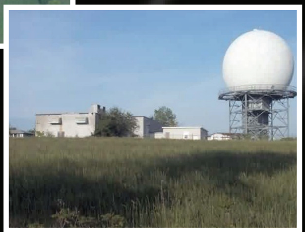
Final Feasibility Study Report

Former Kirksville Air Force Station Greentop, MO

Formerly Used Defense Site Number B07MO023204



Prepared for:

US Army Corps of Engineers
Kansas City District
Contract No. W912DQ-05-D-0002
Delivery Order No. 0006

Prepared by:

Conti and CH2MHILL

October 2008

STATEMENT OF TECHNICAL REVIEW

Performance Work Statement for Performance Based Contract, Formerly Used Defense Sites, Former Kirksville Air Force Station, Greentop, MO

Final Feasibility Study Report

The Conti/CH2M HILL Team has completed the technical review of the submittal of the Final Feasibility Study Report. Notice is hereby given that an independent technical review has been conducted that is appropriate to the level of risk and complexity inherent in the project, as defined in the Quality Control Plan. During the independent technical review, compliance with established policy principles and procedures, utilizing justified and valid assumptions, was verified. This included review of assumptions; methods, procedures and material used in analyses; the appropriateness of data used and level of data obtained; and reasonableness of the results including whether the product meets the customer's needs consistent with the law and existing USACE policy.

Technical Reviewer	Signature	Date of Review
Catherine Barnett		10/13/08

Quality Control System Manager (for QCP) or Project Manager	ITR Leader
Luis Seijido	Catherine Barnett
Signature	Signature

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CH2MHILL

Executive Summary

This feasibility study report presents the results of the development and evaluation of remedial alternatives for the former Kirksville Air Force Station P-64 (KAFS) site in Adair County near Greentop, Missouri, as part of the Formerly Used Defense Site program. The report was prepared for the U.S. Army Corps of Engineers–Kansas City District (USACE).

A Phase II remedial investigation (RI) was performed at the KAFS site (CH2M HILL 2008) to investigate and characterize the extent of contamination to assess risk posed to human health by the presence of trichloroethene (TCE) and its degradation products cis-1,2-dichloroethene (cDCE), and vinyl chloride (VC) at the KAFS site or adjacent properties.

For exposures that were quantified in the Phase II RI human health risk assessment (HHRA) (soil and hypothetical potable water pathways), the excess lifetime cancer risk (ELCR) and hazard index (HI) estimates calculated for the north and south groundwater plumes indicate that future potential risks posed by TCE, cDCE, and VC exceed the MDNR risk threshold of 1×10^{-5} ELCR, the Comprehensive Environmental Response, Compensation and Liability Act acceptable risk range of 1×10^{-4} to 1×10^{-6}, and the noncancer HI of 1 using California Environmental Protection Agency toxicity values. Screening of groundwater against the maximum contaminant levels (MCLs) indicates that TCE, cDCE, and VC concentrations in the south and north plumes are unacceptable for hypothetical potable use. The hypothetical future vapor intrusion concentrations were modeled from measured soil and groundwater concentrations. Potential future vapor intrusion risks were identified for various hypothetical receptors above the north plume, but not the south plume. The hypothetical future vapor intrusion risk estimates may be overestimated since significant quantities of soil gas were not present at the site.

The object of the feasibility study was to develop and evaluate groundwater remedial alternatives that will address potential unacceptable risks to human health and the environment and meet applicable or relevant and appropriate requirements (ARARs). The remedial action objective was established based on regulatory requirements, standards, and guidance. General response actions were identified for groundwater at the site to develop remedial alternatives. Based on the risks present at the site, three alternatives were developed: Alternative 1, No Action; Alternative 2, Monitored Natural Attenuation and Alternative Water Supply; and Alternative 3, Enhanced Biodegradation with Monitoring and Alternative Water Supply. The alternatives were evaluated against seven feasibility evaluation criteria as defined in the National Contingency Plan and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). Alternative 1 does not meet the evaluation criteria. Alternatives 2 and 3 both met the threshold criteria of protectiveness and compliance with ARARs and were evaluated following CERCLA criteria. The preferred alternative will be presented in the Proposed Plan, which will be released to the public for review and comment. Public input on the alternatives is paramount in the selection process. The preferred alternative may be modified based on the comments received.

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Acronyms and Abbreviations

ARAR	applicable or relevant and appropriate requirement
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
cDCE	cis-1,2-dichloroethene
COC	chemical of concern
cVOC	chlorinated volatile organic compound
ELCR	excess lifetime cancer risk
FAA	Federal Aviation Administration
FS	feasibility study
FUDS	Formerly Used Defense Site
GRA	general response action
HHRA	human health risk assessment
HI	hazard index
HQ	hazard quotient
JEM	Johnson & Ettinger Vapor Intrusion Model
KAFS	Kirksville Air Force Station
MCL	maximum contaminant level
MDNR	Missouri Department of Natural Resources
MIP	membrane interface probe
µg/L	micrograms per liter
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
NCEA	National Center for Environmental Assessment
NCP	National Contingency Plan
NPDES	National Pollutant Discharge Elimination System
PID	photoionization detector
PRG	preliminary remediation goal
RAO	remedial action objective
RI	remedial investigation
TCE	trichloroethene
USACE	United States Army Corps of Engineers
USAF	United States Air Force
USEPA	United States Environmental Protection Agency
VC	vinyl chloride

1. Introduction

This feasibility study (FS) report was prepared for the U.S. Army Corps of Engineers (USACE), Kansas City District, for the Former Kirksville Air Force Station P-64 (KAFS) site in Adair County near Greentop, Missouri (Figure 1-1), as part of the Formerly Used Defense Site (FUDS) program.

1.1 Regulatory Framework

The Department of Defense (DOD) serves as lead agency for the FUDS program, and the U.S. Army is designated as the executive agency for the DOD. The U.S. Army delegated the management and execution of the FUDS program to the USACE. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) is followed for FUDS responses to hazardous substances, pollutants and contaminants as set forth in the Defense Environmental Restoration Program Statute at 10 USC 2701.

1.2 Site Setting

The Federal Aviation Administration (FAA) owns 1 acre of land within the KAFS site boundary and uses the property for operation of an air route surveillance radar (ARSR-3) (Figure 1-2). Truman State University owns the remaining area within the KAFS site boundary (about 77.5 acres) and uses the property for storage. Privately owned residential properties surround the site (Figure 1-2). It is our understanding that neither FAA nor Truman State University plan to change the property use in the near future.

1.3 Site History

In 1951, the United States Air Force (USAF) acquired 78.5 acres for a radar station. The USAF made improvements to the property by constructing four main roads and more than 20 buildings. The station was declared surplus on May 13, 1968, and on October 2, 1969, 1 acre was transferred to the FAA, Central Region, Kansas City, Missouri. On October 21, 1970, the remaining property was transferred to Northeast Missouri State University (now Truman State University) for agricultural research and for storage. Remnants of several buildings and the radar ball still remain on the property (Figure 1-2).

1.4 Previous Investigations

According to available information, the following site investigations were performed at the KAFS site:

- Removal of underground storage tanks, HWS Consulting Group, 1992
- Transformer removal, Environmental Chemical Corporation, 1996

- Site characterization studies, HWS Consulting Group, 1996
- Missouri Department of Natural Resources (MDNR) and FAA groundwater and soil sampling, 1999
- Phase I remedial investigation (RI), USACE, 2006
- Phase II RI, CH2M HILL, 2008

1.5 Objectives and Scope

According to the United States Environmental Protection Agency's (USEPA's) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (1988) and the National Contingency Plan (NCP), an FS is conducted by developing remedial alternatives, screening those alternatives to reduce the number, and analyzing selected alternatives in detail. The object of the FS was to develop and evaluate alternatives that will address potential unacceptable risks to human health and the environment and satisfy applicable or relevant and appropriate requirements (ARARs).

The following steps were used to develop and evaluate remedial alternatives:

1. Identify ARARs.
2. Develop remedial action objectives (RAOs).
3. Determine preliminary remediation goals (PRGs) and areas exceeding the PRGs.
4. Evaluate chemicals of concern (COCs) against remediation goals.
5. Develop general response actions (GRAs).
6. Develop and screen technologies and process options.
7. Develop remedial alternatives.
8. Perform detailed analysis of remedial alternatives.
9. Perform comparative analysis of each alternative's ability to satisfy the evaluation criteria.

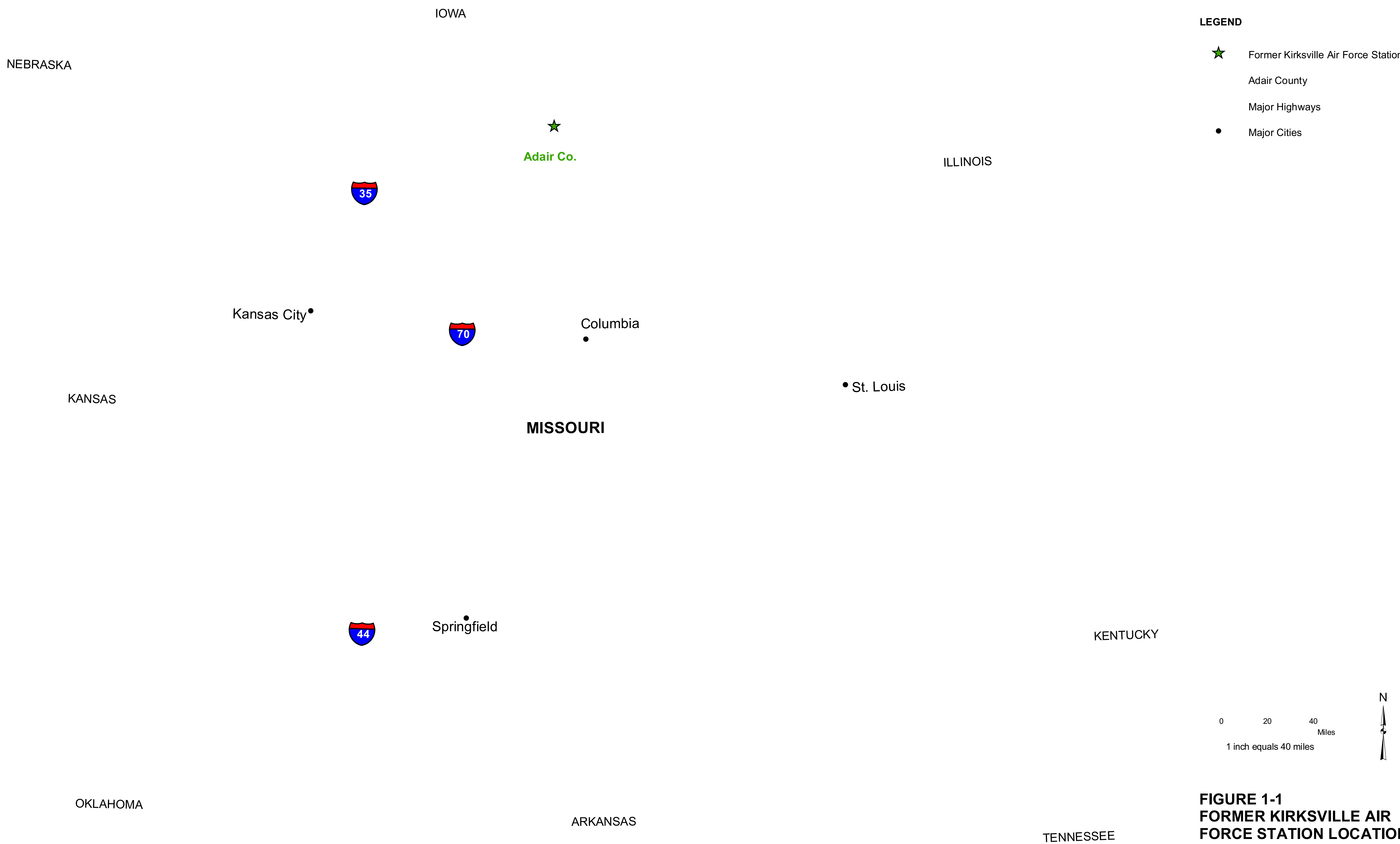

FIGURE 1-1
FORMER KIRKSVILLE AIR FORCE STATION LOCATION MAP
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

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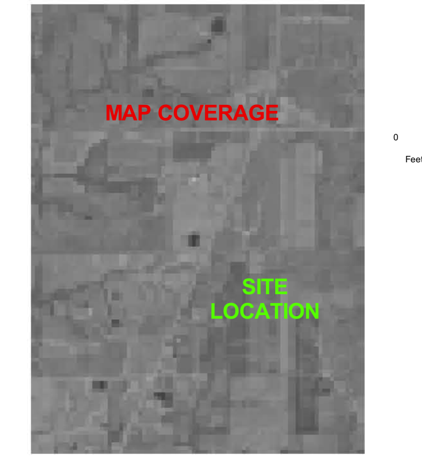
VICINITY MAP



LEGEND

- RESIDENTIAL WELL
- TOPOGRAPHIC CONTOUR
- TOPOGRAPHIC CONTOUR
- TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
- FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
- EXISTING BUILDINGS
- FORMER BUILDINGS
- OLD RADAR BALL LOCATION
- FORMER SEWAGE LAGOON
- SURFACE WATER
- STREAM

NOTES:

1. Monitoring wells / piezometers and residential wells were sampled during the phase I RI.
2. Contour interval = 10 ft.

0 150 300
Feet
1 inch equals 300 feet

FIGURE 1-2
SITE LAYOUT
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

RDD \\LOKI\PROJECTS\RDDGIS\350464_KIRKSVILLEAFS\MAPFILES\FS\FIG1-2_SITE_FS.MXD 8/4/2008 15:53:43

2. Conceptual Site Model

This section summarizes the physical and contamination characteristics of the KAFS site regarding site geology, hydrogeology, and contaminants of concern as developed during the Phase I and Phase II RIs. The RIs identified plumes of chlorinated solvents in groundwater in two areas at the site: an area in the north associated with the former Paint Storage Building, and an area in the south associated with maintenance at the former radar ball area.

2.1 Soil Characteristics

Overburden soils at the KAFS site are primarily clays and silts. Sand-to-gravel material scattered randomly throughout the clay. There is evidence that a few permeable lenses of clayey sand and gravel are present at a depth greater than 20 feet, as well as a silty sand lens encountered at a depth of 11 feet below ground surface near the area around the former Paint Storage Building. Fill material likely from construction of the facility, including gravel, silt, and sand, is present from ground surface to a depth of less than 2 feet on the FAA site. The surficial material encountered consists mainly of soft silt with some humus. The surficial material varies in thickness across the site but is generally less than 2 feet (CH2M HILL 2008). A well installed at the site by the USACE in 1950 encountered bedrock at a depth of 230 feet (USACE 2006). Based on the information provided on the boring log, the uppermost bedrock unit encountered was the Lagonda Formation. Figure 2-1 shows the locations of the conceptual site model cross sections provided for the plume areas, which are depicted in Figures 2-2, 2-3, 2-4, and 2-5.

2.2 Groundwater Characteristics

The uppermost water-bearing zone at the site is the glacial drift that overlies the Lagonda Formation (Figures 2-2 through 2-5). Saturated soil conditions exist in the thin layers of coarser material (sand and gravel) below the water table. Moist soil conditions in clay, indicative of the capillary fringe were observed at depths ranging from 2 to 15 feet below ground in borings across the site. Groundwater elevations generally range from 4 to 20 feet below ground. A groundwater divide trends east to west across the northern part of the site. Shallow groundwater flow generally is toward the west, with a northwesterly component north of the divide and a southwesterly component south of the divide. Figure 2-6 depicts the groundwater potentiometric surface based on well gauging conducted on March 14, 2007 (CH2M HILL 2008).

The horizontal groundwater gradient ranges from 0.04 to 0.5 foot per foot in the northern part of the site and from 0.02 to 0.07 foot per foot in the southern part of the site. The hydraulic conductivity ranges from 1.4×10^{-5} to 2.8×10^{-5} centimeters per second (CH2M HILL 2008). The Phase I RI data indicate that the groundwater velocity is 4.6 feet per year in the northern plume and 7 feet per year in the southern (USACE 2006).

Groundwater flow and recharge rates are very slow because of the low permeability soils at the KAFS site. In the area of current groundwater contamination, groundwater is not used for consumption because it is unavailable in sufficient quantities, of low natural quality, or too deep to be a feasible public water supply (USACE 2006). The Kirksville Water Supply District Water supplies water to the site and adjacent properties from two surface water reservoirs (CH2M HILL 2008).

Nearby residents who have domestic water wells were contacted regarding their use of the wells (Figure 1-2). Four domestic wells are in place on three properties adjacent to the site. Residence B has one well (RW5, 40 feet deep). Residence A has two wells (RW3, 14 feet deep; RW4, 20 feet deep). Residence C has one well (RW6). Well RW6, which is upgradient of the groundwater plumes, is used occasionally to water a lawn. The other two domestic well owners indicated that the wells on their properties are not in use (USACE 2006).

The topographic relief of the site is roughly 17 feet, ranging from a high of 983.9 feet above mean sea level near the center of the site to 967 feet near the western property boundary. Surface water runoff from the affected areas of the site is primarily from east to west, toward the Buck Branch of Hazel Creek.

Groundwater from the KAFS site appears to be discharging to surface water bodies west of the site (Figures 2-2, 2-3, 2-5). Two ponds drain the northern part of the KAFS site. The pond north of the residential property west of the northern plume was constructed in a low lying area of the property in 2005. The pond south of the residential property that is west of the northern plume was breached by the residential property owner in 2005 or 2006, by removing part of the western wall of the pond. The west wall was not entirely removed, and so the pond still holds up to 1 foot of water. An unnamed tributary of Buck Branch Creek drains the southern part of the KAFS site (Figure 2-7). Buck Branch Creek is an intermittent stream that begins immediately west of the site and joins Hazel Creek about 2 miles west of the KAFS site. Hazel Creek is a tributary of the Chariton River.

2.3 Nature and Extent of Contamination Summary

The Phase I RI identified potential risk associated with two main areas of chlorinated solvent contamination: an area in the north associated with the former Paint Storage Building, and an area in the south associated with the former radar ball area. The Phase II RI focused on trichloroethene (TCE), cis-1,2-dichloroethene (cDCE), and vinyl chloride (VC) contamination in onsite soil, onsite and offsite groundwater, and offsite surface water. Soil gas data is not available because a sufficient volume of soil gas could not be obtained due to the tight soil formation.

The primary source of contaminants most likely was the release of TCE near the former Paint Storage Building and near the former radar ball. Note that dense nonaqueous phase liquid (DNAPL) was not found at the KAFS site during previous investigations or the Phase II RI. The term "original source area" in this report describes the likely location of the original release. A current unsaturated soil source zone of TCE was not identified in the Phase II RI investigation. Spills would have contaminated the unsaturated zone soils (that is, soil above the water table), volatilized to the atmosphere, leached to the groundwater, and biograded. Volatilization to the air would have been significant from the upper 1 to 2 feet of soil because the soil is high permeability fill, and TCE volatilizes relatively rapidly in surficial soils. The soil is much less permeable at depths below 2 feet, and volatilization would not be a significant loss mechanism.

2.3.1 Soil

A current soil source of the TCE contamination in the north and south contaminant plumes was not found during a source area investigation and does not appear to be present in the unsaturated zone. The soil contamination found in the unsaturated zone of the original source area of either plume was in an area of elevated TCE concentration in the zone of water table fluctuation in the north plume. The presence of TCE in the unsaturated zone soil of the north plume at a concentration above its screening level of 0.053 mg/kg was found roughly 10 to 14 feet below ground surface and is a result of groundwater transport resulting from fluctuations in the groundwater table. The more conservative screening level for TCE (i.e., draft National Center for Environmental Assessment [NCEA]–based direct contact preliminary remediation goal [PRG] of 0.053 mg/kg) was used as the screening level on the tables and figures in the RI Report (CH2M HILL 2008); however, in accordance with the DOD’s preferred approach (DOD 2006), human health risks were estimated based on the California Environmental Protection Agency (Cal/EPA) toxicity values along with the risk estimates using draft USEPA toxicity values for comparison in the human health risk assessment (HHRA). The TCE in soil at concentrations exceeding the direct contact screening level are associated with the area within the 2,000-µg/L groundwater concentration contour, which is about 10,500 square feet in size (Figure 2-8). The increase in TCE concentrations near the water table indicates that the contamination is related to groundwater transport rather than a current overlying source. A similar area was not found in the south plume, most likely because of the much lower concentration of TCE.

2.3.2 Groundwater

2.3.2.1 North Plume

The horizontal extent of groundwater contamination in the north plume is roughly 3 acres. The highest concentration of TCE detected in 2005 was 13,186 µg/L in PZ-03 (USACE 2006). In 2007 the highest detected concentration was 4,590 µg/L. Concentrations of cDCE (1,000 µg/L) and VC (34.1 µg/L) at this location were the highest detected concentrations within the north plume in 2007. Figure 2-9 depicts the area where TCE exceeds the drinking water maximum contaminant level (MCL) of 5 µg/L. The plume associated with TCE contamination exceeding the MCL is larger than the plumes associated with cDCE and VC contamination. The area where the cDCE MCL of 70 µg/L and the VC MCL of 2 µg/L was exceeded is generally within the TCE plume (Figure 2-9).

The TCE plume has migrated laterally to the north, west, northwest, and southwest. TCE concentrations exceeding the MCL have migrated laterally about 200 feet in the north lobe of the north plume, about 400 feet in the southwest lobe of the north plume, and about 500 feet in the northwest lobe of the north plume from the original source area (Figure 2-9).

The highest TCE concentrations in the shallow groundwater were observed near the original source area at an elevation of 963 feet at PZ-03. TCE concentrations decline vertically within a few feet of this location to 0.86 µg/L (MW-17D) at an elevation of 910 feet (Figure 2-8). TCE was detected at 131 µg/L (SB-54N) at an elevation of 907 feet 50 feet horizontally downgradient of MW-17D. At SB-57N, located an additional 150 feet horizontally downgradient of MW-17D, TCE declines to 5.4 µg/L at an elevation of 892 feet, demonstrating that the plume has been characterized.

Phase I RI membrane interface probe (MIP) data and Phase II RI photoionization detector (PID) readings provide additional evidence of the vertical delineation of TCE. MIP data collected from PSB9 and PS180910 (Figure 2-10) defined the most highly contaminated parts of the subsurface in the shallow part of the aquifer, and were nondetect at an elevation of 925 and 922 feet, respectively. These depths correlate with those at which PID readings measured during the Phase II RI in deep borings (SB-54N and SB-55N) declined. PID readings in SB-54N and SB-55N were as high as 50 parts per million (ppm) until at an elevation of roughly 930 feet. PID readings from these borings ranged from 0 to 4.8 ppm below the depths that show evidence of contamination in MIP data offsite. The TCE plume in the deep part of the plume has lower TCE concentrations as compared to the TCE in the shallow part. Figures 2-2 through 2-4 are cross sections depicting TCE concentrations in the north plume.

An ongoing TCE source to the north plume was not found during the RI as indicated by the lack of DNAPL and decreasing TCE concentrations detected in groundwater from the Phase I RI sampling results compared to the Phase II RI results. Also, TCE concentrations in soil indicative of pure phase TCE were not observed. The north plume will continue to migrate to the west with decreasing TCE concentrations. Contaminant fate and transport is discussed further in Section 2.4 below.

2.3.2.2 South Plume

The horizontal extent of groundwater contamination in the south plume is roughly 4.4 acres. The highest concentration of TCE detected in 2007 was 1,090 µg/L near the original source area, at an elevation of 965 feet. Figure 2-9 depicts the area in which TCE exceeds the drinking water MCL of 5 µg/L. The area where the cDCE MCL of 70 µg/L is exceeded is entirely within the TCE plume (Figure 2-9). VC was not detected in the south plume.

The southern TCE groundwater plume has migrated west and southwest of the original source area (Figure 2-9). The plume in which TCE concentrations exceed the MCL has migrated about 600 feet from the original source area. The TCE is delineated vertically in the south plume, as demonstrated by TCE data from MW-7DD. TCE was not detected above the reporting limit in groundwater from MW-7DD, which is at an elevation of 901 feet and 40 feet horizontally downgradient of the highest shallow TCE groundwater concentrations. Figure 2-5 is a cross section depicting TCE concentrations in the south plume.

An ongoing TCE source was not found in the south plume. As with the north plume, the south plume will continue to migrate to the west with decreasing TCE concentrations.

2.3.3 Surface Water

Contamination was not observed in surface water. Concentrations of TCE, cDCE, and VC in three surface water samples collected offsite at groundwater discharge points of both the north and south plumes were below the reporting limit (CH2M HILL 2008).

2.3.4 Soil Gas

Numerous attempts were made to collect soil gas samples from the north and south plumes, near offsite residences, and adjacent to the FAA building onsite to assess the potential for TCE, cDCE, and VC concentrations in soil and groundwater to migrate into indoor air (known as vapor intrusion). Attempts included varied approaches to obtain soil gas. Because of the tight soil formation beneath the KAFS site and offsite properties, the actual concentrations of TCE, cDCE, and VC in soil gas could not be obtained and soil vapor migration into buildings is not likely (CH2M HILL 2008). As discussed in Section 2.5 below, the vapor intrusion exposure pathway was further evaluated using the Johnson & Ettinger Vapor Intrusion Model (JEM).

2.4 Contaminant Fate and Transport

2.4.1 Soil

Contamination in the unsaturated soil zone was found only in an area of elevated TCE in soil in the zone of water table fluctuation in the north plume. The contamination is likely the result of groundwater transport. TCE in the soil can leach back into groundwater. This area generally is associated with the area within the 2,000 µg/L TCE contour and is about 10,500 square feet in size. The Phase I RI did not identify a current source in the unsaturated zone, and the more extensive Phase II RI original source area investigation did not find evidence of a current source in the unsaturated zone.

The elevated concentrations of TCE in soil in the zone of water table fluctuation will slowly diminish in concentration over time as a result of leaching to groundwater, reductive dechlorination, and downgradient advection when the groundwater level is high. A similar area was not found within the south plume, most likely because of the much lower TCE concentrations in groundwater.

2.4.2 Groundwater

Groundwater data for TCE, cDCE, VC, and natural attenuation parameters support the conclusion that biological reductive dechlorination is occurring (CH2M HILL 2008). The presence of cDCE, which is a TCE breakdown product, is a result of reductive dechlorination occurring in anaerobic reducing conditions. Dissolved oxygen concentrations suggestive of anaerobic reducing conditions were found in the original source areas and downgradient wells. In most wells, however, dissolved oxygen concentrations are indicative of aerobic conditions. The results indicate either temporal variations in the subsurface or reflect the difficulty in obtaining accurate geochemical parameters in low permeability formations that recharge very slowly (i.e., oxygen from the atmosphere may diffuse into the monitoring well water during sampling).

Iron (Fe II), manganese, and sulfate concentrations were not indicative of strong reducing conditions in groundwater. However, nitrate, methane, ethene, TOC, and chloride concentrations and ORP readings indicate reductive dechlorination is occurring in the original source area. The data indicate that the microbial community has the ability to effect complete reductive dechlorination when geochemical (redox) conditions are favorable. In summary, it appears that biodegradation has occurred and continues to occur in the original source areas, and it may also be occurring in the downgradient parts of the plume. Specific concentrations and a detailed discussion are presented in the Final RI Report (CH2M HILL 2008).

In addition to the reductive dechlorination processes in the original source area, dilution and dispersion mechanisms are reducing COC concentrations in the outer edges of the plume as the plume migrates downgradient. Below is a summary of COC transport estimates, which takes into account reductive dechlorination, dilution, and dispersion for the north and south plume. Due to reduction mechanisms reducing concentrations and lack of a source (e.g., DNAPL) present, the contaminant mass in the groundwater plumes is diminishing. As explained below the groundwater plumes will decrease in concentrations as the plumes move downgradient and discharge to surface water. Due to rapid volatilization and dilution, concentrations of COCs in the surface water (i.e., contamination of surface water) are not expected.

2.4.2.1 North Plume

Figures 2-2, 2-3, and 2-4 are cross sections of the north plume (the cross section locations are indicated in Figure 2-1). Figure 2-2 is a cross section of the north lobe of the north plume. The downgradient extent of groundwater contamination in the north lobe of the north plume has been defined. The lobe has migrated about 200 feet from the original source area in the 56 years that have elapsed since the first release, which may have occurred in 1951. This distance is consistent with the groundwater migration velocity of about 2.5 ft/yr. The nearest potential discharge location for the groundwater in this part of the north plume is the pond in the southwest corner of the intersection of Glacier Drive and County Road 37A. Given the slow migration velocity, the relatively low concentration of TCE in the north lobe of the north plume, and the likely reductive dechlorination occurring, the north lobe of contamination may not reach the pond area at detectable concentrations.

Figure 2-3 is a cross section of the southwest lobe of the north plume. The downgradient extent of groundwater contamination in the southwest lobe of the north plume has been defined. The lobe has migrated about 400 feet from the original source area in the 56 years that have elapsed since the first release, which may have occurred in 1951. This distance is consistent with the groundwater migration velocity of about 7 ft/yr. The nearest potential discharge location for the groundwater in this portion of the north plume is the breached pond located adjacent to SB-53N. This pond was sampled and no TCE, cDCE, or VC were detected. Based on the measured potentiometric surface, this pond would be an intermittent groundwater discharge location when the water table was elevated. The more likely discharge location is in a small creek located 800 feet downgradient of the original source area where flowing surface water was sampled during the Phase II RI (SW-01). No TCE, cDCE, or VC was detected in this sample.

Figure 2-4 is a cross section of the northwest lobe of the north plume, which has also been defined. The lobe has migrated 500 feet from the original source area in the 56 years that have elapsed since the first release, which may have occurred in 1951. This distance is consistent with a groundwater migration velocity of about 8.4 ft/yr.

The fate and transport of TCE, cDCE, and VC in the southwest and northwest lobes of the north plume were modeled using the BIOCHLOR Natural Attenuation Decision Support System, Version 2.2 (developed for Air Force Center for Environmental Excellence).

BIOCHLOR is a screening model that simulates remediation by natural attenuation of dissolved solvents in groundwater. The software is based on the Domenico analytical solute transport model. It has the ability to simulate one dimensional advection, three-dimensional dispersion, linear adsorption, and biotransformation by reductive dechlorination. Because of the many simplifying assumptions, specific results should be considered only in a broad framework of understanding the fate and transport of the TCE, cDCE, and VC at the KAFS site.

The BIOCHLOR model predicts that TCE will arrive from the southwest lobe at the most likely discharge location (SW-01) at a maximum concentration of about 5 µg/L. The southwest lobe was modeled because it has the highest concentrations and the closest discharge point. The model predicts that it would take the TCE will take about 100 years for to reach the discharge location. The model also suggests that the plume will exhibit TCE concentrations above the MCL for more than 100 years (Table 2-1).

TABLE 2-1
Summary of Model Results for the Southwest Lobe of the North Plume
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Estimated Maximum Travel Distance of 5 µg/L TCE contour	800 ft (discharge area)
Estimated Time to Reach Maximum Travel Distance	100 yr
Estimated Maximum TCE Concentration at Discharge Location	5 µg/L
Estimated Time for Plume to Attenuate to MCLs	> 100 yr

TCE contamination from the north plume that eventually discharges to the small creek west of the site would be expected to volatilize rapidly because the creek is only a few inches deep, and the flow rate from the plume is only an estimated 0.15 gallon per minute (gpm). Note the entire flow of the north plume is estimated at 0.15 gpm, observable as a small trickle or a damp to wet area along the banks of the small creek. It is doubtful that the TCE would be detectable in surface water because of the rapid volatilization and dilution.

The fate and transport of TCE, cDCE and VC in the northwest lobe of the north plume were also modeled using BIOCHLOR to predict future maximum groundwater concentrations at Residence B because of the proximity to the north plume. The model predicts TCE in the northwest lobe to arrive below Residence B at a maximum concentration of about 149 µg/L. The model indicates that the maximum TCE concentration will arrive at Residence B in about 25 years from the present (Table 2-2).

TABLE 2-2
Summary of Model Results for the Northwest Lobe of the North Plume
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Estimated Time to Reach Maximum at Offsite Residence	25 yr
Estimated Maximum TCE Concentration at Offsite Residence	149 µg/L

2.4.2.2 South Plume

The downgradient extent of groundwater contamination in the south plume has been defined. The plume has migrated about 600 feet from the original source area in the 56 years that have elapsed since the first release, which may have occurred in 1951 (Figure 2-9). This distance is consistent with the groundwater migration velocity of about 11.5 ft/yr. The nearest potential discharge location for the groundwater in the south plume is a small creek 1,000 feet downgradient of the original source area, where flowing surface water was sampled during the Phase II RI (SW-01). No TCE, cDCE, or VC was detected in the sample.

The fate and transport of TCE, cDCE, and VC in the south plume were modeled using BIOCHLOR. The model predicts that TCE will arrive at the most likely discharge location (SW-01) at a maximum concentration of about 3 µg/L. The prediction is that it will take about 70 years for the TCE to reach this discharge location. The model also suggests that the plume will remain at TCE concentrations above the MCL for more than 100 years (Table 2-3).

TABLE 2-3
Summary of Model Results for the South Plume
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Estimated Maximum Travel Distance of 5 µg/L TCE contour	850 ft
Estimated Time to Reach Maximum Travel Distance	70 yr
Estimated Maximum TCE Concentration at Discharge Location	3 µg/L
Estimated Time for Plume to Attenuate to MCLs	> 100 yr

TCE contamination from the south plume that eventually discharges to the small creek west of the site would be expected to volatilize rapidly because the creek is only a few inches deep, and the flow rate from the plume is only an estimated 0.29 gpm. As noted for the north plume, the entire flow of the south plume is estimated at 0.29 gpm, a very small flow observable as a small trickle or a damp to wet area along the banks of the small creek. It is doubtful that the TCE would be detectable in surface water because of the rapid volatilization and dilution.

2.4.2.3 Fate and Transport Modeling Conclusions

The following conclusions have been reached as a result of the plume modeling:

- The migration rates for TCE, cDCE, and VC in the north and south plumes are slow, and it will take many decades before the plumes arrive at the most likely discharge points west of the original source areas.
- Site-specific biodegradation rates for TCE and cDCE are at the low end of those reported in the literature for reductive dechlorination (CH2M HILL 2008), but biodegradation appears to play a significant role in reducing concentrations of those chemicals in the plumes because of the slow travel times.
- TCE, cDCE, and VC concentrations are likely to be significantly less than existing plume concentrations once the plumes reach discharge zones.

Given the slow rates of TCE biodegradation, the plumes are likely to persist at the site for decades, even to beyond 100 years from today.

2.5 Human Health Risk Assessment Summary

The Phase I and II RI HHRAs identify the risk drivers (TCE, cDCE, and VC) at the KAFS site and quantify risk estimates for potential exposures to soil, groundwater, and ambient air.

The human health conceptual site model presents potential exposure media, exposure points, receptors (current and future), and exposure routes. The following potential exposure media and receptors were evaluated in the Phase II HHRA:

- **Current onsite industrial worker—**South plume soil
- **Current offsite residents—**Surface water
- **Future offsite residents—**Surface water and hypothetical potable use of offsite groundwater
- **Future onsite residents—**South or north plume soil, ambient air, and hypothetical potable use of groundwater
- **Future onsite/offsite construction workers—**South or north plume soil, groundwater, and ambient air

Surface soil, subsurface soil, groundwater, and surface water data were evaluated in the HHRA for the three risk drivers (TCE, cDCE, and VC).

For soil, the maximum detected concentrations were compared to the Region 9 residential soil PRGs (USEPA 2004). Because the PRGs for TCE and VC are based on excess lifetime cancer risk (ELCR), a noncarcinogenic hazard index (HI) of 1 is an appropriate basis for the PRG selected for cDCE. For TCE, the lower of the two available PRGs (based on provisional draft USEPA and Cal/EPA toxicity values) was used to screen detected concentrations. cDCE was the only risk driver detected in surface soil; cDCE was observed at concentrations below the residential PRG. Therefore, potential risks were not quantified for direct exposure to surface soil or ingestion of crops grown in surface soil. TCE, cDCE, and VC concentrations in subsurface soil in the south plume area were below residential PRGs. Because residential PRGs are based on more conservative exposure assumptions than are industrial PRGs, the subsurface soil concentrations in the south plume area are also considered acceptable for the worker scenarios; therefore, risks were not quantified for direct exposure to subsurface soil in the south plume area. For subsurface soil in the north plume area, TCE exceeded the residential PRG; therefore, risks were quantified for direct exposure to subsurface soil in the north plume area. To evaluate cumulative impacts from soil exposure, cDCE and VC were quantitatively evaluated in the north plume area.

For groundwater, the federal MCLs (USEPA 2006) were selected as the source of groundwater screening levels. MCLs are ARARs for public drinking water supply systems. As stated in USEPA policy presented in *Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions* (USEPA 1991), "For groundwater actions, MCLs and non-zero maximum contaminant level goals will generally be used to gauge whether remedial action is warranted." If MCLs are exceeded, unacceptable risks may be posed by the water supply. Contaminant concentrations in groundwater exceed the MCLs with the exception of VC in the onsite south plume and cDCE in the offsite south plume. In the Phase I RI HHRA, future hypothetical residential exposures to groundwater were evaluated. In the Phase II HHRA, although groundwater concentrations exceeding MCLs indicate unacceptable groundwater concentrations that warrant remediation, potential risks associated with potable groundwater use were quantified.

The risk drivers were not detected in surface water or in groundwater samples collected from residential wells. Therefore, risks were not quantified for surface water or existing residential well exposure points.

For exposures that were quantified in the Phase II HHRA (soil and potable water pathways), the ELCR and HI estimates calculated for the north and south groundwater plumes indicate that potential risks from TCE, cDCE, and VC exceed the MDNR risk threshold of 1×10^{-5} ELCR and the CERCLA acceptable risk range of 1×10^{-4} to 1×10^{-6}, and exceed the noncancer HI of 1 using Cal/EPA toxicity values per DOD's current approach. In the south groundwater plume area, soil concentrations did not exceed conservative risk-based screening levels, and the ELCR and HI estimates calculated for soil exposures in the north plume area are within acceptable levels. For comparison purposes, in accordance with DOD's current approach, risk estimates for TCE were also provided using draft USEPA toxicity values, which yield higher risk estimates. By presenting the draft toxicity values in addition to the Cal/EPA values, risk managers can better understand the potential range of risk estimates from exposure to TCE.

Soil gas samples could not be collected because of the low air movement in the soil. Since geologic conditions do not support volatile migration, modeling was not performed as part of the risk calculations for the site. However, the hypothetical vapor intrusion concentrations were modeled and presented in the uncertainty analysis section of the Phase II RI Report from measured soil and groundwater concentrations using the JEM. Potential future vapor intrusion risks were identified for various receptors above the north plume, but not the south plume, as presented below.

- Current Industrial Worker, Onsite South Plume (based on maximum detected concentrations in total soil and shallow groundwater): ELCR = 5×10^{-6}; HI = 0.03.
- Future Resident, Onsite South Plume (based on maximum detected concentrations in total soil and shallow groundwater for vapor intrusion impacts, and 95% UCL concentrations in groundwater for potable water use): HI = 0.04 for an adult resident; HI = 0.09 for a child resident; for an aggregate child/adult resident, ELCR = 1×10^{-5}.
- Future Resident, Offsite South Plume (based on maximum detected concentrations in total soil and shallow groundwater for vapor intrusion impacts, and 95% UCL concentrations in groundwater for potable water use): HI = 0.005 for an adult resident; HI = 0.01 for a child resident; for an aggregate child/adult resident, ELCR = 3×10^{-7}.
- Future Resident, Onsite North Plume (based on 95% UCL concentrations in total soil, maximum detected concentrations in total soil and shallow groundwater for vapor intrusion impacts, and 95% UCL concentrations in groundwater for potable water use): HI =0.2 for an adult resident; HI = 0.5 for a child resident; ELCR for the aggregate child/adult resident = 6×10^{-5}.
- Future Resident at Property Line (based on maximum detected concentrations in total soil and shallow groundwater for vapor intrusion impacts, and 95% UCL concentrations in groundwater for potable water use), Offsite North Plume: HI = 0.1 for an adult

resident; HI = 0.2 for a child resident; for an aggregate child/adult resident, ELCR = 3×10^{-5}.

- Future Residence B, Modeled Offsite (based on future maximum concentration from the north plume): HI = 0.002 for an adult resident; HI = 0.005 for a child resident; ELCR for the aggregate child/adult resident = 1×10^{-6}.
- Current offsite residences are within the acceptable risk range because the TCE concentration is low (below 5 µg/L) at the current homes.

As noted, these risk estimates may be overestimated since significant quantities of soil gas were not present at the site, yet the JEM was used to calculate hypothetical soil gas concentrations for use in the risk calculations. The U.S. Army guidance states that if risk is calculated using the output models, such as JEM, a finding merely indicates the potential for risk and it is not meant to demonstrate an actual risk, nor should it be construed to be a highly certain estimate (U.S. Army 2006). In addition, the U.S. Army guidance states that the DOD will notify the current property owners that there is a potential for vapor intrusion risk if there are future changes in land use. The USACE submitted letters on March 28, 2008 to the current property owners discussing the potential vapor intrusion risks if future land changes The HHRA concluded that the potential risk posed by the presence of TCE, cDCE, and VC in the groundwater supply in the north and south plume areas exceeds acceptable risk levels and the MCLs. Therefore, it is appropriate to conduct a FS to evaluate remedial alternatives to address the groundwater contamination.

2.6 Ecological Risk Assessment Summary

An ecological risk assessment (ERA) was conducted as part of the Phase I RI. The USACE performed a Tier I Baseline ERA in accordance with the USACE guidance document, *Risk Assessment Handbook, Volume II: Environmental Evaluation (EM 200-1-4)* as part of the Phase I RI. The first step in identifying the potential for risk is to determine if completed exposure pathways exist. Without exposure, there can be no risk. It was concluded that none of the potential exposure pathways for the site are complete (USACE 2006). The pathways are incomplete primarily because of the lack of site contaminants in media that can be contacted or the lack of exposure opportunity to the affected media. In other words, contaminants are not suspected to be present in surface soils where exposure is likely to occur, but are likely to be present in the deeper soil and in groundwater where exposure opportunity does not exist (USACE 2006). TCE, cDCE, and VC were not detected at concentrations above the reporting limits in surface water bodies, and the fate and transport model indicates that future concentrations in surface water bodies will be less than the MCLs and will volatize rapidly into the atmosphere. Therefore, complete pathways are also unlikely in the future. Since there are no complete exposure pathways, no ecological risks were identified for the site (USACE 2006).

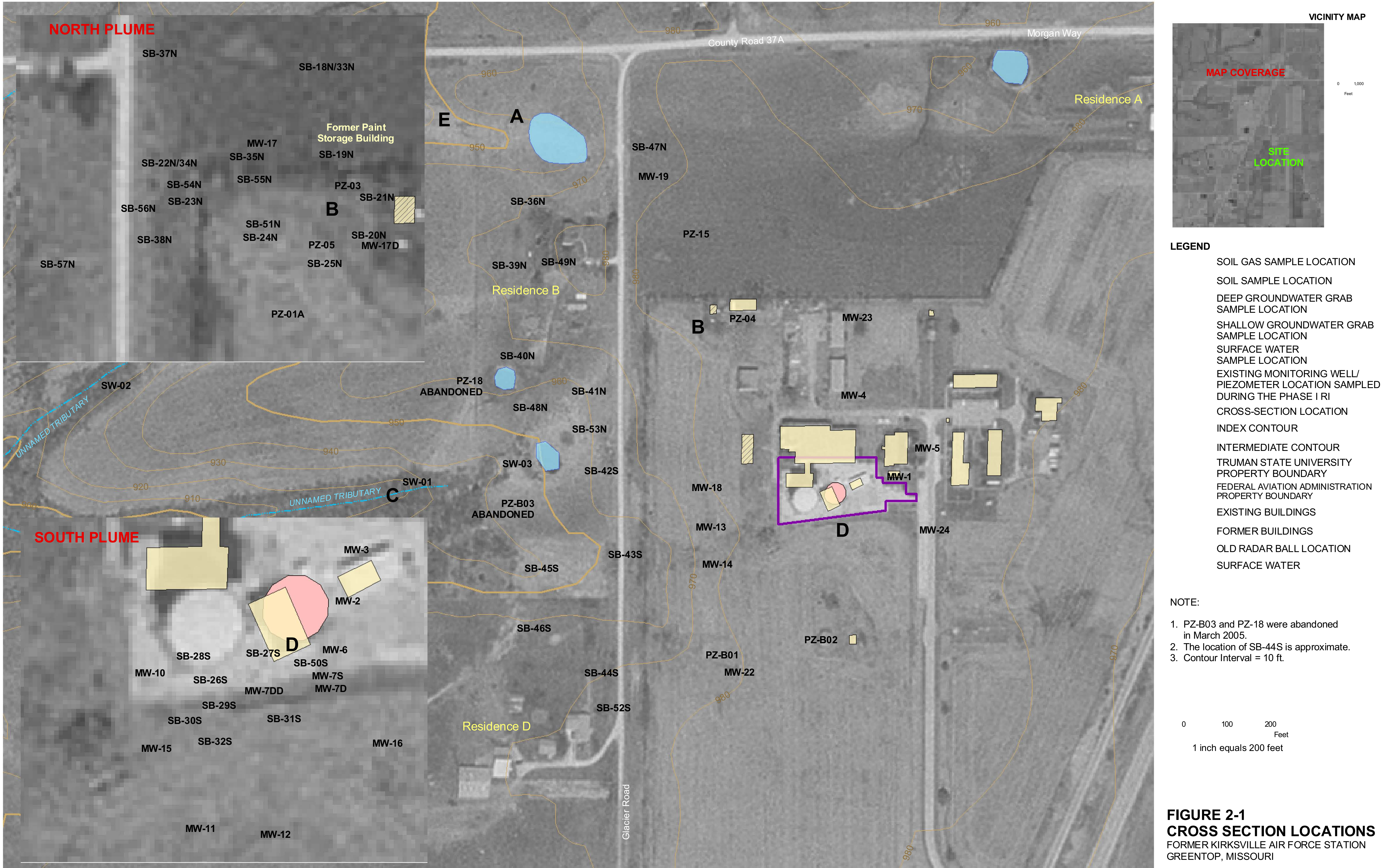


FIGURE 2-1
CROSS SECTION LOCATIONS
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

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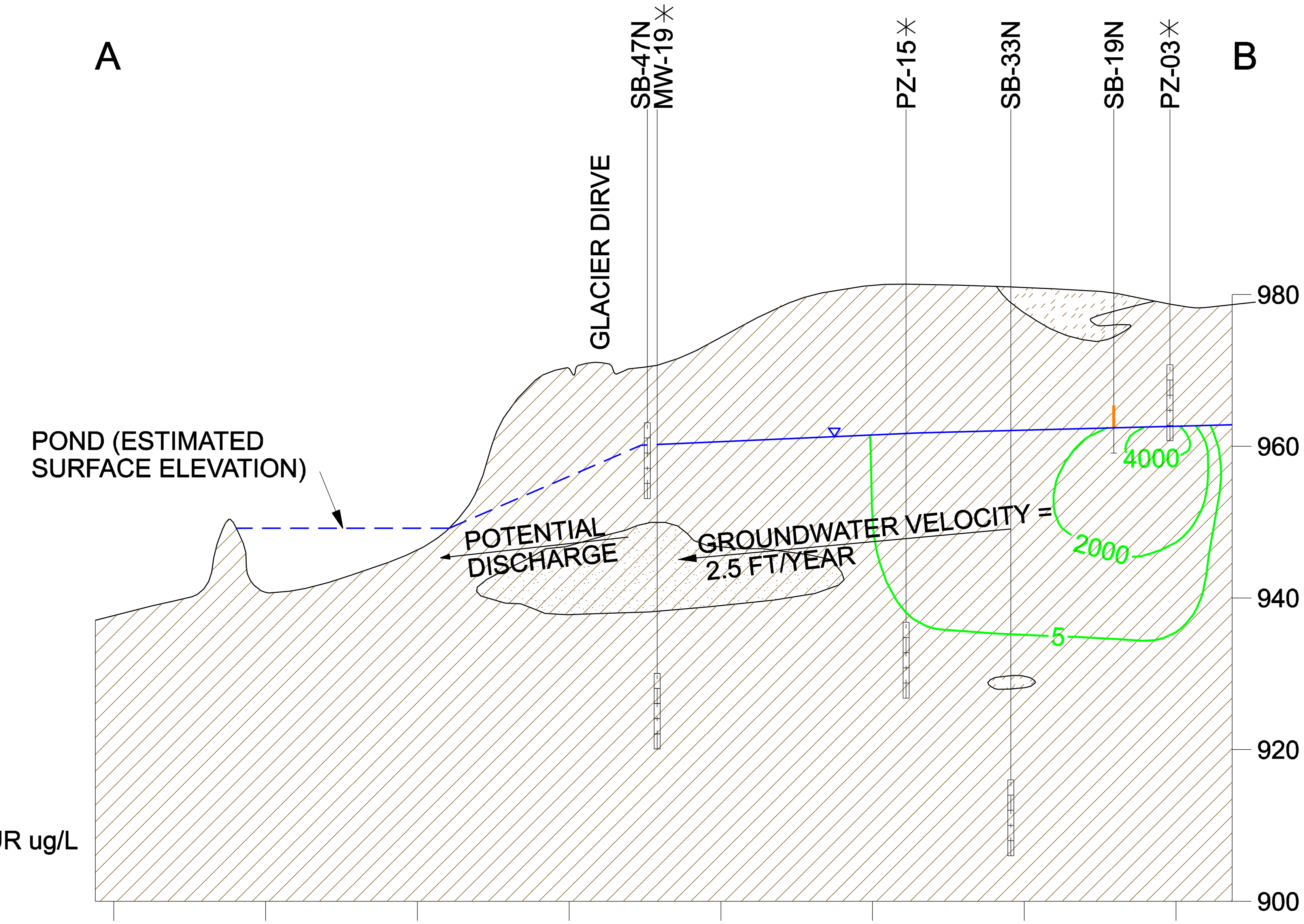

LEGEND

- TCE CONCENTRATION COUNTOUR ug/L
- GROUNDWATER TABLE
- INFERRED GROUNDWATER TABLE
- PID READING < 20 ppm
- PID READING > 20 ppm
- ⚹ PID READING NOT AVAILABLE
- LEAN/FAT CLAY
- SANDY CLAY
- SILT

NOTE:
THIN SAND OR GRAVEL LENSES THAT MAY BE PRESENT ARE NOT SHOWN.

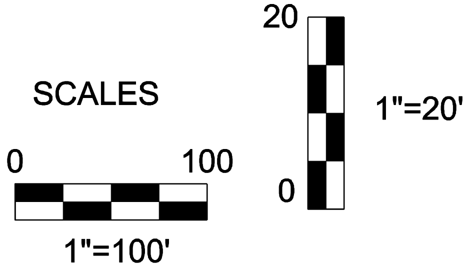

FIGURE 2-2
CONCEPTUAL SITE MODEL CROSS SECTION A-B
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

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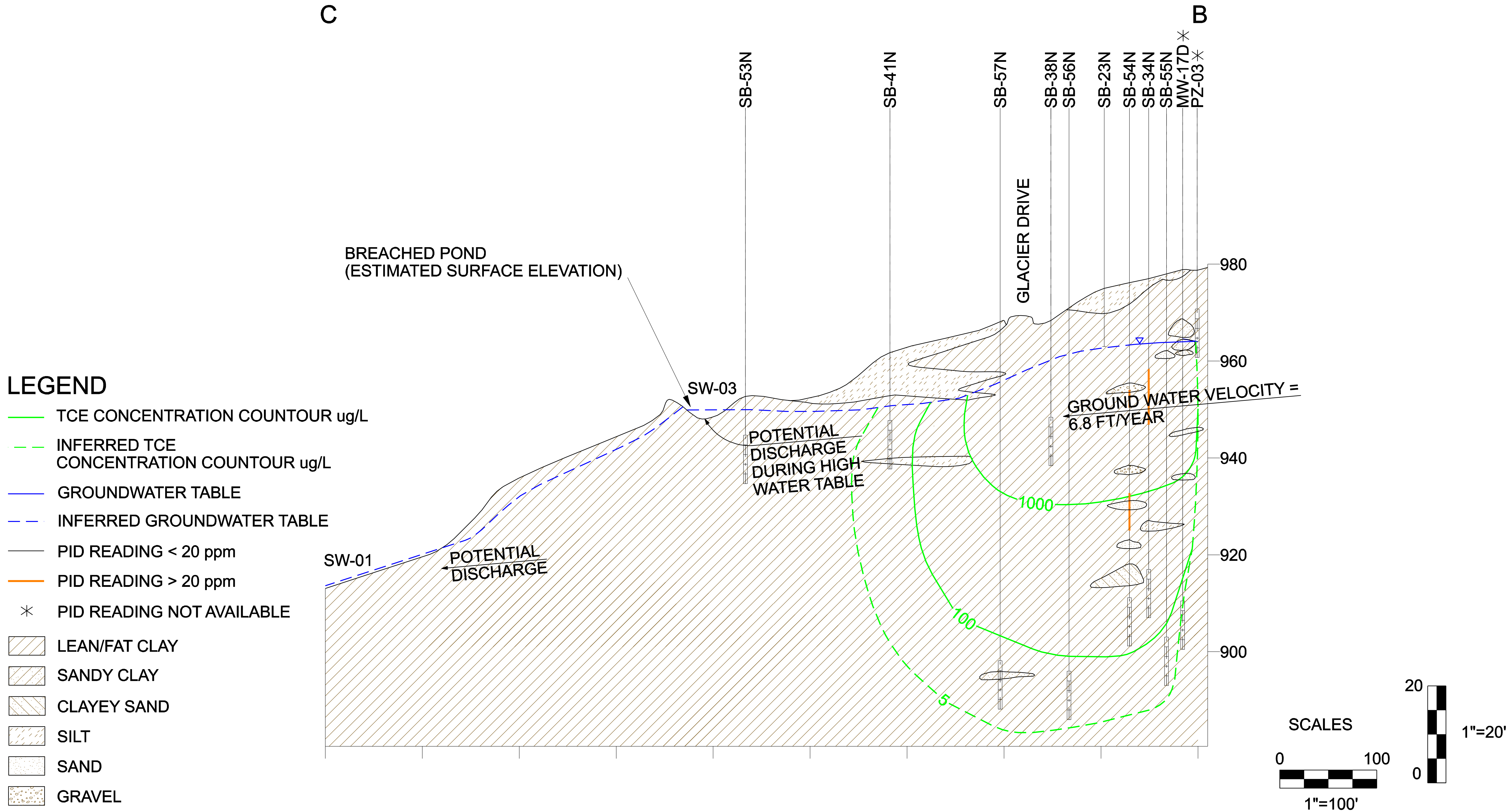

NOTE:
THIN SAND OR GRAVEL LENSES THAT
MAY BE PRESENT ARE NOT SHOWN.

FIGURE 2-3
CONCEPTUAL SITE MODEL CROSS SECTION B-C
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

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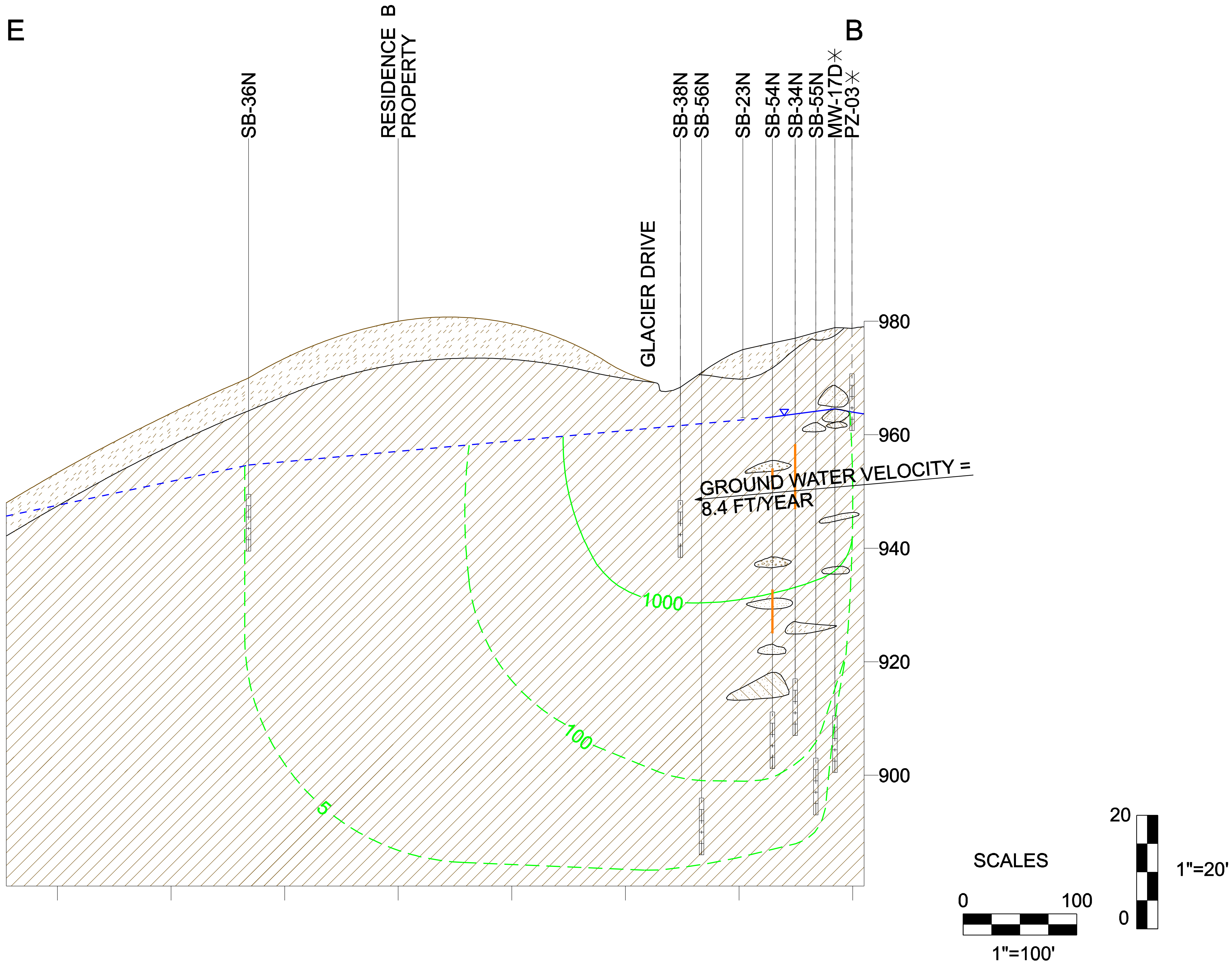

LEGEND

- TCE CONCENTRATION COUNTOUR ug/L
- INFERRED TCE CONCENTRATION COUNTOUR ug/L
- GROUNDWATER TABLE
- INFERRED GROUNDWATER TABLE
- PID READING < 20 ppm
- PID READING > 20 ppm
- ✳ PID READING NOT AVAILABLE
- LEAN/FAT CLAY
- SANDY CLAY
- CLAYEY SAND
- SILT
- SAND
- GRAVEL

NOTE:
THIN SAND OR GRAVEL LENSES THAT MAY BE PRESENT NOT SHOWN.

FIGURE 2-4
CONCEPTUAL SITE MODEL
CROSS SECTION B-E
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

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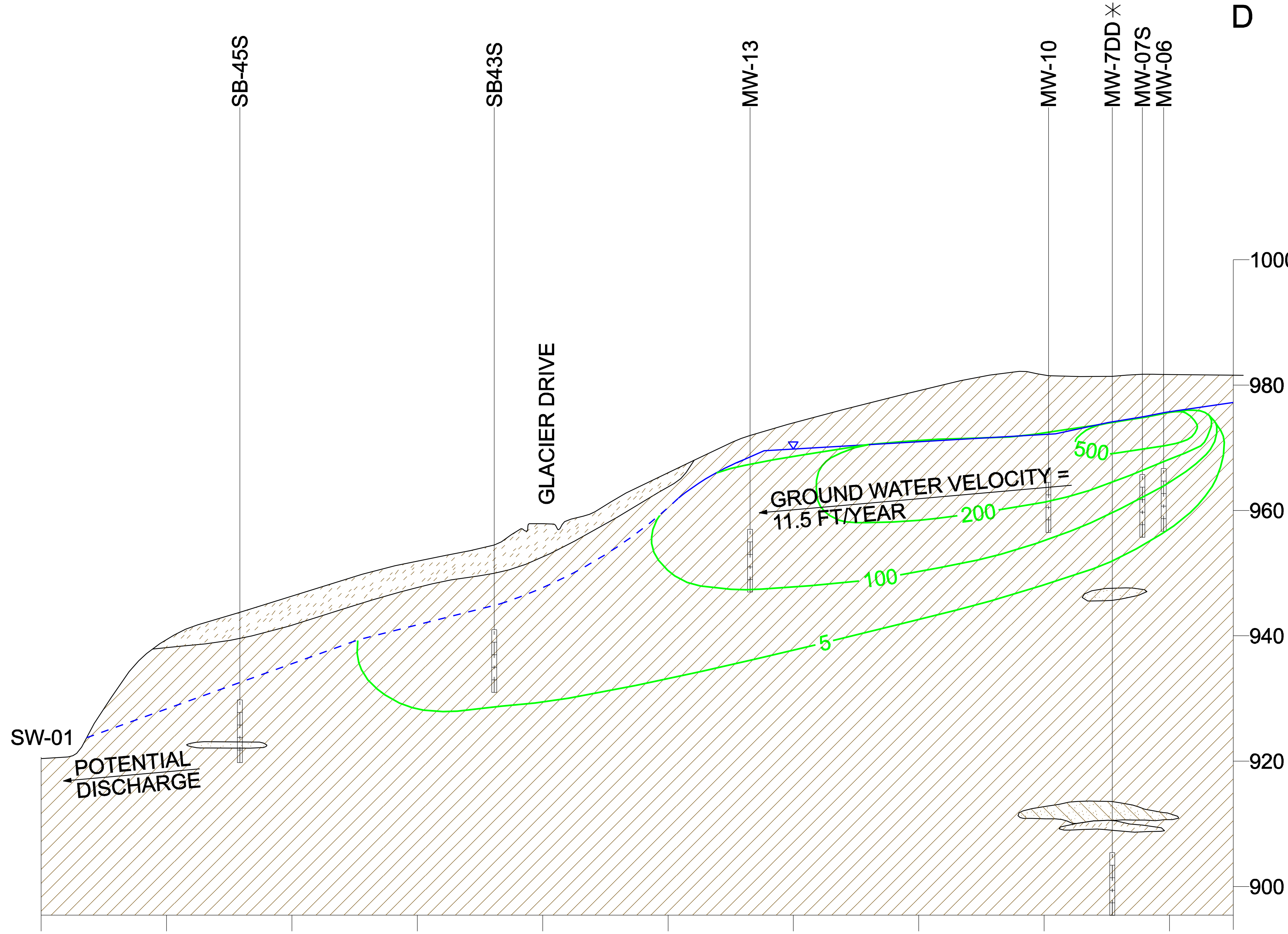

SCALES

0 100

1"=100'

20 0

1"=20'

LEGEND

- TCE CONCENTRATION COUNTOUR ug/L
- GROUNDWATER TABLE
- INFERRED GROUNDWATER TABLE
- PID READING < 20 ppm
- * PID READING NOT AVAILABLE
- LEAN/FAT CLAY
- SANDY CLAY
- CLAYEY SAND
- SILT

NOTE:
THIN SAND OR GRAVEL LENSES THAT MAY BE PRESENT ARE NOT SHOWN.

FIGURE 2-5
CONCEPTUAL SITE MODEL CROSS SECTION C-D
FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

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VICINITY MAP

LEGEND

MONITORING WELL/PIEZOMETER

976 POTENTIOMETRIC SURFACE CONTOUR

976 INFERRED POTENTIOMETRIC SURFACE CONTOUR

GROUNDWATER FLOW DIRECTION

TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY

FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY

EXISTING BUILDING

FORMER BUILDING

OLD RADAR BALL LOCATION

TOPOGRAPHIC CONTOUR

TOPOGRAPHIC CONTOUR

NOTES:

1. Water level reported in feet above mean sea level.
2. Water level Contour Interval = 2 ft.
3. Ground surface Contour Interval = 10 ft.

0 60 120
Feet

1 inch equals 120 feet

FIGURE 2-6
GROUNDWATER POTENTIOMETRIC SURFACE MAP (MARCH 14, 2007)

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

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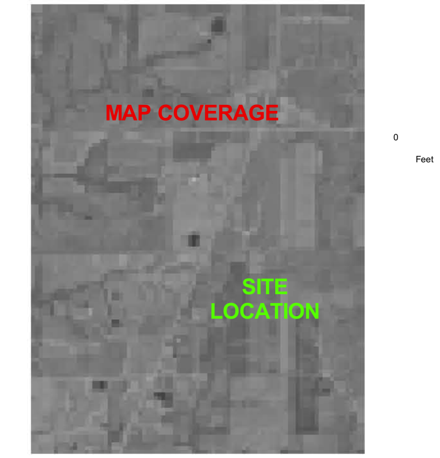
VICINITY MAP



LEGEND

- TOPOGRAPHIC CONTOUR
- TOPOGRAPHIC CONTOUR
- SURFACE WATER FLOW DIRECTION
- TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
- FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
- EXISTING BUILDINGS
- FORMER BUILDINGS
- OLD RADAR BALL LOCATION
- FORMER SEWAGE LAGOON
- SURFACE WATER

CONTOUR INTERVAL = 10 FT

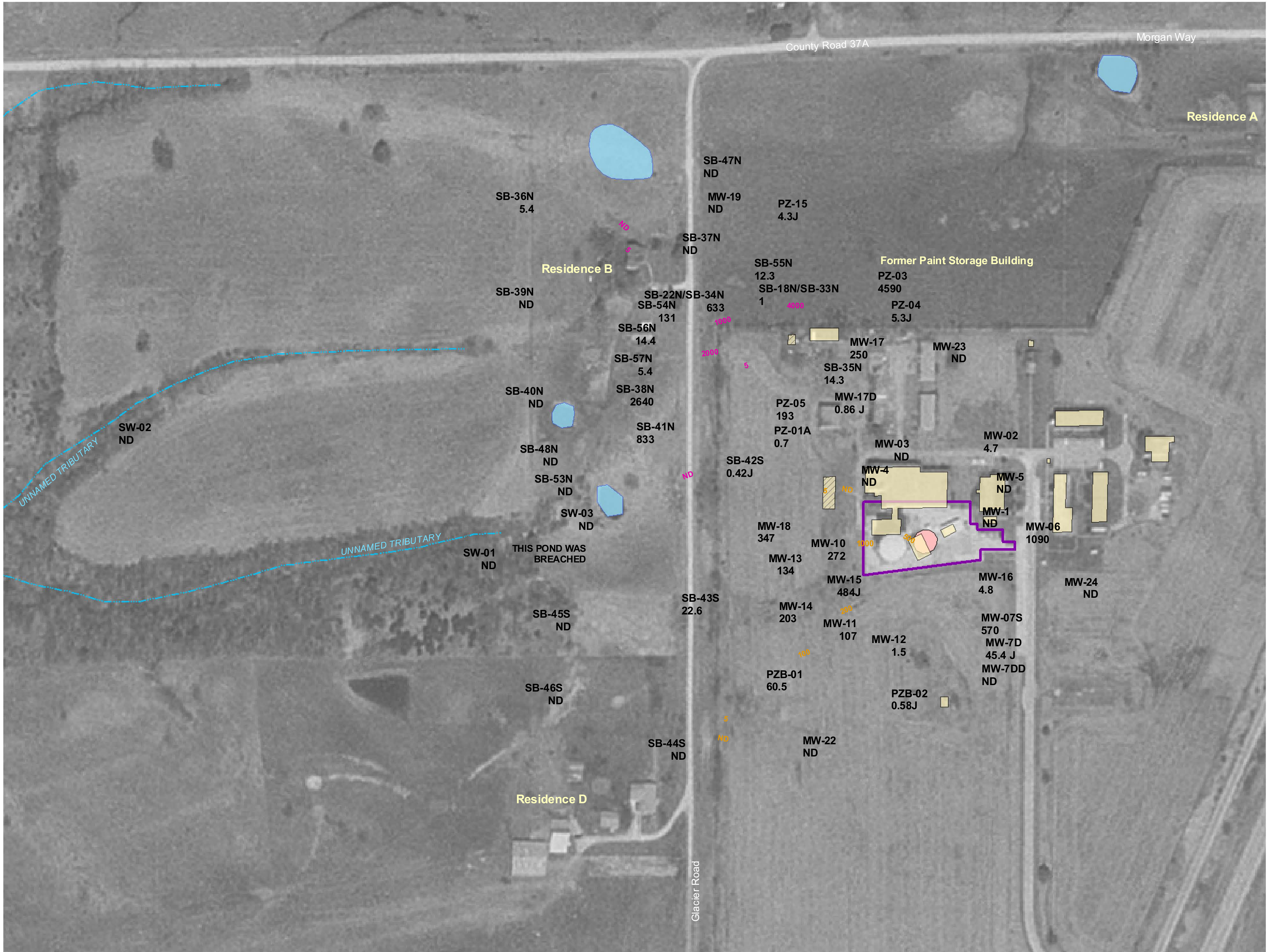
0 200 400
Feet

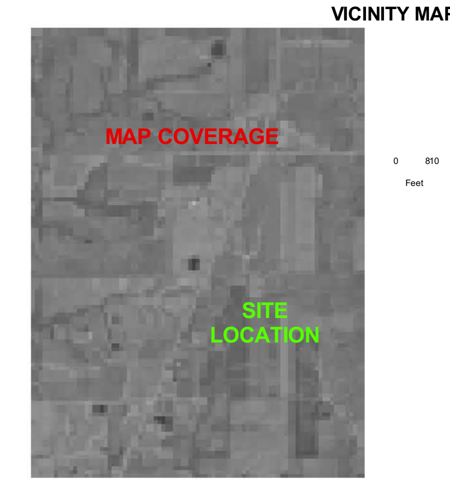
1 inch equals 400 feet

FIGURE 2-7
SITE TOPOGRAPHY AND SURFACE WATER DRAINAGE MAP

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL





LEGEND

SHALLOW GROUNDWATER GRAB SAMPLE LOCATION
DEEP GROUNDWATER GRAB SAMPLE LOCATION
SURFACE WATER SAMPLE LOCATION
EXISTING MONITORING WELL/ PIEZOMETER LOCATION SAMPLED DURING THE PHASE II RI
TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
EXISTING BUILDINGS
FORMER BUILDINGS
OLD RADAR BALL LOCATION
SURFACE WATER

PHASE II RI TCE CONTOURS

NORTHERN PLUME
SOUTHERN PLUME

NOTE:

1. Trichloroethene (TCE) concentrations reported in micrograms per liter (µg/L).
2. TCE concentration contours in deep (> 60 feet) zones of the aquifer are not shown. However, the concentrations observed in the deep zone are within the shallow zone plume contours.
3. The location of SB-44S is approximate.

0 100 200 Feet

1 inch equals 200 feet

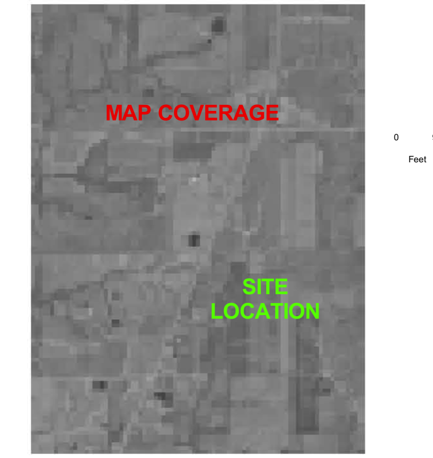
FIGURE 2-8
TCE GROUNDWATER CONCENTRATION CONTOURS (MARCH 2007)

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

RDD \\LOKI\PROJECTS\RDDGIS\350464_KIRKSVILLEAFS\MAPFILES\FS\FIG2-8_TCE_FS.MXD 8/4/2008 15:46:13

VICINITY MAP



LEGEND

- SOIL SAMPLE LOCATION
- DEEP GROUNDWATER GRAB SAMPLE LOCATION
- SHALLOW GROUNDWATER GRAB SAMPLE LOCATION
- SURFACE WATER SAMPLE LOCATION
- EXISTING MONITORING WELL/ PIEZOMETER LOCATION SAMPLED DURING THE PHASE I RI
- TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
- FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
- EXISTING BUILDINGS
- FORMER BUILDINGS
- OLD RADAR BALL LOCATION
- SURFACE WATER

PHASE II RI TCE CONTOUR

- NORTHERN PLUME (5 ug/L)
- SOUTHERN PLUME (5 ug/L)

NOTES:
1. TCE - trichloroethene
2. cDCE - cis-1,2-dichloroethene
3. VC - vinyl chloride
4. Groundwater concentrations reported in micrograms per liter (µg/L).
5. Concentrations shown in red are greater than the USEPA Maximum Contaminant Levels (MCLs)
6. PZB-03 and PZ-18 were abandoned in March 2005.
7. The location of SB-44S is approximate.
8. Concentrations were below the USEPA MCLs if not shown.

0 100 200
Feet

1 inch equals 200 feet

FIGURE 2-9
PHASE II RI TCE, cDCE, AND VC GROUNDWATER CONCENTRATIONS

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

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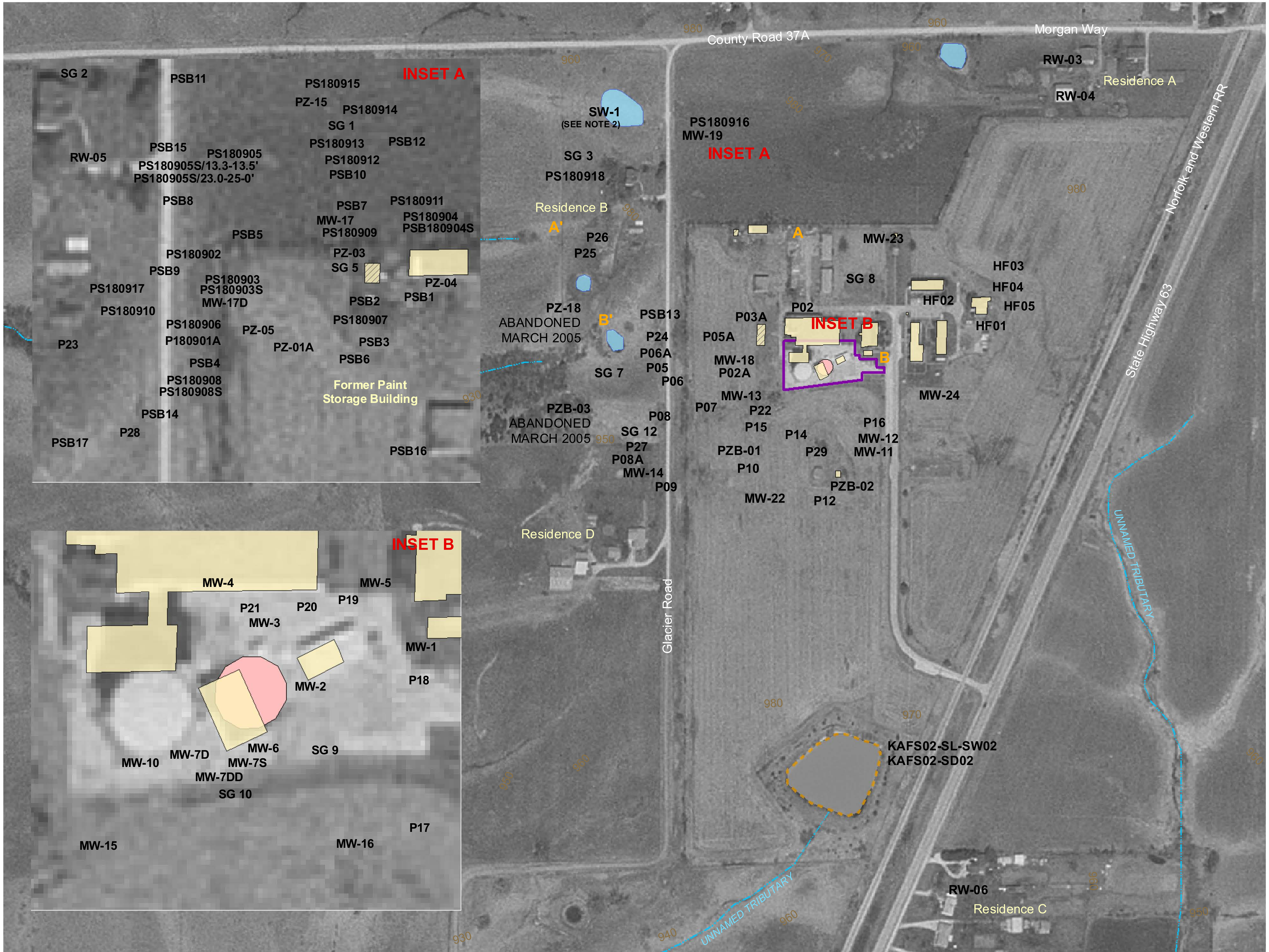
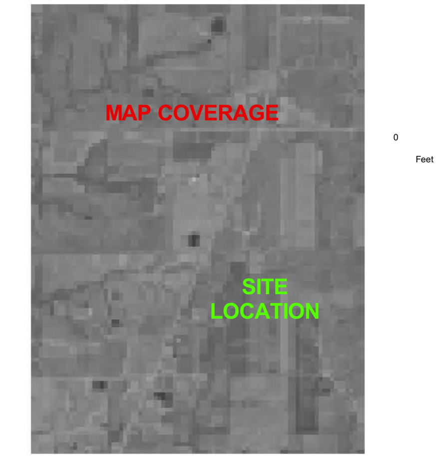


VICINITY MAP



LEGEND

- MONITORING WELL / PIEZOMETER LOCATION
- RESIDENTIAL WELL LOCATION
- SOIL GAS LOCATION
- MIP SOIL BORING LOCATION WITH SOIL SAMPLE
- MIP SOIL BORING LOCATION
- SURFACE WATER SAMPLE LOCATION
- SURFACE WATER/SEDIMENT SAMPLE LOCATION
- TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
- FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
- EXISTING BUILDINGS
- FORMER BUILDINGS
- OLD RADAR BALL LOCATION
- FORMER SEWAGE LAGOON
- SURFACE WATER
- STREAM

NOTES:

1. MIP - Membrane Interface Probe
2. Location of SW-1 was adjusted with pond location correction.
3. Contour Interval = 10 ft.

0 150 300
Feet

1 inch equals 300 feet

FIGURE 2-10
PHASE I RI SAMPLE LOCATIONS

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

3. Alternative Development and Evaluation

The following steps were taken to develop and evaluate remedial alternatives:

1. Identify ARARs.
2. Develop RAOs.
3. Determine PRGs and areas exceeding the PRGs.
4. Evaluate COCs against remediation goals.
5. Develop general response actions.
6. Identify and screen technologies and process options.
7. Develop remedial alternatives.
8. Perform detailed analysis of remedial alternatives.
9. Perform comparative analysis of each alternative's ability to satisfy the evaluation criteria.

3.1 Applicable or Relevant and Appropriate Requirements

Potential ARARs are discussed in this section because they can affect the development of RAOs. After remedial alternatives have been developed, they are evaluated against whether they meet ARARs. Once a remedy is selected, final ARARs are identified in the Decision Document.

The DOD serves as lead agency for the FUDS program, and the U.S. Army is designated as the executive agency for the DOD. The U.S. Army delegated the management and execution of the FUDS program to the USACE. CERCLA is followed for FUDS responses to hazardous substances, pollutants and contaminants set forth in the Defense Environmental Restoration Program Statute at 10 USC 2701.

CERCLA remedial actions must meet ARARs for selected remedies unless a waiver is requested. ARARs are federal, state, and local public health and environmental requirements that define the extent of site cleanup, identify sensitive land areas or land uses, develop remedial alternatives, and direct site remediation. CERCLA and the NCP require that remedial actions comply with federal ARARs and also with state and local ARARs that are more stringent than their federal counterparts, as long as they are enforceable and consistently enforced.

Where the state of Missouri is authorized to implement a program in lieu of a federal agency (for example, the National Pollutant Discharge Elimination System [NPDES]), state laws arising out of the state program may be ARARs, not the federal authorizing legislation.

There are three types of ARARs. *Location-specific ARARs* restrict the occurrence of chemicals in certain sensitive environments, such as wetlands (for example, the Endangered Species Act). *Action-specific ARARs* are activity-based or technology-based, and typically control remedial activities that generate hazardous wastes (for example, Resource, Conservation and Recovery Act). *Chemical-specific ARARs* are health-based or risk management-based numbers that provide concentration limits for the occurrence of a chemical in the environment (for example, USEPA drinking water MCLs).

Section 121 of CERCLA requires that primary consideration be given to remedial alternatives that attain or exceed ARARs. The purpose is to make CERCLA response actions consistent with other pertinent federal, state, and local environmental requirements and to adequately protect human health and the environment.

ARARs include promulgated environmental requirements, criteria, standards, and other limitations. Other factors are "to be considered." Factors to be considered in remedy selection may include guidance and other limitations, but attainment of them is not a threshold criteria during alternative selection. Instead, they can be used to evaluate whether the selected remedy is protective of human health and the environment. Implementation of the selected remedial actions must be in compliance with the ARARs, or a specific ARAR waiver must be requested per the National Contingency Plan.

Applicable requirements means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable. 40 CFR 300.5

Relevant and appropriate requirements means those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than federal requirements may be relevant and appropriate. 40 CFR 300.5

A requirement must first be determined to be relevant, then appropriate. In general, this involves a comparison of a number of site-specific factors, including the characteristics of the remedial action, the nature of the hazardous substance present at the site, and applicable regulatory requirements. In some cases, a requirement may be relevant but not appropriate; it is possible for only a part of a requirement to be considered relevant and appropriate in a given case. When the analysis results in a determination that a requirement is both relevant and appropriate, such a requirement must be complied with as if it were applicable.

"To be considered" factors are nonpromulgated advisories or guidance issued by federal, state, or local government that are not legally binding and do not have the status of potential ARARs. In many circumstances such factors will be considered along with ARARs in determining the level of cleanup required to protect human health and the environment.

Remedial actions must comply with federal, state, and local ARARs. For a state or local requirement to be an ARAR, it must meet three criteria:

- It must meet the definition of an ARAR.
- It must be more stringent than federal requirements.
- It must be a promulgated standard, requirement, criterion, or limitation under a state or local environmental or facility siting law and consistently enforced.

Table 3-1 lists statutes and regulations containing requirements deemed to be potential ARARs and "to be considered" criteria for the KAFS site. Of the potential ARARs evaluated in Table 3-1, the Federal Safe Drinking Water Act MCLs for the COCs TCE, cDCE, and VC and the Missouri Water Well Drillers Act were determined to be ARARs for the KAFS site based on the alternatives presented in the following sections.

TABLE 3-1
Potential Chemical-Specific ARARs and To Be Considered Criteria for Remediation
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Requirement	Requirement Synopsis
Federal	
Federal Safe Drinking Water Act (40 U.S.C. 300 et seq.)	The Safe Drinking Water Act promulgated in 1974 is intended to protect human health by controlling contaminants that can occur in drinking water. It is an amendment of the original Public Health Service Act. Through the Act, the USEPA developed chemical concentration limits and management standards for public drinking water supplies, known as maximum contaminant levels (MCLs) and MCL goals. The drinking water standards are applicable only to water supply systems. They are considered relevant and appropriate (and thus ARARs) for current or potential usable aquifers.
Clean Water Act (33 U.S.C. 1251 et seq.)	The Clean Water Act was passed in 1977. It is a major amendment of the original 1972 Federal Water Pollution Control Act. Its chief purpose is to restore and maintain surface water quality by controlling discharges of chemicals (priority toxic pollutants) to surface water. The Act is closely linked to CERCLA: all 126 priority toxic pollutants under the Act are CERCLA hazardous substances. Direct and indirect discharges of priority pollutants to surface water are regulated through NPDES. The NPDES program also includes ambient water quality standards and antidegradation policy standards.
State	
Missouri Clean Water Law (Chapter 644 RSMo)	The Missouri Clean Water Law was promulgated in 1973 and transferred in 1986. The law, under Title 10, Division 20 of the CSR, established a water contaminant control agency known as the Missouri Clean Water Commission. The state policy is consistent with the federal policy: to conserve the waters of the state and to protect, maintain, and improve the quality of the waters of the state. The commission carries out the policy through the Water Protection and Soil Conservation Division, Water Protection Program, and Water Pollution Control Branch. Standards for discharge of pollutants to state waters are set forth consistent with the Clean Water Act. Specific requirements are defined in 10 CSR 20-7.

3.2 Develop Remedial Action Objectives

RAOs are goals specific to media or operable units for protecting human health and the environment. The identified risks can be associated with current or potential future exposures. RAOs should be as specific as possible but not so specific that the range of alternatives that can be developed is unduly limited. Objectives aimed at protecting human health and the environment should specify (1) COCs; (2) exposure routes and receptors; and (3) an acceptable contaminant level or range of levels for each exposure route (that is, a PRG) (USEPA 1998).

RAOs were developed for the site in part based on the contaminant levels and exposure pathways found to present potentially unacceptable human health determined during the RI. The RAOs, remediation goals, and remediation strategies developed address constituents posing unacceptable risks to the residential scenario.

The HHRA found that the north and south plumes pose unacceptable risks to human health if the groundwater is used as a potable source in the future. Therefore, the RAO for the site is to prevent unacceptable risk to human health from potable use of groundwater containing TCE, cDCE, or VC in concentrations exceeding the MCLs. This RAO can be met through various remedial approaches, ranging from preventing exposure to remediating the groundwater.

3.3 Identify Preliminary Remediation Goals and Areas Exceeding the Preliminary Remediation Goals

PRGs are risk- or ARAR-based chemical-specific concentrations that help refine the RAO. PRGs are considered preliminary, in that the final remedial goals are defined in the Decision Document once a remedy is selected for the site. The PRGs are used to define the extent of contaminated media requiring remedial action. The following PRGs for COCs in groundwater are the Federal Drinking Water Act, MCLs:

- TCE: 5 μg/L
- cDCE: 70 μg/L
- VC: 2 μg/L

Figure 3-1 shows the locations where TCE, cDCE, and VC exceed their respective PRGs.

3.4 Develop General Response Actions

After the RAO and PRGs are developed, GRAs are identified to address them for affected media at the site. As defined in the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final*, GRAs are media-specific actions that satisfy RAOs. Actions for mitigating risk posed by affected media may be applied individually or in combination. Table 3-2 summarizes the development of GRAs for achieving the RAO in groundwater.

3.5 Identify and Screen Technologies and Process Options

Within each remaining general response action, remedial technologies were identified and screened based on the following criteria:

- **Effectiveness** is the ability of the technology or process option to perform adequately to achieve the remedial objectives alone or as part of an overall system.

- **Implementability** refers to the relative degree of difficulty expected in implementing a particular measure under practical technical, regulatory, and schedule constraints.

- **Relative cost** is comparative only and is judged similar to the effectiveness criterion. It is used to preclude further evaluation of process options that are very costly where there are other choices that perform similar functions with comparable effectiveness. It includes construction and long-term operation and maintenance costs.

TABLE 3-2
General Response Actions Retained for the KAFS Site
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

GRA	Approach to Achieving the RAO
No action	A baseline alternative will be evaluated because it is required by CERCLA, but no action will not achieve the RAO.
Alternative Water Supply	Controls the use of groundwater as a potable water source as a result of the implementation of an alternative water supply.
Monitoring	Establishes a program with appropriately identified locations to monitor chemical plume concentrations, degradation, and migration. Monitoring does not achieve the RAO as a stand-alone GRA. However, monitoring may be used in conjunction with other GRAs to satisfy the RAO.
Containment	Includes prevention of contaminant migration offsite. Examples of containment include slurry walls, grout curtains, sheet pilings, etc. Groundwater containment options will not reduce contaminant mass and must be combined with other GRAs to address risk. Given the minimal extent of the plume and the already very slow migration, further containment of the plume does little to reduce risk. Therefore, containment will not be evaluated further.
In situ treatment	Involves treating contaminants in the original source area without removing the groundwater. In situ treatment typically is used in conjunction with monitored natural attenuation for groundwater downgradient of the original source area. Examples of in situ treatments include chemical oxidation, chemical reduction, permeable reactive barriers, air sparging, steam flushing, enhanced bioremediation, anaerobic bioremediation, natural attenuation, and phytoremediation. In situ treatment would satisfy the RAO if used in conjunction with other GRAs to limit exposure during the time it takes for the in situ treatment of the original source area and the monitored natural attenuation of the downgradient groundwater to return groundwater to below MCLs.
Collection and ex situ treatment	Involves removing the groundwater followed by treatment or removal of contaminants. Examples of ex situ treatment include chemical oxidation, air stripping, and carbon adsorption. Collection of groundwater to remove the contaminants exceeding the PRGs would require multiple pore volume flushes and is not as effective as in situ treatment technologies. Pump and treat systems result in long periods of operation and maintenance requirements. In addition, removal of groundwater is infeasible, considering the subsurface formation (e.g., low yielding clay). As a result, groundwater collection and ex situ treatment will not be evaluated further.
Discharge	Includes discharging treated groundwater to surface water or to groundwater by reinjection. Discharge is not needed because collection of groundwater is infeasible.

Table 3-3 summarizes the screening process for groundwater. Technologies and process options considered infeasible based on effectiveness, implementability, and costs are shown in shaded background. Screening was based on professional experience, published sources, and other relevant documentation. The technologies retained following screening include alternative water supply, monitoring, and in situ treatment.

3.6 Identify Remedial Alternatives

The technologies that remained following screening were assembled into remedial alternatives that meet the RAO for groundwater. The specific details of the remedial components discussed for each alternative are intended to serve as representative examples to allow order-of-magnitude cost estimates. Process options within the same remedial technology that achieve the same objectives may be evaluated during the remedial design.

There remedial alternatives were developed for groundwater: Alternative 1, No Action; Alternative 2, Monitored Natural Attenuation and Alternative Water Supply; and

Alternative 3, Enhanced Biodegradation with Monitoring and Alternative Water Supply. As noted in Section 2 above, there is some uncertainty related to potential future vapor intrusion risks due to the concentrations in the groundwater. Five-year site reviews are a component of Alternatives 2 and 3.

3.6.1 Alternative 1—No Action

Alternative 1 consists of taking no action. The NCP requires that a No-Action Alternative be retained throughout the FS process as a baseline for comparison to the other approaches. No action would leave affected groundwater in place at the KAFS site. No mechanisms would be in place to prevent or control exposure to contaminants. Alternative 1 allows natural attenuation to reduce contaminants in groundwater. Lack of active cleanup or controls may allow users to be exposed to contaminants in the groundwater even as natural attenuation occurs. This is a remote possibility for the site because:

- Shallow groundwater is not used as a potable source.
- Potable water is supplied by a public water system.
- The shallow aquifer is not expected to be used as a potable source because the silt and clay soils have very low permeability, the water-bearing zone has insufficient yield, and the water is of poor natural quality.

There are no capital or O&M costs for the No-Action Alternative.

3.6.2 Alternative 2—Monitored Natural Attenuation and Alternative Water Supply

Alternative 2 relies on natural attenuation processes as defined by the USEPA to reduce contaminant concentrations. Groundwater monitoring of natural attenuation parameters is included to allow the progress of natural attenuation to be documented and evaluated over the long term. The RI indicated that natural attenuation is occurring as evidenced by reducing TCE concentrations in monitoring wells located in the original source area (e.g., MW-17, PZ-03, and PZ-05), the presence of TCE breakdown products (e.g., cDCE), and groundwater geochemistry information (e.g., low nitrate concentrations, elevated methane, ethane, and TOC concentrations, chloride, and low ORP readings). The natural attenuation is likely attributed to natural reductive dechlorination within the areas of the plume with the highest detected TCE concentrations and dilution and dispersion within areas of the plume with lower concentrations of TCE.

As part of this alternative, the COC concentrations in groundwater would be monitored likely through the collection of groundwater samples at least every 5 years from new or existing monitoring wells. The details of the monitoring program, such as the precise number of wells to be sampled, will be provided in the remedial design work plan. The objectives of the monitoring program are as follows:

- Verify that contaminant concentrations are declining with time at a rate and in a manner so that cleanup standards will be met in around 100 years.
- Ensure that the lateral migration does not significantly extend beyond the current area of impact.

TABLE 3-3
Groundwater Technology and Process Option Screening
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
No Action								
None	None	No action.	None.	No action does not achieve RAOs.	None.	Implementable.	Low.	Required by CERCLA for comparison.
Alternative Water Supply								
Alternative Water Supply	Residential connection to public water supply/bottled water/granular activated carbon system.	Properties in the areas with groundwater concentrations exceeding the clean up goals will be provided alternative water supply that may consist of bottled water, a granular activated carbon system, public water supply or a combination of these to limit groundwater consumption.	None.	Alternative Water Supply may need to be used in conjunction with other GRAs. Alternative Water Supply does not prevent contaminant migration.	Effective as a mechanism to protect human health by minimizing ingestion or contact with groundwater.	Implementable.	Moderate	Retained.
Monitoring								
Monitoring	Groundwater Monitoring	Short- or long-term routine monitoring is implemented to record site conditions and concentration levels.	None.	Monitoring may need to be used in conjunction with other GRAs.	Effective as a tool to evaluate natural attenuation parameters and other actions taken.	Implementable.	Moderate.	Critical to monitor effectiveness of in situ treatment actions.
In Situ Treatment								
Chemical	Chemical Oxidation	Aqueous injection of oxidizing agents (peroxide/iron, permanganate, or ozone) to promote abiotic in situ oxidation of chlorinated organic compounds.	Effective on most cVOCs.	Unproductive oxidant consumption by natural media. Application involves injection of aqueous phase reagents will be significantly constrained in low permeability media.	Theoretically effective, but requires good contact between contaminant and reagent.	Difficult to implement and achieve good mixing in situ.	Moderate to high. Oxidation not cost-effective on dilute dissolved VOC plumes.	Not retained because the aquifer in the area of the portion of the plume with highest cVOC concentrations is under reducing conditions, necessitating high oxidant demand.
	Chemical Reduction	Aqueous injection of reducing agents (zero-valent iron, hydrogen) to promote abiotic in situ reduction of chlorinated organic compounds.	Effective on most cVOCs.	Application involves injection of aqueous phase reagents will be significantly constrained in low permeability media.	Effective when used as a whole plume treatment given good distribution of the zero-valent iron. Also effective when used as permeable treatment barrier for the migration of affected groundwater. Life of treatment media and need/method of media replacement a key issue.	Implementable as either a whole plume treatment technology or as a permeable reactive barrier.	High capital cost for whole plume treatment because of large amount of zero-valent iron needed. Cost effective when used as a permeable reactive barrier.	Not retained for whole plume treatment because of high cost compared to other in situ technologies.

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Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Permeable Reactive Barriers (Passive Treatment Walls)	Permeable treatment wall consisting of zero valent iron would be installed across the flow path of the CVOC plume. As groundwater moves through the treatment wall, cVOCs are reductively dechlorinated.	Effective on cVOCs.	May lose reactive capacity, requiring replacement of the reactive medium. Permeability may decrease because of biological activity or chemical precipitation.	Effective in treating groundwater to reduce plume cVOC concentrations at wall. Remediates upgradient and downgradient groundwater passively as it naturally flushes through the aquifer.	Implementable to the needed depth of 25 to 30 feet using continuous trenching machine.	Moderate to high. Where applicable, considered a cost-effective alternative to conventional remedial action technologies.	Not retained for whole plume treatment because of high cost compared to other in situ technologies and the slow migration velocity and desorption from low permeability soils makes this relatively ineffective for plume remediation.
Physical	In-Well Air Stripping (Circulating Wells)	Groundwater is aerated and lifted within a well bore, re-infiltrates a different strata of the formation, and creates groundwater circulation.	Effective on cVOCs. Air strippers generally are more effective at sites with high concentrations of dissolved contaminants with high Henry's law constants.	Infiltrating precipitation containing oxidized constituents may foul the system. Shallow aquifers may limit process effectiveness.	Ineffective in low permeability environments because sufficient groundwater flow to create an effective recirculation cell is not present.	Requires close well spacing.	Moderate to high. Extensive system capital investment required relative to alternatives.	Not retained because of poor effectiveness.
	Air Sparging	Air in injected into saturated matrices to remove VOCs through volatilization. May also be used at lower air flow rates to promote biodegradation of petroleum VOCs. Often coupled with SVE for collection/treatment of displaced VOCs.	Effective on cVOCs.	Shallow, tight aquifers may limit process effectiveness.	Ineffective in low permeability environments because the tight soil formation will prohibit air flow.	Requires close well spacing.	Generally considered cost-effective where applicable.	Not retained because of poor effectiveness.
	Dual Phase Extraction	Dual phase extraction uses a high vacuum system to remove liquid (such as contaminated groundwater, NAPL) and soil vapor. It removes contaminants from above and below the water table. Once above ground, the extracted vapors, liquid-phase organics, or groundwater are separated and treated. Systems may be designed to recover only product, mixed product and water, or separate streams of product and water.	Effective on cVOCs.	Dual phase extraction is more effective than SVE for heterogeneous clays and fine sands. However, it is not recommended for lower permeability formations because of limited radius of influence. Infiltrating precipitation containing oxidized constituents may foul the system.	Ineffective in low permeability environments because the tight soil formation will prohibit groundwater flow.	Dual phase extraction is a full-scale technology and commercially available.	High. Extensive system capital investment required relative to alternatives.	Not retained because of poor effectiveness.
	Hot Water or Steam Flushing/Stripping (Hydrous Pyrolysis/ Oxidation)	Steam (and possibly oxygen) is forced into an aquifer through injection wells. Vaporized components rise to the unsaturated zone, where they are removed by vacuum extraction and treated. Heating options include hot water injection, steam injection, in situ heating via six phase heating, radio frequency, etc.	cVOCs can be treated by this technology, but there are more cost-effective processes for sites contaminated with cVOCs.	The system can be clogged by small particles, microorganisms destroyed by steam, or from the increase in carbonates and silicates in the extracted liquids because of high temperatures. The process uses a large amount of energy for steam production	Ineffective in low permeability environments because the tight soil formation will prohibit air or steam flow.	Requires close well spacing.	High. Costs are higher than conventional SVE because of heating equipment and power requirements. Costs are higher in saturated zone.	Not retained because of poor effectiveness.

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Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Dynamic Underground Stripping	A combination of in situ steam injection, electrical resistance heating and fluid extraction to enhance contaminant removal from the subsurface.	Laboratory tests have been successful for a variety of VOCs.	The process uses a large amount of energy. Steam adds significant amounts of water to the subsurface. Precautions must be taken so as not to mobilize contaminants past the capture zones. There has been some concern that dynamic underground stripping will sterilize the subsurface so that microorganisms will not attack the contaminants. The treatment units can foul because of microorganisms that are destroyed by steam. Small particles that are pumped to the surface can also clog the system, and high temperatures increase carbonates and silicates in the extracted liquids.	Ineffective in low permeability environments because the tight soil formation will prohibit steam and groundwater flow.	Requires close well spacing.	Relatively extensive capital system requirements, but becomes more cost-effective in larger applications. Considerable uncertainly in actual full-scale application.	Not retained because of poor effectiveness.
Biological	Cometabolic Bioremediation	Injection of dilute solution containing inducers to enhance cometabolic breakdown. Inducers serve as carbon sources that activate aerobic enzyme systems know to degrade cVOCs (fortuitous cometabolism). Options of methane, nitrate, toluene, or phenol as inducers.	Target compounds are the cVOCs. The addition of methane or methanol has been demonstrated to degrade cVOCs. Toluene, propane, and butane also have been used to support the cometabolism of TCE.	Regulatory approval for use of specific cometabolites may be required. Higher permeability zones are cleaned up much faster because groundwater flow rates are greater.	Considerable uncertainty on rate and extent of biodegradation that can be achieved, particularly in low permeability soils.	Requires site-specific bench- or pilot-scale testing.	High. The cost to operate and maintain can be significant because a continuous source of methane or other inducer solution must be delivered to the contaminated groundwater.	Not retained because of relatively high cost and poor effectiveness in low permeability soils.
	Enhanced Aerobic Bioremediation	The rate of bioremediation of organic compounds by microbes is enhanced by increasing the concentration of electron acceptors and nutrients in groundwater, surface water, and leachate. Oxygen is the main electron acceptor for aerobic bioremediation. Nitrate serves as an alternative electron acceptor under anoxic conditions.	Effective on VOCs. TCE and cDCE present at the site are not treated by aerobic bioremediation.	Where the subsurface is heterogeneous, it is very difficult to deliver the nitrate or hydrogen peroxide solution throughout the contaminated zone. Higher permeability zones will be cleaned up much faster because groundwater flow rates are greater. Concentrations of hydrogen peroxide greater than 100 to 200 ppm in groundwater are inhibiting to microorganisms. Microbial enzymes and high iron content of subsurface materials can rapidly reduce concentrations of hydrogen peroxide and reduce zones of influence. A groundwater circulation system must be created so that contaminants do not escape from zones of active biodegradation. Many states prohibit injection of nitrate into groundwater because nitrate is regulated through drinking water standards.	Uncertainty on rate and extent of biodegradation that can be achieved and may take considerable time to achieve cleanup goals. Not effective on TCE, cDCE, and VC.	Requires site-specific bench- or pilot-scale testing. Constraints in lower permeability media may result as with any technology relying on permeability for reagent delivery to treatment zone. State regulations may prevent implementation.	Moderate to high. Variables affecting the cost are the nature and depth of the contaminants, use of bioaugmentation or hydrogen peroxide or nitrate addition, and groundwater pumping rates. The cost to operate and maintain a hydrogen peroxide enhancement system can be significant because a continuous source of hydrogen peroxide must be delivered to the contaminated groundwater.	Not retained because of limited effectiveness on cVOCs.
	Enhanced Anaerobic Bioremediation	Subsurface delivery of substrates (lactate, vegetable oil, molasses etc.) that serve as electron donors within the target zone to stimulate anaerobic biodegradation of cVOCs by reductive dechlorination.	Target compounds are cVOCs.	Requires necessary organic substrate to maintain anaerobic conditions.	Effectiveness demonstrated on numerous sites given good distribution of substrate, but maybe limited due to the low permeability environment.	Implementable either as a grid-based or curtain-based injection system.	Cost is moderate to high.	Retained for further evaluation.

TABLE 3-3
Groundwater Technology and Process Option Screening
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Remedial Technology	Process Options	Descriptions	Treated Compounds	Limitations	Effectiveness	Implementability	Relative Cost Range	Screening Comment
	Monitored Natural Attenuation	Short- or long-term routine monitoring is implemented to record site conditions, concentration levels, and natural attenuation parameters. Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce concentrations to acceptable levels.	Target contaminants for natural attenuation are VOCs.	Data used as input parameters for modeling need be collected. Activities and Use Limitations may be required, and the site may not be available for reuse until contaminant levels are reduced.	Site natural attenuation data indicate conditions are conducive to reductive dechlorination.	Implementable.	Low.	Retained for further evaluation.
	Phytoremediation	Phytoremediation is a set of processes that uses plants to remove, transfer, stabilize, and destroy organic and inorganic contamination in groundwater, surface water, and leachate. These mechanisms include enhanced rhizosphere biodegradation, hydraulic control, phytodegradation and phytovolatilization.	Phytoremediation may be applicable for the remediation of cVOCs. Poplar trees have been used for TCE.	Toxicity and bioavailability of biodegradation products is not always known. Degradation byproducts may be mobilized in groundwater or bioaccumulated in animals. More research is needed to determine the fate of various compounds in the plant metabolic cycle. Climatic or seasonal conditions may interfere or inhibit plant growth, slow remediation efforts, or increase the length of the treatment period. It can transfer contamination across media (from soil to air, for example). Phytoremediation likely will require a large land area. Phytoremediation for extraction or degradation generally is limited to relatively shallow depths of root penetration.	Not effective at the site because depth to groundwater is beyond the depths effected by plant roots.	Not implementable because depth to water table is beyond plant root penetration.	Low to moderate costs depending on type of application.	Not retained because cVOC-contaminated groundwater is located at a depth of greater than 13 feet below ground.

Note: Highlighted technologies are screened from further consideration in the development of remedial alternatives.

Effectiveness is the ability to perform as part of an overall alternative that can meet the RAOs under conditions and limitations that exist onsite.

Implementability is the likelihood that the process could be implemented under the physical, regulatory, technical, and schedule constraints.

Relative cost is for comparative purposes only and it is judged relative to the other processes and technologies that perform similar functions.

- Monitor hydrogeologic conditions at the site over time in order to identify changes in groundwater flow direction that might affect the protectiveness of the selected remedy.

An alternative water supply would be provided by USACE for future residences in areas with groundwater concentrations above MCLs. Alternative water supply may consist of bottled water, a granular activated carbon system, public water supply, or a combination of these. The current residents use the public water supply for potable use.

The NCP requires 5-year site reviews as long as hazardous substances remain at the site at concentrations that do not allow unlimited use and unrestricted exposure. As part of the 5-year review, the USACE will evaluate the vapor intrusion pathway.

The time that natural attenuation takes to return groundwater to the drinking water MCLs was estimated using the BIOCHLOR model (Section 2 above).

A time of remediation of greater than 100 years was estimated using the best estimates for the critical parameters (hydraulic conductivity, fraction organic carbon, decay rate). The estimated time of remediation should be viewed as general order-of-magnitude estimate that is useful for comparing alternatives, but should not be viewed as a definitive estimate of the actual time to achieve drinking water MCLs. For cost estimating purposes, the estimated duration of this alternative was chosen as 50 years. Although the actual monitoring period is expected to exceed 100 years, cost estimating periods beyond 50 years have little effect on the present worth estimate.

Administrative risk management tools will also be included as part of the remedy in the remedial design work plan. The risk management tools that may be used to educate current and future land owners include:

- Periodic inspections of land use in the area providing site-specific information to persons involved in new construction or changed land use.
- Periodic visits to the County Assessor’s office to update property ownership records in the affected area.
- Periodic newsletters to land owners surrounding the site.

In addition, USACE will assist the Missouri Division of Geology and Land Survey to determine the feasibility of a well restriction area codified through legislative rulemaking.

3.6.2.1 Major Components

The major components of Alternative 2 include the following:

- Sampling and analysis of new and/or existing monitoring wells
- Provision of future residences in areas with groundwater concentrations above MCLs with alternative water supply
- Performance of 5-year reviews, which includes implementing administrative risk management tools and an evaluation of the vapor intrusion pathway

3.6.3 Alternative 3—Enhanced Biodegradation with Monitoring and Alternative Water Supply

Under Alternative 3, TCE, cDCE and VC in groundwater would be treated using injection of a substrate, such as emulsified vegetable oil or another slow-release product, to provide an electron donor supply for enhancing biological reductive dechlorination. This technology has been implemented at numerous sites with cVOCs. At sites with low permeability clay such as this, it is used in conjunction with fracturing to enhance distribution of the substrate.

The substrate would be applied within the area of north plume containing higher TCE concentrations. A target treatment area will include the area with the greatest TCE groundwater concentrations and with potential residual TCE in the area of water table fluctuation that, if left untreated, could serve as a sporadic source of cVOCs to groundwater. The site groundwater data suggest that biological reductive dechlorination is occurring. The substrate injection would accelerate that process in the shallow subsurface and allow natural attenuation to continue in the downgradient part of the plume. However, the substrate injection will likely also mobilize naturally occurring iron and potentially manganese and reduce these chemicals to their soluble forms. Iron in groundwater may migrate and discharge to the nearby creek where it has the potential to cause both toxic and indirect physical effects to aquatic life. The majority of iron would be expected to rapidly oxidize following discharge to form ferric oxides and iron-humus colloids, and physical effects are expected to have the greatest potential to impact aquatic life by accumulating on fish gills, reducing invertebrate access to food, and altering the structure and quality of the benthic habitat. Mitigating measures to control iron breakout would be undertaken if necessary. An example mitigating technique is an air sparge curtain in a permeable fill trench downgradient of the treatment area.

Prior to injection, the subsurface in the treatment area will be fractured hydraulically to allow easier delivery and better distribution of the substrate in the low permeability subsurface from the injection well. Fracturing is necessary because of the tight clays present in the subsurface. However, even with fracturing, distribution of the substrate is difficult in tight clays.

The in situ treatment of the north plume area is expected to reduce TCE concentrations within the treatment area within several years. However, the treatment will likely not significantly affect the areas with lower TCE concentrations in the downgradient portions of the current TCE plume. The treatment will not affect the TCE concentrations in the south plume. Predicting the effect of treatment on the overall time of remediation is difficult, but it can be approximated by BIOCHLOR modeling. BIOCHLOR was used in the RI to predict the migration of the plumes if no action is taken (CH2M HILL 2008). Although BIOCHLOR does not allow modeling of a source to be turned off in a specific year after the initial release (year 50 in this case) to represent source remediation, the principal of superposition can be used to estimate the effect of source treatment. By this method, the plume is generated using the assumptions as presented in the RI for a specific duration, such as 150 years. Then assuming the original source area is remediated in year 50, a second plume is generated with a duration of 100 years. The concentrations along the plume centerline of the 100 year plume are then subtracted from the 150-year plume and the resulting plume represents the plume at year 150 with remediation at year 50.

This methodology was performed for years 100 and 150, which correspond respectively to 50 and 100 years following source treatment. The onsite north plume would indicate reductions in cVOC concentrations within 10 years. The offsite part of the north plume and the south plume would continue to migrate slowly and discharge to the small discharge zones. Fifty years after source treatment, the maximum offsite concentration of TCE was estimated to be about 110 µg/L, diminishing to about 15 µg/L after another 50 years. MCLs are finally achieved within the entire plume 150 years after source treatment. The maximum future concentration (at Residence B) after injection was also estimated using the model. The estimated maximum TCE concentration at Residence B is expected to occur 25 years from the present and is 100 µg /L. The maximum future concentration at Residence B is expected to be 149 µg/L without injection. As noted in the RI, these estimates have a high degree of uncertainty and are intended only to provide a rough comparison of effectiveness between alternatives.

Although, injection with fracturing has been successful at other sites with similar characteristics, there is some uncertainty of the effectiveness of this alternative because of the tight subsurface formation and disconnected sand lenses. Typically, the biggest concern for injection remedial actions for this type of hydrogeology is adequate distribution (i.e., will the substrate be distributed throughout the treatment zone ?). The fracture extent and geometry are difficult to predict and will have significant effect on the distribution of the substrate.

The effectiveness of this alternative would be evaluated through review of TCE concentrations within the north plume treatment area over time. If Alternative 3 is selected, the reduction of TCE mass in the treatment zone of the north plume would be measured during remedial action implementation to evaluate contaminant reduction. Failure to achieve this contaminant reduction would likely be related to difficulty in distribution of substrate material and reinjection of additional material would likely not be warranted since the subsurface conditions that inhibited distribution would still be present.

Following the injection event in the treatment area of the north plume, TCE, cDCE, and VC concentrations would be monitored for compliance with the cleanup objectives developed as part of the FS and for natural attenuation assessment purposes. Alternative water supply and 5-year site reviews will be implemented as required and will remain in place until groundwater monitoring results indicate that concentrations have declined to below the cleanup levels.

Following the injection event, a groundwater sampling plan would be implemented. For cost estimating purposes, the assumed duration of this alternative is 50 years. Although the actual monitoring period is expected to exceed 100 years, cost estimating periods beyond 50 years have little effect on the present worth cost estimate.

As with Alternative 2, alternative water supply, groundwater monitoring, 5-year site reviews, administrative risk management tools, and a vapor intrusion risk evaluation would be implemented and would remain until groundwater monitoring results indicate concentrations have declined to below the PRGs.

3.6.3.1 Major Components

Major components of the alternative include the following:

- Substrate injection (creating reducing conditions and providing a long-lived supply of electron donor) targeting the part of the north plume with high concentrations of TCE
- Sampling and analysis of existing and/or new monitoring wells
- Provision of future residences in areas with groundwater concentrations above MCLs with alternative water supply
- Performance of 5-year reviews, which includes implementing administrative risk management tools and an evaluation of the vapor intrusion pathway

3.7 Detailed Analysis of Remedial Alternatives

The detailed analysis of alternatives presents the information needed to compare the remedial alternatives. Detailed analysis of alternatives consists of a detailed evaluation of each alternative against the evaluation criteria, followed by a comparative evaluation.

3.7.1 Evaluation Criteria

The evaluation criteria allow comparison of the relative performance of the alternatives and provide a means for identifying their relative advantages and disadvantages. In accordance with the NCP, remedial actions must accomplish the following:

- Be protective of human health and the environment.
- Attain ARARs or provide grounds for invoking a waiver of ARARs that cannot be achieved.
- Be cost-effective.
- Use permanent solutions and alternative treatment technologies or resource-recovery technologies to the maximum extent practicable.
- Satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element.

Provisions of the NCP require that each alternative be evaluated against nine criteria listed in 40 Code of Federal Regulations (CFR) 300.430(e)(9). These criteria were published in the *Federal Register* for March 8, 1990 (55 *FR* 8666), to provide grounds for comparison of the relative performance of the alternatives and to identify their advantages and disadvantages. This approach is intended to provide sufficient information to adequately compare the alternatives and to select the most appropriate alternative for implementation at the site as a remedial action. The evaluation criteria are:

- Overall protection of human health and the environment
- Compliance with ARARs
- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

Two other criteria—state acceptance and community acceptance—will be evaluated following public comment on the selected remedy, as described in the Proposed Plan. The extent to which alternatives are evaluated depends on the available data and the number and types of alternatives analyzed. The detailed analysis includes total present worth of the alternatives, consisting of capital costs and operation, maintenance, and monitoring costs. The detailed analyses and costs are described below.

There are three types of evaluation criteria: threshold, balancing, and modifying. Threshold criteria must be met by a particular alternative for it to be eligible for selection as a remedial action. The two threshold criteria are overall protection of human health and the environment, and compliance with ARARs. If ARARs cannot be met, a waiver may be obtained when one of the six exceptions listed in the NCP occurs (see 40 CFR 300.430 (f)(1)(ii)(C)(1 to 6)).

The five balancing criteria weigh the trade-offs among alternatives. The five balancing criteria are:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost

The modifying criteria are community and state acceptance. These are evaluated following public comment and are used to modify the selection of the recommended alternative. Community and state acceptance are not addressed in the FS but will be addressed in the Proposed Plan for the site.

3.7.1.1 Threshold Criteria

Threshold criteria are standards an alternative must meet to be eligible for selection as a remedial action. There is little flexibility in meeting the threshold criteria—the alternative must meet them or it is unacceptable. If ARARs cannot be met, a waiver may be obtained where one or more site exception defined in the NCP occurs.

Overall Protection of Human Health and the Environment. Protectiveness is the main requirement that remedial actions must meet under CERCLA. It is an assessment of whether each alternative achieves and maintains adequate protection of human health and the environment. A remedy is protective if it eliminates, reduces, or controls current and potential risks posed by the site through each exposure pathway.

Compliance with ARARs. Compliance with ARARs is a statutory requirement of remedy selection. This criterion is used to determine whether the selected alternative would meet the federal, state, and local ARARs identified above. The compliance of each alternative with chemical-, location-, and action-specific ARARs is discussed. Section 3.1 contains a discussion of potential ARARs for the KAFS site.

3.7.1.2 Balancing Criteria

Balancing criteria are used to weigh tradeoffs between alternatives. They represent the standards upon which the detailed evaluation and comparative analysis of alternatives are based. A high rating on one balancing criterion generally can offset a low rating on another.

Long-Term Effectiveness and Permanence. Long-term effectiveness and permanence reflect CERCLA's emphasis on remedies that will protect human health and the environment in the long term. Under this criterion, results of a remedial alternative are evaluated in terms of the risk remaining at the site after response objectives are met. The primary focus of the evaluation is the extent and effectiveness of the actions or controls that may be required to manage the risk posed by treatment residuals or untreated wastes.

Factors to be considered and addressed are magnitude of residual risk, adequacy of controls, and reliability of controls. Magnitude of residual risk is the assessment of the risk remaining from untreated waste or treatment residuals after remediation. Adequacy and reliability of controls is the evaluation of the controls that can be used to manage treatment residuals or untreated wastes that remain at a site.

Reduction of Toxicity, Mobility, or Volume through Treatment. This criterion addresses the statutory preference for remedies that employ treatment to reduce the toxicity, mobility, or volume of the hazardous substances. That preference is satisfied when treatment is used to reduce the principal threats at a site significantly by destroying toxic chemicals or reducing the total mass or total volume of affected media. This criterion is specific to evaluating only how the treatment reduces the toxicity, mobility, and volume. It does not pertain to containment actions, such as capping.

Short-Term Effectiveness. This criterion addresses short-term impacts of the remedial alternatives by examining the effectiveness of alternatives in protecting human health and the environment during construction and implementation activities.

Implementability. The technical and administrative feasibility of executing an alternative and the availability of services and materials required during its implementation must be considered.

Cost. For the detailed cost analysis of alternatives, the expenditures required to complete each measure are estimated in terms of both capital and annual O&M costs. Given these values, a present-worth calculation for each alternative can be calculated for comparison. The cost estimates in this section provide an accuracy of –30 percent to +50 percent. Costs are projected for a period of 50 years in accordance with *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 540-R-00-002; July 2000).

3.7.1.3 Modifying Criteria

Modifying criteria are used to modify the selection of the recommended alternative.

State Acceptance. This criterion pertains to the technical and administrative issues and concerns the state may have regarding the alternatives. MDNR's comments on the FS report and also on the Proposed Plan will factor into state acceptance of the recommended alternative.

Community Acceptance. This criterion pertains to the issues and concerns the public may have regarding the alternatives. This is not addressed in this report but will be addressed upon receipt of comments on the Proposed Plan and documented in the remedy decision document.

3.7.2 Remedial Alternatives Evaluation

Table 3-4 discusses each alternative with respect to the criteria for groundwater.

TABLE 3-4
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation and Alternative Water Supply	Alternative 3 Enhanced Biodegradation with Monitoring and Alternative Water Supply
Overall Protection to Human Health and the Environment			
Protection of human health and the environment	Not protective.	Alternative water supply would minimize exposure to groundwater, ensuring that the potential exposure pathway would remain incomplete.	Active remediation of contaminated groundwater in the onsite north plume will reduce the time until remedial goals are met. However, the time will likely exceed 100 years as with Alternative 2. In the interim, alternative water supply would minimize exposure to groundwater, ensuring that the potential exposure pathway would remain incomplete.
Compliance with ARARs			
Chemical-specific ARARs	Not in compliance.	In compliance. MCLs are eventually met.	In compliance. MCLs are eventually met.
Long-Term Effectiveness and Permanence			
Magnitude of residual risk	Risks are minimal because the probability of potable use of groundwater is minimal. Risk will remain above risk thresholds throughout the entire plume for more than 100 years.	Risks are minimal because the probability of potable use of groundwater is minimal. Risk will remain above risk thresholds throughout the entire plume for more than 100 years. Alternative water supply would minimize exposure to residents, ensuring that the potential exposure pathway would remain incomplete.	Risks are minimal because the probability of potable use of groundwater is minimal. Risk will remain above risk thresholds throughout the entire plume for more than 100 years. Risks following completion of the remediation period are expected to be reduced within most of the onsite north plume, but not likely below the MCLs. However, the risks associated with the offsite north plume and the onsite and offsite south plume will be the same as Alternatives 1 and 2. There are uncertainties related to the magnitude of the risk reduction related to biodegradation due to the tight clays. As with Alternative 2, an alternative water supply would minimize exposure to residents.
Adequacy and reliability of controls	Not applicable.	The groundwater monitoring program will evaluate contaminant migration. Five-year reviews allow for future evaluation of site conditions.	The groundwater monitoring program will evaluate contaminant migration. Five-year reviews allow for future evaluation of site conditions.

TABLE 3-4
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation and Alternative Water Supply	Alternative 3 Enhanced Biodegradation with Monitoring and Alternative Water Supply
Potential environmental impacts of remedial action	Natural attenuation would slowly reduce chemical mass, but amount of reduction would remain unknown.	Monitored natural attenuation will not introduce new environmental impacts.	Substrate injection will result in the biodegradation of COCs in groundwater in the onsite north plume. As a result of the injection, negative effects on stream quality may occur; although mitigation techniques can be implemented.
Reduction of Toxicity, Mobility, or Volume Through Treatment			
Treatment processes used and materials treated	None.	None.	A substrate will be used to enhance the anaerobic biodegradation of COCs.
Amount of hazardous material destroyed or treated	Natural attenuation would slowly reduce concentrations of COCs in the groundwater over a period of more than 100 years, but amount of reduction would remain unknown.	Natural attenuation would slowly reduce concentrations of COCs in the groundwater over a period of more than 100 years. Monitoring will evaluate the amount of reduction.	Substrate injection would result in reduction of COCs in the groundwater within the onsite north plume. Natural attenuation would slowly reduce concentrations of COCs in the groundwater in the rest of the north plume and the south plume over a period of more than 100 years. Monitoring will evaluate the amount of reduction.
Expected reduction in toxicity, mobility, or volume of the waste	Natural attenuation would slowly reduce chemical mass, but amount of reduction would remain unknown.	Natural attenuation would slowly reduce chemical mass. Monitoring will evaluate the rate of attenuation.	Substrate injection in north plume coupled with natural attenuation would reduce chemical mass. Monitoring will evaluate the rate of attenuation. There are uncertainties related to the reduction in volume of the chemical mass because of the tight clays.
Irreversibility of treatment	Not applicable.	Once COCs are degraded, they will not recur.	Once COCs are degraded, they will not recur.
Type and quantity of residuals that will remain following treatment	Not applicable.	Ultimately no treatment residuals will remain. Concentrations of VC will be generated, but VC is expected to biodegrade and not accumulate beyond current concentrations. Monitoring will evaluate the residuals.	Ultimately no treatment residuals will remain. Concentrations of VC will be generated, but VC is expected to biodegrade and not accumulate beyond current concentrations. Monitoring will evaluate the residuals.
Statutory preference for treatment	Does not satisfy.	Does not satisfy.	Meets preference for treatment.

TABLE 3-4
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation and Alternative Water Supply	Alternative 3 Enhanced Biodegradation with Monitoring and Alternative Water Supply
Short-Term Effectiveness			
Protection of workers during remedial action	Not applicable.	No additional risks will be introduced based on the proposed monitoring program.	Implementation of enhanced biodegradation is not expected to create additional risk to onsite workers.
Protection of the community during remedial action	Not applicable.	No additional risks will be introduced based on the proposed monitoring program.	Implementation of enhanced biodegradation is not expected to create additional risk to the community.
Potential environmental impacts of remedial action	Natural attenuation would slowly reduce chemical mass, but amount of reduction would remain unknown.	Monitored natural attenuation will not introduce new short-term environmental impacts.	Substrate injection will not introduce new short-term environmental impacts.
Time until protection is achieved	Unknown and not monitored or evaluated.	Natural attenuation is expected to require more than 100 years to reduce concentrations to MCLs. Immediate protection from contamination because of alternative water supply.	Enhanced biodegradation in conjunction with natural attenuation is expected to require over 100 years to reduce concentrations to MCLs. Immediate protection from contamination because of alternative water supply.
Implementability			
Technical feasibility	Not applicable.	Installation of groundwater monitoring wells, completion of routine monitoring, and alternative water supply protocols are technically understood, feasible remedial activities.	Injection points for the delivery of the substrate are technically feasible based on experience with this technology. However, fracturing the tight clays is difficult. Injection is this type of subsurface is not ideal. Installation of groundwater monitoring wells, completion of routine monitoring, and alternative water supply protocols are technically understood, feasible remedial activities.
Reliability of technology	Not applicable.	Monitored natural attenuation will eventually result in achievement of MCLs, but the time it takes has a high degree of uncertainty.	Application of substrates to enhance biodegradation has been shown to result in mass reduction. However, treatments in low permeability soil, such as clay, are not reliable in attaining very low concentrations such as MCLs. Monitored natural attenuation will eventually result in achievement of MCLs, but the time it takes has a high degree of uncertainty.

TABLE 3-4
Detailed Evaluation of Remedial Alternatives
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Evaluation Criteria	Alternative 1 No Action	Alternative 2 Monitored Natural Attenuation and Alternative Water Supply	Alternative 3 Enhanced Biodegradation with Monitoring and Alternative Water Supply
Administrative feasibility	Not expected to be feasible based on regulatory opposition.	No significant administrative problems are expected.	No significant administrative problems are expected.
Availability of services, equipment, and materials	Not applicable.	Equipment and materials are readily available.	Equipment and materials are readily available.
Cost			
Capital cost	$0	$255,000	$648,000
Present worth	$0	$1,814,000	$1,814,000
Period of analysis (yr)	50[a]	50[a]	50[a]
Capital and present worth	$0	$2,070,000[b]	$2,460,000[b]

[a] Based on USEPA, 2000, *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA 540-R-00-002).

[b] Cost estimate is provided in Appendix A.

3.8 Perform Comparative Analysis of Remedial Alternatives

Following the detailed analysis of the retained remedial alternatives, it was necessary to compare how well each alternative satisfied the evaluation criteria. Table 3-5 summarizes the comparative analysis results for remedial alternatives.

TABLE 3-5
Comparative Analysis Results
Feasibility Study Report—Former Kirksville Air Force Station, Greentop, Missouri

Criteria	Alternative 1	Alternative 2	Alternative 3
Overall Protection of Human Health and the Environment	1	4	4
Compliance with ARARs	1	4	4
Long-Term Effectiveness and Permanence	1	3	3
Reduction of Toxicity, Mobility, or Volume Through Treatment	1	2	3
Short-Term Effectiveness	1	4	4
Implementability	4	3	2
Cost	4	3	2
Total Score	**13**	**23**	**22**

1—poor 2—satisfactory 3—good 4—excellent

4. Summary and Conclusions

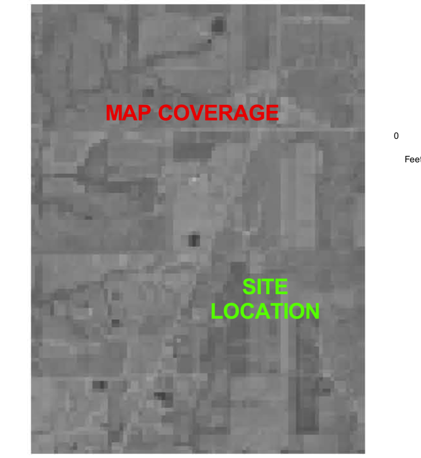
The object of the feasibility study was to develop and evaluate groundwater remedial alternatives that will address potential unacceptable risks to human health and the environment and meet ARARs. As part of the evaluation, action-, chemical-, and location-specific ARARs were evaluated to develop remedial alternatives.

A RAO was established based on regulatory requirements, standards, and guidance. The RAO is to prevent unacceptable risk to human health from potable use of groundwater containing TCE, cDCE or VC (i.e., COCs) in concentrations exceeding the MCLs.

Groundwater PRGs are the MCLs for TCE (5 μg/L), cDCE (70 μg/L), and VC (2 μg/L). The areal extent of COCs presently exceeding MCLs is 150,000 ft^2 in the north plume and 230,000 ft^2 in the south plume.

GRAs are remedial actions that will accomplish the RAO. First GRAs were identified. Next, potential remedial technologies were screened on the basis of effectiveness, implementability, and cost. Finally, the following three remedial alternatives were developed and assessed for each media based using the seven NCP evaluation criteria and compared in terms of ability to satisfy the criteria: Alternative 1, No Action; Alternative 2, Natural Attenuation with Monitoring and Alternative Water Supply; and Alternative 3, Enhanced Biodegradation with Monitoring and Alternative Water Supply. Alternative 1 does not meet the evaluation criteria. Alternatives 2 and 3 both met the threshold criteria. Alternative 3 will reduce some COC mass, but with uncertainty due to the tight clays. The three alternatives will likely take over 100 years to reduce COC-concentrations in groundwater to the MCLs. The preferred alternative will be presented in the Proposed Plan. In accordance with the NCP, the Proposed Plan, and other documents in the administrative record will be released to the public for review and comment. Public input on the alternatives is paramount in the selection process. The preferred remedy may be modified based on the comments received.

VICINITY MAP



LEGEND

- TRUMAN STATE UNIVERSITY PROPERTY BOUNDARY
- FEDERAL AVIATION ADMINISTRATION PROPERTY BOUNDARY
- EXISTING BUILDINGS
- FORMER BUILDINGS
- OLD RADAR BALL LOCATION
- SURFACE WATER

TCE CONTOURS

- NORTHERN PLUME AREA EXCEEDING PRGs
- SOUTHERN PLUME AREA EXCEEDING PRGs

NOTE:

1. Concentrations contours are reported in micrograms per liter (µg/L).
2. PRG = Preliminary Remediation Goals

0 100 200
Feet

1 inch equals 200 feet

FIGURE 3-1
PROPOSED CONCENTRATIONS EXCEEDING PRGs

FORMER KIRKSVILLE AIR FORCE STATION
GREENTOP, MISSOURI

CH2MHILL

RDD \\LOKI\PROJECTS\RDDGIS\350464_KIRKSVILLEAFS\MAPFILES\FS\FIG3-1_PROP_MW_FS.MXD 9/3/2008 01:53:43

5. References

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Appendix A
Cost Estimate for Remedial Alternatives

Cost Estimate for Alternative 2—Monitored Natural Attenuation and Alternative Water Supply
Former Kirksville Air Force Station
Greentop, Missouri

Estimator: MMM
Date: 10/11/08

	Item Description	**Units**	**Qty**	**Unit Cost ($)**	**Total Cost ($)**	**Task Subtotal ($)**	**Source**
CAPITAL COSTS							
1.0	*ESTABLISHING MONITORING NETWORK*						
1.1	Driller Mobilization/Demobilization	LS	3	3,618.00	10,854		Vendor Quote
1.2	Well Installation, Hollow Stem Auger, 2-inch diam.	LF	360	39.60	14,256		Vendor Quote
1.3	Decontamination Pad Construction	LS	1	150.00	150		Vendor Quote
1.4	Equipment Decontamination	LS	1	2,154.00	2,154		Vendor Quote
1.5	MDNR Well Registration	EA	9	102.00	918		Vendor Quote
1.6	Well Abandonment, 2-inch diam.	LF	885	7.80	6,903		Vendor Quote
1.7	Well Abandonment, 1-inch diam.	LF	580	1.20	696		Vendor Quote
1.8	Well Abandonment Forms	EA	36	12.00	432		Vendor Quote
1.9	55-Gallon DOT-Approved Drums	EA	36	25.20	907		Vendor Quote
1.10	IDW Management	EA	36	33.60	1,210		Vendor Quote
1.11	IDW Transport and Disposal	LS	1	20,520.00	20,520		Vendor Quote
1.12	Oversight Labor	HR	324	102.00	33,048		Vendor Quote
1.13	Oversight Travel	DAY	30	222.00	6,660		Vendor Quote
1.14	Utility Clearance	LS	1	12.00	12		Vendor Quote
1.15	Survey Subcontractor	LS	1	4,200.00	4,200		Vendor Quote
						102,920	
2.0	*GROUNDWATER MONITORING, INSPECTION, AND REPORTING -YEAR 1*						
2.1	Off Site Laboratory Analytical Costs	EA	21	108.00	2,268		Vendor Quote
2.2	55-Gallon DOT-Approved Drums	EA	1	25.20	25		Vendor Quote
2.3	IDW Characterization	EA	1	3,000.00	3,000		Vendor Quote
2.4	IDW Management	EA	1	33.60	34		Vendor Quote
2.5	IDW Transport and Disposal	EA	1	252.00	252		Vendor Quote
2.6	Labor	HR	100	102.00	10,200		Engineer's Estimate
2.7	Travel	EA	5	222.00	1,110		Engineer's Estimate
2.8	Equipment	LS	1	900.00	900		Engineer's Estimate
2.9	Reporting	LS	1	17,000.00	17,000		Engineer's Estimate
2.10	Data Management	LS	1	2,400.00	2,400		Engineer's Estimate
						37,189	
	SUBTOTAL					140,109	
	Contigency	**30%**				42,033	
	SUBTOTAL					182,141	
	Project Management	**10%**				18,214	Engineer's Estimate
	Remedial Design	**15%**				27,321	Engineer's Estimate
	Construction Management	**15%**				27,321	Engineer's Estimate

	Item Description	Units	Qty	Unit Cost ($)	Total Cost ($)	Task Subtotal ($)	Source
	TOTAL CAPITAL COSTS FOR YEAR 1					**255,000**	
OPERATION AND MAINTENANCE COSTS							
1.0	*GROUNDWATER MONITORING, INSPECTION, AND REPORTING - YEAR 2 through 50*						
1.1	Off Site Laboratory Analytical Costs	EA	21	108.00	2,268		Vendor Quote
1.2	55-Gallon DOT-Approved Drums	EA	1	25.20	25		Vendor Quote
1.3	IDW Characterization	EA	1	3,000.00	3,000		Vendor Quote
1.4	IDW Management	EA	1	33.60	34		Vendor Quote
1.5	IDW Transport and Disposal	EA	1	252.00	252		Vendor Quote
1.6	Labor	HR	100	102.00	10,200		Engineer's Estimate
1.7	Travel	EA	5	222.00	1,110		Engineer's Estimate
1.8	Equipment	LS	1	900.00	900		Engineer's Estimate
1.9	Reporting	LS	1	12,000.00	12,000		Engineer's Estimate
1.10	Data Management	LS	1	2,400.00	2,400		Engineer's Estimate
1.11	Granular Activated Carbon System	LS	1	7,200.00	7,200		Vendor Quote
1.12	New Water Supply Service Connections	EA	1	552.00	552		Engineer's Estimate
	SUBTOTAL					39,941	
	Contigency	**30%**				11,982	
	SUBTOTAL					51,923	
	Project Management	**10%**				5,192	Engineer's Estimate
	Technical Support	**15%**				7,788	Engineer's Estimate
	TOTAL OPERATION AND MAINTENANCE COSTS PER EVENT					**65,000**	
2.0	*PERIODIC COSTS - YEAR 5 through 50*						
2.1	5-year Review	LS	1	15,000.00	15,000		Engineer's Estimate
	TOTAL PERIODIC COSTS PER 5-YEAR REVIEW					**15,000**	
					2.8%	Discount Rate	
					0.0%	Inflation Rate	
	Present Worth of Annual O&M Cost				26.7361	1,737,850	
	Present Worth of Periodic Costs in Year 5				0.8710	13,065	
	Present Worth of Periodic Costs in Year 10				0.7587	11,380	
	Present Worth of Periodic Costs in Year 15				0.6609	9,913	
	Present Worth of Periodic Costs in Year 20				0.5756	8,634	
	Present Worth of Periodic Costs in Year 25				0.5014	7,521	
	Present Worth of Periodic Costs in Year 30				0.4367	6,551	
	Present Worth of Periodic Costs in Year 35				0.3804	5,706	
	Present Worth of Periodic Costs in Year 40				0.3313	4,970	
	Present Worth of Periodic Costs in Year 45				0.2886	4,329	
	Present Worth of Periodic Costs in Year 50				0.2514	3,771	
	TOTAL PRESENT WORTH COSTS					1,814,000	
	TOTAL CAPITAL AND PRESENT WORTH COSTS					**$ 2,070,000**	

Disclaimer: The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected.

Source: USEPA. July 2000. *A Guide to Preparing and Documenting Cost Estimates during the Feasibility Study.* EPA 540-R-00-002.1

Notes:

1. Unit costs are based on 2007 dollars.
2. G&A and fee are included in each unit cost.
3. Constant dollars are used for the present value analysis, per the USEPA cost estimate guidance (USEPA 2000).

Cost Estimate Assumptions:

The following assumptions were used in developing the cost estimates presented for Alternative 2:

The areal extent of TCE, cDCE, and VC concentrations exceeding MCLs in the north and south plumes is 150,000 ft^2 and 230,000 ft^2, respectively

The remedy will be in place for at least 50 years.

A monitoring network will consist of a total of 16 wells in the north and south plumes to monitor the natural attenuation of TCE in the lateral and vertical extents. New wells may be installed within and downgradient of the north and south plumes.

A monitoring program will consist of a baseline sampling event to document current conditions for the site, and an annual sampling event after the baseline sampling event until year 50. One remedial action work plan will be developed for the site.

For cost estimating purposes, it is assumed that one interim (i.e., 1 year) granular activated carbon system (for a 3 bedroom home) and one service connection to public water supply will be provided by the USACE for future residents every 5 years.

Cost Estimate for Alternative 3—Enhanced Biodegradation with Monitoring and Alternative Water Supply
Former Kirksville Air Force Station
Greentop, Missouri

Estimator: MMM
Date: 10/11/08

	Item Description	Units	Qty	Unit Cost ($)	Total Cost ($)	Task Subtotal ($)	Source
CAPITAL COSTS							
2.0	*ENHANCED BIODEGRADATION*						
2.1	Permit for Underground Injection Control Wells	LS	1	1800.00	1,800		State Fee
2.2	Driller Mobilization/Demobilization	LS	1	5,700.00	5,700		Vendor Quote
2.3	EOS 450 emulsible edible oil product	EA	27	780.00	21,060		Vendor Quote
2.4	EOS 450 emulsible edible oil shipping	LS	1	3,626.40	3,626		Vendor Quote
2.5	Fracture and well materials, 39 fractures	LS	1	11,700.00	11,700		Vendor Quote
2.6	Direct push and fracture services	LS	1	59,700.00	59,700		Vendor Quote
2.7	Injection Services	DAY	5	1,110.00	5,550		Vendor Quote
2.8	55-Gallon DOT-Approved Drums	EA	11	25.20	277		Vendor Quote
2.9	IDW Characterization	EA	1	3,000.00	3,000		Vendor Quote
2.10	IDW Management	EA	11	33.60	370		Vendor Quote
2.11	IDW Transport and Disposal	LS	1	6,090.00	6,090		Vendor Quote
2.12	Utility Clearance	LS	1	102.00	102		Vendor Quote
2.13	Oversight Labor	HR	576	102.00	58,752		Engineer's Estimate
2.14	Oversight Travel	DAY	54	222.00	11,988		Engineer's Estimate
						189,715	
3.0	*ESTABLISHING MONITORING NETWORK*						
3.1	Driller Mobilization/Demobilization	LS	3	3,618.00	10,854		Vendor Quote
3.2	Well Installation, Hollow Stem Auger, 2-inch diam.	LF	360	39.60	14,256		Vendor Quote
3.3	Decontamination Pad Construction	LS	1	150.00	150		Vendor Quote
3.4	Equipment Decontamination	LS	1	2,154.00	2,154		Vendor Quote
3.5	MDNR Well Registration	EA	9	102.00	918		Vendor Quote
3.6	Well Abandonment, 2-inch diam.	LF	885	7.80	6,903		Vendor Quote
3.7	Well Abandonment, 1-inch diam.	LF	580	1.20	696		Vendor Quote
3.8	Well Abandonment Forms	EA	36	12.00	432		Vendor Quote
3.9	55-Gallon DOT-Approved Drums	EA	36	25.20	907		Vendor Quote
3.10	IDW Management	EA	36	33.60	1,210		Vendor Quote
3.11	IDW Transport and Disposal	LS	1	20,520.00	20,520		Vendor Quote
3.12	Oversight Labor	HR	324	102.00	33,048		Engineer's Estimate
3.13	Oversight Travel	DAY	30	222.00	6,660		Engineer's Estimate
3.14	Utility Clearance	LS	1	12.00	12		Vendor Quote
3.15	Survey Subcontractor	LS	1	4,200.00	4,200		Vendor Quote
						102,920	
4.0	*GROUNDWATER MONITORING-YEAR 1 (6 months and 1 year following Remedial Action)*						
4.1	Off Site Laboratory Analytical Costs	EA	42	108.00	4,536		Vendor Quote
4.2	55-Gallon DOT-Approved Drums	EA	2	25.20	50		Vendor Quote
4.3	IDW Management	EA	2	33.60	67		Vendor Quote
4.4	IDW Transport and Disposal	EA	2	252.00	504		Vendor Quote
4.5	Labor	HR	200	102.00	20,400		Engineer's Estimate
4.6	Travel	EA	10	222.00	2,220		Engineer's Estimate
4.7	Equipment	LS	2	900.00	1,800		Engineer's Estimate
4.8	Reporting	LS	2	17,000.00	34,000		Engineer's Estimate
						63,578	
	SUBTOTAL					356,213	
	Contigency	**30%**				106,864	
	SUBTOTAL					463,076	
	Project Management	**10%**				46,308	
	Remedial Design	**15%**				69,461	
	Construction Management	**15%**				69,461	
	TOTAL CAPITAL COSTS FOR YEAR 1					**648,000**	

Estimator: MMM
Date: 10/11/08

Item Description	Units	Qty	Unit Cost ($)	Total Cost ($)	Task Subtotal ($)	Source
OPERATION AND MAINTENANCE COSTS						
1.0 GROUNDWATER MONITORING - YEAR 2 through 50						
1.1 Off Site Laboratory Analytical Costs	EA	21	108.00	2,268		Vendor Quote
1.2 55-Gallon DOT-Approved Drums	EA	1	25.20	25		Vendor Quote
1.3 IDW Characterization	EA	1	3,000.00	3,000		Vendor Quote
1.4 IDW Management	EA	1	33.60	34		Vendor Quote
1.5 IDW Transport and Disposal	EA	1	252.00	252		Vendor Quote
1.6 Labor	HR	100	102.00	10,200		Engineer's Estimate
1.7 Travel	EA	5	222.00	1,110		Engineer's Estimate
1.8 Equipment	LS	1	900.00	900		Engineer's Estimate
1.9 Reporting	LS	1	12,000.00	12,000		Engineer's Estimate
1.10 Data Management	LS	1	2,400.00	2,400		Engineer's Estimate
1.11 Granular Activated Carbon System	LS	1	7,200.00	7,200		Vendor Quote
1.12 New Water Supply Service Connections	EA	1	552.00	552		Engineer's Estimate
SUBTOTAL					39,941	
Contigency	**30%**				11,982	
SUBTOTAL					51,923	
Project Management	**10%**				5,192	Engineer's Estimate
Technical Support	**15%**				7,788	Engineer's Estimate
TOTAL OPERATION AND MAINTENANCE COSTS PER EVENT					**65,000**	
2.0 PERIODIC COSTS - YEAR 5 through 50						
2.1 5-year Review	LS	1	15,000.00	15,000		Engineer's Estimate
PERIODIC COSTS PER 5-YEAR REVIEW					**15,000**	
				2.8%	Discount Rate	
				0.0%	Inflation Rate	
Present Worth of Annual O&M Cost				26.7361	1,737,850	
Present Worth of Periodic Costs in Year 5				0.8710	13,065	
Present Worth of Periodic Costs in Year 10				0.7587	11,380	
Present Worth of Periodic Costs in Year 15				0.6609	9,913	
Present Worth of Periodic Costs in Year 20				0.5756	8,634	
Present Worth of Periodic Costs in Year 25				0.5014	7,521	
Present Worth of Periodic Costs in Year 30				0.4367	6,551	
Present Worth of Periodic Costs in Year 35				0.3804	5,706	
Present Worth of Periodic Costs in Year 40				0.3313	4,970	
Present Worth of Periodic Costs in Year 45				0.2886	4,329	
Present Worth of Periodic Costs in Year 50				0.2514	3,771	
TOTAL PRESENT WORTH COSTS					1,814,000	
TOTAL CAPITAL AND PRESENT WORTH COSTS					**$ 2,460,000**	

Disclaimer: The information in this cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. Changes in the cost elements are likely to occur as a result of new information and data collected.

Source: USEPA. July 2000. A Guide to Preparing and Documenting Cost Estimates during the Feasibility Study. EPA 540-R-00-002.

Notes:

1. Unit costs are based on 2007 dollars.
2. G&A and fee are included in each unit cost.
3. Constant dollars are used for the present value analysis, per the USEPA cost estimate guidance (USEPA 2000).

Cost Estimate Assumptions:

The following assumptions were used in developing the cost estimates presented for Alternative 3:

The areal extent of the cVOCs to be treated by substrate injection in the north plume is 10,500 ft^2 (210 by 50 feet).

A commercially-available emulsified vegetable oil product was used as the substrate for cost estimating purposes.

Prior to substrate injection, hydraulic fractures will be created at 13 locations.

One substrate injection application will be performed to create a reductive environment. Monitoring the progress of the enhanced reductive dechlorination and natural attenuation will continue for 50 years.

The monitoring network will be as described for Alternative 2.

A monitoring program will consist of a baseline sampling event after the remedial action is performed and the remedial design will be monitored after 6 months, 1 year, and annually thereafter until year 50.

One remedial action work plan will be developed for the site.

One monitoring report will be generated after each sampling event, which will include groundwater sample data, current configuration of the plume, historical trend analysis, and the progress of the enhanced bioremediation processes.

For cost estimating purposes, it is assumed that interim (i.e., 1 year) granular activated carbon system (for a 3 bedroom home) and one service connection to public water supply will be provided by the USACE for future residents every 5 years.