of lactate to completely reduce chlorinated solvents (Regenesis, 2001). Natural attenuation processes will also act to further reduce contaminant concentrations. Temporary mounding of the groundwater table may result during injection of the lactate, thus increasing the mobility of any mobile phase while the new gradient is in effect.

5.3.3.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in eight years. The inclusion of a groundwater monitoring program, institutional controls, and contingency for future action addresses short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.3.2.6. Implementability

There are no anticipated technical difficulties in implementing this alternative. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

5.3.3.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $2,200,000, with a capital cost of $450,000, total O&M cost of $1,900,000, periodic costs totaling $80,000, and a total project cost of $2,500,000. Detailed cost analysis tables are presented in Appendix A.

5.3.3.3. Additional Criteria

5.3.3.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.
- Minimizes human exposure to contaminants during remediation because neither contaminated groundwater nor aquifer materials are brought to the ground surface.
- Destroys contaminants in-situ, rather than transferring them to another medium.
- Can be injected using direct-push methods.
- Low disruption to surface.
- No permanent surface structures/facilities.
- Following injection, there are virtually no O&M issues.

5.3.3.3.2. Limitations and Considerations

- Possibility for VC to accumulate, although unlikely due to low level concentrations of contaminants at this Site and the reported effectiveness of lactate to completely reduce chlorinated solvents (Regenesis, 2001).
- Re-injections may be required if contaminant levels do not decrease as predicted.
- Success is dependent on site-specific aquifer conditions and the microbial population, and the final design will likely require pilot testing.

5.3.4. Alternative 4 – Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring

5.3.4.1. Description

This alternative consists of installing a Fe^0 PRB downgradient of the higher concentration area (under current conditions this would be slightly downgradient of Monitoring Well FP-98-31) to remediate the most contaminated area(s) of the plume.

The Fe^0 PRB chemically reacts with chlorinated solvents and yields non-toxic and non-chlorinated by-products. In this process, iron and chlorinated organics undergo an abiotic oxidation/reduction reaction, which results in the reductive elimination of the contaminants. The Fe^0 acts as an electron donor being oxidized into ferrous/ferric iron, while carbon atoms of the chlorinated solvents act as electron acceptors being reduced to lower valence states. In this reduction process, the carbon atoms release chlorine atoms, which are replaced by hydrogen. As a result, the reductive elimination process yields non-toxic, chlorine-free organic compounds. TCE for example, is abiotically reduced to chloroacetylene, then to acetylene, and finally to ethene by reductive elimination (Szecsody et al., 2000; Vermeul et al., 2000). The minor reduction pathway, sequential hydrogenolysis (see Section 4.3.8.11), is also possible but is 100 to 400 times less prevalent than the major pathway, reductive elimination (Szecsody et al., 2000; Vermeul et al., 2000). Under the minor reduction pathway, TCE for example is reduced to cis-1,2-DCE, then to VC, then finally to ethene. Vertical barriers may be used with this alternative to construct a funnel-and-gate type design if necessary.

Conceptual design of this reactive barrier uses a 250 feet linear Fe^0 PRB to intercept and treat chlorinated solvents at this Site. The Fe^0 PRB is installed in the intermediate and deep aquifer zones only (to a depth of approximately 65 feet bgs), because there is no contamination in the shallow zone at the proposed location of the PRB (see Figure 5-2). These dimensions are anticipated to be of sufficient size to intercept concentrations above MCLs. Envirometal Technologies, Inc. (ETI) [ETI, 2000] recommends a straight-line configuration with no funneling walls as the most efficient design for this Site (ETI, 2000). If the Fe^0 PRB is properly designed so the permeability of the PRB is greater than or equal to the permeability of the aquifer, contaminants will not flow around the ends of the PRB (ETI, 2000). In addition, it is more cost effective to use a straight-line design rather than a funnel and gate design. All of the estimated dimensions for the Fe^0 PRB may need to be verified through a field investigation, should this alternative be selected for remedial action. Bench-scale testing may also be needed to better determine the thickness of iron required for complete degradation of VOCs. The Fe^0 PRB technology has been used at over 80 groundwater remediation sites (ETI, 2002).

Installation of the Fe^0 PRB could be performed using modified excavation equipment and a biodegradable guar-based slurry to support the excavation during installation. The Fe^0 would be emplaced into the open excavation through the guar slurry (ETI, 2000). Proper management of any soil, guar, or groundwater removed from the trench during excavation may be required during construction. If elevated contaminant levels are present, special care are anticipated to be taken to minimize risk to human health and the environment during implementation of Fe^0 PRB.

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan.

5.3.4.2. Evaluation

5.3.4.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

Since construction activities associated with this alternative may result in contaminated materials being brought to the surface during installation, these materials will require characterization and management in accordance with state and federal regulations and Fort Riley's Investigative Derived Waste (IDW) plan, to minimize risk to human health and the environment.

5.3.4.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in nine years, as predicted by contaminant transport modeling of this alternative (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs are anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs are anticipated to be met because remedial construction activities will not result in any permanent structures or surface improvements. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. OSHA requirements are anticipated to be met during implementation of this alternative. All action-specific RCRA-related ARARs are anticipated to be met.

5.3.4.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.4.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in nine years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the treatment zone shown on Figure 5-2 was entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through reductive elimination of chlorinated solvents, which does not result in accumulation of intermediate daughter products such as VC. Natural attenuation processes will also act to further reduce contaminant concentrations. Mounding of the groundwater table may result from the installation of the PRB, thus increasing the mobility of any mobile phase.

5.3.4.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in nine years. The inclusion of a groundwater monitoring program and institutional controls address short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site as projected. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.4.2.6. Implementability

Technical difficulties may arise when installing the Fe^0 PRB at the depth required (65+ ft bgs). This technology is more easily installed in shallow settings. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

Since construction activities associated with this alternative may result in contaminated materials being brought to the surface during installation, these materials will require characterization and management in accordance with state and federal regulations and Fort Riley's IDW plan, to minimize risk to human health and the environment.

5.3.4.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $4,100,000, with a capital cost of $2,200,000, total O&M cost of $2,100,000, and periodic costs totaling $108,000, and a total project cost of $4,400,000. Detailed cost analysis tables are presented in Appendix B. Note that if replacement of the Fe^0 PRB and/or disposal (potentially as hazardous waste) is required, the costs would increase substantially.

5.3.4.3. Additional Criteria

5.3.4.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.

- Destroys contaminants in-situ, rather than transferring them to another media.
- Proven technology, used at numerous sites worldwide.
- Would not require pilot testing because it is widely used and is a proven technology.
- Abiotic process degrades chlorinated solvents to innocuous end-products. No intermediate daughter products are typically created, if designed properly.
- Provides long-term treatment and non-toxic end-products.
- Passive technology with potential to reduce O&M costs.

5.3.4.3.2. Limitations and Considerations

- Implementability is the primary concern with this alternative. Installing a PRB to a depth of 67 feet bgs may require methods other than trenching, which are generally not as effective and are difficult to measure the success.
- High ionic strength aquifers may allow precipitates to form within the PRB, thus decreasing the hydraulic conductivity of the Fe^0 PRB and requiring the need for rejuvenation. This may be a concern at this Site (see *RI Report* for information on Site geochemistry [BMcD, 2001]).
- Required location of Fe^0 PRB to capture all contaminants above MCLs only reduces the cleanup time by one year.
- Construction activities will likely cause significant disruption of the land surface, and landowner agreements to install the Fe^0 PRB are anticipated.
- Potential for the PRB to become less permeable than the surrounding aquifer materials with time.
- Limiting or preventing migration around the Fe^0 PRB, and allowing proper residence time for complete contaminant destruction (to avoid possible formation of intermediate degradation products) are potential design issues that would need to be addressed.
- If required, rejuvenation of the Fe^0 PRB may be necessary if the reactivity of the PRB decreases to a level where it no longer is completely degrading the VOCs.

5.3.5. Alternative 5 – In-Situ Redox Manipulation with Institutional Controls and Monitoring

5.3.5.1. Description

This alternative consists of creating an in-situ ferrous iron (Fe^{+2}) passive treatment zone downgradient of the higher concentration area (under current conditions this would be slightly downgradient of Monitoring Well FP-98-31) to remediate the most contaminated area(s) of the plume.

ISRM is a technology based upon the in-situ manipulation of natural processes to destroy contaminants in the subsurface. ISRM creates a permeable treatment zone by injection of chemical reagents into the subsurface. This concept requires the presence of natural iron, which can be reduced from its oxidized state in the aquifer sediments to serve as a long-term reducing agent (DOE, 2000). The ISRM technology has been used at five groundwater remediation sites (PNNL, 2002).

A chemical reducing agent, such as sodium dithionite, is injected into the aquifer through a groundwater injection well. The reducing agent reacts with the ferric iron (Fe^{+3}) naturally present in the aquifer sediments in the form of various minerals (clays, oxides, etc.). During the residence phase (24 to 36 hours), the reagent is allowed to react with the aquifer sediments. The reductant reacts with the iron in the sediments by the following reaction: $SO_2^- + Fe^{+3} + H_2O = SO_3^{-2} + Fe^{+2} +2H^+$. Buffers are added to balance the groundwater pH, which decreases with the addition of sodium dithionite.

Once the residence phase is complete, unreacted reagent, buffers, and reaction products are withdrawn through the same wells used for injection and disposed of. Once Fe^{+3} in the aquifer has been reduced to Fe^{+2}, reductive elimination of chlorinated solvents is initiated. Redox sensitive contaminants that migrate through the reduced zone in the aquifer undergo degradation. The major pathway for reduction of chlorinated solvents is by reductive elimination. TCE for example, is abiotically reduced to chloroacetylene, then to acetylene, and finally to ethene by reductive elimination. The minor pathway, sequential hydrogenolysis (see Section 4.3.8.11), is also possible but is 100 to 400 times less prevalent (Szecsody et al., 2000; Vermeul et al., 2000).

Conceptual design of the ISRM treatment zone uses a 250-foot long barrier placed slightly downgradient of Monitoring Well FP-98-31 to intercept and treat chlorinated solvents at this Site (Figure 5-2). This width is anticipated to be of sufficient size to intercept concentrations above MCLs. The ISRM treatment zone would be injected (through seven injection wells spaced 35 feet apart) into the intermediate and deep aquifer zones only, because there is no contamination in the shallow zone at the proposed location of the ISRM treatment zone (Figure 5-2). This conceptual spacing requirement was provided by the technology vendor (Pacific Northwest National Laboratory [PNNL]) based on Site-specific conditions (PNNL, 2000). Pilot testing is required to finalize application design.

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan.

5.3.5.2. Evaluation

5.3.5.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

Since construction activities associated with this alternative may result in contaminated materials being brought to the surface during installation, these materials will require careful management to minimize risk to human health and the environment.

5.3.5.2.2. Compliance with ARARs

This alternative will control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in nine years, as predicted by contaminant transport modeling (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs are anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs are anticipated to be met because remedial construction activities are not anticipated to result in any permanent structures or surface improvements. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. A permit will not likely be required to inject chemicals into the subsurface, since CERCLA sites are exempt. OSHA requirements are anticipated to be met during implementation of this alternative. All action-specific RCRA-related ARARs are anticipated to be met.

5.3.5.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.5.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in nine years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the treatment zone shown on Figure 5-2 was entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through reductive elimination of chlorinated solvents, which does not result in accumulation of intermediate daughter products such as VC. Natural attenuation processes will also act to further reduce contaminant concentrations.

5.3.5.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in nine years. The inclusion of a groundwater monitoring program and institutional controls address short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site as projected. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.5.2.6. Implementability

Since this technology has limited field application, unforeseeable difficulties may develop. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

5.3.5.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $3,800,000, with a capital cost of $2,000,000, total O&M cost of $2,100,000, periodic costs totaling $108,000, and a total project cost of $4,100,000. Detailed cost analysis tables are presented in Appendix A.

5.3.5.3. Additional Criteria

5.3.5.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.
- Minimizes human exposure to contaminants during remediation because contaminated groundwater is treated in-situ and not brought to the ground surface.
- Destroys contaminants in-situ, rather than transferring them to another media.
- Can be implemented at a greater depth than traditional iron PRB methods.
- No long-term O&M costs.
- No permanent surface structures/facilities, other than seven injection wells.
- Although there is very limited information available because of the recent development of the technology, significant precipitation of metals is not observed, as with Fe^0 applications (PNNL, 2000).
- Treatment zone is estimated to remain active for hundreds of pore volumes (PNNL, 2000).
- Abiotic process degrades chlorinated solvents to innocuous end-products. No intermediate daughter products are typically created, if designed properly.

5.3.5.3.2. Limitations and Considerations

- Limited field-scale application. Would require extensive bench scale and pilot testing.
- PNNL suggests that the MAAF Site displays conditions that suggest that ISRM may be successful. However, PNNL also indicates that the applicability of this technology at this Site can not be fully determined without bench scale testing.
- At least 50 percent of the naturally occurring Fe^{+3} needs to be reduced to achieve reasonable reduction rates.
- The amount of naturally occurring iron in the aquifer is critical. Too little iron results in insufficient reducing capability. Too much iron results in a small treatment zone, because the sodium dithionite is consumed before it travels sufficiently away from the injection well.
- It is necessary to use argon during mixing and injection of the dithionite to limit oxygen contact with the sodium dithionite. This increases the complexity of implementing this technology.
- Fe^0 is more reactive (i.e., efficient) than Fe^{+2}.
- Injection of sodium dithionite will require installation of injection and recovery wells.
- Landowner agreements to install injection/extraction wells would be needed.
- Required location of ISRM treatment zone to capture all contaminants above MCLs only reduces the estimated cleanup time by one year.

5.3.6. Alternative 6 – Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

5.3.6.1. Description

This alternative consists of installing an in-situ treatment system in the higher concentration areas within all the aquifer zones of the plume to remediate the most contaminated area(s) of the plume. BNP are submicron ($<10^{-6}$ meters) particles of Fe^0 that are small enough to migrate along with the groundwater flow. When injected into an aquifer contaminated with chlorinated solvents, the BNP and chlorinated organics undergo an abiotic oxidation/reduction reaction, which results in the reductive elimination of the contaminants. Fe^0 acts as an electron donor being oxidized into ferrous/ferric iron, while carbon atoms act as electron acceptors being reduced to lower valance states. In this reduction process, the carbon atoms release chlorine atoms which are replaced by hydrogen. As a result, the reductive elimination process yields non-toxic, chlorine-free organic compounds. The minor pathway, sequential hydrogenolysis (see Section 4.3.8.11), is also possible but is 100 to 400 times less prevalent (Szecsody et al., 2000; Vermeul et al., 2000). The BNP technology has been used at nine groundwater remediation sites (PARS, 2002).

The microscopic size of BNP provides a large surface area that is available to react with chlorinated solvents, thus resulting in a much lower iron-contaminant ratio than required by a Fe^0 PRB. Some fraction of the injected nanoparticle mass remains relatively immobile, functioning as a semi-permeable in-situ PRB. The remainder will travel to some degree with the groundwater flow. The proportion varies with the hydrogeologic conditions at the site and could be better assessed during a pilot study (Elliot, 2002). No extraction or recovery is necessary with BNP. The particles will be completely consumed by the contaminants or the other reduction processes present in the aquifer. The concentration and application rate of BNP can be designed to limit or prevent the BNP from moving too far downgradient before they are consumed by the aquifer, if necessary.

To remediate the chlorinated solvent plume at this Site, a multi-curtain approach is anticipated to provide an effective and efficient design. Conceptual design of this alternative uses nine curtains spaced approximately 500 feet apart (Figure 5-1). Each curtain consists of one row of 25 injection points spaced on ten-foot centers and extending 250 feet across the plume. Curtain numbers 1 and 2, at the south end of the plume, will be injected into the shallow and intermediate zones only (i.e., from 20 to 50 ft. bgs); curtain numbers 3, 4, and 5 will be injected into the intermediate zone only (i.e., from 35 to 50 ft. bgs); and the remaining four curtains (numbers 6 through 9) will be injected into the intermediate and deep zones only (i.e., from 35 to 65 ft. bgs) [see Figure 5-1]. This design is consistent with the horizontal and vertical extent of the contaminant plume at the Site (for addition information, refer to the *RI Report* and/or the current DSR). BNP is applied at four pounds per point for the 30-ft interval curtains and at three pounds per point for the 15-ft curtains; and is injected into the aquifer using direct-push equipment. The estimated number of wells, spacing, and application rate was based on an estimate provided by a BNP vendor (PARS Environmental, Inc.). Pilot testing is required to finalize the application design.

The 500-foot curtain spacing will allow one pore volume of groundwater to flow through the treatment curtains in approximately one year. This estimate assumes a conservative groundwater velocity of 1.4 ft/day, based on a conservative hydraulic conductivity of 600 ft/day, and average effective porosity of 0.30, and an average gradient of 6.92×10^{-4} (refer to Section 6.5 of the *RI Report* for details on hydrogeologic parameters for this Site). This configuration was chosen for consistency with the EAB alternative (Alternative 3), because these two technologies are very similar and are applied in the same manner.

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan. The contingency for future action provides for the designing and implementation of more aggressive remediation, should conditions change from those anticipated. At a minimum, CERCLA requires administrative reassessments every five years, if the Site is not open for unrestricted use, whenever contaminants are left in place. If justified by this review, additional remedial actions could be implemented if unexpected monitoring results (e.g., unexplainable increases in contaminant levels) or land use changes indicate that such action is warranted. As dictated by the NCP, all potentially appropriate process options would be considered during the development of the contingency action should future changes in site and/or contaminant conditions show institutional controls and monitoring under this alternative are no longer adequately protective of human health and the environment.

5.3.6.2. Evaluation

5.3.6.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment since the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

5.3.6.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in eight years, as predicted by contaminant transport modeling of this alternative (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs is anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs are anticipated to be met because remedial construction activities will not result in any permanent structures or surface improvements. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. An underground injection permit will not likely be required to inject BNP into the subsurface, since CERCLA sites are exempt. OSHA requirements are anticipated to be met during implementation of this alternative. All action-specific RCRA-related ARARs are anticipated to be met.

5.3.6.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.6.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in eight years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the treatment curtains shown on Figure 5-1 were entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through reductive elimination of chlorinated solvents, which does not result in accumulation of intermediate daughter products such as VC. Natural attenuation processes will also act to further reduce contaminant concentrations. Temporary mounding of the groundwater table may result during injection of the lactate, thus increasing the mobility of any mobile phase while the new gradient is in effect.

5.3.6.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in eight years. The inclusion of a groundwater monitoring program, institutional controls, and contingency for future action address short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site as projected. Institutional controls are anticipated to be protective of potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.6.2.6. Implementability

Availability of BNP in the quantities required for this project may be a concern, although is uncertain at this time. Technical difficulties may arise when installing the BNP barriers. This technology has limited field application and unforeseeable difficulties may develop. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

5.3.6.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $2,400,000, with a capital cost of $650,000, total O&M cost of $1,900,000, periodic costs totaling $84,000, and a total project cost of $2,700,000. Detailed cost analysis tables are presented in Appendix A.

5.3.6.3. Additional Criteria

5.3.6.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.
- Minimizes human exposure to contaminants during remediation because neither contaminated groundwater nor aquifer materials are brought to the ground surface.
- Destroys contaminants in-situ, rather than transferring them to another media.
- BNP is anticipated to flow with the groundwater and destroy chlorinated solvents it contacts.
- High surface area results in smaller iron requirement than commercial Fe^0 PRBs.
- Fe^0 is more reactive (i.e., efficient) than Fe^{+2}.

- Injectable, low disruption to surface.
- Abiotic process degrades chlorinated solvents to innocuous end-products. No intermediate daughter products are typically created.
- Very rapid reaction times. Should expect to begin measuring results within two months of injection.
- Can be injected using direct-push methods.
- No permanent surface structures/facilities.
- Following injection, there are virtually no O&M issues.

5.3.6.3.2. Limitations and Considerations

- High ionic strength of aquifer sediments may be a limitation, because BNP are 30 to 40 times more attracted to ions in the aquifer than organics. Bench-scale or pilot testing is anticipated to address this issue.
- High pH groundwater is a limitation, since BNP tend to form colloids with other precipitates in high pH environments.
- Limited field-scale applications. Would require bench-scale and pilot testing.
- Since BNP are mobile, it is important to consider their migration rate relative to the rate of contaminant migration. Pilot testing would likely be needed to determine if this is an issue.
- BNP are being produced in relatively small quantities such that commercial availability may be limited.

5.3.7. Alternative 7 – Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring

5.3.7.1. Description

This alternative consists of installing an in-situ treatment system in the higher concentration areas within all the aquifer zones of the plume to remediate the most contaminated area(s) of the plume. Air sparging is an in-situ groundwater technology that involves the injection of a gas (e.g., air or nitrogen) under pressure into a well installed into the saturated zone. Gas injected below the water table volatilizes contaminants that are dissolved in groundwater, exist as a separate aqueous phase, and/or are sorbed onto saturated soil particles. The volatilized contaminants migrate upward into the vadose zone, where they are removed using SVE techniques. Air sparge/SVE systems have been used at hundreds of groundwater remediation sites (NFEC, 2001; Leeson, 1999; USACE, 1997; and CLU-IN, 2002).

To remediate the chlorinated solvent plume at this Site, a multi-curtain approach is anticipated to provide an effective and efficient design. Conceptual design of this alternative uses nine curtains spaced approximately 500 feet apart (Figure 5-1). Each curtain consists of 25 injection points spaced on ten-foot centers, and extends 250 feet across the plume. Curtain numbers 1 and 2, at the south end of the plume, will be injected into the shallow and intermediate zones only (i.e., from 20 to 50 ft. bgs); curtain numbers 3, 4, and 5 will be injected into the intermediate zone only (i.e., from 35 to 50 ft. bgs); and the remaining four curtains (numbers 6 through 9) will be injected into the intermediate and deep zones only (i.e., from 35 to 65 ft. bgs) [see Figure 5-1]. This design is consistent with the horizontal and vertical extent of the contaminant plume at the Site (for addition information, refer to the *RI Report* and/or the current DSR).

To facilitate that natural reducing conditions are maintained, it may be necessary to sparge using nitrogen. Nitrogen is anticipated to limit the oxygenating effect that sparging with air can have on an anaerobic aquifer. Depending on the nature and extent of contamination at the time of the final design, should this alternative be selected, nitrogen may or may not be necessary and is included for comparison as an option in the cost estimate for this alternative.

A system of horizontal SVE wells will be installed in the soil above each treatment curtain to collect vapors resulting from the air sparging. Due to the low concentrations of contaminants in the plume, it is anticipated that an off-gas treatment system will not be needed. The mass of VOCs discharged to the atmosphere is anticipated to be far below the regulatory limit of 25 tons per year of a single hazardous air pollutant (HAP).

The 500-foot spacing will allow one pore volume of groundwater to flow through the treatment curtains in approximately one year (using a conservative groundwater velocity of 1.4 ft/day). This configuration was chosen for comparison with Alternatives 3 and 6, because application of these technologies is very similar and is applied in the same manner (i.e., multiple curtains).

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan.

5.3.7.2. Evaluation

5.3.7.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease since institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

5.3.7.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in three years, as predicted by contaminant transport modeling of this alternative (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs are anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs are anticipated to be met because any structures or surface improvements built as part of the remedial action will be temporary and are not anticipated to be occupied. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. OSHA requirements are anticipated to be met during implementation of this alternative. All action-specific RCRA-related ARARs are anticipated to be met. Confirmation air samples may be required for the SVE system to meet the Ambient Air Quality Standards and Air Pollution Control ARAR (see BMcD, 2002).

5.3.7.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.7.2.4. Reduction of Toxicity, Mobility, or Volume

Modeling results (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in three years, and that it is unlikely the contaminant plume will migrate to unimpacted areas of the aquifer (see Section 5.3.1.2.4 above). This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the treatment curtains shown on Figure 5-1 were entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through volatilization of chlorinated solvents. Natural attenuation processes will also act to further reduce contaminant concentrations.

5.3.7.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in three years. However, the time estimated to reach MCLs is under ideal conditions and does not consider a number of factors that could significantly increase the estimated time for this alternative. These factors include the following: removal efficiency at low concentrations, system down time, introduction of oxygen into the aquifer impacting geochemistry, and decreased efficiency over time due to fouling and plugging.

The inclusion of a groundwater monitoring program and institutional controls address short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site. Periodic operation and maintenance visits to the Site will be used to check and maintain the remediation system to verify that it remains operational and functioning properly. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.7.2.6. Implementability

Technical difficulties may arise with the air sparge/SVE system due to the size of the system and the area it is designed to cover. Since typical air sparge/SVE systems are often used to remediate small hot spot type areas, unforeseeable difficulties may develop when installing the system at this Site. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

5.3.7.2.7. Cost Evaluation

The present worth cost of this alternative using atmospheric gas (i.e., air) is estimated to be $3,900,000, with a capital cost of $2,400,000, total O&M cost of $1,500,000, periodic costs totaling $60,000, and a total project cost of $4,000,000. Detailed cost analysis tables are presented in Appendix A.

If it is determined that sparging with nitrogen is necessary to avoid disrupting the geochemistry of the aquifer, the present worth cost of this alternative increases to $10,000,000, with a capital cost of $4,600,000, total O&M cost of $6,300,000, periodic costs totaling $180,000, and a total project cost of $11,000,000.

5.3.7.3. Additional Criteria

5.3.7.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.
- No intermediate daughter products are typically created.
- Proven technology.

5.3.7.3.2. Limitations and Considerations

- Temporary surface structures/facilities required.
- Transfers contaminants to another media (i.e., soil and then air via SVE) rather than destroy in-situ.
- High O&M costs.
- May not be able to reach contaminants in fine-grained zones due to preferential flow paths of air bubbles.
- Landowner agreements to install remedial components and operate the system would need to be reached.
- Design and implementability are anticipated to be complex.

5.3.8. Alternative 8 – Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

5.3.8.1. Description

This alternative consists of installing a groundwater extraction system downgradient of the higher concentration area (under current conditions this would be slightly downgradient of Monitoring Well FP-98-31). Groundwater extraction and treatment (pump and treat) is designed in this alternative to provide containment of concentrations above MCLs while natural attenuation processes work to reduce contaminant levels. While the limitations of pump and treat as a remediation technology are well documented (EPA, 1996a; NAP, 1994; and DOE, 2002), pump and treat is still recognized as an effective method of providing containment while other technologies are used for remediation, and has been implemented at hundreds of sites (EPA, 1996a).

The contaminant transport model developed in the *RI Report* (Section 6.5) was utilized to determine an effective and efficient placement of the extraction well(s) and the approximate pumping rates. This was accomplished through multiple modeling simulations where the pumping rate was varied and particle tracking was used to verify the capture zone of the well(s). Conceptual modeling of this alternative indicated that a single well screened in the intermediate and deep aquifer zones pumping at approximately 150 gallons per minute (gpm) is adequate to capture the chlorinated solvent plume at this Site. This pumping rate was determined to be sufficient through several trial modeling simulations. The purpose of this modeling effort was for cost estimating purposes, additional modeling may be required for determination of the final pump and treat design, should this alternative be selected. Groundwater is anticipated be treated by air stripping and discharged into the Kansas River.

The inclusion of institutional controls, monitoring, and alternate water supply wells with this alternative reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site (see Section 5.3.2.1 above). Details of institutional controls will be provided as part of the Proposed Plan.

5.3.8.2. Evaluation

5.3.8.2.1. Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), this alternative is protective of human health and the environment since the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations.

5.3.8.2.2. Compliance with ARARs

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls, proprietary controls, and alternate water supply. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) in seven years, as predicted by contaminant transport modeling of this alternative (see Appendix B). A list of preliminary ARARs for this Site is presented in Section 2.2.2.1.

Location-specific ARARs are anticipated to be adequately met by this alternative as follows. Compliance with endangered and/or threatened species ARARs is anticipated to be achieved because disruption of critical habitat is not anticipated with this alternative. Compliance with floodplain related ARARs is anticipated to be met because any structures or surface improvements built as part of the remedial action will be temporary and are not anticipated to be occupied. Before implementing a remedy, the need for an archeological investigation for compliance with archeological/historical related ARARs should be determined.

Action-specific ARARs are anticipated to be adequately met by this alternative as follows. OSHA requirements are anticipated to be met during implementation of this alternative. The Kansas Ambient Air Quality Standards and Air Pollution Control Regulations are anticipated to be met because the mass of VOCs discharged to the atmosphere is anticipated to be far below the 25 tons per year limit for a single HAP. A NPDES permit is not anticipated to be required to discharge treated groundwater into the Kansas River, since CERCLA sites are exempt. The Kansas Water Well Construction Regulations are anticipated to be complied with when installing the groundwater extraction well as part of this alternative. All action-specific RCRA-related ARARs are anticipated to be met.

5.3.8.2.3. Long-Term Effectiveness and Permanence

Once RAOs are achieved at the Site, groundwater contaminant levels are anticipated to remain below MCLs because there is no ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5). Therefore, the magnitude of risk to human health and the environment is anticipated to be less than current risk conditions, which are already within the EPA accepted limits at this Site (see Section 1.4.1). However contaminants sorbed to the aquifer matrix may serve as a low-level source after remediation is completed. A review of groundwater contamination at the Site would be required every five years, if the Site is not open for unrestricted use, to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c). An alternate water supply and institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

5.3.8.2.4. Reduction of Toxicity, Mobility, or Volume

Results from modeling (see Appendix B) predict that this alternative will reduce COPC concentrations at the Site to below MCLs in seven years, and that the contaminant plume will not migrate to unimpacted areas of the aquifer. This prediction is to be used only for comparative purposes with other alternatives. To simulate this technology, the pumping well shown on Figure 5-2 was entered into the model. Reduction in contaminant volume is anticipated to be achieved with this alternative through groundwater extraction. Natural attenuation processes will also act to further reduce contaminant concentrations.

5.3.8.2.5. Short-Term Effectiveness

Contaminant transport modeling performed for this alternative (see Appendix B) predicts that all COPCs at the Site will be reduced below MCLs in seven years. However, the time estimated to reach MCLs is under ideal conditions and does not consider a number of factors that could significantly increase the estimated time for this alternative. These factors include the following: removal efficiency at low concentrations, system down time, and decreased efficiency over time due to fouling and plugging.

The inclusion of a groundwater monitoring program and institutional controls address short-term reliability in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the Site. The pump and treat system will likely be equipped with a remote telemetry system to notify key personnel when operational problems occur. Site visits would then be made to maintain the system and to verify that it remains operational and functioning properly. Frequent and intensive O&M repairs on pump and treat systems are typically required. Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

5.3.8.2.6. Implementability

Technical difficulties are anticipated to be minimal during installation and startup of the system but may arise during the operation of the system. Fouling of the air stripper may occur due to the high levels of naturally occurring iron in the groundwater. Other technical difficulties may occur during the operation of the system. The current groundwater monitoring well network is anticipated to provide adequate coverage for evaluating the effectiveness of this technology and monitoring any changes in the nature and extent of contamination at the Site.

Administrative implementability issues may involve landowner compensation for easements, groundwater use restrictions, and permission to install remedial components on private property.

5.3.8.2.7. Cost Evaluation

The present worth cost of this alternative is estimated to be $3,800,000, with a capital cost of $840,000, total O&M cost of $3,300,000, periodic costs totaling $84,000, and a total project cost of $4,200,000. Detailed cost analysis tables are presented in Appendix A.

5.3.8.3. Additional Criteria

5.3.8.3.1. Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the Site.
- Includes a groundwater monitoring program to assess future changes in Site and/or contaminant conditions.

5.3.8.3.2. Limitations and Considerations

- Contaminated groundwater is brought to the ground surface during remediation.
- Transfers contaminants to another media (i.e., air) rather than destroy in-situ.
- Temporary structures such as a pumping well and housing, treatment shed/building, and discharge piping will be required.
- Moderate to high O&M requirements are anticipated for pump and treat systems.
- Pump and treat is more applicable to high concentration plumes and is not cost effective in addressing dilute low concentration plumes.
- Tailing effects can result in residual concentrations in excess of the cleanup standard (EPA, 1996a).
- Pump and treat will flush the permeable conduits while contaminant migration from less permeable zones will be diffusion limited and may sustain parts per billion (ppb) range concentrations indefinitely (DOE, 2002).
- Rebounding of concentration levels once pumping is discontinued is a common problem with these systems, and usually results in longer cleanup times than originally predicted (EPA, 1996a).

* * * * *

6.0 COMPARATIVE EVALUATION OF ALTERNATIVES

6.1. INTRODUCTION

In this section, remedial options are assessed relative to one another for the two threshold criteria and five balancing criteria. The final two criteria, state acceptance and community acceptance, were not considered in this evaluation, but will be evaluated after publication of the PP as part of the development of the ROD. The purpose of this analysis is to identify and discuss the relative advantages or disadvantages of each alternative to aid in the decision-making process.

6.2. EVALUATION METHOD

The alternatives were scored on a pass/fail basis for the two threshold criteria (protection of human health and environment, and compliance with ARARs). Those alternatives passing the threshold criteria were then evaluated for the five balancing criteria on the basis of incremental differences between alternatives. Sections 6.3.3 through 6.3.7 summarize the evaluations for each of the balancing criteria.

An evaluation and semi-quantitative comparison was performed to facilitate a rating of the alternatives evaluated in the detailed analysis. Evaluations were based on vendor information, published reports, past experiences, and professional judgment (see Section 7.0 for references). Equal rating was given if it was not possible to differentiate performance for the given criteria. The range was on a scale of 1 to 10. Any alternative that completely fails the criteria was given a 10. Other alternatives were placed appropriately within the range based on their expected performance relative to the other alternatives and in accordance with the following further justification for specific ratings.

1	Most favorable alternative
3	Good, generally favorable
5	Fair, potentially unfavorable
7	Poor, unfavorable
10	Completely fails the criteria

Ratings of 2, 4, 6, 8, and 9 were used to differentiate between alternatives with similar qualifications where one slightly outperformed the other (e.g., two alternatives were considered "fair" but one was slightly more favorable). This method was employed for each of the five balancing criteria (see Sections 6.3.3 through 6.3.7).

6.3. COMPARATIVE ANALYSIS

6.3.1. Overall Protection of Human Health and the Environment

This is a pass/fail criterion. Based on the risk assessments (human health and ecological) performed in the *RI Report* (BMcD, 2001), all of the alternatives are protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the EPA accepted risk levels.

6.3.2. Compliance with ARARs

This is a pass/fail criterion. All of the remedial alternatives, except Alternative 1 (No Action), are anticipated to comply with preliminary chemical-, potential location-, and potential action-specific ARARs. Alternative 1 does not comply with chemical-specific ARARs (i.e., MCLs) because contaminant levels are currently above MCLs and this alternative takes no action to address the ARAR. Therefore, Alternative 1 is dropped from further consideration because it does not meet one of the threshold criteria (i.e., either Overall Protection of Human Health and the Environment; or Compliance with ARARs).

6.3.3. Long-Term Effectiveness and Permanence

Since there is not an ongoing source at this Site (see Sections 1.3.6 and 1.3.7.1.5), once RAOs are met, Alternatives 2 through 8 are anticipated to provide similar long-term effectiveness and permanence at the Site. However, due to the known rebounding effects associated with Alternatives 7 (Air Sparge) and 8 (Pump & Treat), these alternatives are considered less favorable in terms of long-term effectiveness and permanence than Alternatives 2 through 6 (EPA, 1996a). Rebounding effects occur when the system is shut down and contaminants diffuse out of the low permeability areas back into the bulk groundwater (EPA, 1996a). Alternative 8 is slightly less favorable than Alternative 7 due to the removal of water from the aquifer. Preference is given to alternatives that preserve the aquifer as a resource (EPA, 1988a). The ratings for long-term effectiveness and permanence are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (EAB)	1
Alternative 4 (Fe^0 PRB)	1
Alternative 5 (ISRM)	1
Alternative 6 (BNP)	1
Alternative 7 (Air Sparge)	3
Alternative 8 (Pump & Treat)	4

6.3.4. Reduction of Toxicity, Mobility, or Volume

Alternatives 2 through 8 are anticipated to provide similar levels of reduction in toxicity, mobility, and volume of contaminants in the plume. However, due to the known rebounding effects associated with Alternatives 7 (Air Sparge) and 8 (Pump & Treat), these alternatives are considered less favorable in terms of reducing the toxicity, mobility, and volume of contaminants in the plume than Alternatives 2 through 6. The ratings for reduction in toxicity, mobility, and volume are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (EAB)	1
Alternative 4 (Fe^0 PRB)	1
Alternative 5 (ISRM)	1
Alternative 6 (BNP)	1
Alternative 7 (Air Sparge)	5
Alternative 8 (Pump & Treat)	5

6.3.5. Short-Term Effectiveness

Alternative 7 (Air Sparge) is predicted to reach RAOs in three years. However, construction activities during implementation of this alternative are intensive, due to the large number of sparge wells, trenching to install air lines, construction of building(s), and start up.

Alternative 8 (Pump & Treat) is predicted to reach RAOs in seven years. Construction activities during implementation of Alternative 8 are anticipated to be moderate and include installation of an extraction well, construction of a treatment building, installation of discharge piping to the Kansas River, and start up.

Alternatives 3 (EAB) and 6 (BNP) are predicted to reach RAOs in eight years. However, the effectiveness of BNP is less certain due to the infancy of this technology. Construction activities during implementation of these alternatives are anticipated to be minimal, because both technologies inject treatment fluids into the aquifer using direct-push equipment, resulting in very little impact to the surface.

Alternatives 4 (Fe^0 PRB) and 5 (ISRM) are predicted to reach RAOs in nine years. Alternative 4 has the advantage over Alternative 5 due to the proven effectiveness of this technology versus the fairly new technology of Alternative 5. In addition, Fe^{+2} (Alternative 5) is not as reactive (i.e., efficient) as Fe^0 (Alternative 4). Construction activities during implementation of these alternatives are fairly intensive, especially for Alternative 4. To implement Alternative 4, a 67-ft deep trench is required to place the Fe^0

in the aquifer. This alternative would have the highest risk to workers during implementation. Alternative 5 uses injection wells to inject chemicals into the aquifer.

Alternative 2 (MNA) relies on natural processes to remediate the plume, and is predicted to require ten years to reach RAOs. This alternative will have low impact to the surface, low risk to workers during implementation of the alternative, and has been demonstrated to be actively reducing contaminant concentrations at this Site. The ratings for short-term effectiveness are assigned as follows:

Alternative 7 (Air Sparge)	3
Alternative 8 (Pump & Treat)	4
Alternative 3 (EAB)	4
Alternative 6 (BNP)	5
Alternative 5 (ISRM)	5
Alternative 2 (MNA)	6
Alternative 4 (Fe^0 PRB)	7

6.3.6. Implementability

Alternative 2 (MNA) would be the simplest alternative to implement because there are no construction activities associated with this alternative. Administrative implementability of the institutional controls associated with this alternative would be the same as the other alternatives.

Alternatives 3 (EAB) and 6 (BNP) would be fairly simple to implement because both technologies inject treatment fluids into the aquifer using direct-push equipment, however, the availability of BNP in the quantities required for this project may be a concern. Preferential pathways for the injected materials to move during injection may be an implementability issue with these alternatives. Administrative implementability of the institutional controls associated with these alternatives would be the same as other alternatives.

Alternatives 5 (ISRM) and 8 (Pump & Treat) would be more intensive to implement (intensive permanent off-site well installation) and will likely require more time and more equipment than Alternatives 3 (EAB) and 6 (BNP). Administrative implementability of the institutional controls associated with these alternatives would be the same as other alternatives.

Alternatives 4 (Fe^0 PRB) and 7 (Air Sparge) would be the most difficult to implement due to the complexity of installing the Fe^0 PRB to a depth of 67 ft, and the difficulties associated with assembling all of the air sparge/SVE piping, equipment, and structures for housing the equipment. The potential of unforeseeable problems during implementation is highest with these alternatives. Administrative implementability of the institutional controls associated with these alternatives would be the same as other alternatives. The ratings for implementability are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (EAB)	2
Alternative 6 (BNP)	4
Alternative 5 (ISRM)	5
Alternative 8 (Pump & Treat)	5
Alternative 4 (Fe^0 PRB)	7
Alternative 7 (Air Sparge)	7

6.3.7. Cost Evaluation

A summary of the cost evaluation is provided in Table 6-1. Details of the cost estimates are provided in Appendix A.

The ratings for cost are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (EAB)	2
Alternative 6 (BNP)	3
Alternative 5 (ISRM)	5
Alternative 8 (Pump & Treat)	5
Alternative 7 (Air Sparge)	5
Alternative 4 (Fe^0 PRB)	6

6.4. SUMMARY

The alternatives were first evaluated as either compliant or non-compliant with the threshold criteria (Protection of Human Health and the Environment, and Compliance with ARARs). The no action alternative was the only alternative that does not comply with the threshold criteria (non-compliant with ARARs), and therefore it was removed from further consideration in the ranking of alternatives. Each alternative that met the threshold criteria was then comparatively evaluated using the five balancing criteria. Following the comparative evaluation of alternatives using the five balancing criteria, the two alternatives with the most favorable rankings were Alternative 3 (EAB) and Alternative 2 (MNA). Discussions of the results are presented below, and a semi-quantitative summary of the rankings is presented in Table 6-2.

The favorable EAB rating was due to the ease of implementability (direct push application), favorable cleanup time, no permanent structures, reliability, and cost effectiveness. EAB provides similar or greater levels of long-term effectiveness and reduction of toxicity, mobility, and volume as the other alternatives. The favorable MNA rating was due to the ease of implementation (no physical systems required except for monitoring), effectiveness of the process (reduces contaminants at this Site), and low costs (monitoring and evaluation costs). This Alternative has the longest cleanup time frame, but is still in the range of the other alternatives (7-9 years), with the exception of SVE (3 years).

Alternative 6 (BNP) appears to be adequate for the Site and similar to EAB and MNA for many of the criteria, however concerns with the availability of BNP, potential dispersion problems, and limited full scale implementation decreased the overall rating when compared to MNA and EAB.

While Alternative 5 (ISRM) appears to be acceptable for the Site, the mid-level ranking was due to short-term effectiveness issues (intensive permanent off-site well installation) and the possibility of implementability problems, since this is an innovative technology with limited full-scale information available. The cost for this alternative was higher than MNA, EAB, and BNP and was a factor in the ranking.

Alternative 4 (Fe^0 PRB) was acceptable for long-term effectiveness and reduction of toxicity, mobility, and volume. The alternative's low ranking was primarily due to possible implementability issues related to the installation of a 67' deep PRB in the Kansas River alluvium, and high cost. These issues range from the impact on the landowner to the possible collapse of the trench which leads to possible breakthrough or bypass of contaminants (decreasing the short-term effectiveness of the alternative). The short-term effectiveness was also lower because of the cleanup time, reliability issues, and higher risk to workers during installation.

Low rankings of Alternatives 7 (Air Sparge) and 8 (Pump & Treat) were primarily due to their less favorable rating for long-term effectiveness and reduction of toxicity, effectiveness, and permanence based on the potential for rebound of contaminant levels after the system is shut down (EPA, 1996a). The base costs for the systems and the potential increase in costs due to additional operation of the systems if rebound occurs lowered the ranking. While the short-term effectiveness rating for these alternatives were relatively high for these, alternatives this rating does not overcome the potential for rebound, surface implementability issues off site, and potential for increased costs.

This evaluation of alternatives utilized the two threshold criteria and the five balancing criteria to rank the remedial alternatives for the Site. The ranking was an evaluation, not a selection, of the alternatives considered at the Site. The final two criteria, state acceptance and community acceptance, were not considered in this evaluation, but will be evaluated after publication of the PP as part of the development of the ROD.

* * * * *

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* * * * *

FIGURES

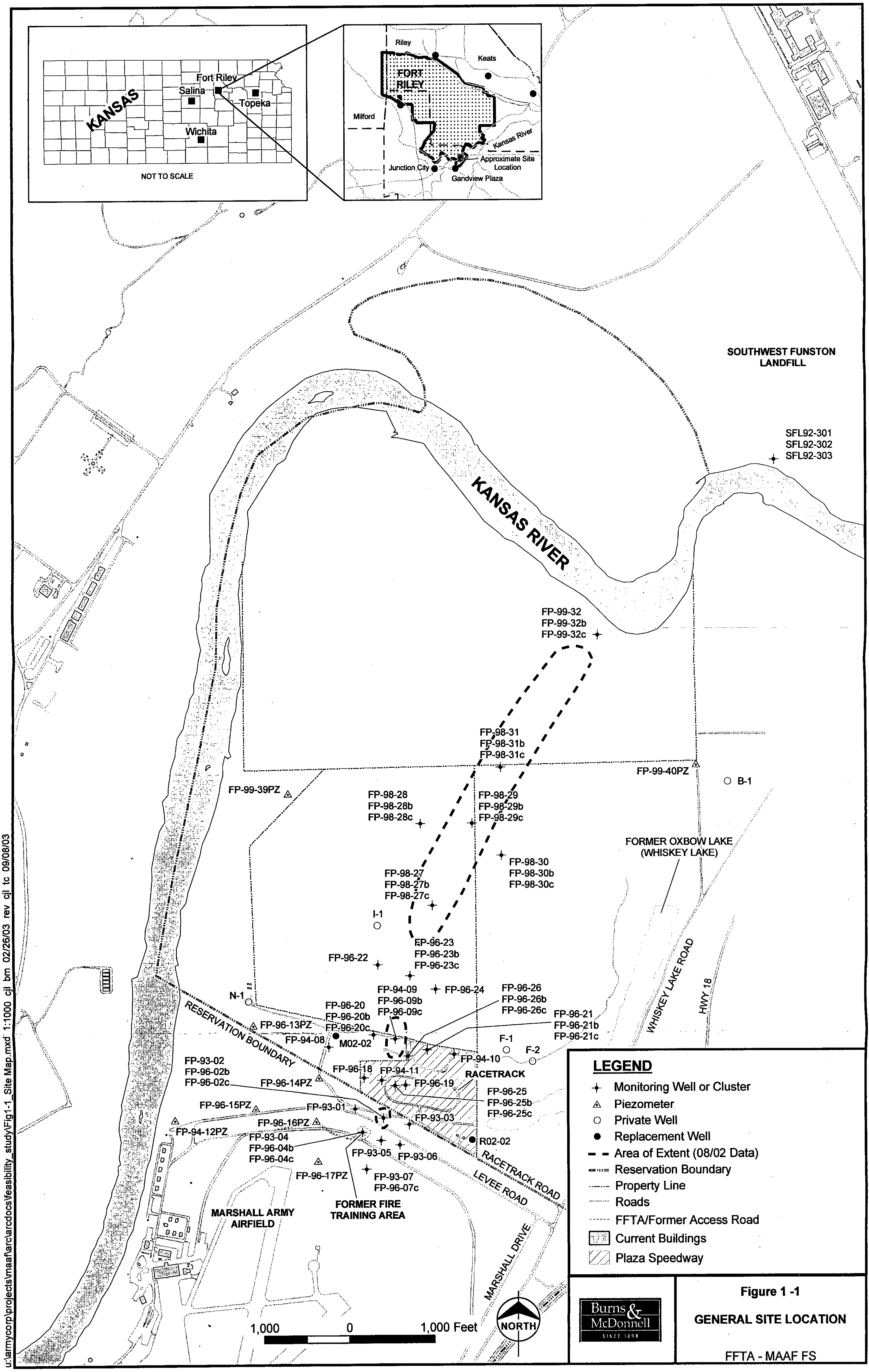

Figure 1 -1

GENERAL SITE LOCATION

FFTA - MAAF FS

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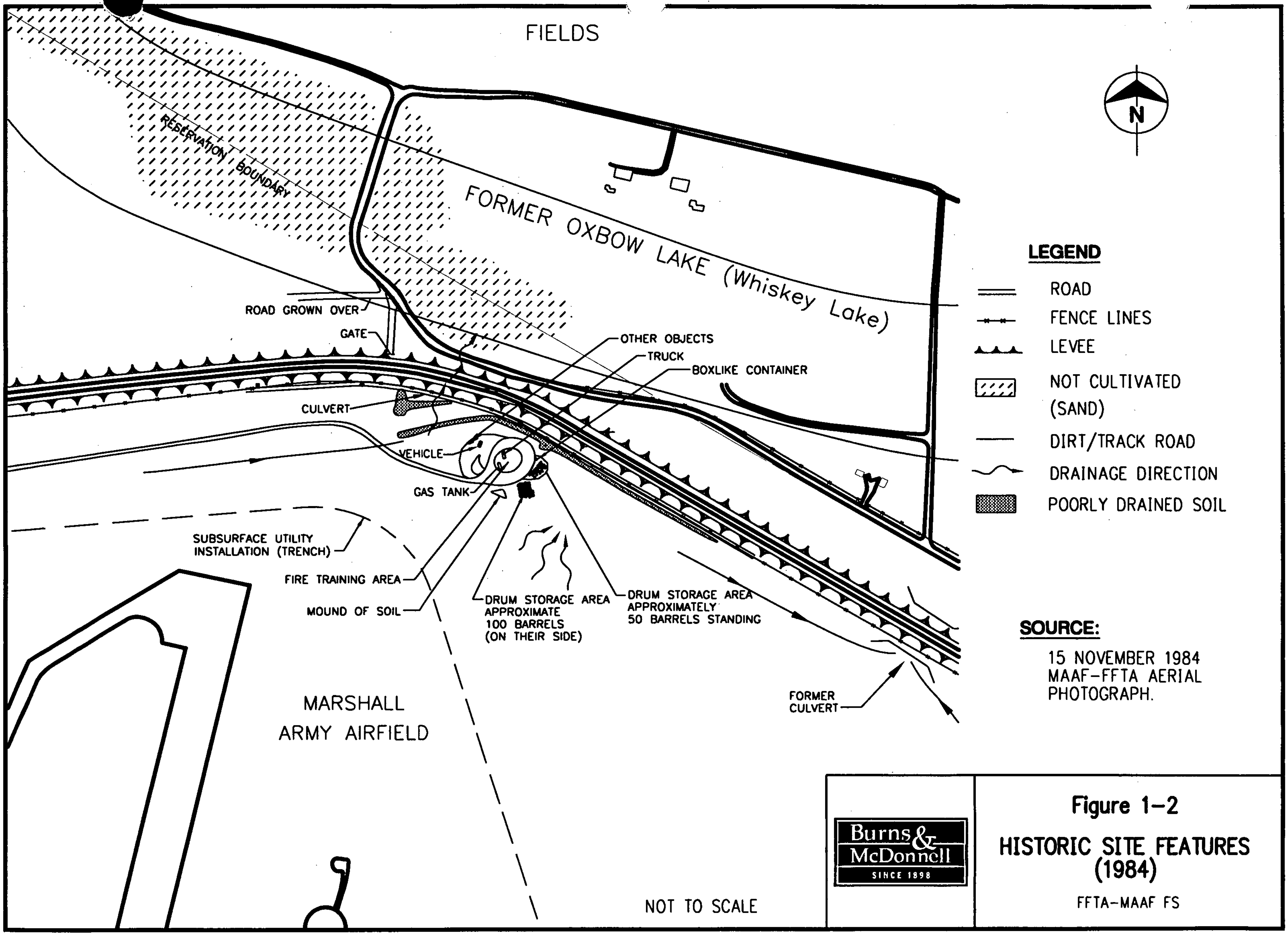

SOURCE:

15 NOVEMBER 1984
MAAF-FFTA AERIAL
PHOTOGRAPH.

Burns & McDonnell
SINCE 1898

Figure 1-2

HISTORIC SITE FEATURES (1984)

FFTA-MAAF FS

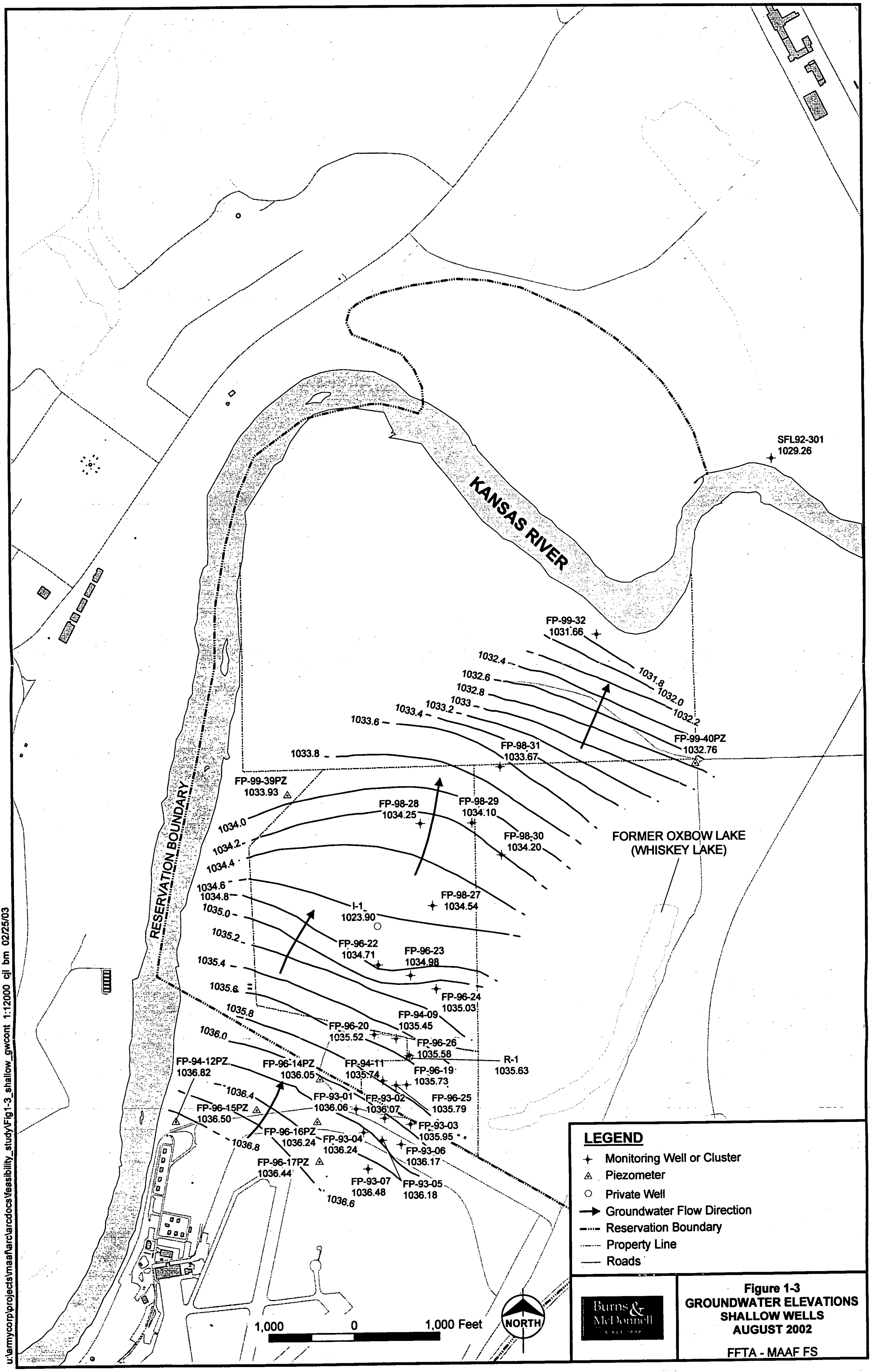

Figure 1-3
GROUNDWATER ELEVATIONS
SHALLOW WELLS
AUGUST 2002

FFTA - MAAF FS

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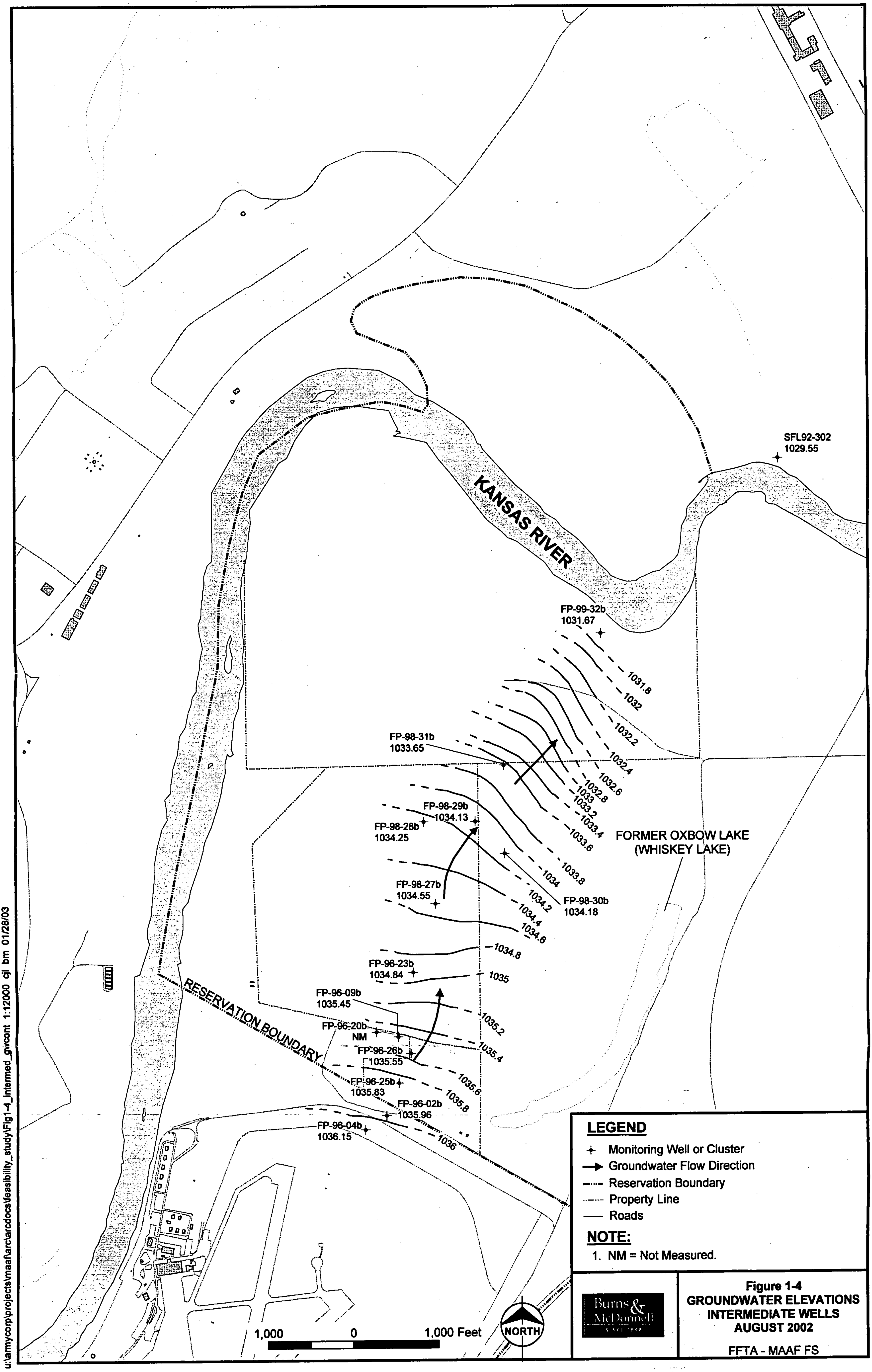

Figure 1-4
GROUNDWATER ELEVATIONS
INTERMEDIATE WELLS
AUGUST 2002

FFTA - MAAF FS

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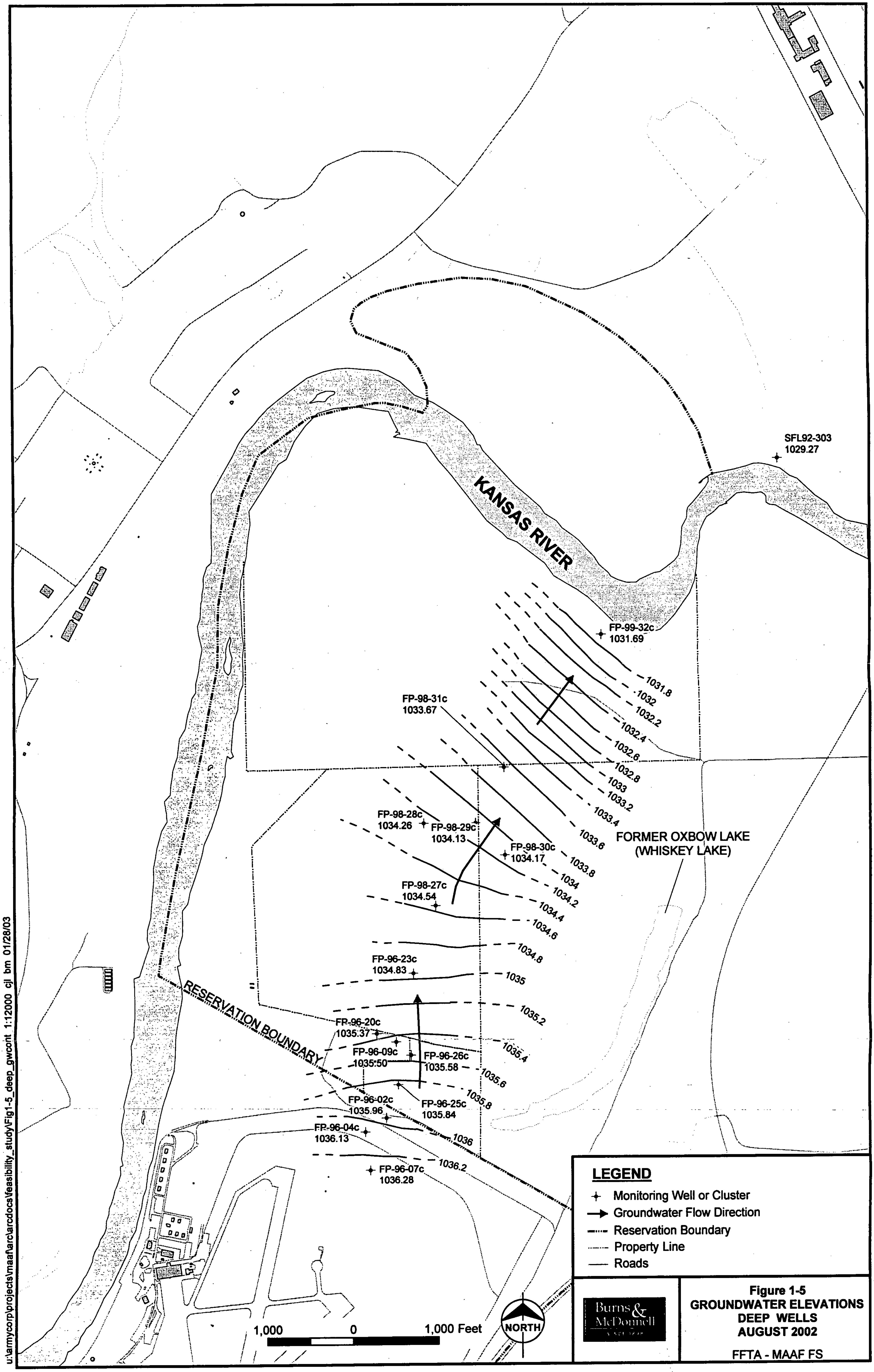

Figure 1-5
GROUNDWATER ELEVATIONS
DEEP WELLS
AUGUST 2002

FFTA - MAAF FS

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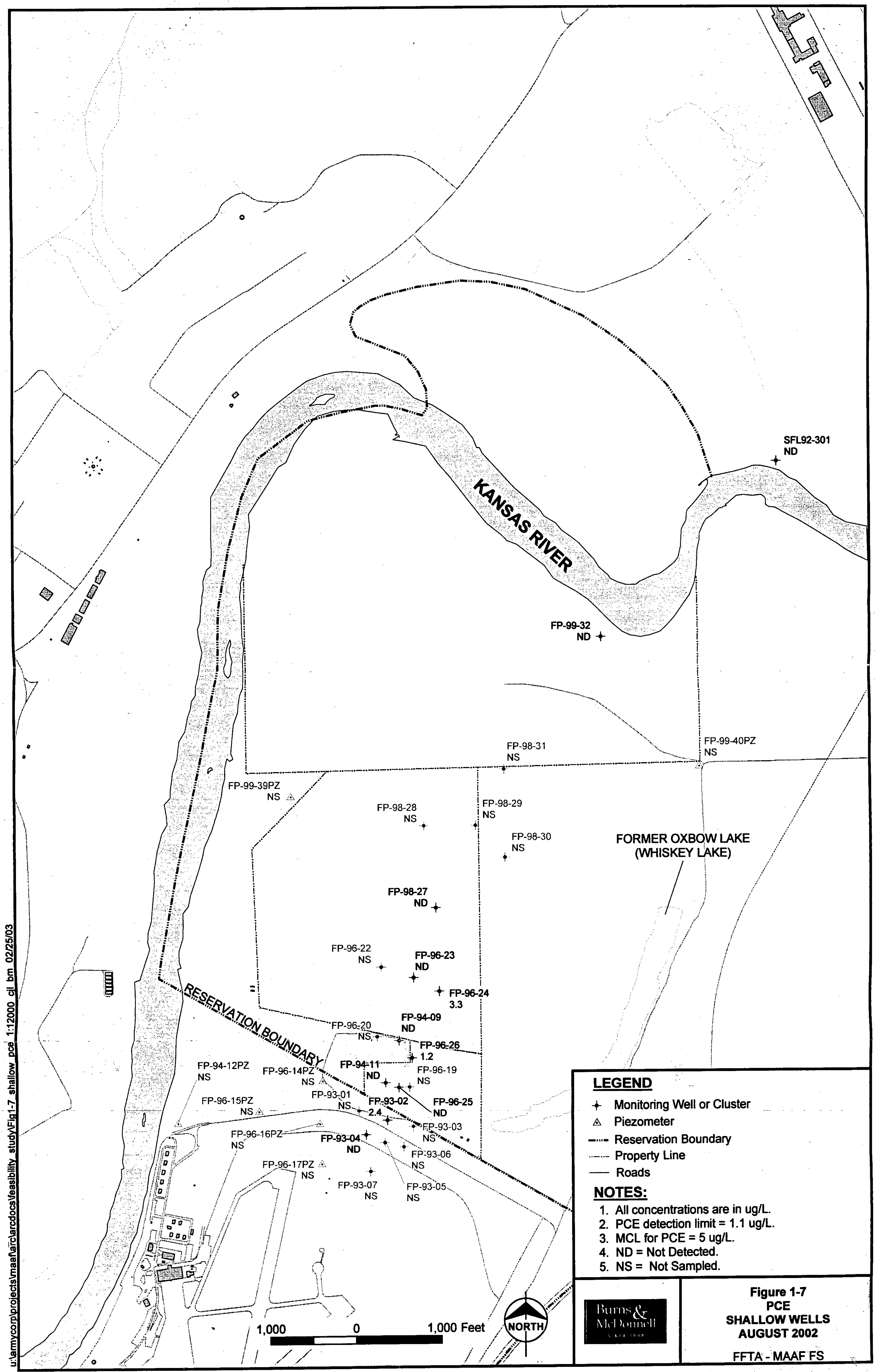
Notes:

750 ft = Distance between wells along centerline of the plume.

Zero entries on the data table indicate non-detects, and blank entries represent Not Sampled (NS). See Data Summary Reports (DSRs) for analytical reporting limits.

Burns & McDonnell
SINCE 1898

Figure 1-6
Chlorinated Solvents
Trend Chart
FFTA-MAAF FS



LEGEND

- ✦ Monitoring Well or Cluster
- △ Piezometer
- Reservation Boundary
- Property Line
- Roads

NOTES:

1. All concentrations are in ug/L.
2. PCE detection limit = 1.1 ug/L.
3. MCL for PCE = 5 ug/L.
4. ND = Not Detected.
5. NS = Not Sampled.

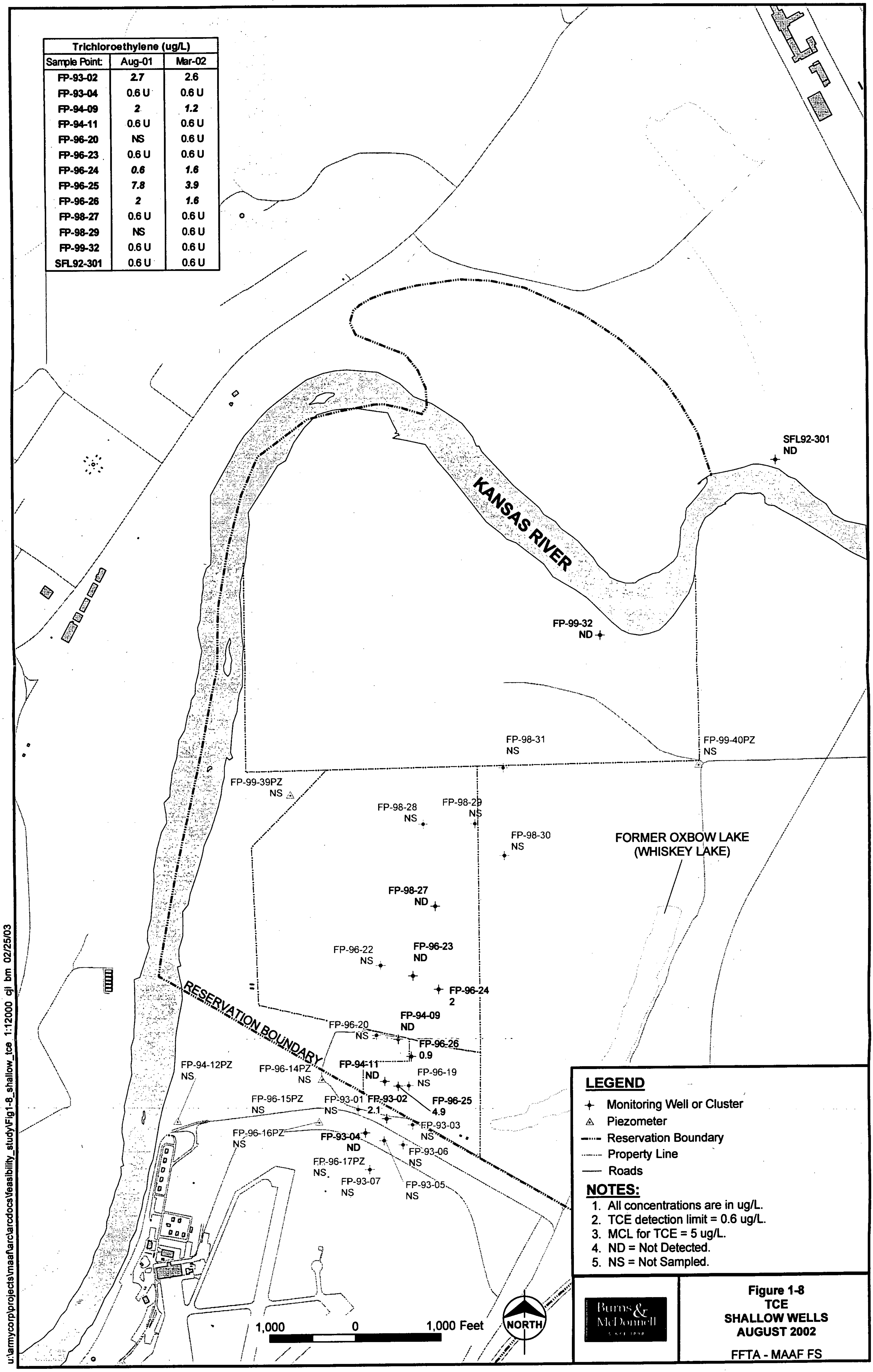
Burns & McDonnell
SINCE 1898

Figure 1-7
PCE
SHALLOW WELLS
AUGUST 2002

FFTA - MAAF FS

u:\armycorp\projects\maaf\arc\arcdocs\feasibility_study\Fig1-7_shallow_pce 1:12000 cjl bm 02/25/03

Trichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-93-02	2.7	2.6
FP-93-04	0.6 U	0.6 U
FP-94-09	2	*1.2*
FP-94-11	0.6 U	0.6 U
FP-96-20	NS	0.6 U
FP-96-23	0.6 U	0.6 U
FP-96-24	*0.6*	*1.6*
FP-96-25	*7.8*	*3.9*
FP-96-26	2	*1.6*
FP-98-27	0.6 U	0.6 U
FP-98-29	NS	0.6 U
FP-99-32	0.6 U	0.6 U
SFL92-301	0.6 U	0.6 U



LEGEND

- ✦ Monitoring Well or Cluster
- △ Piezometer
- -··- Reservation Boundary
- -··- Property Line
- — Roads

NOTES:

1. All concentrations are in ug/L.
2. TCE detection limit = 0.6 ug/L.
3. MCL for TCE = 5 ug/L.
4. ND = Not Detected.
5. NS = Not Sampled.

Burns & McDonnell

Figure 1-8
TCE
SHALLOW WELLS
AUGUST 2002

FFTA - MAAF FS

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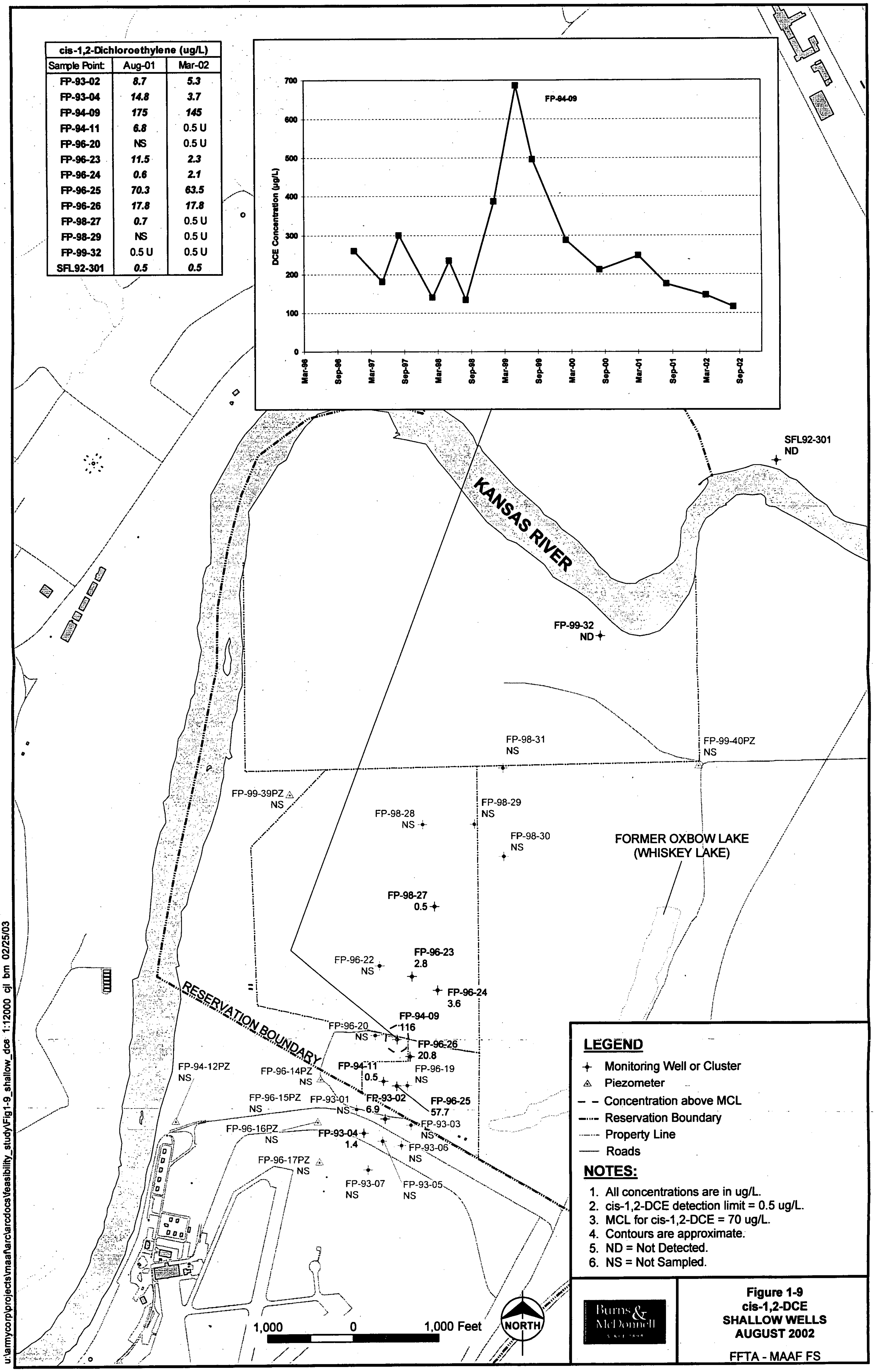

cis-1,2-Dichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-93-02	***8.7***	***5.3***
FP-93-04	***14.8***	***3.7***
FP-94-09	***175***	***145***
FP-94-11	***6.8***	0.5 U
FP-96-20	NS	0.5 U
FP-96-23	***11.5***	***2.3***
FP-96-24	***0.6***	***2.1***
FP-96-25	***70.3***	***63.5***
FP-96-26	***17.8***	***17.8***
FP-98-27	***0.7***	0.5 U
FP-98-29	NS	0.5 U
FP-99-32	0.5 U	0.5 U
SFL92-301	***0.5***	***0.5***

LEGEND

- ✦ Monitoring Well or Cluster
- △ Piezometer
- – – Concentration above MCL
- -··- Reservation Boundary
- ····· Property Line
- —— Roads

NOTES:

1. All concentrations are in ug/L.
2. cis-1,2-DCE detection limit = 0.5 ug/L.
3. MCL for cis-1,2-DCE = 70 ug/L.
4. Contours are approximate.
5. ND = Not Detected.
6. NS = Not Sampled.

Burns & McDonnell

Figure 1-9
cis-1,2-DCE
SHALLOW WELLS
AUGUST 2002

FFTA - MAAF FS

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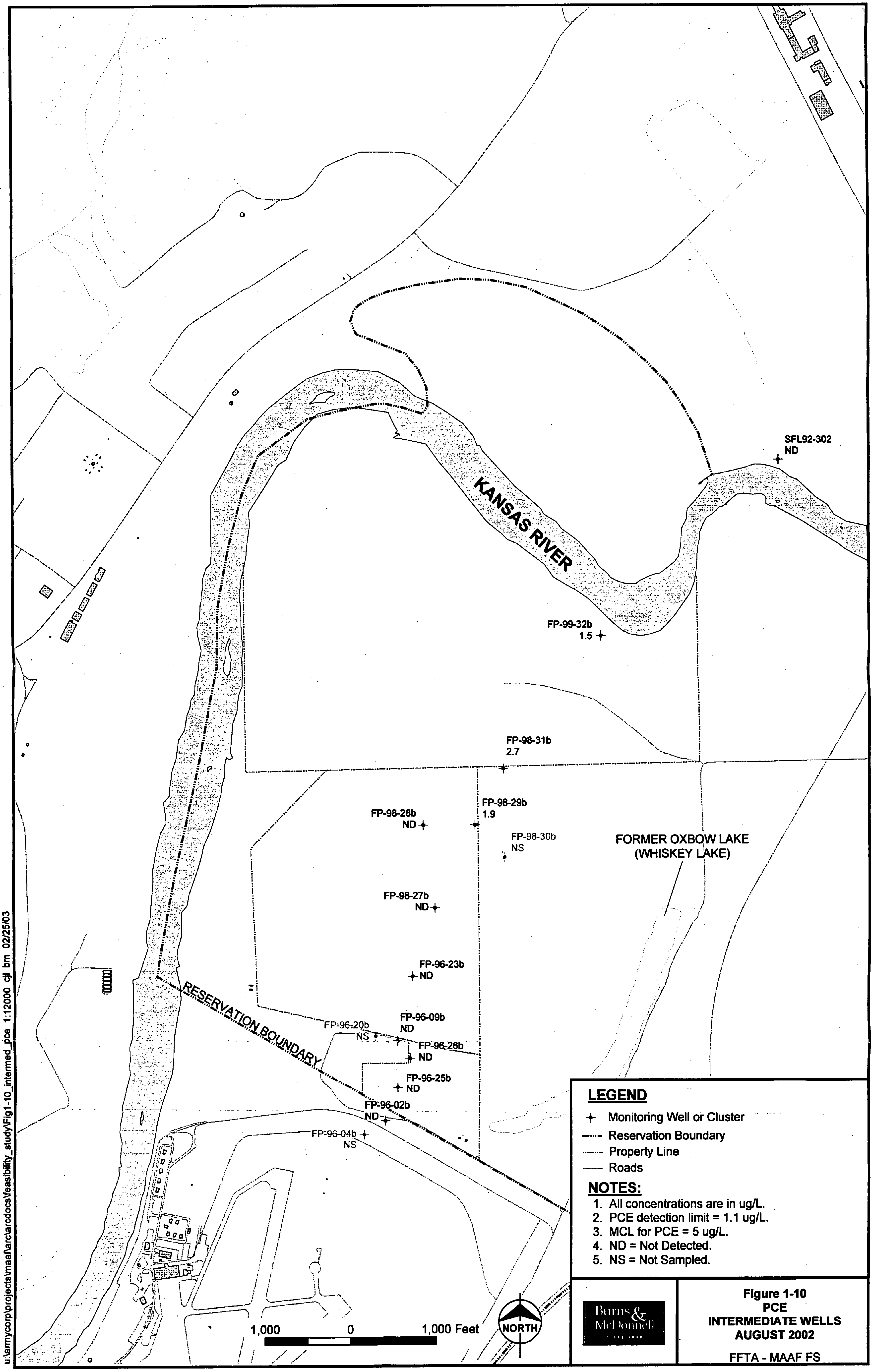

LEGEND

- ✦ Monitoring Well or Cluster
- -··- Reservation Boundary
- ---- Property Line
- —— Roads

NOTES:

1. All concentrations are in ug/L.
2. PCE detection limit = 1.1 ug/L.
3. MCL for PCE = 5 ug/L.
4. ND = Not Detected.
5. NS = Not Sampled.

Figure 1-10
PCE
INTERMEDIATE WELLS
AUGUST 2002

FFTA - MAAF FS

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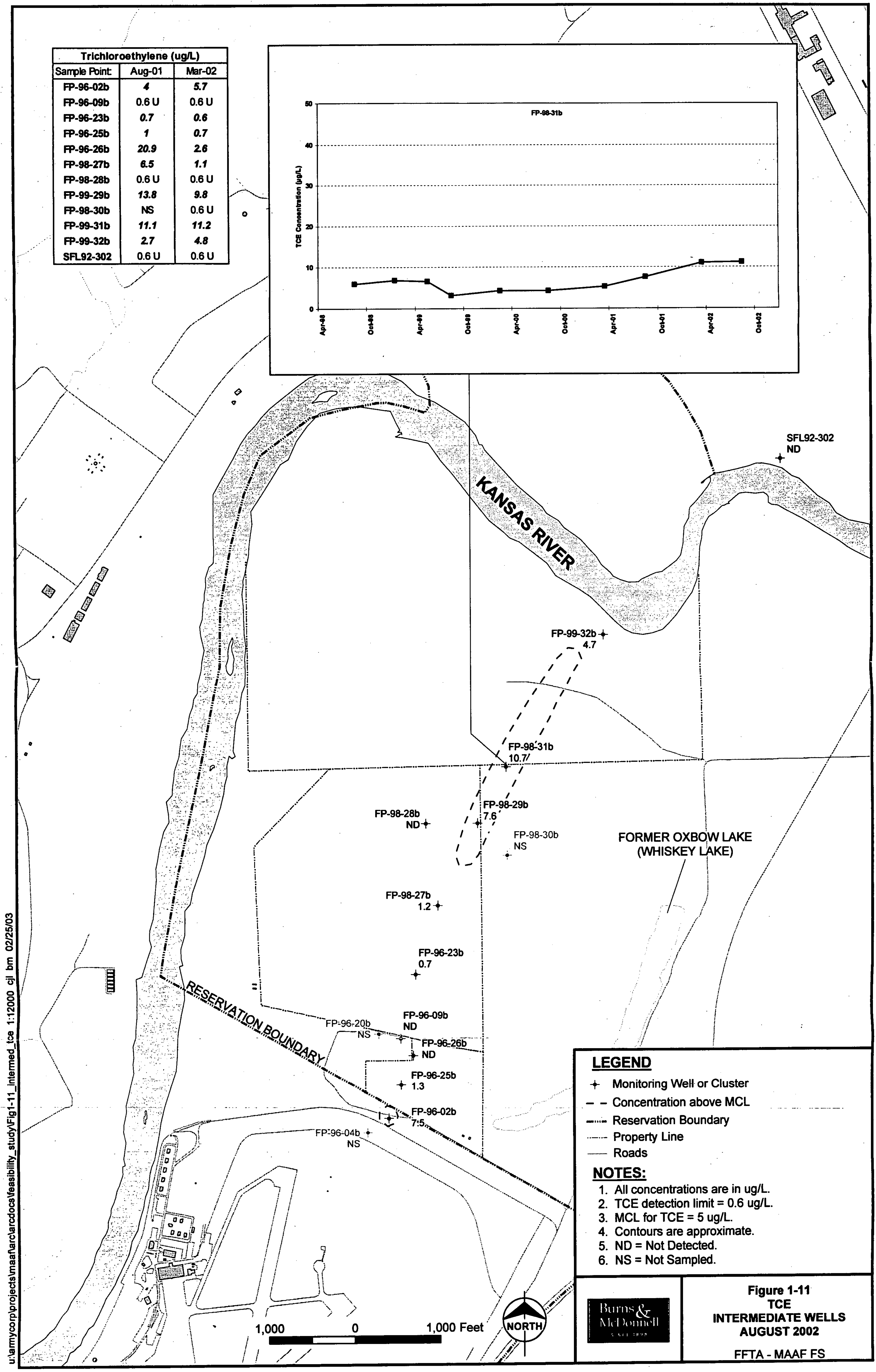


Trichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-96-02b	*4*	*5.7*
FP-96-09b	0.6 U	0.6 U
FP-96-23b	*0.7*	*0.6*
FP-96-25b	*1*	*0.7*
FP-96-26b	*20.9*	*2.6*
FP-98-27b	*6.5*	*1.1*
FP-98-28b	0.6 U	0.6 U
FP-99-29b	*13.8*	*9.8*
FP-98-30b	NS	0.6 U
FP-99-31b	*11.1*	*11.2*
FP-99-32b	*2.7*	*4.8*
SFL92-302	0.6 U	0.6 U

LEGEND

- ✦ Monitoring Well or Cluster
- – – Concentration above MCL
- -··- Reservation Boundary
- ---- Property Line
- —— Roads

NOTES:

1. All concentrations are in ug/L.
2. TCE detection limit = 0.6 ug/L.
3. MCL for TCE = 5 ug/L.
4. Contours are approximate.
5. ND = Not Detected.
6. NS = Not Sampled.

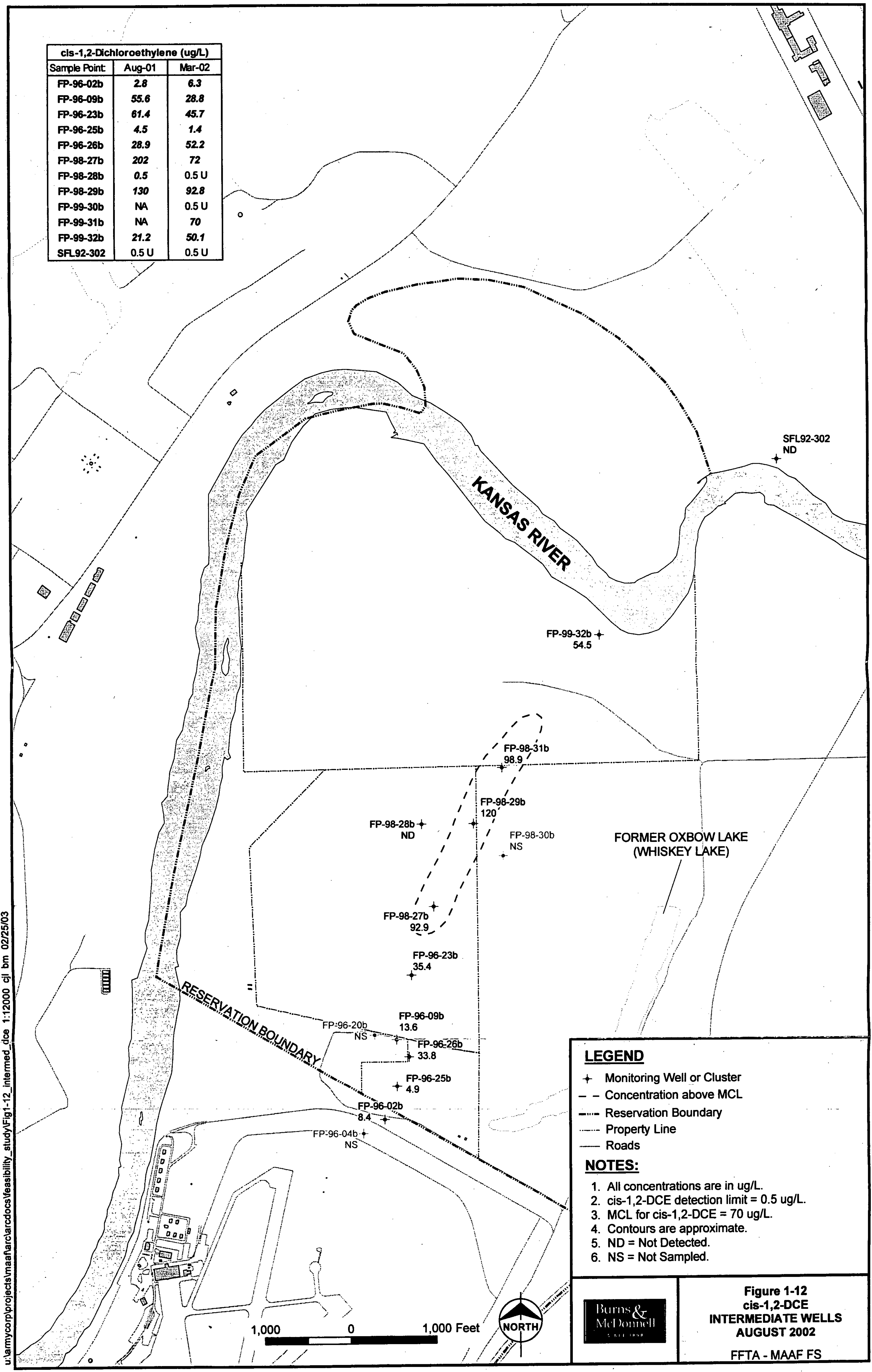
Burns & McDonnell

Figure 1-11
TCE
INTERMEDIATE WELLS
AUGUST 2002

FFTA - MAAF FS

u:\armycorp\projects\maaf\arcdocs\feasibility_study\Fig1-11_intermed_tce 1:12000 cjl bm 02/25/03

cis-1,2-Dichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-96-02b	2.8	6.3
FP-96-09b	55.6	28.8
FP-96-23b	61.4	45.7
FP-96-25b	4.5	1.4
FP-96-26b	28.9	52.2
FP-98-27b	202	72
FP-98-28b	0.5	0.5 U
FP-98-29b	130	92.8
FP-99-30b	NA	0.5 U
FP-99-31b	NA	70
FP-99-32b	21.2	50.1
SFL92-302	0.5 U	0.5 U



LEGEND

- ✢ Monitoring Well or Cluster
- – – Concentration above MCL
- -··- Reservation Boundary
- -·-·- Property Line
- —— Roads

NOTES:

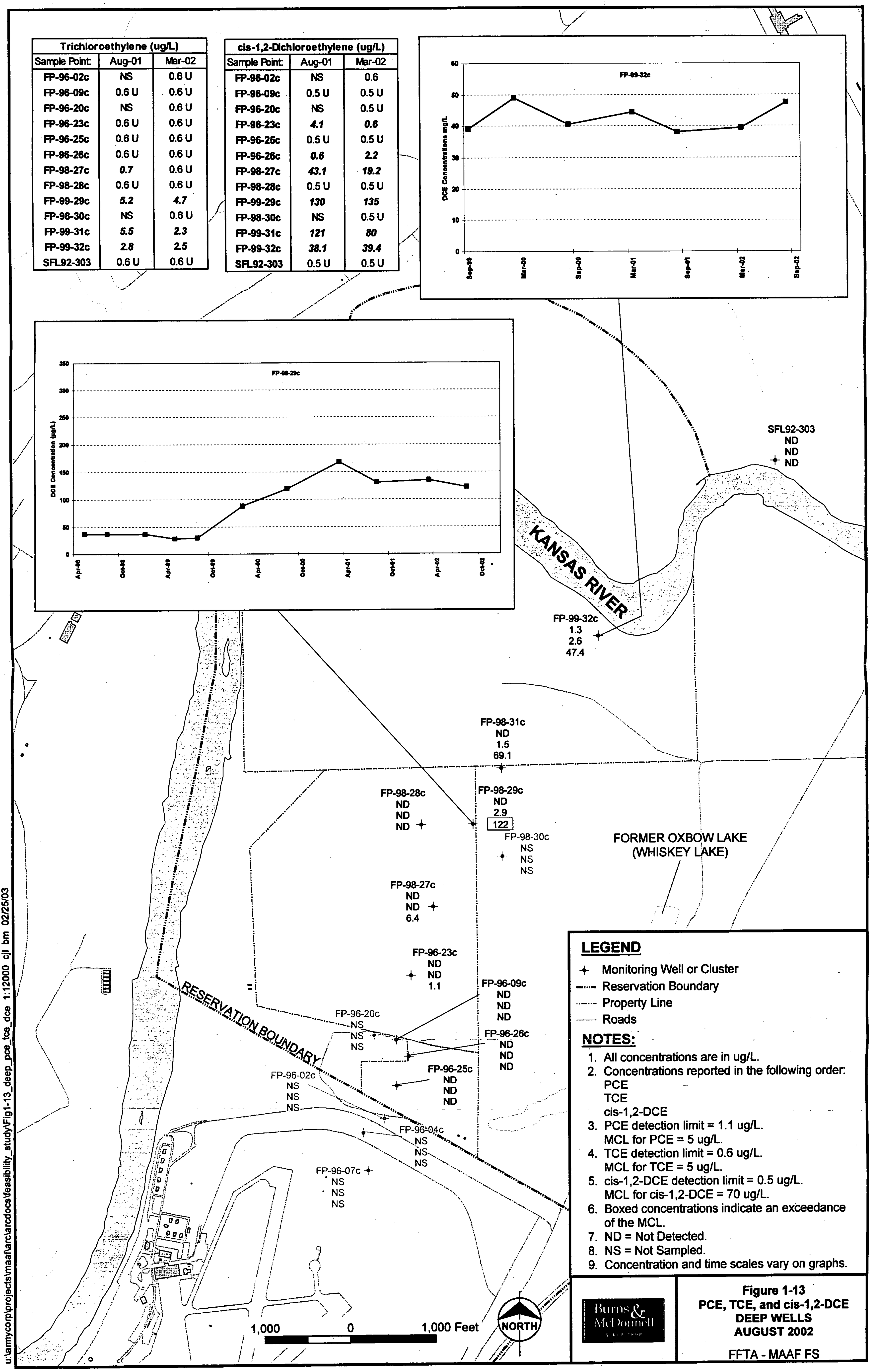
1. All concentrations are in ug/L.
2. cis-1,2-DCE detection limit = 0.5 ug/L.
3. MCL for cis-1,2-DCE = 70 ug/L.
4. Contours are approximate.
5. ND = Not Detected.
6. NS = Not Sampled.

Burns & McDonnell

Figure 1-12
cis-1,2-DCE
INTERMEDIATE WELLS
AUGUST 2002

FFTA - MAAF FS

u:\armycorp\projects\maaf\arcdocs\feasibility_study\Fig1-12_intermed_dce 1:12000 cjl bm 02/25/03



Trichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-96-02c	NS	0.6 U
FP-96-09c	0.6 U	0.6 U
FP-96-20c	NS	0.6 U
FP-96-23c	0.6 U	0.6 U
FP-96-25c	0.6 U	0.6 U
FP-96-26c	0.6 U	0.6 U
FP-98-27c	*0.7*	0.6 U
FP-98-28c	0.6 U	0.6 U
FP-99-29c	*5.2*	*4.7*
FP-98-30c	NS	0.6 U
FP-99-31c	*5.5*	*2.3*
FP-99-32c	*2.8*	*2.5*
SFL92-303	0.6 U	0.6 U

cis-1,2-Dichloroethylene (ug/L)		
Sample Point	Aug-01	Mar-02
FP-96-02c	NS	0.6
FP-96-09c	0.5 U	0.5 U
FP-96-20c	NS	0.5 U
FP-96-23c	*4.1*	*0.6*
FP-96-25c	0.5 U	0.5 U
FP-96-26c	*0.6*	*2.2*
FP-98-27c	*43.1*	*19.2*
FP-98-28c	0.5 U	0.5 U
FP-99-29c	*130*	*135*
FP-98-30c	NS	0.5 U
FP-99-31c	*121*	*80*
FP-99-32c	*38.1*	*39.4*
SFL92-303	0.5 U	0.5 U

LEGEND

✦	Monitoring Well or Cluster
-··-	Reservation Boundary
-·-·-	Property Line
——	Roads

NOTES:

1. All concentrations are in ug/L.
2. Concentrations reported in the following order:
   PCE
   TCE
   cis-1,2-DCE
3. PCE detection limit = 1.1 ug/L.
   MCL for PCE = 5 ug/L.
4. TCE detection limit = 0.6 ug/L.
   MCL for TCE = 5 ug/L.
5. cis-1,2-DCE detection limit = 0.5 ug/L.
   MCL for cis-1,2-DCE = 70 ug/L.
6. Boxed concentrations indicate an exceedance of the MCL.
7. ND = Not Detected.
8. NS = Not Sampled.
9. Concentration and time scales vary on graphs.

Burns & McDonnell

Figure 1-13
PCE, TCE, and cis-1,2-DCE
DEEP WELLS
AUGUST 2002

FFTA - MAAF FS

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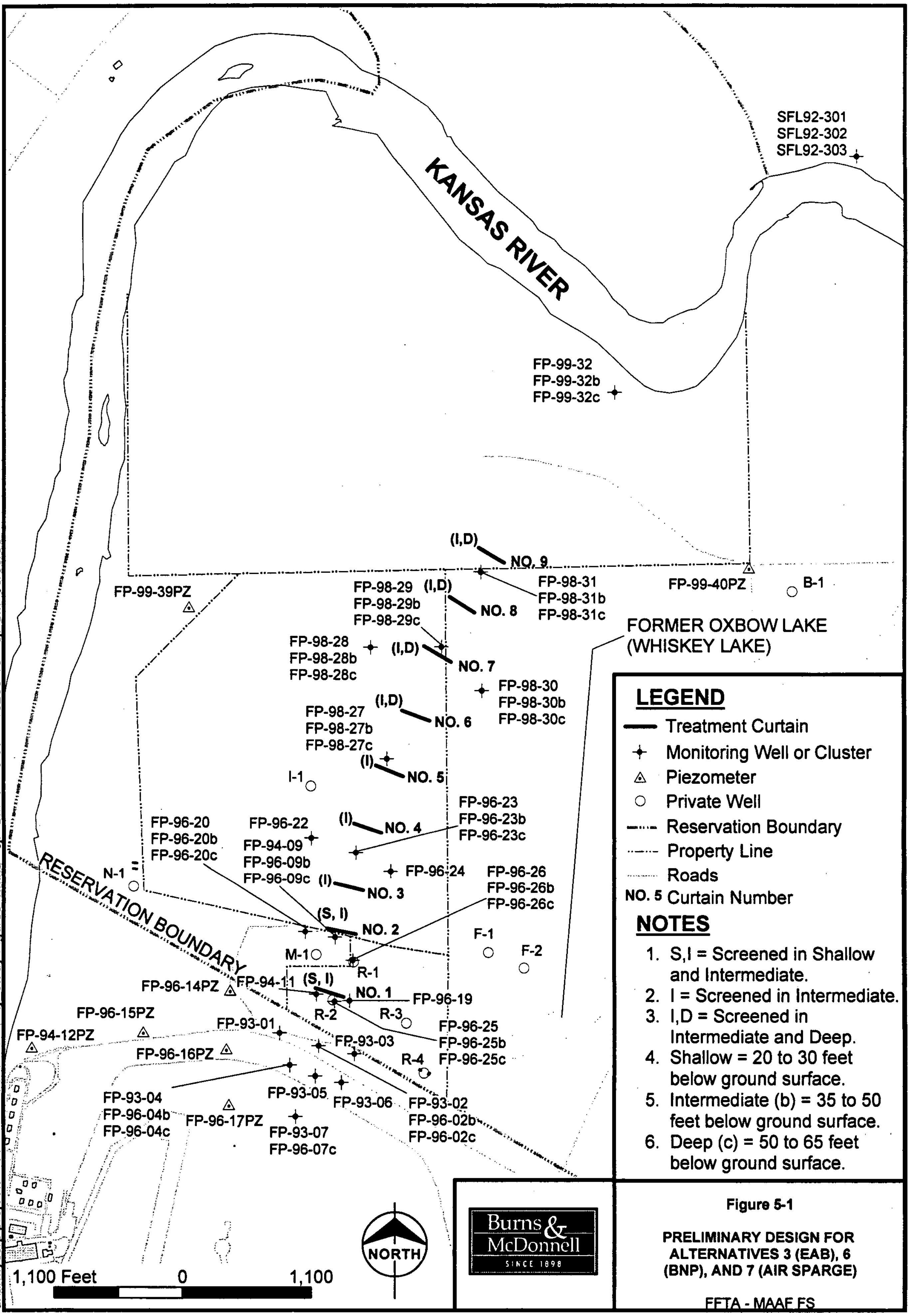

LEGEND

- Treatment Curtain
- ✦ Monitoring Well or Cluster
- △ Piezometer
- ○ Private Well
- Reservation Boundary
- Property Line
- Roads
- NO. 5 Curtain Number

NOTES

1. S,I = Screened in Shallow and Intermediate.
2. I = Screened in Intermediate.
3. I,D = Screened in Intermediate and Deep.
4. Shallow = 20 to 30 feet below ground surface.
5. Intermediate (b) = 35 to 50 feet below ground surface.
6. Deep (c) = 50 to 65 feet below ground surface.

Figure 5-1

PRELIMINARY DESIGN FOR ALTERNATIVES 3 (EAB), 6 (BNP), AND 7 (AIR SPARGE)

FFTA - MAAF FS

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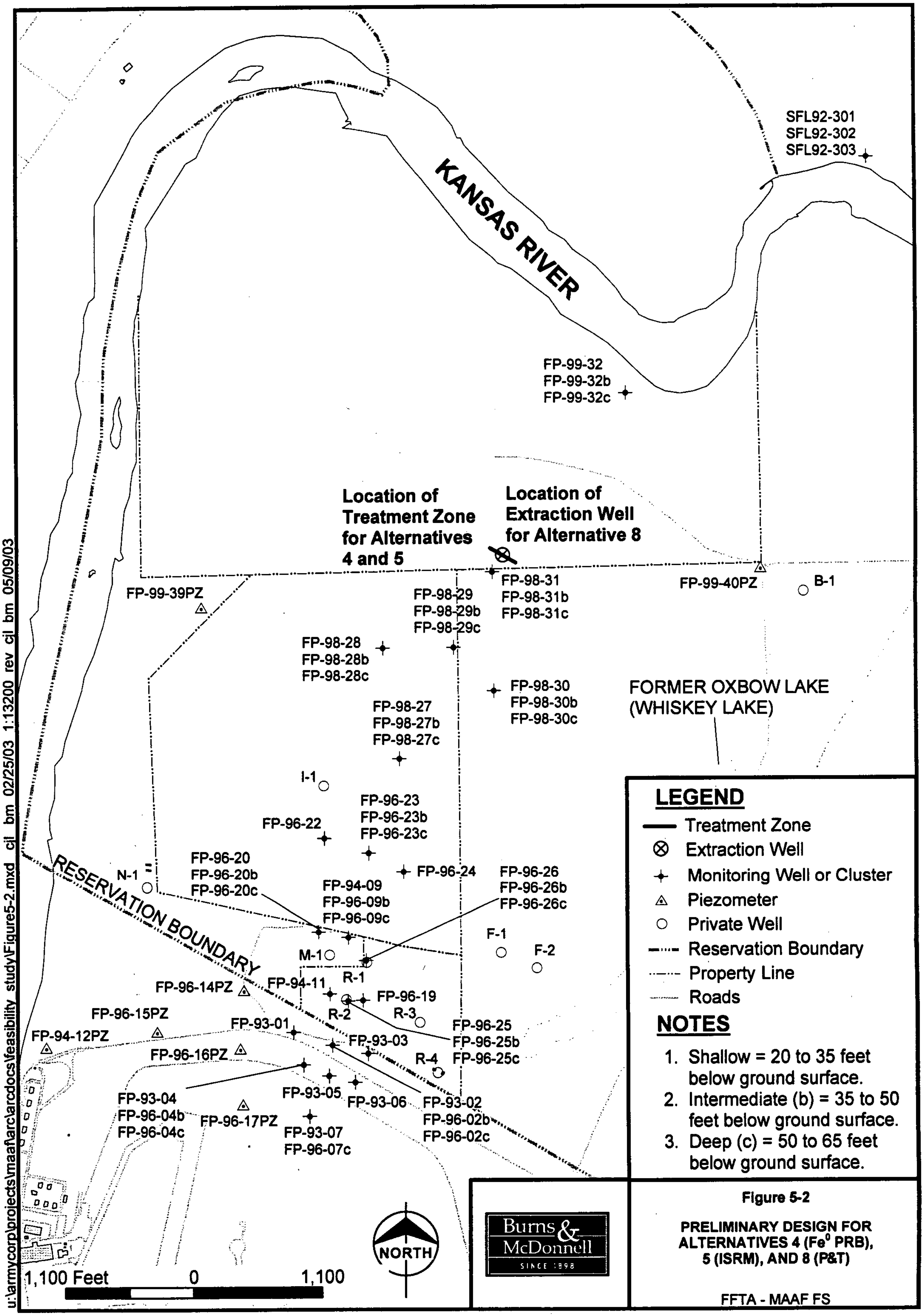

NOTES

1. Shallow = 20 to 35 feet below ground surface.
2. Intermediate (b) = 35 to 50 feet below ground surface.
3. Deep (c) = 50 to 65 feet below ground surface.

Figure 5-2

PRELIMINARY DESIGN FOR ALTERNATIVES 4 (Fe^0 PRB), 5 (ISRM), AND 8 (P&T)

FFTA - MAAF FS

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TABLES

Table 4-1
Technologies and Process Options for Groundwater Remediation
FFTA-MAAF FS

General Response Actions	Technologies	Process Options
No Action	No Action	No Action
Institutional Controls	Government Controls	Zoning Ordinance Amendment County Resolution
	Proprietary Controls	Negative Easements and Restrictive Covenants Affirmative Easements
Other Controls	Monitoring	Groundwater Monitoring
	Alternative Water Supply	Rural Water Supply New Supply Wells
	Individual Well Treatment	Low Profile Air Stripping Activated Carbon Adsorption UV Oxidation
Monitored Natural Attenuation	Monitored Natural Attenuation	Monitored Natural Attenuation
Containment	Vertical Barriers	Vertical Barriers
	Horizontal Barriers	Horizontal Barriers
	Capping	Capping
Extraction, Ex-Situ Treatment, and Discharge	Collection/Extraction	Interceptor Trenches Pumping Wells: Vertical Pumping Wells: Directional Dual Phase Vapor Extraction (DPVE)
	Biological Treatment	Aerobic Biological Reactors Cometabolic Aerobic Biological Reactors Anaerobic Biological Reactors

Table 4-1 (Continued)
Technologies and Process Options for Groundwater Remediation
FFTA-MAAF FS

General Response Actions	Technologies	Process Options
Extraction, Ex-Situ Treatment, and Discharge (Continued)	Physical/Chemical Treatment	Oil/Water Separation
		Precipitation
		Flocculation
		Air Stripping
		Steam Stripping
		Carbon Adsorption
		Resin Adsorption/Ambersorb®
		Organoclay Adsorption
		Oxidation/Reduction
		Ultrafiltration/Reverse Osmosis
		Cross-Flow Pervaporation
		Ion Exchange
		Distillation
		Liquefied Gas Solvent Extraction
		High-Energy Electron Irradiation
		Surfactants
	Thermal Treatment	Evaporation
		Wet Air/Supercritical Oxidation
		Catalytic Oxidation
		Gas-Phase Chemical Reduction
		Photo-Dechlorination
		Pyrolysis
		Incineration
	Off-Gas Treatment	Biofiltration
		Vapor Phase Carbon Adsorption
		Catalytic/Thermal Oxidation
		High Energy Corona
		Membrane Separation
		Photolytic Oxidation
	Discharge (treated or untreated)	Discharge to Fort Riley Wastewater Treatment Plant
		Discharge to Kansas River
		Spray/Sprinkler Irrigation
		Recharge
		Deep Well Injection
		Vapors Discharged to the Atmosphere

Table 4-1 (Continued)
Technologies and Process Options for Groundwater Remediation
FFTA-MAAF FS

General Response Actions	Technologies	Process Options
In-Situ Treatment	Biological Treatment	Biosparging Aerobic Bioremediation with Lab-Isolated Solvent-Degrading Bacteria Cometabolic Aerobic Bioremediation Enhanced Anaerobic Bioremediation Nitrate Enhanced Bioremediation H_2O_2 Enhanced Bioremediation Electric Induced Redox Barriers Oxygen Release Compound® (ORC) In-Situ Biofilters
	Physical/Chemical Treatment	Air Sparging C-Sparger™ Groundwater Circulation Wells Soil Vapor Extraction (SVE) In-Situ Chemical Oxidation Permeable Reactive Barrier: Zero Valent Iron Permeable Reactive Barrier: In-Situ Air Stripping Permeable Reactive Barrier: In-Situ Adsorption In-Situ Redox Manipulation Bimetallic Nanoscale Particles In-Situ Chemical Flushing Electrical Separation In-Situ Radio Frequency Heating Steam Injection Dynamic Underground Stripping (DUS) Hydrous Pyrolysis/Oxidation (HPO) Six-Phase Soil Heating
	Components - Fluid Delivery Systems	Vertical Wells Horizontal Wells

Table 4-2
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
No Action			
No Action	No Action	Yes	Consideration of no action alternative is required by NCP and provides baseline to compare other alternatives.
Institutional Controls			
Government Controls			
Zoning Ordinance Amendment	Amendment to the Geary County zoning ordinance creating a groundwater restriction overlay district (DPRA, 2000).	Yes	Potentially applicable.
County Resolution	Enactment of a Geary County environmental and health resolution designed to restrict contaminated groundwater use (DPRA, 2000).	Yes	Potentially applicable.
Proprietary Controls			
Negative Easements and Restrictive Covenants	A negative easement acts as a land use restriction and imposes limits on how the landowner can use his or her property. Restrictive covenants provide promises concerning the use of land. Such covenants act as a contract between the parties who originally enter into it, and as such, its terms may be enforced under contract law (DPRA, 2000).	Yes	Potentially applicable.
Affirmative Easements	An affirmative easement allows the holder of the easement to enter upon or use another's property for a particular purpose (e.g., an access easement) - DPRA, 2000.	Yes	Potentially applicable.
Other Controls			
Monitoring			
Groundwater Monitoring	Periodic sampling and analysis of groundwater from monitoring wells.	Yes	Groundwater monitoring is currently in place at the Site.
Alternative Water Supply			
Rural Water Supply	Extension of municipal water distribution system to serve residents in the area of influence.	Yes	Potentially applicable.
New Supply Wells	New uncontaminated wells to serve residents in the area of influence.	Yes	Potentially applicable.
Individual Well Treatment			
Low Profile Air Stripping	Volatilization of contaminants from water by either passing air through water or water through air.	Yes	Potentially applicable.
Activated Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	Yes	Potentially applicable.
UV Oxidation	Oxidation of organic contaminants by addition of H_2O_2 and/or O_3 and catalyzed by ultraviolet (UV) light.	Yes	Potentially applicable.
Monitored Natural Attenuation			
Monitored Natural Attenuation	Natural subsurface processes such as dispersion, volatilization, biodegradation, adsorption, and chemical reactions combine to reduce contaminant levels over time.	Yes	Applicable. Data indicates that natural attenuation processes are acting to significantly reduce contaminant concentrations at the Site.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
Containment			
Vertical Barriers	Low permeability wall made of soil-bentonite, reinforced concrete, chemical grout, or steel sheets.	Yes	Potentially applicable to focus or funnel contaminants.
Horizontal Barriers	Low permeability barrier typically used to prevent leaching of contaminants to groundwater.	No	No active sources or exposure risk at this Site make it unnecessary.
Capping	Surface is covered with impermeable materials to prevent leaching of contaminants to groundwater.	No	No active sources or exposure risk at this Site make it unnecessary.
Extraction, Ex-Situ Treatment, and Discharge			
Collection/Extraction			
Interceptor Trenches	Perforated pipe in trenches backfilled with porous media to collect contaminated water for further treatment or disposal.	No	Trenches are more applicable to low-yield aquifers.
Pumping Wells: Vertical	Series of vertical wells with water pumps to extract contaminated groundwater.	Yes	Potentially applicable.
Pumping Wells: Directional	Series of horizontal or inclined wells with water pumps to extract contaminated ground water.	No	Typically advantageous when contaminants are confined vertically or when physical obstructions are present.
Dual Phase Vapor Extraction (DPVE)	A high vacuum system is applied to simultaneously remove various combinations of contaminated groundwater, free-phase petroleum product, and hydrocarbon vapor from the subsurface.	No	This technology is more applicable to low yield aquifers, soil remediation, and for the removal of LNAPL. DPVE is more applicable to source zone remediation.
Biological Treatment			
Aerobic Biological Reactors	Contaminated water is pumped to a suspended growth- or attached growth-type reactor where microbial population aerobically oxidizes organics.	Yes	Potentially applicable.
Cometabolic Aerobic Biological Reactors	Chlorinated VOCs are transformed as secondary substrate by methanotrophic bacteria (methane degraders). For this to occur, methane and O_2 must be provided to the reactor.	Yes	Potentially applicable.
Anaerobic Biological Reactors	Contaminated water is pumped to a closed reactor where microbial population degrades organic contaminants in absence of oxygen. Other carbon sources, such as acetate, are added to act as electron donors in anaerobic conditions.	No	Due to the low contaminant concentrations, other carbon sources would need to be added in excess to sustain microbial population. Lengthy treatment times may also be required.
Physical/Chemical Treatment			
Oil/Water Separation	Separation of free oils by gravity and/or emulsified products by chemical pretreatment and/or coalescing media.	No	Contaminants are dissolved in ground water, so there is no free-phase product.
Precipitation	Alteration of chemical equilibrium to reduce solubility of dissolved contaminants, such as metals.	No	Contaminants are below the solubility limit, so precipitation is not applicable.
Flocculation	Destabilization of colloids to aggregate them into flocs.	No	Typically used to remove metals from water.
Air Stripping	Volatilization of contaminants from water by either passing air through water or water through air.	Yes	Potentially applicable.
Steam Stripping	Volatilization of contaminants from water by passing steam through water usually in multiple tray columns.	No	Technology is more applicable to high concentration waste streams.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge (Continued)			
Physical/Chemical Treatment (Continued)			
Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	Yes	Potentially applicable.
Resin Adsorption/Ambersorb®	Ambersorb® is a regenerable resin-type adsorbent that treats groundwater contaminated with hazardous organics. It has 5 to 10 times the capacity of activated carbon for low concentrations of VOCs.	No	The availability of resin adsorbents for full-scale projects is questionable. Not commonly used full-scale to remove organics from wastewater.
Organoclay Adsorption	Bentonite is organically modified to render it hydrophobic and oleophilic. This organoclay attracts a wide range of organic contaminants.	Yes	Potentially applicable.
Oxidation/Reduction	Oxidation or reduction of organic contaminants through addition of strong oxidizing or reducing agents. May be coupled with irradiation from UV light.	Yes	Potentially applicable.
Ultrafiltration/Reverse Osmosis	Use of high pressure to force water through a semi-permeable membrane leaving contaminants behind.	No	Although ultrafiltration/reverse osmosis has been typically used for separating inorganics from solution, some semipermeable membranes also reject organics, including halogenated solvents. It usually requires extensive pretreatment.
Cross-Flow Pervaporation	Membrane-process that uses an organophilic membrane that absorb organics in solution. The organics diffuse through membrane by a vacuum and condense into a highly concentrated permeate.	No	Since water needs to be heated to 165°F, process applies only to high contaminant concentrations.
Ion Exchange	Contaminated water is passed through a resin bed where ions are exchanged between resin and water.	No	Applicable only to ions (anions or cations).
Distillation	Separation of substances (e.g., contaminants and water) relying on boiling point differences.	No	Technology is more applicable to high concentration waste streams and/or small volumes of waste.
Liquefied Gas Solvent Extraction	Contaminated organics in groundwater are extracted by liquefied carbon dioxide in a continuous trayed extraction tower. The solvent (CO_2) is subsequently vaporized and recycled.	No	Technology is more applicable to soils. May be feasible when other ex-situ technologies, such as air stripping, are not.
High-Energy Electron Irradiation	Contaminated water is irradiated with high-energy electrons which promote reductive dehalogenation and also produce highly oxidizing chemical species, such as OH^0, which break down contaminants.	No	Technology is more applicable to high concentration waste streams. May be feasible when other ex-situ technologies, such as air stripping, are not.
Surfactants	Surfactants are added to the groundwater to dissolve NAPL or highly adsorbed contaminants. The mixture is then separated using phase separation, ultrafiltration, and air flotation. Contaminants are finally separated from surfactants by desorption.	No	Technology is more applicable to high concentration waste streams. May be feasible when other ex-situ technologies, such as air stripping, are not.
Thermal Treatment			
Evaporation	Complete volatilization of solvent(s) leaving the solutes behind.	No	Technology is more applicable to small volumes of waste.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge (Continued)			
Thermal Treatment (Continued)			
Wet Air/Supercritical Oxidation	Oxidation of organic contaminants by O_2 or H_2O_2 under elevated temperatures and pressures.	No	Technology is more applicable to high concentration waste streams. Still in development/pilot status.
Catalytic Oxidation	Oxidation of organic contaminants by O_2 at elevated temperatures and under the presence of catalysts such as V_2O_5.	No	Technology is more applicable to high concentration waste streams. Little reported experience with liquid phase chlorinated solvents.
Gas-Phase Chemical Reduction	Gas-phase reductive reaction of hydrogen with chlorinated VOCs at elevated temperatures. After passing through scrubber, main gas products are H_2, N_2, CH_4, CO and H_2O.	No	Technology is potentially applicable to chlorinated VOCs. However, PCBs have been the main application. Technology is more applicable to high concentration waste streams.
Photo-Dechlorination	This technology uses ultraviolet light in a reducing atmosphere to dechlorinate (break Cl - C bonds) chlorinated organic contaminants. Products are hydrocarbons and HCl. The latter is separated in a scrubber.	No	Liquids need to be vaporized before treatment. Process is more suited for vapor phase treatment.
Pyrolysis	Degradation of organic compounds at elevated temperatures and absence of oxygen.	No	Technology is more applicable to small volumes of waste.
Incineration	Combustion of organic compounds.	No	Technology is more applicable to small volumes of waste.
Off-Gas Treatment			
Biofiltration	Vapor-phase organic contaminants are passed through a bed (organic or inert) where they are degraded by microorganisms.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.
Vapor Phase Carbon Adsorption	Pollutants are removed from air by adsorption onto activated carbon grains.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.
Catalytic/Thermal Oxidation	Contaminated air is passed through catalyst bed where pollutants are oxidized at elevated temperatures.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.
High Energy Corona	Technology uses high-voltage electricity to destroy VOCs at room temperature.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.
Membrane Separation	High pressure separation system based on the preferential transport of organic vapors through nonporous gas separation membrane.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation

FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge (Continued)			
Off-Gas Treatment (Continued)			
Photolytic Oxidation	Process applies short wavelength UV light at very high intensities to contaminants in the gas phase. UV light energy transforms electrons to higher energy states and breaks molecular bonds.	No	Treatment unnecessary. Expected vapor concentrations are below regulatory levels. Vapors are allowed to discharge directly to the atmosphere.
Discharge (treated or untreated)			
Discharge to Fort Riley Wastewater Treatment Plant	Water discharged to Fort Riley Wastewater Treatment Plant.	Yes	Potentially applicable.
Discharge to Kansas River	Water discharged to the Kansas River.	Yes	Potentially applicable.
Spray/Sprinkler Irrigation	Direct irrigation of water onto land surface. Sprinkler heads are designed to treat (volatilize) VOCs during application.	Yes	Potentially applicable.
Recharge	Water is recharged back to the aquifer it was removed from via injection wells, recharge trenches, or recharge basins.	Yes	Potentially applicable.
Deep Well Injection	Water is injected into underlying aquifers, which are hydraulically disconnected from the aquifer it was removed from, through deep wells.	No	Difficult and lengthy process to obtain permit. May not be possible if underlying aquifer is a potential drinking water source.
Vapors Discharged to the Atmosphere	Vapors discharged to the atmosphere.	Yes	Potentially applicable.
In-Situ Treatment			
Biological Treatment			
Biosparging	Uses low flow air sparging to stimulate aerobic biodegradation of contaminants by delivering oxygen to the saturated zone in permeable aquifers.	No	Some chlorinated solvents present at this Site are not readily biodegradable under aerobic conditions.
Aerobic Bioremediation with Lab-Isolated Solvent-Degrading Bacteria	Bacteria capable of biodegrading chlorinated aliphatics is isolated and used at the site for in-situ aerobic bioremediation.	No	Not feasible in large-scale bioremediation applications. However, it could be applicable using in-situ biofilters (see below).
Cometabolic Aerobic Bioremediation	Chlorinated VOCs are transformed as secondary substrate by methanotrophic bacteria (methane degraders). For this to occur, methane and O_2 must be provided in an injection-recovery well system.	No	Some chlorinated solvents present at this Site are not readily biodegradable under aerobic conditions.

Table 4-2 (Continued)

Initial Screening of Potential Technologies for Groundwater Remediation

FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
In-Situ Treatment (Continued)			
Biological Treatment (Continued)			
Enhanced Anaerobic Bioremediation	Technology designed to treat chlorinated solvents using anaerobic conditions. Oxygen depletors, such as acetate, methanol, and sodium lactate are used to consume dissolved O_2 and to act as electron donors in anaerobic reactions. Nutrients such as nitrogen, phosphorus, and carbon sources are added to promote the growth of anaerobic microbes. The patented method, Hydrogen Release Compound (HRC™), consists of injecting time-release lactic acid which is metabolized by anaerobic microbes and releases hydrogen. The resulting hydrogen is then used by other microbes to stimulate rapid degradation of chlorinated solvents. Other carbon sources such as molasses and vegetable oil may also be used to enhance anaerobic degradation.	Yes	Potentially applicable.
Nitrate Enhanced Bioremediation	Solubilized nitrate is circulated throughout contaminated zone to provide electron acceptors for biological degradation.	No	Some chlorinated solvents present at this Site are not readily biodegradable under aerobic (presence of electron acceptors) conditions.
H_2O_2 Enhanced Bioremediation	A dilute solution of H_2O_2, which breaks down into O_2 and water, is circulated throughout contaminated zone to increase O_2 content of groundwater and promote aerobic degradation.	No	Some chlorinated solvents present at this Site are not readily biodegradable under aerobic conditions.
Electric Induced Redox Barriers	Electric current is used to produce hydrogen from water. The resulting hydrogen is utilized by microbes to stimulate reductive dechlorination of chlorinated organics.	No	Technology is still in a development phase, has only been tested in a laboratory setting, and limited information is available. Developers indicate that small scale field tests and more rigorous laboratory studies are required before the effectiveness of the technology can be fully evaluated.
Oxygen Release Compound® (ORC)	ORC formulation is placed in passive wells. Groundwater hydrates the ORC, which slowly releases molecular oxygen. O_2 is then used by microorganisms to degrade contaminants aerobically.	No	Some chlorinated solvents present at this Site (TCE and PCE) are not readily biodegradable under aerobic conditions. ORC may inhibit the natural anaerobic biodegradation that is occurring at this Site. May require regulatory approval to inject ORC into the aquifer.
In-Situ Biofilters	Sand-filled trench that intercepts contaminated plume is inoculated with non-indigenous methanotrophic bacteria. Chlorinated VOCs are degraded by resting-state microorganisms with intermittent provision of methane.	Yes	Potentially applicable.
Physical/Chemical Treatment			
Air Sparging	Air is injected into the saturated zone which forms bubbles that volatilize contaminants and carry them to the surface. Vacuum extraction wells in the unsaturated zone capture volatilized contaminants.	Yes	Potentially applicable.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
In-Situ Treatment (Continued)			
Physical/Chemical Treatment (Continued)			
C-Sparger™	An air/ozone mixture is injected into saturated zone to chemically oxidize contaminants in-situ. An in-well water pump is provided to help disperse oxidant through formation.	Yes	Potentially applicable.
Groundwater Circulation Wells	Air is introduced into screened well to promote air stripping within the well. Less dense, aerated water is lifted creating a circulation pattern. Mass transfer of VOCs occurs as air/water mixture rises and contaminated air is extracted by a blower or discharged into the vadose for treatment by biodegradation.	Yes	Potentially applicable.
Soil Vapor Extraction (SVE)	A vacuum is applied to wells screened in the vadose zone to promote increased volatilization of VOCs. Vapors are collected for treatment and disposal if necessary.	Yes	Potentially applicable to remove contaminants that are volatilized during the groundwater remediation. May be used in combination with other technologies.
In-Situ Chemical Oxidation	Solubilized oxidant (H_2O_2, $KMnO_4$, or O_3), and sometimes catalysts, are circulated throughout contaminated zone to chemically oxidize organic contaminants.	Yes	Potentially applicable.
Permeable Reactive Barrier: Zero Valent Iron	Permeable zero-valent iron reactive wall is installed across the flow path of contaminant plume, which moves through the wall under natural gradient. Iron chemically reacts (reductive dehalogenation) with chlorinated organics, removing chlorine.	Yes	Potentially applicable.
Permeable Reactive Barrier: In-Situ Air Stripping	Permeable reaction trench is installed across flow path of contaminant plume, which moves through the treatment zone under natural gradient. Air is injected into the trench to volatilize contaminants. Contaminated air is collected at the surface.	Yes	Potentially applicable.
Permeable Reactive Barrier: In-Situ Adsorption	Surfactants are injected as an aqueous solution into the subsoil to create organoclays. Organoclays attract and hold toxic organic contaminants. The clay then can be disposed of or may be bioremediated on site.	No	Feasible in low permeability (clay) aquifers. Not applicable in high permeability media, even if commercial organoclay is used, since groundwater would bypass the wall.
In-Situ Redox Manipulation	Sodium dithionite, potassium carbonate, and potassium bicarbonate are injected into the aquifer to chemically reduce the ferric iron in sediments to ferrous iron. The ferrous iron chemically reacts (reductive dehalogenation) with chlorinated, organics removing chlorine.	Yes	Potentially applicable.
Bimetallic Nanoscale Particles	Submicron ($<10^{-6}$ meters) particles of zero-valent iron coated with palladium (Pd) are mixed in a slurry and injected into the aquifer. The iron particles chemically react (reductive dehalogenation) with chlorinated organics, removing chlorine.	Yes	Potentially applicable.
In-Situ Chemical Flushing	Surfactants and/or cosolvents (e.g., alcohol) added to injection wells can mobilize and/or solubilize nonaqueous phase liquids and/or sorbed contaminants.	No	Concentrations of contaminants are generally below solubility limit, so free-phase product is not likely to exist. In the dissolved phase, contaminants are fairly mobile, so mobility enhancement does not appear to be necessary.

Table 4-2 (Continued)
Initial Screening of Potential Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Retain*	Screening Comments
In-Situ Treatment (Continued)			
Physical/Chemical Treatment (Continued)			
Electrical Separation	Two series of electrodes (anode and cathode) are placed in boreholes and current is applied across the electrodes. This process promotes migration of specific contaminants or chemical reagents.	No	More applicable to low hydraulic conductivity materials. Has mainly been used to remove metals and organic ions.
In-Situ Radio Frequency Heating	Heat is applied to the subsurface through electromagnetic radiation. Raises the soil temperature to enhance soil vapor extraction, air sparging, or product recovery methods.	No	More applicable to vadose zone remediation.
Steam Injection	Steam is forced into the aquifer through injection wells to vaporize volatile and semivolatile contaminants. Vaporized components are then removed by vacuum extraction.	No	More applicable to vadose zone remediation.
Dynamic Underground Stripping (DUS)	Uses steam injection to heat permeable layers and electric current to heat impermeable layers. Vaporized volatile and semivolatile components are then removed by soil vapor extraction.	Yes	Potentially applicable.
Hydrous Pyrolysis/Oxidation (HPO)	Used in combination with DUS (above), or similar heating technology,where oxygen is injected into the pre-heated subsurface to rapidly oxidize VOCs.	No	More applicable to sites with high VOC concentrations.
Six-Phase Soil Heating	Electricity is used to heat aquifer materials to enhance the volatilization of VOCs. Volatilized VOCs are collected by soil vapor extraction.	Yes	Potentially applicable.
Components - Fluid Delivery Systems			
Vertical Wells	Permanent or temporary (i.e., using direct push technology) wells used to distribute chemicals or other fluids (i.e., air, nutrients, etc.) into the aquifer.	Yes	Potentially applicable.
Horizontal Wells	Horizontally placed wells used to distribute chemicals or other fluids (i.e., air, nutrients, etc.) into the aquifer.	Yes	Potentially applicable.

NOTES:

* Retain for further consideration as an applicable technology that may be considered as a part of a remedial alternative.

No Technology eliminated from further consideration based on technical implementability.

Table 4-3
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
No Action						
No Action	No Action	o	o	o	Yes	Consideration of no action alternative is required by NCP and provides baseline to compare other alternatives.
Institutional Controls						
Government Controls						
Zoning Ordinance Amendment	Amendment to the Geary County zoning ordinance creating a groundwater restriction overlay district (DPRA, 2000).	o	-	o	Yes	May have difficulty meeting Kansas' requirements for fixed boundary zoning districts, because a groundwater restriction zoning amendment would cover contaminated groundwater where and whenever it occurred. May face regulatory takings issues (DPRA, 2000).
County Resolution	Enactment of a Geary County environmental and health resolution designed to restrict contaminated groundwater use (DPRA, 2000).	o	o	o	Yes	May face regulatory takings issues (DPRA, 2000).
Proprietary Controls						
Negative Easements and Restrictive Covenants	A negative easement acts as a land use restriction and imposes limits on how the landowner can use his or her property. Restrictive covenants provide promises concerning the use of land. Such covenants act as a contract between the parties who originally enter into it, and as such, its terms may be enforced under contract law (DPRA, 2000).	-	o	-	Yes	Kansas law is silent on the enforceability of negative easements. Landowners are not obliged to grant easements or restrictive covenants. Thus, they may demand monetary consideration in exchange for their promise to refrain from groundwater use (DPRA, 2000).
Affirmative Easements	An affirmative easement allows the holder of the easement to enter upon or use another's property for a particular purpose (e.g. an access easement) - DPRA, 2000.	o	+	-	Yes	Landowners are not obliged to grant easements. Thus, they may demand monetary consideration in exchange for the easement (DPRA, 2000).
Other Controls						
Monitoring						
Groundwater Monitoring	Periodic sampling and analysis of groundwater from monitoring wells.	o	+	-	Yes	Groundwater monitoring is currently in place at the Site.
Rural Water Supply	Extension of municipal water distribution system to serve residents in the area of influence.	+	o	-	No	Private wells on the Thompson and Moore properties were replaced in August 2002. Water supply is no longer an issue at this Site.

NOTE: Evaluation parameters are described at end of this table.

- \+ Relatively Effective, Easily Implementable, or Low Cos
- o No Relative Advantage/Disadvantage
- \- Relatively Ineffective, Difficult to Implement, or High Cos
- ? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
Other Controls (Continued)						
Alternative Water Supply						
New Supply Wells	New uncontaminated wells to serve residents in the area of influence.	o	+	+	No	Private wells on the Thompson and Moore properties were replaced in August 2002. Water supply is no longer an issue at this Site.
Individual Well Treatment						
Low Profile Air Stripping	Volatilization of contaminants from water by either passing air through water or water through air.	+	o	+	No	Unnecessary because supply wells were installed to replace private wells in August 2002. O&M is more dependent on individuals to maintain the system. Pretreatment may be necessary to remove metals and/or solids.
Activated Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	o	o	o	No	Unnecessary because supply wells were installed to replace private wells in August 2002. O&M is more dependent on individuals to maintain the system. Not very effective for some transformation products such as vinyl chloride. Pretreatment may be necessary to remove metals and/or solids.
UV Oxidation	Oxidation of organic contaminants by addition of H_2O_2 and/or O_3 and catalyzed by ultraviolet (UV) light.	+	o	-	No	Unnecessary because supply wells were installed to replace private wells in August 2002. This technology is more appropriate for concentrated waste streams. Very effective for the destruction of organic contaminants, but also expensive.
Monitored Natural Attenuation						
Monitored Natural Attenuation	Natural subsurface processes such as dispersion, volatilization, biodegradation, adsorption, and chemical reactions combine to reduce contaminant levels over time.	o	o	o	Yes	Data indicates that natural attenuation processes are acting to significantly reduce contaminant concentrations at the Site.
Containment						
Vertical Barriers	Low permeability wall made of soil-bentonite, reinforced concrete, chemical grout, or steel sheets.	o	o	o	Yes	May be used to focus or funnel contaminants to in-situ treatment zones. Depth of aquifer (> 60 ft) may make installation difficult.

NOTE: Evaluation parameters are described at end of this table.

+ Relatively Effective, Easily Implementable, or Low Cos
o No Relative Advantage/Disadvantage
- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge						
Collection/Extraction						
Pumping Wells: Vertical	Series of vertical wells with water pumps to extract contaminated groundwater.	o	o	o	Yes	Groundwater extraction (i.e., "Pump and Treat") is ineffective in reducing concentrations to MCLs. However this technology is retained for use as a potential containment system. This technology is retained at the request of EPA/KDHE.
Biological Treatment						
Aerobic Biological Reactors	Contaminated water is pumped to a suspended growth- or attached growth-type reactor where microbial population aerobically oxidizes organics.	-	-	-	No	Not as effective and more difficult to implement and maintain than competing technologies.
Cometabolic Aerobic Biological Reactors	Chlorinated VOCs are transformed as secondary substrate by methanotrophic bacteria (methane degraders). For this to occur, methane and O_2 must be provided to the reactor.	-	-	-	No	Not as effective and more difficult to implement and maintain than competing technologies.
Physical/Chemical Treatment						
Air Stripping	Volatilization of contaminants from water by either passing air through water or water through air.	+	o	o	Yes	May have issues with fouling due to the high levels of naturally occurring iron in the groundwater.
Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	-	o	-	No	Not as effective due to the high flow rates and low concentration levels. Carbon replacement would be frequent due to fouling.
Organoclay Adsorption	Bentonite is organically modified to render it hydrophobic and oleophilic. This organoclay attracts a wide range of organic contaminants.	o	o	o	No	More applicable to high concentration waste streams.
Oxidation/Reduction	Oxidation or reduction of organic contaminants through addition of strong oxidizing or reducing agents. May be coupled with irradiation from UV light.	+	o	-	No	More applicable to high concentration waste streams.
Discharge (treated or untreated)						
Discharge to Fort Riley Wastewater Treatment Plant	Water discharged to Fort Riley Wastewater Treatment Plant.	+	-	o	No	Would require pumping water 8,000 ft. to nearest intake.
Discharge to Kansas River	Water discharged to the Kansas River.	+	+	+	Yes	NPDES permit will be required.

NOTE: Evaluation parameters are described at end of this table.

+ Relatively Effective, Easily Implementable, or Low Cos
o No Relative Advantage/Disadvantage
- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge (continued)						
Discharge (treated or untreated)						
Spray/Sprinkler Irrigation	Direct irrigation of water onto land surface. Sprinkler heads are designed to treat (volatilize) VOCs during application.	-	o	-	No	Not effective because it could only operate when temperatures are above freezing.
Recharge	Water is recharged back to the aquifer it was removed from via injection wells, recharge trenches, or recharge basins.	+	o	-	No	Unnecesary for this aquifer because groundwater velocities are so high.
Vapors Discharged to the Atmosphere	Vapors discharged to the atmosphere.	+	+	+	Yes	Vapors from air stripper are expected to be well below the state limit of 25 tons/year.
In-Situ Treatment						
Biological Treatment						
Enhanced Anaerobic Bioremediation	Technology designed to treat chlorinated solvents using anaerobic conditions. Oxygen depletors, such as acetate, methanol, and sodium lactate are used to consume dissolved O_2 and to act as electron donors in anaerobic reactions. Nutrients such as nitrogen, phosphorus, and carbon sources are added to promote the growth of anaerobic microbes. The patented method, Hydrogen Release Compound (HRC™), consists of injecting time-release lactic acid which is metabolized by anaerobic microbes and releases hydrogen. The resulting hydrogen is then used by other microbes to stimulate rapid degradation of chlorinated solvents. Other carbon sources such as molasses and vegetable oil may also be used to enhance anaerobic degradation.	o	+	?	Yes	Due to the large plume volume, this technology is not applicable to remediation of the entire plume, but may be used as a reactive barrier zone and/or to remediate the high concentration area of the plume. May require regulatory approval to inject chemicals into the aquifer.
Physical/Chemical Treatment						
In-Situ Biofilters	Sand-filled trench that intercepts contaminated plume is inoculated with non-indigenous methanotrophic bacteria. Chlorinated VOCs are degraded by resting-state microorganisms with intermittent provision of methane.	?	-	-	No	Issues with the longevity of non-indigenous bacteria are limitations of this technology. More applicable to low permeability aquifers, where in-situ air sparging is less effective.
Air Sparging	Air is injected into the saturated zone which forms bubbles that volatilize contaminants and carry them to the surface. Vacuum extraction wells in the unsaturated zone capture volatilized contaminants.	-	o	o	Yes	Not effective on low concentrations of VOCs. Similar limitations to pump and treat. No distinct advantage over other competing technologies. This technology is retained at the request of EPA/KDHE.

NOTE: Evaluation parameters are described at end of this table.

+ Relatively Effective, Easily Implementable, or Low Cos
o No Relative Advantage/Disadvantage
- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
In-Situ Treatment (Continued)						
Physical/Chemical Treatment (continued)						
C-Sparger™	An air/ozone mixture is injected into saturated zone to chemically oxidize contaminants in-situ. An in-well water pump is provided to help disperse oxidant through formation.	-	o	-	No	Not effective on low concentrations of VOCs. Similar limitations to pump and treat. No distinct advantage over other competing technologies
Groundwater Circulation Wells	Air is introduced into screened well to promote air stripping within the well. Less dense, aerated water is lifted creating a circulation pattern. Mass transfer of VOCs occurs as air/wate mixture rises and contaminated air is extracted by a blower or discharged into the vadose for treatment by biodegradation.	-	o	-	No	Not effective on low concentrations of VOCs. Similar limitations to pump and treat. No distinct advantage over other competing technologies
Soil Vapor Extraction (SVE)	A vacuum is applied to wells screened in the vadose zone to promote increased volatilization of VOCs. Vapors are collected for treatment and disposal if necessary.	o	+	o	Yes	SVE may be used in conjunction with air sparging.
In-Situ Chemical Oxidation	Solubilized oxidant (H_2O_2, $KMnO_4$, or O_3), and sometimes catalysts, are circulated throughout contaminated zone to chemically oxidize organic contaminants.	-	+	-	No	This technology is mainly applicable to small source zone type settings and has mainly been used to remediate high concentration sites (mg/L range). Large quantities of oxidants will likely be required for the high permeability aquifer at the Site. Technology may be limited by the high organic carbon content of the aquifer. May be detrimental to the ongoing anaerobic degradation of chlorinated solvents at this Site. Unforeseeable problems may occur when implementing this technology at a scale as large as the FFTA-MAAF Site. May require regulatory approval to inject chemicals into the aquifer.
Permeable Reactive Barrier: Zero-Valent Iron	Permeable zero-valent iron reaction wall is installed across flow path of contaminant plume, which passively moves through wall. Iron chemically reacts (reductive dehalogenation) with chlorinated organics, removing chlorine.	+	-	-	Yes	High permeability aquifer may create difficulty in reactive wall design and construction. Depth to bedrock (>60 ft) will likely increase the cost of this technology.

NOTE: Evaluation parameters are described at end of this table.

+ Relatively Effective, Easily Implementable, or Low Cos
o No Relative Advantage/Disadvantage
- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
In-Situ Treatment (Continued)						
Physical/Chemical Treatment (Continued)						
Permeable Reactive Barrier: In-Situ Air Stripping	Permeable reaction trench is installed across flow path of contaminant plume, which passively moves through the treatment zone. Air is injected into the trench to volatilize contaminants. Contaminated air is collected at the surface.	-	-	-	No	Technology is more applicable to low conductivity materials where aquifer air sparging is limited. Depth to bedrock (>60 ft) will likely increase the cost of this technology.
In-Situ Redox Manipulation	Sodium dithionite, potassium carbonate, and potassium bicarbonate are injected into the aquifer to chemically reduce the ferric iron in sediments to ferrous iron. The ferrous iron chemically reacts (reductive dehalogenation) with chlorinated organics, removing chlorine.	?	o	-	Yes	Technology is still in the testing phase. May require regulatory approval to inject chemicals into the aquifer.
Bimetallic Nanoscale Particles	Submicron ($<10^{-6}$ meters) particles of zero-valent iron are mixed in a slurry and injected into the aquifer. The iron particles chemically react (reductive dehalogenation) with chlorinated organics, removing chlorine.	?	+	?	Yes	Technology has had limited application. May require regulatory approval to inject into the aquifer.
Dynamic Underground Stripping (DUS)	Uses steam injection to heat permeable layers and electric current to heat impermeable layers. Vaporized volatile and semivolatile components are then removed by soil vapor extraction.	+	-	-	No	This technology is more applicable to relatively small source zone type settings. Has mainly been used to remediate high concentration sites (mg/L range). Potential implementability limitations associated with the numerous above ground structures required for this technology. Unforeseeable problems may occur when implementing this technology at a scale as large as the FFTA-MAAF Site.
Six-Phase Soil Heating	Electricity is used to heat aquifer materials to enhance the volatilization of VOCs. Volatilized VOCs are collected by soil vapor extraction (SVE).	+	-	-	No	This technology is more applicable to relatively small source zone type settings. Has mainly been used to remediate high concentration sites (mg/L range). Potential implementability limitations associated with the numerous above ground structures required for this technology. Unforeseeable problems may occur when implementing this technology at a scale as large as the FFTA-MAAF Site.

NOTE: Evaluation parameters are described at end of this table.

+ Relatively Effective, Easily Implementable, or Low Cos
o No Relative Advantage/Disadvantage
- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
FFTA-MAAF FS

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
In-Situ Treatment (Continued)						
Components - Fluid Delivery Systems						
Vertical Wells	Permanent or temporary (i.e., using direct push technology) wells used to distribute chemicals or other fluids (i.e., air, nutrients, etc.) into the aquifer.	o	o	+	Yes	May require large number of wells to distribute chemicals or other fluids into the aquifer.
Horizontal Wells	Horizontally placed wells used to distribute chemicals or other fluids (i.e., air, nutrients, etc.) into the aquifer.	o	o	-	Yes	Will likely require fewer wells than traditional vertical well applications, but at a higher relative cost.

+ Relatively Effective or Low Cos
o No Relative Advantage/Disadvantage
\- Relatively Ineffective, Difficult to Implement, or High Cos
? Unknown

NOTES:
* Retain for further consideration as an applicable technology that may be considered as a part of a remedial alternative.
- Evaluation parameters are relative to each general response action group and not to entire list of technologies.
- Effectiveness focuses on: (1) the applicability of the process for the given site characteristics and its ability to meet the remediation goals identified in the RAOs;
  (2) the potential impacts to human health and the environment during the implementation of the technology; and
  (3) how proven and reliable the process is for the given contaminants and site conditions.
- Implementability considers the technical and primarily the administrative feasibility of implementing the process option at the site.
- Relative cost focuses on a qualitative evaluation of the capital and O&M costs to implement the technology. Costs will vary significantly from site to site and are used only as a preliminary indication.
- ▨ No Technology eliminated from further consideration

Table 6-1
Cost Summary
FFTA-MAAF Feasibility Study

Alternative		Total Capital Costs[1]	Total O&M Costs[2]	Total Periodic Costs[3]	Total Project Cost[4]	Total Present Value Cost at 3.2%[5]
1	No Action	$ -	$ -	$ 490,000	$ 490,000	$ 370,000
2	MNA	$ 48,000	$ 2,200,000	$ 108,000	$ 2,300,000	$ 2,000,000
3	EAB	$ 450,000	$ 1,900,000	$ 80,000	$ 2,500,000	$ 2,200,000
4	Fe^0 PRB	$ 2,200,000	$ 2,100,000	$ 108,000	$ 4,400,000	$ 4,100,000
5	ISRM	$ 2,000,000	$ 2,100,000	$ 108,000	$ 4,100,000	$ 3,800,000
6	BNP	$ 650,000	$ 1,900,000	$ 84,000	$ 2,700,000	$ 2,400,000
7	Air Sparge	$ 2,400,000	$ 1,500,000	$ 60,000	$ 4,000,000	$ 3,900,000
	with Nitrogen	$ 4,600,000	$ 5,800,000	$ 120,000	$ 11,000,000	$ 10,000,000
8	Pump & Treat	$ 840,000	$ 3,300,000	$ 84,000	$ 4,200,000	$ 3,800,000

Notes:

[1] Includes costs for design, bench and pilot testing (if necessary), equipment/chemical costs, construction and implementation, and institutional controls.

[2] Includes costs for groundwater monitoring, reporting (if necessary), electricity (if necessary), periodic maintenance (if necessary), and periodic parts (if necessary).

[3] Includes costs for five-year reviews and closure reporting.

[4] Total Capital Costs + Total O&M Costs + Total Periodic Costs

[5] Present value cost for a 30-year period using a 3.2 percent discount rate (EPA, 1993)

All costs are rounded to two significant figures.

Table 6-2
Comparative Evaluation Summary
FFTA-MAAF Feasibility Study

Alternatives	**Alt. 1**	**Alt. 2**	**Alt. 3**	**Alt. 4**	**Alt. 5**	**Alt. 6**	**Alt. 7**	**Alt. 8**
	No Action	**MNA**	**EAB**	**Fe^0 PRB**	**ISRM**	**BNP**	**Air Sparge**	**Pump & Treat**
Protection of Human Health and the Environment	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Compliance with ARARs	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Long-term Effectiveness and Permanence	NC	1	1	1	1	1	3	4
Reduction of Toxicity, Mobility, or Volume	NC	1	1	1	1	1	5	5
Short-term Effectiveness	NC	6	4	7	5	5	3	4
Implementability	NC	1	2	7	5	4	7	5
Cost	NC	1	2	6	5	3	5	5
Total of Rankings	**NC**	**10**	**10**	**22**	**17**	**14**	**23**	**23**
Overall Rank	**NC**	**1**	**1**	**5**	**4**	**3**	**6**	**6**

Notes

Ranking 1 Most favorable alternative
3 Good, generally favorable
5 Fair, potentially unfavorable
7 Poor, unfavorable
10 Completely fails the criteria

Yes Meets the requirements of the threshold criteria.
No Does not meet the requirements of the threshold criteria.
NC Not considered. Does not meet the threshold criteria.

APPENDIX A

Cost Analysis Tables

Table A-1
Cost Estimate for Alternative 1
FFTA-MAAF Feasibility Study

No Action

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Periodic Costs					
Five-Year Review of Remedial Action[2]	ea	1	$ 20,000.00	$ 20,000	BMcD
Groundwater Sampling[2]	ea	1	$ 107,452.00	$ 107,452	BMcD
Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$ 157,452**
Contingency (20%)[3]	**$ 31,490**
Total Periodic Costs	**$ 188,942**
Total Project Cost	**$ 494,827**
Total Present Value Project Cost at 3.2%	**$ 371,744**

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.
2) It is assumed that five-year reviews performed under the "no action" alternative will require groundwater samples to be collected once every five years. The estimated cost of one round of groundwater sampling is assumed to be the same as described in Alternative 2 (Table A-3).
3) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).

BMcD Burns & McDonnell Engineering Company, Inc.
ea Each
ls Lump Sum

Table A-2
Present Value Costs for Alternative 1
FFTA-MAAF Feasibility Study

No Action

Year	Capital Costs	Annual O&M Costs	Periodic Costs[1]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ -	$ -	$ -	$ -	1.000	$ -
1	$ -	$ -	$ -	$ -	0.969	$ -
2	$ -	$ -	$ -	$ -	0.939	$ -
3	$ -	$ -	$ -	$ -	0.910	$ -
4	$ -	$ -	$ -	$ -	0.882	$ -
5	$ -	$ -	$ 152,942	$ 152,942	0.854	$ 130,656
6	$ -	$ -	$ -	$ -	0.828	$ -
7	$ -	$ -	$ -	$ -	0.802	$ -
8	$ -	$ -	$ -	$ -	0.777	$ -
9	$ -	$ -	$ -	$ -	0.753	$ -
10	$ -	$ -	$ 152,942	$ 152,942	0.730	$ 111,617
11	$ -	$ -	$ -	$ -	0.707	$ -
12	$ -	$ -	$ 188,942	$ 188,942	0.685	$ 129,471
Total	**$ -**	**$ -**	**$ 494,827**	**$ 494,827**		**$ 371,744**

Notes:

1) $152,942 includes the cost of a five-year review plus one round of groundwater sampling. $188,942 includes the cost of a five-year review, one round of groundwater sampling, and a closure report.

Table A-3
Cost Estimate for Alternative 2
FFTA-MAAF Feasibility Study

Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs					
Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD

Subtotal Capital Costs	**$**	**40,000**
Contingency (20%)[2]	**$**	**8,000**
Total Capital Costs	**$**	**48,000**

Description	Quantity	Unit	Unit Cost	Line Cost	Source
Annual Operation and Maintenance Costs					
Semiannual Natural Attenuation/Groundwater Monitoring[3]					
Groundwater Sampling	ea	2	$ 29,887.00	$ 59,774	BMcD
Laboratory Analyses	ea	2	$ 28,827.00	$ 57,654	BMcD
Quality Control Summary Report (QCSR)	ea	2	$ 14,092.00	$ 28,184	BMcD
Data Summary Report (DSR)	ea	2	$ 21,966.00	$ 43,932	BMcD
E Data Submittal	ea	2	$ 3,018.00	$ 6,036	BMcD
Project Administration	ea	2	$ 5,813.00	$ 11,626	BMcD
Maintenance	ea	2	$ 3,849.00	$ 7,698	BMcD

Subtotal Annual O&M	**$**	**214,904**
Contingency (20%)[2]	**$**	**42,981**
Total Annual O&M	**$**	**257,885**

Description	Quantity	Unit	Unit Cost	Line Cost	Source
Periodic Costs					
Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$**	**50,000**
Contingency (20%)[2]	**$**	**10,000**
Total Periodic Costs	**$**	**60,000**

Total Project Cost	**$ 2,348,021**
Total Present Value Project Cost at 3.2%	**$ 1,982,598**

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.

2) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a). Contingency for future action (a component of this alternative) was not included in this cost estimate.

3) Unit costs taken from *Proposal for Groundwater Sampling Events (2000/2001/2002) at Marshall Army Airfield* (BMcD, 1999b).

BMcD	Burns & McDonnell Engineering Company, Inc.
ea	Each
ls	Lump Sum

Table A-4
Present Value Costs for Alternative 2
FFTA-MAAF Feasibility Study

Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 48,000	$ -	$ -	$ 48,000	1.000	$ 48,000
1	$ -	$ 257,885	$ -	$ 257,885	0.969	$ 249,888
2	$ -	$ 257,885	$ -	$ 257,885	0.939	$ 242,140
3	$ -	$ 257,885	$ -	$ 257,885	0.910	$ 234,632
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 24,000	$ 281,885	0.854	$ 240,809
6	$ -	$ 128,942	$ -	$ 128,942	0.828	$ 106,738
7	$ -	$ 128,942	$ -	$ 128,942	0.802	$ 103,428
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ -	$ 128,942	0.753	$ 97,113
10	$ -	$ 128,942	$ 24,000	$ 152,942	0.730	$ 111,617
11	$ -	$ 128,942	$ -	$ 128,942	0.707	$ 91,184
12	$ -	$ 128,942	$ 60,000	$ 188,942	0.685	$ 129,471
Total	**$ 48,000**	**$ 2,192,021**	**$ 108,000**	**$ 2,348,021**		**$ 1,982,598**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.
2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after ten years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.
3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

Table A-5
Cost Estimate for Alternative 3
FFTA-MAAF Feasibility Study

Enhanced Anaerobic Bioremediation with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

Description		Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs						
	Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
	Engineering and Design.[2]	ls	1	$ 50,000.00	$ 50,000	BMcD
	Permitting: budget to prepare applications and obtain permits.	ls	1	$ 10,000.00	$ 10,000	BMcD
	Pilot test to determine spacing, application rate, and other design parameters.[3]	ls	1	$ 35,000.00	$ 35,000	BMcD
	Install two additional monitoring well clusters (two wells per cluster) downgradient of pilot test.[4]	ea	2	$ 30,000.00	$ 60,000	BMcD
	HRC material cost.[5]	lb	84,375	$ 1.00	$ 84,375	BMcD
	Geoprobe contractor costs to inject lactate					
	Mob/demob	ls	1	$ 1,000.00	$ 1,000	BMcD
	Daily Rate	day	30	$ 2,000.00	$ 60,000	BMcD
	Lactate Pump	day	30	$ 150.00	$ 4,500	BMcD
	Construction Oversight (30 days).					
	Labor	day	30	$ 800.00	$ 24,000	BMcD
	Per Diem	day	30	$ 100.00	$ 3,000	BMcD
	Pickup Truck	day	30	$ 40.00	$ 1,200	BMcD

Subtotal Capital Costs	**$ 373,075**
Contingency (20%)[6]	**$ 74,615**
Total Capital Costs	**$ 447,690**

Annual Operation and Maintenance Costs						
	Semiannual Groundwater Monitoring.[7]	ea	2	$ 107,452.00	$ 214,904	BMcD

Subtotal Annual O&M	**$ 214,904**
Contingency (20%)[6]	**$ 42,981**
Total Annual O&M	**$ 257,885**

Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$ 50,000**
Contingency (20%)[6]	**$ 10,000**
Total Periodic Costs	**$ 60,000**

Total Project Cost	**$ 2,465,826**
Total Present Value Project Cost at 3.2%	**$ 2,187,905**

Table A-5 (continued)
Cost Estimate for Alternative 3
FFTA-MAAF Feasibility Study

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.
2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, and Project Management.
3) It assumed that one lactate curtain will be used for the pilot study. This estimate is based on ten injection points (100 wide spaced on ten foot centers) and an assumed 15 pounds per vertical foot (30 foot saturated thickness) lactate application rate. 15 lbs/ft was provided by Regenesis. lactate material costs for the pilot study are estimated at $5,000. Geoprobe contractor costs and construction oversite costs are estimated at $30,000.
4) This cost includes well construction, well development, additional bladder pumps, and disposal of soil and development water (BMcD, 1997).
5) It assumed that nine lactate curtains will be used. Six will be applied over a 30 ft. thickness, and three will be applied over a 15 ft thickness. This estimate is based on 25 injection points per barrier (250 ft. wide spaced on ten foot centers) and an assumed 15 pounds per vertical foot (30 foot saturated thickness) lactate application rate. Application rate and spacing was provided by Regenesis. The treatment area for the full scale application is assumed to be 4,500 ft x 250 ft x 45 ft. The unit cost of lactate was supplied by JRWTechnologies.

6) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
7) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
ea	Each
lb	Pound
ls	Lump Sum

Table A-6
Present Value Costs for Alternative 3
FFTA-MAAF Feasibility Study

Enhanced Anaerobic Bioremediation with Institutional Controls and Monitored Natural Attenuation

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 471,690	$ -	$ -	$ 471,690	1.000	$ 471,690
1	$ -	$ 257,885	$ -	$ 257,885	0.969	$ 249,888
2	$ -	$ 257,885	$ -	$ 257,885	0.939	$ 242,140
3	$ -	$ 257,885	$ -	$ 257,885	0.910	$ 234,632
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 24,000	$ 281,885	0.854	$ 240,809
6	$ -	$ 128,942	$ -	$ 128,942	0.828	$ 106,738
7	$ -	$ 128,942	$ -	$ 128,942	0.802	$ 103,428
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ -	$ 128,942	0.753	$ 97,113
10	$ -	$ 128,942	$ 60,000	$ 188,942	0.730	$ 137,890
Total	**$ 471,690**	**$ 1,934,136**	**$ 84,000**	**$ 2,489,826**		**$ 2,211,905**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.
2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after eight years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.
3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

Table A-7
Cost Estimate for Alternative 4
FFTA-MAAF Feasibility Study

Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs					
Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
Engineering and Design[2]	ls	1	$ 200,000.00	$ 200,000	BMcD & ETI
Bench scale testing - Laboratory column tests to establish residence time, treatment wall thickness, potential mineral precipitation, etc. (bench fee, sample collection, shipping)[3]	ls	1	$ 60,000.00	$ 60,000	BMcD & ETI
Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000.00	$ 10,000	BMcD
Budget for investigation to establish depth to confining layer, evaluate soil properties along PRB construction corridor, and to investigate lateral extent of contaminants above MCL to determine required width of the PRB[4]	ls	1	$ 40,000.00	$ 40,000	BMcD
Zero Valent Iron (8,000 ft^3)[5,6,7]	ton	640	$ 600.00	$ 384,000	ETI
Biodegradable slurry excavation and installation of wall (Unit cost includes excavation, materials, mobilization/demobilization, and all subcontractor costs)	vsf	16,750	$ 50.00	$ 837,500	RACER & ETI
Backfill top 35 feet of trench with excavated soil, sand, and gravel[7]	cy	648	$ 25.00	$ 16,204	BMcD
ETI Royalty Fee (15% of construction and material)	ls	1	15%	$185,655.56	ETI
Construction Oversight (2 month on-site field supervisor = 40 day)					
Labor	day	40	$ 800.00	$ 32,000	BMcD
Per Diem	day	40	$ 100.00	$ 4,000	BMcD
Pickup Truck	mo	2	$ 1,100.00	$ 2,200	BMcD
Manage and dispose of excavated soil (assume soil can be spread and compacted on-Site)					
Manage excavated soil, collect drainage/leachate, prevent risk to human health and environment	cy	1,241	$ 20.00	$ 24,815	RACER
Haul soil off-Site	cy	1,241	$ 5.00	$ 6,204	RACER
Spread and compact soil with dozer[8]	hr	16	$ 130.00	$ 2,080	RACER
Revegetate area	ls	1	$ 10,000.00	$ 10,000	BMcD

Subtotal Capital Costs $ 1,854,658

Contingency (20%)[8] $ 370,932

Total Capital Costs $ 2,225,589

Table A-7 (Continued)
Cost Estimate for Alternative 4
FFTA-MAAF Feasibility Study

Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring

Annual Operation and Maintenance Costs						
	Semiannual Groundwater Monitoring[10]	ea	2	$ 107,452.00	$ 214,904	BMcD

Subtotal Annual O&M $ 214,904

Contingency (20%)[9] $ 42,981

Total Annual O&M $ 257,885

Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs $ 50,000

Contingency (20%)[9] $ 10,000

Total Periodic Costs $ 60,000

Total Project Cost $ 4,396,668

Total Present Value Project Cost at 3.2% $ 4,073,146

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.
2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, Project Management, and $10,000 subconsulting design to ETI.
3) A pilot test is not necessary with this technology since it has been widely used, and design issues are better understood than with other innovative technologies.
4) Based on existing data, the PRB width is assumed to be 250 ft.
5) Density of granular iron is 0.08 ton/ft^3.
6) ETI indicates an equivalent iron wall thickness of 2.0 ft is required for complete degradation of all chlorinated solvents at the Site. This estimate was based on an assumed maximum flow velocity of 2.7 ft/day. This estimate has since been updated by BMcD to 1.0 ft thick due to a substantial decrease in contaminant concentrations. Sand will be mixed with the iron for construction and porosity purposes.
7) The depth to contaminated groundwater is assumed to be 35 feet, and the average depth to base of contamination is assumed to be 65 feet. Therefore, the vertical thickness of the PRB is assumed to be 32 feet (30 feet contaminated thickness, plus an additional 2 feet to key PRB into the bedrock). The horizontal thickness of the PRB is assumed to be 1.0 feet.
8) Spreading soil on-Site is contingent upon the soil not having significant contamination. This is assumed to be the case.
9) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
10) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
cy	Cubic Yard
ea	Each
ETI	Envirometal Technologies Inc. (ETI, 2000)
hr	Hour

Table A-7 (Continued)
Cost Estimate for Alternative 4
FFTA-MAAF Feasibility Study

ls	Lump Sum
mo	Month
RACER	Remediation Action Cost Engineering and Requirements (RACER, 2000)
vsf	Vertical Square Foot

Table A-8
Present Value Costs for Alternative 4
FFTA-MAAF Feasibility Study

Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 2,225,589	$ -	$ -	$ 2,225,589	1.000	$ 2,225,589
1	$ -	$ 257,885	$ -	$ 257,885	0.969	$ 249,888
2	$ -	$ 257,885	$ -	$ 257,885	0.939	$ 242,140
3	$ -	$ 257,885	$ -	$ 257,885	0.910	$ 234,632
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 24,000	$ 281,885	0.854	$ 240,809
6	$ -	$ 128,942	$ -	$ 128,942	0.828	$ 106,738
7	$ -	$ 128,942	$ -	$ 128,942	0.802	$ 103,428
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ -	$ 128,942	0.753	$ 97,113
10	$ -	$ 128,942	$ 24,000	$ 152,942	0.730	$ 111,617
11	$ -	$ 128,942	$ 60,000	$ 188,942	0.707	$ 133,614
Total	**$ 2,225,589**	**$ 2,063,078**	**$ 108,000**	**$ 4,396,668**		**$ 4,073,146**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.
2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after nine years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.
3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

Table A-9
Cost Estimate for Alternative 5
FFTA-MAAF Feasibility Study

In-Situ Redox Manipulation with Institutional Controls and Monitoring

	Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs						
	Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
	Engineering and Design[2]	ls	1	$ 100,000.00	$ 100,000	BMcD
	Bench scale testing - Laboratory tests to establish residence time, reduction rates, potential mineral precipitation, etc. (bench fee, sample collection, shipping)	ls	1	$ 100,000.00	$ 100,000	PNNL
	Pilot test to determine spacing, application rate, and other design parameters[3]	ls	1	$ 250,000.00	$ 250,000	PNNL
	Install two additional monitoring well clusters (two wells per cluster) downgradient of pilot test[4]	ea	2	$ 30,000.00	$ 60,000	BMcD
	Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000.00	$ 10,000	BMcD
	Budget for investigation to establish depth to confining layer, evaluate soil properties along ISRM construction corridor, and to investigate lateral extent of contaminants above MCL to determine required width of the ISRM barrier[5]	ls	1	$ 40,000.00	$ 40,000	BMcD
	Installation of ISRM injection wells	ea	7	$ 15,000.00	$ 105,000	PNNL & BMcD
	Drummed cutting disposal (non-haz)	drum	18	$ 200.00	$ 3,600	RACER
	Injection and recovery of chemicals. Includes management and disposal of chemicals and other wastes	ls	1	$ 900,000.00	$ 900,000	PNNL & BMcD
	Construction Oversight (2 month on-site field supervisor = 40 day)					
	Labor	day	40	$ 800.00	$ 32,000	BMcD
	Per Diem	day	40	$ 100.00	$ 4,000	BMcD
	Pickup Truck	mo	2	$ 1,100.00	$ 2,200	BMcD

Subtotal Capital Costs	**$ 1,646,800**
Contingency (20%)[6]	**$ 329,360**
Total Capital Costs	**$ 1,976,160**

Table A-9 (Continued)
Cost Estimate for Alternative 5
FFTA-MAAF Feasibility Study

In-Situ Redox Manipulation with Institutional Controls and Monitoring

Annual Operation and Maintenance Costs						
	Semiannual Groundwater Monitoring[7]	ea	2	$ 107,452.00	$ 214,904	BMcD

Subtotal Annual O&M	**$**	**214,904**
Contingency (20%)[6]	**$**	**42,981**
Total Annual O&M	**$**	**257,885**

Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$**	**50,000**
Contingency (20%)[6]	**$**	**10,000**
Total Periodic Costs	**$**	**60,000**

Total Project Cost	**$ 4,147,238**
Total Present Value Project Cost at 3.2%	**$ 3,823,717**

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.
2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, and Project Management.
3) It assumed that three wells spaced 35 feet apart will be used for the pilot study. Well spacing and pilot test cost estimate was provided by the technology vendor (PNNL).
4) This cost includes well construction, well development, additional bladder pumps, and disposal of soil and development water (BMcD, 1997).
5) Based on existing data, the ISRM width is assumed to be 250 ft.
6) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
7) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
ea	Each
ls	Lump Sum
mo	Month
PNNL	Pacific Northwest National Laboratory
RACER	Remediation Action Cost Engineering and Requirements (RACER, 2000)

Table A-10
Present Value Costs for Alternative 5
FFTA-MAAF Feasibility Study

In-Situ Redox Manipulation with Institutional Controls and Monitoring

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 1,976,160	$ -	$ -	$ 1,976,160	1.000	$ 1,976,160
1	$ -	$ 257,885	$ -	$ 257,885	0.969	$ 249,888
2	$ -	$ 257,885	$ -	$ 257,885	0.939	$ 242,140
3	$ -	$ 257,885	$ -	$ 257,885	0.910	$ 234,632
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 24,000	$ 281,885	0.854	$ 240,809
6	$ -	$ 128,942	$ -	$ 128,942	0.828	$ 106,738
7	$ -	$ 128,942	$ -	$ 128,942	0.802	$ 103,428
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ -	$ 128,942	0.753	$ 97,113
10	$ -	$ 128,942	$ 24,000	$ 152,942	0.730	$ 111,617
11	$ -	$ 128,942	$ 60,000	$ 188,942	0.707	$ 133,614
Total	**$ 1,976,160**	**$ 2,063,078**	**$ 108,000**	**$ 4,147,238**		**$ 3,823,717**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.
2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after nine years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.
3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

Table A-11
Cost Estimate for Alternative 6
FFTA-MAAF Feasibility Study

Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs					
Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
Engineering and Design[2]	ls	1	$ 50,000.00	$ 50,000	BMcD
Bench scale test evaluate aquifer materials	ls	1	$ 40,000.00	$ 40,000	BMcD and PARS
Pilot test to determine spacing, application rate, and other design parameters[3]	ls	1	$ 80,000.00	$ 80,000	BMcD
Install two additional monitoring well clusters (two wells per cluster) downgradient of pilot test[4]	ea	2	$ 30,000.00	$ 60,000	BMcD
Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000.00	$ 10,000	BMcD
BNP material cost[5]	lb	825	$ 200.00	$ 165,000	BMcD & PARS
Geoprobe contractor costs to inject BNP					
Mob/demob	ls	1	$ 1,000.00	$ 1,000	BMcD
Daily Rate	day	30	$ 2,000.00	$ 60,000	BMcD
Pump	day	30	$ 150.00	$ 4,500	BMcD
Construction Oversight (30 days)					
Labor	day	30	$ 800.00	$ 24,000	BMcD
Per Diem	day	30	$ 100.00	$ 3,000	BMcD
Pickup Truck	day	30	$ 40.00	$ 1,200	BMcD

Subtotal Capital Costs	**$ 538,700**
Contingency (20%)[4]	**$ 107,740**
Total Capital Costs	**$ 646,440**

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Annual Operation and Maintenance Costs					
Semiannual Groundwater Monitoring[5,6]	ea	2	$ 107,452.00	$ 214,904	BMcD

Subtotal Annual O&M	**$ 214,904**
Contingency (20%)[4]	**$ 42,981**
Total Annual O&M	**$ 257,885**

Table A-11 (continued)
Cost Estimate for Alternative 6
FFTA-MAAF Feasibility Study

Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

Description		Quantity	Unit	Unit Cost	Line Cost	Source[1]
Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs $ 50,000

Contingency (20%)[6] $ 10,000

Total Periodic Costs $ 60,000

Total Project Cost $ 2,664,576

Total Present Value Project Cost at 3.2% $ 2,386,655

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.

2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, and Project Management.

3) It assumed that one BNP curtain will be used for the pilot study. This estimate is based on ten injection points (100 wide spaced on ten foot centers) and an assumed four pounds per point (30 foot saturated thickness) application rate. four lbs/point was provided by PARS. PARS has estimated the pilot test at $80,000.

4) This cost includes well construction, well development, additional bladder pumps, and disposal of soil and development water (BMcD, 1997).

5) It assumed that nine BNP curtains will be used. Six will be applied over a 30 ft. thickness, and three will be applied over a 15 ft thickness. This estimate is based on 25 injection points per barrier (250 wide spaced on ten foot centers) and an assumed four lbs/point for the 30 ft. thickness and three lbs/point for the 15 ft. thickness BNP application rate. These rates were provided by PARS Environmental, Inc. The treatment area for the full scale application is assumed to be 4,500 ft x 250 ft x 45 ft.

6) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).

7) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
ea	Each
lb	Pound
ls	Lump Sum
PARS	PARS Environmental, Inc.

Table A-12
Present Value Costs for Alternative 6
FFTA-MAAF Feasibility Study

Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 646,440	$ -	$ -	$ 646,440	1.000	$ 646,440
1	$ -	$ 257,885	$ -	$ 257,885	0.969	$ 249,888
2	$ -	$ 257,885	$ -	$ 257,885	0.939	$ 242,140
3	$ -	$ 257,885	$ -	$ 257,885	0.910	$ 234,632
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 24,000	$ 281,885	0.854	$ 240,809
6	$ -	$ 128,942	$ -	$ 128,942	0.828	$ 106,738
7	$ -	$ 128,942	$ -	$ 128,942	0.802	$ 103,428
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ -	$ 128,942	0.753	$ 97,113
10	$ -	$ 128,942	$ 60,000	$ 188,942	0.730	$ 137,890
Total	**$ 646,440**	**$ 1,934,136**	**$ 84,000**	**$ 2,664,576**		**$ 2,386,655**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.

2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after eight years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.

3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

Table A-13
Cost Estimate for Alternative 7
FFTA-MAAF Feasibility Study

Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs					
Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
Engineering and Design[2]	ls	1	$ 150,000.00	$ 150,000	BMcD
Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000.00	$ 10,000	BMcD
Sparge Wells[4]					
Lines 1,2 (sparge interval 15 to 45 ft.), 75 wells	ls	1	$ 233,000.00	$ 233,000	RACER
Lines 3,4,5 (sparge interval 30 to 45 ft.), 75 wells	ls	1	$345,000.00	$ 345,000	RACER
Lines 6, 7,8,9 (sparge interval 30 to 60 ft.), 100 wells	ls	1	$552,000.00	$ 552,000	RACER
Horizontal SVE Wells[5] - screened interval 250 each, Lines 1 to 9	ea	9	$ 32,000.00	$ 288,000	RACER
Air Sparge Blowers	ea	9	$ 5,500.00	$ 49,500	BMcD
Vapor Extraction Pumps	ea	3	$ 9,500.00	$ 28,500	BMcD
Equipment Building	ls	1	$ 50,000.00	$ 50,000	BMcD
Valves, Fittings, Meters, etc.	ls	1	$ 10,000.00	$ 10,000	BMcD
Drummed cutting disposal (non-haz)	drum	662	$ 200.00	$ 132,400	RACER
Power Hookup, electrical[6]	ls	1	$ 65,000.00	$ 65,000	BMcD
Construction Oversight (60 days)					
Labor	day	60	$ 800.00	$ 48,000	BMcD
Per Diem	day	60	$ 100.00	$ 6,000	BMcD
Pickup Truck	day	60	$ 40.00	$ 2,400	BMcD

Subtotal Capital Costs **$ 2,009,800**

Contingency (20%)[7] **$ 401,960**

Total Capital Costs **$ 2,411,760**

Description	Quantity	Unit	Unit Cost	Line Cost	Source
Annual Operation and Maintenance Costs					
Semiannual Groundwater Monitoring[8]	ea	2	$ 107,452.00	$ 214,904	BMcD
Electrical - SVE/Air Sparge	ls	1	$ 49,300.00	$ 49,300	BMcD
SVE/Air- System Parts Budget	ls	1	$ 5,000.00	$ 5,000	BMcD
Monthy SVE discharge analytical (VOCs monthly, vapor)	ea	12	$ 175.00	$ 2,100	BMcD
Monthly reporting (air emissions 8 hr/mo.)	hr	96	$ 80.00	$ 7,680	BMcD

Subtotal Annual O&M **$ 278,984**

Contingency (20%)[7] **$ 55,797**

Total Annual O&M **$ 334,781**

Table A-13 (continued)
Cost Estimate for Alternative 7
FFTA-MAAF Feasibility Study
Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring

	Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$ 50,000**
Contingency (20%)[7]	**$ 10,000**
Total Periodic Costs	**$ 60,000**
Total Project Cost	**$ 3,991,872**
Total Present Value Project Cost at 3.2%	**$ 3,854,015**

Notes:

1) BMcD costs represent estimates obtained from similar projects and/or professional experience.

2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, and Project Management.

3) A pilot test is not necessary with this technology since it has been widely used, and design issues are better understood than with other innovative technologies.

4) It assumed that nine sparge curtains will be used. Six will be applied over a 30 ft. thickness, and three will be applied over a 15 ft thickness. Conceptual design of this alternative consists of 25 injection points spaced on ten-foot centers extending 250 feet across the plume. The treatment area for the full scale application is assumed to be 4,500 ft x 250 ft x 45 ft.

5) Assume SVE wells trenched in at shallow depth (10 feet) parallel to sparge curtain. One SVE well per sparge curtain.

6) The nearest electricity is approximately 500 ft from sparge curtain number one. Assume that multiple blowers will be used along different sectors of system rather than one large centralized blower; therefore power will be distributed along length of system.

7) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).

8) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
ea	Each
hr	hour
lb	Pound
ls	Lump Sum
mo	month
RACER	Remediation Action Cost Engineering and Requirements (RACER, 2000)
SVE	Soil Vapor Extraction
VOCs	Volatile Organic Compounds

Table A-14
Present Value Costs for Alternative 7
FFTA-MAAF Feasibility Study

Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 2,411,760	$ -	$ -	$ 2,411,760	1.000	$ 2,411,760
1	$ -	$ 334,781	$ -	$ 334,781	0.969	$ 324,400
2	$ -	$ 334,781	$ -	$ 334,781	0.939	$ 314,341
3	$ -	$ 334,781	$ -	$ 334,781	0.910	$ 304,594
4	$ -	$ 257,885	$ -	$ 257,885	0.882	$ 227,356
5	$ -	$ 257,885	$ 60,000	$ 317,885	0.854	$ 271,563
Total	**$ 2,411,760**	**$ 1,520,112**	**$ 60,000**	**$ 3,991,872**		**$ 3,854,015**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.

2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after three years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.

3) $60,000 includes the cost of a five-year review and a closure report

Table A-15
Cost Estimate for Alternative 8
FFTA-MAAF Feasibility Study

Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Capital Costs					
Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000.00	$ 40,000	BMcD
Engineering and Design[2,3]	ls	1	$ 100,000.00	$ 100,000	BMcD
Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000.00	$ 10,000	BMcD
Groundwater extraction well - 150 gpm[4]	ls	1	$ 30,500.00	$ 30,500	RACER
Groundwater Pump - 150 gpm	ls	1	$ 10,000.00	$ 10,000	BMcD
Air Stripper	ls	1	$108,000.00	$ 108,000	RACER
Flow Line to River - 2,000 ft.[5]	ls	1	$233,000.00	$ 233,000	RACER
Equipment Building	ls	1	$ 50,000.00	$ 50,000	BMcD
Valves, Fittings, Meters, etc.	ls	1	$ 10,000.00	$ 10,000	BMcD
Drummed cutting disposal (non-haz)	drum	6	$ 200.00	$ 1,200	RACER
Power Hookup, electrical[6]	ls	1	$ 65,000.00	$ 65,000	BMcD
Construction Oversight (45 days)					
Labor	day	45	$ 800.00	$ 36,000	BMcD
Per Diem	day	45	$ 100.00	$ 4,500	BMcD
Pickup Truck	day	45	$ 40.00	$ 1,800	BMcD

Subtotal Capital Costs	**$ 700,000**
Contingency (20%)[7]	**$ 140,000**
Total Capital Costs	**$ 840,000**

Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Annual Operation and Maintenance Costs					
Semiannual Groundwater Monitoring[8]	ea	2	$ 107,452.00	$ 214,904	BMcD
Electrical - Pump and Treat	ls	1	$ 94,452	$ 94,452	BMcD
Pump/Treat- System Parts Budget	ls	1	$ 10,000	$ 10,000	BMcD
O & M Labor - ave. 10 hr per week	hr	520	$ 80	$ 41,600	BMcD
Monthy NPDES monitoring/ off gas sampling - labor (8 hr/mo.)	hr	96	$ 80	$ 7,680	BMcD
Monthy NPDES analytical (VOCs monthly)	ea	12	$ 175	$ 2,100	BMcD
Air stripper analytical (VOCs monthly, vapor)	ea	12	$ 175	$ 2,100	BMcD
Monthly reporting - NPDES, air monitoring (16 hr/mo)	hr	192	$ 80	$ 15,360	BMcD

Subtotal Annual O&M	**$ 388,196**
Contingency (20%)[7]	**$ 77,639**
Total Annual O&M	**$ 465,835**

Table A-15 (continued)
Cost Estimate for Alternative 8
FFTA-MAAF Feasibility Study

Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

	Description	Quantity	Unit	Unit Cost	Line Cost	Source[1]
Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$ 50,000**
Contingency (20%)[7]	**$ 10,000**
Total Periodic Costs	**$ 60,000**
Total Project Cost	**$ 4,184,844**
Total Present Value Project Cost at 3.2%	**$ 3,773,392**

Notes:
1) BMcD costs represent estimates obtained from similar projects and/or professional experience.
2) Includes Workplan, Safety Plan, Engineering Design, Scheduling, and Project Management.
3) A pilot test is not necessary with this technology since it has been widely used, and design issues are better understood than with other innovative technologies.
4) Preliminary modeling results suggest that a flow rate of 150 gallons per minute (gpm) is sufficient to capture the contaminant plume at the Site.
5) Assume combination gravity and force main for discharge to river.
6) Nearest Electricity 4,500 ft.
7) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
8) Groundwater monitoring costs are the same as Alternative 2 (Table A-3).

BMcD	Burns & McDonnell Engineering Company, Inc.
drum	55-gallon storage drum
ea	Each
gpm	gallons per minute
lb	Pound
ls	Lump Sum

Table A-16
Present Value Costs for Alternative 8
FFTA-MAAF Feasibility Study

Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring

Year	Capital Costs	Annual O&M Costs[1,2]	Periodic Costs[3]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 840,000	$ -	$ -	$ 840,000	1.000	$ 840,000
1	$ -	$ 465,835	$ -	$ 465,835	0.969	$ 451,390
2	$ -	$ 465,835	$ -	$ 465,835	0.939	$ 437,394
3	$ -	$ 465,835	$ -	$ 465,835	0.910	$ 423,831
4	$ -	$ 465,835	$ -	$ 465,835	0.882	$ 410,689
5	$ -	$ 465,835	$ 24,000	$ 489,835	0.854	$ 418,457
6	$ -	$ 336,892	$ -	$ 336,892	0.828	$ 278,877
7	$ -	$ 336,892	$ -	$ 336,892	0.802	$ 270,230
8	$ -	$ 128,942	$ -	$ 128,942	0.777	$ 100,221
9	$ -	$ 128,942	$ 60,000	$ 188,942	0.753	$ 142,302
Total	**$ 840,000**	**$ 3,260,844**	**$ 84,000**	**$ 4,184,844**		**$ 3,773,392**

Notes:

1) It is assumed that groundwater monitoring for the first five years will be performed semi-annually. Subsequent sampling will be performed annually.
2) Contaminant transport modeling for this alternative estimates that MCLs will be reached after seven years (from 2002) [Appendix B]. It is assumed that annual groundwater monitoring will be required for two years after the remediation is complete, and then a final review and closure report would be submitted.
3) $24,000 included the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report

APPENDIX B

Summary of Remedial Alternative Modeling

Appendix B

Summary of Remedial Alternative Modeling

Purpose

The purpose of the contaminant fate and transport modeling performed in this *FS Report* is to compare the relative clean-up times of each alternative in order to improve the cost estimates and comparative analysis of the alternatives. The clean-up times predicted by the model represent the length of time required for concentrations to decrease below MCLs. However, the clean-up times predicted by the model are for comparison purposes only and do not represent actual dates. The actual clean-up times may vary significantly due to a number of factors (e.g., detailed final design, effectiveness of alternatives at low concentrations, system down time, concentration rebound, etc.).

Introduction

The contaminant fate and transport model developed in the *RI Report* was utilized for the modeling of alternatives performed in this *FS Report*. To simulate groundwater flow at the Site, BMcD used the USGS modular flow model MODFLOW (McDonald and Harbaugh, 1988). MODFLOW is a three-dimensional finite-difference groundwater flow model and is currently the most widely used numerical model for groundwater flow studies.

To simulate contaminant transport of chlorinated solvents at the Site, BMcD used the U.S. Department of Energy modular transport model: Reactive Multi-species Transport in 3-Dimensional Groundwater Aquifers (RT3D), (Clement, 1998). RT3D is a finite-difference reactive transport model designed for use in conjunction with MODFLOW. RT3D is a valuable tool for natural attenuation modeling because it includes sequential reductive dechlorination of PCE and its daughter products, as well as the other natural attenuation processes sorption and dispersion.

To develop the appropriate data files for MODFLOW and RT3D, BMcD utilized the U.S. DoD Groundwater Modeling System (GMS). GMS is a widely used graphical user interface package designed for the pre-processing and post-processing of data files for numerical models including MODFLOW and RT3D. GMS allows the user to develop a conceptual flow model of the Site, which is then converted to an appropriate format and executed by the MODFLOW package. Results from MODFLOW and RT3D simulations are then imported back into GMS for interpretation and analysis.

For a complete description of the model developed in the *RI Report*, refer to Section 6.5 of the *RI Report* (BMcD, 2001).

Model Setup

To model the remedial alternatives presented in Section 4.4 of this *FS Report*, the modeling setup developed in the *RI Report* was used. Since there were actually three contaminant transport modeling scenarios simulated in the *RI Report*, the most representative of Site conditions was selected for use in the modeling of alternatives. The three scenarios are: the model developed for use in the risk assessment (see Section 6.5.3.5 of the *RI Report*), the zero degradation model (see Section 6.5.3.5.1 of the *RI Report*), and the aerobic degradation model (see Section 6.5.3.5.1 of the *RI Report*). The model developed for use in the risk assessment was the main focus of the *RI Report* modeling effort. However, because this model was developed for the purpose of risk assessment, conservative assumptions were used that do not accurately represent Site conditions. A more appropriate choice for modeling the remedial alternatives is the aerobic degradation model. The following is an excerpt from the *RI Report* discussing the aerobic degradation model.

> ### Aerobic Degradation Model
>
> An additional model simulation was performed to evaluate the fate and transport of chlorinated solvents through an aerobic zone. Results of this simulation are presented in Figures 6-53 through 6-60 (in the *RI Report*), and may be contrasted with results of the calibrated model simulation (i.e., the risk assessment model) shown in Figures 6-38 through 6-51 (in the *RI Report*). Site data (see Section 6.3.1 of the *RI Report*) indicates that an aerobic degradation zone is located in the shallow zone starting between Monitoring Well FP-96-23 and Monitoring Well FP-98-27 and extending to the Kansas River. The purpose of this model simulation is to evaluate the fate and transport of the chlorinated solvents and is not intended to provide results for the human health risk assessment. Although aerobic degradation of cis-1,2-DCE and VC is believed to be occurring in the aerobic zone, this situation was not included in the initial modeling (see Section 6.5.3.5 of the *RI Report*) because obtaining calibrated degradation rates for this zone was not possible due to the limited concentration data in this zone and because ignoring the aerobic degradation represents a more conservative approach in terms of risk, i.e. overprediction of VC concentrations. The occurrence of aerobic oxidation of cis-1,2-DCE and/or VC beyond Monitoring Well FP-98-27 is supported by the absence of cis-1,2-DCE and VC detections at and beyond Monitoring Well FP-98-27, the portion of the shallow zone with aerobic conditions.
>
> The aerobic degradation model was constructed by dividing the shallow zone along a line perpendicular to the flow direction and located halfway between Monitoring Well FP-96-23 and Monitoring Well FP-98-27. This location was chosen because Site data indicates that the cis-1,2-DCE plume does not extend past Monitoring Well FP-98-27, and the geochemical data suggests that the aerobic zone starts somewhere between Monitoring Well FP-96-23 and Monitoring Well FP-98-27 (see Section 6.5.3.5 of the *RI Report*). Since historic Site concentration data suggests the cis-1,2-DCE plume will not reach the Kansas River in the

shallow zone, several degradation rates were used until this situation was successfully simulated. Positive detections of cis-1,2-DCE and VC have never been reported in shallow monitoring wells downgradient from Monitoring Well FP-98-27, and detections reported in Monitoring Well FP-98-27 have been below 5 µg/L.

After numerous simulations, aerobic degradation rates of cis-1,2-DCE = 0.01 day^{-1} and VC = 1.0 day^{-1} were determined sufficient to match the behavior of the cis-1,2-DCE plume. Using these rates prevented the cis-1,2-DCE plume from extending past Monitoring Well FP-98-27 in concentrations above 5 µg/L and prevented an accumulation of VC in the aerobic zone. The results of this model are presented in Figures 6-53 to 6-60 (in the *RI Report*).

Due to the reductive dechlorination method used in RT3D (Module 6), the model is incapable of simulating direct aerobic mineralization of cis-1,2-DCE. Degradation of cis-1,2-DCE as simulated by the model must progress through VC which is then degraded to ethene or ethane. Research (Bradley, et at., 1998a) suggests that aerobic degradation of cis-1,2-DCE leads to complete mineralization without VC as an intermediate. Therefore, to simulate direct mineralization of cis-1,2-DCE, a VC rate of 1.0 day^{-1} was required to prevent VC from artificially accumulating in the aerobic zone. Although the degradation rate chosen for VC is high, it is still a reasonable estimation of Site conditions, within the limitations of the model.

Because aerobic mineralization of cis-1,2-DCE will not lead to VC as an intermediate, the amount of VC potentially occurring in the aerobic shallow zone can only come from the anaerobic degradation of cis-1,2-DCE further upgradient, and the subsequent migration of VC into the aerobic zone. From the aerobic model, the amount of VC appearing in the aerobic zone over time can be estimated. These estimates were then compared to the concentration of VC determined from the calibrated (no aerobic zone) model run.

The only difference in the two models is the addition of the shallow aerobic zone beyond Monitoring Well FP-98-27, therefore, only the concentrations of VC and cis-1,2-DCE in the shallow aerobic zone are different. Since PCE and TCE never reach the area of the aerobic shallow zone in either model, they are not discussed further.

Cis-1,2-DCE levels for each simulation are the same in the shallow anaerobic zone and intermediate and deep zones, but in the shallow aerobic zone simulation, cis-1,2-DCE is degraded much more rapidly. In the aerobic simulation, the leading edge of the cis-1,2-DCE plume is very well defined, and only extends to Monitoring Well FP-98-27 after six years, but by nine years, the plume is almost gone. In contrast, cis-1,2-DCE in the calibrated model reaches Monitoring Well FP-98-27 after only one year, is still present after 20 years, and the leading edge of the shallow plume has migrated to the Kansas River after nine years.

In the calibrated model, VC starts to appear at the river at six years, and is still present after twenty years at the river, although at concentrations below 0.2 µg/L. VC in the calibrated model does reach concentrations as high as 1.4 µg/L in the area close to and upgradient of Monitoring Well FP-98-29, which is designated to be in the aerobic zone in the aerobic model. In the portions of the plume closer to the river, the VC concentrations are significantly lower in the calibrated model.

In contrast, VC in the aerobic model is no longer present above 0.1 µg/L after only nine years, and never reaches the river. The highest concentrations of VC, up to 0.5 µg/L, in the area designated as aerobic occur just downgradient of the line separating the two zones (anaerobic and aerobic), between Monitoring Wells FP-98-23 and FP-98-27. These concentrations occur after six years in the model.

The purpose of performing this simulation with estimated aerobic degradation rates for cis-1,2-DCE and VC was to more closely represent conditions as they are actually occurring at the Site. Chlorinated solvents are not migrating all the way to the river in the shallow zone, and may be degrading rapidly in the aerobic shallow zone. This is supported by the historical data that shows no cis-1,2-DCE or VC detections at or beyond Monitoring Well FP-98-27.

Modeling of Remedial Alternatives

To model the remedial alternatives outlined in Section 4.4 of the *FS Report*, the aerobic degradation model (hereinafter referred to as the RI Model) developed in the *RI Report*, and described above, was utilized. The technology used in each alternative was simulated in the model and used to predict relative clean-up times. Several of the alternatives were combined together in the same model because the technologies are applied in a similar manner and are therefore expected to yield similar results if designed properly. The relative clean-up times were determined when all of the COPCs (i.e., TCE and cis-1,2-DCE) decreased below MCLs. In each of the modeling simulations, the contaminant that dictated the clean-up time was cis-1,2-DCE in the intermediate zone.

The clean-up times predicted by the model represent the length of time required for concentrations to decrease below MCLs. However, the clean-up times predicted by the model are for comparison purposes only and do not represent actual dates. The actual clean-up times may vary significantly due to a number of factors (e.g., detailed final design, effectiveness of alternatives at low concentrations, system down time, concentration rebound, etc.). In addition, since the RI Model's input concentrations are based on August 1999 data, the actual clean-up times are expected to be lower since chlorinated solvent concentrations at this Site have significantly decreased from August 1999.

Alternatives 1 and 2

Alternative 1 (No Action) and Alternative 2 (Monitored Natural Attenuation with Institutional Controls and Contingency for Future Action) were modeled together in this scenario because their approach to groundwater remediation is essentially the same (i.e., natural attenuation). This modeling scenario is identical to the RI Model (described above). The modeling of these alternatives acts as a baseline clean-up time. Results from this modeling scenario show that all of the COPCs are at levels below MCLs at the ten-year time step.

Alternatives 3 and 6

Alternative 3 (Enhanced Anaerobic Bioremediation with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action) and Alternative 6 (Bimetallic Nanoscale Particles with Institutional Controls, Monitored Natural Attenuation, and Contingency for Future Action) were modeled together in this scenario. Since it is not possible to determine accelerated degradation rates for Alternative 3 without performing a pilot test, and modeling of this alternative using assumed degradation rates would produce questionable results. Therefore, the same modeling scenario outlined for Alternative 6 was used for Alternative 3. This was based on the assumption that both alternatives will provide similar results if the systems are properly designed. In other words, BNP reacts quickly (a process which is relatively easy to simulate) but it does not last as long as HRC, whereas HRC lasts approximately one year but its reaction rate is highly site-dependent. If both of these systems are properly designed, they should provide similar rates of cleanup of the entire plume.

To model these alternatives, it was assumed that injection curtains would be placed perpendicular to the contaminant plume along that portion to the plume exceeding MCLs. Lines of cells corresponding to the injection curtain lines shown on Figure 5-1 were selected for the appropriate model layer. For example, for curtain No. 1 only the cells in the shallow and intermediate zones were selected; and for curtain No. 6, only the cells in the intermediate and deep were selected. Each of the selected cells were assigned an extremely high degradation rate of 1.0 day^{-1} for each of the CPCs modeled (i.e., TCE and cis-1,2-DCE) to simulate abiotic reductive elimination. The rest of the model was left unchanged from the original RI Model (i.e., the Alternatives 1 and 2 scenario).

BNP is reported to last approximately three months before it is consumed, but this will vary depending on site-specific conditions. Therefore, the model was executed using the high degradation rates (i.e. 1.0 day^{-1}) at the curtain locations shown on Figure 5-1 for three months to simulate abiotic reductive elimination. Following the three-month simulation, the resulting contaminant concentrations were then imported back into the model as new starting concentrations, the high degradation rates in the injection cells were removed, and the model was executed for the remaining time of the simulation (i.e., 9 years 9 months). Results from this modeling scenario indicate that all COPCs are below MCLs at the eight-year time step.

Alternatives 4 and 5

Alternative 4 (Zero-Valent Iron Permeable Reactive Barrier with Institutional Controls and Monitoring) and Alternative 5 (In-Situ Redox Manipulation with Institutional Controls and Monitoring) were modeled together in this scenario since their groundwater remediation approach is essentially the same (i.e., abiotic reductive elimination). Since both alternatives consist of installing a treatment zone at the location shown on Figure 5-2, these alternatives can be modeled together. If constructed properly, both of these alternatives are expected to provide similar results.

To model these alternatives, lines of cells in both the intermediate and deep aquifer zones that corresponded to the treatment zone line shown on Figure 5-2 were selected. Each of the selected cells were assigned an extremely high degradation rate of 1.0 day^{-1} for each of the COPCs modeled (i.e., TCE and cis-1,2-DCE) to simulate abiotic reductive elimination. The rest of the model was left unchanged from the original RI Model (i.e. the Alternatives 1 and 2 scenario), and the model was executed for a ten-year time period. Results from this modeling scenario show all of the COPCs below MCLs at the nine-year time step.

Alternative 7

To model Alternative 7 (Air Sparge/Soil Vapor Extraction with Institutional Controls and Monitoring), lines of cells corresponding to the curtain lines shown on Figure 5-1 were selected for the appropriate model layer. This is the same procedure described for the Alternatives 3 and 6 modeling scenario. Each of the selected cells was assigned very high degradation rates to simulate volatilization. The following degradation rates were used: TCE = 0.2 day^{-1} and cis-1,2-DCE = 0.4 day^{-1}. These rates compare to the original degradation rates used in the RI Model as follows: TCE = 0.0025 day^{-1} and cis-1,2-DCE = 0.0017 day^{-1}.

To prevent an accumulation of daughter products in the model simulation, each of the PCE daughter products had to have a degradation rate twice the rate of its parent. Since the primary removal mechanism of air sparging is not biological and the technology treats all of the COPCs at once, it is appropriate to set up the model this way to prevent an unrealistic accumulation of daughter products. The rest of the model was left unchanged from the original RI Model and was executed for a ten-year time period. Results from this modeling scenario show all of the COPCs below MCLs at the three-year time step.

Alternative 8

To model Alternative 8 (Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitoring), several model simulations were performed to determine the most effective and efficient placement of the extraction well(s) and the approximate pumping rates. The pumping rate was confirmed by using particle tracking to verify the capture zone of the well(s). Preliminary modeling of this alternative indicated that a single well screened in the intermediate and deep aquifer zones pumping at approximately 150 gpm is more than adequate to provide containment of the chlorinated solvent plume at this Site. The rest of the model was left unchanged from the original RI Model and was executed for a ten-year time period. Results from this modeling scenario show the COPCs below MCLs at the seven-year time step.

Summary of Model Predictions

Alternative	Predicted Cleanup Time
Alternative 1 and 2	10 Years
Alternative 3 and 6	8 Years
Alternative 4 and 5	9 Years
Alternative 7	3 Years
Alternative 8	7 Years

The clean-up times predicted by the model represent the length of time required for concentrations to decrease below MCLs. However, the clean-up times predicted by the model are for comparison purposes only and do not represent actual dates. The actual clean-up times may vary significantly due to a number of factors (e.g., detailed final design, effectiveness of alternatives at low concentrations, system down time, concentration rebound, etc.). In addition, since the RI Model's input concentrations are based on August 1999 data, the actual clean-up times are expected to be lower since chlorinated solvent concentrations at this Site have significantly decreased from August 1999.

Interpreting the Results

The last COPC to decrease below MCL in every modeling scenario was cis-1,2-DCE from the intermediate zone. This is the dominant factor affecting the cleanup time of each alternative.

Alternatives 4 and 5 are the least effective of the active treatment technologies, as determined by the modeling effort, because it takes several years before the high concentration cis-1,2-DCE area reaches the treatment zone. The results for Alternative 8 are similar. To improve the cleanup times of these alternatives, additional treatment zones could be added to divide the plume into segments and allow for faster treatment. However, this improvement in cleanup time would likely come with a substantial increase in cost. Cost/benefit issues could be addressed in the PP should these technologies be selected.

Alternatives 3 and 6 are slightly more effective, as determined by the modeling effort, because they divide the plume into segments. However, since these technologies actively treat the plume for such a short period of time, and then rely on MNA to further decrease the concentrations, not enough of the high concentration cis-1,2-DCE area is reduced before the active treatment is exhausted. The cleanup time of these alternatives could be improved by considering multiple injections or more treatment curtains. However, this is a cost/benefit issue that would be addressed in the PP should either of these technologies be selected.

The most effective alternative, as determined by the modeling effort, is Alternative 7. This alternative is effective because it uses treatment curtains to divide the plume into segments, and treats the plume continuously. The other alternatives are not configured in this manner, due to economical considerations, although a cost/benefit analysis should be performed for the selected alternative in the PP to determine the appropriate design.

References

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Clement, T. P., 1998. "A Modular Computer Code for Simulating Reactive Multi-species Transport in 3-Dimensional Groundwater Aquifers." U.S. Department of Energy DE-AC06-76RLO 1830

McDonald, M. G. and A. W. Harbaugh, 1988. "A Modular Three-Dimensional Finite-Difference Ground-Water Flow Model." USGS. Open-File Report 83-875.

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Directorate of Environment & Safety
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Draft Final Feasibility Study for the Former Fire Training Area
Marshall Army Airfield at Fort Riley, Kansas
BMcD Project No. 20774
Contract No. DACA41-96-D-8010 Task Order #0029

Enclosed are seven (7) copies of change pages for the document referenced above. The additions on page 1-19 were made to address EPA's comments on the risk assessment action. A discrepancy was also noted in the costs associated with Tables A-7 and A-8 (the changes were minor and did not effect the overall cost evaluation). An updated pdf/cd's will be shipped this week. If you have any questions, please call me at (816) 822-3369.

Sincerely,

Tracy Cooley

Tracy Cooley
Project Manager

Enclosures

Replacement pages

1-19
Table A-7 - 3 pages
Table A-8

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