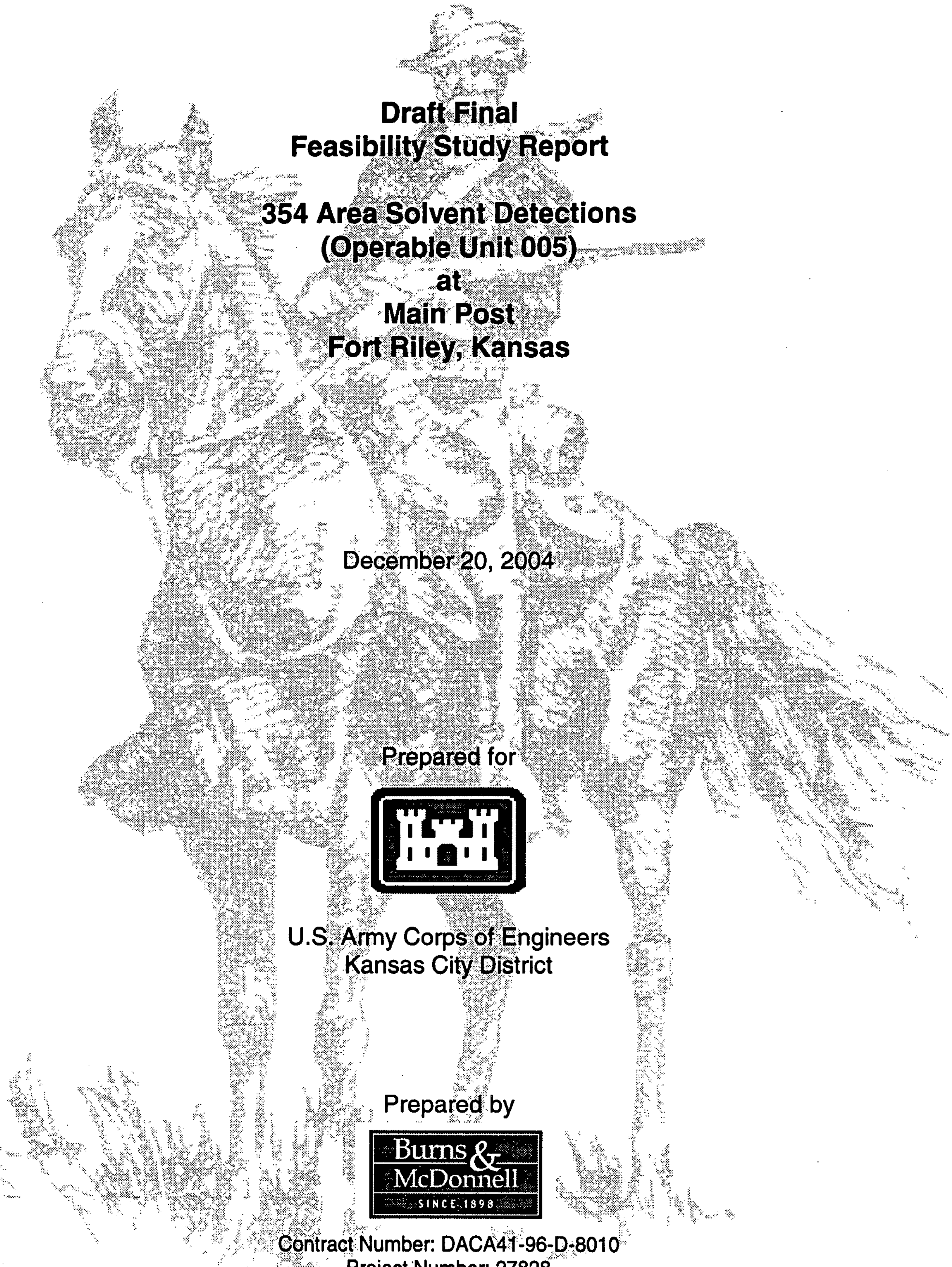

Draft Final
Feasibility Study Report

354 Area Solvent Detections
(Operable Unit 005)
at
Main Post
Fort Riley, Kansas

December 20, 2004

Prepared for

U.S. Army Corps of Engineers
Kansas City District

Prepared by

Burns & McDonnell
SINCE 1898

Contract Number: DACA41-96-D-8010
Project Number: 27828

354_5_2_001

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LIST OF ACRONYMS AND ABBREVIATIONS

ACL	Alternate Concentration Limits
AR	Army Regulation
ARAR	Applicable or Relevant and Appropriate Requirements
BER	Bureau of Environmental Remediation (State of Kansas)
bgs	below ground surface
BMcD	Burns & McDonnell Engineering Company, Inc.
BTEX	Benzene, Toluene, Ethylbenzene, and Total Xylenes
$CaCO_3$	Calcium Carbonate
CCl_4	Carbon Tetrachloride
C/D	Construction/Demolition
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
Chemox	Chemical Oxidation
CO_2	Carbon Dioxide
COPC	Chemicals of Potential Concern
COPEC	Chemicals of Potential Ecological Concern
DA	Department of the Army
DAA	Detailed Analysis of Alternatives
DCA	Dichloroethane
DCE	Dichloroethene
DDC	Density Driven Convection
DES	Directorate of Environment and Safety
DO	Dissolved Oxygen
DPW	Directorate of Public Works
EAB	Enhanced Anaerobic Bioremediation
ECORA	Ecological Risk Assessment
EE/CA	Engineering Evaluation/Cost Analysis
Fe^0	Zero-Valent Iron
Fe^{+2}	Ferrous Iron
Fe^{+3}	Ferric Iron
FFA	Federal Facility Agreement
ft	feet
ft^2	square feet
ft/day	feet per day
ft/ft	feet per feet
FS	Feasibility Study
g	grams
GCW	Groundwater Circulation Wells

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

gpm	gallons per minute
GRA	General Response Action
H^+	Hydrogen Ion
HCl	Hydrochloric Acid
H_2O	Water
H_2O_2	Hydrogen Peroxide
HHBRA	Human Health Baseline Risk Assessment
IAG	Interagency Agreement
IFI	Initial Field Investigation
IFIR	Initial Field Investigation Report
IRP	Installation Restoration Program
ISRM	In-Situ Redox Manipulation
IWSA	Installation Wide Site Assessment
KAR	Kansas Administrative Record
KCD-CoE	Kansas City District – Corps of Engineers (U.S. Army)
KDHE	Kansas Department of Health and Environment
kg	kilogram
$KMnO_4$	Potassium Permanganate
LBA	Louis Berger & Associates
lbs	pounds
LRC	Long-Range Component
MCLs	Maximum Contaminant Levels
MNA	Monitored Natural Attenuation
MnO_4^-	Permanganate Ion
mg/L	milligrams per liter
µg/kg	micrograms per kilogram
µg/L	micrograms per liter
MPEO	Master Plan Environmental Overlay
NA	Natural Attenuation
NAPL	Non-Aqueous Phase Liquid
NCP	National Contingency Plan
NO_3^-	Nitrate
NOD	Natural Oxidant Demand
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
O_2	Oxygen
O_3	Ozone
OH^-	Hydroxyl Ion
$OH^\bullet$	Hydroxyl Radical
O&M	Operation & Maintenance

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

ORP	Oxidation Reduction Potential
OSHA	Occupational Safety and Health Administration
OU	Operational Unit
PAH	Polycyclic Aromatic Hydrocarbon
PAOC	Potential Area of Concern
PCE	Tetrachloroethene
POL	Petroleum, Oil, and Lubricants
PP	Proposed Plan
ppb	parts per billion
PRB	Permeable Reactive Barrier
PRG	Preliminary Remediation Goal
PSWP	Pilot Study Work Plan
PSWPA	Pilot Study Work Plan Addendum
RAO	Remedial Action Objective
RATD	RAO/ARAR/TID/DAA
RCRA	Resource Conservation & Recovery Act
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
RI/FS WP	Remedial Investigation/Feasibility Study Work Plan
RME	Reasonable Maximum Exposure
RPMP	Real Property Master Plan
ROD	Record of Decision
RSK	Risk Standards for Kansas
S^{-2}	Sulfide
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
354 Site	354 Area Solvent Detections at Fort Riley, Kansas
SO_2	Sulfur Dioxide
SO_3^{-2}	Sulfite Ion
SO_4^{-2}	Sulfate Ion
SVE	Soil Vapor Extraction
SVOC	Semi-Volatile Organic Compounds
TBC	To Be Considered
TCA	Trichloroethane
TCE	Trichloroethene
Tech Memo	Technical Memorandum
TID	Technology Identification
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
UCL	Upper Confidence Limit
UPRR	Union Pacific Railroad
USACE	United States Army Corps of Engineers
USC	United States Code

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	Underground Storage Tanks
VVW	Vacuum Vaporizer Well
VC	Vinyl Chloride
VOCs	Volatile Organic Compounds
yd^3	cubic yards

*****

1.0 INTRODUCTION

1.1 PURPOSE OF REPORT

The purpose of this Feasibility Study (FS) Report (FS Report) is to develop and evaluate remedial alternatives to allow selection of an appropriate remedy for contamination associated with the 354 Area Solvent Detections (Operable Unit [OU] 005) (354 Site) on Main Post, Fort Riley, Kansas. This FS Report was developed in support of the Fort Riley Directorate of Environment and Safety (DES) Installation Restoration Program (IRP). This report was also written 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. This FS Report was prepared by Burns & McDonnell Engineering Company, Inc. (BMcD) under contract DACA41-96-D-8010 with the Kansas City District, U.S. Army Corps of Engineers (KCD-CoE), and represents Fort Riley's on-going 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 was submitted as a secondary document, as per the Federal Facilities Agreement (FFA) (United States Environmental Protection Agency [USEPA], 1991):

- *RAO/ARAR/TID/DAA Technical Memorandum, 354 Area Solvent Detections (Operable Unit 005) at Main Post, Fort Riley, Kansas* (RATD Tech Memo) (BMcD, 2004a)

The purpose of this submittal was to provide necessary information so the USEPA and the Kansas Department of Health and Environment (KDHE) could provide guidance to Fort Riley during the production of the FS Report. This document was a communication milestone between the lead agency (Fort Riley) and the support agencies (USEPA and KDHE) to obtain input and agreement on the requirements, technologies/processes, and alternatives considered for implementation at the 354 Site. In addition to the submittal of this report (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. The review of the FS Report should be fairly straightforward, since there is essentially little new information presented in this report that has not already been reviewed and commented on by both the USEPA and the KDHE.

Specific objectives for this FS Report are:

- Develop remedial action objectives (RAOs) and preliminary remediation goals (PRGs) that are protective of human health and the environment;
- Identify treatment technologies relevant to the nature and extent of contamination present at the 354 Site;
- Screen and assemble appropriate technologies into remedial action alternatives; and
- Define, evaluate, and compare alternatives based on the criteria defined by relevant USEPA guidance documents.

1.2 REPORT ORGANIZATION

- **Section 1.0 Introduction** – This section provides a brief description of the 354 Site, a summary of the hydrogeology, a description of nature and extent of contamination, an evaluation of contaminant fate and transport in groundwater, and a summary of the baseline risk assessment. Section 1.0 essentially provides an overview of the *Remedial Investigation (RI) Report, 354 Area Solvent Detections (Operable Unit 005) at Main Post, Fort Riley, Kansas* (RI Report) (BMcD, 2003a).

- **Section 2.0 Applicable or Relevant and Appropriate Requirements (ARARs) and To Be Considered (TBC) Information** – This section discusses federal, state, and other statutes, regulations, and guidance documents that may be applicable or relevant and appropriate to the 354 Site.

- **Section 3.0 RAOs and PRGs** – This section is taken from the RATD Tech Memo (BMcD, 2004a), and describes the media of concern, contaminants, RAOs, and PRGs. General response actions for the media of interest are also identified.

- **Section 4.0 Identification and Screening of Technologies** – This section (also referred to as the technology identification [TID]) is identical to the equivalent section presented in the RATD Tech Memo (BMcD, 2004a).

- **Section 5.0 Detailed Analysis of Alternatives (DAA)** – This section is also based on Section 5.0 of the RATD Tech Memo (BMcD, 2004a), and evaluates the remedial alternatives with respect to the CERCLA screening criteria, including the estimated cost associated with each alternative.

- **Section 6.0 Comparative Evaluation of Alternatives** – This section provides comparative analyses of remedial alternatives, and ranks the most feasible and effective alternative for the 354 Site.

- **Section 7.0 References.**

1.3 BACKGROUND INFORMATION

Detailed background on the 354 Site is provided in the RI Report (BMcD, 2003a). The following information was abstracted from that document and updated as required.

1.3.1 Site Description

Fort Riley is located along the Republican and Kansas Rivers in Geary and Riley Counties. The more developed areas of Fort Riley are in the southern portion of the reservation along the Kansas River (Figure 1-1). The developed areas are divided into six cantonment areas, one of which is Main Post. The 354 Site currently encompasses portions of Main Post as far north as Godfrey Avenue, and virtually the entire point bar south of the Union Pacific Railroad (UPRR) grade and east of the Henry Drive Bridge (See Figure 1-2). This point bar and an alluvial terrace dominate the topography across the study area. The point bar is part of the active floodplain and consists of approximately 60 feet (ft) of alluvial sediments overlying shale or limestone bedrock. The terrace, located to the north of the railroad grade, also consists of alluvial sediments deposited on shale and limestone bedrock; however, this area is topographically higher than the floodplain and the unconsolidated terrace deposits vary in thickness from nine to 64 ft.

1.3.2 Site History

Over the years, a variety of activities have been conducted at the 354 Site, which could have resulted in sources of both chlorinated solvent and hydrocarbon contamination. These include the operation of facilities for the storage and maintenance of motorized equipment, facilities for storing and dispensing fuel and oil for vehicles, and at least one area where fire fighting equipment may have been serviced or used for training.

The former Building 354 was constructed in 1935 as a gasoline service station. In addition to gasoline and diesel fuel, it may have been subsequently used as a storage site for solvents and road oil. Two 10,000-gallon steel underground storage tanks (USTs), one 12,800-gallon steel UST, and one 8,500-gallon steel UST were installed at the site in either 1933 (Dames & Moore, 1995) or 1935 (United States Army Corps of Engineers [USACE], 1995), and were used for gasoline and diesel storage. Two 10,000-gallon steel USTs were installed at the site in 1980 and were used for diesel storage (Dames & Moore, 1995). USACE indicated that the USTs at this site were also used to store road oil, and may have been used to store solvents (USACE, 1996). The former USTs (including the solvent tank) were 20 ft south of the former Building 354 and approximately 60 ft northwest of the site (see Figure 1-2). A drawing dated June 1982, obtained from the Fort Riley Directorate of Public Works (DPW), indicated plans to replace the pump on a solvent tank located approximately 15 ft southeast of former Building 354. The drawing does not indicate if the tank was an UST or an above-ground tank.

Five of the six USTs, shown on historical drawings of the site, were removed in 1990 and 1991. The 8,500-gallon steel UST, reportedly used for diesel storage, was not found (Dames & Moore, 1995). Fort Riley Real Property records of the DPW Compound indicate that five USTs were located at this site, which corresponds to the number removed in 1990 and 1991.

Building 367 is located on Carr Avenue and was constructed in 1903. The building originally served as a post artillery gun shed and presently serves as storage space for post commands. The one-story building contains 15,024 square-ft (ft^2) and is constructed of limestone on a limestone foundation. Building 367 is on the National Register of Historic Places as a member of the Cavalry and Artillery thematic group within the Main Post Historic District.

Building 430 is located on Godfrey Avenue and was constructed in 1932. The building was originally built and is still maintained as a fire station. The one-story building contains 4,369 ft^2 and is constructed of course ashlar limestone. Building 430 is on the National Register of Historic Places as a member of the 1927-1940 thematic group within the Main Post Historic District.

1.3.3 Current and Future Land Uses

The portion of the 354 Site located within Main Post, to the north and west of the UPRR right-of-way, is used for vehicle maintenance and storage, office blocks, warehouses, barracks, and some residential housing units. Much of this area is covered with either concrete or asphalt, and has a high density of buried utilities, including water, sewer, electricity, gas, telephone, and fiber-optic cable. Much of the area to the south and east of the UPRR grade, which is located on the Kansas River floodplain, is in a natural or semi-natural state, with large tracts of deciduous forest. Much of the forest area along the Kansas River is conserved as critical habitat for a transient population of bald eagles. There are some structures in this area, mainly along the UPRR grade, which are used for warehouses and as administrative offices. Underground utilities are present, but are not as dense as in the Main Post area.

Land use at the 354 Site is classified under the Real Property Master Plan (RPMP). It is anticipated that land use activities will remain unchanged into the foreseeable future. The Main Post area to the north of the UPRR grade is classified as a national historical area. The area to the south of the UPRR grade should not see significant changes in current land use. This is because it is within the active flood plain of the Kansas River and the area within 100 meters of the current Kansas River bank is critical wildlife habitat for bald eagles that winter over at Fort Riley.

Groundwater is the primary source of drinking water for Fort Riley and many of the surrounding communities. Alluvial sand and gravel deposits in the Kansas and Republican River valleys are excellent aquifers. The large capacity supply wells, which provide water for Fort Riley, are located upstream from the 354 Site. There are no supply wells located in either the terrace or Kansas River alluvial aquifers at the 354 Site. Because of the very low transmissivity of the terrace aquifer and the prolific supply available from the Kansas River alluvial aquifer, it is unlikely that supply wells will ever be completed within the terrace deposits.

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 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. Potential sources of contamination include landfills; printing, dry cleaning, and furniture shops; and pesticide storage facilities. On July 14, 1989, the USEPA proposed inclusion of Fort Riley on the National Priority List (NPL) pursuant to the CERCLA. The USEPA included the site on the NPL, promulgated in August 1990. Fort Riley is identified by the USEPA as the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) Site KS6214020756.

Effective June 1991, the DA entered into a Federal Facilities Agreement (FFA), Docket No. VII-90-F-0015, with the KDHE and the USEPA Region VII to address environmental pollution subject to the CERCLA, the National Contingency Plan (NCP), and/or the Resource Conservation and Recovery Act (RCRA) (USEPA, 1991). This agreement is also referred to as the Interagency Agreement (IAG).

Pursuant to the IAG, Fort Riley conducted an Installation Wide Site Assessment (IWSA) in 1992 [Louis Berger & Associates (LBA), 1992] to identify sites having the potential to release hazardous substances to the environment. The IWSA did not specifically identify the 354 Site as a potential area of concern (PAOC) requiring further evaluation. It did address petroleum, oil, and lubricant (POL) facilities (including the 354 Site) as sites which might be evaluated under the UST programs and would normally be excluded from the CERCLA since the CERCLA was not intended to cover sites impacted exclusively by petroleum contamination. However, following the removal of the USTs at the 354 Site, investigation of soil and groundwater revealed the presence of chlorinated solvent contamination. During January 1997, the 354 Area Solvent Detections was formally designated an OU and the RI was subsequently initiated.

BMcD completed an initial field investigation (IFI) in 1997 (BMcD, 1998). Following completion of the IFI, fieldwork was initiated for the RI. An Engineering Evaluation/Cost Analysis (EE/CA) was undertaken in late 2002 to investigate the possibility of an interim removal action to treat a shallow soil 'hot-spot' located east of Building 367. The EE/CA was not completed because there was not sufficient risk to justify the completion of an interim removal action. In late 2003, the decision was made to conduct a pilot study at the Building 367 'hot-spot' in order to evaluate the effectiveness of an innovative in-situ method for mixing chemical oxidant into shallow surface soil. The pilot study was conducted beginning in March 2004, with soil removal being completed in December 2004. A detailed summary of the pilot study is provided below in Section 1.3.6 of this report.

The RI Report (BMcD, 2003a) was completed in late 2003. This document 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. A brief summary of these topics will be covered in subsequent sections of this report.

1.3.5 Aquifer Characteristics

1.3.5.1 Geology

The bedrock geology at the 354 Site consists of alternating beds of limestone and calcareous shale, which dip very gently to the west-northwest. This bedrock has been eroded by the major rivers and streams, which have also deposited alluvial sediments. The bedrock surface across the study area consists of a terrace area to the north and a bedrock channel of the ancestral Kansas River to the south. These two areas are separated by an abrupt, south-facing drop-off with about 25 to 30 ft of relief. The bedrock surface on the terrace has up to ten ft of relief locally, and is cut by north-south trending swales and ridges. To the south, on the point bar of the Kansas River, a series of bedrock channels of the ancestral

Kansas River are developed. These are oriented roughly sub-parallel to the modern Kansas River channel and have a modest relief of just a few feet.

Both modern alluvial and older alluvial terrace deposits were deposited on top of this bedrock surface. Soil borings advanced in these areas revealed deposits that exhibited the upward-fining sequence typical of alluvial sediments, with coarse-grained sands at depth, grading upward into medium- to fine-grained sands, then fine-grained silts and clays near the surface. The thickness of these deposits on the terrace ranges from approximately eight to 65 ft. On the point bar, alluvial deposits can be up to 60 ft thick.

A more detailed description of the 354 Site geology is presented in Section 2.3 of the RI Report (BMcD, 2003a).

1.3.5.2 Hydrogeology

Unconfined groundwater is present within both the terrace deposits (terrace aquifer) and the Kansas River alluvium (Kansas River alluvial aquifer). Groundwater within the terrace aquifer is present directly above the bedrock surface, with a saturated thickness ranging from zero (dry) along the southern margin of the terrace to about 16 ft in the vicinity of Building 430. Depth to water on the terrace varies between less than ten ft below ground surface (bgs) to about 55 ft bgs. Values for the hydraulic conductivity of the terrace aquifer are based only on laboratory analysis of permeability. These values ranged from 1,200 feet per day (ft/day) to 9.6 X 10^{-4} ft/day. Groundwater flow is controlled by the topography of the bedrock surface on the terrace, which imparts a southerly direction of groundwater flow (Figure 1-3). Groundwater gradients within the terrace aquifer range from about 0.006 feet per foot (ft/ft) to about 0.015 ft/ft.

The thickness of saturated material within the Kansas River alluvial aquifer is as thick as 35 ft in some areas, with depths to water ranging from as little as 12 ft bgs along the floodplain margin to approximately 25 ft bgs in the central portion of the point bar. Values of the hydraulic conductivity, based on several pump tests, ranged from a high of approximately 1,000 ft/day to about 450 ft/day. Groundwater flow here is controlled in large part by the Kansas River and is to the east/southeast, across the point bar (Figure 1-3). Gradients here range from approximately 0.0005 to 0.0008 ft/ft.

A more detailed description of the 354 Site hydrogeology is presented in Section 2.5 of the RI Report (BMcD, 2003a).

1.3.6 Pilot Study (In-Situ Soil Treatment)

The decision was made in late 2003 to conduct a pilot study at the 354 Site to test the effectiveness of an innovative soil treatment technology. The area selected for the pilot test was the shallow soil "hot-spot" located just east of Building 367. The justification for conducting the pilot test was based on this "hot-spot" as a source for chlorinated solvent contamination in the underlying groundwater. This groundwater plume impacted the Kansas River alluvial aquifer, resulting in exceedances in the USEPA maximum contaminant levels (MCLs) for tetrachloroethene (PCE) within this aquifer. The pilot study was conducted to remove the "hot-spot" in order to reduce groundwater contaminant levels and ensure that there would not be a violation of the anti-degradation requirements of the State of Kansas Surface Water Quality Regulations.

The shallow soil "hot-spot" was an area with primarily PCE contamination, with measured concentrations up to 29,000 micrograms per kilogram (µg/kg). After a review of several different remedial technologies and an evaluation of costs, the decision was made to use an innovative in-situ mixing technology to treat the soil with potassium permanganate ($KMnO_4$). A work plan was developed to treat a 2,800-ft^2 area to a depth of approximately ten ft bgs with approximately 14,000 pounds (lbs) of $KMnO_4$ (BMcD, 2003b).

The pilot study began in early March 2004. Approximately five weeks after the completion of soil treatment, confirmation samples were collected from the treated area and were sent to an off-site laboratory for analysis of volatile organic compounds (VOCs). A total of 32 soil intervals were sampled within the treatment area. PCE concentrations ranged from 22 to 2,522 µg/kg, with an average of approximately 450 µg/kg. Sixty-eight percent of the sample results fell between 200 and 600 µg/kg. Analytical results indicated that reductions in discrete contaminant levels of one to two orders of magnitude took place as a result of the $KMnO_4$ treatment. The total mass of PCE in the treated soil volume was reduced from approximately 1,600 grams (g) to about 700 g.

Following the initial treatment with $KMnO_4$, a decision was made by Fort Riley and the KCD-CoE to excavate the treated soil and complete treatment in a lined cell located in Camp Funston. This would serve the dual purpose of allowing for the additional volatilization of chlorinated solvent and would facilitate the drying of the material for use as cover material at the construction debris (C/D) landfill on the post. The excavated treatment area at Building 367 would be filled in with clean borrow material and re-paved. As of mid-December 2004, this work has been completed and the treated soil was located within the treatment cell at Camp Funston. These activities completed the removal of the "hot-spot" at Building 367. Details on this activity are presented in the *Work Plan Addendum, Pilot Study for Soil Remediation, 354 Area Solvent Detections (Operable Unit 005) at Main Post, Fort Riley, Kansas* (BMcD, 2004b). Complete information on the pilot study will be included in the Pilot Study Report (in preparation).

1.3.7 Nature and Extent of Contamination

Contaminants which were identified as soil and/or groundwater COPCs at the 354 Site in the RI Report included chlorinated solvents and benzene, toluene, ethylbenzene, and xylene (BTEX) compounds (BMcD, 2003a). This section provides a brief summary of the nature and extent of contamination at the 354 Site.

COPCs identified in the FS Report are presented in Section 3.3, and include PCE, trichloroethene (TCE), cis-1,2-dichloroethene (DCE), and benzene.

Specific areas identified in the RI Report as possible source areas include the following:

- Building 367 and adjacent paved areas (removed during the pilot study);
- Building 332, former Building 354, its associated USTs, and adjacent areas of the DPW Compound;
- Building 430;
- Former service station northwest of UPRR depot; and
- Petroleum unloading facility and pipeline along the UPRR grade.

1.3.7.1 Soil and Vadose Zone

<u>Metals</u>

Arsenic, barium, cadmium, chromium, and lead were detected in soils at the 354 Site. Metals in soils were generally detected at concentrations below regional background levels, with the exception of lead. Although the detected concentrations of lead in soil were above background levels, they were below regulatory screening levels. Since most metals in soil were detected at concentrations below background, and the detected concentrations of all metals were below regulatory screening levels, no metals in soil were retained as COPCs. However, in accordance with recent USEPA guidance and United States Army Corps of Engineers (USACE) policy, an evaluation of potential human health risks associated with exposure to background levels of metals was added to the discussion of uncertainties in the RI Report. No specific sources for metals have been identified at the 354 Site; however, tetraethyl lead was once a common fuel additive. For additional information, refer to Section 5.2 of the RI Report (BMcD, 2003a).

Volatile Organic Compounds

The following bullets provide a summary of VOC contamination in subsurface soils:

- The highest chlorinated VOC contamination was present in shallow soils in the area immediately to the east of Building 367. PCE was the primary contaminant, with lesser concentrations of TCE and cis-1,2-DCE. Concentrations of PCE as high as 29,000 µg/kg were detected in this area. Off-site analytical data indicated that the highest concentrations of soil contamination were present between the ground surface and four-ft bgs in virtually all direct-push borings. These concentrations decreased as the ten-ft bgs depth was approached. At the seven- to ten-ft bgs depth, chlorinated VOC concentrations were either below or rapidly approaching the risk standards for Kansas (RSK) values for the soil-to-groundwater protection pathway. This soil was treated in-situ and then removed during the pilot study described in Section 1.3.6.

- Some chlorinated solvent contamination in soil has been detected in the vicinity of former Building 354/Building 332/DPW Compound; however, concentrations were all below regulatory standards.

- Although carbon tetrachloride (CCl_4) was detected in soil gas (at low concentrations) in the vicinity of Building 430, VOCs were not detected in any soil samples collected in this area.

- Contamination of soils at depth (within a few feet of the overburden-bedrock interface) is probably the result of lateral transport of contaminated groundwater, combined with vertical fluctuations in water table elevation.

For additional information, refer to Section 5.4.1 of the RI Report (BMcD, 2003a).

Semi-Volatile Organic Compounds

Polycyclic aromatic hydrocarbons (PAHs) were the only semi-volatile organic compounds (SVOCs) detected in soils at the 354 Site. All detections were at concentrations below the residential KDHE RSK standards for both the soil and the soil-to-groundwater protection pathway. For additional information, refer to Section 5.4.2 of the RI Report (BMcD, 2003a).

Petroleum Compounds

BTEX and total petroleum hydrocarbons (TPH) were detected in soil samples collected from four areas. These were the former Building 354 area, in the vicinity of the former service station located along Dickman Avenue, the Building 367 area, and along the sanitary sewer running parallel to the UPRR grade. Only benzene was detected at concentrations that exceeded the KDHE RSK soil and soil-to-groundwater protection standards (residential). These detections were located near the site of the former Building 354. For additional information, refer to Section 5.4.3 of the RI Report (BMcD, 2003a).

1.3.7.2 Groundwater

Metals

Arsenic, barium, chromium, lead, and mercury were detected in the groundwater at the 354 Site. Only arsenic and lead were detected at concentrations in excess of the USEPA MCL or action level (in the case of lead). These detections were all located within or immediately adjacent to the Kansas River alluvial aquifer. The lack of detections in terrace monitoring wells suggested that these were not site-related contaminants. Because groundwater is not considered useable as a drinking water source and is generally too deep to be directly contacted, metals in groundwater were not evaluated quantitatively as part of the human health risk assessment. For additional information, refer to Section 5.2 of the RI Report (BMcD, 2003a).

Volatile Organic Compounds

VOC contamination follows the general direction of groundwater flow off the alluvial terrace onto the modern floodplain of the Kansas River. The plume originates in the vicinity of Building 367 (the presumed source) and runs south to the UPRR grade. Once the plume impinges on the alluvial aquifer of the Kansas River, it becomes more diffuse and trends in an easterly direction. PCE and TCE predominate as contaminants in the terrace aquifer, while cis-1,2-DCE is more widespread in the Kansas River alluvial aquifer.

The following discussion of VOCs will concentrate on PCE, TCE, cis-1,2-DCE, and CCl_4, since these are the high interest chlorinated solvents. For additional information on VOCs in groundwater, refer to Section 5.5.1 of the RI Report (BMcD, 2003a).

The PCE contaminant plume appears to originate in the vicinity of Building 367 (Figure 1-4). Monitoring Well B354-99-08, which was located just east of Building 367 and has been abandoned, had the highest detections of PCE in groundwater at the 354 Site (Monitoring Well B354-99-08 was abandoned when the pilot study was conducted because the well location was within the treatment area). Groundwater samples taken from this monitoring well in February 2000 had a PCE concentration of 4,630 micrograms per liter (µg/L). Concentrations subsequently dropped to a level of 386 µg/L by the fall of 2003. The PCE plume extends south from the vicinity of Building 367 to the area just south of the UPRR grade. Overall, average PCE values display a decreasing trend to the south, with detected concentrations one or two orders of magnitude in excess of the USEPA MCL value of 5.0 µg/L. Once into the Kansas River alluvial aquifer, the PCE plume remains along the northern margin of the alluvial floodplain. Detected concentrations of PCE were below 10 µg/L. There were no detections of PCE out into the central portion of the point bar or near the Kansas River.

As is the case with the PCE plume, the TCE contamination also appears to originate in the vicinity of Building 367 (Figure 1-5). TCE concentrations ranged from 160 µg/L (February 2000) to 21 µg/L in the fall of 2003 at the now abandoned Monitoring Well B354-99-08. TCE concentrations decrease dramatically to the south of the Building 367 source area, with no detections in excess of the USEPA MCL of 5.0 µg/L. It appears this segment of the plume ends just to the north of the UPRR grade. TCE is present in the Kansas River alluvial aquifer, but at very low concentrations. Concentrations have ranged from a high of 1.9 µg/L to non-detect. The TCE plume does not extend to the Kansas River.

cis-1,2-DCE is present at two discontinuous areas on the terrace (Figure 1-6). The first area is in the vicinity of Building 367, where cis-1,2-DCE had been detected at concentrations ranging from 260 µg/L (February 2000) to 41 µg/L (October 2000). In the fall 2003, cis-1,2-DCE was detected at a concentration of 110 µg/L. A second area of contamination on the terrace was just south of Building 332. Concentrations in this area did not exceed 25 µg/L. There is an extensive area of cis-1,2-DCE contamination within the Kansas River alluvial aquifer on the point bar; however, all detections are below 10 µg/L. The contamination to the south of the UPRR grade does appear to extend to the Kansas River at the eastern side of the point bar.

At the 354 Site, most detections of CCl_4 have been in the terrace aquifer. The principle area of CCl_4 contamination extends from the vicinity of Building 367 south to the vicinity of former Building 354 (Figure 1-7). Only one monitoring well (MW95-06) has had detections over the USEPA MCL of 5.0 (5.3 µg/L in November 1998). CCl_4 has also been detected in direct-push groundwater screening samples in the vicinity of Building 430, where detected concentrations were as high as 5.1 µg/L. Monitoring Well B354-01-26 had a detection of 4.3 µg/L for CCl_4 in the September/October 2003 sampling event. There have been occasional, low level detections of CCl_4 in samples collected from monitoring wells completed in the Kansas River alluvial aquifer. These have not exceeded 1.6 µg/L.

Semi-Volatile Organic Compounds

There were only three SVOCs detections during the groundwater sampling events. bis(2-Ethylhexyl)phthalate was detected at Monitoring Well TS0292-01 at a concentration of 19 µg/L in January 2002. This compound was also detected at Monitoring Well B354-99-09 at a concentration of 63 µg/L in July 2002. These concentrations both exceeded the USEPA MCL of 6.0 µg/L for that compound. Diethyl phthalate was detected at Monitoring Well MPL94-01 at a concentration of 7.3J µg/L in September 1997. There is no USEPA MCL for diethyl phthalate; however, the KDHE RSK value for the groundwater protection pathway (residential) is 12,000 µg/L. bis(2-Ethylhexyl)phthalate and diethyl phthalate are both used in the production of plastics. The fact that these detections represent single hits at a given monitoring well, with no other detections either before or after at a given location, strongly suggest that these are the result of sample contamination. These detections probably do not represent compounds present in the groundwater.

Petroleum Compounds

BTEX compounds have been detected at the 354 Site, mainly in the area at and to the south of the former Building 354 site and the DPW Compound. Benzene has been detected at four monitoring wells at the 354 Site. Only one monitoring well (TS0292-02) has had detections above the USEPA MCL of 5.0 µg/L. These detections have ranged from 40.3 to 14.6 µg/L. Toluene, ethylbenzene, and xylenes have also been detected, but at very low concentrations two to four orders of magnitude below their respective USEPA MCLs. For additional information on the BTEX compounds, refer to Section 5.5.2 of the RI Report (BMcD, 2003a).

1.3.7.3 Surface Water

Surface-water samples have been collected from the Kansas River by the United States Geological Survey (USGS) in March 2000, July 2000, and July 2001. Ten samples were collected on each of three transects across the Kansas River. These transects were located both upstream and downstream from the area where the groundwater plume enters the river. All samples were analyzed for VOCs. VOCs were not detected in any samples.

1.3.8 Contaminant Fate and Transport

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 (NA) processes, combine to reduce and disperse contaminant concentrations in groundwater.

The fate and transport of contaminants in groundwater was evaluated in Section 6.0 of the RI Report (BMcD, 2003a). This was accomplished through an evaluation of the aerial distribution of contamination and by evaluating geochemical indicator parameters, and is summarized in the following section.

As detailed in the RI Report, the primary chlorinated solvent source appeared to be located immediately east of Building 367. This source consisted mostly of PCE, based on both soil and groundwater data. TCE and cis-1,2-DCE were present as well, but at significantly lower levels. This shallow soil source was removed in 2004 during the pilot study described in Section 1.3.6. Secondary chlorinated solvent sources may exist in the vicinity of Building 430, Building 332, and the DPW Compound, but the evidence for this (from soil samples) is not conclusive. There are sources of BTEX contamination in the vicinity of Building 332, the former Building 354, and along the UPRR grade, based on both soil and groundwater evidence.

The fate and transport of contaminants within soils and the vadose zone is a physically more complex process than fate and transport within the saturated zone. Sorption, volatilization, and degradation are active processes in both the vadose and saturated zones. In addition, multiphase flow takes place within the vadose zone since air, water, and organic liquids (contaminants) are present within the soil pore space. Saturation, wettability, imbibition, drainage, and relative permeability all affect the physical behavior of contaminants within unsaturated soils. In situations where contaminants are present at low concentrations, continuing dissolution or volatilization are probably the main threat to groundwater in the saturated zone (Domenico and Schwartz, 1990).

Chlorinated solvent contamination is transported south of the source area, within the terrace aquifer, to the Kansas River alluvial aquifer. Advection appears to be the dominant transport process, with adsorption playing a major role in reducing the aqueous phase mass of PCE along flowpath. Volatilization might have a minor role in reducing PCE mass within the terrace aquifer. An evaluation of NA parameters and contaminant chemistry within the terrace aquifer suggests that little or no biotransformation of chlorinated solvents is occurring. Dissolved oxygen (DO), oxidation-reduction potential (ORP), and nitrate (NO_3^-) levels are high, while ferrous iron (Fe^{+2}) levels remain low, all suggesting an environment unsuitable for reductive dechlorination. High levels of PCE within the groundwater confirm this, and modest amounts of the daughter products (TCE and cis-1,2-DCE) are present.

Once the contaminant plume intersects the Kansas River alluvial aquifer, the aquifer geochemistry changes and the direction of transport becomes easterly, moving with the general direction of flow of the

Kansas River. Dispersion becomes more significant, relative to advection, as groundwater flow velocities tend to be only one-tenth of those within the terrace aquifer (see Section 6.3.1 of the RI Report [BMcD, 2003a]). Within the Kansas River alluvial aquifer, geochemical conditions are more conducive for reductive dechlorination. DO, ORP, and NO_3^- levels drop significantly, and Fe^{+2} levels increase, thus improving the effectiveness of reductive dechlorination. In addition, PCE disappears shortly after entering the Kansas River alluvial aquifer, to be replaced with TCE, and finally low levels of cis-1,2-DCE.

cis-1,2-DCE is less amenable to dechlorination in an anaerobic reducing environment, compared to PCE and TCE. In this system, it appears that once the degradation pathway reaches cis-1,2-DCE, the dechlorination process slows, leaving cis-1,2-DCE to be further attenuated by nondestructive processes. The absence of vinyl chloride (VC) (except the unexplained detections at Monitoring Well B354-00-10) and ethane/ethene throughout the plume also points to stalling of the reductive dechlorination process at cis-1,2-DCE.

Another factor influencing reductive dechlorination is the availability of primary carbon sources to act as electron donors. BTEX is present in groundwater in the area where the plume impacts the Kansas River alluvial aquifer, but is not present downgradient. These organics can serve as a primary substrate for microorganisms facilitating reductive dechlorination. As BTEX is degraded, the reduction of chlorinated substances stalls, leaving cis-1,2-DCE. Total organic carbon (TOC) levels are below the 20 milligrams per liter (mg/L) threshold considered optimal for reductive dechlorination, which may inhibit the continued dechlorination of cis-1,2-DCE.

Regardless of the actual processes that result in the attenuation and transformation of chlorinated solvents at the 354 Site, the evidence from isoconcentration plots of PCE, TCE, and cis-1,2-DCE indicates that reductions in both concentration and mass are taking place down flowpath. By the time the plume impacts the Kansas River, only cis-1,2-DCE is detected at concentrations ranging from less than 10 µg/L down to nondetect.

1.4 RISK ASSESSMENT SUMMARIES

1.4.1 Human Health Risk Assessment

The potential for human health risk from exposure to chemicals at the 354 Site was considered for the soil, groundwater, and air media. COPCs at the 354 Site include the following: PCE and related compounds (TCE, cis-1,2-DCE, trans-1,2-DCE, 1,1-DCE, and VC), 1,1,2-trichloroethane (TCA), CCl_4 and related compound chloroform, BTEX petroleum constituents, acetone, and carbon disulfide. Because there are three distinct areas of contamination at the 354 Site, risk was evaluated separately for the Building 367 Area, the Building 354/332/DPW Compound Area, and the Building 430 Area. Based on observed 354 Site conditions, it was concluded that current and potential future populations could be exposed to site-related constituents through direct contact with soil and/or inhalation of chemical vapors from soil, soil gas, and groundwater. Potential intakes of the COPCs were calculated using standard USEPA equations for intake from ingestion, dermal contact, and inhalation of contaminants. Cancer and noncancer risks were calculated for the following scenarios: current indoor worker exposure to vapors from soil or groundwater (Building 367 and Building 354/332/DPW Compound Areas); future utility excavation worker exposure to impacted soil and vapors from soil or groundwater while excavating (Building 367 Area); current groundskeeper exposure to impacted soil and vapors from soil or groundwater while mowing (Building 354/332/DPW Compound Area); and current child resident exposure to impacted soil and vapors (Building 430 Area) from soil gas or groundwater. Site conditions at Building 367 have changed following completion of the pilot study; however, risk calculations were not updated for this FS since the original results were below the USEPA target risk range.

For exposure concentrations, 95 percent upper confidence limits (UCLs) of the mean were calculated assuming log normally distributed soil and groundwater data. Exposure concentrations represented the lower of either the 95 percent UCL or maximum detected concentration. In the Building 367 and Building 430 Areas, the exposure concentrations were predominantly represented by 95 percent UCLs, whereas maximum detected concentrations were primarily used in the Building 354/332/DPW Compound Area. For exposure concentrations that might be experienced in the future by a utility excavation worker, soil chemical concentrations under current conditions were assumed. Vapor concentrations used in the exposure calculations were determined by modeling contaminant partitioning from soil and/or groundwater to soil gas, migration of soil gas to the surface, and dilution in the breathing zone at the receptor point. Since vapor migration is a competitive process, it would be duplicative to evaluate inhalation of vapors from both soil and groundwater. Therefore, the higher of the two vapor concentrations was used in the vapor inhalation intake calculations.

The results of the risk characterization indicate that the excess cancer risks for all populations evaluated were below the USEPA's target risk range of 10^{-4} to 10^{-6} (Table 1-1). The hazard indices for the populations assessed were also below the USEPA's level of concern of one.

While the excess cancer risk characterization and hazard indices demonstrated no risk, a pilot study was undertaken and completed, as documented in Section 1.3.6, to comply with the requirements of the

USEPA's and the KDHE's policies on Monitored Natural Attenuation and the chemical-specific ARAR of the anti-degradation section of the Kansas Surface Water Quality regulations.

1.4.2 Ecological Risk Assessment

The potential for ecological risk from exposure to chemicals at the 354 Site was considered for soil and groundwater media. Based upon site conditions, it was concluded that flora and fauna could be exposed to site-related constituents through direct contact and/or ingestion of soil and groundwater. Chemicals of potential ecological concern (COPECs) identified included PAHs in soils and VOCs in groundwater. The impacts of the COPECs upon potential receptors were assessed qualitatively by a field biologist and by a quantitative screening.

The 354 Site was evaluated for the presence of ecological receptors and completed ecological exposure pathways. Ecological receptors and/or potentially completed exposure pathways were identified within the terrace area (main operational portion) of the 354 Site. Completed exposure pathways for terrestrial ecological receptors were not identified in the point bar area of the 354 Site because the contaminant sources at the 354 Site include spills and underground storage tanks associated with Buildings 430, 367, 332, and 354 in the terrace area. None of the spills and underground storage tanks associated with these buildings are in the point bar area. Since habitat is limited and human activity makes the area unattractive for the establishment of natural communities, exposure pathways to soil and groundwater in the terrace area of the 354 Site were determined to be incomplete. Therefore, COPECs at this location present no ecological risk. Groundwater was evaluated in the point bar area of the 354 Site due to the aquatic communities observed in the Kansas River.

Potentially completed exposure pathways were identified at the 354 Site, and these pathways were evaluated. Representative terrestrial receptors (short-tailed shrew, white-footed mouse, meadow vole, cottontail rabbit, red fox, and white-tailed deer) were assessed semi-quantitatively. The preliminary screening did not provide any indications of adverse ecological effect from exposure to soil contamination. All other terrestrial receptors, including plants and soil organisms, were qualitatively assessed and determined to exhibit no adverse effects. The qualitative risk characterization was based on the lack of any visible adverse effects within the plant and animal communities of the 354 Site. Based on the results of the semi-quantitative and qualitative evaluations of soil contaminants, ecological risk is minimal to terrestrial flora and fauna inhabiting the 354 Site. Additionally, protected species are unlikely to experience adverse effects from exposure to contaminated soil since their presence is transitory.

Potential for risk to benthic organisms inhabiting the Kansas River was assessed quantitatively. Existing chemical concentrations in groundwater near the Kansas River (as measured in samples collected from monitoring wells within the point bar area of the 354 Site) were compared to benchmark values for benthic organisms. The maximum detected concentrations of VOCs in groundwater near the Kansas River were below the benchmarks used for this evaluation. Therefore, current VOC concentration conditions within the point bar area of the 354 Site are unlikely to pose appreciable risk to benthic organisms in the Kansas River.

Critical habitat for the bald eagle, piping plover, and interior least tern occurs along the Kansas River at the southern edge of the 354 Site. Bald eagles are migratory and known to winter along the Kansas River. Both the piping plover and the interior least tern are seasonal inhabitants along the Kansas River. Although the food gathered along the Kansas River may make up a significant dietary component of wintering bald eagles, piping plovers, and interior least terns, the approximate one-mile stretch of the Kansas River in the 354 Site would only account for approximately one-quarter to one-half of each species' foraging range during a limited time. There is minimal risk to bald eagles, piping plovers, and interior least terns in the vicinity of the 354 Site. Risks to other state and federally listed species known to occur in Riley County are also likely to be minimal.

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

2.1 IDENTIFYING ARARS AND TBCS

2.1.1 Introduction

The 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 use permanent solutions and alternative technologies or resource recovery technologies to the maximum extent practicable. The 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 the CERCLA (42 United States Code [USC] § 9601 et. Seq.) and the NCP (40 Code of Federal Regulations [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 RAOs to assess remedial alternatives for the site.

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

2.1.2 ARAR Identification Process

The process of identifying ARARs and TBCs is specified in the CERCLA Section 121 and the NCP. In addition to the above-mentioned statutory and regulatory requirements, the USEPA has published numerous guidance documents for identification of ARARs and TBCs.

The process of identification of ARARs is described and graphically depicted in Section 1.2.4 of the *CERCLA Compliance with Other Laws Manual: Part I* (USEPA, 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 type of activities the statute or regulations require, limit, or prohibit.

These statutory or regulatory provisions must then be compared to the pertinent facts about the CERCLA site and the CERCLA response actions being considered. 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 addresses 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 that 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 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 the 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 the 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. Chemical-specific ARARs specify requirements that may define acceptable exposure levels and can be used in establishing preliminary remediation goals. Location-specific ARARs specify requirements that may set restrictions on activities within locations such as floodplains or wetlands. Action-specific ARARs may set controls or restrictions for particular treatment and disposal activities related to the management of hazardous waste (USEPA, 1988).

The regulations and the USEPA 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 DAA. 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.

2.1.3 TBC Identification Process

TBCs are to be used as guidance in assisting with the determination of 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. The basic criterion to determine when a TBC should be used is to determine whether use of the TBC is helpful in aiding the protection of human health and the environment at the site. Those TBCs that may be useful in developing the CERCLA remedies should be identified.

2.2 PRELIMINARY ARAR/TBC IDENTIFICATION

2.2.1 Introduction

An initial evaluation of potential ARARs for the 354 Site was performed as a part of the remedial investigation/feasibility study (RI/FS) work plan development. This was included in Section 3.0 of the *Remedial Investigation / Feasibility Study Work Plan for the Former Building 354 Solvent Detection Site at Main Post, Fort Riley, Kansas* (BMcD, 1999) (RI/FS WP). In accordance with the FFA, the KDHE identified all potential ARARs for the 354 Site early in the remedial process. This list of all potential ARARs identified by the KDHE is provided as Appendix 2A of this document. ARAR identification is an iterative process and possible ARARs are re-examined throughout the RI/FS process.

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 354 Site. The ARAR evaluation was conducted in accordance with the *CERCLA Compliance with Other Laws Manual, Parts I and II* (USEPA, 1989a and USEPA, 1989b).

Following the ARAR evaluation process, preliminary chemical-, location-, and action-specific ARARs for the 354 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. record of decision [ROD]). The list of ARARs for the 354 Site may be updated as necessary throughout the CERCLA process.

2.2.2.1 Preliminary Chemical-Specific ARARs

The preliminary chemical-specific ARARs for the 354 Site are:

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

2.2.2.2 Preliminary Location-Specific ARARs

The preliminary location-specific ARARs for the 354 Site are:

- Archaeological and Historic Preservation Act of 1974 (16 USC § 469 et seq.)
- Endangered Species Act of 1973 (7 USC § 136 and 16 USC § 460 et seq.)
- Fish and Wildlife Conservation Act (16 USC § 2901 and 2911)
- Flood Control Act of 1944 (16 USC § 460)
- National Historic Preservation Act of 1966 (16 USC § 470 et seq.)
- Kansas Historic Preservations Act (KAR § 118-3)
- Non-Game, Threatened or Endangered Species (KAR § 115-15)

2.2.2.3 Preliminary Action-Specific ARARs

The preliminary action-specific ARARs for the 354 Site are:

- Clean Air Act (42 USC § 7401 et seq.)
- Clean Water Act (33 USC § 1251 et seq.)
- CERCLA of 1980 (42 USC § 9601 et seq. as amended by the SARA of 1986)

- Occupational Safety and Health Act (OSHA) of 1970 (29 USC § 651 et seq.). Includes both workplace standards (29 CFR 1910) and construction standards (29 CFR 1926)
- Ambient Air Quality Standards and Air Pollution Control (KAR § 28-19)
- Water Well Contractor's License; Water Well Construction and Abandonment (KAR § 28-30)
- Underground Injection Control Regulations (KAR § 28-46)
- Emergency Planning and Right-to-Know (KAR § 28-65)
- Kansas Board of Technical Professions (KAR § 66-6 through 66-14)

2.2.3 Overview of Guidance 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 list of major guidance materials considered during the preparation of the FS and the evaluation of remedial alternatives.

TBCs used to evaluate alternatives for this Site include:

- *Risk-Based Standards for Kansas (RSK Manual – 3rd Version)* (KDHE, 2003)
- *Land Use in the CERCLA Remedy Selection Process* (USEPA, 1995)
- *Groundwater Protection Strategy* (USEPA, 1984)
- *Consideration for Hydraulic Containment*, Bureau of Environmental Remediation (BER)/Remedial Section, BER Policy # BER-RS-028 (KDHE, 1994)
- *Monitored Natural Attenuation*, 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 (USEPA, 1999)

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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 (both surface and subsurface) at the 354 Site include ingestion or direct contact, inhalation of vapors, and leaching to groundwater. The results of both the human health baseline risk assessment (HHBRA) and the ecological risk assessment (ECORA) concluded that risks for all populations were below the USEPA's allowable levels (BMcD, 2003a).

The potential existed for leaching to groundwater from the shallow soil hot spot located immediately east of Building 367. Levels of PCE, TCE, and cis-1,2-DCE in this area exceeded KDHE RSK values for the soil to groundwater protection pathway. While contaminant levels in groundwater samples taken over the last four years in this area had decreased and indicated that soil was no longer a significant source of contamination to groundwater, the area nonetheless was targeted for a pilot study. In-situ permanganate (MnO_4^-) treatment was performed to reduce the concentrations of chlorinated solvents in soils, followed by soil excavation. Details of this activity are presented in Section 1.3.6 of this FS Report. Additional background on the pilot study was provided in the *Pilot Study Work Plan* (PSWP) (BMcD, 2003b). A Pilot Study Report is being prepared.

3.2.2 Groundwater

The only potentially completed exposure pathway for groundwater identified in the HHBRA was for the inhalation of VOCs in vapors. The risks for this scenario were below the USEPA allowable levels (BMcD, 2003a). However, because the chlorinated solvent plume impacts the Kansas River alluvial aquifer (although at concentrations mainly below MCLs) and may be reaching the Kansas River proper, groundwater is the primary medium of interest at the 354 Site.

3.2.3 Other Media

Surface water is not considered a medium of interest at the 354 Site. Surface water (other than the Kansas River) is not present except following significant precipitation events. Surface-water sampling of the Kansas River conducted by the USGS during 2000 and 2001 resulted in no detections of any COPCs (BMcD, 2003a).

The potential for impacts to indoor air was evaluated in the HHBRA by modeling vapor migration from groundwater. The results of the modeling effort indicated that potential human health risks were below the USEPA's allowable levels; therefore, indoor air will not be discussed in this document.

3.3 CHEMICALS OF POTENIAL CONCERN

The HHBRA and ECORA concluded that COPCs in groundwater and soils did not pose significant risks to human health or the environment. However, some COPCs in groundwater occur at levels above MCLs/action level. These are: PCE, TCE, cis-1,2-DCE, benzene, arsenic and lead. Since lead and arsenic are within background levels and appear unrelated to the 354 Site based on the locations of detections exceeding MCLs/action level, only the organics listed above are addressed in this document.

Based on the results of the HHBRA, the ARAR analysis, and the COPCs currently present at concentrations above MCLs, the following are considered COPCs in groundwater for the 354 Site:

PCE	cis-1,2-DCE	TCE
Benzene		

3.4 REMEDIAL ACTION OBJECTIVES

As identified in the USEPA guidance *Rules of Thumb for Superfund Remedy Selection* (USEPA, 1997), 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 the 354 Site, only item number (4) above applies, in that chemical-specific ARARs are being exceeded. The drinking water standard (i.e., MCL) is exceeded in the groundwater, which is impacting the Kansas River alluvial aquifer at two piezometers on the north margin of the point bar.

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:

> "USEPA expects to return usable groundwaters to their beneficial uses wherever practicable, within a time frame that is reasonable given the particular circumstances of the site. When restoration of groundwater to beneficial uses is not technically practicable, USEPA 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 354 Site; 2) beneficial use of groundwater at the 354 Site; 3) results of risk assessment; and 4) anticipated fate and transport of contaminants beneath the 354 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, 2003a). The following sections provide additional discussion of anticipated future land use and beneficial groundwater use at the 354 Site.

3.4.1 Land Use

3.4.1.1 General

Land use assumptions are an integral factor in the development of RAOs. Known current uses and anticipated future use assumptions are the basis for the populations and pathways evaluated in the risk assessment. Realistic land use assumptions allow the FS to be focused on developing practicable and cost-effective remedial alternatives.

The USEPA's directives on land use in the CERCLA remedy selection process (USEPA, 1995 and 2001) 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 RAO and PRG selection process are the following:

- RAOs should reflect the reasonably anticipated future land use or uses.
- Future land use assumptions allow the baseline risk assessment and the FS 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 selection of RAOs and PRGs. 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 USEPA guidance, an assessment of current and future land uses for the 354 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 354 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 354 Site as it pertains to the selection of RAOs and PRGs.

3.4.1.2 Anticipated Future Land Use

It is anticipated that the Army will retain operational control of the 354 Site and that future land use will be as described in the Fort Riley RPMP (BMcD, 2003a). This anticipated use consists of:

- Continued multiple use of the area north and west of the UPRR grade. This would include offices, barracks, family housing units, warehouses, and maintenance facilities.
- The area south and east of the UPRR grade (the point bar) will remain as forested open space. There will continue to be some use of structures for warehouse and office spaces along the UPRR grade.

These anticipated land uses should be considered in defining RAOs and evaluating remedial alternatives. In is anticipated that Fort Riley will continue to remain as an active U.S. Army post into the foreseeable future with no change in its basic mission. Land use at the 354 Site should remain essentially as is. Based on projected land uses, the current availability of an ample supply of potable water from existing supply wells, and the projected potable water demands for the post, it is unlikely that groundwater from the point bar will be exploited. Future land and groundwater uses are anticipated to remain essentially the same as their current usage.

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, groundwater at the 354 Site is not currently used as a drinking water source, nor is such use anticipated in the future. Fort Riley possesses sufficient excess capacity from the existing supply wells to provide potable water for any foreseeable expansion on the post. Additionally, the evaluation of environmental risk concluded that there is no detrimental exposure to environmental receptors at the Site.

The Kansas River reach flowing through Fort Riley is a major classified river under the Kansas State Water Plan. This reach of the river has multiple designated uses, one of which is domestic supply (KDHE, 2002). Because of this designated use, the Kansas River and its associated alluvial aquifer fall under the Kansas Antidegradation Policy. This policy applies in those situations where either an intentional or unintentional release of pollutants from a point source results in contamination or potential contamination of an alluvial aquifer that threatens to preclude attainment of the designated use of the alluvial aquifer or its associated surface water.

Although there is virtually no prospect for supply wells to be installed within the Kansas River alluvial aquifer on the point bar, groundwater here does discharge from the alluvial aquifer to the Kansas River along this reach. Therefore the beneficial use of the groundwater would be as a potential source of domestic supply once it discharges to and enters the surface water system. RAO and PRG development should reflect this.

Because of low transmissivities, the terrace aquifer is not considered to be a potential source for supply wells.

3.4.3 Defined RAOs

Based on the HHBRA and ECORA, 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 the potential of degradation of the surface waters of the Kansas River by reducing levels or eliminating contaminants from the margin of the alluvial aquifer of the Kansas River.
- Reduce contamination levels to below MCLs within the alluvial aquifer of the Kansas River through the use of natural and/or active remedial processes.
- Reduce contaminant levels, to the extent practicable and appropriate, within the terrace aquifer, through natural and/or active remedial processes.

The RAOs are listed in the general sequence in which they should be addressed (USEPA, 1997). These RAOs will be used in the development and evaluation of remedial alternatives.

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 RME 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.

The CERCLA Alternate Concentration Limits (ACLs) may also be used if the requirements of the 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 (USEPA, 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 the 354 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.

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 the 354 Site is considered to have a potential beneficial use as a drinking water source due to its hydraulic connection to the Kansas River; therefore, the PRGs are defined as the MCLs. The PRGs for the 354 Site are as follows:

- PCE 5 µg/L
- TCE 5 µg/L
- cis-1,2-DCE 70 µg/L
- Benzene 5 µg/L

As stated previously, the terrace aquifer yield is too low to be a potential source of supply.

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 purpose of this section is to identify and evaluate potential remedial technologies for the 354 Site. The selection of potentially feasible technologies for the 354 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 the 354 Site are presented below:

- No Action;
- Institutional Controls;
- Other Controls;
- Monitored Natural Attenuation (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 used 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 the 354 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 354 Site. This section describes the evaluation and screening procedures and criteria which result in the selection of feasible remedial technology options.

Following the USEPA guidelines (USEPA, 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 354 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 USEPA'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 (USEPA, 2000a). While governmental 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. Proprietary controls include private land use restrictions that typically result by agreement with the landowner and an enforcing party that 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. 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 (USEPA, 2000b).

Since Fort Riley is a federal reservation, neither governmental controls nor proprietary controls are considered appropriate mechanisms for the application of institutional controls and will not be discussed further.

Institutional controls could be applied through use of the Fort Riley RPMP. The RPMP ensures compatibility of land uses are considered when planning for locations of functions or facilities. It is the equivalent of a city or county zoning plan. It also serves as a framework for maintenance and repair resource allocation, and development activities. Army Regulation (AR) 210-20 "establishes a relationship between environmental planning and real property master planning to ensure that the environmental consequences of planning decisions are addressed." This is accomplished by the long-range component (LRC) in the RPMP. It consists of a variety of narratives and supporting graphics. One of these graphic representations is the Master Plan Environmental Overlay (MPEO). This graphic reflects operational and environmental constraints. The RPMP is the means the post authorities have to control and limit development and other activities on the post. This includes overall controls on land use, the issuing of excavation permits that could define and limit potential exposure for utility and grounds workers, and tactical dig permits that control potential exposure for soldiers.

In addition, the RPMP would be the appropriate planning mechanism for addressing the issue of water supply well locations. Fort Riley currently has a supply well field that is not operating near capacity. There is currently no reason to construct water supply wells at the 354 Site since the post has sufficient surplus capacity to meet future contingencies (BMcD, 2003a). A restriction on the construction of supply wells at the 354 Site could be incorporated into the RPMP as a remedial alternative (institutional control).

Institutional controls, through use of the RPMP, will be retained for inclusion as a potential component of remedial alternatives.

4.3.4 Other Controls

Other controls include monitoring, rural water supply, new supply wells, and individual well treatment. Only monitoring will be addressed in this section. Rural water supply, new supply wells, and individual well treatment are not addressed since these were eliminated from consideration during the initial screening of technologies (Table 4-2).

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 354 Site. A network of groundwater monitoring wells is currently in place at the 354 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 the 354 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.

4.3.5 Monitored Natural Attenuation

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 time frames 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.

MNA 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. Destructive mechanisms include abiotic and biotic degradation processes.

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 produces 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 (USEPA, 1996). 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 low 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 and Chapelle, 1998). The reductive dechlorination pathway for PCE is as follows: PCE → TCE → cis or trans-1,2-DCE → VC → Ethene → Carbon Dioxide (CO_2)+ water (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, NO_3^-, sulfate (SO_4^{-2})

/sulfide (S^{-2}), chloride, TOC, DO, 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 MNA is likely to be protective of human health and the environment.

For MNA to be a considered a stand-alone remedial alternative for the 354 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* (USEPA, 1999).

Site geochemical and contaminant concentrations, and results from the USEPA reductive dechlorination screening protocol (USEPA, 1998) performed in the RI, indicate there is strong evidence for reductive dechlorination (and thus natural attenuation) of chlorinated solvents at the 354 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.

Vertical barriers are removed from further evaluation because of the difficulty of construction in aquifers at depths of approximately 50 ft below the ground surface.

4.3.7 Extraction, Ex-Situ Treatment, and Discharge

4.3.7.1 Collection/Extraction

Vertical Wells

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 MCLs (within a reasonable duration) have been well documented (USEPA, 1996). 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.

Horizontal Wells

Horizontal pumping wells are an emerging technology, which is finding increased applications to ground-water remediation. Horizontal collection wells can have an advantage over vertical wells because of the ability of a single horizontal well to contact a large horizontal area, and because horizontal aquifer transmissivity is generally greater than vertical transmissivity (Domenico and Schwartz, 1990). This provides an advantage in plumes which are laterally extensive, but vertically restricted. Horizontal wells are more expensive to install per well than vertical wells, but usually fewer are required to accomplish the same results.

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 Physical/Chemical Treatment

Air Stripping

In the air stripping process, VOCs (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, which can damage well screens, may be an issue due to the relatively high level of naturally occurring iron at the 354 Site.

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

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 retained for additional consideration as a potential ex-situ treatment technology, which could be used as part of the pump and treat remedy.

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 and may be more appropriate than activated carbon for treating high concentration wastes. However, these adsorbents are usually more expensive products to manufacture than activated carbon. Another negative aspect of organically-modified clays is that they cannot be regenerated on the 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 the 354 Site has relatively low contaminant concentrations.

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 $KMnO_4$, hydrogen peroxide (H_2O_2), ozone (O_3), 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 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.

4.3.7.3 Disposal (Treated or Untreated)

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. Numerous intakes are located within the treatment area.

Discharge of groundwater to the Fort Riley Wastewater Treatment Plant is retained for further consideration.

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 the cost is high relative to the cost of surface discharge.

Discharge to Atmosphere

Discharge of vapors to the atmosphere becomes an issue if technologies such as soil vapor extraction (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 the 354 Site.

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 the 354 Site.

4.3.8 In-Situ Treatment

4.3.8.1 Enhanced Anaerobic Bioremediation

Common electron acceptors used by microorganisms to degrade organic compounds under aerobic (oxygen [O_2]) or anoxic (NO_3^-, 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 hydrogen atoms) 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.

Enhanced anaerobic bioremediation (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 United States Air Force for EAB. One of the benefits of organic oils is the partitioning of the contaminants in the oil rather than 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, other similar compounds use sodium lactate to obtain similar results as lactic acid. These compounds are referred hereinafter as lactate. The lactate is applied into 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, 2003). 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, 2003).

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 nanomolar) resulting in contaminant degradation and site restoration (Regenesis, 2003).

EAB is retained for inclusion as a potential component in remedial alternatives due to the potential for enhancing reductive dechlorination of chlorinated solvents at the 354 Site.

4.3.8.2 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.

Air sparging systems require a homogeneous and permeable aquifer for effective operation. Alluvial aquifers, such as is present at the 354 Site, tend towards heterogeneity, which could significantly reduce the effectiveness of this technology. An effective remediation system also 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.

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, land access needs, occupied buildings, and increased costs may limit implementation of this technology. Air sparging is removed from inclusion as a potential component in remedial alternatives.

4.3.8.3 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/O_3 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 hydrochloric acid (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.

4.3.8.4 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 screen, 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;
- Vacuum vaporizer well (VVW) 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 VVW 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 a 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., VVW) 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 CO_2 (or highly alkaline waters) and aquifer anisotropy can present serious problems in the design of a successful GCW system.

Chlorinated VOCs, the main contaminants at the 354 Site, have high vapor pressures and are likely to be effectively volatilized by this technology. However, this aquifer may present marginal hydrogeological conditions. Due to inherent anisotropy present within virtually all aquifers, vertical hydraulic conductivity would probably be two orders of magnitude less than horizontal hydraulic conductivity. The only practical way to overcome this is to design a significant hydraulic head difference within the GCW system. Due to the thin nature of the saturated layer of the terrace aquifer, it would be very difficult to design a system to this constraint.

GCW are removed from further consideration because they have no distinct advantage over competing technologies, are not very effective on low concentration VOC plumes, and have the design limitations outlined in the previous paragraph.

4.3.8.5 Soil Vapor Extraction

Soil vapor extraction (SVE) 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 five ft or greater and have been successfully applied as deep as 300 ft. 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.

Groundwater depression pumps may be used to reduce groundwater 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.

SVE is removed from consideration as a potential component in remedial alternatives since there is no requirement to address vadose zone contamination at the 354 Site due to shallow soil treatment conducted under the 354 Pilot Study.

4.3.8.6 In-Situ Chemical Oxidation

Chemical oxidants, such as H_2O_2, $KMnO_4$, or 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 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 CO_2 and H_2O, both of which are 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 H_2O_2 is used as the oxidant in the process, Fe^{2+}, 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. Fe^{2+} enhances the production of hydroxyl radicals, which are very strong oxidants. The addition of H_2O_2 may also increase DO levels in the aquifer, which may promote aerobic degradation. Highly chlorinated VOCs do not readily biodegrade aerobically, but some of the transformation products, such as DCE, dichloroethane (DCA), and 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 retained as a technology that could be applied to the relatively localized deep groundwater hot spot on the terrace.

4.3.8.7 Permeable Reactive Barrier: Zero-Valent Iron

Permeable reactive barriers (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 Fe^{2+}, 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. Administrative considerations do not significantly limit the implementability of this technology.

Fe^0 PRB is removed from consideration as a potential remedial alternative because of difficulties related to construction and uncertainty with regard to its affecting complete treatment.

4.3.8.8 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 to be used 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., ferric iron state [Fe^{+3}]), which can be reduced from its oxidized state in the aquifer sediments to serve as a long-term reducing agent (United States Department of Energy [USDOE, 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:

$$\text{sulfur dioxide } (SO_2^-) + Fe^{+3} + H_2O = \text{sulfite } (SO_3^{-2}) + Fe^{+2} + 2 \text{ hydrogen } (H^+)$$

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.

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 removed from consideration as a potential component in remedial alternatives. Because ISRM is a relatively new innovative technology, extensive pilot testing would likely be required before a full-scale system is implemented.

4.3.8.9 Fluid Delivery Systems

Fluids such as nutrients, oxidants, and other chemical compounds can be added to the subsurface through use of vertical or horizontal wells/borings delivery systems. 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 used 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 used 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, the following five remedial alternatives are identified for this Site:

Alternative 1	No Action
Alternative 2	MNA and Institutional Controls
Alternative 3	In-Situ Chemical Oxidation, MNA, and Institutional Controls
Alternative 4	EAB, MNA, and Institutional Controls
Alternative 5	Groundwater Extraction and Ex-Situ Treatment, MNA, and Institutional Controls

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5.0 DETAILED ANALYSIS OF ALTERNATIVES

5.1 INTRODUCTION

This discussion 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 summarized to compare the alternatives and identify the key tradeoffs among them in Section 6.0 of this report. 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 (USEPA, 1988).

5.2 EVALUATION CRITERIA

To address the CERCLA requirements adequately, nine evaluation criteria have been developed by the USEPA (USEPA, 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 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 final ROD. The evaluation of these two factors can only be completed after the CERCLA proposed plan (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 preliminary ARARs and TBCs are 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 the 354 Site are presented in Section 2.0 of this report. Table 5-1 presents a matrix indicating which of the ARARs have been identified as preliminary ARARs for each of the remedial alternatives presented herein.

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 risk 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 (USEPA, 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 can be 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 (USEPA, 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 is 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 (USEPA, 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

Both capital and 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 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, 2003), 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. Because 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 the USEPA guidelines (USEPA, 1993 and 2000a), a discount rate of 3.2 percent is appropriate to use for federal facilities. This discount rate is based on the 'difference' between the return rate on an annuity investment 'less' the inflation rate. For this cost analysis, the rate of return was based on the 30-year treasury bill of 5.2 percent and an inflation rate of two percent. This resulted in a discount rate equal to 1 – 1.052/1.02, or 3.14 percent. This was rounded up to 3.2 percent.

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 the costs are proportional to the 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 5A.

All cost figures presented in Section 5 have been rounded to two significant figures.

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 agency input regarding each of the remedial alternatives. At the 354 Site, the state is represented by the KDHE and the USEPA Region VII, along with the lead agency (the 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 PP and 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 five remedial alternatives identified in Section 4.0 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 from the PP process. The five remedial alternatives are as follows:

Alternative 1	No Action
Alternative 2	MNA and Institutional Controls
Alternative 3	In-Situ Chemical Oxidation, MNA, and Institutional Controls
Alternative 4	EAB, MNA, and Institutional Controls
Alternative 5	Groundwater Extraction and Ex-Situ Treatment, MNA, and Institutional Controls

In addition to the screening criteria evaluation, this DAA presents advantages and disadvantages of each alternative. These are included to provide 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.

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 the comparison of active remedial alternatives developed for the 354 Site. Under the "no action" alternative, institutional controls are not implemented, and remediation and monitoring of the groundwater contamination are not conducted. There are no supply wells within the area impacted by the chlorinated solvent plume. By definition, this alternative requires that the current monitoring program be discontinued. At a minimum, the CERCLA requires administrative reassessments every five years, if the 354 Site is not open for unrestricted use, whenever contaminants are left in place.

Because the "no action" alternative is an idealized baseline, even though institutional controls are in place due to the location of the 354 Site on a military base, the "no action" alternative does not acknowledge these controls. Similarly, the "no action" alternative also does not acknowledge that a pilot test (see

Section 1.3.6) was performed to treat shallow soils that might have potentially served as a source for the groundwater plume and that natural processes are indicated to be operating to further attenuate the plume.

5.3.1.2 Evaluation

Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the RI Report (BMcD, 2003a), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the USEPA accepted risk levels. However, because this alternative does not include institutional controls, there is no control of future use. Therefore, an unforeseen exposure scenario (not characterized in the RI Report baseline risk assessment, BMcD, 2003a) is possible when no institutional controls are acknowledged for the property. Based on this, plus the fact that Alternative 1 functions as a baseline for the comparison of all remedial alternatives, no action will be considered not protective of human health and the environment.

Compliance with ARARs

Preliminary chemical-specific ARARs for Alternative 1 are presented in Table 5-1. Location- and action-specific ARARs do not apply to Alternative 1, since no active measures will be taken at the 354 Site under this alternative.

Groundwater sampling results, up to and including the Fall 2003 sampling round, indicate that preliminary chemical-specific ARARs (i.e., MCLs) were exceeded for all four of the COPCs at the 354 Site (PCE, TCE, cis-1,2-DCE, and benzene) (BMcD, 2004c), but the exceedances were localized.

With the exception of the detection of PCE at concentrations of about 5 μg/L at Piezometers PZ-C and PZ-D, and Monitoring Well MW95-04 (along the northern margin of the Kansas River alluvial aquifer), ARARs are being met within the Kansas River alluvial aquifer. Concentrations of PCE, TCE, and cis-1,2-DCE that exceed the ARARs were primarily within the plume in the terrace aquifer and, therefore, localized with little effect on the Kansas River alluvial aquifer.

Under the "no action" alternative there is no groundwater monitoring to determine concentration trends in the plume. Therefore, under the "no action" alternative the evaluation assumes that contaminant concentrations remain essentially unchanged. However, NA processes active within the aquifer are probably destroying contaminants and reducing contaminant concentrations. Without monitoring, the evolution of concentrations remains an unknown and, for the purposes of this evaluation, the assumption will be made that under the "no action" alternative that MCLs will continue to be slightly exceeded. No credit is given for the in-situ treatment and excavation of the shallow soil hot spot completed east of Building 367 and the current indications of stable to declining trends. Even under these very conservative constraints, the MCL exceedances are localized, are not exceeded at the Kansas River, and do not impact a drinking water supply.

Long-Term Effectiveness and Permanence

There are no on-going industrial processes at the shallow soil hot spot east of Building 367 that could potentially leach additional contamination of groundwater. Therefore, it is anticipated that contamination levels will not increase. Based on the risk assessment (BMcD 2003a), the magnitude of risk to human health and the environment is below the USEPA accepted limits at the 354 Site. A review of groundwater contamination at the 354 Site would be required every five years, if the 354 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 the CERCLA 121(c).

Institutional controls are not acknowledged with this alternative; therefore, there is a hypothetical possibility that an unforeseen exposure scenario could occur under the "no action" alternative.

Reduction of Toxicity, Mobility, or Volume

Because the distal portion of the contaminant plume terminates at the Kansas River, there are no unimpacted areas of the aquifer. It is anticipated that there will not be any additional lateral spread of contamination within either the terrace or the Kansas River alluvial aquifers.

Reductions in contaminant volume are probably taking place within these aquifers, based upon the documented reductions in contaminant concentrations at monitoring wells. This is especially apparent in those monitoring wells located within the terrace aquifer. Concentrations in those monitoring wells located in the Kansas River alluvial aquifer are low level and stable.

Natural attenuation appears dominated by physical processes in the terrace aquifer and biological processes in the alluvial aquifer. Based upon the results of periodic groundwater sampling events, the effects of natural attenuation within the Kansas River alluvial aquifer should continue to reduce concentrations of COPCs and reduce the risk of exposure to both human and environmental receptors.

Under the "no action" alternative there is no monitoring and interpretation of monitoring results to verify that natural attenuation processes are operating. Therefore, when comparing the "no action" alternative to other more comprehensive alternatives, the reduction of toxicity, mobility, or volume is not reconciled until the first 5-year review. The limitation of a discrete 5-year review is that it is not as comprehensive as a set of measurements over time to corroborate that the sampling event results are consistent and reproducible.

Short-Term Effectiveness

Because no quantitative modeling was performed at the 354 Site, it is difficult to predict how long it will take to achieve RAOs across the entire site. However, RAOs have already been achieved across virtually the entire Kansas River alluvial aquifer, with the exception of the extreme northern portion immediately south of the UPRR grade (elevated PCE concentrations at PZ-C and PZ-D). The "no action" alternative poses no additional detrimental effects to human health or the environment as a result of implementation.

Implementability

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

Cost Evaluation

The present worth cost of this alternative is estimated to be $300,000, with total periodic costs totaling $440,000, and a total project cost of $440,000 (undiscounted). 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 5A (Tables 5A-1 and 5A-2).

5.3.1.3 Additional Criteria

Advantages

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

Limitations and Considerations

- Without an annual groundwater monitoring program, changes in the site and/or contaminant conditions would only be assessed during the five-year reviews.

5.3.2 Alternative 2 – Monitored Natural Attenuation and Institutional Controls

5.3.2.1 Description

Site Specific Description

This alternative includes MNA and institutional controls. NA is the process by which contaminant concentrations are reduced through mechanisms such as advection, dispersion, diffusion, volatilization, sorption, and degradation. 354 Site data indicate that biodegradation and other NA processes capable of reducing contaminant concentrations below MCLs are occurring within the area of impacted groundwater at the 354 Site (see Section 5.3.1.2).

MNA refers to the periodic sampling and monitoring of geochemical and contaminant conditions at the 354 Site. Contaminant concentrations and NA parameters will be monitored periodically to evaluate if the NA processes are continuing to reduce contaminant concentrations below MCLs. NA parameters may include the following: temperature, pH, conductivity, methane, ethane, ethene, alkalinity, NO_3^-, SO_4^{-2}, S^{-2}, chloride, TOC, DO, ORP, and Fe^{+2}. These parameters were used in the RI Report (BMcD, 2003a) to demonstrate that NA is occurring at the 354 Site; however, not all of these parameters are needed to demonstrate that NA is continuing during MNA. For the purposes of cost estimation, MNA will be performed using a modified suite of 16 monitoring wells (Figure 5-1).

The pilot study, which was described in detail in Section 1.3.6, virtually eliminated the shallow soil hot spot east of Building 367. This in-situ treatment and soil removal action was completed in December 2004. This will ensure that there is no remobilization of chlorinated solvent contamination from the shallow soils in this vicinity. The result should be decreasing concentrations of contaminants in groundwater both within the terrace aquifer and the Kansas River alluvial aquifer; therefore, credit will be given for the pilot study when evaluating Alternative 2.

Institutional Controls

The inclusion of institutional controls, such as restrictions on groundwater use, reduces the potential for human ingestion, inhalation, or direct contact with contaminated groundwater at the 354 Site. The USEPA guidance on institutional controls suggests that controls should by "layered" to enhance the effectiveness and protectiveness of the remedy (USEPA, 2000b). Layering refers to using different types of institutional controls together or in series to enhance their effect. The variety of institutional controls available at the 354 Site is probably more restricted, because the 354 Site is on an active military reservation. Tools such as zoning and easements generally apply to private property. However, post authorities could apply controls as part of the RPMP. The purpose of institutional controls is to limit exposure to contaminants in the groundwater. The principal institutional control that would be applied by Fort Riley would be a prohibition against the installation of water supply wells at the 354 Site within those portions of the Kansas River alluvial aquifer that are impacted by contamination at concentrations above MCLs. The small area impacted is in a developed and/or paved portion of the post between the UPRR grade and warehouses. It would not be an optimal location for the installation of a drinking water well. Since the existing Fort Riley supply well field has sufficient excess capacity to easily meet future demand, this institutional control would place no hardship on the post. This would also eliminate a potential pathway between contaminated groundwater and potential consumers of this water.

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 (USEPA, 1999).

5.3.2.2 Evaluation

Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed as part of the RI Report (BMcD 2003a), this alternative is protective of human health and the environment because the risk estimates for current and future RME scenarios do not exceed the USEPA accepted risk levels. It is anticipated that the potential future risk to human health or the environment will decrease because institutional controls are anticipated to be in place to limit or prevent exposure to contaminated groundwater and natural degradation within the aquifer will further reduce the concentrations of contaminants. The elimination of the shallow soil hot spot east of Building 367 under the pilot test program should also result in lower amounts of VOCs being released to the dissolved plume.

Compliance with ARARs

A list of preliminary ARARs for the 354 Site is presented in Section 2.2.2. A description of these is provided in Appendix 2A. Preliminary ARARs that could apply to Alternative 2 are identified in Table 5-1. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs). It is estimated that RAOs will be achieved across this site within 15 years, based on a qualitative assessment of site conditions. Groundwater monitoring will provide data for the continuing evaluation of progress. It is anticipated that institutional controls could also be relaxed at the time RAOs are achieved across the 354 Site. The elimination of the soil hot spot at Building 367 under the pilot test program should also assist in meeting chemical-specific ARARs.

Preliminary location-specific ARARs for Alternative 2 mainly concern endangered species. Location-specific ARARs will be met by coordinating remedial activities with Fort Riley Conservation Division personnel to minimize or eliminate adverse impact to wildlife. Preliminary action-specific ARARs included CERCLA, OSHA, and water well construction and abandonment. It is anticipated that there would be no difficulties complying with all of these.

In addition to ARARs, this alternative is anticipated to comply with the TBCs discussed in *Monitored Natural Attenuation, Bureau of Environmental Remediation/Remedial Section Policy* (KDHE, 2001), and

Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (USEPA, 1999). 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 USEPA accepted risk levels (BMcD, 2003a). MNA is not anticipated to allow continued degradation of groundwater quality, because the contaminant levels at the 354 Site are continuing to decrease. Samples collected from the Kansas River indicate that the plume is not impacting the river.

Long-Term Effectiveness and Permanence

Once RAOs are achieved at the 354 Site, groundwater contaminant levels are anticipated to remain below MCLs because the shallow soil hot spot located east of Building 367 has been eliminated with the completion of the pilot study soil removal activities in November 2004. 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 USEPA accepted risk limits at the 354 Site (BMcD 2003a). However, contaminants sorbed to the aquifer matrix may leach low levels of COPCs after remediation is completed. In order to ensure long-term reliability, a review of groundwater contamination at the 354 Site would be required every five years until closure to verify that the remedy continues to provide adequate protection of human health and the environment in accordance with CERCLA 121(c).

Reduction of Toxicity, Mobility, or Volume

Based upon the results of periodic groundwater sampling events, the effects of natural attenuation within the Kansas River alluvial aquifer should continue to reduce concentrations of COPCs and reduce the risk of exposure to both human and environmental receptors. NA appears dominated by physical processes in the terrace aquifer and biological processes in the alluvial aquifer.

Because the distal portion of the contaminant plume terminates at the Kansas River, there are no unimpacted areas of the aquifer. It is anticipated that there will be no additional lateral spread of contamination within either the terrace or the Kansas River alluvial aquifers.

Reductions in contaminant volume are probably taking place within the aquifer, based upon the documented reductions in contaminant concentrations at monitoring wells (i.e., B354-99-08 and B354-01-27). This is especially apparent in those monitoring wells located within the terrace aquifer. Concentrations in those monitoring wells located in the Kansas River alluvial aquifer are low level and stable.

With respect to hot spot control, the removal of contaminated shallow soil at Building 367 as part of the pilot study has the potential to eliminate the leaching of contaminants to groundwater. This reduction of the available contaminant mass may reduce the mass flux to the dissolved groundwater plume. Given that the groundwater plume is presently stable to decreasing, future monitoring could show additional decreases in dissolved plume concentrations and extent. Several years of monitoring after shallow soil hot spot removal may be necessary to establish such a trend.

NA processes, especially biologically remediated processes such as are taking place within the Kansas River alluvial aquifer, destroy contaminants in groundwater. Therefore, this alternative should be considered as non-reversible.

Short-Term Effectiveness

RAOs have already been achieved across virtually the entire Kansas River alluvial aquifer, with the exception of the extreme northern portion immediately south of the UPRR grade (elevated PCE concentrations at PZ-C, PZ-D, and MW95-04). A groundwater monitoring program and institutional controls are included in the event the remedial technology used in this alternative does not reduce the contaminant levels at the 354 Site. Institutional controls (i.e., restricting water supply wells) will protect potential receptors by limiting or preventing exposure to contaminated groundwater. Therefore, risks of adverse effects to human health during the remedial phase are low.

Implementability

There are no anticipated technical difficulties implementing this alternative. The modified groundwater monitoring well network (Figure 5-1) 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 354 Site. Implementation reliability is high, since NMA depends on the natural processes on going within the aquifer to effect treatment and groundwater monitoring is very straightforward.

Because this is an active government installation, it is anticipated that there will be no problems with implementing a program of institutional controls through the post RPMP (see Section 4.3.3.1).

Cost Evaluation

The present worth cost of this alternative is estimated to be $1,000,000, with a capital cost of $48,000, total O&M cost of $1,200,000, periodic costs totaling $110,000, and a total project cost of $1,300,000 (undiscounted). Detailed cost analysis tables are presented in Appendix 5A (Tables 5A-3 and 5A-4).

5.3.2.3 Additional Criteria

Advantages

- Reduces the potential for human ingestion, inhalation, or direct contact with contaminated groundwater at the 354 Site.
- No additional risk to the community or environment.
- Includes a groundwater monitoring program to assess future changes in site and/or contaminant conditions.

Limitations and Considerations

- More extensive education and outreach efforts may be required in order to gain public acceptance of MNA.

5.3.3 Alternative 3 – In-Situ Chemical Oxidation, Monitored Natural Attenuation, and Institutional Controls

5.3.3.1 Description

General Technology Description

Chemical oxidation (chemox) converts hazardous contaminants to non-hazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are O_3, H_2O_2, and MnO_4^-. O_3 gas can oxidize contaminants directly or through the formation of hydroxyl radicals ($OH^•$). A liquid H_2O_2 solution, in the presence of native or supplemental Fe^{2+}, produces Fenton's Reagent, which yields various reactive free radicals including $OH^•$. Both O_3 and H_2O_2 are most effective in systems with an acidic pH. MnO_4^- (typically provided as either sodium or potassium salts) can destroy contaminants by either direct electron transfer or free radical advanced oxidation. MnO_4^- treatment is effective over a pH ranging from acidic to alkaline (3.5 to 12). MnO_4^- is a selective oxidant in that it has the potential to be less reactive with some of the natural organics and can persist longer in the subsurface than Fenton's reagent or ozone. MnO_4^- is generally effective in treating chlorinated ethenes (i.e., PCE, TCE, and cis-1,2-DCE). A system of vertical or horizontal wells could deliver these oxidants to selected aquifer zones.

For the purposes of conceptual design, cost estimation, and applicability evaluation, the $KMnO_4$ technology and vertical injection points will be used as a representative option. Other oxidant options may be evaluated in detail in the PP.

Site-Specific Description

Alternative 3 consists of in-situ treatment of contaminated groundwater within the terrace aquifer located directly below the shallow soil hot spot just east of Building 367 (see Figure 5-2). This will include sampling of water-saturated aquifer material (i.e., approximately 50 to 60 ft bgs). For cost estimating purposes, it is assumed up to nine deep borings (i.e., similar to shallow pilot test scope) could be installed with four of the borings converted to monitoring wells screened from the top of bedrock to the top of groundwater (approximately ten ft thick). The monitoring wells would be used to evaluate if the dissolved groundwater concentrations are sufficiently high to justify treatment and to monitor the effectiveness of treatment once implemented.

Alternative 3 is designed to treat groundwater within the terrace aquifer that exhibits concentrations of COPCs significantly in excess of MCLs. If monitoring results indicate that this groundwater contamination contributes to the plume such that natural processes are not attenuating the plume within a reasonable time frame, then this alternative is an option. Although, groundwater monitoring indicates that the plume poses no adverse risk to human health and the environment, by discovering and treating additional groundwater with contaminant levels well above MCLs, it may be possible to reach site closure in a shorter time and possibly reduce the cost of long-term monitoring. This alternative focuses on treating the saturated zone from the top of bedrock to approximately 50 ft bgs.

Alternative 3 includes bench-scale testing of groundwater and aquifer matrix to evaluate natural oxidant demand (NOD). The NOD is primarily a function of natural organic content, oxidizable minerals/mineral surfaces, and oxidizable material dissolved or suspended in the groundwater. Although a bench-scale study has been performed for shallow soils, the aquifer matrix at depth combined with groundwater may exert a different NOD than the shallow soils that have been previously tested.

Depending on bench scale treatability and the distribution of potential deep contamination, MnO_4^- can be injected into the subsurface by the following methods:

- Injection of concentrated (dense) MnO_4^- solution in one or multiple layers or "pancakes" with density flow of MnO_4^- to distribute MnO_4^- as curtains within the saturated zone. Injection in discrete layers is intended to limit the displacement of contaminated groundwater outside the treatment zone.

- Injection of MnO_4^- slurry in layer(s) via pressure injection or fracturing. MnO_4^- acts as a long-term supply of oxidant to treat residual contamination.

- Injection and circulation of lower concentration MnO_4^- solution for gradual treatment of groundwater contamination.

For the purpose of this FS, injection of concentrated MnO_4^- solution or slurry is assumed to avoid longer-term O&M associated with solution injection, circulation, and recovery system. The injection can be implemented using direct-push technology with an injection pump and mixing equipment at the ground surface. Although the area of groundwater with elevated contaminant levels may be no larger in area than the shallow soil contamination, it is assumed that a small pilot test will be conducted to evaluate the application mechanics including direct-push ease, injectability, and estimate effective injection radius, prior to full-scale implementation. For full-scale design, it is assumed that injection is effective over an approximate ten-ft radius and that eight direct push injections (40-ft x 70-ft area) can be performed within five days. A total oxidant demand based on proposed bench-scale testing and contingency for excess oxidant added to the subsurface is assumed to be slightly higher than the shallow soil bench test results or 6.0 g $KMnO_4$/kilograms (kg) (0.006 lbs $KMnO_4$/lb of soil). This would require an estimated injection of approximately 7,000 lbs of $KMnO_4$, assuming a 40-ft by 70-ft treatment area approximately ten-ft thick with an aquifer matrix density of 1.5 tons per cubic yard (yd^3).

The inclusion of institutional controls and MNA with this alternative reduces the potential for human ingestion, inhalation, or direct contact with contaminated groundwater at the 354 Site. These institutional controls are the same as described for Alternative 2 (see Section 5.3.2.1).

The pilot study, which was described in detail in Section 1.3.6, virtually eliminated the shallow soil hot spot east of Building 367. This in-situ treatment and soil removal action was completed in December 2004. This will ensure that there is no remobilization of chlorinated solvent contamination from the shallow soils in this vicinity. The result should be decreasing concentrations of contaminants in groundwater both within the terrace aquifer and the Kansas River alluvial aquifer.

5.3.3.2 Evaluation

Protection of Human Health and the Environment

Based on the risk assessments performed in the RI Report (BMcD, 2003a), this alternative is protective of human health and the environment because the risk estimates do not exceed the USEPA 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 contaminant concentrations. The elimination of the shallow soil hot spot east of Building 367 under the pilot test program should also result in lower amounts of VOCs being released to the dissolved plume.

Compliance with ARARs

A list of preliminary ARARs for the 354 Site is presented in Section 2.2.2. A description of these is provided in Appendix 2A. Preliminary ARARs that could apply to Alternative 3 are identified in Table 5-1. It is estimated that RAOs will be achieved across this site within 20 years, based on a qualitative assessment of site conditions. Groundwater monitoring will provide data for the continuing evaluation of progress. It is anticipated that institutional controls could also be relaxed at the time RAOs are achieved across the 354 Site.

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls and proprietary controls. Therefore, the use of groundwater during the time when levels are decreasing is restricted by this alternative. This alternative potentially could accelerate meeting preliminary chemical-specific ARARs (i.e., MCLs) in the terrace and alluvial aquifer by reducing contaminant mass that contributes to the dissolved plume. The elimination of the soil hot spot at Building 367 under the pilot test program should also assist in meeting chemical-specific ARARs.

Preliminary location-specific ARARs for Alternative 3 mainly concern endangered species. Location-specific ARARs will be met by coordinating remedial activities with Fort Riley Conservation Division personnel to minimize or eliminate adverse impacts on wildlife. Preliminary action-specific ARARs are anticipated to be met by this alternative as follows. An underground injection permit will not likely be required to inject permanganate into the subsurface, because CERCLA sites are exempt. However, the functional equivalent of a permit may be necessary for the KDHE concurrence because the substantive requirements of a permit typically must be satisfied. There should be no problems meeting all the OSHA requirements during implementation of this alternative.

Long-Term Effectiveness and Permanence

Once RAOs are achieved at the 354 Site, groundwater contaminant levels should continue to remain very low because the shallow soil hot spot located east of Building 367 has been eliminated with the completion of the pilot study soil removal activities in November 2004. 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 USEPA accepted limits at this site (BMcD, 2003a). However, contaminants sorbed to the aquifer matrix may continue to leach COPCs after remediation is completed.

To ensure long-term reliability, a review of groundwater contamination at the 354 Site would be required every five years 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 anticipated to limit exposure to present and future users of the groundwater, if necessary.

Reduction of Toxicity, Mobility, or Volume

Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through chemical oxidation of groundwater contamination east of Building 367. Reduction of concentrations would be anticipated to lower dissolved concentrations in the terrace aquifer portion of the plume and further reduce the already low level concentrations of VOCs entering the alluvial aquifer. NA processes will also act to further reduce contaminant concentrations, primarily physical attenuation processes in the terrace aquifer and biological processes in the Kansas River alluvial aquifer.

MnO_4^- treatment is not expected to interfere with NA processes that are presently operating. Specifically, MnO_4^- has limited mobility and oxidizing conditions would be limited to the immediate treatment area. Any excess MnO_4^- would be consumed by the NOD at the location of chemox injection.

The use of chemical oxidation processes destroys contaminants in groundwater. Therefore, this alternative should be considered as non-reversible.

Short-Term Effectiveness

A groundwater monitoring program and institutional controls are included in this alternative in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the 354 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. A health and safety plan will address any short-term risks associated with implementation.

Implementability

There are no anticipated technical difficulties in implementing this alternative. Because it is based on the injection of a reagent, it will be reliable to implement, with essentially no O&M concerns. The modified groundwater monitoring well network (Figure 5-1) 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 354 Site.

Cost Evaluation

The present worth cost of this alternative is estimated to be $1,900,000, with a capital cost of $650,000, total O&M cost of $1,600,000, periodic costs totaling $130,000, and a total project cost of $2,300,000. Detailed cost analysis tables are presented in Appendix 5A (Tables 5A-5 and 5A-6). While cost estimates are sound, unexpected costs could occur during implementation of this alternative.

5.3.3.3 Additional Criteria

Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the 354 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 no O&M issues or costs.

Limitations and Considerations

- Re-injections may be required if contaminant levels do not decrease as predicted.

5.3.4 Alternative 4 – Enhanced Anaerobic Bioremediation, Monitored Natural Attenuation, and Institutional Controls

5.3.4.1 Description

General Technology Description

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 biodegradation. 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, 2003).

Site Specific Description

This alternative consists of installing an in-situ treatment system within the terrace aquifer portion of the plume to remediate the most contaminated area of the plume. Attenuation of contamination is occurring in the terrace aquifer, but monitoring indicates that biological processes may not be significant compared to physical attenuation mechanisms such as adsorption, dilution, and dispersion. Natural biological degradation processes are indicated to be operating where the plume enters the alluvial aquifer. No biostimulation is proposed for the downgradient portion of the plume because the natural attenuation rates appear adequate to polish any residual dissolved contamination that may escape an upgradient treatment zone in the terrace aquifer. Specifically, existing attenuation rates appear sufficient in the alluvial portion of the plume because under the present conditions, where unremediated terrace aquifer plume water enters the alluvial environment, contamination is attenuated such that concentrations exceeding MCLs do not reach the Kansas River.

Conceptual design of this alternative makes use of two curtains spaced approximately 600 ft apart (Figure 5-3). Each curtain consists of one row of 30 injection points spaced on ten-foot centers and extending 300 ft across the plume. Injection will be performed within the saturated portion of the terrace aquifer from the top of bedrock to the top of groundwater, approximately 10 ft thick. This design is consistent with the horizontal and vertical extent of the contaminant plume at the 354 Site. Lactate is typically applied at a rate of 15 pounds per vertical ft and is injected into the aquifer using direct-push equipment. In addition to the two treatment curtains, 28 lactate injection points will be placed east of Building 367 in the groundwater, directly below the 40-ft x 70-ft shallow soil hot spot. This allows for a treatment zone in the plume origin area, a mid-plume treatment curtain, and a downgradient curtain prior to the transition from the terrace aquifer to the alluvial aquifer.

The 600 ft curtain spacing will allow over one pore volume of groundwater to flow through the treatment curtains in approximately six months. The six-month time frame is based on estimating that the injected lactate will reside in the aquifer for a six- to 12-month time period. This estimate assumes an average linear groundwater velocity of 3.3 ft/day, based on a hydraulic conductivity of 100 ft/day, an average effective porosity of 0.30, and an average gradient of 1.00 x 10^{-2} (refer to Section 2.5 of the RI Report [BMcD, 2003a] for details on hydrogeologic parameters for the 354 Site). There have been no slug or pump tests in the terrace aquifer; however, aquifer testing in the alluvial aquifer estimates hydraulic conductivities between 450 ft/day to 1,000 ft/day. For the terrace aquifer, an estimated hydraulic conductivity of 100 ft/day is assumed as it may be less conductive than the Kansas River alluvial aquifer, but within the same order of magnitude. Any contaminants remaining above MCLs following the lactate treatment are anticipated to be remediated through MNA.

The inclusion of institutional controls and MNA with this alternative reduces the potential for human ingestion, inhalation, or direct contact with contaminated groundwater at the 354 Site. These institutional controls are the same as described for Alternative 2 (see Section 5.3.2.1). At a minimum, CERCLA requires administrative reassessments every five years whenever contaminants are left in place, if the site is not open for unrestricted use.

The pilot study, which was described in detail in Section 1.3.6, virtually eliminated the shallow soil hot spot east of Building 367. This in-situ treatment and soil removal action was completed in December 2004. This will ensure that there is no remobilization of chlorinated solvent contamination from the shallow soils in this vicinity. The result should be decreasing concentrations of contaminants in groundwater both within the terrace aquifer and the Kansas River alluvial aquifer.

5.3.4.2 Evaluation

Protection of Human Health and the Environment

Based on the risk assessments performed in the RI Report (BMcD, 2003a), this alternative is protective of human health and the environment because the risk estimates do not exceed the USEPA 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. The elimination of the shallow soil hot spot east of Building 367 under the pilot test program should also result in lower amounts of VOCs being released to the dissolved plume.

Compliance with ARARs

A list of preliminary ARARs for the 354 Site is presented in Section 2.2.2. A description of these is provided in Appendix 2A. Preliminary ARARs that could apply to Alternative 4 are identified in Table 5-1.

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls and proprietary controls. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. This alternative potentially could meet preliminary chemical-specific ARARs (i.e., MCLs) in the terrace and alluvial aquifer by stimulating microbes and accelerating natural biological processes that are operating at the 354 Site. It is estimated that RAOs will be achieved across the 354 Site within 15 years, based on a qualitative assessment of site conditions. Groundwater monitoring will provide data for the continuing evaluation of progress. It is anticipated that institutional controls could also be relaxed at the time RAOs are achieved across the 354 Site. The elimination of the soil hot spot at Building 367 under the pilot test program should also assist in meeting chemical-specific ARARs.

Preliminary location-specific ARARs for Alternative 4 mainly concern endangered species. Location-specific ARARs will be met by coordinating remedial activities with Fort Riley Conservation Division personnel to minimize or eliminate adverse impacts on wildlife. Action-specific ARARs are anticipated to be met by this alternative as follows. An underground injection permit will not likely be required to inject lactate into the subsurface, because CERCLA sites are exempt. However, the functional equivalent of a permit may be necessary for the KDHE concurrence because the substantive requirements of a permit typically must be satisfied. The OSHA requirements are anticipated to be met during implementation of this alternative.

Long-Term Effectiveness and Permanence

Once RAOs are achieved at the 354 Site, groundwater contaminant levels are anticipated to remain below MCLs because the shallow soil hot spot located east of Building 367 has been eliminated with the completion of the pilot study removal activities in November 2004. 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 USEPA accepted limits at the 354 Site (BMcD 2003a). However contaminants sorbed to the aquifer matrix may leach low levels of COPCs after remediation is completed.

Long-term reliability concerns would be met by periodic review of site conditions and institutional controls. A review of groundwater contamination at the 354 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). Institutional controls are anticipated to limit exposure to present and future users of the groundwater, if necessary.

Reduction of Toxicity, Mobility, or Volume

Reduction in contaminant volume is anticipated to be achieved with this alternative primarily through EAB. Accumulation of VC is unlikely due to low level concentrations of contaminants at the 354 Site and the reported effectiveness of lactate to completely reduce chlorinated solvents (Regenesis, 2003). Natural attenuation processes will also act to further reduce contaminant concentrations. With respect to hot spot control, the removal of contaminated shallow soil at Building 367 as part of the pilot study has the potential to eliminate the leaching of contaminants to groundwater.

One consideration is that the lactate injection must stimulate enough microbial activity that reducing conditions are created in the groundwater. A pilot test is necessary to evaluate if reducing conditions can be achieved consistently across a 300-ft wide treatment curtain. Due to the relatively steep hydraulic gradient (average 0.01), possible heterogeneity of the terrace aquifer, and infiltration of relatively oxidizing precipitation and rapid recharge of potentially oxidizing groundwater from up gradient locations, the feasibility of achieving reducing conditions in potential higher velocity channels is not known.

Lactate injection results in an increase in biological activity within the aquifer and the development of reducing conditions, thereby resulting in the destruction of contaminants in groundwater. Therefore, this alternative should be considered as non-reversible.

Short-Term Effectiveness

A groundwater monitoring program and institutional controls are included in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the 354 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. A health and safety plan will address any short-term risks associated with implementation.

Implementability

There are no anticipated technical difficulties in implementing this alternative. Because it is based on the injection of a reagent, it will be reliable to implement, with essentially no O&M concerns. The modified groundwater monitoring well network (Figure 5-1) 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 354 Site.

Cost Evaluation

The present worth cost of this alternative is estimated to be $1,600,000, with a capital cost of $470,000, total O&M cost of $1,200,000, periodic costs totaling $270,000, and a total project cost of $1,900,000 (undiscounted). Detailed cost analysis tables are presented in Appendix 5A (Tables 5A-7 and 5A-8). While cost estimates are sound, unexpected costs could occur during implementation of this alternative.

5.3.4.3 Additional Criteria

Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the 354 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 no O&M issues with the EAB treatment.

Limitations and Considerations

- Possibility for VC to accumulate, although unlikely due to low level concentrations of contaminants at the 354 Site and the reported effectiveness of lactate to completely reduce chlorinated solvents (Regenesis, 2003).
- 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.

5.3.5 Alternative 5 – Groundwater Extraction and Ex-Situ Treatment, Monitored Natural Attenuation, and Institutional Controls

5.3.5.1 Description

Site Specific Description

This alternative consists of installing a groundwater extraction system in the area of plume origin immediately east of Building 367 and additional wells along the axis of the dissolved plume within the terrace aquifer. For conceptual design purposes, a single extraction well is placed in the plume origin area (east of Building 367) and an additional four wells are placed as two extraction lines (two wells per line) across the plume at the mid-plume, and down-plume positions (Figure 5-4). An average pumping rate of four gallons per minute (gpm) per well is estimated based on establishing a total system pumping rate of approximately 20 gpm. The 20 gpm pumping rate is based on the amount of groundwater that will pass (pre-pumping) through a 300-ft wide by ten-ft thick plume cross-section using a hydraulic gradient of 0.01 and hydraulic conductivity of 100 ft/day (because all input parameters are accurate to a single digit, the result of 15.6 gpm was rounded up to 20 gpm for accuracy to a single digit). For actual design, terrace aquifer testing is required to determine site-specific hydraulic conductivities, sustainable pumping rates, and radii of influences. Existing monitoring wells will be used to the extent practical for hydraulic testing. Due to possible heterogeneity of the aquifer, a range of hydraulic conductivities may result. For cost estimating purposes, it is assumed that all the extraction wells will be of new construction.

Due to extremely low VOC concentrations and evidence of natural biodegradation occurring in the alluvial aquifer, no extraction wells are proposed to be placed in the alluvial aquifer. The purpose of the groundwater extraction is to capture and remove contamination from the terrace aquifer and minimize any contamination that may enter the alluvial aquifer.

Groundwater extraction and treatment (pump and treat) is designed in this alternative to provide containment of concentrations above MCLs while NA processes in the alluvial aquifer further reduce or polish any residual dissolved contaminants. While the limitations of pump and treat as a remediation technology are well documented (USEPA, 1996; NAP, 1994; and USDOE, 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 (USEPA, 1996).

Groundwater is anticipated to be treated by air stripping, followed by discharging the treated water to the sanitary sewer, then ultimately to the Kansas River. Depending on final design/treatability testing, a combination of air stripping, followed by activated carbon treatment is also an option. For cost estimating purposes, it is assumed that activated carbon polishing will be used after air-stripping. No off-gas treatment of the air-stripper discharge is proposed due to the small mass of chlorinated compounds that are in the plume.

The inclusion of institutional controls and MNA with this alternative reduces the potential for human ingestion, inhalation, or direct contact with contaminated groundwater at the 354 Site. These institutional controls are the same as described for Alternative 2 (see Section 5.3.2.1).

The pilot study, which was described in detail in Section 1.3.6, virtually eliminated the shallow soil hot spot east of Building 367. This in-situ treatment and soil removal action was completed in December 2004. This will ensure that there is no remobilization of chlorinated solvent contamination from the shallow soils in this vicinity. The result should be decreasing concentrations of contaminants in groundwater both within the terrace aquifer and the Kansas River alluvial aquifer.

5.3.5.2 Evaluation

Protection of Human Health and the Environment

Based on the risk assessments (human health and ecological) performed in the RI Report (BMcD, 2003a), this alternative is protective of human health and the environment because the risk estimates do not exceed the USEPA accepted risk levels. The potential for future risk to human health or the environment is anticipated to decrease because institutional controls are expected to be in place to limit or prevent exposure to contaminated groundwater and remediation of contaminants will further reduce concentrations. The elimination of the shallow soil hot spot east of Building 367 under the pilot test program should also result in lower amounts of VOCs being released to the dissolved plume.

Compliance with ARARs

A list of preliminary ARARs for the 354 Site is presented in Section 2.2.2. A description of these is provided in Appendix 2A. Preliminary ARARs that could apply to Alternative 5 are identified in Table 5-1.

This alternative is anticipated to control exposure to the contaminated groundwater through governmental controls and proprietary controls. Therefore, the use of groundwater during the time when levels are decreasing to MCLs is restricted by this alternative. With respect to the terrace aquifer where the higher concentrations are detected, the relatively thin nature of the aquifer (i.e., ten-ft average saturated zone) limits the potential use of this water given the option for better well yields in the thicker alluvial aquifer. This alternative is anticipated to meet preliminary chemical-specific ARARs (i.e., MCLs) by reducing the contaminant mass already undergoing suspected natural biodegradation. It is estimated that RAOs will be achieved across this site within 20 years, based on a qualitative assessment of site conditions. The elimination of the soil hot spot at Building 367 under the pilot test program should also assist in meeting chemical-specific ARARs. Groundwater monitoring will provide data for the continuing evaluation of progress. It is anticipated that institutional controls could also be relaxed at the time RAOs are achieved across the 354 Site.

Preliminary location-specific ARARs for Alternative 5 mainly concern endangered species, and archaeological and historical preservation. Location-specific ARARs will be met by coordinating remedial activities with Fort Riley Conservation Division personnel to minimize or eliminate adverse impacts on either wildlife, archaeological sites, or historical structures.

Action-specific ARARs are anticipated to be met by Alternative 5 as follows. This alternative will be compliant with air quality regulations because of the small quantities of VOCs that will be discharged to the atmosphere during stripping. Treated water will be discharged to the Fort Riley sanitary sewer system under its National Pollutant Discharge Elimination System (NPDES) permit, meeting water quality requirements. The OSHA and water well construction requirements are anticipated to be met during implementation of this alternative.

Long-Term Effectiveness and Permanence

Once RAOs are achieved at the 354 Site, groundwater contaminant levels are anticipated to remain below MCLs because the shallow soil hot spot located east of Building 367 has been eliminated with the completion of the pilot study soil removal activities in December 2004. 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 USEPA accepted limits at the 354 Site (BMcD 2003a). However, contaminants sorbed to the aquifer matrix may leach low levels of COPCs after groundwater extraction is completed. In order to assure long-term reliability, a review of groundwater contamination at the 354 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). Institutional controls are anticipated to limit exposure to present and future users of the groundwater.

Reduction of Toxicity, Mobility, or Volume

Groundwater pumping removes a limited mass of dissolved contaminants from the groundwater plume. The contaminants are then removed from the pumped groundwater by air stripping and polishing of the effluent through activated carbon adsorption. Air stripping results in the transfer of the contaminants to the atmosphere and carbon adsorption treatment of the secondary water effluent transfers almost all of the remaining contaminants that have not been stripped to the activated carbon. Once the activated carbon becomes depleted, the carbon must be treated by thermal regeneration, a process similar to incineration. Because the plume is undergoing NA, with biological processes actually metabolizing the contaminants, the act of pumping and treating increases mobility by transferring the contaminants that would otherwise be metabolized to the atmosphere. The remaining fraction is treated by thermal regeneration of the carbon at an off-site facility; however, this process is energy intensive and expends fossil fuel resources. A larger volume of atmospheric CO_2 is produced via fuel consumption and oxidation of the contaminants than would be produced by microbial action in the subsurface. In addition, the operation of pumps and blowers to operate the system also depends on electrical power generation, which results in the release of additional greenhouse gases to the atmosphere. In summary, although groundwater pumping and treatment remove a limited mass from the groundwater plume and reduce the volume and mass of contaminants in the plume, it does so in a very inefficient manner that otherwise would be performed more efficiently by natural biological processes. In addition, rebounding of concentration levels once pumping is discontinued is a common problem with these systems, resulting in a situation where the effects of the technology are reversible (USEPA, 1996).

Short-Term Effectiveness

The time estimated to reach MCLs is dependent on 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.

A groundwater monitoring program and institutional controls are included in the event that the remedial technology used in this alternative does not reduce the contaminant levels at the 354 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 is 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. In terms of protection of workers during construction and operation, a site-specific Health and Safety Plan will be required. Potential chemical exposure risks are anticipated to be minimal and the primary source of risk involves working with heavy machinery including drilling, trenching, hauling, and erection equipment.

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. Implementation reliability would be high initially, but could fall off during system operation as a result of O&M concerns, since this alternative is physically more complicated than the others. The current groundwater monitoring well network (Figure 5-1) 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 354 Site.

Administrative implementability issues include routine procedures such as obtaining drilling permits. This alternative uses equipment that is available in the marketplace through numerous vendors.

Cost Evaluation

The present worth cost of this alternative is estimated to be $3,700,000, with a capital cost of $590,000, total O&M cost of $4,100,000, periodic costs totaling $130,000, and a total project cost of $4,800,000. Detailed cost analysis tables are presented in Appendix 5A (Tables 5A-9 and 5A-10). While cost estimates are sound, unexpected costs could occur during implementation of this alternative.

5.3.5.3 Additional Criteria

Advantages

- Reduces the potential for human ingestion, inhalation, or dermal contact with contaminated groundwater at the 354 Site.
- Includes a groundwater monitoring program to assess future changes in site and/or contaminant conditions.

Limitations and Considerations

- Contaminated groundwater is brought to the ground surface during remediation.
- Transfers contaminants to another medium (i.e., air, carbon) rather than destroying in-situ.
- Temporary structures such as a pumping well and housing, treatment shed/building, and discharge piping will be required. Extensive subsurface trenching is required to bury flow lines.
- 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 (USEPA, 1996).

- 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 (USDOE, 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 (USEPA, 1996).

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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) in Sections 6.3.1 and 6.3.2, respectively. 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, 2003a), 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 USEPA accepted risk levels. However, for the purposes of this comparative analysis, Alternative 1 will be considered as not protective of human health and the environment. This is not unreasonable if an unforeseen exposure scenario develops and there are no institutional controls in place to deal with it.

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-specific ARARs. Additionally, it appears that possible location- and action-specific ARARs will not be a factor. 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. It is probable the Alternative 1 would eventually meet preliminary chemical-specific ARARs as a result of NA processes active within the aquifer. However, Alternative 1 provides no mechanism to ensure that ARARs have been met. 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

It is assumed that the shallow soil treatment (pilot study) eliminated the soil hot spot at the 354 Site (see Sections 1.3.6). Once RAOs are met, Alternatives 2 through 5 should all provide similar long-term effectiveness and permanence at the Site. However, due to the known rebounding effects associated with Alternative 5 (Pump & Treat), this alternative is considered less favorable in terms of long-term effectiveness and permanence than Alternatives 2 through 4 (USEPA, 1996). Rebounding effects occur when the system is shut down and contaminants diffuse out of the low permeability zones within the aquifer (USEPA, 1996). Alternative 5 is also less desirable because contaminated water is removed from the aquifer. The ratings for long-term effectiveness and permanence are assigned as follows:

Alternative 2 (MNA)	2
Alternative 3 (Chemox)	1
Alternative 4 (EAB)	1
Alternative 5 (Pump & Treat)	5

6.3.4 Reduction of Toxicity, Mobility, or Volume

Alternatives 2 through 5 are anticipated to provide similar levels of reduction in toxicity, mobility, and volume of contaminants in the plume. Alternative 5 (Pump & Treat) transfers contaminants to another medium (i.e., air and carbon) rather than destroying them in-situ. The ratings for reduction in toxicity, mobility, and volume are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (Chemox)	1
Alternative 4 (EAB)	1
Alternative 5 (Pump & Treat)	5

6.3.5 Short-Term Effectiveness

Because no quantitative modeling was performed at this Site, only a qualitative estimate can be made on the length of time required to achieve RAOs. This was done as a ranking of the four alternatives, with Alternative 5 (Pump & Treat) achieving RAOs most quickly, and Alternative 2 (MNA) taking the longest to achieve RAOs. Alternatives 3 and 4 (Chemox and EAB) would probably take an intermediate length of time.

Institutional controls address potential receptors during remedial actions by limiting or preventing exposure to contaminated groundwater. Alternatives 2 (MNA), 3 (Chemox), and 4 (EAB) all involve the treatment of the groundwater in-situ, which limits the potential for direct contact with contaminated media. Alternative 5 (Pump & Treat) involves pumping contaminated groundwater to the ground surface for treatment, which would increase the potential for contact.

There are construction and/or operation hazards associated with Alternatives 3, 4, and 5 (Chemox, EAB, and Pump & Treat). These include risks involved with working with heavy machinery including drilling, trenching, hauling, and erection equipment. There are also unique hazards associated with handling chemical oxidants in the field. A site-specific safety and health plan will minimize hazards associated with construction and/or operation.

The most reliable of the alternatives is 2 (MNA). Alternatives 3 and 4 do not require any O&M following the initial injection; however, it is possible that re-injection of reagent might be required in the event contaminant levels do not decrease as predicted. The pump and treat system (Alternative 5) would likely be equipped with a remote telemetry system to notify key personnel in the event operational problems occur. A site visit would then be made to correct the problem(s). Pump and treat systems require frequent O&M visits to ensure they continue to function as designed. The inclusion of a groundwater monitoring program and institutional controls address short-term reliability in the event the selected remedial alternative does not reduce contaminant levels at the Site.

Alternative 2 (MNA)	4
Alternative 3 (Chemox)	4
Alternative 4 (EAB)	4
Alternative 5 (Pump & Treat)	3

6.3.6 Implementability

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

Alternatives 3 and 4 (Chemox and EAB) would be fairly simple to implement since both require the use of direct-push equipment to inject treatment fluids into the aquifer. No permanent support infrastructure on the surface is required. Preferential pathways for the injected materials to move during injection may be an implementability issue with Alternatives 3 and 4. Administrative implementability of the institutional controls associated with this alternative would be the same as for the other alternatives.

Alternative 5 (Pump & Treat) would be the most difficult alternative to implement. This alternative would require an extensive surface support infrastructure and would likely require trenching during the construction phase. It would be difficult to perform these construction tasks because of the built-up nature of Main Post. Administrative implementability of the institutional controls associated with this alternative would be the same as for the other alternatives.

The ratings for implementability are assigned as follow:

Alternative 2 (MNA)	1
Alternative 3 (Chemox)	3
Alternative 4 (EAB)	3
Alternative 5 (Pump & Treat)	6

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 5A. Alternative 5 (Pump & Treat) is the only alternative which requires a significant O&M cost. While cost estimates are sound, unexpected costs could occur during implementation of Alternatives 3, 4, or 5. The rating for cost are assigned as follows:

Alternative 2 (MNA)	1
Alternative 3 (Chemox)	3
Alternative 4 (EAB)	3
Alternative 5 (Pump & Treat)	7

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 alternative with the most favorable ranking is 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 MNA rating was due to the ease of implementation (no physical systems required except for monitoring), effectiveness of the process (reduces contaminants at the 354 Site), and low costs (monitoring and evaluation costs).

The pilot study to treat the shallow soil 'hot spot' adjacent to Building 367 (see Section 1.3.6) had an overall beneficial effect on Alternatives 2 – 5. Its impact appears to enhance the ability of MNA to contend with the residual groundwater contamination. Thereby, potentially decreasing the length of time needed to achieve the RAOs for the Site and boosting the efficacy and rating of Alternative 2.

Alternatives 3 (Chemox) and 4 (EAB) had equivalent ratings, also within a favorable range. This was due to the ease of implementability (direct-push application), favorable cleanup time, no permanent structures, reliability, and cost effectiveness. Chemox and EAB provide similar or greater levels of long-term effectiveness and reduction of toxicity, mobility, and volume than the other alternatives.

The low ranking of Alternative 5 (Pump & Treat) was primarily due to its 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 (USEPA, 1996). The base costs for the system 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 this alternative was relatively high, this rating does not overcome the potential for rebound, surface implementability issues off site, and potential for increased costs.

In summary, Alternatives 2, 3, and 4 are overall more favorable than Alternative 5. Each of these alternatives (2, 3, and 4) is comparable with respect to effectiveness (short and long term), permanence, and reduction of toxicity, mobility, or volume. However, the comparable ease of implementability and lower cost of Alternative 2 relative to 3 and 4 make it the most favorable at this point in the analysis and evaluation of alternatives that meet the threshold criteria.

This evaluation of alternatives utilized the two threshold criteria and the five balancing criteria to rank the remedial alternatives for the 354 Site. The ranking was an evaluation, not a selection, of the alternatives considered at the 354 Site. The final two criteria, state 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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Tables

Table 1-1
Summary of Risk Results
Feasibility Study Report
354 Area Solvent Detections

Population	Noncarcinogenic Hazard Quotients	Carcinogenic Risks
Building 367 Area		
Future Indoor Worker		
Inhalation of Vapors Pathway	3E-04	2E-07
Future Indoor Worker Total	**3E-04**	**2E-07**
Future Utility Excavation Worker		
Ingestion Pathway	8E-05	2E-08
Dermal Pathway	1E-07	2E-09
Inhalation of Dust Pathway	5E-10	2E-13
Inhalation of Vapors Pathway	2E-05	2E-08
Future Utility Excavation Worker Total	**1E-04**	**4E-08**
Building 354/332/DPW Compound Area		
Current Indoor Worker		
Ingestion Pathway	2E-05	5E-07
Inhalation of Vapors Pathway	3E-03	2E-08
Current Indoor Worker Total	**3E-03**	**5E-07**
Current Groundskeeper		
Ingestion Pathway	5E-06	1E-07
Dermal Pathway	5E-07	9E-09
Inhalation of Dust Pathway	NAp	1E-12
Inhalation of Vapors Pathway	8E-04	1E-09
Current Groundskeeper Total	**9E-04**	**1E-07**
Building 430 Area		
Current Child Resident		
Ingestion Pathway	2E-04	6E-07
Dermal Pathway	7E-05	2E-07
Inhalation of Dust Pathway	NAp	5E-12
Inhalation of Vapors Pathway	4E-05	1E-10
Current Child Resident Total	**3E-04**	**8E-07**

Note:
NAp - Not applicable

Table 4-1
Technologies and Process Options for Groundwater Remediation
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General Response Actions	Technologies	Process Options
No Action	No Action	No Action
Institutional Controls	Governmental Controls	Zoning Ordinance Amendment County Resolution
	Proprietary Controls	Negative Easements and Restrictive Covenants Affirmative Easements
	Other Institutional Controls	Real Property Master Plan
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
Feasibility Study Report
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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 Groundwater Recharge Deep Well Injection Vapors Discharged to the Atmosphere

Table 4-1 (continued)
Technologies and Process Options for Groundwater Remediation
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354 Area Solvent Detections

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
Feasibility Study Report
354 Area Solvent Detections

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			
Governmental Controls			
Zoning Ordinance Amendment	Amendment to the county zoning ordinance creating a groundwater restriction overlay district.	No	Not applicable. Property is on U.S. military reservation and outside jurisdiction of Geary County.
County Resolution	Enactment of a county resolution designed to restrict contaminated groundwater use.	No	Not applicable. Property is on U.S. military reservation and outside jurisdiction of Geary County.
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.	No	Not applicable. Property is on U.S. military reservation.
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).	No	Not applicable. Property is on U.S. military reservation.
Other Institutional Controls			
Real Property Master Plan (RPMP)	The RPMP is the means for codifying land use controls, including the location of water supply wells, on the post.	Yes	Applicable. Use the RPMP to apply institutional controls on the post.
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.	No	There are no water supply wells within the area of influence.
New Supply Wells	New uncontaminated wells to serve residents in the area of influence.	No	There are no water supply wells within the area of influence.
Individual Well Treatment			
Low Profile Air Stripping	Volatilization of contaminants from water by either passing air through water or water through air.	No	There are no water supply wells within the area of influence.
Activated Carbon Adsorption	Adsorption of contaminants onto activated carbon by passing water through carbon column.	No	There are no water supply wells within the area of influence.
UV Oxidation	Oxidation of organic contaminants by addition of H_2O_2 and/or O_3 and catalyzed by ultraviolet (UV) light.	No	There are no water supply wells within the area of influence.
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 reduce contaminant concentrations at the 354 Site.

Table 4-2 (continued)
Initial Screening of Potential Technologies for Groundwater Remediation
Feasibility Study Report
354 Area Solvent Detections

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 the 354 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 the 354 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: Horizontal	Series of horizontal or inclined wells with water pumps to extract contaminated groundwater.	Yes	Potentially applicable.
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 light non-aqueous phase liquids. 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.	No	Process is not applicable to treat all of the compounds present at the 354 Site.
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	Process is not applicable to treat all of the compounds present at the 354 Site.
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
Feasibility Study Report
354 Area Solvent Detections

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	Ultrafiltration/reverse osmosis has been typically used for separating inorganics from solution, although 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 absorbs 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
Feasibility Study Report
354 Area Solvent Detections

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
Feasibility Study Report
354 Area Solvent Detections

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.	No	Discharge to the river not practical because of distance from the treatment area.
Spray/Sprinkler Irrigation	Direct irrigation of water onto land surface. Sprinkler heads are designed to treat (volatilize) VOCs during application.	No	No appropriate location for discharge via direct irrigation.
Groundwater 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
Feasibility Study Report
354 Area Solvent Detections

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 the 354 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 the 354 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 the 354 Site (TCE and PCE) are not readily biodegradable under aerobic conditions. ORC may inhibit the natural anaerobic biodegradation that is occurring at the 354 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.	No	Issues with the longevity of non-indigenous bacteria are limitations of this technology. More applicable to low permeability aquifers.
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
Feasibility Study Report
354 Area Solvent Detections

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.	No	Technology is more applicable to materials with low hydraulic conductivity where aquifer air sparging is limited. Depth to bedrock (>50 ft) will likely increase the cost of this technology.
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.	No	Bench scale technology that has not been extensively field tested.
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
Feasibility Study Report
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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.	No	Has been used mainly to remediate sites with high contaminant concentrations (mg/L). Requires extensive above-ground support infrastructure.
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.	No	Has been used mainly to remediate sites with high contaminant concentrations (mg/L). Requires extensive above-ground support infrastructure.
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
Feasibility Study Report
354 Area Solvent Detections

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						
Other Institutional Controls						
Real Property Master Plan (RPMP)	The RPMP is the mechanism by which the post codifies land use controls.	+	+	+	Yes	The RPMP is used to formalize land use controls on the post. The RPMP could be used to establish areas where supply wells could not be installed; for example, within the 354 Site. It could be used to codify other types of restrictions as well.
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.
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 reduce contaminant concentrations at the 354 Site.
Containment						
Vertical Barriers	Low permeability wall made of soil-bentonite, reinforced concrete, chemical grout, or steel sheets.	o	-	-	No	Depth of aquifer (> 50 ft) will make installation difficult and more expensive.
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.

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

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
Feasibility Study Report
354 Area Solvent Detections

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
Extraction, Ex-Situ Treatment, and Discharge (Continued)						
Collection/Extraction (Continued)						
Pumping Wells: Horizontal	Series of horizontal or inclined 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.
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	o	Yes	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.	+	+	+	Yes	Numerous discharge locations within the treatment area.
Groundwater 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 since 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 lbs/day.

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

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
Feasibility Study Report
354 Area Solvent Detections

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
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	This technology may be appropriate to enhance remediation within the terrace aquifer (the high concentration area of the plume). May require regulatory approval to inject chemicals into the aquifer.
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.	-	o	o	No	Not effective on low concentrations of VOCs. No distinct advantage over other competing technologies.
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 ozone 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/water 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	No	No requirement to address vadose zone contamination at the Site.

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

Table 4-3 (Continued)
Evaluation of Technologies for Groundwater Remediation
Feasibility Study Report
354 Area Solvent Detections

Process Options	Description	Effectiveness	Implementability	Relative Cost	Retain*	Screening Comments
In-Situ Treatment (Continued)						
Physical/Chemical Treatment (Continued)						
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.	o	+	o	Yes	This technology is mainly applicable to small source zone type settings.
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.	+	-	-	No	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.
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	-	No	Technology is still in the testing phase. May require regulatory approval to inject chemicals into the aquifer.
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 Cost
o No Relative Advantage/Disadvantage
\- Relatively Ineffective, Difficult to Implement, or High Cost
? 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.
- [shaded box] Technology eliminated from further consideration

Table 5-1
Preliminary ARARs Matrix
Feasibility Study Report
354 Area Solvent Detections

	Alternative 1 No Action	Alternative 2 MNA	Alternative 3 Chemox	Alternative 4 EAB	Alternative 5 P&T
Chemical-Specific ARARs					
Kansas Surface Water Quality Standards	X	X	X	X	X
Kansas Water Pollution Control, Antidegradation Policy	X	X	X	X	X
Safe Drinking Water Act (SDWA), National Primary Drinking Water Regulations	X	X	X	X	X
Kansas Drinking Water Standards	X	X	X	X	X
Location-Specific ARARs					
Archaeological and Historic Preservation Act of 1974					X
Endangered Species Act of 1973		X	X	X	X
Fish and Wildlife Conservation Act		X	X	X	X
Flood Control Act of 1944		X	X	X	X
National Historic Preservation Act of 1966					X
Kansas Historic Preservation Act					X
Non-Game, Threatened, or Endangered Species (State of Kansas)		X	X	X	X
Action-Specific ARARs					
CERCLA		X	X	X	X
Clean Air Act					X
Clean Water Act					X
OSHA (workplace standards)		X	X	X	X
OSHA (construction standards)					X
Ambient Air Quality Standards and Air Pollution Control (State of Kansas)					X
Underground Injection Control Regulations (State of Kansas)			X	X	
Emergency Planning and Right-to-Know (State of Kansas)			X		
Kansas Board of Technial Professions		X	X	X	X
Water Well Contractor License; Water Well Construction and Abandonment		X			X

Notes:

1. See Section 2.2.2 and Appendix 2A for a detailed description of these ARARs

Chemox - Chemical Oxidation

EAB - Enhanced Anaerobic Bioremediation

MNA - Monitored Natural Attenuation

P&T - Pump & Treat

Table 6-1
Cost Summary
Feasibility Study Report
354 Area Solvent Detections

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	$ -	$ -	$ 440,000	$ 440,000	$ 300,000
2	MNA	$ 48,000	$ 1,200,000	$ 110,000	$ 1,300,000	$ 1,000,000
3	Chemical Ox.	$ 650,000	$ 1,600,000	$ 130,000	$ 2,300,000	$ 1,900,000
4	Enhanced Bio.	$ 470,000	$ 1,200,000	$ 270,000	$ 1,900,000	$ 1,600,000
5	Pump & Treat	$ 590,000	$ 4,100,000	$ 130,000	$ 4,800,000	$ 3,700,000

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 (when necessary), electricity (when necessary), periodic maintenance (when necessary), and periodic parts (when necessary).
3. Includes costs for five-year reviews and closure reporting.
4. Total Capital Costs + Total O&M Costs + Total Periodic Costs = Total Project Cost
5. Present value cost using a 3.2 percent discount rate (EPA, 1993). For this analysis, the rate of return was based on the 30-year treasury bill of 5.2 percent and an inflation rate of 2 percent (formula = 1 - 1.052/1.02), which yields a value of 3.14 percent, rounded up to 3.2 percent.
6. All costs are rounded to two significant figures.

MNA - Monitored Natural Attenuation
O&M - Operation & Maintenance

Table 6-2
Comparative Evaluation Summary
Feasibility Study Report
354 Area Solvent Detections

Alternatives	Alt. 1 No Action	Alt. 2 MNA	Alt. 3 Chemox	Alt. 4 EAB	Alt. 5 P&T
Protection of Human Health and the Environment	No	Yes	Yes	Yes	Yes
Compliance with ARARs	No	Yes	Yes	Yes	Yes
Long-term Effectiveness and Permanence	NC	2	1	1	5
Reduction of Toxicity, Mobility, or Volume	NC	1	1	1	5
Short-term Effectiveness	NC	4	4	4	3
Implementability	NC	1	3	3	6
Cost	NC	1	3	3	7
Total of Rankings	**NC**	**9**	**12**	**12**	**26**
Overall Rank	**NC**	**1**	**2***	**2***	**4**

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.
* Chemox and EAB are tied for second ranking (there is no third ranking).

ARAR - Applicable or Relevant and Appropriate Requirements
Chemox - Chemical Oxidation
EAB - Enhanced Anaerobic Bioremediation
MNA - Monitored Natural Attenuation
P & T - Pump & Treat

Figures

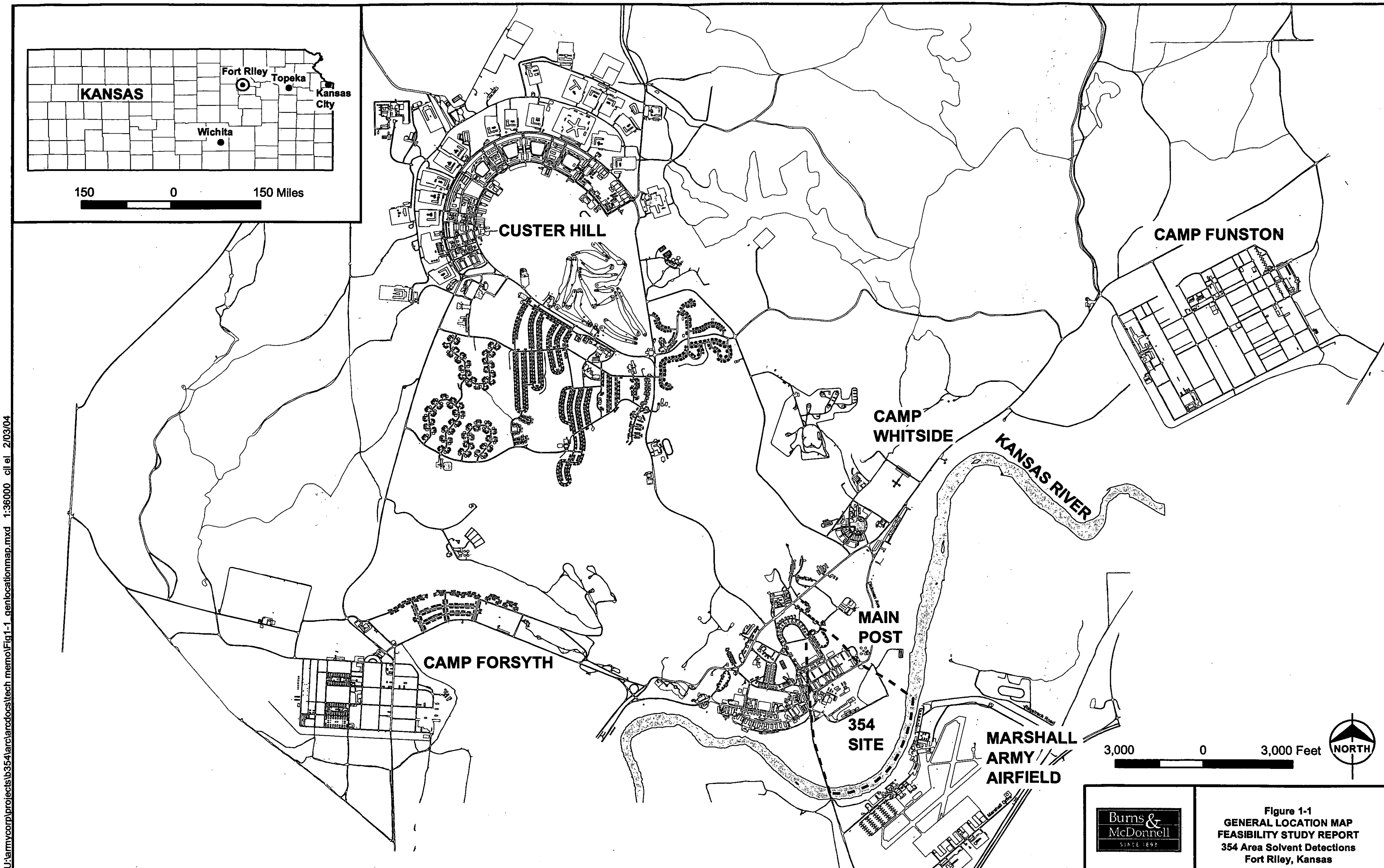

Figure 1-1
GENERAL LOCATION MAP
FEASIBILITY STUDY REPORT
354 Area Solvent Detections
Fort Riley, Kansas

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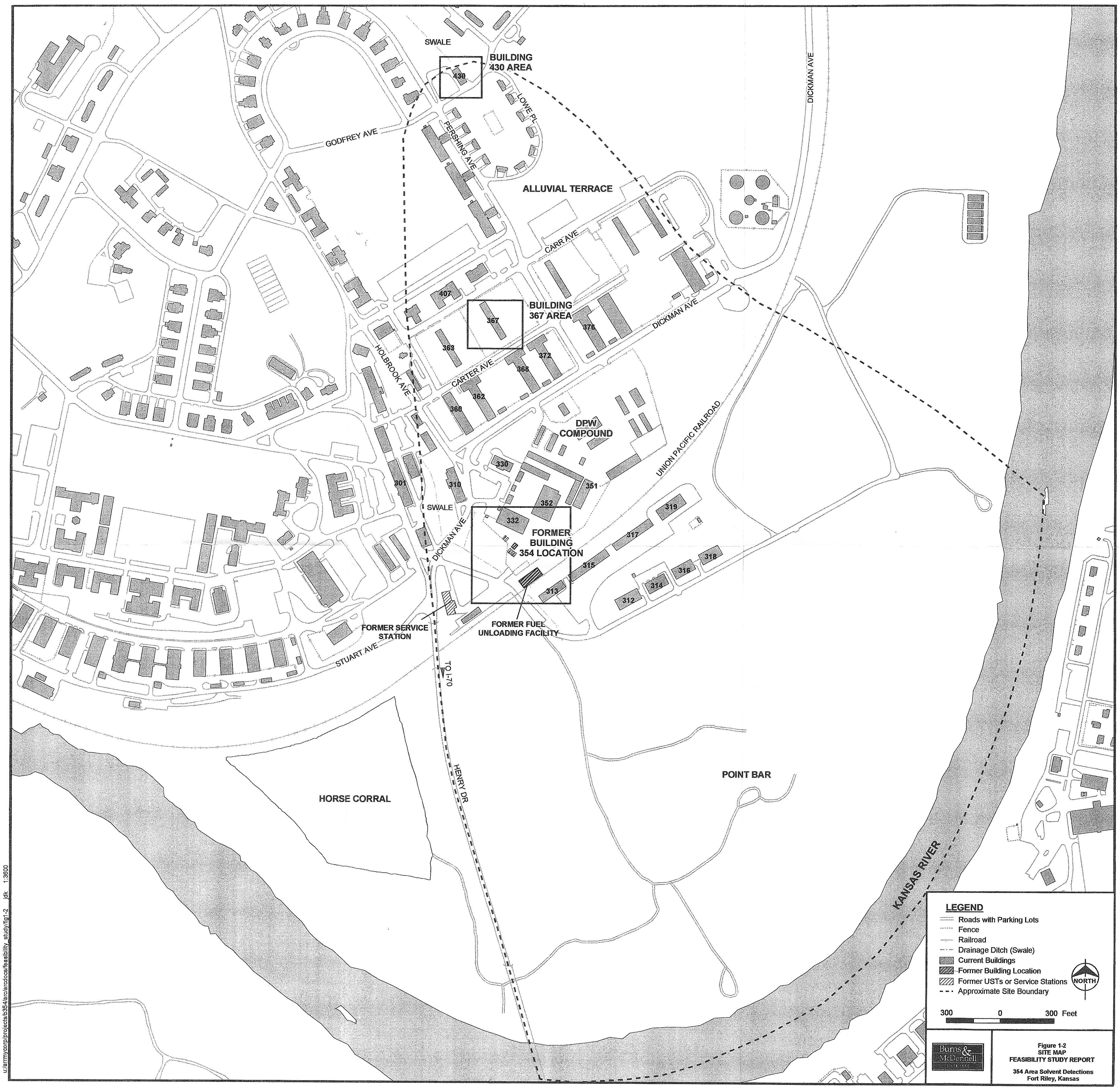

Figure 1-2
SITE MAP
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas

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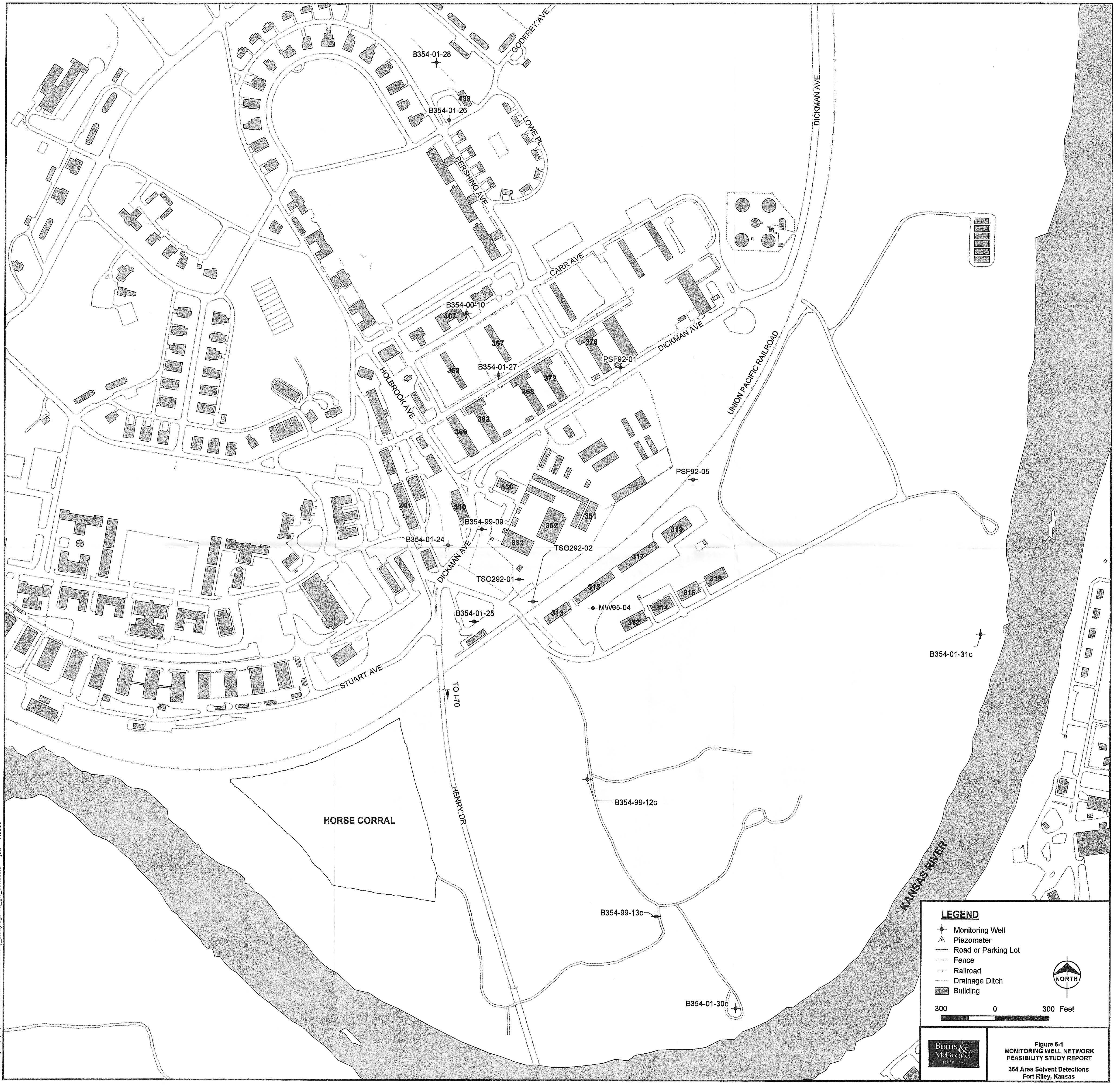

Figure 5-1
MONITORING WELL NETWORK
FEASIBILITY STUDY REPORT
354 Area Solvent Detections
Fort Riley, Kansas

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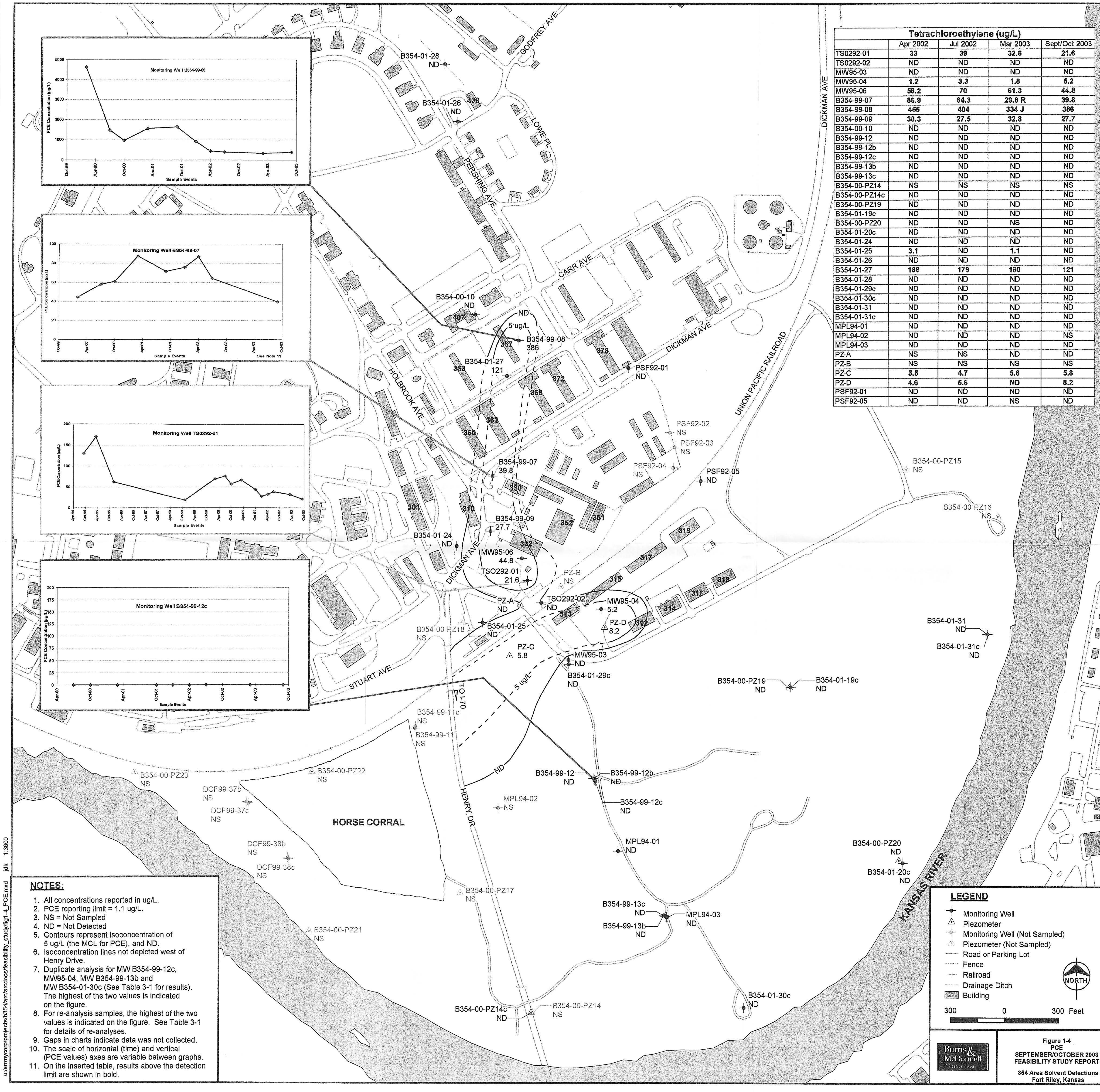

Tetrachloroethylene (ug/L)				
	Apr 2002	Jul 2002	Mar 2003	Sept/Oct 2003
TS0292-01	**33**	**39**	**32.6**	**21.6**
TS0292-02	ND	ND	ND	ND
MW95-03	ND	ND	ND	ND
MW95-04	**1.2**	**3.3**	**1.8**	**5.2**
MW95-06	**58.2**	**70**	**61.3**	**44.8**
B354-99-07	**86.9**	**64.3**	**29.8 R**	**39.8**
B354-99-08	**455**	**404**	**334 J**	**386**
B354-99-09	**30.3**	**27.5**	**32.8**	**27.7**
B354-00-10	ND	ND	ND	ND
B354-99-12	ND	ND	ND	ND
B354-99-12b	ND	ND	ND	ND
B354-99-12c	ND	ND	ND	ND
B354-99-13b	ND	ND	ND	ND
B354-99-13c	ND	ND	ND	ND
B354-00-PZ14	NS	NS	NS	NS
B354-00-PZ14c	ND	ND	ND	ND
B354-00-PZ19	ND	ND	ND	ND
B354-01-19c	ND	ND	ND	ND
B354-00-PZ20	ND	ND	NS	ND
B354-01-20c	ND	ND	ND	ND
B354-01-24	ND	ND	ND	ND
B354-01-25	**3.1**	ND	**1.1**	ND
B354-01-26	ND	ND	ND	ND
B354-01-27	**166**	**179**	**180**	**121**
B354-01-28	ND	ND	ND	ND
B354-01-29c	ND	ND	ND	ND
B354-01-30c	ND	ND	ND	ND
B354-01-31	ND	ND	ND	ND
B354-01-31c	ND	ND	ND	ND
MPL94-01	ND	ND	ND	ND
MPL94-02	ND	ND	ND	NS
MPL94-03	ND	ND	ND	ND
PZ-A	NS	NS	ND	ND
PZ-B	NS	NS	NS	NS
PZ-C	**5.5**	**4.7**	**5.6**	**5.8**
PZ-D	**4.6**	**5.6**	**ND**	**8.2**
PSF92-01	ND	ND	ND	ND
PSF92-05	ND	ND	NS	ND

NOTES:

1. All concentrations reported in ug/L.
2. PCE reporting limit = 1.1 ug/L.
3. NS = Not Sampled
4. ND = Not Detected
5. Contours represent isoconcentration of 5 ug/L (the MCL for PCE), and ND.
6. Isoconcentration lines not depicted west of Henry Drive.
7. Duplicate analysis for MW B354-99-12c, MW95-04, MW B354-99-13b and MW B354-01-30c (See Table 3-1 for results). The highest of the two values is indicated on the figure.
8. For re-analysis samples, the highest of the two values is indicated on the figure. See Table 3-1 for details of re-analyses.
9. Gaps in charts indicate data was not collected.
10. The scale of horizontal (time) and vertical (PCE values) axes are variable between graphs.
11. On the inserted table, results above the detection limit are shown in bold.

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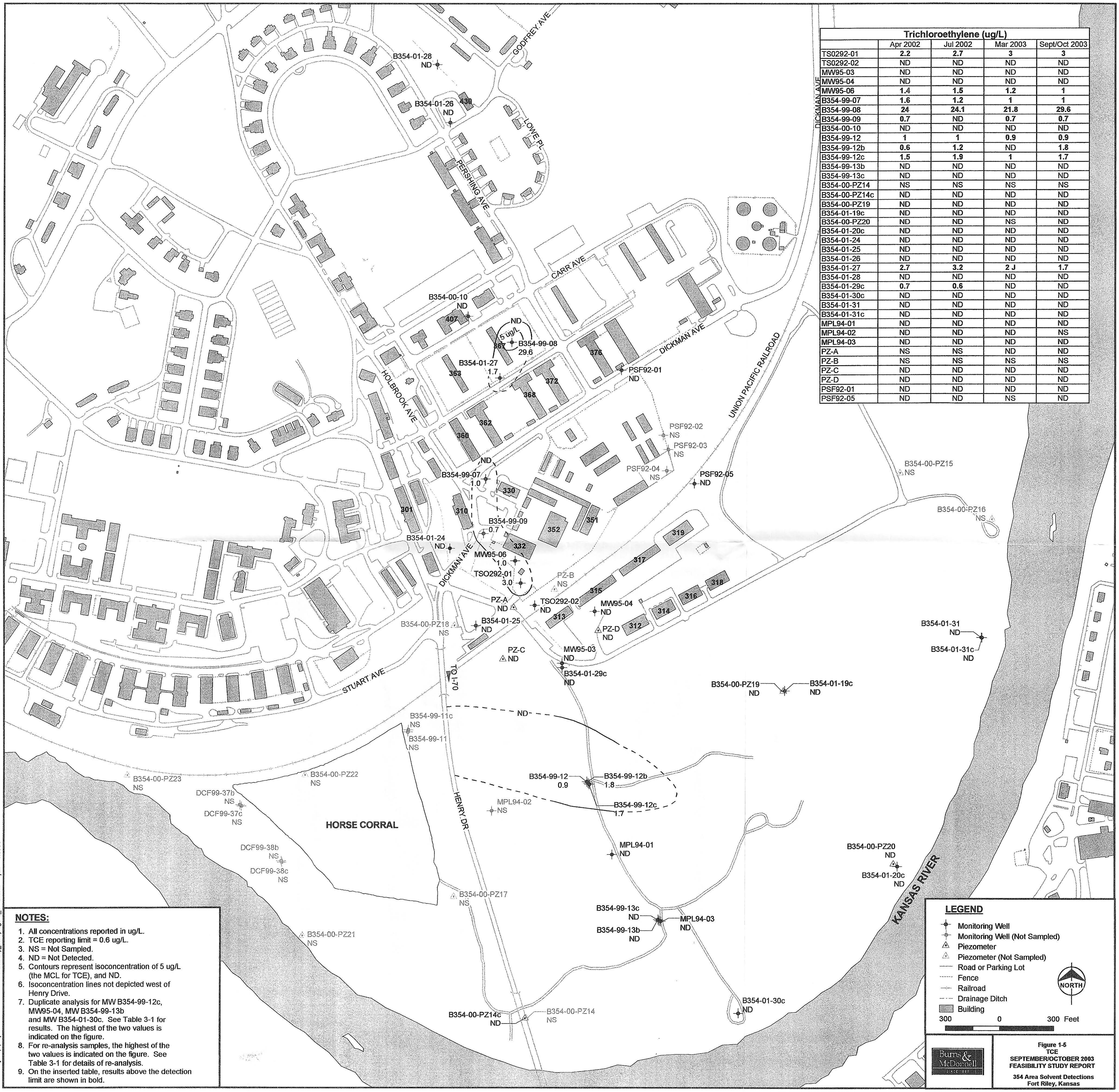
Figure 1-4
PCE
SEPTEMBER/OCTOBER 2003
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas



Trichloroethylene (ug/L)				
	Apr 2002	Jul 2002	Mar 2003	Sept/Oct 2003
TS0292-01	**2.2**	**2.7**	**3**	**3**
TS0292-02	ND	ND	ND	ND
MW95-03	ND	ND	ND	ND
MW95-04	ND	ND	ND	ND
MW95-06	**1.4**	**1.5**	**1.2**	**1**
B354-99-07	**1.6**	**1.2**	**1**	**1**
B354-99-08	**24**	**24.1**	**21.8**	**29.6**
B354-99-09	**0.7**	ND	**0.7**	**0.7**
B354-00-10	ND	ND	ND	ND
B354-99-12	**1**	**1**	**0.9**	**0.9**
B354-99-12b	**0.6**	**1.2**	ND	**1.8**
B354-99-12c	**1.5**	**1.9**	**1**	**1.7**
B354-99-13b	ND	ND	ND	ND
B354-99-13c	ND	ND	ND	ND
B354-00-PZ14	NS	NS	NS	NS
B354-00-PZ14c	ND	ND	ND	ND
B354-00-PZ19	ND	ND	ND	ND
B354-01-19c	ND	ND	ND	ND
B354-00-PZ20	ND	ND	NS	ND
B354-01-20c	ND	ND	ND	ND
B354-01-24	ND	ND	ND	ND
B354-01-25	ND	ND	ND	ND
B354-01-26	ND	ND	ND	ND
B354-01-27	**2.7**	**3.2**	**2 J**	**1.7**
B354-01-28	ND	ND	ND	ND
B354-01-29c	**0.7**	**0.6**	ND	ND
B354-01-30c	ND	ND	ND	ND
B354-01-31	ND	ND	ND	ND
B354-01-31c	ND	ND	ND	ND
MPL94-01	ND	ND	ND	ND
MPL94-02	ND	ND	ND	NS
MPL94-03	ND	ND	ND	ND
PZ-A	NS	NS	ND	ND
PZ-B	NS	NS	NS	NS
PZ-C	ND	ND	ND	ND
PZ-D	ND	ND	ND	ND
PSF92-01	ND	ND	ND	ND
PSF92-05	ND	ND	NS	ND

NOTES:

1. All concentrations reported in ug/L.
2. TCE reporting limit = 0.6 ug/L.
3. NS = Not Sampled.
4. ND = Not Detected.
5. Contours represent isoconcentration of 5 ug/L (the MCL for TCE), and ND.
6. Isoconcentration lines not depicted west of Henry Drive.
7. Duplicate analysis for MW B354-99-12c, MW95-04, MW B354-99-13b and MW B354-01-30c. See Table 3-1 for results. The highest of the two values is indicated on the figure.
8. For re-analysis samples, the highest of the two values is indicated on the figure. See Table 3-1 for details of re-analysis.
9. On the inserted table, results above the detection limit are shown in bold.

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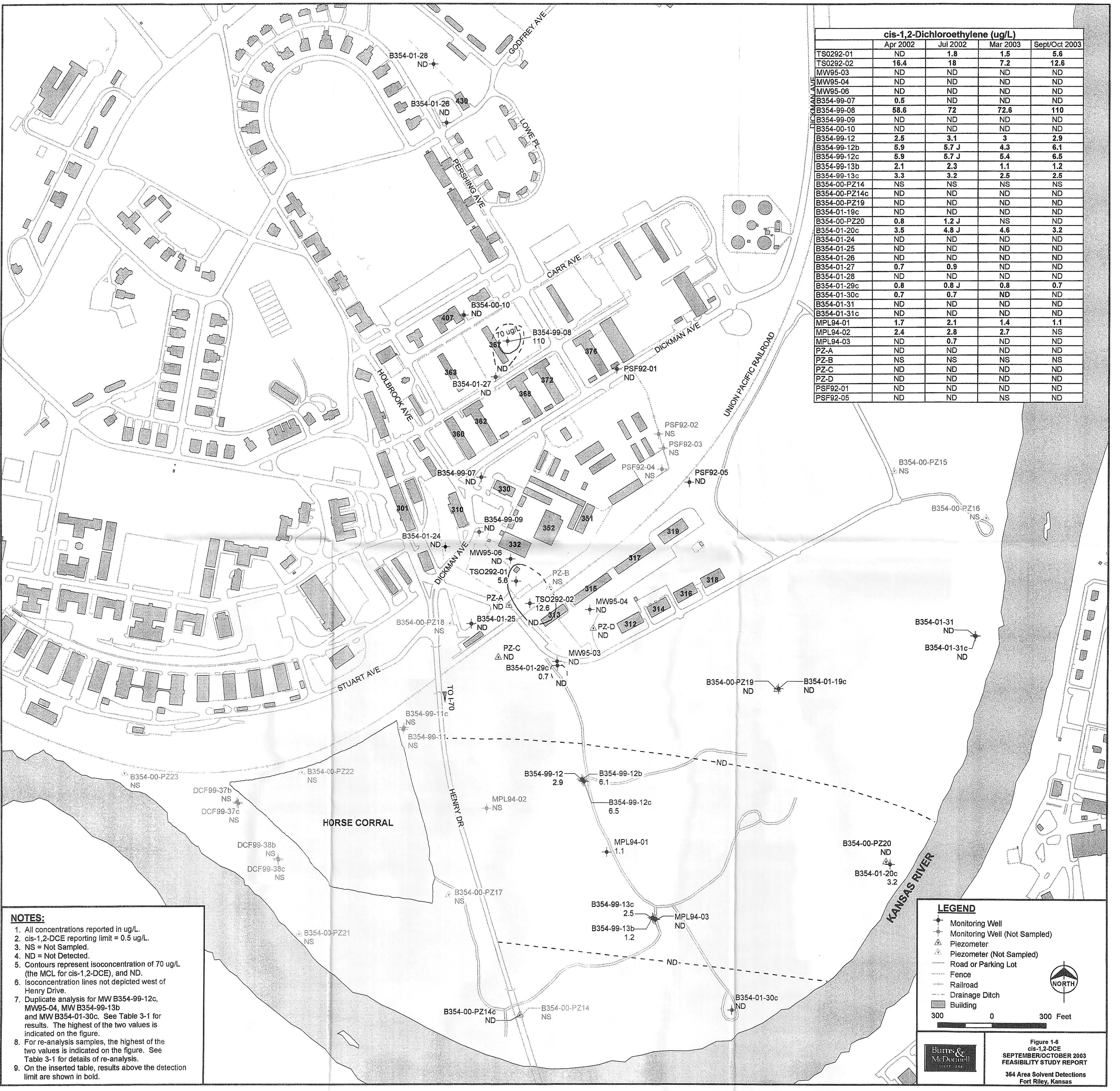
Figure 1-5
TCE
SEPTEMBER/OCTOBER 2003
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas



cis-1,2-Dichloroethylene (ug/L)	Apr 2002	Jul 2002	Mar 2003	Sept/Oct 2003
TS0292-01	ND	**1.8**	**1.5**	**5.6**
TS0292-02	**16.4**	**18**	**7.2**	**12.6**
MW95-03	ND	ND	ND	ND
MW95-04	ND	ND	ND	ND
MW95-06	ND	ND	ND	ND
B354-99-07	**0.5**	ND	ND	ND
B354-99-08	**58.6**	**72**	**72.6**	**110**
B354-99-09	ND	ND	ND	ND
B354-00-10	ND	ND	ND	ND
B354-99-12	**2.5**	**3.1**	**3**	**2.9**
B354-99-12b	**5.9**	**5.7 J**	**4.3**	**6.1**
B354-99-12c	**5.9**	**5.7 J**	**5.4**	**6.5**
B354-99-13b	**2.1**	**2.3**	**1.1**	**1.2**
B354-99-13c	**3.3**	**3.2**	**2.5**	**2.5**
B354-00-PZ14	NS	NS	NS	NS
B354-00-PZ14c	ND	ND	ND	ND
B354-00-PZ19	ND	ND	ND	ND
B354-01-19c	ND	ND	ND	ND
B354-00-PZ20	**0.8**	**1.2 J**	NS	ND
B354-01-20c	**3.5**	**4.8 J**	**4.6**	**3.2**
B354-01-24	ND	ND	ND	ND
B354-01-25	ND	ND	ND	ND
B354-01-26	ND	ND	ND	ND
B354-01-27	**0.7**	**0.9**	ND	ND
B354-01-28	ND	ND	ND	ND
B354-01-29c	**0.8**	**0.8 J**	**0.8**	**0.7**
B354-01-30c	**0.7**	**0.7**	ND	ND
B354-01-31	ND	ND	ND	ND
B354-01-31c	ND	ND	ND	ND
MPL94-01	**1.7**	**2.1**	**1.4**	**1.1**
MPL94-02	**2.4**	**2.8**	**2.7**	NS
MPL94-03	ND	**0.7**	ND	ND
PZ-A	ND	ND	ND	ND
PZ-B	NS	NS	NS	NS
PZ-C	ND	ND	ND	ND
PZ-D	ND	ND	ND	ND
PSF92-01	ND	ND	ND	ND
PSF92-05	ND	ND	NS	ND

NOTES:

1. All concentrations reported in ug/L.
2. cis-1,2-DCE reporting limit = 0.5 ug/L.
3. NS = Not Sampled.
4. ND = Not Detected.
5. Contours represent isoconcentration of 70 ug/L (the MCL for cis-1,2-DCE), and ND.
6. Isoconcentration lines not depicted west of Henry Drive.
7. Duplicate analysis for MW B354-99-12c, MW95-04, MW B354-99-13b and MW B354-01-30c. See Table 3-1 for results. The highest of the two values is indicated on the figure.
8. For re-analysis samples, the highest of the two values is indicated on the figure. See Table 3-1 for details of re-analysis.
9. On the inserted table, results above the detection limit are shown in bold.

LEGEND

- Monitoring Well
- Monitoring Well (Not Sampled)
- Piezometer
- Piezometer (Not Sampled)
- Road or Parking Lot
- Fence
- Railroad
- Drainage Ditch
- Building

NORTH

300 0 300 Feet

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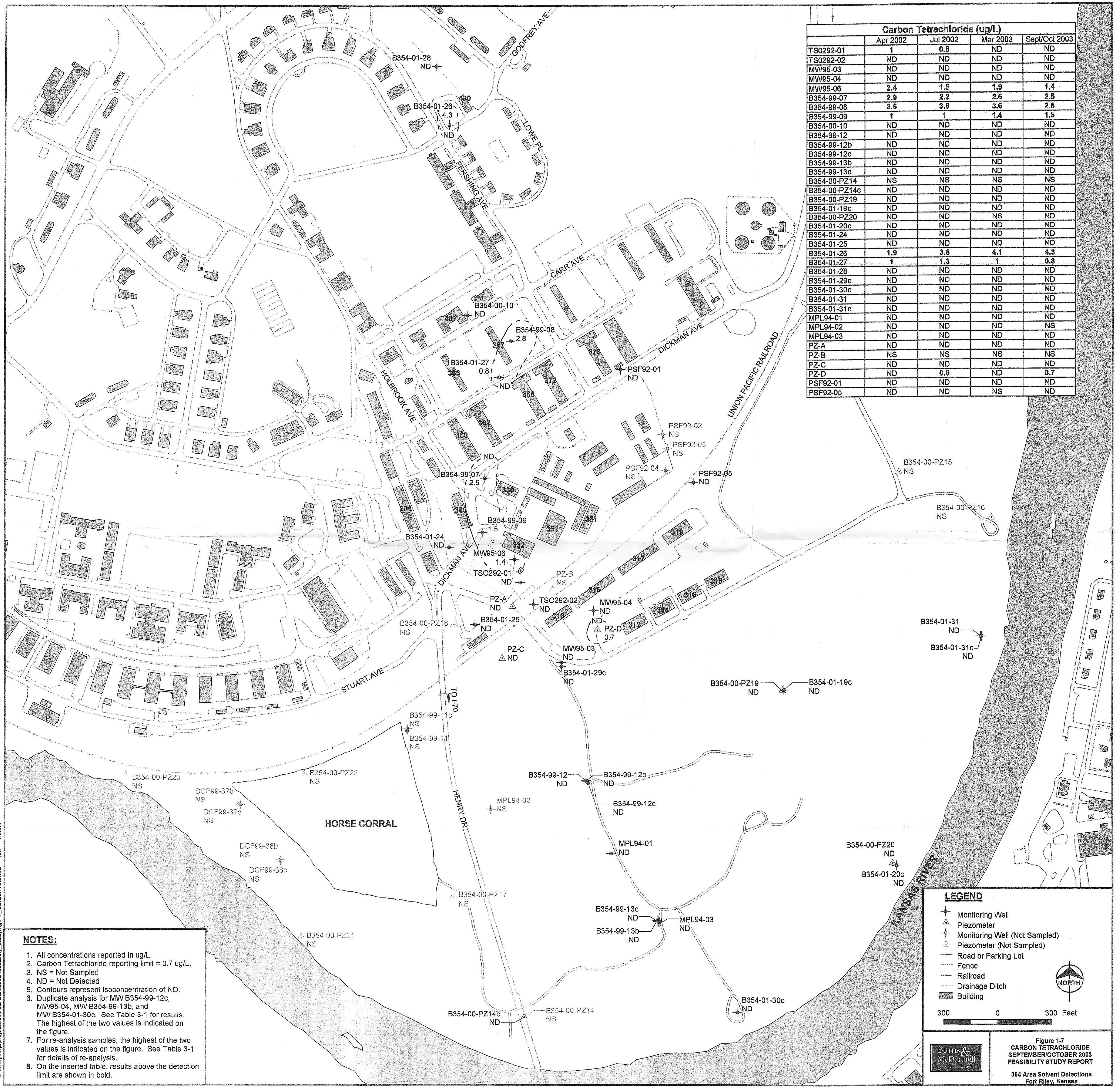
Figure 1-8
cis-1,2-DCE
SEPTEMBER/OCTOBER 2003
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas



Carbon Tetrachloride (ug/L)				
	Apr 2002	Jul 2002	Mar 2003	Sept/Oct 2003
TS0292-01	**1**	**0.8**	ND	ND
TS0292-02	ND	ND	ND	ND
MW95-03	ND	ND	ND	ND
MW95-04	ND	ND	ND	ND
MW95-06	**2.4**	**1.5**	**1.9**	**1.4**
B354-99-07	**2.9**	**2.2**	**2.6**	**2.5**
B354-99-08	**3.6**	**3.8**	**3.6**	**2.8**
B354-99-09	**1**	**1**	**1.4**	**1.5**
B354-00-10	ND	ND	ND	ND
B354-99-12	ND	ND	ND	ND
B354-99-12b	ND	ND	ND	ND
B354-99-12c	ND	ND	ND	ND
B354-99-13b	ND	ND	ND	ND
B354-99-13c	ND	ND	ND	ND
B354-00-PZ14	NS	NS	NS	NS
B354-00-PZ14c	ND	ND	ND	ND
B354-00-PZ19	ND	ND	ND	ND
B354-01-19c	ND	ND	ND	ND
B354-00-PZ20	ND	ND	NS	ND
B354-01-20c	ND	ND	ND	ND
B354-01-24	ND	ND	ND	ND
B354-01-25	ND	ND	ND	ND
B354-01-26	**1.9**	**3.8**	**4.1**	**4.3**
B354-01-27	**1**	**1.3**	**1**	**0.8**
B354-01-28	ND	ND	ND	ND
B354-01-29c	ND	ND	ND	ND
B354-01-30c	ND	ND	ND	ND
B354-01-31	ND	ND	ND	ND
B354-01-31c	ND	ND	ND	ND
MPL94-01	ND	ND	ND	ND
MPL94-02	ND	ND	ND	NS
MPL94-03	ND	ND	ND	ND
PZ-A	ND	ND	ND	ND
PZ-B	NS	NS	NS	NS
PZ-C	ND	ND	ND	ND
PZ-D	ND	**0.8**	ND	**0.7**
PSF92-01	ND	ND	ND	ND
PSF92-05	ND	ND	NS	ND

NOTES:

1. All concentrations reported in ug/L.
2. Carbon Tetrachloride reporting limit = 0.7 ug/L.
3. NS = Not Sampled
4. ND = Not Detected
5. Contours represent isoconcentration of ND.
6. Duplicate analysis for MW B354-99-12c, MW95-04, MW B354-99-13b, and MW B354-01-30c. See Table 3-1 for results. The highest of the two values is indicated on the figure.
7. For re-analysis samples, the highest of the two values is indicated on the figure. See Table 3-1 for details of re-analysis.
8. On the inserted table, results above the detection limit are shown in bold.

LEGEND

- Monitoring Well
- Piezometer
- Monitoring Well (Not Sampled)
- Piezometer (Not Sampled)
- Road or Parking Lot
- Fence
- Railroad
- Drainage Ditch
- Building

NORTH

300 0 300 Feet

Burns & McDonnell

Figure 1-7
CARBON TETRACHLORIDE
SEPTEMBER/OCTOBER 2003
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas

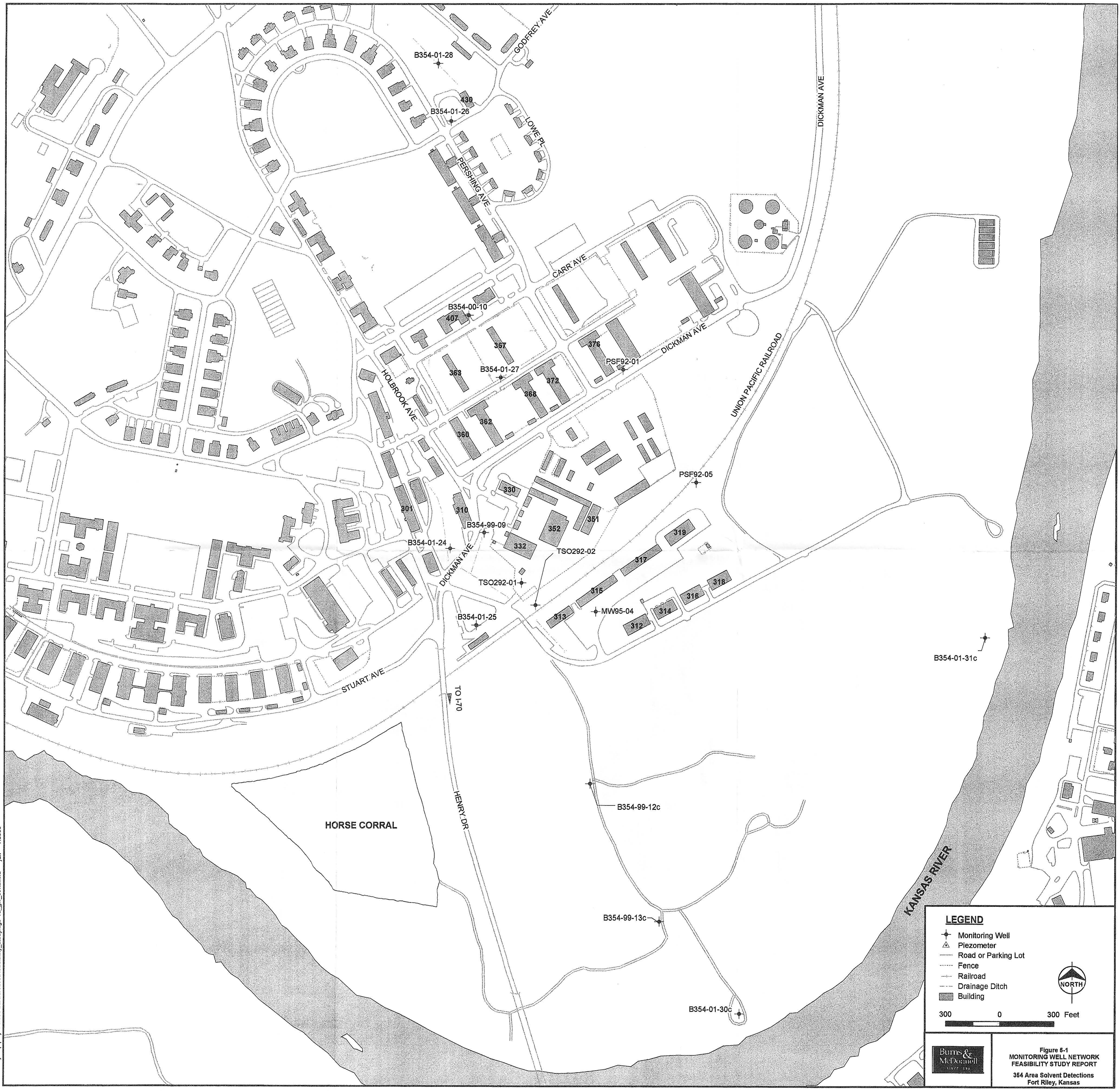


Figure 5-1
MONITORING WELL NETWORK
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas

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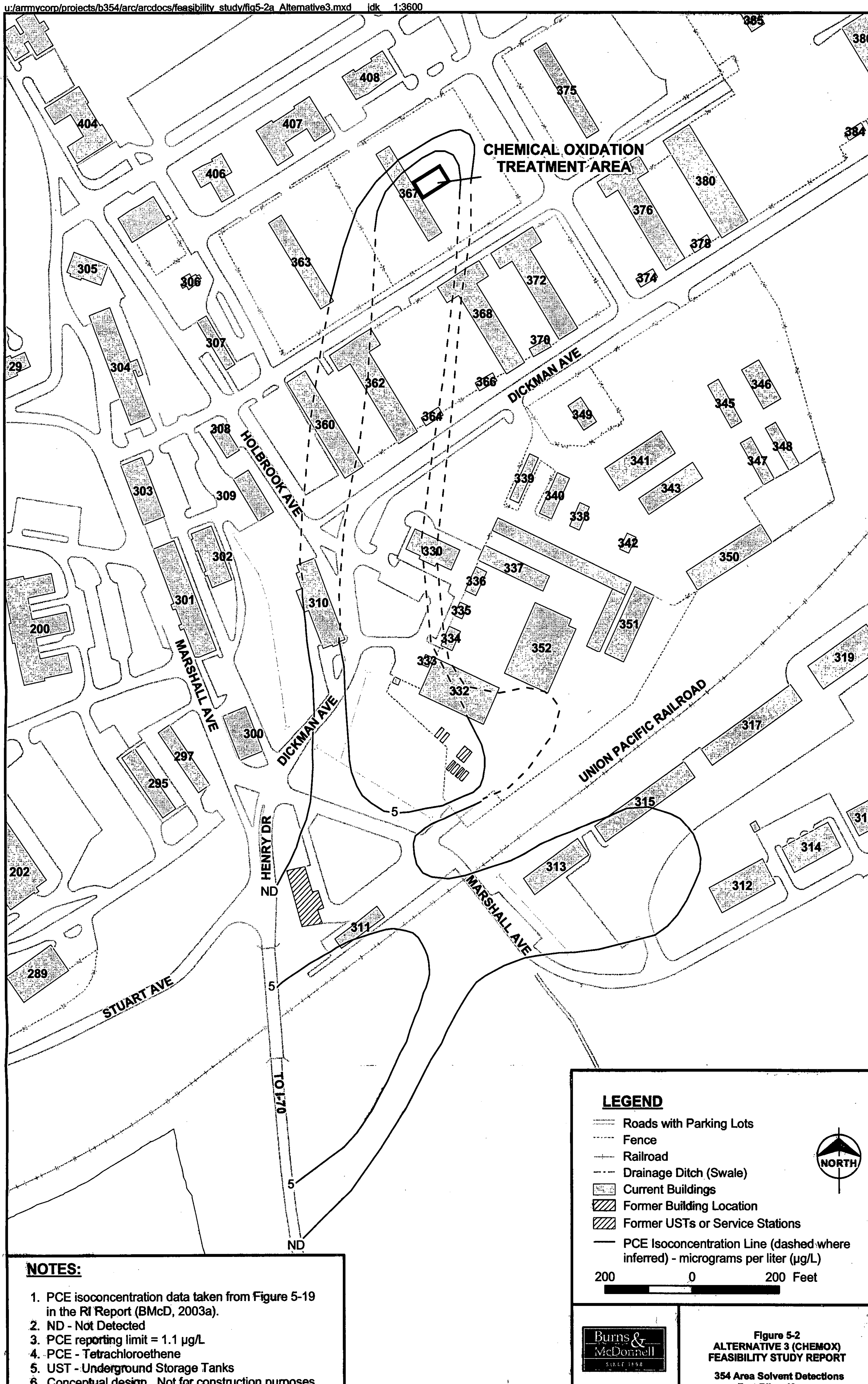

NOTES:

1. PCE isoconcentration data taken from Figure 5-19 in the RI Report (BMcD, 2003a).
2. ND - Not Detected
3. PCE reporting limit = 1.1 µg/L
4. PCE - Tetrachloroethene
5. UST - Underground Storage Tanks
6. Conceptual design. Not for construction purposes.

Burns & McDonnell
SINCE 1898

Figure 5-2
ALTERNATIVE 3 (CHEMOX)
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas

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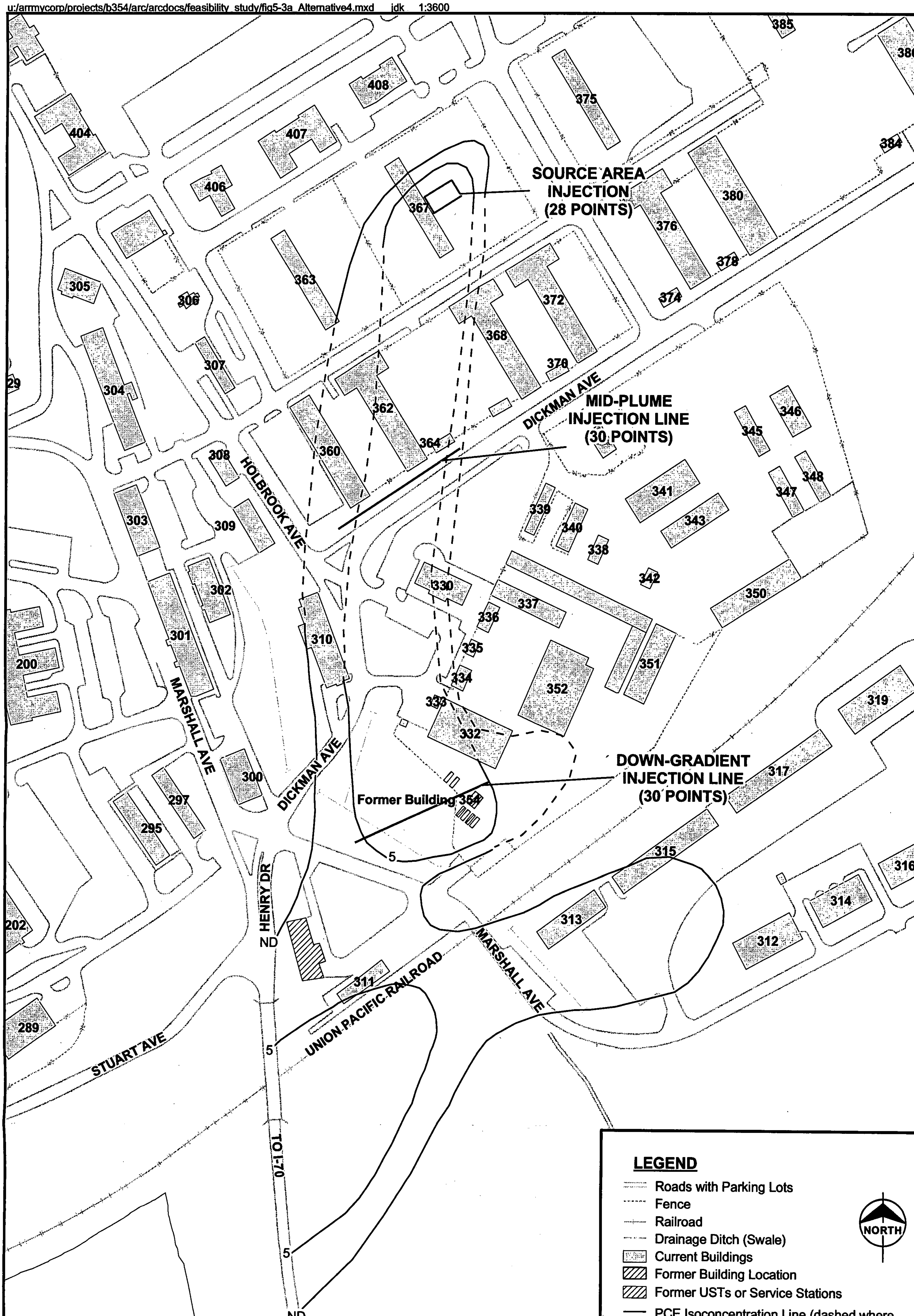

LEGEND

- Roads with Parking Lots
- Fence
- Railroad
- Drainage Ditch (Swale)
- Current Buildings
- Former Building Location
- Former USTs or Service Stations
- PCE Isoconcentration Line (dashed where inferred) - micrograms per liter (µg/L)

200 0 200 Feet

NORTH

NOTES:

1. PCE isoconcentration data taken from Figure 5-19 in the RI Report (BMcD, 2003a).
2. ND - Not Detected
3. PCE reporting limit = 1.1 µg/L
4. PCE - Tetrachloroethene
5. UST - Underground Storage Tanks
6. EAB - Enhanced Anarobic Bioremediation
7. Conceptual design. Not for construction purposes.

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Figure 5-3
ALTERNATIVE 4 (EAB)
FEASIBILITY STUDY REPORT

354 Area Solvent Detections
Fort Riley, Kansas

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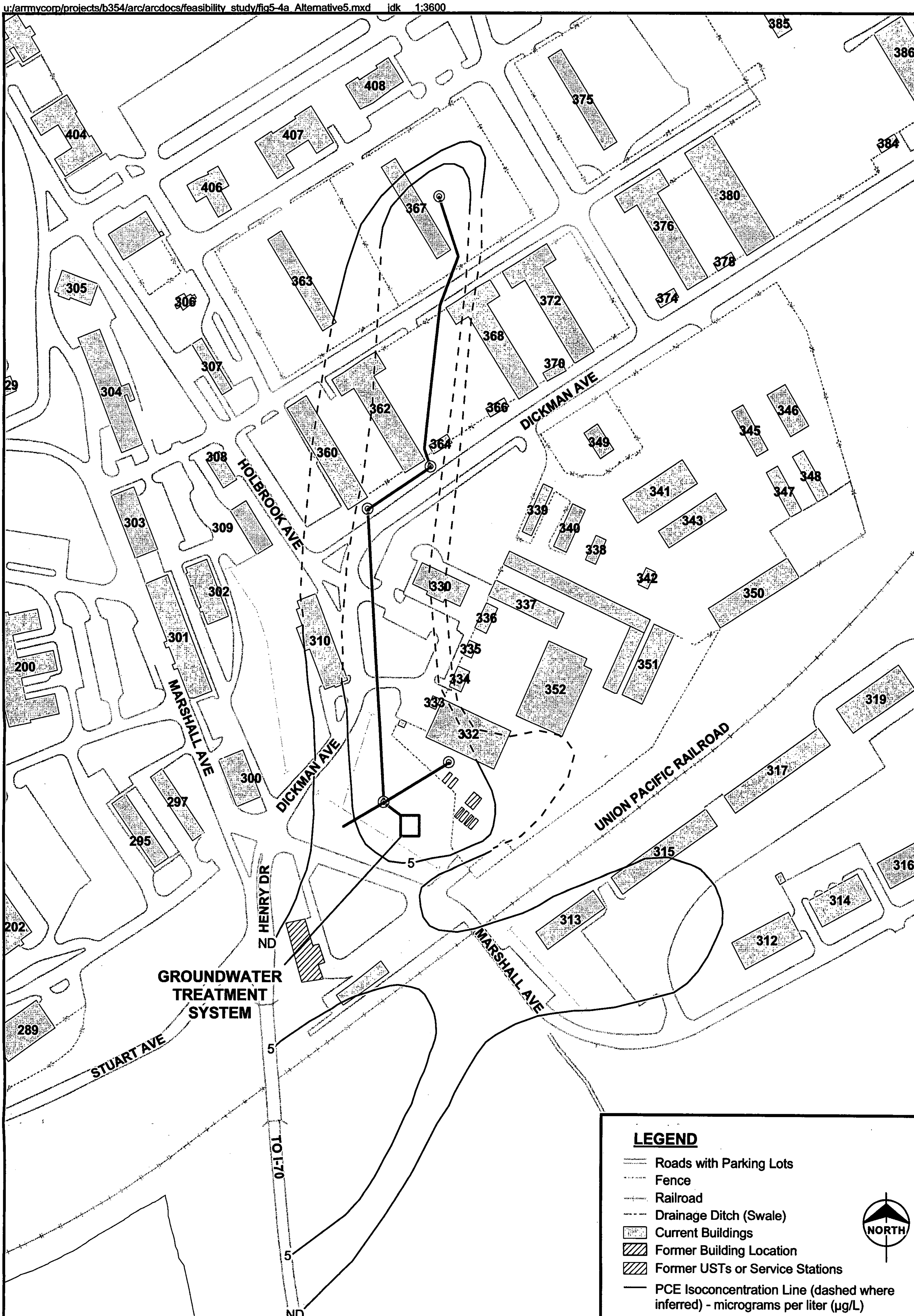

NOTES:

1. PCE isoconcentration data taken from Figure 5-19 in the RI Report (BMcD, 2003a).
2. ND - Not Detected
3. PCE reporting limit = 1.1 µg/L
4. PCE - Tetrachloroethene
5. UST - Underground Storage Tanks
6. Conceptual design. Not for construction purposes.

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Figure 5-4
ALTERNATIVE 5 (PUMP & TREAT)
FEASIBILITY STUDY REPORT
354 Area Solvent Detections
Fort Riley, Kansas

Appendix 2A
List of Potential ARARs
Supplied by the KDHE

Appendix 2A
List of Potential ARARs Supplied by the KDHE
Feasibility Study Report
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Archaeological and Historic Preservation Act of 1974 16 U.S.C. § 469 et seq.	Provides for the preservation of historical or archaeological data which might be destroyed or lost as the result of 1) flooding, building of access roads, relocation of railroads and highways, and other alterations of terrain caused by the construction of a dam by government or persons, or 2) alteration of terrain caused by Federal construction projects or federally licensed activity or program.	Will be applicable if construction projects or alteration of terrain at a site have the potential to destroy historical or archaeological materials.
Clean Air Act (CAA) 42 U.S.C. § 7401 et seq. as amended in 1977 and 1990	Regulates air emissions from area, stationary, and mobile sources. Authorizes EPA to establish National Ambient Air Quality Standards.	May be applicable if remedial actions result in emissions of contaminants to the air.
Standards of Performance for New Stationary Sources (40 CFR 60)	Identifies standards of performance for new stationary sources of air emissions. Provides emission guidelines and compliance times.	Will be applicable for new stationary sources of air emissions.
National Emission Standards for Hazardous Air Pollutants (40 CFR 61)	Identifies emission standards for specific hazardous air pollutants.	Will be applicable if the identified hazardous air pollutants are emitted from a site.
National Emission Standards for Hazardous Air Pollutants for Source Categories (40 CFR 63)	Identifies emission standards for hazardous air pollutants that originate from specific categories of sources.	Will be applicable if the identified hazardous air pollutants are emitted from a specific source category that has been identified.
Clean Water Act (CWA) of 1977 33 U.S.C. § 1251 et seq. as amended in 1987	Implements a system to impose effluent limitations on, or otherwise prevent, discharges of pollutants into any waters of the United States from any point source.	Will be applicable if discharges to streams, rivers, or lakes occur from a site.
National Pollutant Discharge Elimination System (NPDES) (40 CFR 122)	Regulates discharges of pollutants from any point source into waters of the United States.	Will be applicable if water from the site will be discharged onto land or into streams, rivers or lakes.
Storm Water Discharge Requirements NPDES (40 CFR 122.26)	Provide requirements to obtain a permit to discharge to the storm water sewer system under the NPDES program.	Will be applicable if the site has storm water that comes in contact with construction or industrial activity or if the selected remedy involves discharge of treated water to surface waters.
Federal Water Quality Standards (40 CFR 131)	Establishes methods and requirements for states in the development of ambient water quality criteria for the protection of aquatic organisms and/or the protection of human health.	May be indirectly applicable to surface water remediation and is directly applicable to surface water discharges.

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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Clean Water Act (CWA) of 1977		
General Pre-treatment Regulations for Existing and New Sources of Pollution for Publically Owned Treatment Works (POTW) (40 CFR 403)	Provides effluent limitations and guidelines for existing sources, standards of performance for new sources, and pre-treatment standards for new and existing sources.	Will be applicable if wastewater from a site is discharged to a POTW.
Wetlands Protection (40 CFR 22, 40 CFR 230 to 233, and 33 CFR 320 to 330)	Allows for permitting of discharge of dredged or fill material to the waters of the United States if no practicable alternatives exists that are less damaging to the aquatic environment. Applicants must demonstrate that the impact to wetlands is minimized.	Will be applicable if designated wetlands are impacted by a remedy.
Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) of 1980 42 U.S.C. § 9601 et seq. as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986	Enacted to provide Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health and the environment. Established a trust fund (i.e., Superfund) to provide for cleanup when no responsible party is identified. Provides for liability of persons responsible for releases of hazardous substances. Established prohibitions and requirements concerning closed and abandoned hazardous waste sites.	Will be applicable if the site is on the EPA National Priorities List (NPL). May be applicable for any site where a release of hazardous substances has occurred.
National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR 300)	Federal government's blueprint for responding to spills or releases of oil and hazardous substances.	
Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 42 U.S.C. § 11001 et seq.	Designated to help local communities protect public health, safety and the environment from chemical hazards. Enables states and communities to prepare to respond to unplanned releases of hazardous substances. Requires facilities at which hazardous substances are present to report the presence of these materials to emergency responders. Requires companies to report the release of hazardous substances.	Will be applicable if hazardous chemicals are stored or used at a facility.

Appendix 2A
List of Potential ARARs Supplied by the KDHE
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Endangered Species Act of 1973 7 U.S.C. § 136; 16 U.S.C. § 460 et seq.	Provides a program for conservation of threatened and endangered plants and animals and the habitats in which they are found.	Will be applicable if threatened or endangered species, or their habitats are present at or near a site.
Explosives 18 U.S.C. § 847	Regulates commerce in explosives. Requires licensing and permitting, record keeping and reporting for purchase and use of explosives. Provides standards for storage of explosive materials.	Will be applicable if explosives are purchased, stored or used at a site.
Federal Hazardous Materials Transportation Law 49 U.S.C. § 5101 et seq.	Regulates the transportation of hazardous wastes and hazardous substances by aircraft, railcars, vessels, and motor vehicles. Requires employers to train, test and maintain training records for all hazmat employees.	Will be applicable if hazardous materials are transported to or from a site.
Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1972 7 U.S.C. § 136 et seq.	Provides Federal control of pesticide distribution, sale and use. Allows EPA to study the consequences of pesticide use. Requires users of pesticides to take exams for certification as applicators of pesticides. Pesticide users must register purchases of these materials.	May be applicable if pesticides were distributed, sold or used at a site.
Fish and Wildlife Conservation Act 16 U.S.C. § 2901 to 2911	Action to conserve fish and wildlife, particularly those species which are indigenous to the state.	Will be applicable if significant populations are present at a site or they are affected by site activities.
Fish and Wildlife Coordination Act 16 U.S.C. § 661-667e	The Act allows the Departments of Agriculture and Commerce to assist Federal and State agencies to study the effects of domestic sewage, trade wastes, and other polluting substances on wildlife.	Will be applicable if significant populations are present at a site or they are affected by site activities.
Flood Control Act of 1944 16 U.S.C. § 460	Provides the public with knowledge of flood hazards and promotes prudent use and management of flood plains.	Will be applicable if a site is located on a designated flood plain.
National Historic Preservation Act of 1966 16 U.S.C. § 470 et seq.	Establishes a national registry of historic sites. Provides for preservation of historic or prehistoric resources.	Will be applicable if a site is listed on, or is potentially eligible for listing on, the National Register and if activities requiring permitting are initiated at a site.

Appendix 2A
List of Potential ARARs Supplied by the KDHE
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Occupational Safety and Health Act (OSHA) of 1970 29 U.S.C. § 651 et seq.	Enacted to ensure worker and workplace safety. Employers are required to provide workers a place of employment that is free from recognized hazards to safety and health.	Applies to workers and workplaces.
Occupational Safety and Health Standards (29 CFR 1910)	Provides standards for workers and the workplace including: working surfaces; means of egress; ventilation; noise; hazardous materials; personal protective equipment; sanitation; medical services and first aid; fire protection, detection, and suppression; materials handling and storage; machinery and machinery guards; power tools; and welding and electrical equipment. Also requires training for workers.	Will be applicable to workers and workplaces including hazardous waste sites.
Safety and Health Regulations for Construction (29 CFR 1926)	Provides standards for construction activities including: work practices; safety equipment; scaffolding and ladders; fall protection; heavy equipment; excavations; concrete and masonry construction; steel erection; tunnels and shafts; demolition; use of explosives; power transmission and distribution; and overhead protection.	Will be applicable to workers and workplaces where construction activities take place.
Resource Conservation and Recovery Act (RCRA) of 1976 42 U.S.C. § 6901 et seq. as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA) and 1986, the Federal Facilities Compliance Act of 1992, and the Land Disposal Program Flexibility Act of 1996.	Enacted to provide control of hazardous waste by imposing management requirements on generators and transporters of hazardous waste and upon owners and operators of treatment, storage and disposal (TSD) facilities. Also set forth a framework for management of non-hazardous waste. Focuses only on active or future facilities. HSWA requires phasing out land disposal of hazardous waste.	Applies to active hazardous and solid waste operations including facilities that treat, store and dispose of these materials as well as generators and transporters of hazardous wastes.
Solid Waste Disposal Facility Criteria (40 CFR 257 - 258)	Regulations apply to owners and operators of facilities that treat, store or dispose of solid wastes.	Will be applicable if site activities are analogous to solid waste facility activities.
Standards for Identification and Listing of Hazardous Waste (40 CFR 261)	Provides criteria for identification of hazardous and solid wastes.	Will be applicable for identifying hazardous wastes.
Standards Applicable to Generators of Hazardous Waste (40 CFR 262)	Regulates the manifesting, pre-transport requirements, and record keeping and reporting for hazardous waste generators.	Will be applicable if hazardous waste is generated at a site.
Standards Applicable to Transporters of Hazardous	Establishes standards which apply to persons transporting hazardous waste within the United	Will be applicable if hazardous waste is disposed off site.

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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Waste (40 CFR 263)	States if the transportation requires a manifest under RCRA.	
Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (40 CFR 264)	Regulations apply to owners and operators of facilities that treat, store, or dispose of hazardous waste through the use of surface impoundments, waste piles, incinerators, land treatment units, and landfills.	Will be applicable if site activities are analogous to hazardous waste facility activities.
Manifesting, Record Keeping, and Reporting Requirements (40 CFR 264.70 to 264.77)	These standards apply to owners and operators of all facilities which treat, store or dispose of hazardous wastes.	Will be applicable if site activities are analogous to hazardous waste facility activities.
Releases from Solid Waste Management Units (40 CFR 264.90 to 264.101)	Regulations apply to owners or operators of hazardous waste treatment, storage or disposal facilities.	Will be applicable if solid waste is stored at a site.
Closure and Post Closure Requirements (40 CFR 264.110 to 264.120)	Facility owner or operator must close a hazardous waste facility in a way that minimizes the need for further maintenance and maximizes the protection of human health and the environment.	Will be applicable upon the closure and post closure of a hazardous waste facility.
Resource Conservation and Recovery Act (RCRA)		
Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage and Disposal Facilities (40 CFR 265)	Regulations apply to owners and operators of facilities that treat, store, or dispose of hazardous waste.	Will be applicable if site activities are analogous to hazardous waste facility activities.
Land Disposal Restrictions (40 CFR 268)	Identifies hazardous wastes that are restricted from land disposal and defines those limited circumstances under which an otherwise prohibited waste may continue to be land disposed.	Will be applicable depending on the type of waste generated at the site.
Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (40 CFR 280)	Establishes regulations relating to underground storage tanks.	Will be applicable if underground storage tanks are present at a site.

Appendix 2A
List of Potential ARARs Supplied by the KDHE
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354 Area Solvent Detections

Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Safe Drinking Water Act (SDWA) of 1974 42 U.S.C. § 300f et seq. as amended in 1986	Established to protect the quality of drinking water in the Unites States. Focuses on all waters actually or potentially designed for drinking use, whether from above ground or underground sources. The Act authorized EPA to establish safe standards of purity and required all owners or operators of public water supply systems to comply with primary (health-related) standards.	May be applicable, relevant or appropriate at sites where waters that are used or may potentially be used as drinking water supplies are impacted or threatened.
National Primary Drinking Water Regulations and Implementation (40 CFR 141 and 142)	Establishes maximum contaminant levels (MCLs) which are health risk based standards for public water systems.	Will be applicable at the distribution point (i.e., at the tap). Will be relevant and appropriate for groundwater cleanup at sites where potential drinking water sources (aquifers) are impacted.
National Secondary Drinking Water Standards (40 CFR 143)	Establishes welfare-based secondary standards for public water systems.	Will be applicable at the distribution point (i.e., at the tap).
Underground Injection Control Program (40 CFR 144 to 148)	Assures that Underground Injection will not endanger drinking water sources. Provides regulations governing the use of underground injection wells including: identification of the classifications of injection wells; and the permitting, construction, operation, monitoring, testing, and reporting requirements. Also provides requirements for plugging of injection wells.	Will be applicable if underground injection of liquids or air is conducted as part of a site remedy.
Toxic Substances Control Act (TSCA) of 1976 15 U.S.C. § 2601 et seq.	Enacted to give EPA the ability to track industrial chemicals currently produced or imported into the United States. EPA screens these chemicals and may require reporting or testing of those that pose an environmental or human-health hazard. EPA may ban the manufacture and import of those chemicals that pose an unreasonable risk.	Will be applicable if site activities involve handling of toxic substances such as polychlorinated biphenyls (PCBs) or remediation of these substances.

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List of Potential ARARs Supplied by the KDHE
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Ambient Air Quality Standards and Air Pollution Control K.A.R 28-19	Regulates air emissions from processing operations, indirect heating equipment, and incinerators. Establishes requirements for Attainment and Non-Attainment Areas. Establishes requirements for Stack Heights. Restricts open burning.	Will be applicable if a remedy results in the release of contaminants to the air.
Asbestos Control K.A.R 28-50	Established the requirements for licensing of businesses and examination and certification of asbestos workers. Established requirement for notification of asbestos projects. Establishes work practices for asbestos projects.	Will be applicable if asbestos is handled or removed from a site or encapsulated.
Agricultural Chemicals, Commercial Fertilizers, Anhydrous Ammonia, and Chemigation K.A.R. 4-1, 4-4, 4-10 and 4-20	Requires labeling and registration of agricultural chemicals. Provides regulations for storage and secondary containment, transportation and record keeping for commercial fertilizers and anhydrous ammonia. Requires permitting and certification of operators of chemigation equipment.	Will be applicable if agricultural chemicals, commercial fertilizers or anhydrous ammonia are used at site. Will be applicable if chemicals or animal wastes are applied by chemigation.
Construction, Operation, Monitoring and Abandonment of Salt Solution Mining Wells K.A.R 28-43	Regulates the construction, operation, monitoring, testing and abandonment of salt solution mining wells.	Will be applicable if salt solution mining wells are present.
Emergency Planning and Right-to-Know K.A.R 28-65	Designated to help local communities protect public health, safety and the environment from chemical hazards. Enables communities to prepare to respond to unplanned releases of hazardous substances. Requires facilities at which hazardous substances are present to report the presence of these materials to emergency responders. Requires companies to report the release of hazardous substances.	Will be applicable if hazardous chemicals are stored or used at a site.
Explosive Materials K.A.R. 22-4	Requires all contractors to obtain explosive storage site permits before moving, storing or using any explosives or blasting agents at any job site with the state.	Will be applicable if explosives or blasting agents are used or stored at a site.
Hazardous Waste Management Standards and Regulations K.A.R 28-31	Identifies the characteristics and listing of hazardous waste. Prohibits underground burial of hazardous waste except as granted by EPA or KDHE. Establishes restrictions on land disposal. Establishes standards for generators or transporters of hazardous waste. Establishes standards for hazardous waste storage, treatment and disposal	Will be applicable if hazardous wastes are present at a site.

Appendix 2A
List of Potential ARARs Supplied by the KDHE
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
	facilities.	
Hydrocarbon Storage Wells and Well Systems K.A.R 28-45	Establishes a system for permitting of hydrocarbon storage wells. Establishes requirements for construction, operation and monitoring, and plugging of hydrocarbon storage wells.	Will be applicable if hydrocarbon storage wells are present at a site.
Kansas Board of Technical Professions K.A.R. 66-6 through 66-14	Establishes the requirements for licensing of engineers, land surveyors, geologists and architects.	Will be applicable if the services of a geologist, engineer or land surveyor are required for site investigations or remediation.
Kansas Drinking Water Standards K.A.R 28-15	The State of Kansas has promulgated drinking water regulations designed to protect human health from the potential adverse effects of drinking water contaminants. The regulation establishes water quality standards and MCLs.	Will be applicable if groundwater is currently or could potentially be used in the future as a drinking water source.
Kansas Drycleaner Environmental Response Act K.A.R 28-68	Enacted to provide funds to assist with assessment and corrective action of former and existing drycleaner facilities. Requires registration of drycleaning facilities and compliance with waste management measures.	May be applicable if a drycleaner operated onsite.
Kansas Historic Preservation Act K.A.R. 118-3	Provides for the protection and preservation of sites and buildings listed on state or federal historic registries.	Will be applicable if a site or building is listed on the state or federal historic registry and if activities requiring permitting are initiated at a site.
Kansas Water Appropriations Act K.A.R. 5-1 through 5-10 and 5-50	Establishes the requirements for obtaining and maintaining and transferring water appropriations.	Will be applicable if water appropriations are required for groundwater remediation.
Mined Land Reclamation K.A.R. 47-16	Allows for the reclamation of mined land and associated waters.	Will be applicable if mined land or associated waters are to be reclaimed.

Appendix 2A
List of Potential ARARs Supplied by the KDHE
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Non-Game, Threatened or Endangered Species K.A.R. 115-15	Identifies Threatened and Endangered Species.	Will be applicable if any of the identified species are present at a site.
PCB Facility Construction Permit Standards and Regulations K.A.R 28-55	Establishes the requirement for permitting of facilities constructed for the treatment, storage or disposal of materials containing polychlorinated biphenyls (PCBs). Establishes standards for PCB facilities.	Will be applicable if treatment, storage or disposal of materials containing PCBs occurs.
Pesticides K.A.R. 4-13	Requires licensing of pesticide businesses and certification of persons that apply pesticides.	Will be applicable if pesticides are present at a site or application of pesticides occurs.
Petroleum Products Storage Tanks K.A.R 28-44	Provides requirements for permitting of the installation and operation of underground storage tanks (USTs). Provides requirements for design and construction of storage tanks. Provides a system for licensing contractors who install and test USTs. Requires implementation of methods for detecting releases and reporting releases from USTs.	Will be applicable if petroleum storage tanks are or were present at a site.
Radiation K.A.R 28-35	Regulations require registration of radiation producing devices and licensing of sources of radiation. Provides standards for protection against radiation. Provides requirements for industrial radiographic operations and wireline and subsurface tracer studies.	Will be applicable if radiation producing devices or sources of radiation are present at or are used at a site.
Solid Waste Management K.A.R 28-29	Provides standards for management of solid wastes. Establishes administrative procedures. Establishes the requirement for development and submittal of Solid Waste Management Plans.	Will be applicable if solid waste is generated, stored or disposed at a site.
Spill Reporting K.A.R 28-48	Requires reporting of unpermitted discharges or accidental spills. Requires that containment and immediate environmental response measures are implemented. Also provides for technical assistance for mercury-related spills.	Will be applicable if unpermitted discharges or accidental spills occur at a site.

Appendix 2A
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Potentially Applicable Relevant and Appropriate Requirements	Description	Comment
Underground Injection Control Regulations K.A.R 28-46	Provides regulations governing the use of underground injection wells including: identification of the classifications of injection wells; and the permitting, construction, operation, monitoring, testing, and reporting requirements. Also provides requirements for plugging of injection wells.	Will be applicable if the remedy involves the injection of fluids or air into the subsurface.
Voluntary Cleanup and Property Redevelopment Program K.A.R 28-71	Provides a mechanism for property owners, facility operators, prospective purchasers, and local governments to voluntarily address contaminated properties with technical and regulatory guidance from KDHE.	May be applicable if a site meets the criteria for acceptance into the Voluntary Cleanup Program.
Water Pollution Control K.A.R 28-16	Provides regulation of sewage discharge. Establishes pre-treatment standards for industry. Designates uses of rivers and streams. Establishes River Basin Quality Criteria and Surface Water Quality Criteria. Provides for the establishment of Critical Water Quality Management Areas.	Will be applicable if water is to be discharged to state waterways.
Water Well Contractor's License; Water Well Construction and Abandonment K.A.R 28-30	Establishes the requirements for licensing of drillers. Regulates drilling activities including the construction of wells.	Will be applicable if drilling and/or well construction or abandonment is conducted at a site.

Appendix 5A
Cost Analysis Tables

Table 5A-1
Cost Estimate for Alternative 1
Feasibility Study Report
354 Area Solvent Detections

No Action

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Periodic Costs						
1.0	Five-Year Review of Remedial Action[2]	ea	1	$ 20,000.00	$ 20,000	BMcD
1.1	Groundwater Sampling[2]	ea	1	$ 65,000.00	$ 65,000	BMcD
1.2	Closure Report	ls	1	$ 30,000.00	$ 30,000	BMcD

Subtotal Periodic Costs	**$**	**115,000**
Contingency (20%)[3]	**$**	**23,000**
Total Periodic Costs	**$**	**138,000**
Total Project Cost	**$**	**444,000**
Total Present Value Project Cost at 3.2%[4]	**$**	**298,668**

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 5A-3).
3) Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
4) Total present value based on 20 years with 5-year reviews until closure.

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

Table 5A-2
Present Value Costs for Alternative 1
Feasibility Study Report
354 Area Solvent Detections

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	$ -	$ -	$ 102,000	$ 102,000	0.854	$ 87,137
6	$ -	$ -	$ -	$ -	0.828	$ -
7	$ -	$ -	$ -	$ -	0.802	$ -
8	$ -	$ -	$ -	$ -	0.777	$ -
9	$ -	$ -	$ -	$ -	0.753	$ -
10	$ -	$ -	$ 102,000	$ 102,000	0.730	$ 74,439
11	$ -	$ -	$ -	$ -	0.707	$ -
12	$ -	$ -	$ -	$ -	0.685	$ -
13	$ -	$ -	$ -	$ -	0.664	$ -
14	$ -	$ -	$ -	$ -	0.643	$ -
15	$ -	$ -	$ 102,000	$ 102,000	0.623	$ 63,592
16	$ -	$ -	$ -	$ -	0.604	$ -
17	$ -	$ -	$ -	$ -	0.585	$ -
18	$ -	$ -	$ -	$ -	0.567	$ -
19	$ -	$ -	$ -	$ -	0.550	$ -
20	$ -	$ -	$ 138,000	$ 138,000	0.533	$ 73,500
Total	**$ -**	**$ -**	**$ 444,000**	**$ 444,000**		**$ 298,668**

Notes:

1. $102,000 includes the cost of a five-year review plus one round of groundwater sampling. $138,000 includes the cost of a five-year review, one round of groundwater sampling, and a closure report.

Table 5A-3
Cost Estimate for Alternative 2
Feasibility Study Report
354 Area Solvent Detections

Monitored Natural Attenuation with Institutional Controls

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Capital Costs						
2.1	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	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Annual Operation and Maintenance Costs						
2.2	Annual Natural Attenuation/Groundwater Monitoring[3]					
	Groundwater Sampling	ea	1	$ 16,000.00	$ 16,000	BMcD
	Laboratory Analyses	ea	1	$ 18,000.00	$ 18,000	BMcD
	Quality Control Summary Report (QCSR)	ea	1	$ 7,000.00	$ 7,000	BMcD
	Data Summary Report (DSR)	ea	1	$ 16,000.00	$ 16,000	BMcD
	E Data Submittal	ea	1	$ 5,000.00	$ 5,000	BMcD
	Project Administration	ea	1	$ 3,000.00	$ 3,000	BMcD
				Subtotal Annual O&M	**$ 65,000**	
				Contingency (20%)[2]	**$ 13,000**	
				Total Annual O&M	**$ 78,000**	

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Periodic Costs						
2.3	Five-Year Review of Remedial Action	ea	1	$ 20,000.00	$ 20,000	BMcD
2.4	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 **$ 1,326,000**
Total Present Value Project Cost at 3.2%[4] **$ 1,041,256**

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) Monitoring costs are based on current costs per round for the Area 354 monitoring network. Monitoring costs are revised for decreasing existing well network to a focused 16 monitoring well network. Current costs of approximately $104,000 per round for the larger well network are revised to approx. $65,000 per round for the focused network.
4) Total present value based on 15 years with 5-year reviews and monitoring until closure.

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

Table 5A-4
Present Value Costs for Alternative 2
Feasibility Study Report
354 Area Solvent Detections

Monitored Natural Attenuation with Institutional Controls

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	$ -	$ 78,000	$ -	$ 78,000	0.969	$ 75,581
2	$ -	$ 78,000	$ -	$ 78,000	0.939	$ 73,238
3	$ -	$ 78,000	$ -	$ 78,000	0.910	$ 70,967
4	$ -	$ 78,000	$ -	$ 78,000	0.882	$ 68,766
5	$ -	$ 78,000	$ 24,000	$ 102,000	0.854	$ 87,137
6	$ -	$ 78,000	$ -	$ 78,000	0.828	$ 64,568
7	$ -	$ 78,000	$ -	$ 78,000	0.802	$ 62,566
8	$ -	$ 78,000	$ -	$ 78,000	0.777	$ 60,626
9	$ -	$ 78,000	$ -	$ 78,000	0.753	$ 58,746
10	$ -	$ 78,000	$ 24,000	$ 102,000	0.730	$ 74,439
11	$ -	$ 78,000	$ -	$ 78,000	0.707	$ 55,159
12	$ -	$ 78,000	$ -	$ 78,000	0.685	$ 53,449
13	$ -	$ 78,000	$ -	$ 78,000	0.664	$ 51,792
14	$ -	$ 78,000	$ -	$ 78,000	0.643	$ 50,186
15	$ -	$ 78,000	$ 60,000	$ 138,000	0.623	$ 86,037
Total	**$ 48,000**	**$ 1,170,000**	**$ 108,000**	**$ 1,326,000**		**$ 1,041,256**

Notes:

1. Assume 15 years until closure.
2. Assume annual monitoring.
3. $24,000 includes the cost of a five-year review. $60,000 includes the cost of a five-year review and a closure report.

Table 5A-5
Cost Estimate for Alternative 3
Feasibility Study Report
354 Area Solvent Detections

In-Situ Chemical Oxidation with Institutional Controls and Monitored Natural Attenuation

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Capital Costs						
3.1	Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000	$ 40,000	BMcD
3.2	Full-scale Engineering and Design[2]	ls	1	$ 100,000	$ 100,000	BMcD
3.3	Bench scale testing - Laboratory tests to establish natural oxidant demand (bench fee, sample collection, shipping, work plan)					
	Vendor procurement	ls	1	$ 5,000	$ 5,000	BMcD
	Bench fee	ls	1	$ 7,500	$ 7,500	BMcD
	Mob/Demob. Geoprobe	ls	1	$ 1,000	$ 1,000	BMcD
	Geoprobing (2 days)	day	2	$ 2,500	$ 5,000	BMcD
	Utility clear	ls	1	$ 600	$ 600	BMcD
	Surveying	ls	1	$ 600	$ 600	BMcD
	Sample Collection/Field Prep. and Logistics (field 40 hr, prep. 8 hr, log. 8 hr)	ls	1	$ 5,600	$ 5,600	BMcD
	Bench Work Plan	ls	1	$ 10,000	$ 10,000	BMcD
	Misc. shipping, supplies, consumables	ls	1	$ 500	$ 500	BMcD
	Cuttings, VOC sampling, handling to on-site landfill	ls	1	$ 500	$ 500	BMcD
	Field vehicle/per diem	ls	1	$ 500	$ 500	BMcD
	Decon Budget (rig & crew time, steam cleaner)	ls	1	$ 1,500	$ 1,500	BMcD
3.4	Pilot test to determine spacing, application rate, and operational ease/modifications[3]					
	Vendor procurement	ls	1	$ 5,000	$ 5,000	BMcD
	Pilot test work plan	ls	1	$ 10,000	$ 10,000	BMcD
	Surveying	ls	1	$ 600	$ 600	BMcD
	Clear Utilities	ls	1	$ 600	$ 600	BMcD
	Mob/Demob. Geoprobe	ls	1	$ 1,000	$ 1,000	BMcD
	Geoprobing (2 days)	day	2	$ 2,500	$ 5,000	BMcD
	Equipment: feed, mixing, and slurry pump	day	2	$ 1,000	$ 2,000	BMcD
	Permanganate	lbs	1,500	$ 1.70	$ 2,550	BMcD
	Technology vendor charges/license fees	ls	1	$ 5,000	$ 5,000	BMcD
	Field oversight and logistics (40 hr)	ls	1	$ 4,000	$ 4,000	BMcD
	Decon budget (rig & crew time, steam cleaner)	ls	1		$ 1,500	BMcD
	Sampling, 3 existing monitoring wells (month 1 @4 times, then monthly for 6 months, then bimonthly for months 8, 10, 12)					
	VOCs, MNA parameters	ea	39	$ 500.00	$ 19,500	BMcD
	Labor (12 events - est. 240 man-hour)	ls	1	$ 24,000	$ 24,000	BMcD
	Vehicle/mileage	trip	12	$ 200.00	$ 2,400	BMcD
	Interpret Results and Pilot Test Report	ls	1	$ 7,500	$ 7,500	BMcD
3.5	Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000	$ 10,000	BMcD
3.6	Budget for investigation to establish limits of treatment area east of Building 367	ls	1	$ 40,000	$ 40,000	BMcD

Table 5A-5 (continued)
Cost Estimate for Alternative 3
Feasibility Study Report
354 Area Solvent Detections

In-Situ Chemical Oxidation with Institutional Controls and Monitored Natural Attenuation

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
3.7	Full Scale Treatment					
	Vendor procurement	ls	1	$ 5,000	$ 5,000	BMcD
	Surveying	ls	1	$ 1,200	$ 1,200	BMcD
	Utility clear	ls	1	$ 2,400	$ 2,400	BMcD
	Mob/Demob. Geoprobe	ls	1	$ 1,000	$ 1,000	BMcD
	Permanganate Injection - Geoprobing = 1 week	day	5	$ 2,500	$ 12,500	BMcD
	Permanganate	lbs	7,000	$ 1.70	$ 11,900	BMcD
	Technology vendor charges/license fees	ls	1	$ 10,000.00	$ 10,000	BMcD
	Construction Oversight (weeks on-site field supervisor = 5 day)					
	Labor	day	5	$ 800	$ 4,000	BMcD
	Per diem	day	5	$ 100	$ 500	BMcD
	Pickup truck/mileage	day	5	$ 100	$ 500	BMcD
	Post injection effectiveness monitoring (assume 7 wells, month 1(4 times), month 2 to 6 (1 time each)					
	Labor (9 events - est. 180 man-hour)	ls	1	$ 18,000	$ 18,000	BMcD
	VOCs, MNA parameters	ea	63	$ 500.00	$ 31,500	BMcD
	Vehicle/mileage	trip	9	$ 200.00	$ 1,800	BMcD
	Project Report - Full Scale Implementation, procedures, results, interpretations, trends, isoconcentration maps etc.	ls	1	$ 50,000.00	$ 50,000	BMcD
3.8	Re-Treatment (50% of Full Scale Effort)	ls	1	$ 75,150	$ 75,150	BMcD

Subtotal Capital Costs	**$ 544,400**
Contingency (20%)[4]	**$ 108,880**
Total Capital Costs	**$ 653,280**

Annual Operation and Maintenance Costs						
3.9	Semiannual Groundwater Monitoring[5]	ea	1	$ 65,000.00	$ 65,000	BMcD

Subtotal Annual O&M	**$ 65,000**
Contingency (20%)[4]	**$ 13,000**
Total Annual O&M	**$ 78,000**

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

Subtotal Periodic Costs	**$ 50,000**
Contingency (20%)[4]	**$ 10,000**
Total Periodic Costs	**$ 60,000**

Total Project Cost	**$ 2,345,280**
Total Present Value Project Cost at 3.2%	**$ 1,877,490**

Table 5A-5 (continued)
Cost Estimate for Alternative 3
Feasibility Study Report
354 Area Solvent Detections

Notes:

1. BMcD costs represent estimates obtained from similar projects and/or professional experience.
2. Includes Work Plan, Safety Plan, Engineering Design, Scheduling, and Project Management.
3. Based on use of 3 existing wells to monitor residence of permanganate over 6 to 12 months.
4. Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
5. Groundwater monitoring costs are the same as Alternative 2 (Table 5A-3). Although some source control is performed, it is assumed that low concentrations of contaminants will persist. Assume plume concentrations could decrease slightly; but monitoring for 20 years still required.

BMcD - Burns & McDonnell Engineering Company, Inc.
ea - each
lbs - pounds
ls - lump sum
MNA - monitored natural attenuation
mo - month
VOC - volatile organic compound

Table 5A-6
Present Value Costs for Alternative 3
Feasibility Study Report
354 Area Solvent Detections

In-Situ Chemical Oxidation with Institutional Controls and Monitored Natural Attenuation

Year	Capital Costs	Annual O&M Costs[1]	Periodic Costs[2]	Total Cost	Discount Factor at 3.2%	Total Present Value Cost at 3.2%
0	$ 653,280	$ -	$ -	$ 653,280	1.000	$ 653,280
1	$ -	$ 78,000	$ -	$ 78,000	0.969	$ 75,581
2	$ -	$ 78,000	$ -	$ 78,000	0.939	$ 73,238
3	$ -	$ 78,000	$ -	$ 78,000	0.910	$ 70,967
4	$ -	$ 78,000	$ -	$ 78,000	0.882	$ 68,766
5	$ -	$ 78,000	$ 24,000	$ 102,000	0.854	$ 87,137
6	$ -	$ 78,000	$ -	$ 78,000	0.828	$ 64,568
7	$ -	$ 78,000	$ -	$ 78,000	0.802	$ 62,566
8	$ -	$ 78,000	$ -	$ 78,000	0.777	$ 60,626
9	$ -	$ 78,000	$ -	$ 78,000	0.753	$ 58,746
10	$ -	$ 78,000	$ 24,000	$ 102,000	0.730	$ 74,439
11	$ -	$ 78,000	$ -	$ 78,000	0.707	$ 55,159
12	$ -	$ 78,000	$ -	$ 78,000	0.685	$ 53,449
13	$ -	$ 78,000	$ -	$ 78,000	0.664	$ 51,792
14	$ -	$ 78,000	$ -	$ 78,000	0.643	$ 50,186
15	$ -	$ 78,000	$ 24,000	$ 102,000	0.623	$ 63,592
16	$ -	$ 78,000	$ -	$ 78,000	0.604	$ 47,122
17	$ -	$ 78,000	$ -	$ 78,000	0.585	$ 45,660
18	$ -	$ 78,000	$ -	$ 78,000	0.567	$ 44,245
19	$ -	$ 78,000	$ -	$ 78,000	0.550	$ 42,873
20	$ -	$ 78,000	$ 60,000	$ 138,000	0.533	$ 73,500
Total	**$ 653,280**	**$ 1,560,000**	**$ 132,000**	**$ 2,345,280**		**$ 1,877,490**

Notes:

1. It is assumed that groundwater monitoring will be performed annually.
2. $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 5A-7
Cost Estimate for Alternative 4
Feasibility Study Report
354 Area Solvent Detections

Enhanced Anaerobic Bioremediation with Institutional Controls and Monitored Natural Attenuation

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Capital Costs						
4.1	Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000	$ 40,000	BMcD
4.2	Full-Scale Engineering and Design.[2]	ls	1	$ 75,000	$ 75,000	BMcD
4.3	Bench-scale - none					
4.4	Pilot test to determine spacing, application rate, and other design parameters.[3]					
	Vendor procurement	ls	1	$ 5,000	$ 5,000	BMcD
	Pilot test work plan	ls	1	$ 10,000	$ 10,000	BMcD
	Surveying	ls	1	$ 600	$ 600	BMcD
	Clear Utilities	ls	1	$ 600	$ 600	BMcD
	Mob/Demob. Geoprobe	ls	1	$ 1,000	$ 1,000	BMcD
	Geoprobing (2 days)	ls	1	$ 5,000	$ 5,000	BMcD
	Equipment: feed, mixing, and slurry pump	day	2	$ 1,000	$ 2,000	BMcD
	Lactate (est. 10 wells, 15 lb/ft, 10 ft. thick)	lbs	1,500	$ 1.00	$ 1,500	BMcD
	Technology vendor charges/license fees	ls	1	$ 5,000	$ 5,000	BMcD
	Field Oversight and Logistics (40 hr)	ls	1	$ 4,000	$ 4,000	BMcD
	Decon Budget (rig & crew time, steam cleaner)	ls	1	$ 1,500	$ 1,500	BMcD
	Sampling, 3 existing monitoring wells (month 1@4 times, then monthly for 6 months, then bimonthly for months 8, 10, 12)					
	VOCs, MNA parameters	ea	39	$ 500	$ 19,500	BMcD
	Labor (12 events - est. 240 man-hour)	ls	1	$ 24,000	$ 24,000	BMcD
	Vehicle/mileage	trip	12	$ 200	$ 2,400	BMcD
	Interpret results and pilot test report	ls	1	$ 7,500	$ 7,500	BMcD
4.5	Permitting: budget to prepare applications and obtain permits.	ls	1	$ 10,000	$ 10,000	BMcD
4.6	Budget for investigation to establish limits of source area east of Building 367	ls	1	$ 40,000	$ 40,000	BMcD
4.7	Full Scale Treatment[4]					
	Vendor procurement	ls	1	$ 5,000	$ 5,000	BMcD
	Surveying	ls	1	$ 1,200	$ 1,200	BMcD
	Utility clear	ls	1	$ 2,400	$ 2,400	BMcD
	Lactate cost (88 wells, 15lb/ft, 10 ft thick)	lb	13,200	$ 1.00	$ 13,200	BMcD
	Geoprobe contractor costs to inject lactate					
	Mob/demob($1000)+Decon time ($1500)	ls	1	$ 2,500	$ 2,500	BMcD
	Daily Rate	day	20	$ 2,500	$ 50,000	BMcD
	Lactate Pump	day	20	$ 200	$ 4,000	BMcD
	Construction Oversight (20 days).					
	Labor	day	20	$ 100	$ 2,000	BMcD
	Per Diem	day	20	$ 100	$ 2,000	BMcD
	Pickup Truck/mileage	day	20	$ 100	$ 2,000	BMcD
	Sampling, 3 existing monitoring wells (month 1@4 times, then monthly for 6 months, then bimonthly for months 8, 10, 12)					
	VOCs, MNA parameters	ea	39	$ 500	$ 19,500	BMcD
	Labor (12 events - est. 240 man-hour)	ls	1	$ 24,000	$ 24,000	BMcD
	Vehicle/mileage	trip	12	$ 200.00	$ 2,400	BMcD
	Interpret results and post treatment report	ls	1	$ 7,500	$ 7,500	BMcD

Subtotal Capital Costs $ 392,300

Contingency (20%)[5] $ 78,460

Total Capital Costs $ 470,760

Table 5A-7 (continued)
Cost Estimate for Alternative 4
Feasibility Study Report
354 Area Solvent Detections

Annual Operation and Maintenance Costs						
4.8	Semiannual Groundwater Monitoring.[6]	ea	1	$ 65,000	$ 65,000	BMcD
				Subtotal Annual O&M	**$ 65,000**	
				Contingency (20%)[5]	**$ 13,000**	
				Total Annual O&M	**$ 78,000**	

Periodic Costs						
4.9	Reinjection at 2 years	ls	1	$ 137,700	$ 137,700	BMcD
4.10	Five-Year Review of Remedial Action	ea	1	$ 20,000	$ 20,000	BMcD
4.11	Closure Report	ls	1	$ 30,000	$ 30,000	BMcD
				Subtotal Periodic Costs	**$ 187,700**	
				Contingency (20%)[5]	**$ 37,540**	
				Total Periodic Costs	**$ 225,240**	

Total Project Cost	**$ 1,914,000**
Total Present Value Project Cost at 3.2%	**$ 1,619,167**

Notes:
1. BMcD costs represent estimates obtained from similar projects and/or professional experience.
2. Includes Work Plan, Safety Plan, Engineering Design, Scheduling, and Project Management.
3. It assumed that a partial lactate curtain will be used for the pilot study. This estimate is based on ten injection points (100-ft wide spaced on 10-ft centers) and an assumed lactate application amount of 15 lbs per vertical ft and 10-ft saturated thickness.
4. It assumed that source area treatment and mid-plume and dowgradient lactate curtains will be used. Injection will be applied over a 10-ft thickness. Estimate is based on 30 injection points per curtain (300-ft wide spaced on 10-ft centers) and an assumed 15 pounds per vertical ft (10-ft saturated thickness) lactate application rate. The treatment area for the source area application is assumed to be 40-ft x 70-ft x 10-ft saturated thickness.
5. Contingency covers unknowns, unforeseen circumstances, or unanticipated conditions associated with remediation. Twenty percent is an average contingency factor (EPA, 2000a).
6. Groundwater monitoring costs are the same as Alternative 2 (Table 5A-3).

BMcD - Burns & McDonnell Engineering Company, Inc.
ea - each
ft - foot
hr - hour

Table 5A-8
Present Value Costs for Alternative 4

Feasibility Study Report
354 Area Solvent Detections

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	$ 470,760	$ -	$ -	$ 470,760	1.000	$ 470,760
1	$ -	$ 78,000	$ -	$ 78,000	0.969	$ 75,581
2	$ -	$ 78,000	$ 165,240	$ 243,240	0.939	$ 228,389
3	$ -	$ 78,000	$ -	$ 78,000	0.910	$ 70,967
4	$ -	$ 78,000	$ -	$ 78,000	0.882	$ 68,766
5	$ -	$ 78,000	$ 24,000	$ 102,000	0.854	$ 87,137
6	$ -	$ 78,000	$ -	$ 78,000	0.828	$ 64,568
7	$ -	$ 78,000	$ -	$ 78,000	0.802	$ 62,566
8	$ -	$ 78,000	$ -	$ 78,000	0.777	$ 60,626
9	$ -	$ 78,000	$ -	$ 78,000	0.753	$ 58,746
10	$ -	$ 78,000	$ 24,000	$ 102,000	0.730	$ 74,439
11	$ -	$ 78,000	$ -	$ 78,000	0.707	$ 55,159
12	$ -	$ 78,000	$ -	$ 78,000	0.685	$ 53,449
13	$ -	$ 78,000	$ -	$ 78,000	0.664	$ 51,792
14	$ -	$ 78,000	$ -	$ 78,000	0.643	$ 50,186
15	$ -	$ 78,000	$ 60,000	$ 138,000	0.623	$ 86,037
Total	**$ 470,760**	**$ 1,170,000**	**$ 273,240**	**$ 1,914,000**		**$ 1,619,167**

Notes:

1. It is assumed that groundwater monitoring will be performed annually.
2. It is assumed that enhanced bioremediation will treat dissolved contamination; however, it is conservately assumed there will be some source material that is not treated and this results in rebound of very low contamination, such that continued monitoring is required.
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 5A-9
Cost Estimate for Alternative 5
Feasibility Study Report
354 Area Solvent Detections

Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitored Natural Attenuation

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Capital Costs						
5.1	Institutional Controls: Groundwater Restrictions and Access Easements	ls	1	$ 40,000	$ 40,000	BMcD
5.2	Engineering and Design[2,3]	ls	1	$ 100,000	$ 100,000	BMcD
5.3	Permitting: budget to prepare applications and obtain permits	ls	1	$ 10,000	$ 10,000	BMcD
5.4	Groundwater extraction wells and pumps[4]	ls	1	$ 77,790	$ 77,790	RACER
	Surveying (well locations and trenches)	ls	1	$ 5,000	$ 5,000	BMcD
	Utility Clear (well locations, trenches)	ls	1	$ 5,000	$ 5,000	BMcD
	Air Stripper	ls	1	$ 57,800	$ 57,800	RACER
	Activated Carbon System	ls	1	$ 9,900	$ 9,900	RACER
	Flow Line between wells and to sanitary sewer approx. 1650 ft.[5]					
	1.0 cy backhoe (R.S. Means Crew 12A)	day	10	$ 1,229	$ 12,290	Means
	Backfill trench (R.S. Means Crew B10R)	day	10	$ 761	$ 7,610	Means
	Compaction (R.S. Means Crew A-1)	day	10	$ 357	$ 3,570	Means
	4" PVC piping	ft	1,650	$ 11.84	$ 19,536	RACER
	Budget for resodding	ls	1	$ 2,500	$ 2,500	BMcD
	Budget for road crossings, pavement, curbing, etc. repair/replacement.	ls	1	$ 10,000	$ 10,000	BMcD
	Equipment Building	ls	1	$ 50,000	$ 50,000	BMcD
	Valves, Fittings, Meters, etc.	ls	1	$ 10,000	$ 10,000	BMcD
	Drummed cutting disposal (non-haz)	drum	15	$ 200	$ 3,000	BMcD
	Discharge to sewer (ave 21 gpm)	1000 gal	11,037	$ 3.00	$ 33,111	BMcD
	Power Hookup, electrical	ls	1	$ 10,000	$ 10,000	BMcD
	Construction Oversight (20 days)					
	Labor	day	20	$ 1,000	$ 20,000	BMcD
	Per Diem	day	20	$ 100	$ 2,000	BMcD
	Pickup Truck	day	20	$ 100	$ 2,000	BMcD

Subtotal Capital Costs	**$ 491,107**
Contingency (20%)[6]	**$ 98,221**
Total Capital Costs	**$ 589,328**

Table 5A-9 (continued)
Cost Estimate for Alternative 5
Feasibility Study Report
354 Area Solvent Detections
Groundwater Extraction and Ex-Situ Treatment with Institutional Controls and Monitored Natural Attenuation

	Description	Unit	Quantity	Unit Cost	Line Cost	Source[1]
Annual Operation and Maintenance Costs						
	Annual Groundwater Monitoring[7]	ea	1	$ 65,000	$ 65,000	BMcD
	Electrical - Pump and Treat					
	Carbon Treatment - Transfer Pump	kwh	2,870	$ 0.10	$ 287	RACER
	Wells	kwh	125,838	$ 0.10	$ 12,584	RACER
	Air Stripper - Blower	kwh	4,563	$ 0.10	$ 456	RACER
	Treatment Building - Heat	kwh	7,254	$ 0.10	$ 725	RACER
	Pump/Treat- System Parts Budget	ls	1	$ 10,000	$ 10,000	BMcD
	Change out, transport, and disposal/regen	lb	8,000	$ 1.63	$ 13,040	RACER
	O & M Labor - ave. 10 hr per week	hr	520	$ 80	$ 41,600	BMcD
	Monthly monitoring/ off gas sampling - labor (8 hr/mo.)	hr	96	$ 80	$ 7,680	BMcD
	Monthly discharge to sewer analytical (VOCs monthly)	ea	12	$ 175	$ 2,100	BMcD
	Air stripper analytical (VOCs monthly, vapor)	ea	12	$ 175	$ 2,100	BMcD
	Monthly reporting, discharge, air monitoring, maintenance summary (16 hr/mo)	hr	192	$ 80	$ 15,360	BMcD
				Subtotal Annual O&M	**$ 170,933**	
				Contingency (20%)[6]	**$ 34,187**	
				Total Annual O&M	**$ 205,119**	
Periodic Costs						
	Five-Year Review of Remedial Action	ea	1	$ 20,000	$ 20,000	BMcD
	Closure Report	ls	1	$ 30,000	$ 30,000	BMcD
				Subtotal Periodic Costs	**$ 50,000**	
				Contingency (20%)[6]	**$ 10,000**	
				Total Periodic Costs	**$ 60,000**	
				Total Project Cost	**$ 4,823,708**	
				Total Present Value Project Cost at 3.2%	**$ 3,670,247**	

Notes:

1. BMcD costs represent estimates obtained from similar projects and/or professional experience.
2. Includes Work plan, 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. Includes all well installation costs and equipment including mob/deb.
5. Assume combination gravity line for discharge to sewer, locate treatment building near manhole.
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 5A-3).

BMcD - Burns & McDonnell Engineering Company, Inc.
cy - cubic yard
drum - 55-gallon storage drum
ea - each
gpm - gallons per minute
hr - hour
kwh - kilowatt hour
NPDES - National Pollutant Discharge Elimination System
RACER - Remediation Action Cost Engineering and Requirements (RACER, 2003)
lb - pound
ls - lump sum
mo - month
O&M - operation & maintenance
PVC - polyvinyl chloride
VOC - volatile organic compounds

Table 5A-10
Present Value Costs for Alternative 5
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Pump and Treat 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	$ 589,328	$ -	$ -	$ 589,328	1.000	$ 589,328
1	$ -	$ 205,119	$ -	$ 205,119	0.969	$ 198,759
2	$ -	$ 205,119	$ -	$ 205,119	0.939	$ 192,596
3	$ -	$ 205,119	$ -	$ 205,119	0.910	$ 186,624
4	$ -	$ 205,119	$ -	$ 205,119	0.882	$ 180,837
5	$ -	$ 205,119	$ 24,000	$ 229,119	0.854	$ 195,732
6	$ -	$ 205,119	$ -	$ 205,119	0.828	$ 169,796
7	$ -	$ 205,119	$ -	$ 205,119	0.802	$ 164,531
8	$ -	$ 205,119	$ -	$ 205,119	0.777	$ 159,429
9	$ -	$ 205,119	$ -	$ 205,119	0.753	$ 154,486
10	$ -	$ 205,119	$ 24,000	$ 229,119	0.730	$ 167,211
11	$ -	$ 205,119		$ 205,119	0.707	$ 145,054
12	$ -	$ 205,119		$ 205,119	0.685	$ 140,556
13	$ -	$ 205,119		$ 205,119	0.664	$ 136,198
14	$ -	$ 205,119		$ 205,119	0.643	$ 131,975
15	$ -	$ 205,119	$ 24,000	$ 229,119	0.623	$ 142,845
16	$ -	$ 205,119		$ 205,119	0.604	$ 123,917
17	$ -	$ 205,119		$ 205,119	0.585	$ 120,075
18	$ -	$ 205,119		$ 205,119	0.567	$ 116,351
19	$ -	$ 205,119		$ 205,119	0.550	$ 112,744
20	$ -	$ 205,119	$ 60,000	$ 265,119	0.533	$ 141,204
Total	**$ 589,328**	**$ 4,102,380**	**$ 132,000**	**$ 4,823,708**		**$ 3,670,247**

Notes:

1. It is assumed that groundwater monitoring will be performed annually.
2. Pump and treat will remove dissolve phase contamination. It is assumed that pump and treat will provide containment with minimal mass removal of any potential source material. Therefore, it is estimated that pump and treat will not accelarate remedial time -frame compared to natural attenuation processes
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