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FINAL FEASIBILITY STUDY FOR GROUNDWATER OPERABLE UNIT 2 (OU 2) KANSAS
CITY MO
11/1/2002
CH2M HILL



U.S. AIR FORCE



AIR FORCE BASE CONVERSION AGENCY

Final Feasibility Study for Groundwater (Operable Unit-2)

Richards-Gebaur Air Force Base, Missouri

November 2002

Feasibility Study for Groundwater (Operable Unit - 2)

Final

Richards-Gebaur Air Force Base, Missouri

Prepared for

Air Force Base Conversion Agency

Prepared by

CH2MHILL

AFCEE Contract No. F41624-97-D-8019

Project No. UEBL 19997101

Delivery Order 0090

November 2002

G112

Contents

Executive Summary	vi
Acronyms.....	viii
1. Introduction	1-1
1.1 FS Background	1-1
1.2 FS Objectives and Scope.....	1-3
1.3 Report Organization	1-2
2. Base Setting	2-1
2.1 Physical Setting	2-1
2.1.1 Location.....	2-1
2.1.2 Topography	2-1
2.1.3 Climate	2-1
2.1.4 Surface Water Resources.....	2-2
2.1.5 Groundwater Resources.....	2-2
2.2 Historical Facility Operations.....	2-3
2.3 Current Land Use.....	2-3
2.4 Base Geology and Hydrogeology.....	2-4
2.4.1 Geology	2-4
2.4.2 Structural Geology.....	2-5
2.4.3 Groundwater Occurrence	2-5
2.4.4 Groundwater Movement	2-6
2.4.5 Groundwater Quality.....	2-6
2.4.6 Groundwater Use	2-7
2.5 Groundwater Level Monitoring Results.....	2-7
2.5.1 Groundwater Levels, Contours and Apparent Flow Direction.....	2-7
2.5.2 Hydraulic Gradient.....	2-8
2.6 Aquifer Test Results.....	2-8
3. Site Descriptions and RI Results Summary.....	3-1
3.1.1 SS 003—Oil Saturated Area	3-1
3.1.2 SS 006—Hazardous Material Storage Area.....	3-2
3.1.3 SS 009—Fire Valve Area.....	3-4
3.1.4 SS 012—Communications Facility at Building 105	3-5
3.1.5 ST 005—POL Storage Yard	3-7
3.1.6 ST 011—UST 620A (Formerly CS 004).....	3-8
4. Nature and Extent of Contamination.....	4-1
4.1 Identification of COCs	4-1
4.2 Occurrence of COCs in Groundwater.....	4-2
4.2.1 SS 003—Oil Saturated Area	4-2
4.2.2 SS 006—Hazardous Materials Storage Area.....	4-2
4.2.3 SS 009—Fire Valve Area.....	4-3
4.2.4 SS 012—Communications Facility at Building 105	4-4
4.2.5 ST 005—POL Storage Yard	4-4
4.2.6 ST 011—UST 620A (Formerly CS 004).....	4-5
4.3 Fate and Transport of COCs in Groundwater	4-5
4.4 Summary of Site-Related Risks to Human Health	4-6

4.4.1	Exposure Assessment.....	4-6
4.4.2	Quantitative Risk Characterization.....	4-7
4.5	Summary of Site-Related Ecological Risks	4-8
5.	Development of RAOs and PRGs	5-1
5.1	Summary of ARARs	5-1
5.2	ARARs for Groundwater Remediation.....	5-2
5.2.1	State ARARs for Richards-Gebaur AFB	5-7
5.3	RAOs	5-8
5.3.1	Reducing Concentrations of COCs to Regulatory-Acceptable Levels ...	5-9
5.3.2	Preventing Human Exposure to Contaminated Groundwater.....	5-9
5.3.3	Preventing Discharges of Contaminated Groundwater to Surface Water.....	5-9
5.4	PRGs	5-10
6.	Identification and Screening of Remedial Technologies and Process Options	6-1
6.1	General Response Actions.....	6-1
6.2	Potential Remedial Technologies and Process Options	6-1
6.3	Screening of Remedial Technologies / Process Options	6-2
6.3.1	No Further Action	6-2
6.3.2	Land Use Controls.....	6-7
6.3.3	Long-Term Monitoring	6-8
6.3.4	Monitored Natural Attenuation	6-9
6.3.5	Groundwater Treatment.....	6-11
6.4	Development of Remedial Alternatives.....	6-19
7.	Analysis of Remedial Alternatives	7-1
7.1	Evaluation Criteria	7-1
7.1.1	Overall Protection of Human Health and the Environment.....	7-2
7.1.2	Compliance with ARARs.....	7-2
7.1.3	Long-Term Reliability and Effectiveness	7-2
7.1.4	Reduction of Toxicity, Mobility, or Volume through Treatment	7-2
7.1.5	Short-Term Effectiveness	7-3
7.1.6	Implementability.....	7-3
7.1.7	Cost.....	7-3
7.1.8	State Acceptance	7-4
7.1.9	Community Acceptance.....	7-4
7.2	Detailed Analysis of Remedial Alternatives	7-4
7.2.1	Alternative 1—No Further Action	7-4
7.2.2	Alternative 2—LTM and LUCs	7-4
7.2.3	Alternative 3—ANA, LTM, and LUCs.....	7-9
7.3	Comparative Analysis of Remedial Alternatives	7-9
7.3.1	Overall Protection of Human Health and the Environment.....	7-9
7.3.2	Compliance with ARARs.....	7-10
7.3.3	Long-Term Effectiveness and Permanence.....	7-10
7.3.4	Reduction of Toxicity, Mobility, and Volume.....	7-10
7.3.5	Short-Term Effectiveness	7-10
7.3.6	Implementability.....	7-11
7.3.7	Cost.....	7-11
8.	References	8-1

Appendixes

- A Aquifer Test Technical Memorandum
- B Supplemental Groundwater Risk Assessment
- C Screening of Natural Attenuation Potential at Richards-Gebaur AFB
- D LUC/IC Layering Strategy
- E Remedial Alternatives Cost Estimate: Summaries and Assumptions

Tables

2-1	Current Land Use at Former Richards-Gebaur AFB.....	2-4
2-2	Calculation of Groundwater Velocities	2-9
3-1	Tier 1 Screening Levels for CoCs in Groundwater	3-1
5-1	List of ARARs for Richards-Gebaur AFB FS	5-3
5-2	Sites Exceeding PRGs for Groundwater	5-10
6-1	Implementability Screening Summary, Richards-Gebaur AFB	6-3
7-1	Detailed Analysis of Remedial Alternatives	7-5
7-2	Comparative Analysis Results	7-10

Figures

2-1	Base Location Map
2-2	Location Map for Six Groundwater FS Sites
2-3	Graphic Column of Rock Units Exposed at Richards-Gebaur AFB
2-4	Basewide Monitoring Well Locations
2-5	Basewide Potentiometric Map
2-6	Historical Groundwater Elevations for Select Wells at SS 003
2-7	Historical Groundwater Elevations for Select Wells at SS 006
2-8	Historical Groundwater Elevations for Select Wells at SS 009
2-9	Historical Groundwater Elevations for Select Wells at SS 012
2-10	Historical Groundwater Elevations for Select Wells at ST 005
2-11	Historical Groundwater Elevations for Select Wells at ST 011
3-1	Site Layout & Well Location Map for SS 003
3-2	Geological Cross Section for SS 003
3-3	Potentiometric Surface Map, SS 003
3-4	Site Layout & Well Location Map for SS 006
3-5	Geological Cross Section for SS 006
3-6	Potentiometric Surface Map, SS 006
3-7	Site Layout & Well Location Map for SS 009
3-8	Geological Cross Section for SS 009
3-9	Potentiometric Surface Map, SS 009
3-10	Site Layout & Well Location Map for SS 012
3-11	Geological Cross Section for SS 012
3-12	Potentiometric Surface Map, SS 012
3-13	Site Layout & Well Location Map for ST 005
3-14	Geological Cross Section for ST 005
3-15	Potentiometric Surface Map, ST 005
3-16	Site Layout & Well Location Map for ST 011
3-17	Geological Cross Section for ST 011
3-18	Potentiometric Surface Map, ST 011

- 4-1 COC > Tier 1 Screening Levels, SS 003
- 4-2 TCE Plume in Groundwater, SS 003
- 4-3 Temporal Trends of TCE in Groundwater, SS 003
- 4-4 COCs > Tier 1 Screening Levels, SS 006
- 4-5A TCE Plume in Groundwater, SS 006
- 4-5B Cis-1,2-DCE Plume in Groundwater, SS 006
- 4-5C Vinyl Chloride Plume in Groundwater, SS 006
- 4-6 Temporal Trends of COCs in Groundwater, SS 006
- 4-7 COCs > Tier 1 Screening Levels, SS 009
- 4-8A TCE in Groundwater, SS 009
- 4-8B Cis-1,2-DCE Plume in Groundwater, SS 009
- 4-8C Vinyl Chloride Plume in Groundwater, SS 009
- 4-9 Temporal Trends of COCs in Groundwater, SS 009
- 4-10 COCs > Tier 1 Screening Levels, SS 012
- 4-11A TCE Plume in Groundwater, SS 012
- 4-11B Vinyl Chloride Plume in Groundwater, SS 012
- 4-12 Temporal Trends of COCs in Groundwater, SS 012
- 4-13 COCs > Tier 1 Screening Levels, ST 005
- 4-14 TCE Plume in Groundwater, ST 005
- 4-15 Temporal Trends of TCE in Groundwater, ST 005
- 4-16 COCs > Tier 1 Screening Levels, ST 011
- 4-17A Cis-1,2-DCE Plume in Groundwater, ST 011
- 4-17B Vinyl Chloride Plume in Groundwater, ST 011
- 4-18 Temporal Trends of COCs in Groundwater, ST 011
- 5-1 Area Exceeding Groundwater PRGs, SS 003
- 5-2 Area Exceeding Groundwater PRGs, SS 006
- 5-3 Area Exceeding Groundwater PRGs, SS 009
- 5-4 Area Exceeding Groundwater PRGs, SS 012
- 5-5 Area Exceeding Groundwater PRGs, ST 005
- 5-6 Area Exceeding Groundwater PRGs, ST 011

Executive Summary

CH2M HILL recently completed a Basewide Remedial Investigation (RI) and RI Addendum for the former Richards-Gebaur AFB (CH2M HILL, 2001a; CH2M HILL, 2002). The primary goals of the investigation were to delineate the nature and extent of residual chemicals in soils and groundwater at 17 sites across the Base, and to characterize the risks, if any, posed by the individual sites to human health and the environment.

The results of the investigation indicate that, of the 17 RI sites, 6 sites have contaminated groundwater and the contamination at each site is similar. In each case, groundwater was found to be contaminated by volatile organic compounds (VOCs). The principal VOCs consist of trichloroethene (TCE), cis-1,2-dichloroethene (DCE), and vinyl chloride, chemicals typically associated with the past industrial use of solvents as degreasers. Based on RI risk assessment results, the levels of VOCs in groundwater warranted further action. The six sites with VOCs in groundwater requiring further evaluation in a Feasibility Study (FS) are:

- SS 003—Oil Saturated Area
- SS 006—Hazardous Materials Storage Area
- SS 009—Fire Valve Area
- SS 012—Former Communications Facility at Building 105
- ST 005—POL Storage Yard
- ST 011—UST 620A (formerly referred to as CS 004)

This FS Report presents the development and evaluation of remedial action alternatives for contaminated groundwater at Richards-Gebaur AFB. Following a description of the Base setting and of the RI results for the six sites, the report identifies remedial action objectives and preliminary remediation goals for groundwater. The remedial action objectives for the contaminated groundwater are:

- Reducing concentrations of VOCs to regulatory-acceptable levels
- Preventing human exposure to contaminated groundwater that has concentrations of VOCs exceeding the risk range of 1×10^{-4} to 1×10^{-6} (for carcinogens) or a hazard index (HI) of 1 (for noncarcinogens) for the reasonable maximum exposure
- Preventing discharge of contaminated groundwater to surface water at concentrations that result in exceedances of surface water quality standards

Based upon the remedial action objectives, a series of general response actions was designed to achieve those objectives and to satisfy preliminary remediation goals. A preliminary list of technically implementable remedial technologies and process options was then developed based on the identified general response actions. These technologies and process options were further screened according to cost, effectiveness, and implementability.

The outcome of screening was two remedial alternatives to be considered in a detailed analysis along with the CERCLA-required No Further Action alternative:

- Alternative 1—No Further Action
- **Alternative 2—Long-Term Monitoring and Land Use Controls**
- Alternative 3— Accelerated Natural Attenuation, Long-Term Monitoring, and Land Use Controls

These three alternatives were evaluated against seven criteria defined in the NCP (40 CFR 300). The criteria permit comparison of the relative performance of the alternatives and provide a means to identify their advantages and disadvantages. The criteria are:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, and volume
5. Short-term effectiveness
6. Implementability
7. Cost

Two additional criteria—state acceptance and community acceptance—are evaluated in the Record of Decision following public comment on the selected remedy, which will be described in the Proposed Plan for addressing contaminated groundwater at the Base.

A comparative analysis of the relative ability of the alternatives to satisfy each criterion also was conducted. The results of the comparison are shown below.

Criteria	Alternative 1	Alternative 2	Alternative 3
Protection of Human Health and the Environment	1	4	4
Compliance with ARARs	1	3	3
Long-Term Effectiveness and Permanence	1	3	4
Reduction of Toxicity, Mobility, or Volume Through Treatment	1	1	4
Subtotal	4	11	15
Short-Term Effectiveness	1	4	2
Implementability	4	4	1
Cost	4	3	1
Subtotal	9	11	4
Total Score	13	22	19

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

Following completion of the FS, a preferred remedial action that addresses potential risk associated with contaminated groundwater and is protective of human health and the environment will be recommended in a Proposed Plan that will be submitted for public comment. Comments on the Proposed Plan will be reviewed, and a remedy will be selected and formally documented in the Record of Decision.

Acronyms

AF	Air Force
AFB	Air Force Base
AFCEE	Air Force Center for Environmental Excellence
ANA	accelerated natural attenuation
AOC	area of concern
ARAR	Applicable or Relevant and Appropriate Requirements
AST	aboveground storage tank
BCT	BRAC Cleanup Team
BEC	BRAC Environmental Coordinator
BRAC	Base Realignment and Closure
CALM	Cleanup Action Levels for Missouri
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-dichloroethene
COCs	Chemicals of Concern
COPCs	Chemicals of Potential Concern
CS	Compliance Site
1,1-DCE	1,1-dichloroethene
DPE	dual phase extraction
EE/CA	Engineering Evaluation / Cost Analysis
ESA	Endangered Species Act
FS	Feasibility Study
gpm	gallons per minute
HHRA	Human Health Risk Assessment
HRC®	hydrogen releasing compound
LTM	long-term monitoring
LUCs	land use controls
MCL	Maximum Contaminant Level
MDNR	Missouri Department of Natural Resources
MNA	monitored natural attenuation
MW	monitoring well
NCP	National Contingency Plan
NFRAP	No Further Response Action Planned
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PAH	polyaromatic hydrocarbons
PCE	tetrachloroethene
POL	petroleum, oil, and lubricant
ppm	parts per million
ppb	parts per billion
PRG	Preliminary Remediation Goal
QGM	quarterly groundwater monitoring
RAO	Remedial Action Objectives
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation

RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
SOW	Statement of Work
SPSH	Six Phase Subsurface Heating
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TBC	to be considered
TCE	trichloroethene
TDS	total dissolved solids
TPH	total petroleum hydrocarbons
TSCA	Toxic Substances Control Act
USAF	United States Air Force
USEPA	United State Environmental Protection Agency
UST	underground storage tank
VOC	volatile organic compound

1. Introduction

This Feasibility Study (FS) report documents the development and evaluation of remedial action alternatives for six sites with groundwater contamination located at Richards-Gebaur Air Force Base (AFB), Kansas City, Missouri. The report was prepared under the authority of CH2M HILL's prime contract with the Air Force Center for Environmental Excellence (AFCEE) No. F41624-97-D-8019-0090, in response to the Statement of Work (SOW) for Delivery Order 0090, *Basewide Remedial Investigation / Feasibility Study at Richards-Gebaur AFB, Missouri* (May 24, 1999).

The Basewide RI/FS is being conducted under the United States Air Force (USAF) Base Realignment and Closure (BRAC) program. The work is being executed in accordance with applicable United States Environmental Protection Agency (USEPA) and Missouri Department of Natural Resources (MDNR) regulations and guidance. The BRAC Environmental Coordinator (BEC), together with representatives of the USEPA and MDNR, constitute the BRAC Cleanup Team (BCT), a group that oversees the RI/FS process and ensures compliance with the appropriate state and federal regulations.

1.1 FS Background

CH2M HILL recently completed a Basewide Remedial Investigation (RI) and RI Addendum for the former Richards-Gebaur AFB (CH2M HILL, 2001a; 2001b; 2001c; 2002). The goal of the Basewide RI and RI Addendum was to delineate the nature and extent of residual chemicals in soils and groundwater at 17 sites across the AFB. The object was to characterize the risks, if any, posed by the individual sites to human health and the environment. By delineating the nature and extent of contamination, the RI provided the technical foundation for proceeding toward one of three potential future outcomes for a given site, depending on the degree of contamination indicated by the results of the Basewide RI and RI Addendum (referred to throughout as RI Results). The three outcomes are:

- Uncontaminated sites: obtaining No Further Response Action Planned (NFRAP) status
- Sites with soil contamination: evaluating interim remedial actions in an Engineering Evaluation / Cost Analysis (EE/CA)
- Sites with groundwater contamination: evaluating remedial actions in an FS

Of the 17 sites investigated, 6 were found to be uncontaminated and were submitted to USEPA and MDNR as suitable for NFRAP status and closeout. The sites requiring no further action are:

- | | |
|--|--|
| • AOC 010—Building 918 Parking Lot | • SS 004—Hazardous Waste Drum Storage Area |
| • CS 001—Fuel Line 942 Section | • SS 008—Test Cell Area |
| • CS 002—O/W Separator at Building 704 | • XO 001—Belton Training Complex |

Of the remaining 11 sites, 6 were found to have contaminant concentrations in soils that warrant soil remediation based on RI risk assessment results. The sites with soil contamination are:

- AOC 001—Central Drainage Area
- AOC 002—North Drainage Pond
- FT 002—North Burn Pit
- OT 010—Small Arms Firing Range
- ST 005—Petroleum, Oil, and Lubricants (POL) Storage Yard
- ST 007—Former UST Area

These sites are being addressed through the EE/CA process and subsequent interim removal actions (CH2M HILL, 2001d). Site ST 005 also was found to have contaminated groundwater and thus will be addressed as part of the FS.

Six sites were identified with groundwater contamination. The RI results indicate that the contamination at those sites is similar. In each case, groundwater was found to be contaminated by volatile organic compounds (VOCs). Based on RI risk assessment results, the levels of VOCs in groundwater warranted further action. The principal VOCs are trichloroethene (TCE), cis-1,2-dichloroethene (cis-1,2-DCE), and vinyl chloride, chemicals typically associated with the historically common industrial use of solvents as degreasers. The sites with VOCs in groundwater are:

- SS 003—Oil-Saturated Area
- SS 006—Hazardous Materials Storage Area
- SS 009—Fire Valve Area
- SS 012—Former Communications Facility at Building 105
- ST 005—POL Storage Yard
- ST 011—UST 620A (formerly CS 004)

The groundwater contamination at the six sites is the subject of this FS report.

1.2 FS Objectives and Scope

The FS report presents the development and evaluation of remedial action alternatives for contaminated groundwater at Richards-Gebaur AFB. The criteria for selecting remedies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) specify that remedial actions must satisfy the following chief objectives:

- Protect human health and the environment
- Comply with applicable or relevant and appropriate requirements (ARARs) of federal and state environmental laws within a reasonable timeframe
- Be cost-effective
- Use permanent solutions and alternative treatment technologies to the maximum extent practicable
- Satisfy the regulatory preference for treatment that reduces contaminant toxicity, mobility, or volume as a principal element or provide an explanation in the Record of Decision (ROD) as to why it does not

Accordingly, in consultation with MDNR and USEPA, and with input from the public, the USAF will use the above objectives together with appropriate FS guidance to select an appropriate remedial action alternative for the contaminated groundwater at Richards-Gebaur AFB. The selected remedial action will be formally documented in the ROD in accordance with the National Contingency Plan (NCP).

To meet the objectives listed above, the scope of the FS includes:

- Identifying and listing candidate remedial action alternatives
- Screening the alternatives according to effectiveness, implementability, and cost
- Conducting a detailed analysis of the most feasible alternatives according to the nine standard USEPA criteria
- Providing a comparative analysis of each alternative's ability to satisfy the nine criteria

Following completion of the FS, a preferred remedial action that addresses potential risks associated with contaminated groundwater and is protective of human health and the environment will be recommended in a Proposed Plan that will be submitted for public comment. The resulting comments will be reviewed, and a remedy will be selected and formally documented in the ROD.

1.3 Report Organization

This FS report consists of eight sections:

- Section 1 introduces the background of the FS and states the objectives of the study.
- Section 2 summarizes the Base setting (including location, topography, local climate, surface water resources, and current and historical land use) and describes the Base geology and hydrogeology (including the results of groundwater monitoring).
- Section 3 provides capsule descriptions of the six FS sites and summarizes the RI findings on a site-specific basis.
- Section 4 summarizes the nature and extent of groundwater contamination, contaminant fate and transport, and the results of site-specific human health and ecological risk assessments.
- Section 5 identifies ARARs and presents remedial action objectives (RAOs) and preliminary remediation goals (PRGs) intended to provide adequate protection of human health and the environment.
- Section 6 develops general response actions that address RAOs; identifies and screens remedial technologies and process options; and introduces the identification and more detailed screening of remedial action alternatives for groundwater.
- Section 7 presents a detailed analysis of the candidate remedial actions remaining after the screening process using the seven USEPA evaluation criteria and also provides a comparative analysis of the three remedial alternatives.
- Section 8 lists the FS report references.

2. Base Setting

This section describes the physical setting of Richards-Gebaur AFB and its historical and current land uses, and provides summary descriptions of the six sites with groundwater contamination addressed in the FS. Additional details on basewide geology, hydrogeology, the nature and extent of contamination, and risk assessment methodology and results can be found in the Basewide RI Report (CH2M HILL, 2001a) and RI Addendum (CH2M HILL, 2002).

2.1 Physical Setting

The general setting of Richards-Gebaur AFB is described below, and is followed by specific summary descriptions of each of the six FS sites.

2.1.1 Location

Richards-Gebaur AFB is located in west-central Missouri, roughly 18 miles south of downtown Kansas City and 3 miles east of the Kansas-Missouri state line. Figure 2-1 shows the location of the Base in relation to Kansas City and the surrounding areas. The northern part of the Base is located in Jackson County, the southern part in Cass County. The Base is bordered by the city of Belton on the east and south and by Kansas City to the north and west.

2.1.2 Topography

Richards-Gebaur AFB is located within the Osage Plains region of the Central Lowland physiographic province. The Osage Plains region is characterized by low relief, wide, maturely dissected uplands and relatively steep valley slopes carved on sedimentary rocks of Pennsylvanian age. The topography of the Base is gently rolling, with ground surface elevations ranging from 960 feet above mean sea level on the northeast side of the Base to 1,125 feet on the south property margin.

The Base lies on a broad plateau called the Blue Ridge, with the Blue River bordering to the west and the Little Blue River to the east. The rivers are confluent with the Missouri River about 20 miles north of the Base.

2.1.3 Climate

Richards-Gebaur AFB and environs is characterized by a modified continental climate influenced by disparate air masses from the Gulf of Mexico and Canada. This weather system creates rapid changes in the local climate. Severe thunderstorms, including tornadoes, can occur in spring and summer. The prevailing wind direction at the Base is from the south, with an average annual wind speed of 9 knots.

The mean monthly temperature at the Base is 54.9°F, ranging from 28°F in January to 79°F in July. The average annual precipitation is 37.9 inches, with most typically occurring in the late spring, early summer and early fall when warm, wet air currents from the Gulf of Mexico collide with cold, dry continental air from Canada. The average snowfall depth is 21.6 inches but has varied in the past from less than 12 inches to more than 60 inches.

2.1.4 Surface Water Resources

Richards-Gebaur AFB (with the exception of the Belton Training Complex 4 miles south of the main Base) is located primarily within the Missouri River drainage basin. The surface hydrology is dominated by the drainage systems of the Blue and Little Blue rivers.

At the Base, surface runoff usually drains south and east in several small, unnamed streams. Most of these small streams flow downgradient toward Scope Creek (see Figure 2-2) while a few do not reach Scope Creek. Scope Creek is an intermittent stream that carries water most of the time. It flows diagonally from southwest to northeast, past the Small Arms Firing Range and offsite south of the intersection of State Highway 150 and US Route 71, terminating in the Little Blue River.

A number of small streams in and around the Base have been dammed, creating several man-made ponds. Currently, only one pond exists at the base. The pond lies several hundred feet east of SS 012 (formerly Building 105) and consequently has been included within the scope of the FS for this site.

The Missouri River is the drinking water source for the entire region. Drinking water is supplied to the Base and surrounding communities by the Kansas City Water and Pollution Control Department.

2.1.5 Groundwater Resources

Groundwater within and surrounding Richards-Gebaur AFB is of marginal quality and produces low yields. Consequently, it is not used locally for domestic purposes (MDNR, 1997). The underlying geology at the Base is dominated by relatively impermeable limestones and shales of the Kansas City Group. The discharge from shallow wells located within these formations is very low, generally less than 5 gallons per minute (gpm), and, because of the chemical composition of the rock, tends to become increasingly saline with depth.

During the RI, many of the installed wells were slow to recharge, and several wells were found to remain dry. Consequently, the Base and surrounding municipalities of Kansas City, Belton, and Grandview do not use groundwater as a public water supply and use water supplied from the Missouri River by the Kansas City Water and Pollution Control Department.

Groundwater occurs sporadically across the Base, typically in the transition zone between the unconsolidated surficial materials that cover the uplands and slopes and the underlying weathered bedrock. In upland areas, groundwater may be found trapped within clay-filled openings in weathered limestone that occur near the ground surface.

Based on local monitoring well data, groundwater elevations can vary considerably over short distances, and groundwater often is absent. Where present, the depth to groundwater generally is shallow, varying from less than 10 feet to about 30 feet below ground surface. Generally, higher water elevations are observed in the spring and fall, although water levels in most wells remain fairly constant throughout the year. A more detailed account of groundwater levels is provided in Section 3.

2.2 Historical Facility Operations

Prior to development, Richards-Gebaur AFB was originally farmland. In 1941, the city of Kansas City acquired the property for use as an auxiliary municipal airport, and the property was designated Grandview Airport. In 1952, the Central Air Defense Command leased Grandview Airport from Kansas City; and by 1953, the property officially was conveyed to the United States government. In 1957, Grandview Airport was renamed Richards-Gebaur AFB.

In the late 1950s and early 1960s, the USAF purchased additional property adjacent to the installation to lengthen the primary runway and develop family housing areas. At about the same time the USAF purchased the property of the Belton Training Complex, which is 4 miles south of the installation. In total, the installation property encompassed roughly 2,400 acres.

The Air Defense Command retained the primary mission on the Base until 1970, when the Air Force Communications Command relocated its headquarters from Scott AFB, Illinois, to Richards-Gebaur AFB. Subsequently, the Military Airlift Command took control of the Base in 1977 as the Air Force Communications Command returned its headquarters to Scott AFB.

In 1976, the federal government elected to close Richards-Gebaur AFB as an active military facility. At that time, 1,350 acres of USAF property were declared surplus. However, the USAF retained roughly 242 acres of the property, including 67 building facilities, as an Air Force Reserve Station.

The Air Force Reserve assumed operational control of the Base on October 1, 1980. The title to the surplus property eventually was transferred to the city of Kansas City in 1985, leaving Air Force Reserve in control of the remaining Cantonment Area. The Base was designated for closure under the BRAC program in 1991 and officially shut down in 1994.

2.3 Current Land Use

The USAF owns roughly 184 acres of the former installation. That property includes former aircraft hangars, equipment and grounds maintenance shops, materials storage facilities, communication facilities, and administrative support buildings. The USAF also retains ownership of five areas that are not contiguous with the main installation: the fire training area, the air traffic transceiver facility, the small arms firing range, the survival equipment shop, and the nondestructive inspection laboratory.

All USAF property is leased to the Kansas City Aviation Department. Until January 2000, the property was used to support aviation activities at the civilian airport. However, in November 1999, Kansas City passed a referendum to allow use of the airfield as an intermodal transportation facility. As a result, the Kansas City Aviation Department officially deactivated the runway in January 2000. All aircraft operations have ceased, and the airfield is used to stage and load new automobiles onto trucks and railcars for distribution.

Although much of the original USAF property previously was used for industrial and commercial purposes, most of the buildings are vacant and have not been used since the closure of the airfield in 1994. None of the USAF property is used for residential purposes. The distribution of former Richards-Gebaur AFB land (2,400 acres) is shown in Table 2-1.

The discrepancy of 187 acres may be accounted for by considering that previous transfers of former offsite properties—such as the Harrisonville Test Facility (roughly 103 acres) and several remote navigational aids sites in Cass County (instrument landing system middle and outer markers)—were not adequately recorded in relevant Base documents.

Property Owner	Acreage
Kansas City	1,360
Belton	325
Army	195
Air Force	184
Navy	101
Marine Corps	48
Total	2,213

2.4 Base Geology and Hydrogeology

A detailed analysis of the geology and hydrogeology of Richards-Gebaur AFB is presented in the Basewide RI Report and the RI Addendum (CH2M HILL 2001a; CH2M HILL, 2002). This section recapitulates the previous RI information and, where appropriate, refines earlier conclusions according to the most recent site-specific data.

2.4.1 Geology

The unconsolidated surficial materials at the Base consist of red-brown residual clays containing abundant chert fragments derived from in situ weathering of the near-surface limestone bedrock. At higher elevations, the residual clays are sometimes overlain by wind-blown silt deposits. The unconsolidated materials overlying the bedrock range in thickness from zero to 20 feet (Gentile, 1998). The soils belong to the Macksburg-Urban Series and are characterized as poorly drained silt and silt-clay loams (Versar, 1996).

The geology at Richards-Gebaur AFB consists of interbedded limestones and shales belonging to the Kansas City Group of the Missourian Series, Pennsylvanian System. The local bedrock consists of cyclical or repetitive sequences of relatively thin beds of limestone and shale with minor amounts of sandstone, siltstone, and conglomerate. Individual rock units are not more than 40 feet thick. The combined thickness of rock units exposed at the Base is about 140 feet, extending from Scope Creek in the northeast part of the Base to the top of the highest hill at the south boundary of the Base. The Kansas City Group comprises the following formations, listed from the surface downward: Wyandotte, Lane, Iola, Chanute, Drum, and Cherryvale. The Wyandotte, Lane, Iola, and Chanute formations are exposed at several locations on the Base, and are described in detail below. Figure 2-3 presents a stratigraphic section of the geologic units exposed at the Base (Gentile, 1998).

The uppermost bedrock unit is the Argentine Member of the Wyandotte Formation, which crops out at higher elevations. It consists of well-jointed light gray limestone characterized by thin, wavy bedding and is roughly 30 to 35 feet thick. Exposed Argentine limestone develops solution cavities, and existing joints can be enlarged to several feet in width. The solution-widened joints extend throughout the Argentine Member and are commonly filled with red clay and chert fragments.

Beneath the Wyandotte Formation (Argentine Limestone) is the Lane Formation. The Lane Formation consists of a medium-gray to bluish-gray shale that is commonly silty to sandy in the upper part. The shale typically is 25 to 40 feet thick and is considered relatively impermeable, forming a barrier to vertical groundwater flow (Gentile, 1998).

The Iola Formation occurs below the Lane Formation and is primarily limestone with a thin bed of shale at its base. At the Base it has a maximum thickness of 10 feet. The upper member of the Iola Formation is the Raytown Limestone Member, generally a massive bluish-gray, wavy bedded limestone ranging from 6 to 8 feet in thickness and locally containing interbedded lenses of shale roughly 3 inches thick. The upper 2 or 3 feet of the Raytown Limestone Member is massive and weathers to a deep red-brown color. However, unlike the Wyandotte Formation limestone, the Raytown Limestone Member is a hard, finely crystalline rock that is not readily susceptible to solution weathering. The Raytown Member passes downward into a thin shale (Muncie Creek Member) and a second limestone band, known as the Paola Limestone Member before giving way to the Chanute Shale.

The Chanute Formation underlies the Iola and is a maroon and green claystone and shale with local occurrences of cross-bedded sandstone and conglomerate. The formation ranges from 25 to 30 feet in thickness and consists of an upper gray shale overlying 2 or 3 feet of hard, resistant sandstone near its top, and maroon to greenish-gray shales interbedded with a thin nodular limestone near the middle. About 10 feet of greenish-gray shale lies at the base of the formation. The high percentage of shale and claystone and the tightly-cemented sandstone in the upper part of the formation prevents the Chanute Formation from transmitting significant amounts of fluids (Gentile, 1998).

2.4.2 Structural Geology

The Kansas City Group geologic units underlying the Base have been gently folded into a series of synclines, domes, and anticlines that, taken overall, dip north-northwest at about 10 feet per mile. Subsurface water that becomes perched on top of impermeable shale units would tend to drain in a generally north or northwesterly direction (Gentile, 1998).

The limestone formations are well-jointed. The regional joint pattern consists of two major sets that trend NE-SW and NW-SE and are essentially vertical, oriented almost at right angles to one another (Gentile, 1991). It is these joints that weather to form solution channels that are the principal conduits for groundwater flow within limestone at the Base.

2.4.3 Groundwater Occurrence

Richards-Gebaur AFB is located in the Osage Plains groundwater province of the Central Lowland-Nonglaciated Plains region. Groundwater in the Osage Plains province occurs in sedimentary aquifers of Pennsylvanian and Mississippian age. Yields reportedly range from 1 to 20 gpm, although regionally the Pennsylvanian-age geologic units act as a confining unit because of the thick sequences of impermeable strata that make up the formations.

Because of the geological setting, springs are rare and, if present, have small and intermittent discharges (MDNR, 1997). Under ideal conditions, groundwater may flow along bedding planes between permeable and impermeable strata and produce larger springs, such as those reported in the Kansas City area (Gentile, 1998). However, this phenomenon has not been reported at or near the Base.

The presence of shallow groundwater in unconsolidated overburden soils and weathered near-surface bedrock is largely dependent on seasonal rainfall. Groundwater collects and resides in the transition zone between soil and weathered bedrock.

2.4.4 Groundwater Movement

The Argentine Limestone contains two sets of tightly fitted joints oriented almost at right angles to one another. The joints are subject to solution widening by groundwater, which can result in large orthogonal-shaped blocks of limestone measuring 30 to 40 feet on a side. A well drilled into the interior of a joint block will be dry; a well drilled along a joint may produce a limited amount of water. A well drilled at the intersection of the two joint planes has the best opportunity to deliver water and may produce 2 to 3 gallons per minute (gpm) until the source is depleted. The solution-widened joints extend to the top of the Lane Formation. There the jointing becomes tight because the shale is not susceptible to dissolution and joints extending downward to a greater depth tend to become increasingly tight.

The Lane Formation has been thinned or removed by erosion at lower elevations. Erosion has removed the Lane Formation at sites adjacent to Andrews Road and further northwest. Consequently, at those sites the Raytown Limestone is exposed at the surface or it directly underlies the soil. Because of its hard, crystalline composition, joints in the Raytown Limestone are relatively tight and are not widened as a result of chemical solution. Should shallow groundwater penetrate the Raytown Formation, it would tend to stop at the top of the underlying Chanute Formation, another relatively impermeable shale.

In summary, the combination of clay overburden, fractured limestone, and relatively impermeable shale results in subsurface conditions with limited opportunity for vertical groundwater movement. Low flow velocities predominate and near stagnant groundwater conditions are common during dry periods, as demonstrated by numerous site wells that can take days or weeks to recharge following bailing and sampling. Because the regional bedrock dips to the north/northwest, subsurface water that becomes effectively perched on top of impermeable shale units should tend to drain in a generally north or northwesterly direction (Gentile, 1998). However, field observations of shallow groundwater movement indicate that movement typically mirrors the surface topography and concentrates and flows through the soil overburden-weathered bedrock interface zone. Accordingly, if the land slopes to the south, then shallow groundwater also tends to flow south (i.e., downhill).

2.4.5 Groundwater Quality

The groundwater at the Base may be classified as moderately saline, sodium-chloride type, particularly with regard to Pennsylvanian-age (e.g., Kansas City Group) geologic units near the surface. Regionally, total dissolved solids (TDS) range from 330 parts per million (ppm) to 7,000 ppm, because of high concentrations of sodium and chloride (MDNR, 1997). As part of the RI, nine groundwater samples from several sites were tested for TDS. The results indicated that TDS concentrations in Base groundwater varied from 362 to 1,116 ppm, consistent with regional values for naturally occurring groundwater quality.

The wide range of TDS concentrations reflects the relative proximity of wells to the freshwater/saline water interface that runs southwest-northeast through the province. The recommended USEPA Secondary Maximum Contaminant Level for TDS is 500 ppm.

According to the MDNR, because of poor groundwater quality in Cass, Johnson, Jackson, Lafayette, and Saline counties, sources other than groundwater are used for public water supplies. Most of the groundwater production wells in the area were drilled deeper than

250 feet to produce reliable yields of quality water. The minimal use of groundwater contributes to the lack of available groundwater quality data for these areas (MDNR, 1997).

2.4.6 Groundwater Use

There are no complete exposure pathways for contaminated groundwater at the Base because no active water supply wells exist in the area. Available information indicates that there are unlikely to be potentially complete exposure pathways to VOCs in groundwater for potential future residents. The MDNR's Division of Geology and Land Survey conducted a water well search within 1, 2, and 5 miles of the Base in June 2000. The well search verified that shallow groundwater under and near the Base commonly is not used for domestic purposes. Only six water wells were found within a 5-mile radius of the Base. One well was found within 1 mile of the Base; the others were within a 1-to-5-mile radius. None of the wells is believed to be in service.

The wells were installed between 1988 and 1998 and are owned by six individuals. Total depths of the wells vary from 200 to 268 feet. Well screen intervals appear to be set from about 30 feet below ground surface to the bottoms of the wells. Static water levels occur at depths around 70 to 80 feet for 5 of the wells and at 160 feet for the other well. The recorded yields typically are low, varying from 0.4 to 4 gpm.

No record of shallow water wells was found during this search. The Base and nearby communities of Belton, Pleasant Hill, and Grandview obtain their domestic water supply from the Kansas City Water and Pollution Control Department. The former municipal well field at Belton was abandoned several decades ago when supplies of Missouri River water became available to residents through the Kansas City Water and Pollution Control Department.

2.5 Groundwater Level Monitoring Results

The USAF initiated a basewide monthly groundwater level measurement program in 1999. The program subsequently was amended following the RI to include only those wells at the six sites with groundwater contaminated with VOCs. The following section discusses the results of the water level monitoring program.

2.5.1 Groundwater Levels, Contours and Apparent Flow Direction

During the 1999–2000 Basewide RI, 62 monitoring wells were installed to characterize groundwater flow conditions at the Base and to monitor groundwater level and quality at each site with apparent groundwater contamination from VOCs. This network was augmented with 13 additional wells installed as part of the RI Addendum. Figure 2-4 shows the monitoring well locations.

The Air Force began a monthly basewide groundwater level monitoring program in June 1999. Since its inception, water levels have been recorded each month for all wells associated with the 16 original RI sites (not including SS 012) and background wells. This represents wells installed during the Basewide RI and RI Addendum, together with wells already existing at the 16 RI sites. The last round of groundwater level measurements for all wells was completed in October 2001. Accordingly, groundwater levels measured during October 2001 were used to construct the contour maps presented in Figure 2-5. When individual site groundwater levels are combined using data from wells screened in the overburden/weathered bedrock zone, the groundwater contours appear closely to imitate the topography of the Base, decreasing in elevation to the southeast, toward Scope Creek.

The Air Force determined that, starting in December 2000, water levels would be measured only at the sites with groundwater contamination. In general, the groundwater elevations vary throughout the year. The water level variations are illustrated in Figures 2-6 through 2-11. According to the water level temporal trends, it appears that the shallow groundwater fluctuations are influenced primarily by seasonal rainfalls. In general, the groundwater rises in late spring and early summer, and descends in late fall and winter. This is consistent with the seasonal rainfall pattern in Midwest, which is characterized with most rainfall typically occurring in the late spring, early summer and early fall (see section 2).

In addition to a basewide groundwater contour map, groundwater contour maps also were drawn for the six FS sites (see Figures in Section 3). The contour maps were constructed using data collected in October 2001, the month representing the last full round of groundwater level monitoring.

In general, the maps show shallow groundwater present beneath each site, typically within the transition zone between silty clay overburden and the weathered layers of the uppermost bedrock unit, usually a shale. Inspection of the individual site groundwater contour maps supports the view that shallow groundwater moves within the transition zone, parallel to the ground surface, from upland areas of the Base, south and east, generally toward Scope Creek and its valley.

2.5.2 Hydraulic Gradient

The hydraulic gradient can be estimated from the lateral distribution of groundwater contours. As part of the RI, representative hydraulic gradients were calculated for the six sites with VOCs in groundwater and for several non-FS sites with suitable data. Using the available groundwater contours, the basewide hydraulic gradient ranges from 0.014 ft/ft to 0.40 ft/ft, with the steepest gradient found at AOC 002 (adjacent to ST 005) and the flattest gradient at ST 011. These numbers appear to reflect the topography at the two sites, since AOC 002 is located on a hill that slopes toward Andrews Road, whereas ST 011 lies in a flat area adjacent to Andrews Road.

The potential for vertical hydraulic gradients was investigated at SS 009, ST 005, and ST 011. Seven nested well pairs were installed at ST 005 and ST 011, and a slight upward hydraulic gradient was suggested by water level data. At SS 009, the upward gradient was more pronounced and deep well water levels typically were 4 feet higher than their shallow well counterparts. However, the data are inconsistent over time. Unlike the other RI sites, the deeper wells at these three sites screen units in the Raytown Limestone with higher conductivity, a fact that may contribute to the observed head differences. Regardless, the upward gradient indicates a lack of groundwater recharge and effectively eliminates deeper contaminant migration routes at these sites from further consideration.

2.6 Aquifer Test Results

To estimate site-specific hydrogeological parameters such as hydraulic conductivity and groundwater velocity, aquifer tests were conducted in 2000 at sites with groundwater contamination, with the exception of SS 012. Site SS 012 was not investigated until the 2001 RI Addendum, half a year after the aquifer test program terminated.

The aquifer tests were run over periods as long as 2 weeks. Dedicated, downhole digital pressure transducers were used continuously to record changes in water levels in the test and observation wells following removal of all well-bore water from the test well. The

resulting data were analyzed using several standard methodologies. Appendix A is a technical memorandum summarizing the aquifer test methods and results.

Table 2-2 summarizes the results of the analyses, sorted by type of geologic formation (i.e., silty clay/weathered shale overburden or limestone). The table contains estimates of groundwater velocity calculated at the five sites. The water-level change (column 2) and distance over which that change occurred (column 3) were used to calculate the hydraulic gradient for the tests (column 4). The formation through which flow occurs is given in column 5; the same gradient is used for all rock types at each site. The final four columns contain estimates of hydraulic conductivity at each site (including a range, if available), and calculated flow velocity.

Site	Water Level Change (ft)	Distance (ft)	Gradient (ft/ft)	Formation	Effective Porosity	High K (ft/day)	High Velocity (ft/day)	Low K (ft/day)	Low Velocity (ft/day)
SS 003 (west)	6	87	0.069	Overburden	0.10	4.00E-02	0.028	1.30E-02	0.0089
SS 003 (east)	2	118	0.017	Overburden	0.10	4.00E-02	0.0068	1.30E-02	0.0022
SS 006 (west)	22	203	0.11	Argentine Limestone	0.14	2.70E-01	0.21	5.80E-02	0.045
SS 006 (east)*	2	140	0.014	Overburden	0.10	1.00E-01	0.014	6.80E-04	0.0001
SS 009—S	2	97	0.021	Overburden	0.10	7.40E-04	0.00015	7.40E-04	0.00015
SS 009—D	4	77	0.052	Raytown Limestone	0.14	7.30E-03	0.0027	6.20E-04	0.00023
SS 012*	18	580	0.031	Overburden	0.10	1.00E-01	0.031	7.40E-04	0.0002
ST 005—S	14	165	0.085	Overburden	0.10	6.80E-04	0.00058	6.80E-04	0.00058
ST 005—D	14	165	0.085	Raytown Limestone	0.14	3.10E-02	0.019	3.10E-02	0.019
ST 011—S	2	145	0.014	Overburden	0.10	1.00E-01	0.014	3.20E-02	0.0044
ST 011—D	2	145	0.014	Raytown Limestone	0.14	4.30E+00	0.42	4.30E+00	0.42

K = hydraulic conductivity

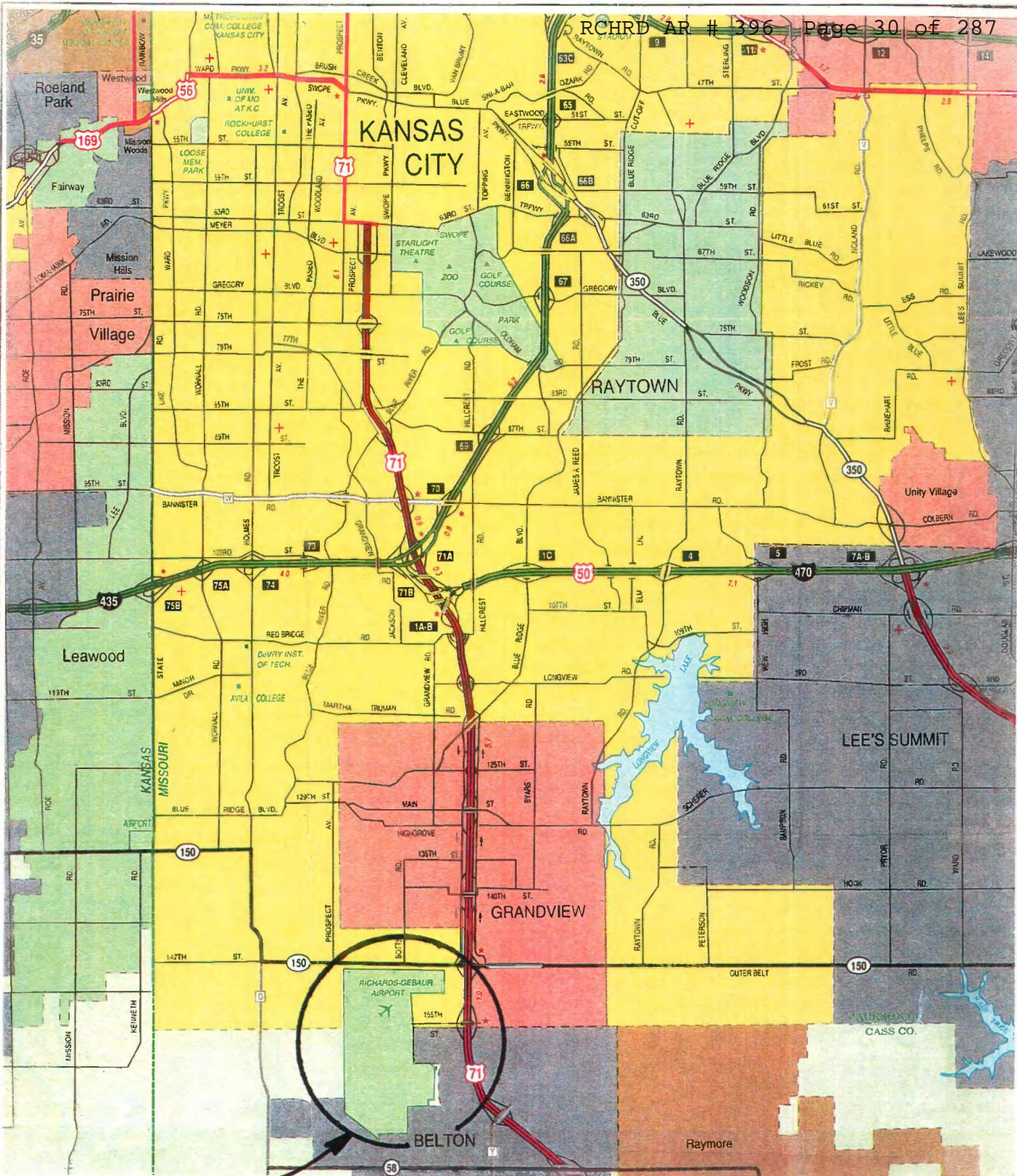
S = shallow D = deep

*Groundwater velocities for SS 006 (east) and SS 012 were estimated using hydraulic conductivities for the same formation at adjacent sites SS 009 and ST 011.

The effective porosity, estimated from McWhorter and Sunada (1977), represents average values obtained from a variety of samples from each of several rock and soil types. McWhorter and Sunada report that the effective porosity of silt ranges from 0.01 to 0.39 (with an average of 0.14) and of clay from 0.01 to 0.18 (with an average of 0.06). Presumably the effective porosity of silty clay will be between these values but on the low end because of the different sizes of grains. Therefore, a value of 0.10 was estimated. McWhorter and Sunada did not provide an estimate of effective porosity for shale but reported that the average for siltstone is 0.12. Presumably, the porosity of weathered shale will be less because, although more bedding planes may be available to transmit groundwater, weathering would produce clay that could fill in many of the bedding planes.

Therefore, a value of 0.10 was estimated. McWhorter and Sunada estimated the average effective porosity of limestone at 0.14, and so that value was used.

In general, the results of the aquifer test analyses are consistent with the previous interpretations of hydrogeology. The tests indicate that hydraulic conductivities within the overburden and bedrock at the five sites are relatively low, with values on the order of those that characterize silt and other fine-grained materials. There are hydraulic connections between some areas at some of the sites, as demonstrated by observable drawdown in wells up to 65 feet or so away from test wells. However, the connections appear to be limited because typically the tests produced only small, if any, drawdown in nearby observation wells.



SITE

Figure 2-1

BASE LOCATION MAP

Richards-Gebaur AFB
Kansas City, Missouri



NOT TO SCALE

CH2MHILL

PLOT DATE: 10-26-98

J:\153673\FIGURES\FIGURE3-1.DWG.DWG

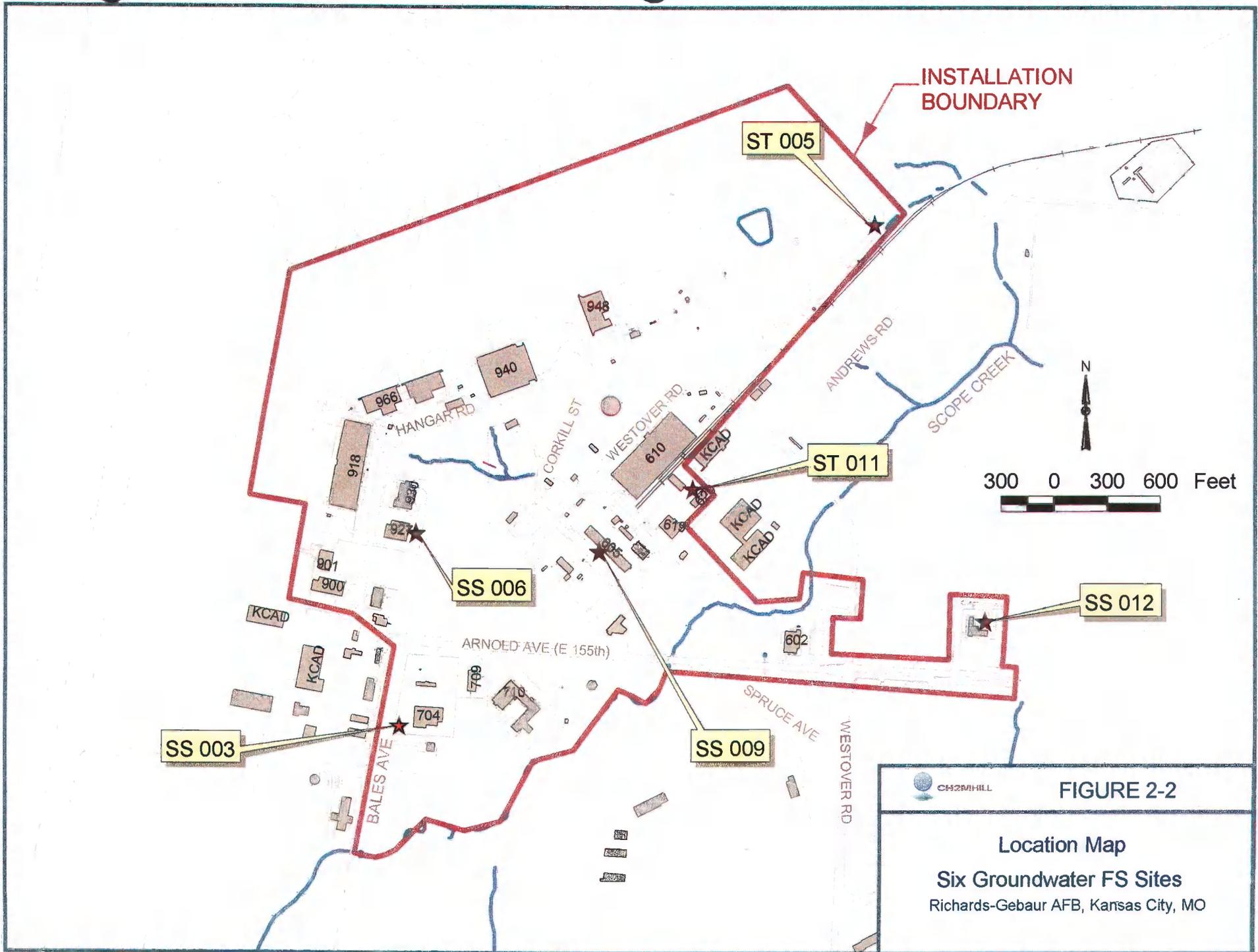


FIGURE 2-2

Location Map

Six Groundwater FS Sites

Richards-Gebaur AFB, Kansas City, MO

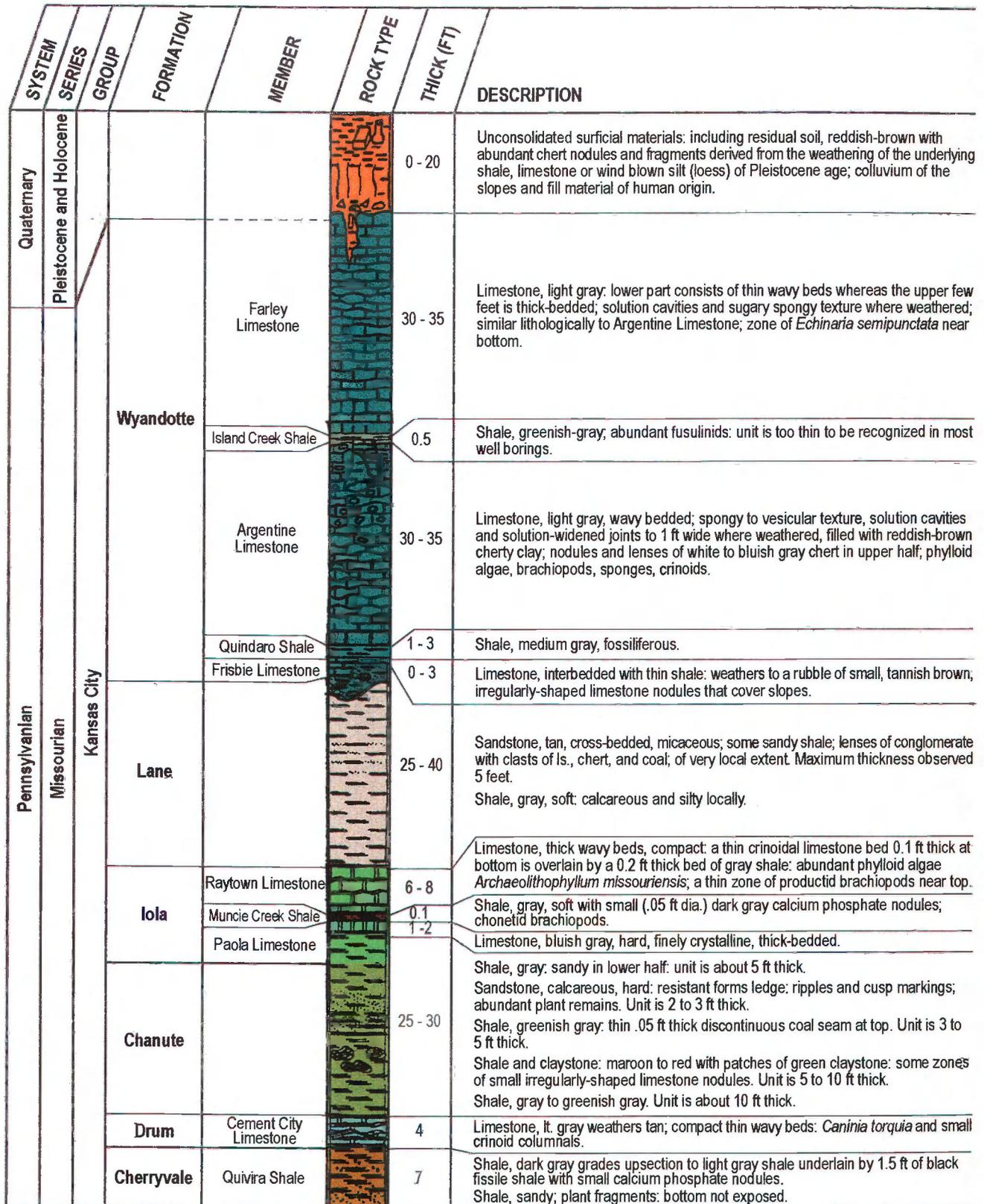
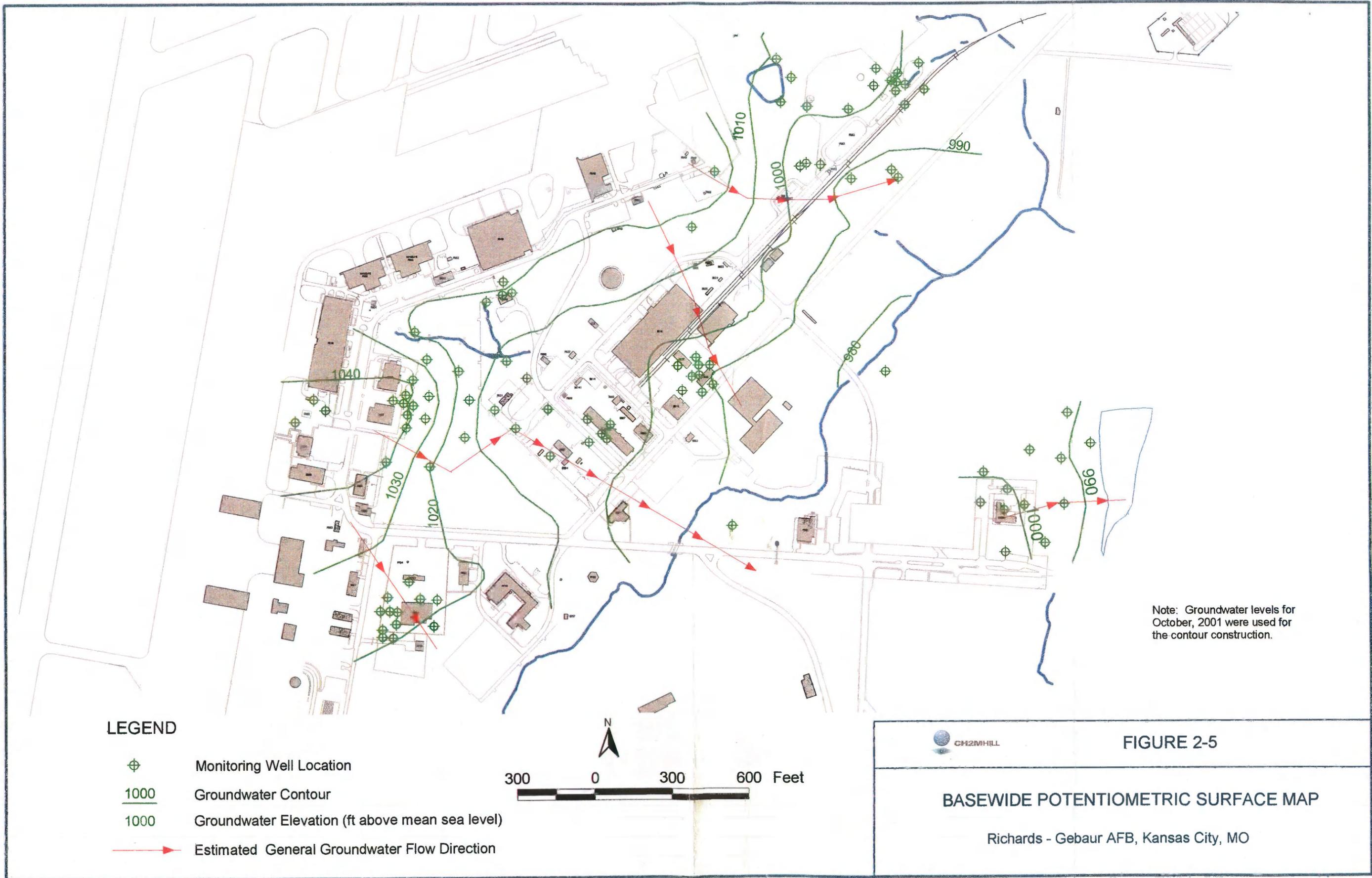


FIGURE 2-3
Graphic Column of the Rock Units Exposed at the
Richards-Gebaur AFB and Adjacent Areas



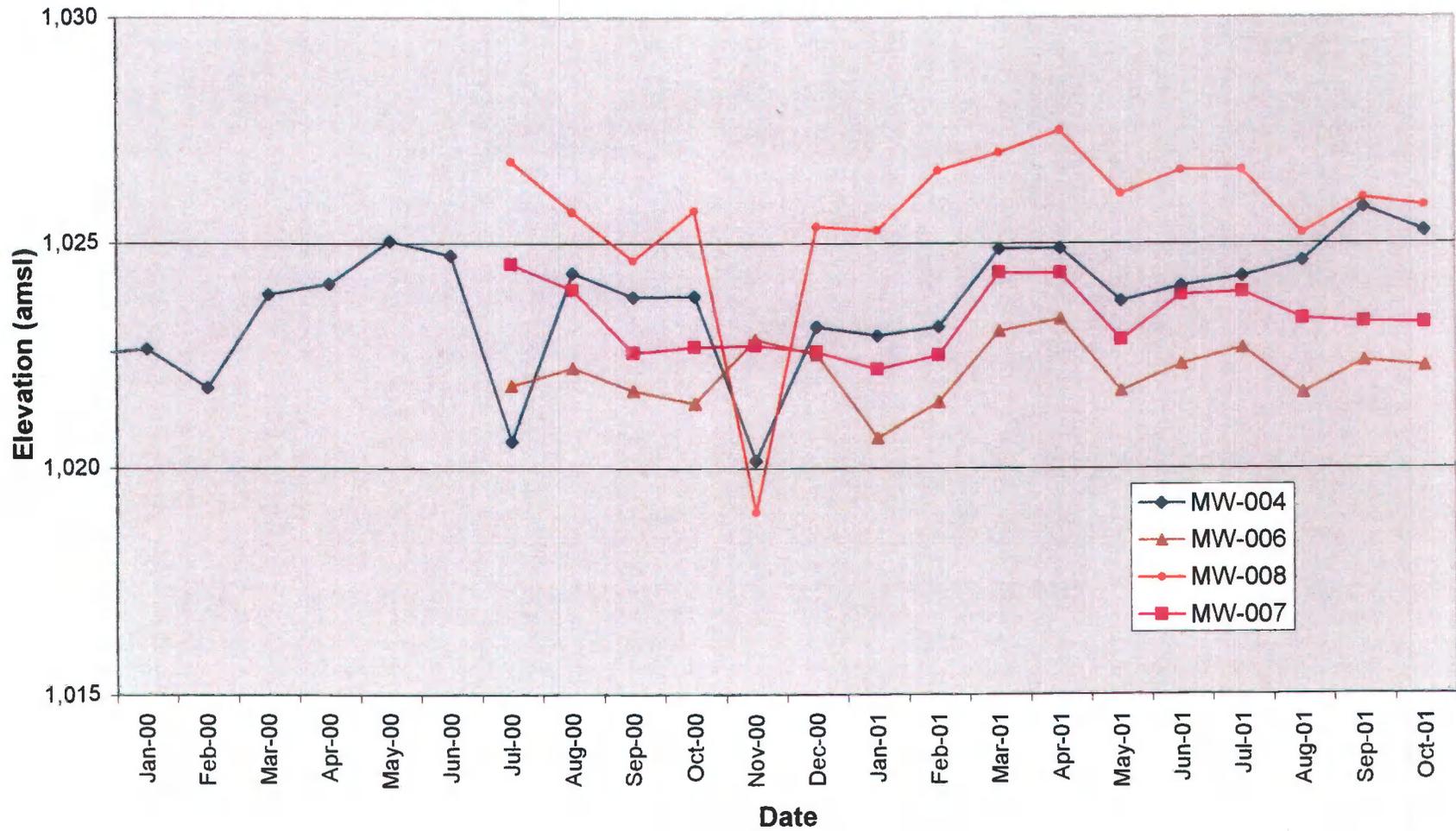


Figure 2-6 Historical Groundwater Elevations for Select Wells at SS 003

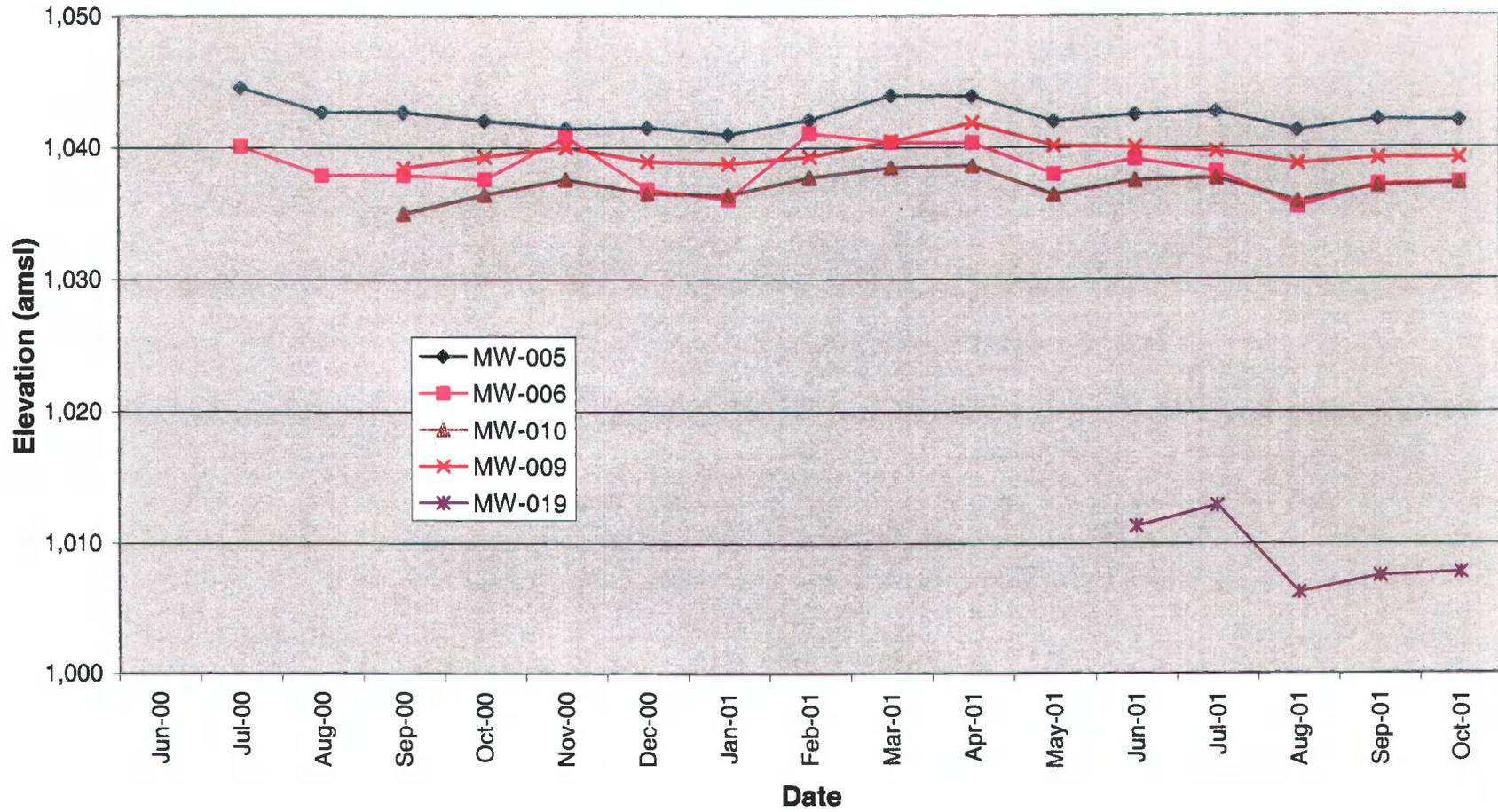


Figure 2-7 Historical Groundwater Elevations for Select Wells at SS 006

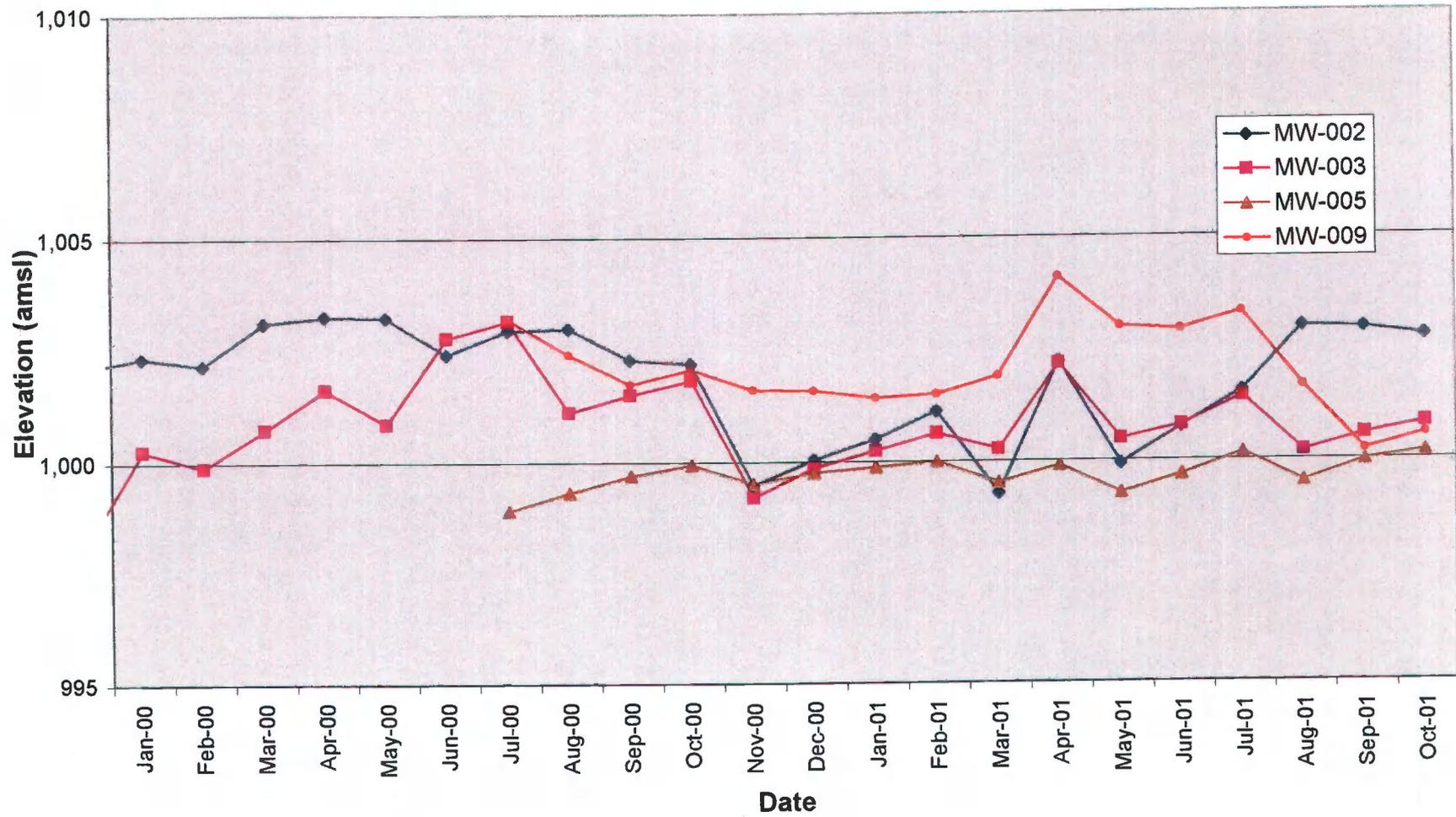


Figure 2-8 Historical Groundwater Elevations for Select Wells at SS 009

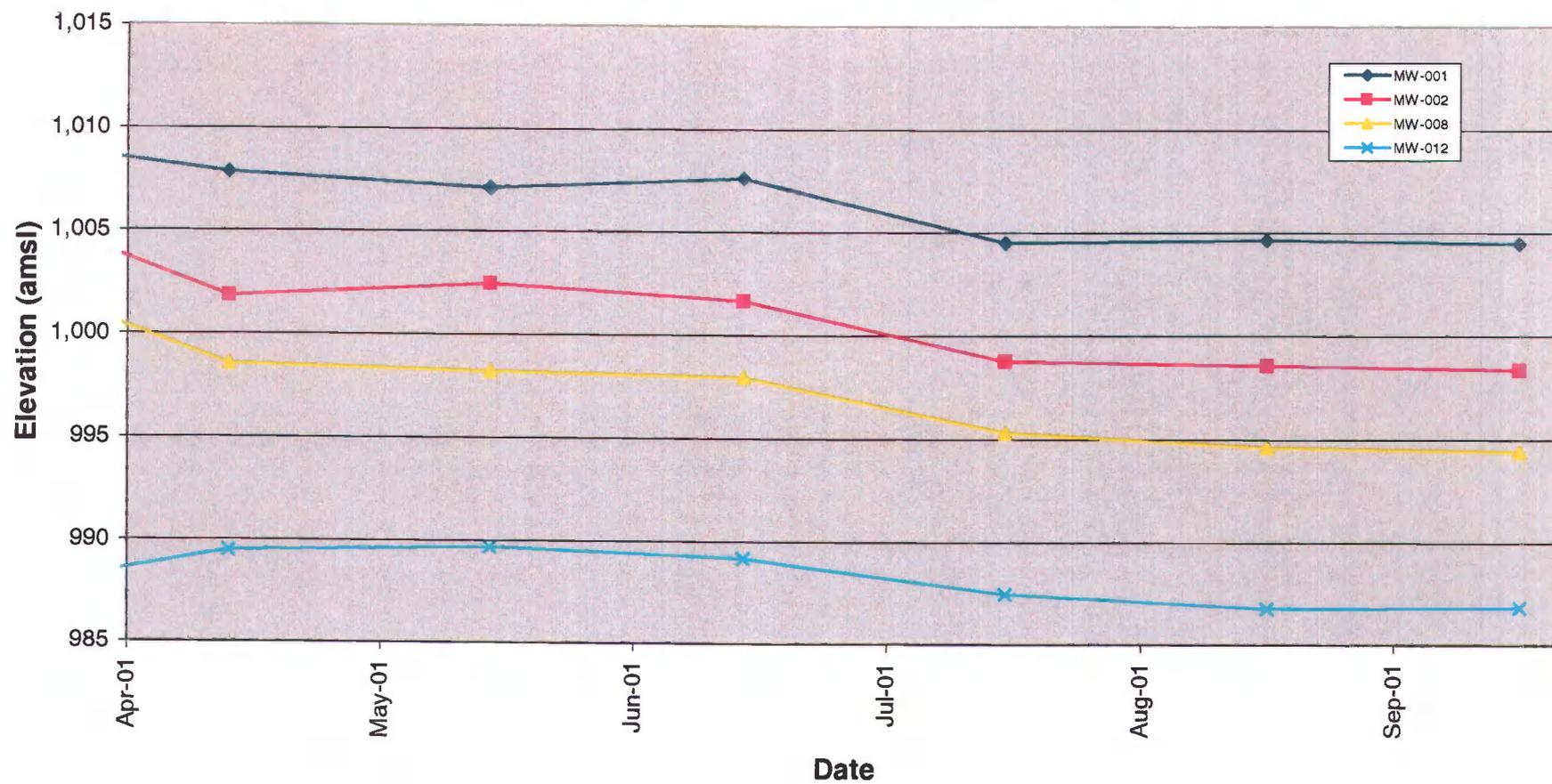


Figure 2-9 Historical Groundwater Elevations for Select Wells at SS 012

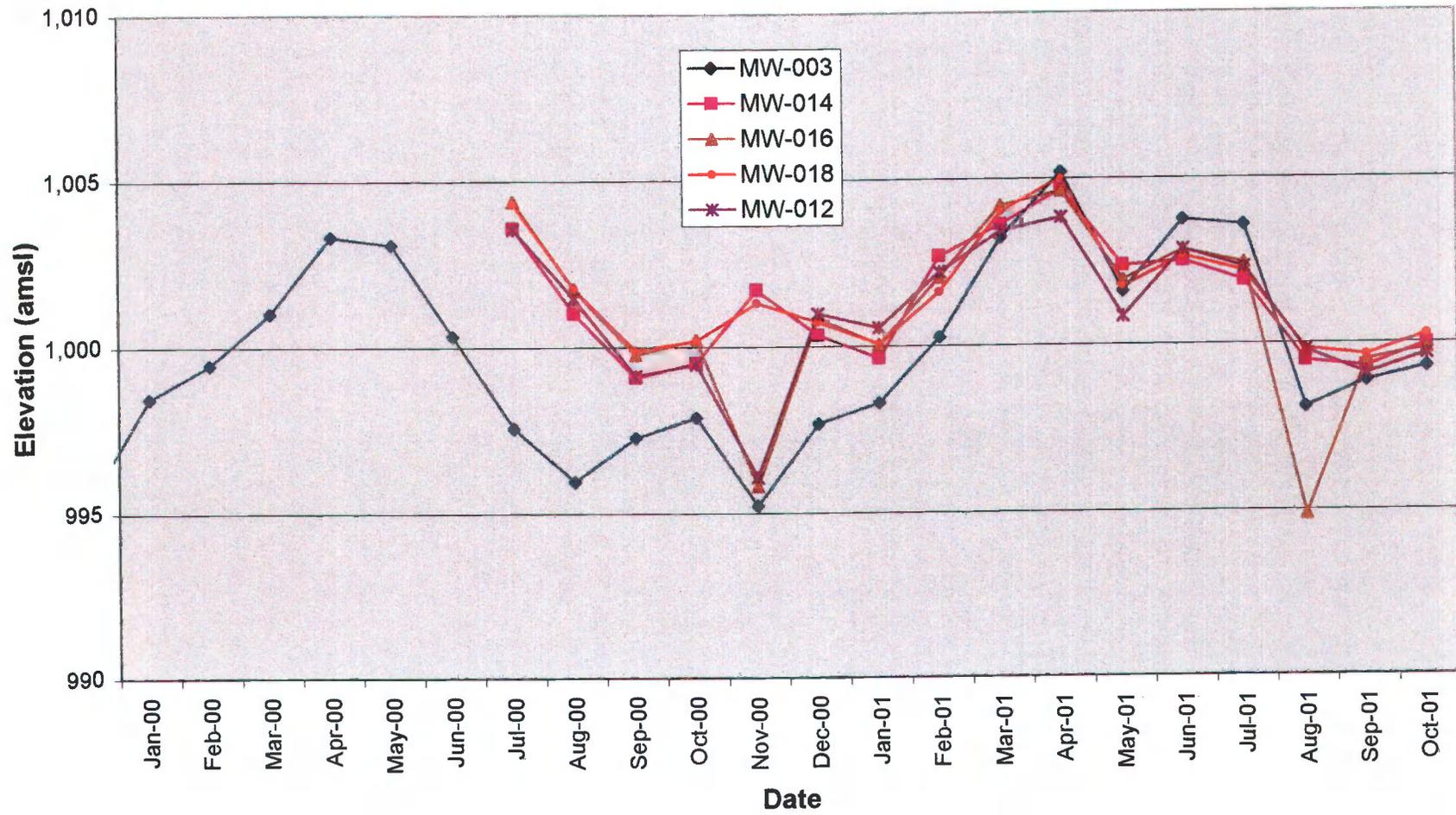


Figure 2-10 Historical Groundwater Elevations for Select Wells at ST 005

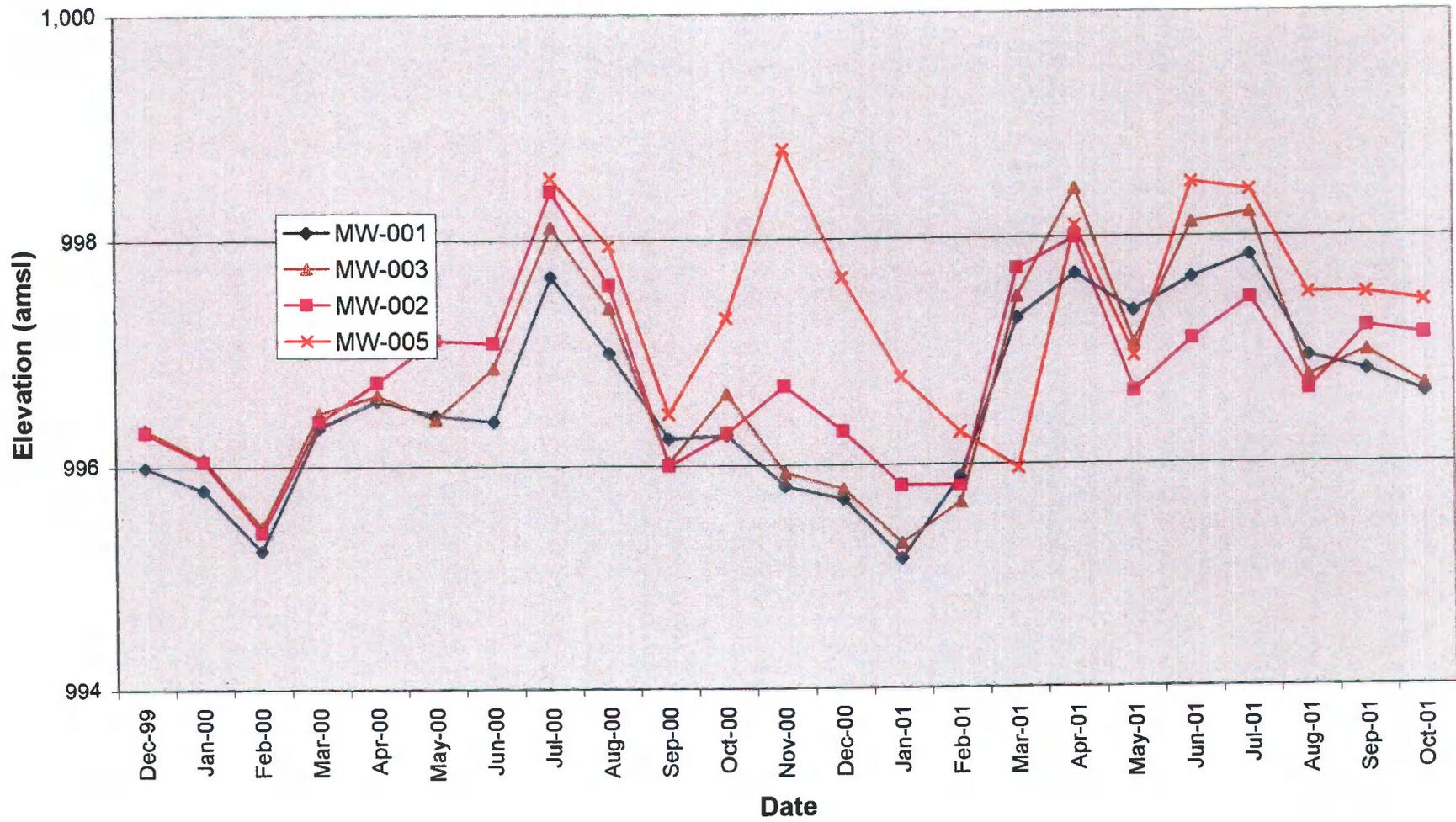


Figure 2-11 Historical Groundwater Elevations for Select Wells at ST 011

3. Site Descriptions and RI Results Summary

Each FS site is described briefly below, including a summary of the results of the RI. Detailed descriptions of the nature and extent of VOCs in groundwater are presented in Section 4, Nature and Extent of Contamination. Each site is part of the ongoing Quarterly Groundwater Monitoring (QGM) program at the Base. Accordingly, the QGM data are included and evaluated in Section 4. Figure 2-2 shows the locations of the six FS sites.

The analytical results were compared to Tier 1 Screening Levels that were developed for the Basewide RI/FS, as agreed by the BCT. The primary sources for Tier 1 Screening Levels for groundwater were: federal Maximum Contaminant Levels (MCLs) and MDNR Cleanup Action Levels for Missouri (CALM) guidance for components of total petroleum hydrocarbons (TPH). For details on the development of chemical specific Tier 1 Screening Levels, refer to Section 5.5 of the Basewide RI Report (CH2M HILL, 2001a).

Analytical results were compared against Tier 1 Screening Levels to identify chemicals of potential concern (COPCs). As described in the Basewide RI Report, COPCs are compounds measured at concentrations exceeding Tier 1 Screening Levels. COPCs were identified for each site. Using the process outlined in Section 5 of the Basewide RI Report, COPCs were evaluated to determine if each chemical should be retained as a chemical of concern (COC) for a risk assessment. Table 3-1 lists the Tier 1 Screening Levels for COCs in groundwater.

Chemicals	Selected Tier 1 Screening Level in Groundwater (ppb)
1,1-DCE	7
Cis-1,2-DCE	70
PCE	5
TCE	5
Vinyl chloride	2

3.1 SS 003—Oil Saturated Area

SS 003, the Oil Saturated Area, is located in the southern part of the Base, south of 155th Street and southwest of Building 704. The site area, including a monitoring well network, comprises 1.4 acres. SS 003 is paved and flat, and a grassy swale runs parallel to the west and south fence lines. Figure 3-1 depicts the site layout and the monitoring well network. The site is adjacent to a former waste oil storage area and covers roughly 1,600 square feet. According to available records, the waste oil storage area was used from the mid-1950s to the late 1980s (USAF, 1994). Small spills or leaks reportedly occurred during its operation (Ecology & Environment, 1988). In 1991 and 1992, roughly 42 cubic yards of contaminated soil were removed from the site (Burns & McDonnell, 1992).

During the 1999 Basewide RI, one additional groundwater monitoring well was installed, and three soil samples were retained from the well borehole for laboratory analyses. Groundwater samples were collected from the new well and from three existing wells at the site. Soil and groundwater samples were analyzed for TPH, VOCs, semivolatile organic compounds (SVOCs), and metals.

Preliminary results of the 1999 investigation revealed the presence of chlorinated VOCs in groundwater. To better delineate groundwater impacts, four monitoring wells were installed as part of the 2000 RI Addendum effort. Each well in the monitoring well network was sampled for VOCs in June 2000. Select groundwater samples also were analyzed for natural attenuation parameters. Based on the data available at that time, it appeared that chemical constituents were delineated sufficiently at SS 003. The area with groundwater contamination was approximately 0.23 acre. This conclusion was further supported by the QGM results.

Borings at SS 003 penetrated 15 to 20 feet of low to medium-plastic silty clay overburden underlain by as much as 10 feet of weathered shale of the Lane Formation. Groundwater generally flows to the east through the silty clay/weathered shale transition zone. The hydraulic gradient appears to be higher in the western part of the site (0.069 ft/ft) than in the eastern part (0.017 ft/ft). Based on aquifer test data from July 2000, flow velocities in the weathered zone appear to range from 0.0022 ft/day to 0.028 ft/day or less than 10 feet per year. Figure 3-2 depicts the geology and Figure 3-3 the potentiometric surface at the site.

During the RI, TCE was detected at concentrations exceeding its Tier 1 Screening Level in four wells. The VOCs cis-1,2-DCE and vinyl chloride were not detected at concentrations exceeding applicable Tier 1 Screening Levels.

A review of natural attenuation parameter data suggests that conditions at SS 003 may not be optimal for anaerobic biodegradation. However, the presence of TCE degradation products indicates that very limited TCE degradation has occurred in the past and may still be occurring. Refer to Appendix C for details.

Analytical results were evaluated in a tiered Human Health Risk Assessment (HHRA). COCs at the site were identified as chlorinated VOCs in groundwater. COCs were not identified in soil. Calculated risks in groundwater were higher than established project risk thresholds of 1×10^{-5} (carcinogenic) and a hazard index of 1 (noncarcinogenic).

A Tier 1 qualitative ecological exposure assessment was conducted for SS 003 according to guidance pertaining to CALM. The assessment consisted of Phase I screening. Ecological risks were not found because there are no ecological receptors or habitats at SS 003.

3.2 SS 006—Hazardous Material Storage Area

SS 006, the Hazardous Material Storage Area, is located in the west central part of the Base, east of Hanger Road and north of 155th Street. The site is unpaved and slopes downhill to the east from the former hazardous materials storage area. The site's surface drainage is separated from the adjacent building drainage by a 6-inch curb (Versar, 1996). Originally, the site covered roughly 600 square feet in area and was situated near the airfield, one of the highest parts of the Base. During the 1999 -2001 Basewide RI, the area of groundwater investigation extended northward close to the Central Drainage Area, eastward to Facility 931, and southward to the parking lot outside of Building 926. It is not located in a floodplain, and no surface water bodies or sediments are present. Figure 3-4 depicts the site layout and the monitoring well network there.

Building 927 was used as an aircraft engine and propeller maintenance shop from 1957 to 1994. The area outside the rear of the building was used to store bulk supplies of degreasers, solvents, and oils until needed inside. The materials routinely were stored in drums or other containers and placed off the ground on racks. According to records, the grass immediately behind the storage racks was discolored and showed signs of stress (Ecology & Environment, 1988). In 1993, roughly 40 cubic yards of contaminated soil were removed from SS 006 (Burns and McDonnell, 1993).

As part of the RI, 14 monitoring wells were installed at the site in three separate phases of fieldwork conducted between May and August 2000. During that period, eight soil samples from the well borings were retained for laboratory analyses, and groundwater samples were collected from the monitoring well network. Soil and groundwater samples were analyzed for TPH, VOCs, SVOCs, and metals. Some of the new wells were found to be dry and could not be sampled. Subsequent QGM sampling found that some of the downgradient wells, previously considered dry, contained groundwater contaminated with VOCs. The wells were incorporated into the QGM program.

To delineate the downgradient presence of VOCs in groundwater, Site SS 006 was further investigated during the 2001 RI Addendum. The RI Addendum focused on the downgradient edge of the VOC contamination, an area near but west of Facility 931, a former liquid oxygen storage unit. Six more monitoring wells were installed between January and October 2001. During the investigation, two soil samples from the well borings were retained for laboratory analysis. Groundwater samples were collected from five of the six monitoring wells, but MW-022 remained dry and could not be sampled. The soil and groundwater samples were analyzed for VOCs.

Well MW-020 contained VOCs at concentrations exceeding Tier I Screening levels. The well is surrounded by wells free of VOCs, suggesting that an isolated, discrete source of VOCs unrelated to the primary source of VOCs in groundwater at SS 006 exists near Facility 931. Based on the available data, it appeared that chemical constituents were delineated sufficiently at Site SS 006, and so no further wells were installed. This contention subsequently was confirmed by the results of the QGM program. The area of groundwater contamination is approximately 5.7 acres.

During the Basewide RI, subsurface materials encountered at higher ground surface elevations near the former storage unit consisted of 2 to 10 feet of low to medium plastic silty clay overburden underlain by 2 to 5 feet of fractured, solution-weathered Argentine Limestone. Weathered shale of the Lane Formation was observed beneath the fractured limestone layer at these locations. However, near Facility 931, where the ground surface sloped downward to the north and west toward AOC 001, the Central Drainage Area, fractured limestone was not observed during drilling. Instead, 3 to 10 feet of weathered shale was encountered beneath the silty clay overburden. The underlying shale belongs to the Lane Formation and is part of the Kansas City Group. The Argentine Limestone has been eroded at lower ground surface elevations and so is absent at Facility 931. Figure 3-5 depicts the geology of the site.

Based on available data, groundwater at SS 006 flows to the southeast at a hydraulic gradient of 0.11 ft/ft. Based on aquifer tests performed in July 2000, flow velocities in the limestone appear to range from 0.045 ft/day to 0.21 ft/day, or less than 80 feet per year. The relatively high groundwater velocity may represent local fracture-flow conditions. At lower elevations where the limestone is absent (e.g., near Facility 931), flow conditions are more similar to those at SS 009. The flow velocity in the overburden appears to range from

0.0001 ft/day to 0.014 ft/day, compared to the range of 0.00023 ft/day to 0.0027 ft/day at SS 009 (see Section 2.6). Figure 3-6 depicts the potentiometric surface at the site.

The RI and QGM sampling results show that TCE has been detected at concentrations exceeding its Tier 1 Screening Level in an area that extends hydraulically downgradient about 400 feet east of the site. TCE also has been detected at concentrations exceeding its Tier 1 Screening Level several hundred feet south of the site. Cis-1,2-DCE and vinyl chloride also have been detected at concentrations exceeding Tier 1 Screening Levels but are not as widespread as TCE. The data indicate that a separate smaller area where TCE, cis-1,2-DCE, and vinyl chloride exceed Tier 1 Screening Levels is present immediately downgradient of Facility 931.

Review of natural attenuation data collected at SS 006 suggested that site conditions may not be optimal for anaerobic biodegradation. However, the presence of several TCE degradation products indicates that limited degradation has occurred or is occurring at the site. Refer to Appendix C for details.

Site health risks associated with VOCs in groundwater were recalculated for SS 006 by including data from monitoring well MW-020 with the original RI data set. The revised results were consistent with the RI results and indicated that calculated risks in groundwater were higher than established risk thresholds of 1×10^{-5} for carcinogenic effects and above a hazard index of 1 for noncarcinogenic effects.

A Tier 1 qualitative ecological exposure assessment was conducted for SS 006 according to MDNR's CALM guidance (MDNR, 2001). The assessment consisted of Phase I and Phase II screening. Ecological risks were not found because there are no complete ecological exposure pathways at SS 006.

3.3 SS 009—Fire Valve Area

SS 009, the Fire Valve Area, is located in the southeastern part of the Base, on the southwestern side of Building 605, southeast of the intersection of Westover and Corkill Roads. The site is located on the far side of a paved parking lot next to a fire valve and adjacent to a small grass drainage swale. The site is generally flat and originally occupied roughly 400 square feet in area. The site is not within a floodplain. Figure 3-7 depicts the site layout and the monitoring well network.

The site was identified in 1992 when petroleum product was detected in soil during repairs to the fire hydrant (USAF, 1993). It was suspected that waste materials may have been disposed of in a drainage swale next to the site (Jacobs, 1995). Roughly 10 cubic yards of petroleum-contaminated soil were excavated from the site in 1993 (USAF, 1993).

In 1999, two groundwater monitoring wells were installed, and two groundwater and three soil samples were analyzed for TPH, VOCs, SVOCs, and metals. Because of dry conditions, one monitoring well borehole was abandoned at the site. Preliminary results of the 1999 investigation revealed the presence of chlorinated VOCs in groundwater. To delineate groundwater impacts, 10 additional monitoring wells were installed. Each well was sampled for VOCs in June 2000. Select groundwater samples also were analyzed for natural attenuation parameters. Based on the data available at that time, it appeared that chemical constituents were sufficiently delineated at SS 009. The area with groundwater contamination is approximately 0.1 acre. This conclusion has been supported by the results of the ongoing QGM program.

Borings at SS 009 penetrated 10 to 13 feet of low to medium-plastic silty clays and weathered shale underlain by 6 to 8 feet of limestone. The shale corresponds to the Lane Formation and the limestone is the Raytown Limestone Member of the Iola Formation. The Chanute Formation was seen beneath the Raytown Limestone at several boreholes. Figure 3-8 shows the geology of the site.

Groundwater level measurements show that a head difference of as much as 5 feet appears to exist between the shallow and deep wells, with the deep well groundwater levels higher than the shallow. Based upon the data, groundwater appears to flow through both the shallow silty clay/weathered shale zone and the lower limestone unit at SS 009. The hydraulic gradient of the shallow silty clay/weathered shale zone was estimated to be 0.021 ft/ft. The hydraulic gradient of the limestone was estimated to be 0.052 ft/ft. Figure 3-9 shows the potentiometric surface at the site.

Because of the presence of VOCs in groundwater, aquifer tests were conducted at SS 009 in July 2000. Based on aquifer test data, flow velocities in the silty clay are low, on the order of 0.00015 ft/day or less than 1 foot per year. Groundwater velocity in the limestone appears to range from 0.00023 ft/day to 0.0027 ft/day, also less than 1 foot per year.

Groundwater sampling results indicated that tetrachloroethene (PCE), TCE, cis-1,2-DCE, and 1,1-dichloroethene (1,1-DCE) are present at SS 009 at levels above the Tier 1 Screening Levels only in shallow well MW-003. In addition, vinyl chloride was detected at concentrations just above its Tier 1 Screening Level at one other shallow well, MW-009. Because the VOCs were detected only in the shallow wells, it appears that there is no hydraulic connection between the shallow and deep wells.

Based on a review of natural attenuation parameters, it appears that subsurface conditions at SS 009 may not be optimal for anaerobic biodegradation. However, the presence of TCE degradation products in groundwater samples does indicate that limited degradation has occurred or is occurring at the site. Refer to Appendix C for details.

Analytical results were evaluated in a tiered HHRA. COCs at the site were identified as chlorinated VOCs in groundwater. COCs were not identified in soil. Calculated risks in groundwater were higher than established risk thresholds of 1×10^{-5} (carcinogenic) and a hazard index of 1 (noncarcinogenic).

A Tier 1 qualitative ecological exposure assessment was conducted for SS 009 according to CALM guidance. The assessment consisted of Phase I screening. Ecological risks were not found because there are no ecological receptors or habitats at SS 009.

3.4 SS 012—Communications Facility at Building 105

SS 012, the Communications Facility at Building 105, is located in the southeastern part of the Base, on the northeast corner of the intersection of 155th Street and Maxwell Avenue. The facility was constructed in 1954. Figure 3-10 shows the site layout and the monitoring well network at the site.

The site consists of a single story concrete building (Building 105) with an adjacent concrete parking lot. A grassy field lies to the east of the facility and extends to a small, unnamed pond constructed about 10 years ago, located about 600 feet east of the site. The facility was vacated when the Base officially closed in 1994 (Booz-Allen & Hamilton, 2000). One former 250-gallon diesel underground storage tank (UST) was used to provide diesel fuel to a backup generator located inside the Communications Building. The UST was removed in

1988 and replaced by a 275-gallon diesel aboveground storage tank (AST) (Booz-Allen & Hamilton, 2000). In August 2001, roughly 275 gallons of diesel fuel were removed from the AST and processed at an offsite reclamation facility and the AST itself was removed.

HDB Construction, Inc., originally investigated the site in 1996 through a subsurface assessment during which one grab groundwater sample was collected from a shallow borehole near the former UST location (HDB, 1996). The sample was analyzed for VOCs, polycyclic aromatic hydrocarbons (PAHs), and diesel-range total petroleum hydrocarbons (TPH-DRO). No PAH or TPH-DRO constituents were detected in groundwater at concentrations exceeding their corresponding Tier 1 Screening Levels. However, three VOCs—TCE, cis-1,2-DCE, and vinyl chloride—were detected in groundwater at concentrations exceeding the screening levels. Because records indicate that the former UST contained diesel fuel, it is not likely that the presence of VOCs in groundwater correlates with use of the former diesel UST.

To delineate potential groundwater impacts at the site, 12 monitoring wells and 9 temporary piezometers were installed. Five soil samples were collected from 3 well boreholes near Building 105. Groundwater samples first were collected from the 12 wells and 6 of 9 piezometers between February and April 2001. The soil and groundwater samples were analyzed for VOCs. Soil and groundwater samples collected from MW-001 also were analyzed for TPH. Based on the available data, it appears that chemical constituents were sufficiently delineated at SS 012. The area with groundwater contamination is 3.5 acres. This conclusion has been confirmed by the results of the QGM program.

Subsurface materials encountered at SS 012 during drilling and sampling generally consisted of 14 feet of low to medium plastic silty clays underlain by limestone, most likely the Raytown member of the Iola formation. Chanute Shale was observed beneath the limestone layer at one location. Figure 3-11 shows the geology of the site.

Based on the site data, groundwater at SS 012 flows to the north and east toward tributaries of Scope Creek, and east to an unnamed pond. Groundwater appears to flow through the silty clay overburden at SS 012 at an estimated hydraulic gradient of 0.03 ft/ft. Figure 3-12 depicts the potentiometric surface at the site.

The sampling results from the 2001 RI Addendum indicated that TCE and vinyl chloride are present in groundwater samples from SS 012 at concentrations exceeding their corresponding Tier 1 Screening Levels. TCE exceeded its screening level in 6 of the 12 monitoring wells and is the most widespread of the VOCs. Vinyl chloride exceeded its screening level in 1 of the 12 wells.

Based on the groundwater contour map for Site SS 012, it appears that groundwater flows to the north and to the east into the unnamed pond. However, because of its chemical properties (vapor pressure = 58 millimeters of mercury at 68°F), any TCE entering the pond will evaporate quickly and will not accumulate in pond sediments. Because of the relatively low TCE concentration in groundwater near the pond, its high potential for evaporation, and dilution caused by stormwater runoff entering the pond, TCE concentrations in the pond will not approach the state's surface water quality standard of 80 ppb for human health protection (10 CSR 20-7).

Natural attenuation parameters suggest that conditions at SS 012 may not be optimal for anaerobic biodegradation. However, the presence of degradation products indicates that very limited degradation has occurred at the site in the past. Refer to Appendix C for details.

Analytical results were evaluated in a tiered HHRA. COCs at the site were identified as chlorinated VOCs in groundwater. Calculated risks in groundwater were found to be higher than established risk thresholds of 1×10^{-5} (carcinogenic) and of a hazard index of 1 (noncarcinogenic).

A Tier 1 qualitative ecological exposure assessment was also conducted for SS 012 according to CALM guidance. The assessment consisted of Phase I screening, Phase II screening, and semiquantitative risk assessment. Ecological risks were found to be insignificant to potential ecological receptors.

3.5 ST 005—POL Storage Yard

ST 005, the POL storage yard, is located in the northeastern part of the Base, east of the flightline and west of Andrews Road. The site is a former AST farm about 12 acres in size. It was used to receive, store, and dispense JP-4 fuel, fuel oil, and gasoline. The yard was decommissioned in 1994. All structures have been removed from the site. Figure 3-13 depicts the site layout and the monitoring well network at the area where VOCs were detected in groundwater. This includes 16 monitoring wells that are part of the QGM program. Note that wells MW-003 (S) and MW-1207 (S) were installed prior to the Basewide RI and the remaining 14 wells were newly installed.

In addition to demolishing aboveground structures, roughly 200 cubic yards of soil and site debris were removed from the site in 1996 (Dames & Moore, 1996a). Petroleum hydrocarbon and polyaromatic hydrocarbon (PAH) compounds have been detected in the site soils and groundwater, and several investigations have been conducted to evaluate the nature and extent of petroleum contamination (Dames and Moore, 1996b; CH2M HILL, 2001c). The soil contamination is being addressed through a soil removal action.

As part of the 1999 RI, groundwater samples were collected from the 17 existing monitoring wells at the site. The samples were analyzed for PAH, VOCs, SVOCs, TPH, and metals. Selected groundwater samples also were analyzed for natural attenuation parameters.

Elevated concentrations of chlorinated VOCs had been detected in well MW-003 located in the northeastern part of the site. The RI Results also indicated contamination at that location. To better delineate VOCs in groundwater near the area, 14 monitoring wells, MW-010 through MW-023, were installed between May and August 2000. During that period, groundwater samples were collected from MW-003 and the newly-installed monitoring wells. Soil and groundwater samples were analyzed for VOCs.

Based on available data at the time, it appeared that VOCs in groundwater were sufficiently delineated at ST 005. That interpretation was confirmed by the results of the ongoing QGM program. The area with groundwater contamination is approximately 0.4 acre.

Drilling logs for ST 005 indicate that borings generally passed through 5 to 10 feet of silty clay followed by roughly 5 to 10 feet of weathered shale, which is in turn underlain by at least 5 feet of limestone. The uppermost shale unit at ST 005 is the Lane Formation, which is underlain by the Raytown Member of the Iola Formation. The Chanute Formation was seen beneath the Raytown limestone layer in deeper site borings. Figure 3-14 depicts the geology of the site.

Shallow and deep monitoring well pairs were installed at ST 005 to help assess the degree of vertical hydraulic communication at the site. The data indicate little head difference between the shallow and deep groundwater monitoring wells, suggesting that the two

screen intervals are effectively connected at the site. Water level data are generally consistent for the wells regardless of the depth of the screened interval. This suggests that groundwater flows within both the silty clay/weathered shale zone and the underlying limestone at the site. However, the chemical data from nested wells reveal that only limited connection exists between the shallow and deep monitoring wells. This is confirmed by the fact that TCE concentrations in the deep wells generally are lower than those in the shallow wells.

In general, groundwater flows to the southeast at an estimated hydraulic gradient of 0.085 ft/ft. Aquifer tests were conducted at the site in July 2000 to investigate the degree of hydraulic communication at the site. Based on aquifer testing results, flow velocities in the shallow silty clay zone appear to be approximately 0.00058 ft/day, or less than 1 foot per year. Groundwater flow velocities in the limestone are estimated to be 0.019 ft/day, or less than 7 feet per year. Figure 3-15 depicts the potentiometric surface at the site.

The RI results showed that TCE is the only chlorinated chemical contaminant exceeding the Tier I Screening Level, and that low concentrations of TCE degradation products below their respective Tier 1 Screening Levels were found in groundwater at the site. Seven wells in the eastern part of the site were found to have TCE at concentrations exceeding Tier 1 Screening Levels. TCE was detected in both shallow and deep wells, supporting the interpretation that a hydraulic connection exists between shallow and deep zones. The groundwater contamination appears to be restricted to a small area, generally north and east of the former POL Yard pump house (i.e., Building 959).

A review of natural attenuation parameter results for groundwater suggests that conditions at ST 005 may not be optimal for groundwater contaminant anaerobic biodegradation. Several TCE degradation products, although below their respective Tier I Screening Levels, were found in groundwater at the site, indicating that very limited degradation has occurred or is occurring. Refer to Appendix C for details.

The RI analytical results were evaluated in a tiered HHRA. Based on the HHRA results, COCs at the site were identified as chlorinated VOCs in groundwater and VOCs and PAHs in soil. Risks calculated for groundwater exceeded the risk thresholds of 1×10^{-5} (carcinogenic) and a hazard index of 1 (noncarcinogenic).

A Tier 1 qualitative ecological risk assessment was conducted for ST 005 according to CALM guidance. The assessment consisted of Phase I and Phase II screening. The results of the evaluation show that potential exposure pathways do not exist on the site.

3.6 ST 011—UST 620A (Formerly CS 004)

ST 011 is a former UST site located in the east-central part of the Base. The site lies at the northwestern corner of Building 620 and is about 400 square feet in area. It is flat and unpaved. The site is not within a floodplain, and no surface water bodies or sediments are present onsite. Figure 3-16 depicts the site layout and the monitoring well network.

Historical records indicate that the UST was installed in 1966. The exact size of the UST cannot be determined because of conflicting documentation. Historical records suggest that the UST capacity was either 260 gallons or 550 gallons (Dames & Moore, 1996b). The UST was used between 1966 and 1988 to receive waste liquids from the adjacent Air Force fuel testing laboratories. As part of a 1988 Air Force project, the UST was removed. Soil sample analytical results indicated the presence of TPH constituents in the soil that surrounded the

UST. In response to the residual soil contamination, about 50 cubic yards of soil were removed from ST 011 in 1995 (Dames & Moore, 1996b).

During the 1999 Basewide RI, three groundwater monitoring wells were installed, and three groundwater samples and five soil samples were analyzed for TPH, VOCs, SVOCs, and metals. Preliminary results of the 1999 investigation revealed the presence of chlorinated VOCs in groundwater.

To delineate groundwater impacts, 13 additional monitoring wells were installed and 3 soil samples were retained for VOC analyses. Each well in the monitoring well network was sampled for VOCs between May and August 2000. Select groundwater samples also were analyzed for natural attenuation parameters. Based on data available at the time, it appeared that chemical constituents were sufficiently delineated at ST 011. This interpretation has been supported by the results of the QGM program. The area with groundwater contamination is approximately 0.2 acre.

Borings at ST 011 penetrated roughly 16 feet of low to medium plastic silty clays and weathered shale underlain by 3 to 5 feet of limestone, most likely the Raytown Limestone Member of the Iola Formation. Chanute Shale was observed beneath the limestone layer. Groundwater appears to flow through both silty clay/weathered shale transition zone and limestone at the site. The hydraulic gradient at the site is estimated to be 0.014 ft/ft. Figure 3-17 depicts the geology of the site.

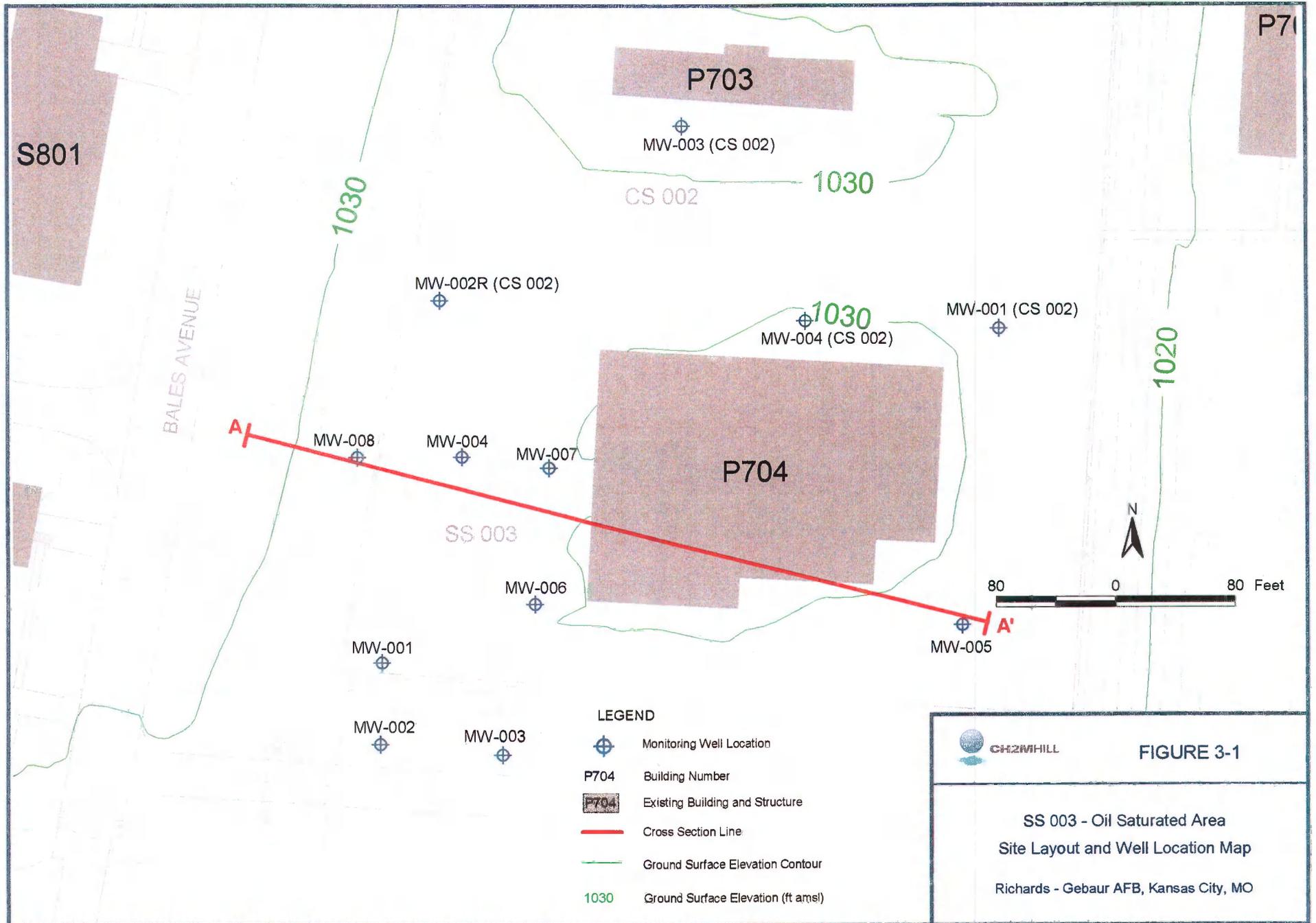
Because chemical constituents in groundwater at ST 011 were measured at concentrations exceeding Tier 1 Screening Levels, aquifer tests were conducted at the site in July 2000. Based on aquifer test data, flow velocities in the silty clay appear to range from 0.0044 ft/day to 0.014 ft/day, or less than 6 feet per year. In contrast, groundwater velocity is estimated at 0.42 ft/day in the limestone, or about 150 feet per year. This latter result likely reflects local fracture-flow conditions. Figure 3-18 shows the potentiometric surface at the site.

Sampling results from the 1999–2000 Basewide RI indicated that five wells had detections of VOCs at concentrations above Tier 1 Screening Levels: TCE was detected once at a concentration exceeding its Tier 1 Screening Level; cis-1,2-DCE exceeded its Tier 1 Screening Level on three occasions, and vinyl chloride exceeded its Tier 1 Screening Level four times. The VOCs were detected in both shallow and deep wells, suggesting a vertical hydraulic connection between shallow and deep zones. The contamination extends northwest of Building 620.

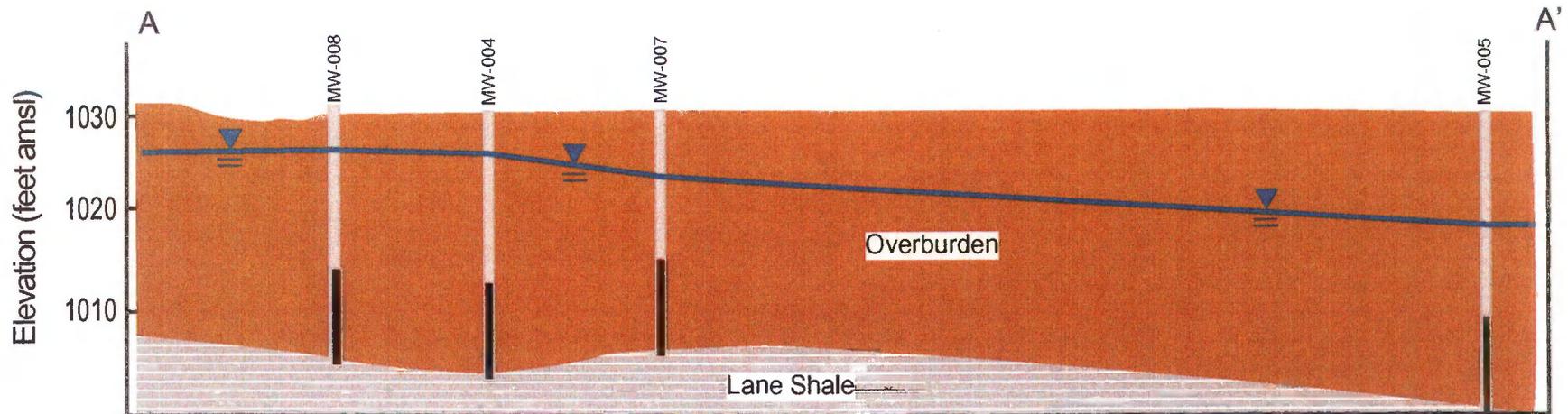
Natural attenuation parameters suggest that conditions at ST 011 may not be optimal for anaerobic biodegradation. However, the presence of degradation products indicates that limited degradation has occurred at the site in the past. Refer to Appendix C for details.

Analytical results were evaluated in a tiered HHRA. COCs at the site were identified as chlorinated VOCs in groundwater. COCs were not identified in soil. Calculated risks in groundwater were higher than established risk thresholds of 1×10^{-5} (carcinogenic) and of a hazard index of 1 (noncarcinogenic).

A Tier 1 qualitative ecological exposure assessment was conducted for ST 011 according to CALM guidance. The assessment consisted of Phase I screening. Ecological risks were found to be insignificant because there are no ecological receptors or habitats at ST 011.



E042002007MKE E163673.02.11.03 Figure 5 ss003 (1# 5-9-02.m)l



LEGEND

-  Groundwater Table (October 2001)
-  Well Screen Interval

amsl Above Mean Sea Level

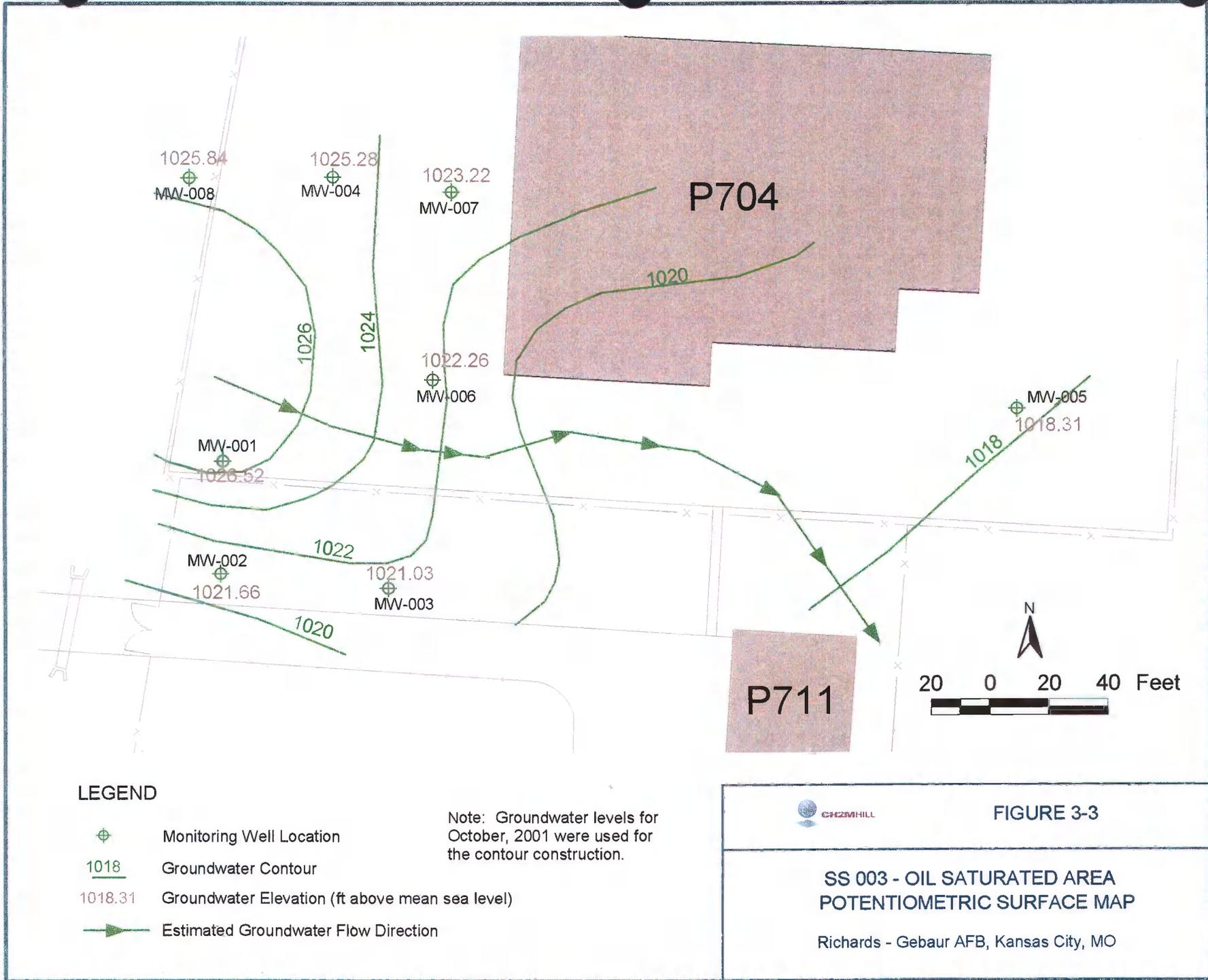
NOT TO SCALE HORIZONTALLY

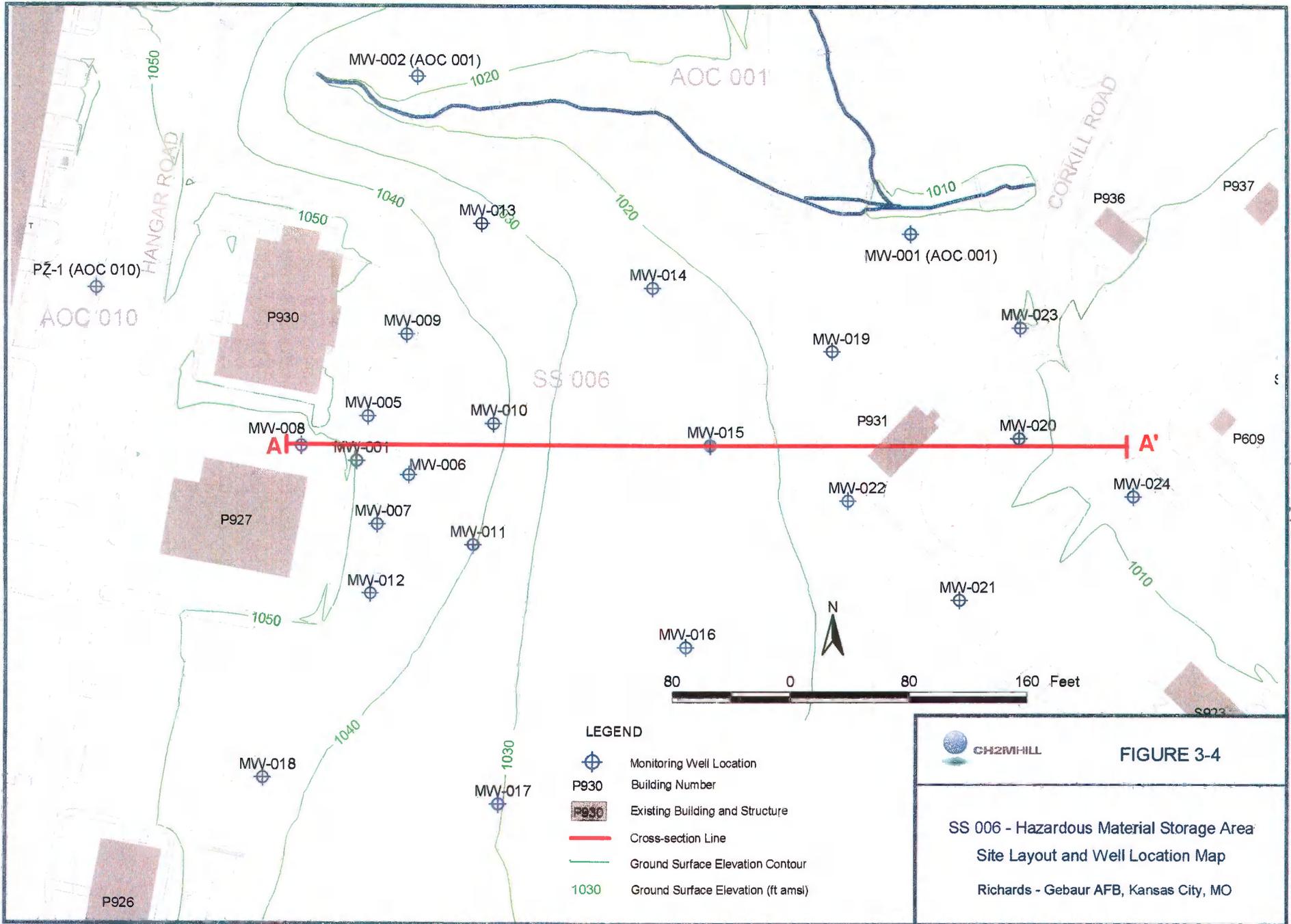


FIGURE 3-2

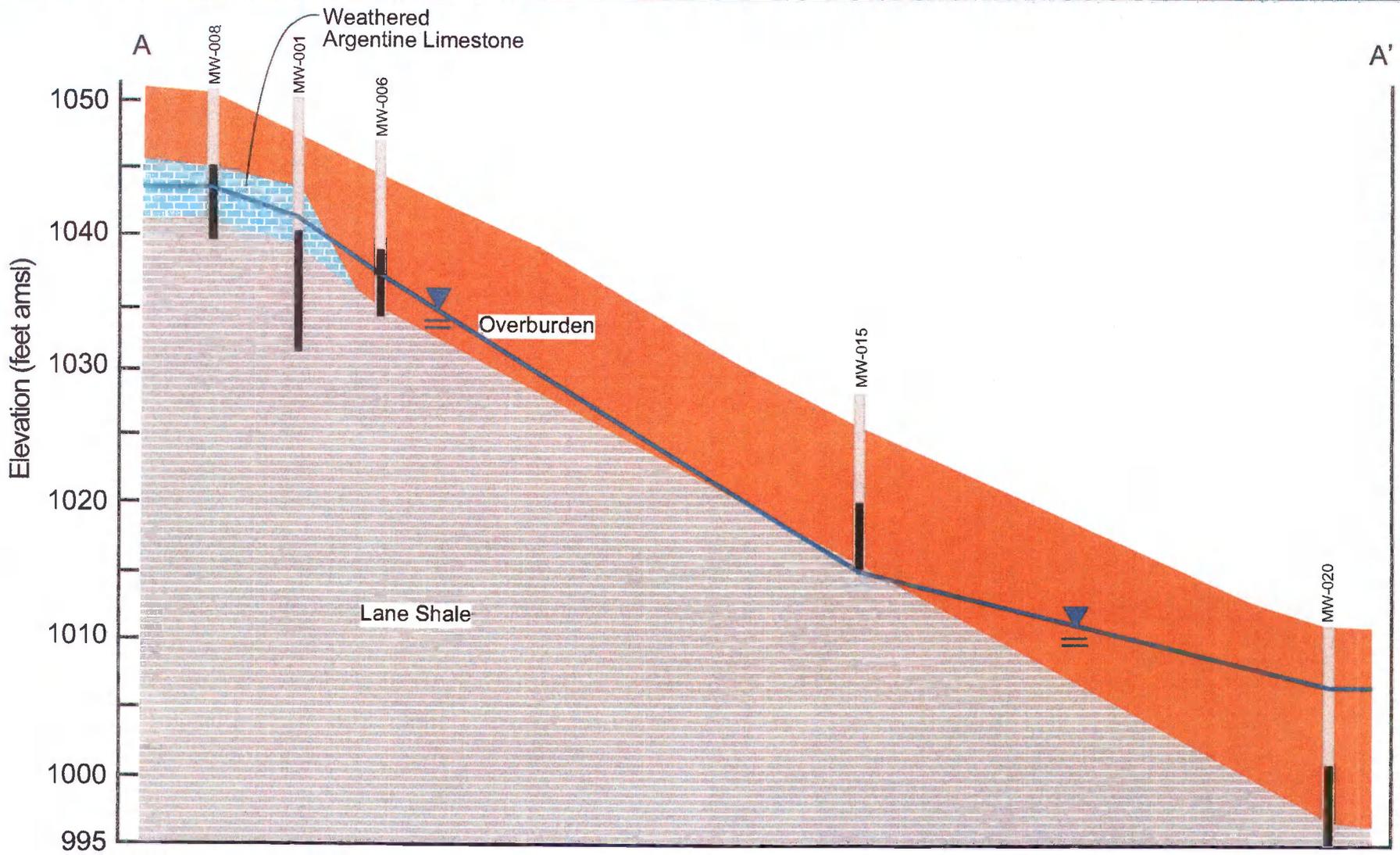
**SS 003 - Oil Saturated Area
Geologic Cross-Section A-A'**

Richards - Gebaur AFB
Kansas City, MO





ES:2002007MKE_E042002007MKE_SS006_CrossSectionA_A_5-8-02



LEGEND

Groundwater Table (October 2001)

Well Screen Interval

amsl Above Mean Sea Level

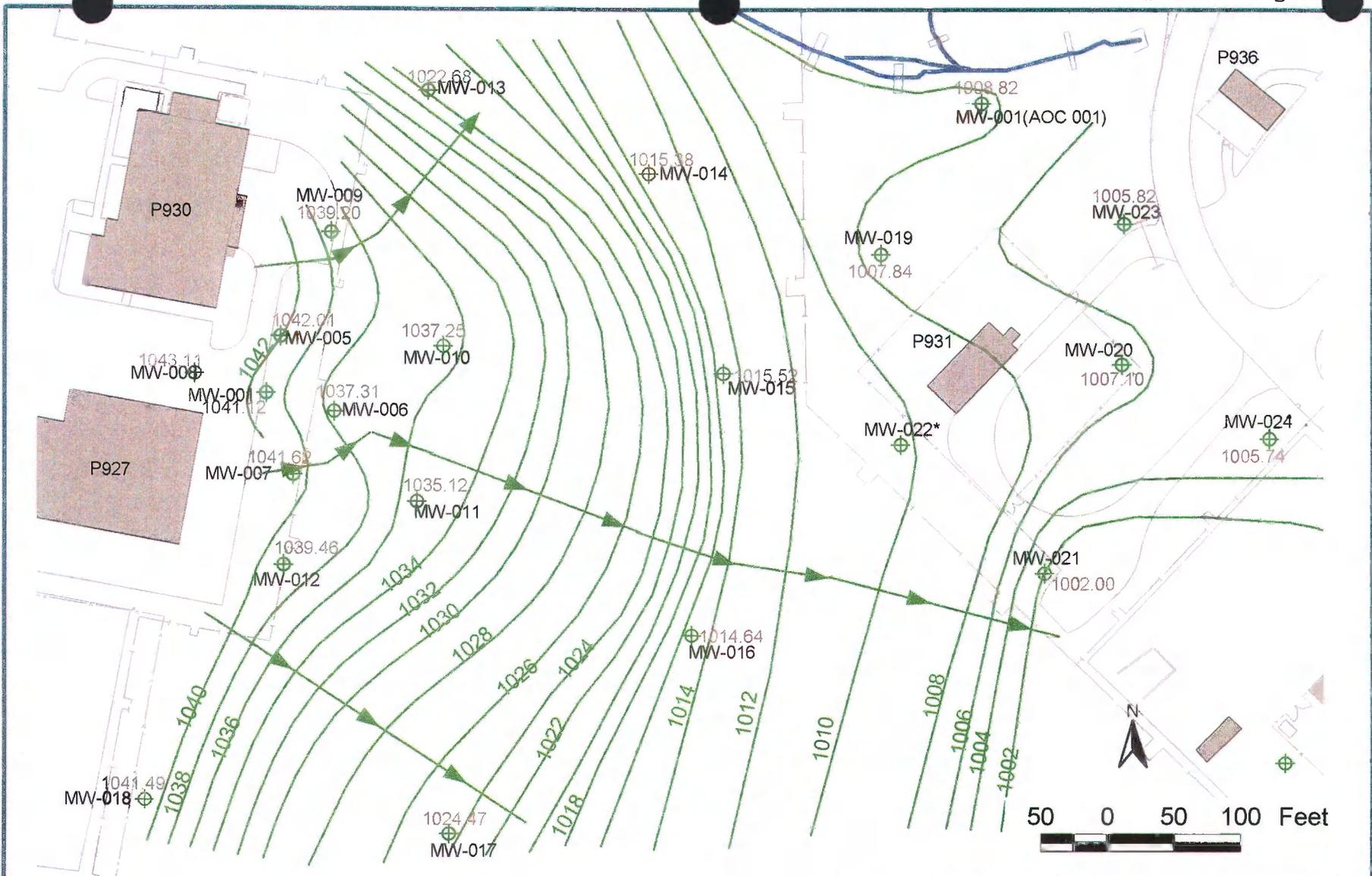
NOT TO SCALE HORIZONTALLY



FIGURE 3-5

**SS 006 - Hazardous Material
Storage Area
Geologic Cross-Section A-A'**

Richards - Gebaur AFB
Kansas City, MO



LEGEND

-  Monitoring Well Location
-  980 Groundwater Contour
-  1045.02 Groundwater Elevation (ft above mean seal level)
-  Estimated Groundwater Flow Direction
-  * Dry Well

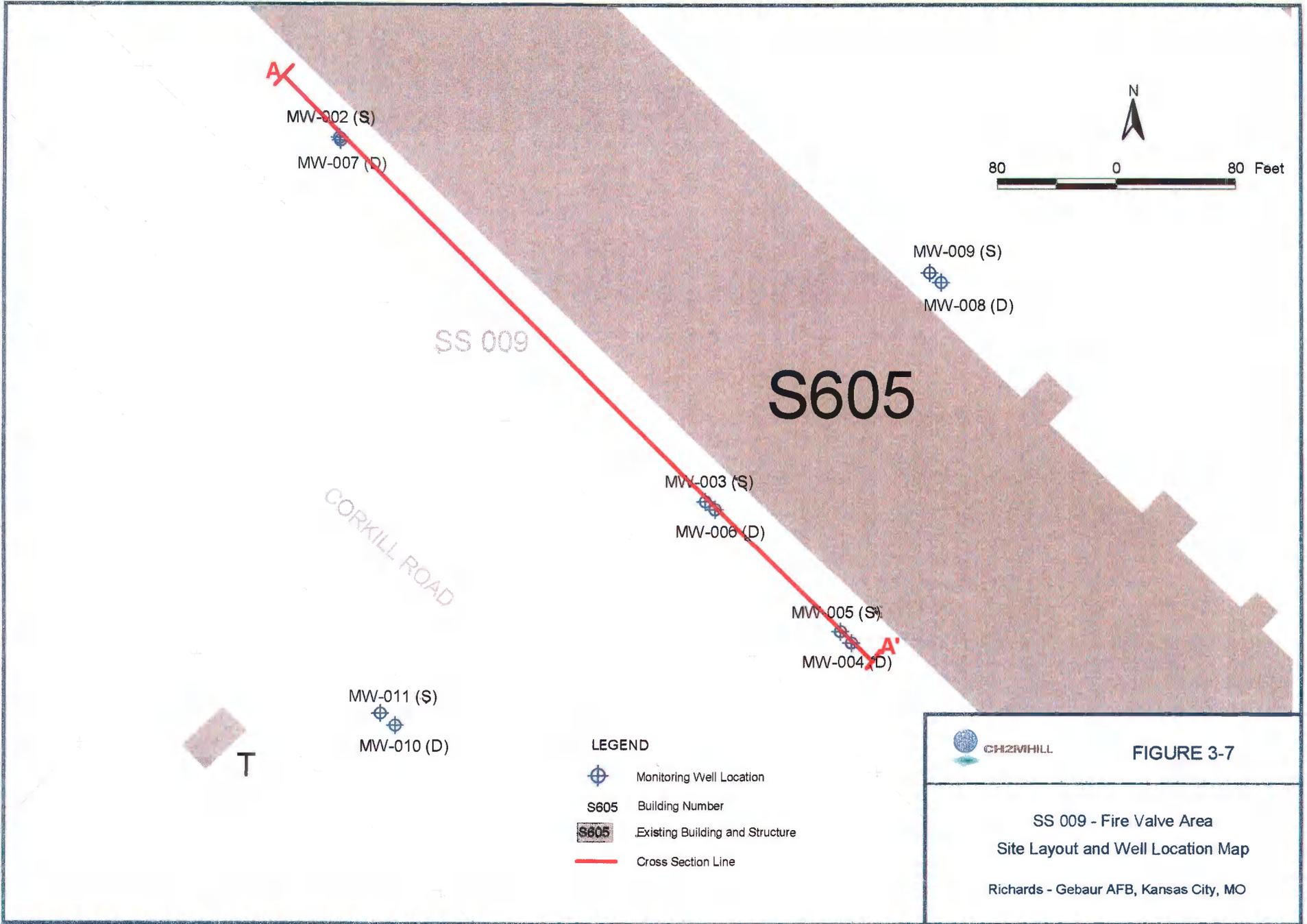
Note: Groundwater levels for October, 2001 were used for the contour construction.



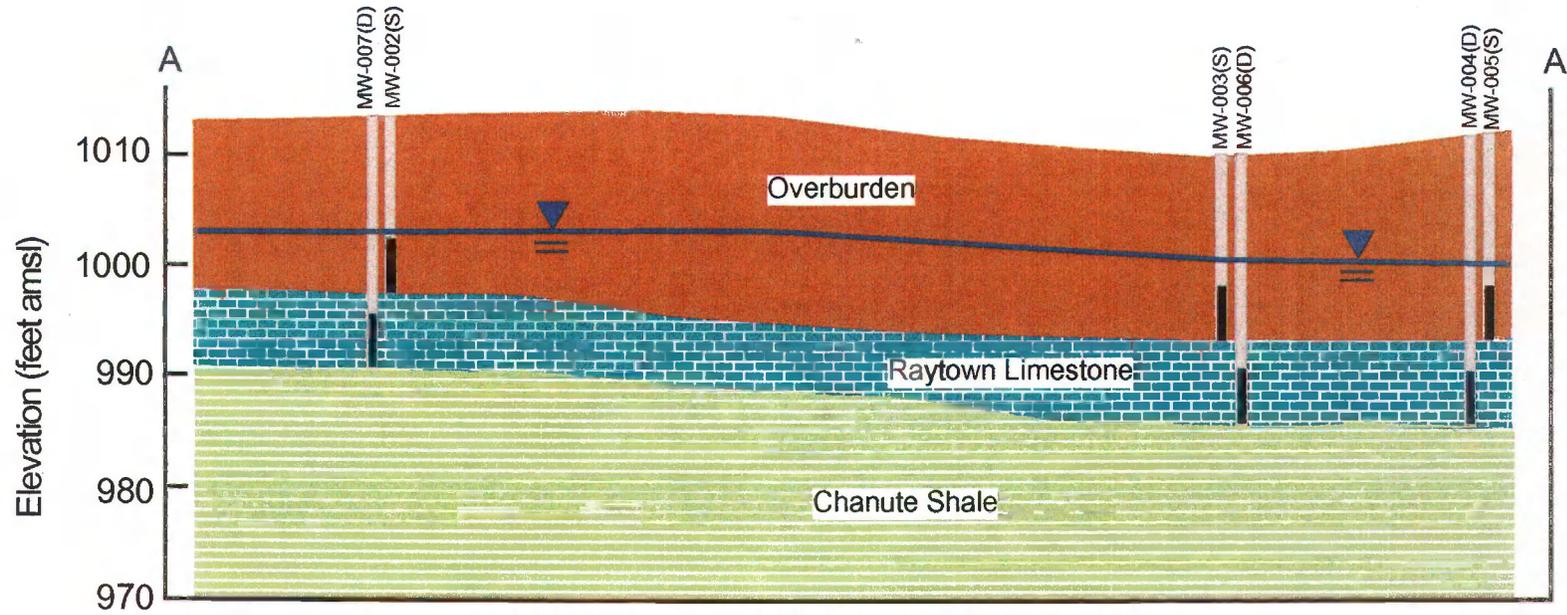
FIGURE 3-6

**SS 006 - HAZARDOUS MATERIAL STORAGE AREA
POTENTIOMETRIC SURFACE MAP**

Richards - Gebaur AFB, Kansas City, MO



EQ:200207MKE E163673.02 11.03 Figure 5-ss09.06 5.8.02.mpl



LEGEND

 Groundwater Table (October 2001)

 Well Screen Interval

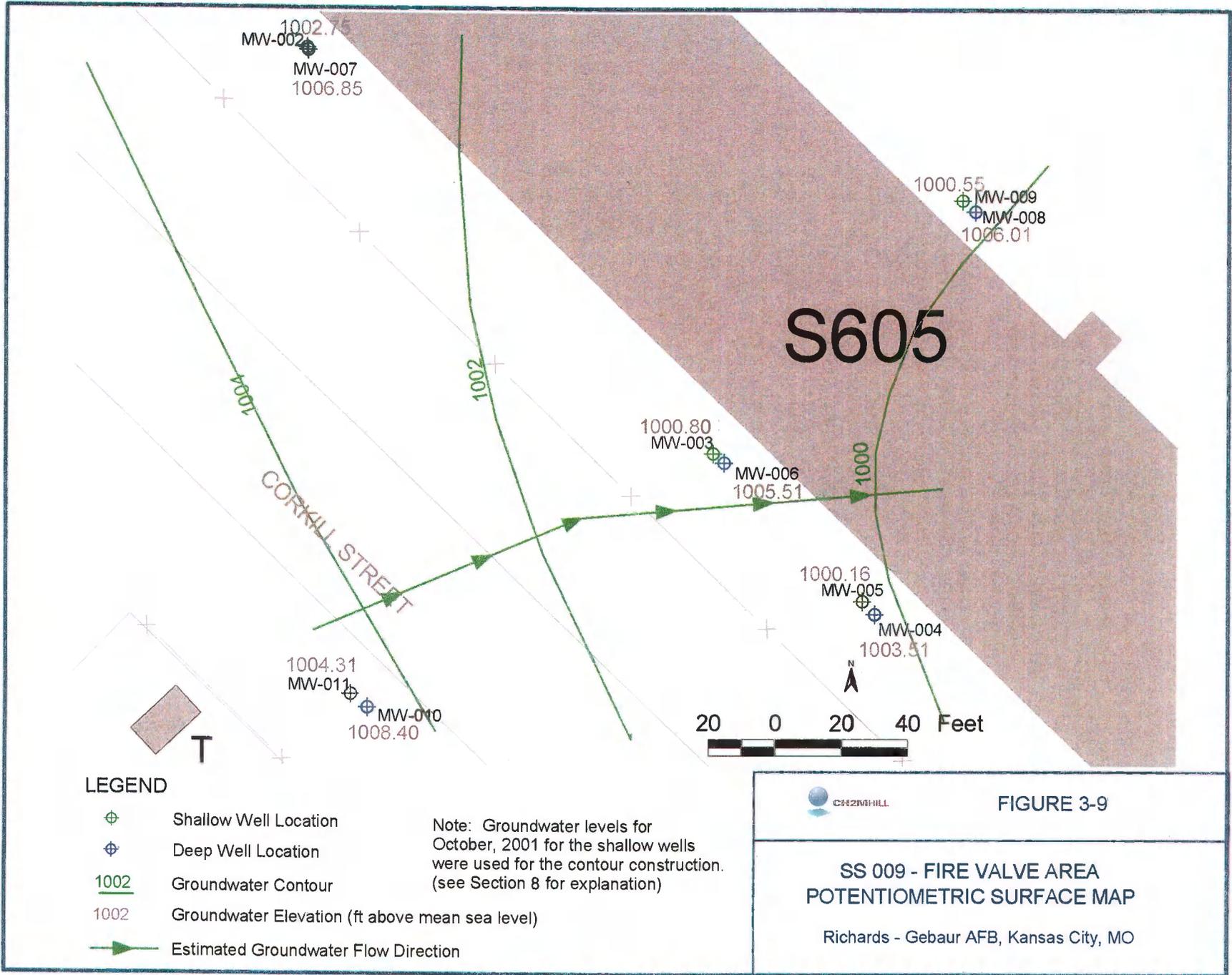
amsl Above Mean Sea Level

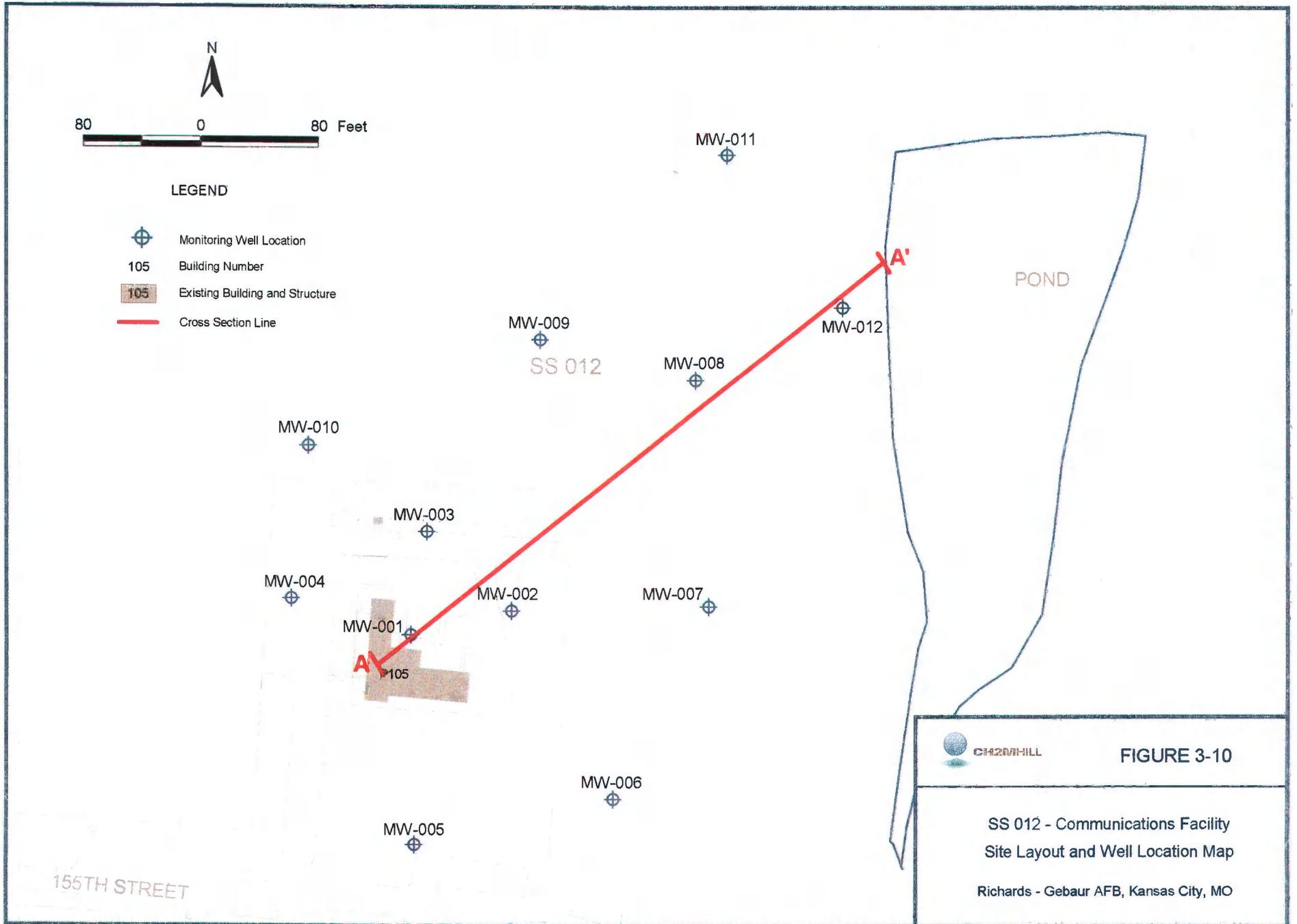
NOT TO SCALE HORIZONTALLY



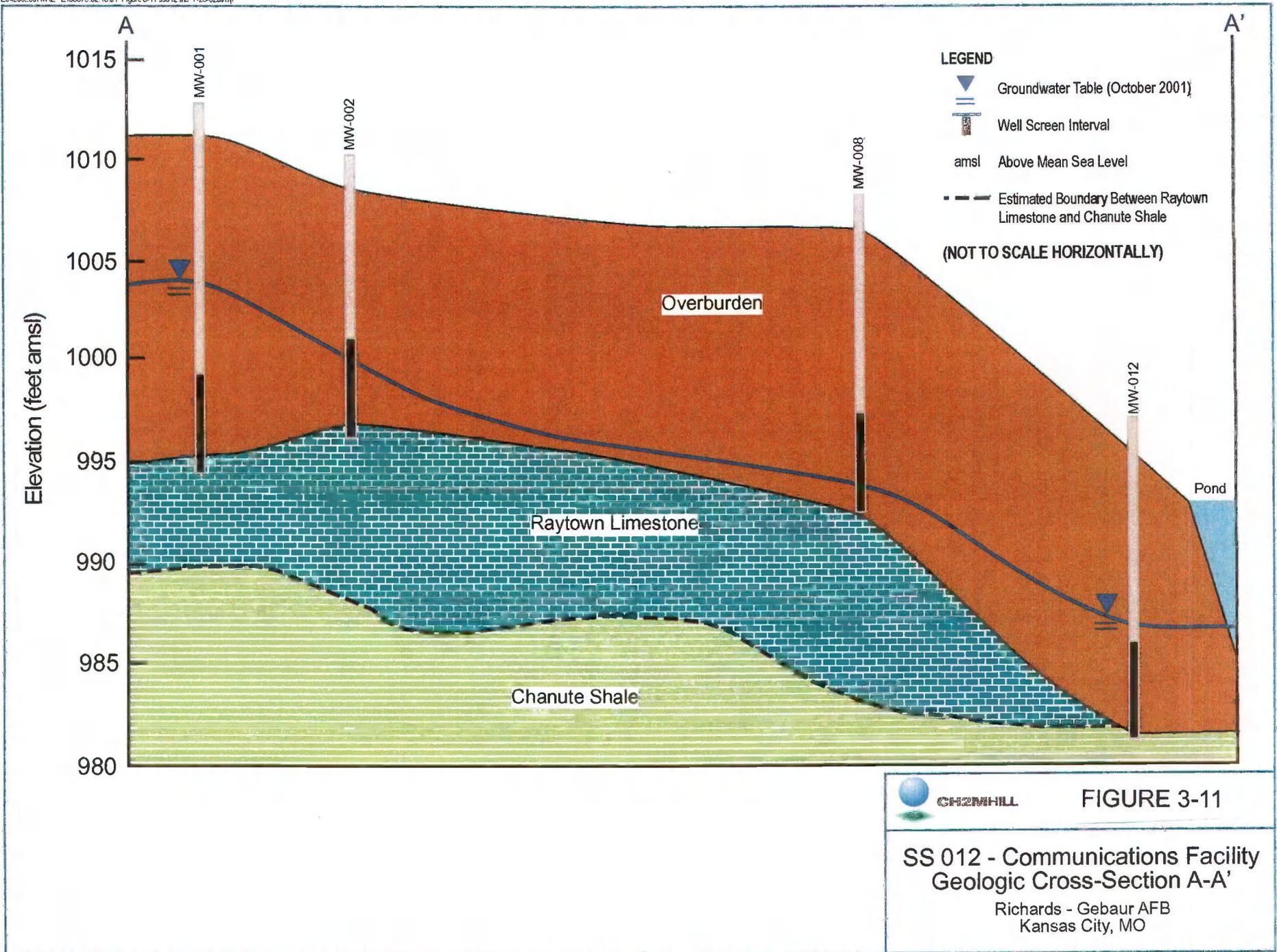
FIGURE 3-8

SS 009 - Fire Valve Area
Geologic Cross-Section A-A'
Richards - Gebaur AFB
Kansas City, MO





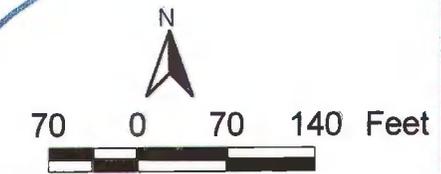
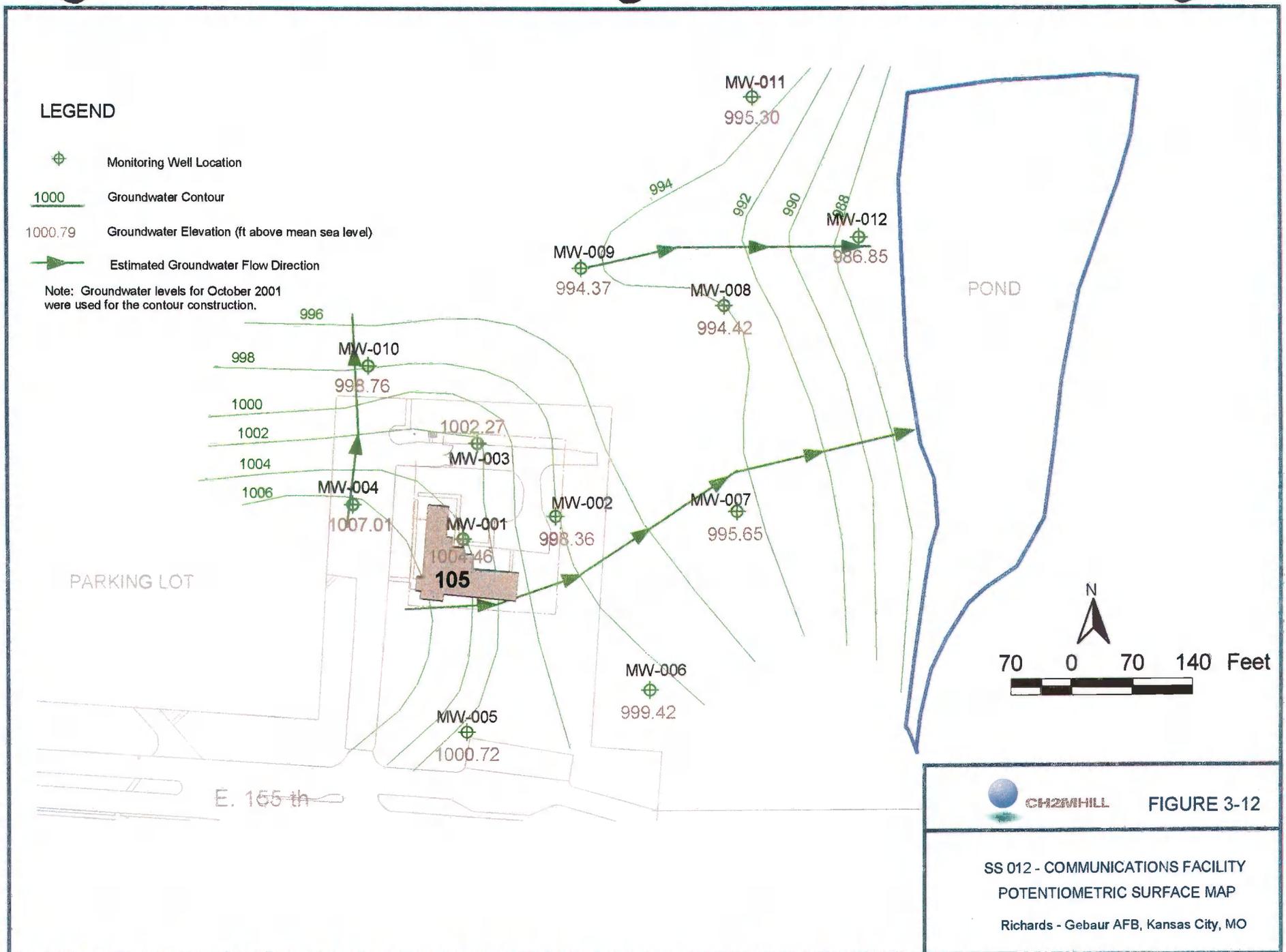
E042002007MKE E153673 02 16 01 Figure 3-11 ss012.tif 7-23-02a/rj



LEGEND

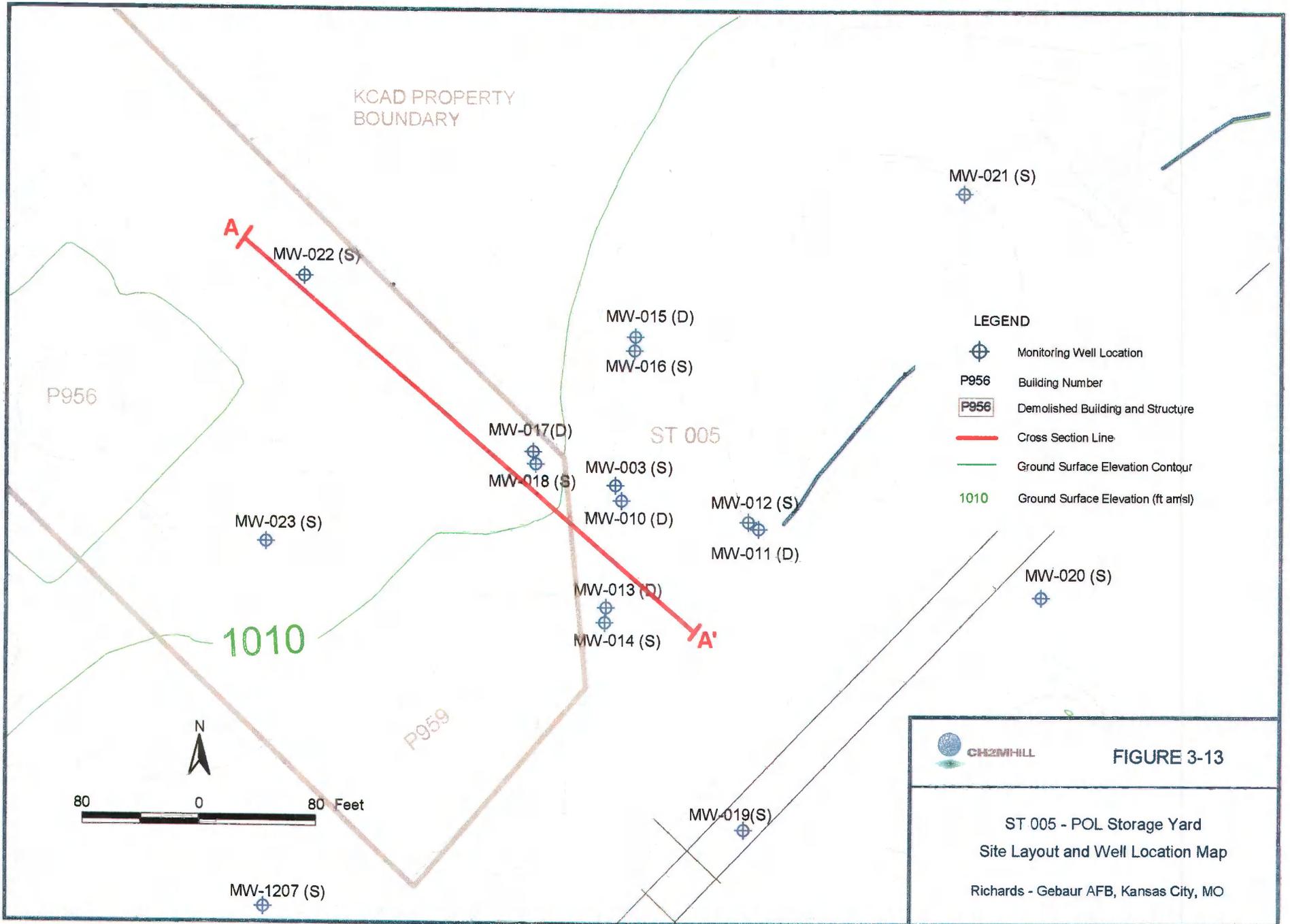
-  Monitoring Well Location
-  1000 Groundwater Contour
- 1000.79 Groundwater Elevation (ft above mean sea level)
-  Estimated Groundwater Flow Direction

Note: Groundwater levels for October 2001 were used for the contour construction.

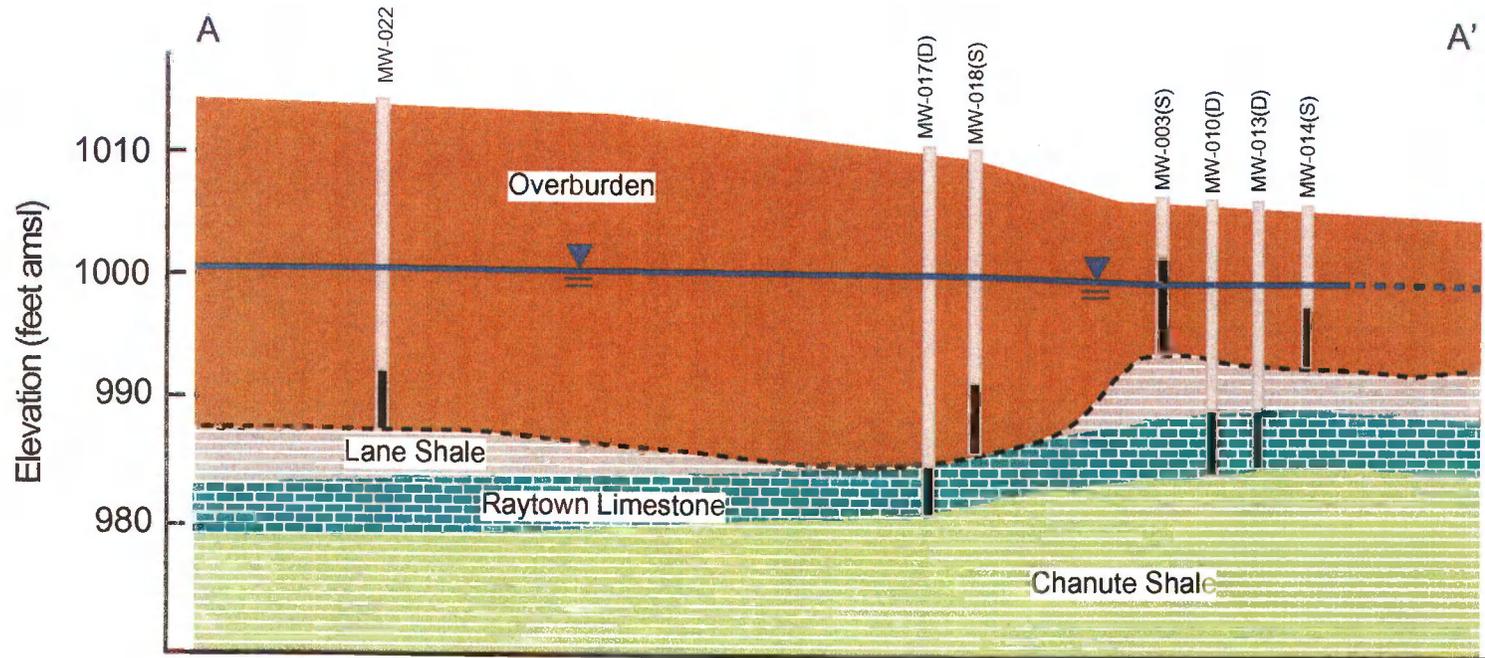


 CH2MHILL **FIGURE 3-12**

SS 012 - COMMUNICATIONS FACILITY
 POTENTIOMETRIC SURFACE MAP
 Richards - Gebaur AFB, Kansas City, MO



E042002007MKE E163673.02.11.03 Figure 5 s1005 5-8-02.mj



LEGEND

-  Groundwater Table (October 2001)
-  Well Screen Interval
- amsl Above Mean Sea Level
-  Estimated Boundary between Weathered Formation and Consolidated Formation

NOT TO SCALE HORIZONTALLY



FIGURE 3-14

**ST 005 - POL Storage Yard
Geologic Cross-Section A-A'**

Richards - Gebaur AFB
Kansas City, MO



LEGEND

-  Shallow Well Location
-  Deep Well Location
-  1000 Groundwater Contour
-  1001.41 Groundwater Elevation (ft above mean sea level)
-  Estimated Groundwater Flow Direction

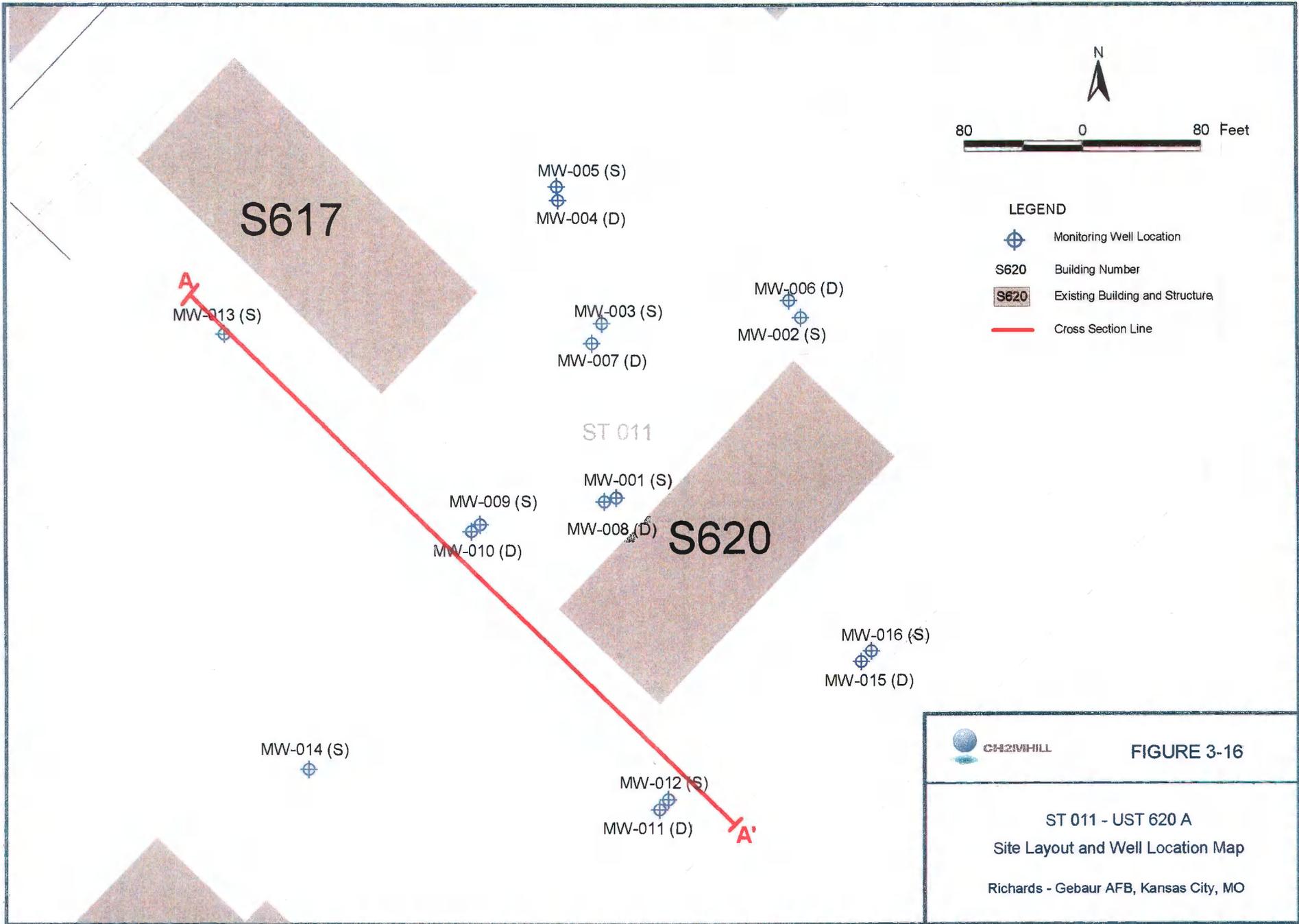
Note: Groundwater levels for October, 2001 were used for the contour construction.

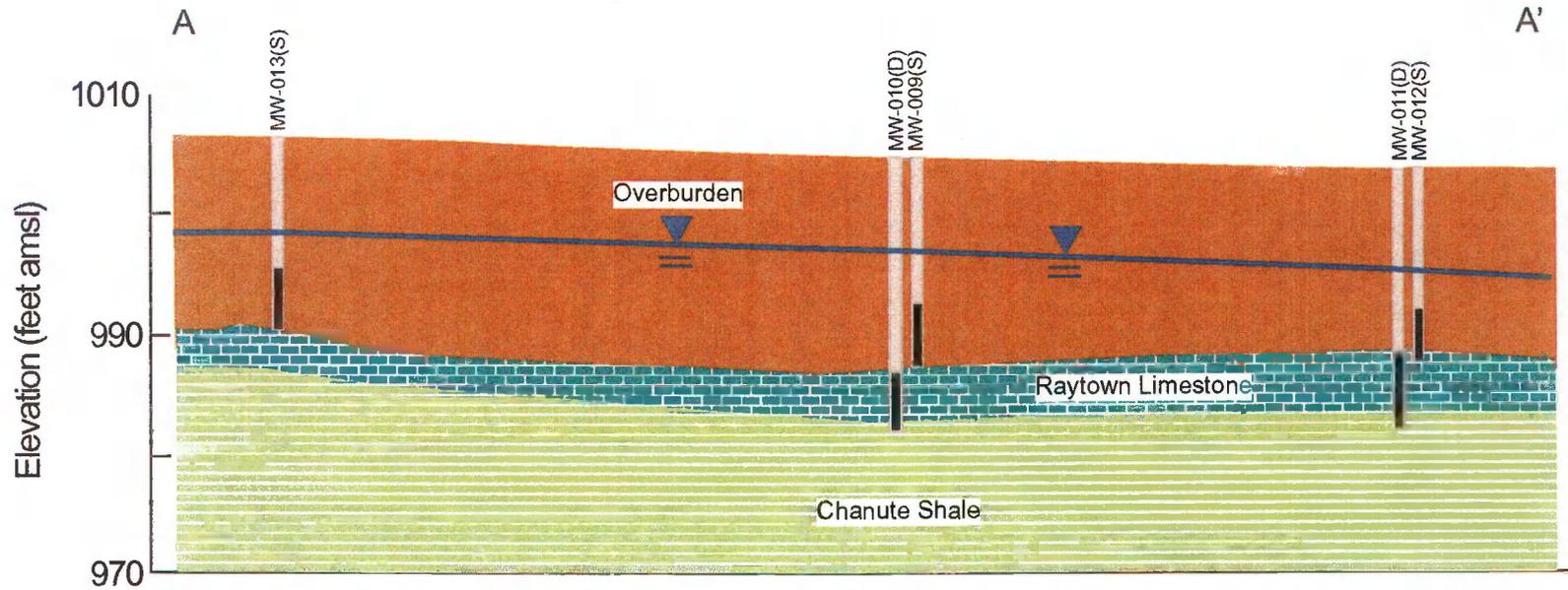


FIGURE 3-15

**ST 005 - POL STORAGE YARD
POTENTIOMETRIC SURFACE MAP**

Richards - Gebaur AFB, Kansas City, MO





LEGEND

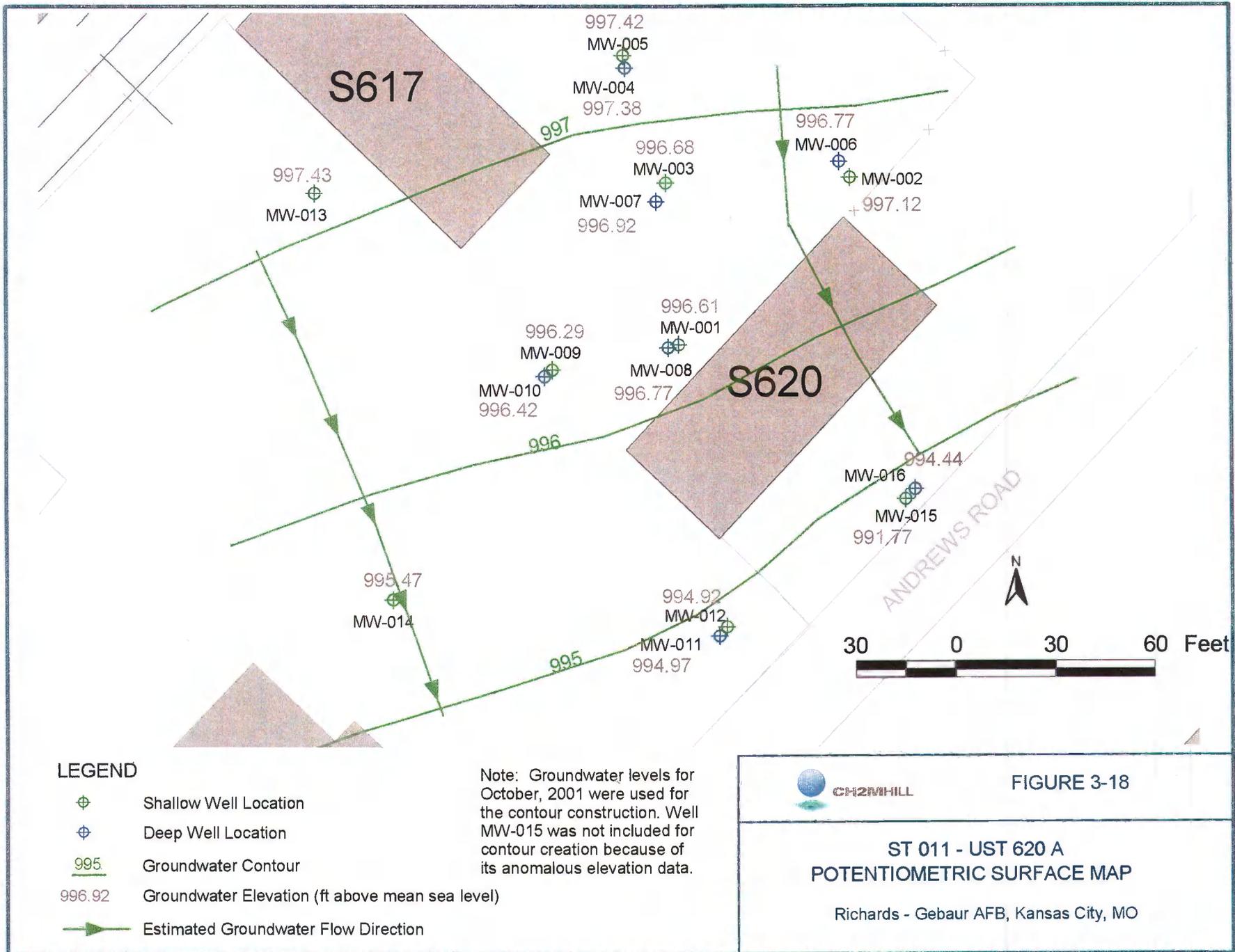
-  Groundwater Table (October 2001)
-  Well Screen Interval

amsl Above Mean Sea Level

NOT TO SCALE HORIZONTALLY

 **CH2M HILL** **FIGURE 3-17**

ST 011 - UST 620A
Geologic Cross-Section A-A'
 Richards - Gebaur AFB
 Kansas City, MO



4. Nature and Extent of Contamination

This section presents an overview of the nature and extent of contaminants in groundwater at Richards-Gebaur AFB. It includes a summary discussion of estimated site risk associated with potential human health and ecological exposure to contaminated groundwater. The following discussion is based mainly on the data gathered during the 1999–2000 Basewide RI and the 2001 RI Addendum. The RI data were compared to RI-specific Tier 1 Screening Levels, consistent with the approach agreed to by the BCT.

The primary sources for groundwater Tier 1 Screening Levels were federal Maximum Contaminant Levels (MCLs) for groundwater. In cases where MCLs were not available, USEPA Region 9 PRGs for drinking water were used as the screening levels. In addition, background concentrations for selected inorganics (metals) also were used, where appropriate. These screening levels provide a conservative evaluation of the potential risk associated with chemicals in groundwater. For further details on the use and derivation of Tier 1 Screening Levels refer to Section 5 of the Basewide RI Report (CH2M HILL, 2001a).

For the purpose of the Basewide RI/FS, chemical concentrations in groundwater were compared with Tier 1 Screening Levels to identify chemical of potential concern (COPC). If the maximum concentration of a chemical detected at a site was less than its respective screening level, then that chemical was removed as a COPC; if higher, it was designated a COC and evaluated further in the risk assessment.

4.1 Identification of COCs

Metals and VOCs were found in groundwater at Richards-Gebaur AFB at concentrations exceeding their corresponding Tier 1 Screening Levels. Therefore, these two groups of chemicals initially were retained during the RI as COPCs for groundwater.

Although exceeding their corresponding Tier 1 Screening Levels, metals were eliminated as COCs in groundwater. The removal of metals as COCs was based on the background data evaluation approach described in the USEPA's *Risk Assessment Guidance for Superfund* (USEPA, 1989). Because the published regional background metal concentrations are ubiquitously high, it is considered likely that the occurrences of metals in groundwater are the result of natural site conditions and unrelated to past site activities (CH2M HILL, 2001a; 2001b; 2001c). A comparison of site groundwater data for metals with background well data for metals showed no significant variation, and metals were dropped from further consideration during the RI/FS. Consequently, VOCs are considered to be the COCs in the groundwater.

The COCs in groundwater consist of chlorinated VOCs such as PCE, TCE, cis-1,2-DCE, 1,1-DCE, and vinyl chloride. TCE, the primary COC, was common in the groundwater at each FS site. Cis-1,2-DCE and vinyl chloride are also present in groundwater beneath most of the FS sites at concentrations exceeding the Tier 1 Screening Levels. PCE and 1,1-DCE were detected at elevated concentrations only at site SS 009.

4.2 Occurrence of COCs in Groundwater

The occurrence of COCs in groundwater at each FS site is presented as follows. Site-specific figures depicting the distribution of VOCs in groundwater have been constructed to estimate the lateral extent of groundwater contamination. For consistency, the October 2001 QGM data were used to represent typical groundwater conditions at each site. In addition to the VOC distribution maps, historical trends of VOC concentrations in groundwater (derived from the entire QGM database) are provided to illustrate the stability of the contaminant plumes.

4.2.1 SS 003—Oil Saturated Area

Eight wells were installed at SS 003. Sampling results from the RI indicated that TCE was detected at concentrations exceeding its Tier 1 Screening Level in wells MW-004, MW-006, MW-007, and MW-008. The VOCs cis-1,2-DCE and vinyl chloride were not detected at the site at concentrations exceeding applicable Tier 1 Screening Levels. The highest concentrations of TCE consistently have occurred in well MW-004. The contamination is limited to a small area west of Building 704.

Figure 4-1 presents the October 2001 QGM analytical results. The highest TCE concentration occurred in well MW-004. Based on Figure 4-2, a plume map contouring TCE concentrations, it appears that TCE plume at the site remains stable. The extent of groundwater contamination at the site is sufficiently delineated. Furthermore, because of the very low groundwater flow velocities at the site (see Section 2), the potential for future downgradient transport is low.

The 1999–2000 RI results and the data collected from the six QGMs for select wells are presented in Figure 4-3 to evaluate the temporal trends of COC concentrations in groundwater at the site. TCE concentrations in MW-004 varied between June 2000 and October 2001, but appeared to stabilize between October 2001 (55.2 ppb) and January 2002 (56 ppb). In addition, MW-008, which is upgradient of the contaminant plume, occasionally exhibits concentrations of TCE exceeding its Tier 1 Screening Level. Note that TCE concentration in well MW-008, which was 5.2 ppb during the 1999–2000 Basewide RI, was less than the Tier 1 Screening Level of 5 ppb during October 2001. The TCE concentration in MW-006 peaked at 16.9 ppb in October 2000 and then decreased to 8.9 ppb in July 2001. The TCE concentration has fluctuated between 5 and 10 ppb since July 2001. TCE concentrations in MW-007 and MW-008 have increased slightly from the October 2001 QGM values.

4.2.2 SS 006—Hazardous Materials Storage Area

At SS 006, 24 wells were installed during the 1999–2000 Basewide RI and the subsequent 2001 RI Addendum. Sampling results from the Basewide RI showed that TCE was detected at concentrations exceeding its Tier 1 Screening Level in nine wells. Cis-1,2-DCE was detected above its Tier 1 Screening Level four times, and vinyl chloride was detected above its Tier 1 Screening Level six times. The contamination extends hydraulically downgradient, east of the site and, to a lesser extent, south of the site.

During the October 2000 QGM, four perimeter wells that previously had been dry for almost 1 year since installation (MW-013 through MW-016) produced water for the first time and thus were sampled. Following the October 2000 sampling, TCE was found to be present in

MW-015 at a concentration exceeding its Tier 1 Screening Level of 5 ppb. However, no VOCs were detected in the other three perimeter wells.

During the January 2001 QGM, two of the perimeter wells found to be free of TCE in October 2000 (MW-013 and MW-014) also showed TCE concentrations exceeding the 5 ppb Tier 1 Screening Level. Consequently, to further delineate the VOC impacts at the site, six more monitoring wells were installed at SS 006 in two separate phases of fieldwork conducted between February and October 2001. The six wells are designated MW-019 through MW-024. The wells were positioned in and around the perimeter fence surrounding Facility 931, a former liquid oxygen storage area. Facility 931 lies roughly 600 feet to the east of the hazardous material storage area behind Facility 927.

COCs were not detected at concentrations exceeding the Tier 1 Screening Level of 5 ppb in five of the six new wells. However, well MW-020, located adjacent to Facility 931, exhibited the highest concentration of TCE at the site (930 ppb). It is likely, therefore, that the area surrounding MW-020 (adjacent to Facility 931, a former Liquid Oxygen Storage Area) represents an isolated hotspot unrelated to the main area of groundwater contamination that appears to stem from Building 927.

Figure 4-4 presents the October 2001 QGM analytical results. Figures 4-5A, 4-5B, and 4-5C are plume maps contouring COC concentrations. Based on the plume maps, it appears that the area of the plume at higher ground elevation near the former storage unit slightly expanded toward the east since the Basewide RI. However, because of the very low groundwater flow velocities at the site (see Section 2), the potential for future further downgradient transport is low.

The 1999–2000 RI results and the data collected from the six QGMs for select wells are presented in Figure 4-6 to evaluate the temporal trends of COC concentrations in groundwater. In general, the concentrations of COCs appear consistent over time. In conclusion, the monitoring well network at SS 006 adequately delineates the extent of VOCs in groundwater at the site.

4.2.3 SS 009—Fire Valve Area

Ten wells were installed at SS 009. Sampling results from the Basewide RI showed that VOCs were detected in two wells: TCE and cis-1,2-DCE each were detected at a concentration exceeding its Tier 1 Screening Level once; and vinyl chloride exceeded its Tier 1 Screening Level twice. PCE and 1,1-DCE also exceeded Tier 1 Screening Levels in MW-003. The VOCs were detected only in shallow wells MW-003 and MW-009, indicating a lack of connection between the shallow and deep wells.

This result is consistent with the geology of SS 009: the deep wells are screened at the bottom of the Raytown Member, which is a massive, hard, crystalline rock that is not susceptible to solution weathering (as opposed to the Argentine Member, which crops out at higher elevations on the Base) and therefore can act as an aquitard.

Figure 4-7 presents the October 2001 analytical results. Figures 4-8A, 4-8B, and 4-8C are plume maps contouring select COC concentrations. Based on the plume maps, it appears that the TCE plume at the site remains stable. The extent of groundwater contamination at the site is sufficiently delineated. Furthermore, because of the very low groundwater flow velocities at the site (see Section 2), the potential for future downgradient transport is low.

Sampling results from the RI and subsequent QGMs for select wells are presented in Figure 4-9 to evaluate the temporal trends of COC concentrations in groundwater. In

general, the concentrations of COCs appear consistent over time. Based on the data, the monitoring well network adequately delineates VOCs in the groundwater.

4.2.4 SS 012—Communications Facility at Building 105

Twelve wells were installed at SS 012. The sampling results from the 2001 RI Addendum indicated that TCE and vinyl chloride were found in groundwater samples from SS 012 at concentrations exceeding their corresponding Tier 1 Screening Levels. TCE exceeded its screening level in 6 of the 12 monitoring wells. Vinyl chloride exceeded its screening level only in well MW-001. The highest TCE concentrations consistently have occurred in well MW-002, which is located about 100 feet northeast and hydraulically downgradient of Building 105.

Figure 4-10 shows the analytical data from the October 2001 QGM. Figures 4-11A and 4-11B are plume maps contouring COC concentrations. Sampling results from the 2001 RI Addendum and subsequent QGMs for select wells are presented in Figure 4-12 to evaluate the temporal trends of COC concentrations in the groundwater. Overall, the concentrations of TCE and vinyl chloride in groundwater have been consistent. Based upon the data, the monitoring well network adequately delineates VOCs in the groundwater.

Groundwater at site SS 012 flows radially to the north and east to an unnamed pond east of the site because the site is situated on a topographic high. Therefore, the potential was considered to exist for ecological receptors to be exposed to groundwater contaminants by surface water discharge at the surface water/ground water interface at the pond bank or stream banks. However, the aquatic toxicity of chlorinated VOCs is very low, and concentrations measured in groundwater are well below ecological benchmarks in surface water. Therefore, the groundwater at site SS 012 poses no risks to aquatic organisms.

4.2.5 ST 005—POL Storage Yard

Thirty-one wells were installed at ST 005. The RI results showed TCE as the only chlorinated chemical contaminant: Seven wells contained TCE at concentrations exceeding Tier 1 Screening Levels. Because TCE was detected in both shallow and deep wells, a hydraulic connection appears to exist between shallow and deep zones. The contamination appears to be restricted to a small area north and east of the former POL Yard pump house (i.e., Building 959).

Figure 4-13 presents the analytical results of the October 2001 QGM. A plume map contouring TCE concentrations is shown in Figures 4-14. Based on the plume map, it appears that the area of the TCE plume have slightly expanded toward the east since the Basewide RI. However, because of the very low groundwater flow velocities at the site (see Section 2), the potential for future further downgradient transport is low.

Sampling results from the 1999–2000 Basewide RI and QGMs for select wells are presented in Figure 4-15 to evaluate the temporal trends of COC concentrations in the groundwater. The highest TCE concentration consistently occur at the same well MW-018, which is located at the center of the site. The magnitude of TCE concentrations in well MW-018 are inconsistent, having increased from 226 ppb in June 2000, to 2,080 ppb in July 2001, falling in January 2002 to 2000 ppb. The reason for the concentration fluctuation in this well, however, remains unknown. The TCE concentrations in the remaining wells had been relatively consistent. In conclusion, the monitoring well network at ST 005 adequately delineates VOCs in groundwater at the site.

4.2.6 ST 011—UST 620A (Formerly CS 004)

Sixteen wells were installed at ST 011. Sampling results from the Basewide RI indicated that five wells had detections of VOCs exceeding Tier 1 Screening Levels: TCE was detected once at a concentration exceeding its Tier 1 Screening Level, cis-1,2-DCE on three occasions, and vinyl chloride four times. The VOCs were detected in both shallow and deep wells, suggesting a vertical hydraulic connection between shallow and deep zones. The contamination extends northwest of Building 620.

Figure 4-16 presents the analytical results of the October 2001 QGM. Figures 4-17A and 4-17B are plume maps contouring the COC concentrations. Based on the plume maps, it appears that the plumes at the site remain stable. The extent of groundwater contamination at the site is sufficiently delineated. Furthermore, because of the very low groundwater flow velocities at the site (see Section 2), the potential for future downgradient transport is low.

The results of the Basewide RI and the data collected from the six QGMs for select wells are presented in Figure 4-18 to evaluate the temporal trends of COC concentrations in groundwater at the site. Based on the available monitoring data, the monitoring well network appears to adequately delineate VOCs in groundwater at the site.

4.3 Fate and Transport of COCs in Groundwater

This section briefly describes the environmental fate of chlorinated VOCs. If released to soil, these compounds are expected to be highly mobile based on their low soil organic matter constants (K_{oc}). Volatilization from soil surfaces is expected to be an important transport process based upon relatively high Henry's law constants. Cometabolic biodegradation has been reported in soils and groundwater under aerobic conditions where additional nutrients have been added. Under anaerobic conditions, as might be seen in flooded soils, sediments, or aquifer environments, chlorinated VOCs such as TCE or PCE biodegrade slowly to 1,2-DCE isomers and vinyl chloride by reductive dechlorination. The extent and rate of degradation depends upon the strength of the reducing environment.

Because of the low-flow groundwater conditions that predominate at the Base and the absence of known active contaminant sources, groundwater contamination has not traveled far at most of the sites except for Site SS 012. Based on the groundwater contour map for SS 012, it appears that groundwater flows to the north and to the east into the unnamed pond. However, because of the volatile properties of the COCs, the relatively low concentration of TCE in groundwater near the pond, and the dilution caused by stormwater runoff entering the pond, the potential for exposure to contaminants through surface water and sediment is considered negligible. This conclusion is supported by the consistent results obtained during the QGM program, which indicate that the overall distribution of VOCs in groundwater appears to be stable.

Consequently, the area of contaminated groundwater at each site has remained largely unchanged over the past 2 years. One possible exception is SS 006; however, the monitoring well network at the site was not completed at the time of the RI and needed augmenting as part of the RI Addendum. The expanded monitoring well network has since shown consistent monitoring results in keeping with the other FS sites.

4.4 Summary of Site-Related Risks to Human Health

A preliminary evaluation of human health risks associated with chlorinated VOCs in groundwater was conducted using the assumption that there will be future residential land use at the Base, and thus groundwater could be used as a future drinking water supply. The residential land use assumption was selected because this represents the highest beneficial potential use of groundwater at the Base. Details of the risk assessment methodology are provided in the Basewide RI Report, Section 5 (CH2M HILL, 2001a).

For the purpose of the FS, the RI risk assessment was used for four sites (SS 003, SS 009, ST 005, and ST 011), but it was updated for two other sites (SS 006 and SS 012). This modification was necessary because additional wells were installed at SS 006 to complete contaminant delineation, and because SS 012 was identified as a new FS site that had not been part of the original basewide RI scope.

The conclusions from this evaluation are that estimated risks associated with hypothetical residential use of groundwater would warrant consideration of remedial action, under risk management guidelines used by the state of Missouri. In other words, it should be kept in mind that the calculated risk estimates are conservatively high and likely overestimate actual risk posed by VOCs in site groundwater.

A VOC-to-indoor air exposure scenario was evaluated in the FS to assess the remaining risk from other relevant pathways, if groundwater extraction and use is prohibited through institutional controls. This scenario was evaluated using the Johnson and Ettinger modeling approach recommended by the BCT (USEPA, 2000). Data from the October 2001 QGM program were used to evaluate human health risks through inhalation exposure potentially from migration of VOCs from groundwater to indoor air.

The October 2001 data were selected to represent the current exposure conditions as the data are inclusive of all sites including Site SS 012 and the expanded Site SS 006. Hydrogeological conditions (described in Section 2.5.1) and trends of VOC concentrations in groundwater (presented in Figures 4-3, 4-6, 4-9, 4-12, 4-15, and 4-18) indicate that VOC concentrations in groundwater are unlikely to increase over time. Therefore, the October 2001 data should provide a reasonable evaluation of potential future exposures and risks from VOCs in groundwater. Appendix B contains the supplemental groundwater risk assessment.

4.4.1 Exposure Assessment

Available information indicates that there are unlikely to be potentially complete exposure pathways to VOCs in groundwater for potential future residents. The MDNR's Division of Geology and Land Survey conducted a water well search within 1, 2, and 5 miles of the Base. The search verified that shallow groundwater beneath and near the Base is not commonly used for domestic purposes. The Base and nearby communities of Belton, Pleasant Hill, and Grandview obtain their domestic water supply from the Kansas City Water and Pollution Control Department.

For the purpose of evaluating groundwater remedial alternatives, health risks were conservatively evaluated assuming that shallow groundwater at the Base could be used as a future residential groundwater supply. Potential exposure pathways considered in this evaluation were ingestion of drinking water and inhalation of VOCs emitted from domestic-use water.

Standard default exposure assumptions for residential land use and USEPA-derived toxicity factors (USEPA, 1999) were used to characterize risk associated with groundwater. Analytical results from individual monitoring wells were used to develop exposure point concentrations, based on the assumption that the monitoring wells represent the hypothetical locations of drinking water wells.

As noted, there is the potential for contaminated groundwater to remain in place under some remedial alternatives. These remedial alternatives have evaluated using land use controls for preventing extraction and use of contaminated groundwater (see Section 6 for further discussion of land use controls). However, depending upon the future land uses at the Base, there could be potential inhalation exposures associated with migration of VOCs from groundwater to indoor air.

The inhalation exposure pathway for potential future workers or residents was evaluated in the supplemental groundwater risk assessment, presented in Appendix B.

4.4.2 Quantitative Risk Characterization

Groundwater Ingestion / Inhalation

Under a residential land use scenario that assumes extraction and consumption of groundwater, excess lifetime cancer risks associated with TCE in groundwater were 1×10^{-5} or greater at all six sites. The highest estimated risks were found at SS 006, SS 012, ST 005, and ST 011. Risks higher than 1×10^{-4} were calculated for all four sites. Noncancer hazard indices greater than 1 were found at all six sites. In general, hazard quotients ranged from 2 to 27.

The quantitative results from the risk evaluation indicate that concentrations of VOCs in shallow groundwater are associated with risks consistently higher than state of Missouri guidelines triggering remedial action, when evaluated assuming a future residential use scenario. The risk-based thresholds are an excess lifetime cancer risk of 1×10^{-5} and a noncancer hazard index greater than 1.

While the quantitative risk estimates are based on the highest beneficial use of groundwater (residential use), available survey information indicates that shallow groundwater is unlikely to be used by residents. The conclusions from this evaluation are that estimated risks associated with hypothetical residential use of groundwater would warrant consideration of remedial action under risk management guidelines used by the state of Missouri.

Groundwater Vapor Intrusion

Depending upon the remedial action selected, there may be residual VOC concentrations left in groundwater in the future while land use controls may be used to prevent extraction and consumption of contaminated groundwater. Under certain circumstances, there may be potentially complete exposure pathways from groundwater to future workers or residents by volatilization of VOCs from groundwater to indoor air. Construction workers also could experience inhalation exposures or direct skin contact with VOCs in groundwater that has seeped into excavations.

The health risks potentially associated with these exposure pathways are addressed in the supplemental risk evaluation provided as Appendix B. The supplemental evaluation used standard default exposure assumptions and methods and was based on the analytical results in groundwater collected during the October 2001 QGM program, the most current data at the time of the FS.

The conclusions of the supplemental groundwater risk assessment are that under the assumed commercial/industrial and residential land uses there are no excess lifetime cancer risks or noncancer health effects associated with the presence of VOCs in groundwater that are higher than the regulatory levels of concern (an excess lifetime cancer risk of 1×10^{-5} and a noncancer hazard index of 1).

This conclusion is based on the assumption that the potential pathway of exposure is vapor intrusion to indoor spaces from VOCs in groundwater. Evaluation of site conditions indicates that construction workers are likely to have very little inhalation or dermal contact with contaminated groundwater. Because the risk assessment is based on conservative, health-protective assumptions, actual risks and exposures are likely to be less than the estimated risk and exposures.

4.5 Summary of Site-Related Ecological Risks

Ecological risk posed by groundwater contamination at the six sites was evaluated using a tiered approach consistent with that outlined in the state of Missouri's CALM guidance (MDNR, 2001) and consistent with methodologies previously presented in the RI Report.

Ecological risk assessment is part of the three-tiered CALM process, wherein the cleanup levels indicated by any of the three tiers are intended to provide an equal level of protection for human health and the environment. Evaluation of ecological risk conducted under the CALM process begins within Tier 1 with a qualitative ecological exposure assessment being required for all sites. If it is determined during the qualitative assessment that ecological receptors could be significantly exposed to site contaminants, then a quantitative assessment, conducted in coordination with MDNR, might be required under Tier 2 or Tier 3 of the CALM process.

The ecological risk evaluation is concluded, and there is no need to proceed to an exposure pathway analysis (Phase II), in cases where few or no ecological receptors are present on or adjacent to the site, providing the absence or reduction of receptors cannot be attributed to a release of contaminants. When potential ecological receptors or habitat were found to be present at a given site, the site proceeded to a Phase II evaluation. Phase II was used to determine whether any receptors or habitat present at or adjacent to a site were at potential risk from contact with a contaminant release on or near the site in question.

For five of the six FS sites, no ecological habitats and no receptors were found during the Phase I exposure pathway analyses. At SS 012, potential receptors were identified, and it was necessary to complete a Phase II evaluation. This evaluation included an assessment of the types of habitats on or near the site, and an assessment of the presence of receptors and migration pathways for site contaminants to potentially reach media where ecological receptors could be potentially exposed (e.g., surface water bodies or contaminated surface soils). Based on the Phase II evaluation, a quantitative evaluation of potential VOC exposures to burrowing animals was conducted. The results indicated that unacceptable risks to burrowing animals were not present at the site.

Following the ecological evaluations at each FS site, it was concluded that no unacceptable risks are posed to ecological receptors, if present, by the presence of VOCs in underlying groundwater at any of the six FS sites at the Base.

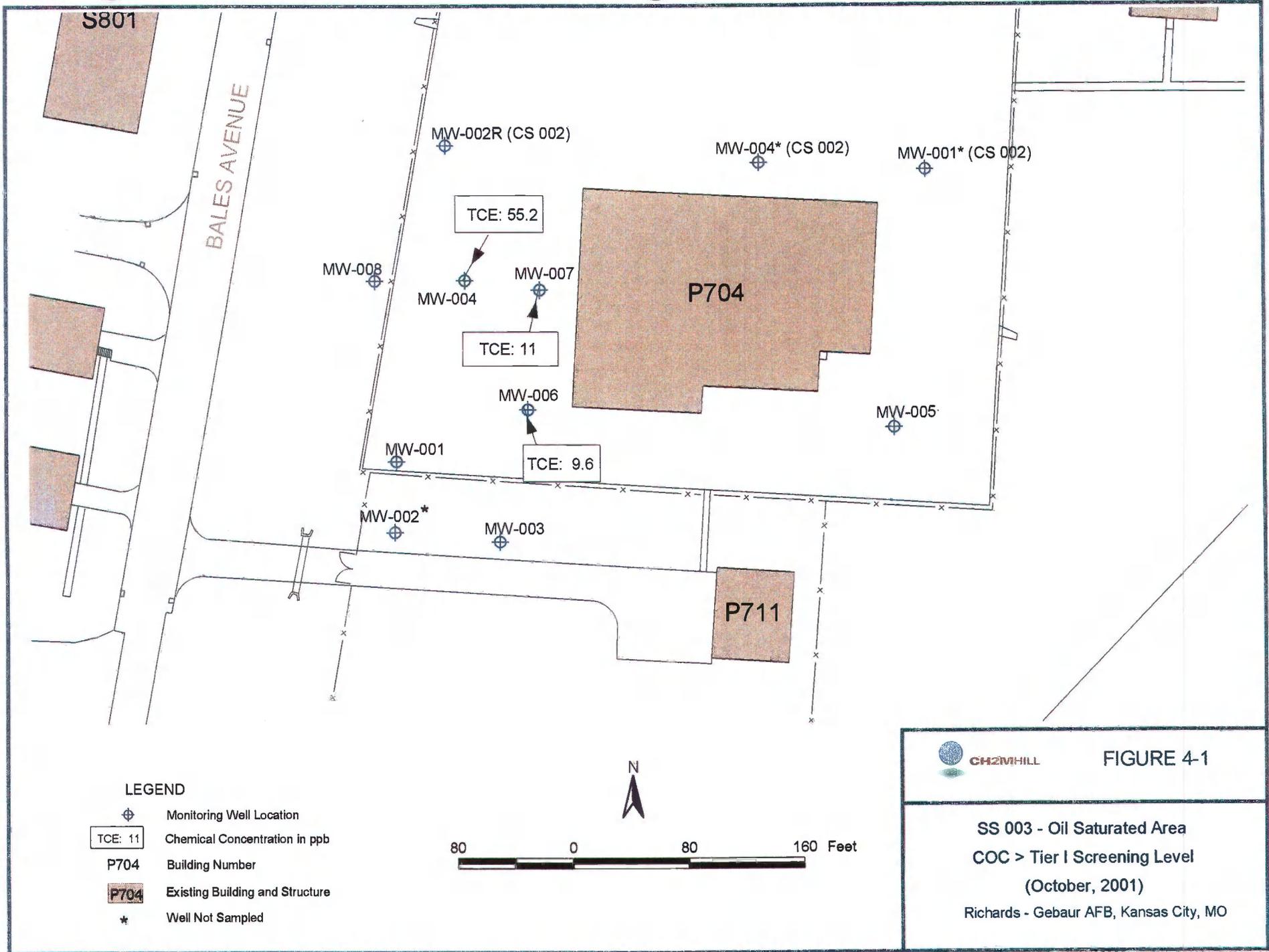
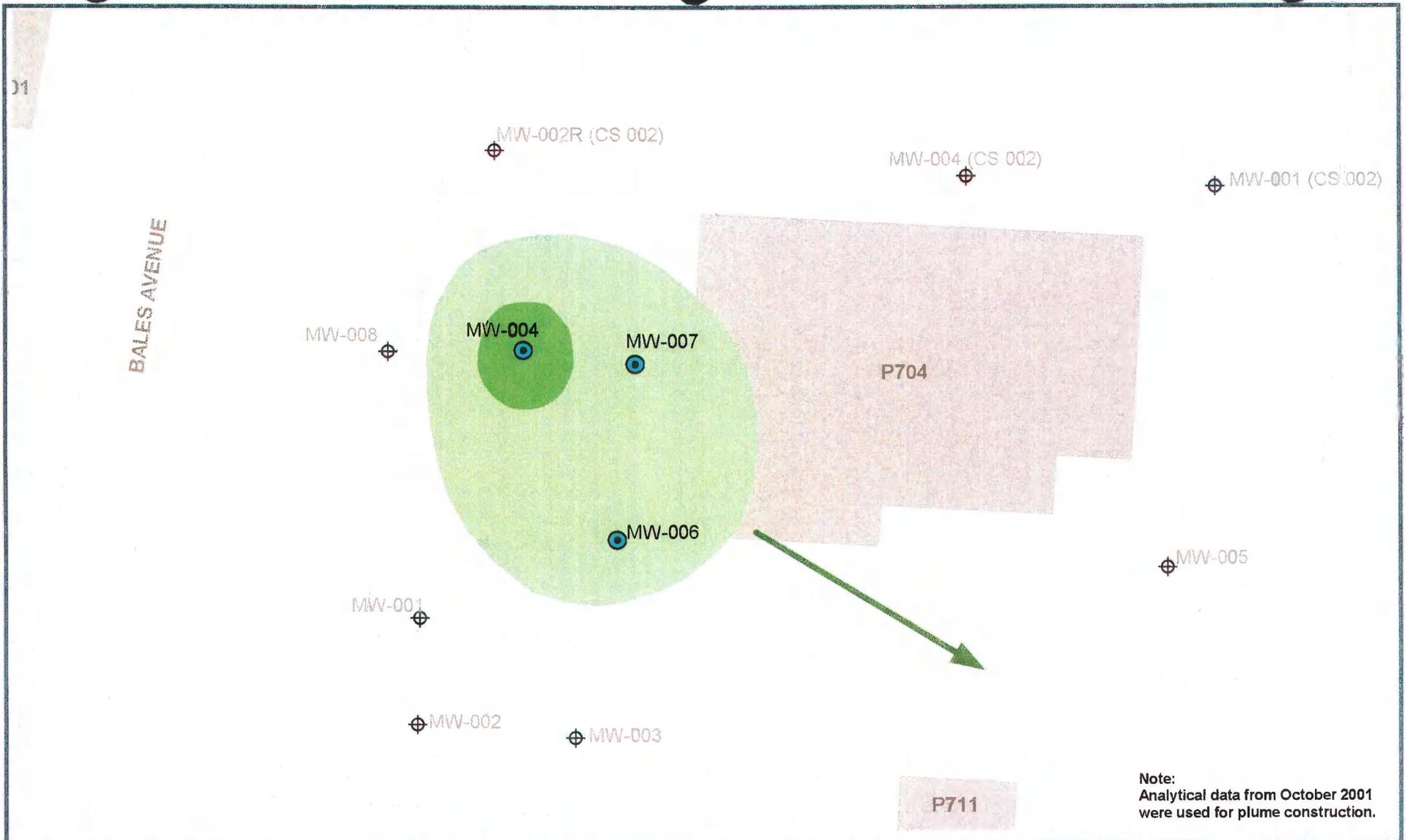


FIGURE 4-1

SS 003 - Oil Saturated Area
 COC > Tier I Screening Level
 (October, 2001)
 Richards - Gebaur AFB, Kansas City, MO



Note:
Analytical data from October 2001
were used for plume construction.

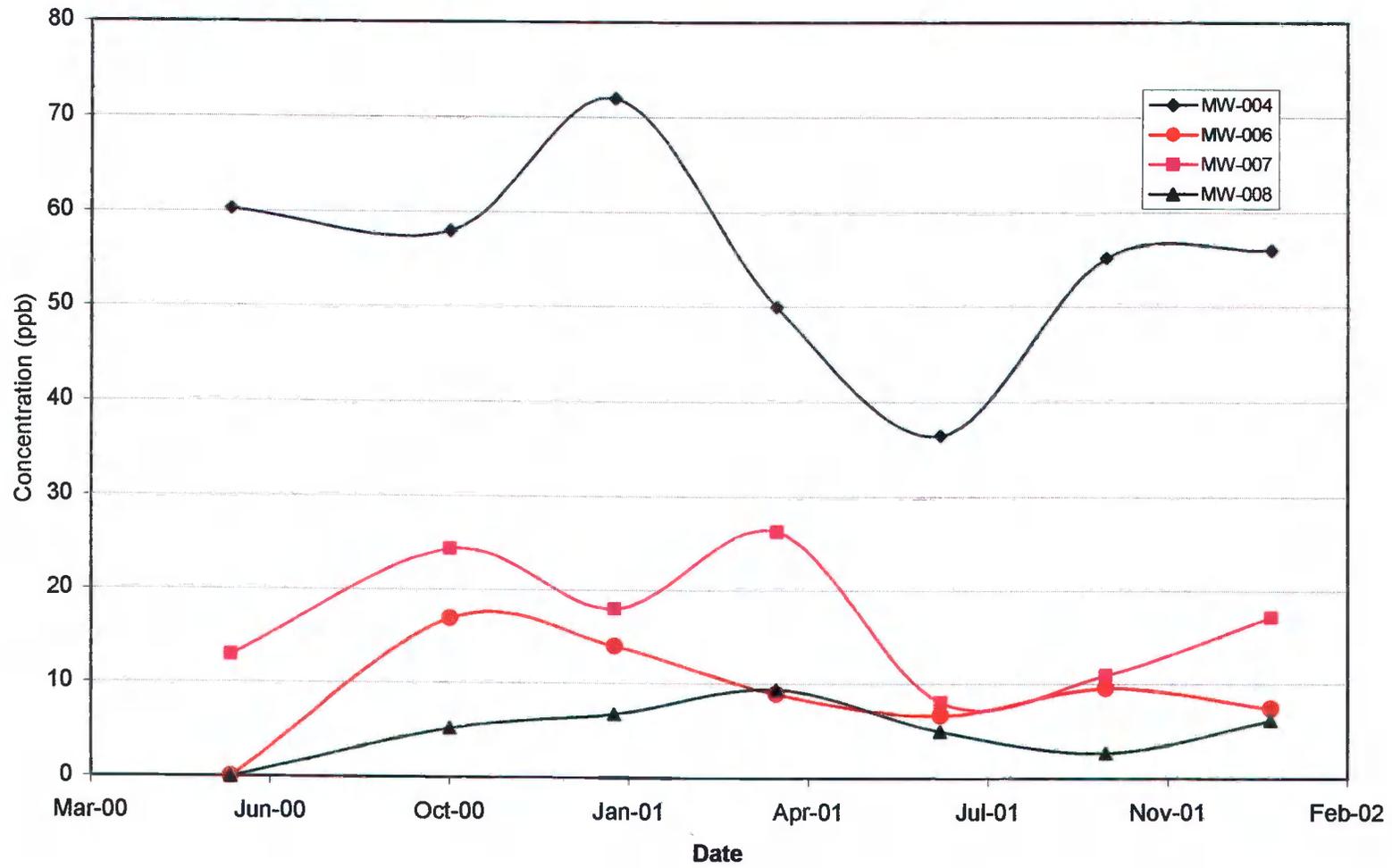
TCE Concentration (ppb)

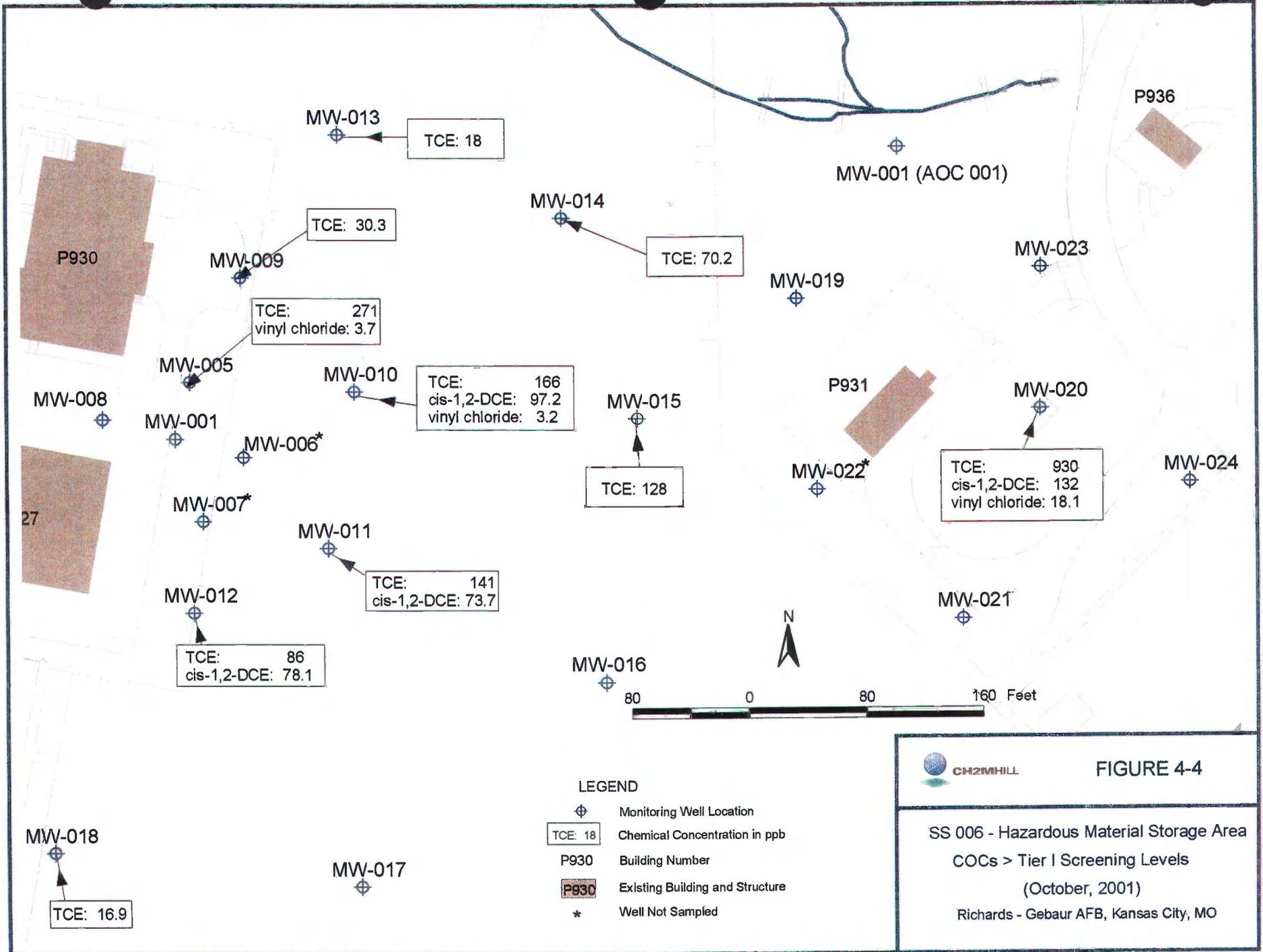
⊕	Groundwater Result < Tier I Screening Level		5 - 30
●	Groundwater Result > Tier I Screening Level		30 - 60
	General Groundwater Flow Direction		

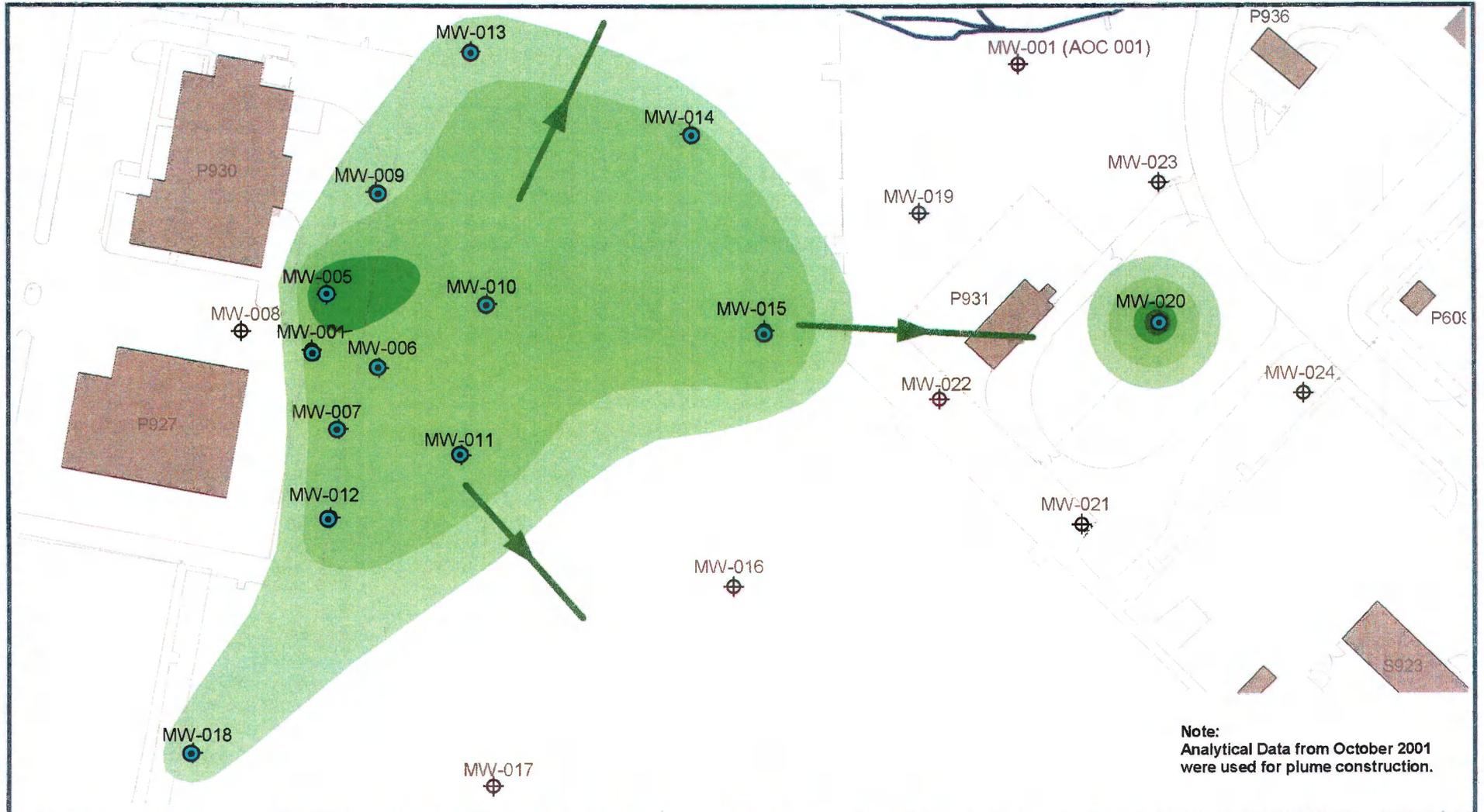
FIGURE 4-2

SS 003 - OIL SATURATED AREA
GROUNDWATER TIER I EXCEEDENCE
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI

Figure 4-3: Temporal Trends of TCE in Groundwater at SS 003







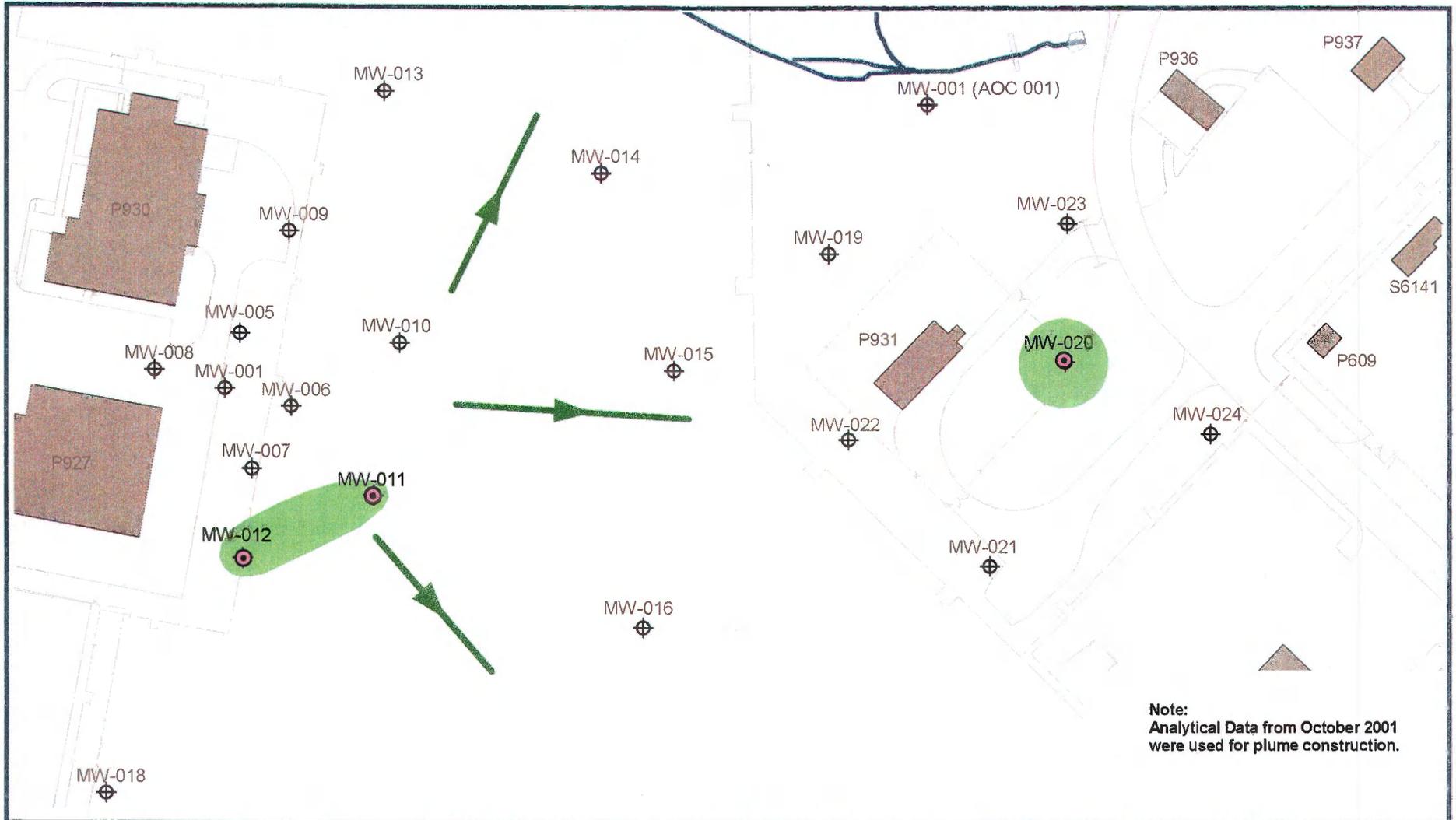
TCE Concentration (ppb)

⊕	Groundwater Result < Tier I Screening Level		5 - 50
⊙	Groundwater Result > Tier I Screening Level		50 - 200
➔	General Groundwater Flow Direction		200 - 400
			>400

80 0 80 160 Feet

FIGURE 4-5A

SS 006 - HAZARDOUS MATERIAL STORAGE AREA
 GROUNDWATER TIER I EXCEEDENCE
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI

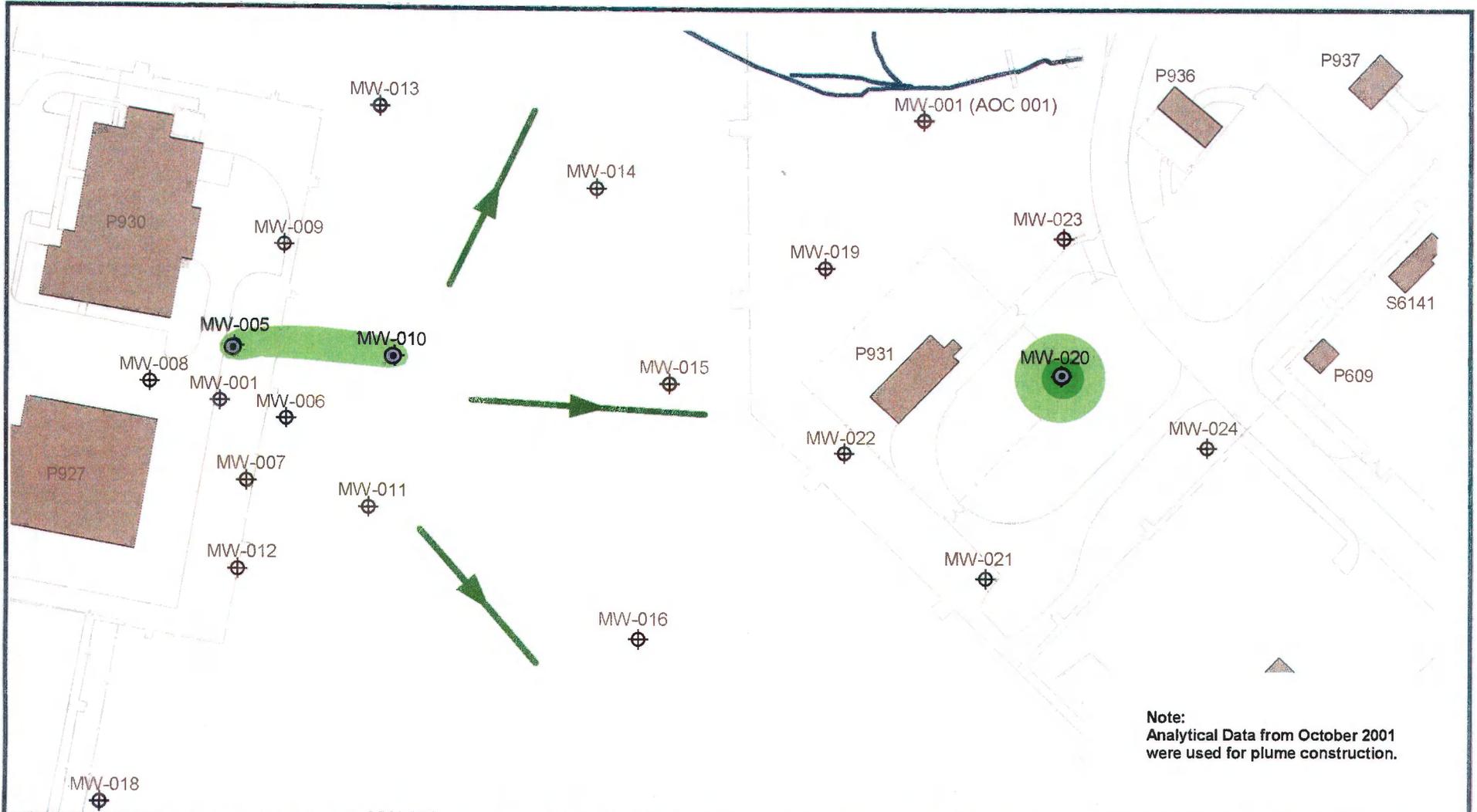


cis-1,2-DCE Concentration (ppb)

FIGURE 4-5B

⊕	Groundwater Result < Tier I Screening Level	 70 - 140
⊙	Groundwater Result > Tier I Screening Level	
→	General Groundwater Flow Direction	
		
		

SS 006 - HAZARDOUS MATERIAL STORAGE AREA
 GROUNDWATER TIER I EXCEEDENCE
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI



Note:
Analytical Data from October 2001
were used for plume construction.

Vinyl Chloride Concentration (ppb)

FIGURE 4-5C

⊕	Groundwater Result < Tier I Screening Level		2 - 10
⊙	Groundwater Result > Tier I Screening Level		10 - 20
	General Groundwater Flow Direction		

SS 006 - HAZARDOUS MATERIAL STORAGE AREA
GROUNDWATER TIER I EXCEEDENCE
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI

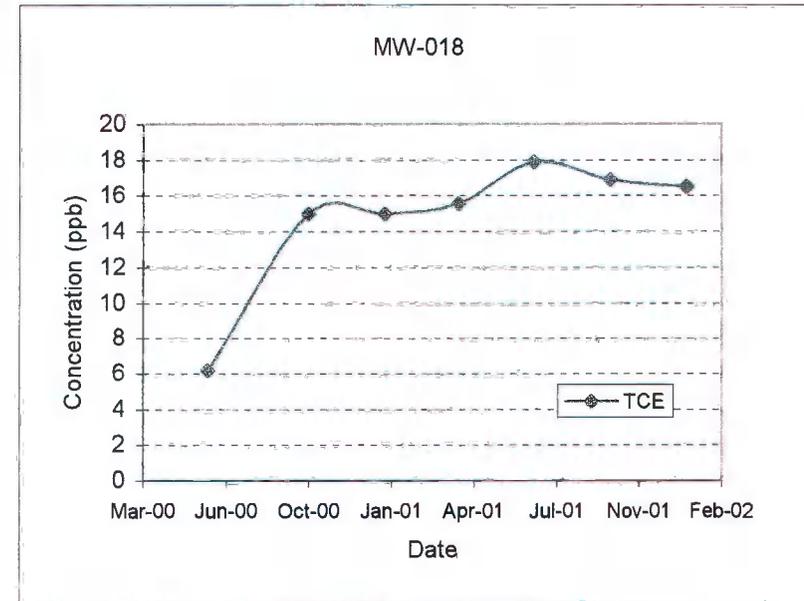
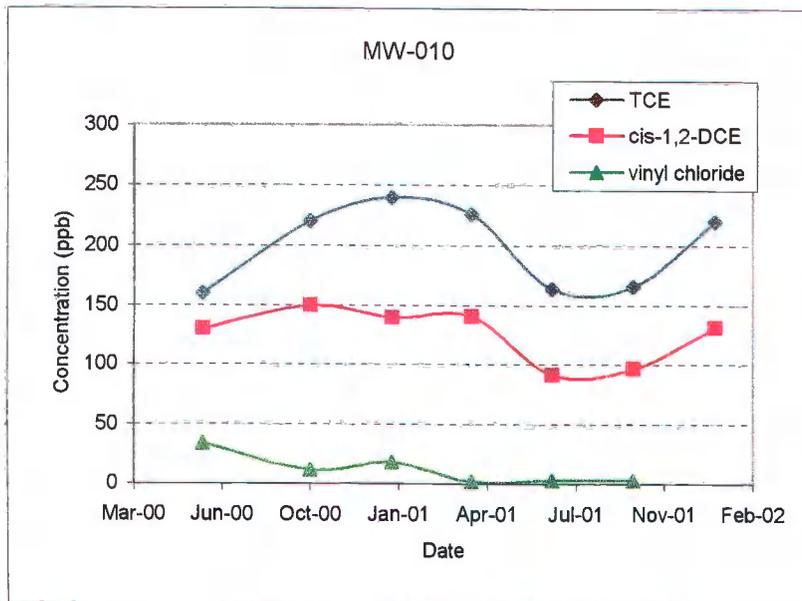
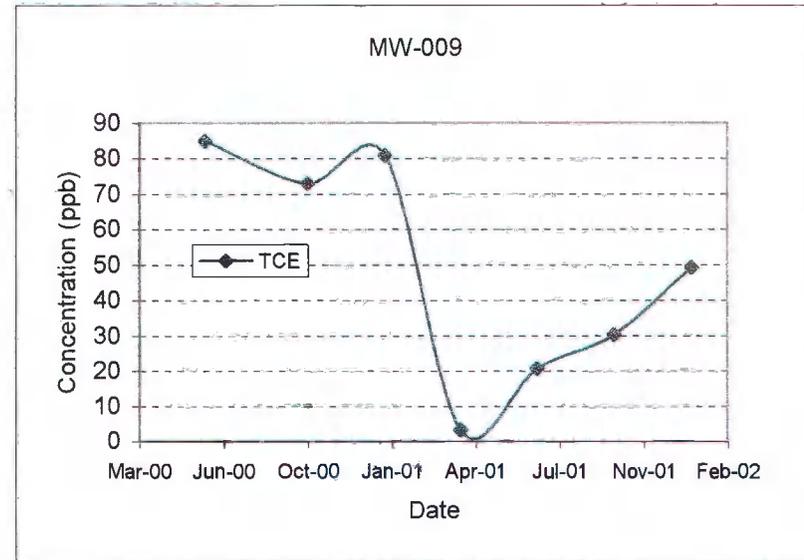
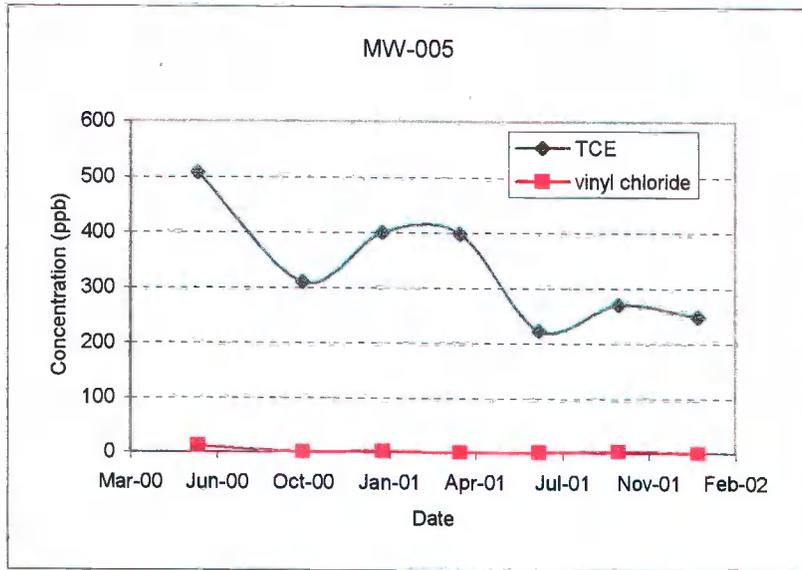
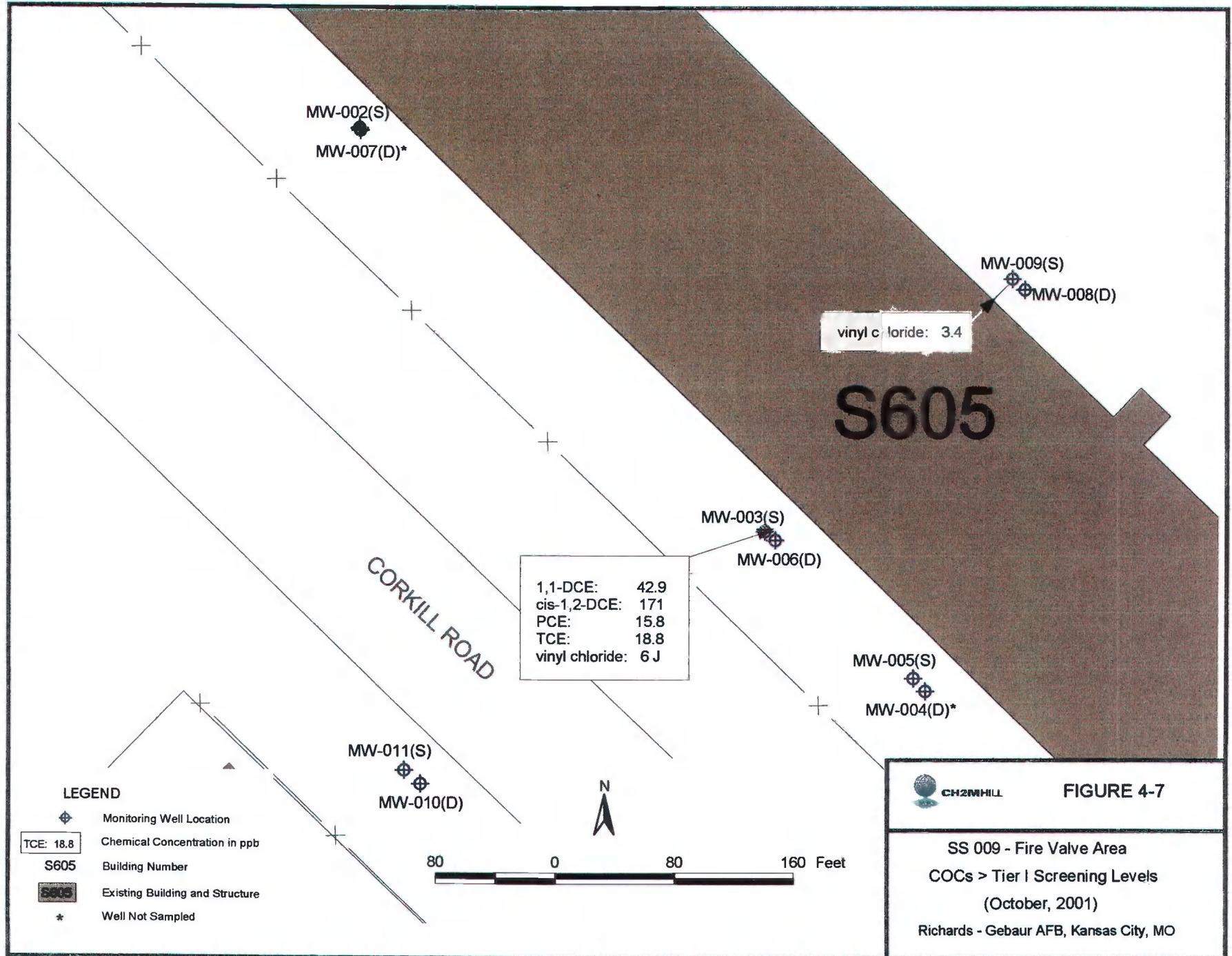
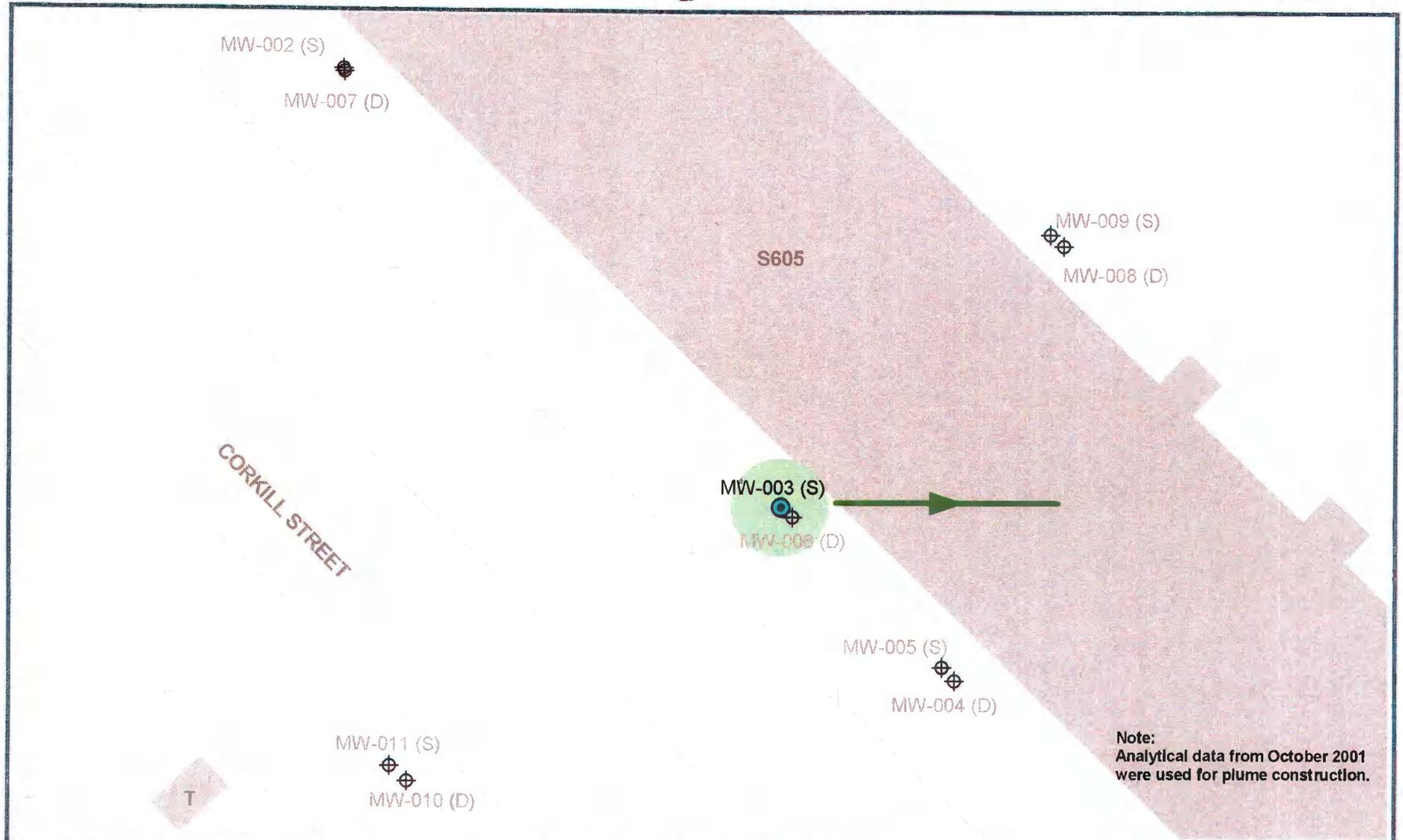


Figure 4-6: Temporal Trends of COCs in Groundwater at SS 006





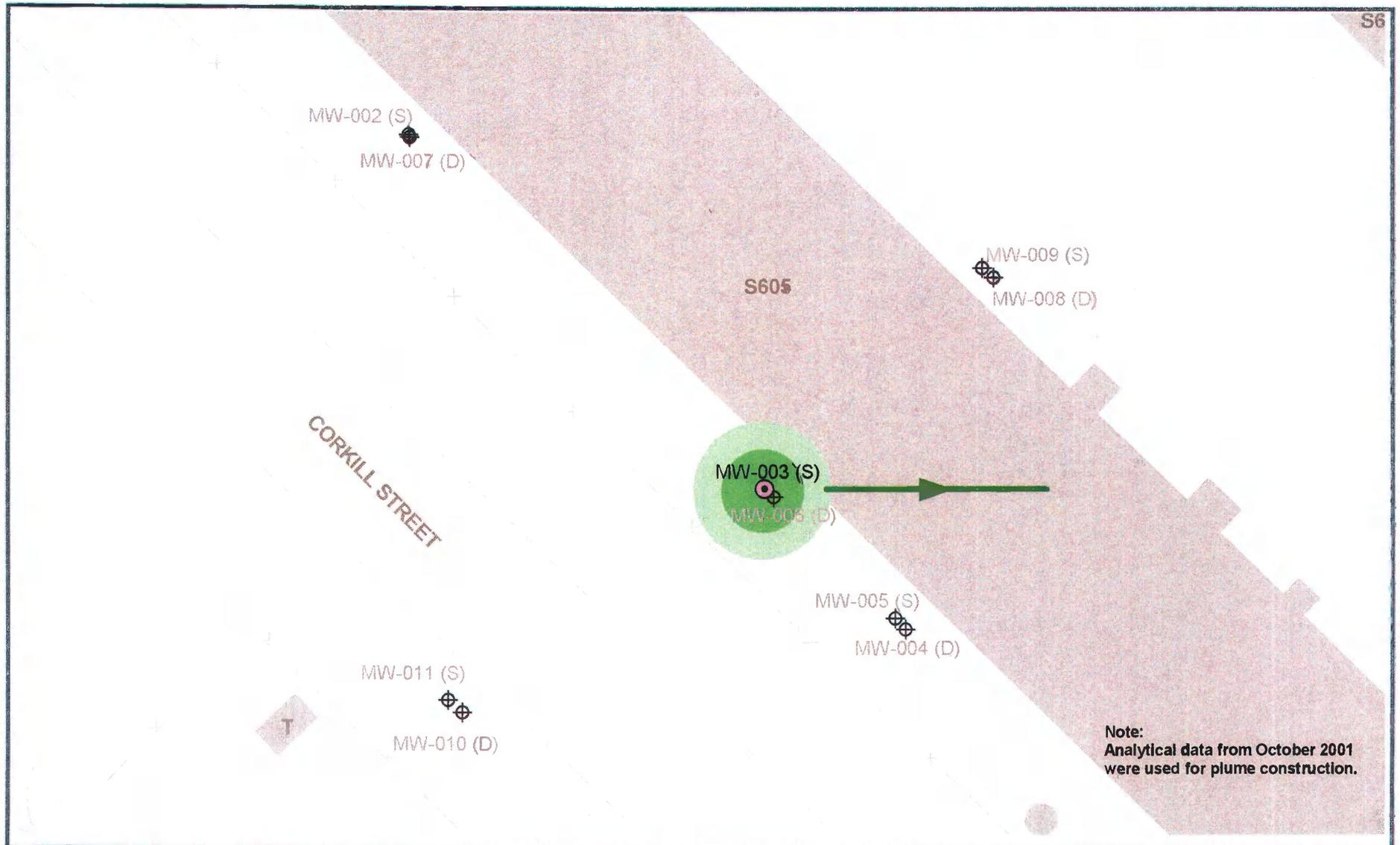
TCE Concentration (ppb)

FIGURE 4-8A

⊕	Groundwater Result < Tier I Screening Level	
●	Groundwater Result > Tier I Screening Level	5 - 30
→	General Groundwater Flow Direction	


 30 0 30 Feet

SS 009 - FIRE VALVE AREA
 GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI



Note:
Analytical data from October 2001
were used for plume construction.

cis-1,2-DCE Concentration (ppb)

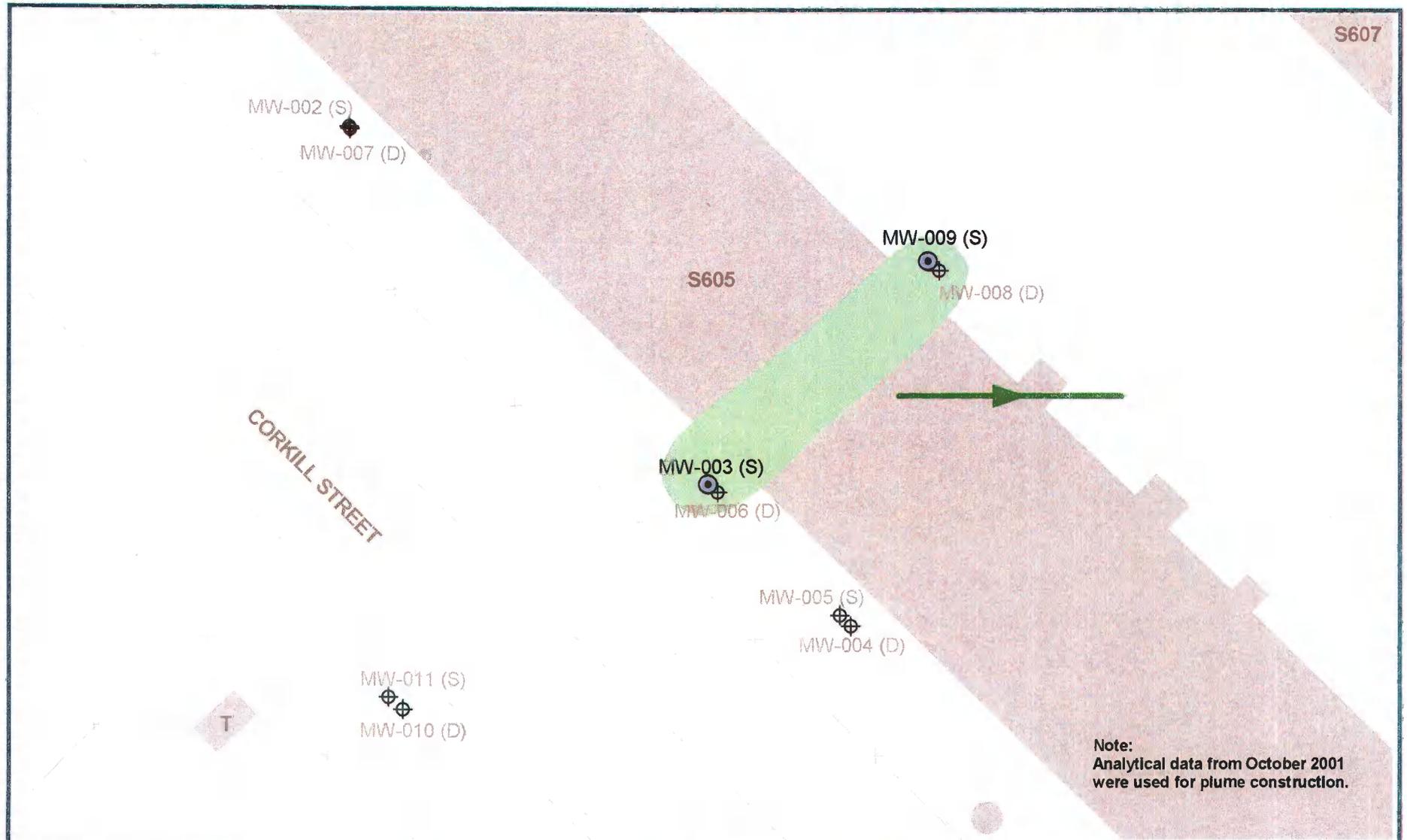
FIGURE 4-8B

- ⊕ Groundwater Result $<$ Tier I Screening Level
- ⊙ Groundwater Result $>$ Tier I Screening Level
- ➔ General Groundwater Flow Direction

- 70 - 140
- 140 - 210



SS 009 - FIRE VALVE AREA
GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI

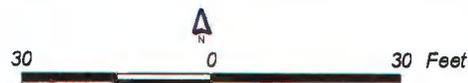


Vinyl Chloride Concentration (ppb)

FIGURE 4-8C

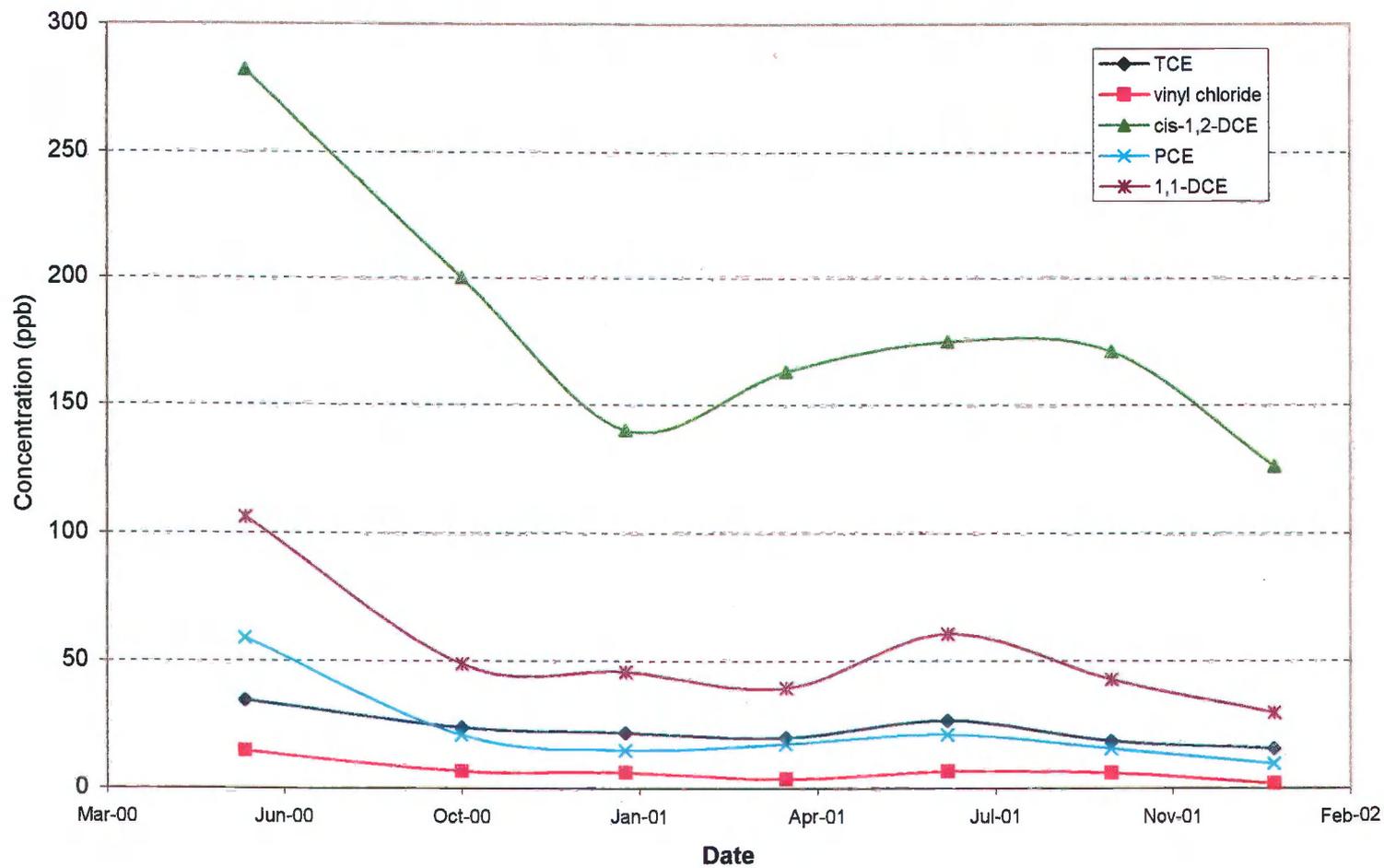
- ⊕ Groundwater Result < Tier I Screening Level
- ⊙ Groundwater Result > Tier I Screening Level
- ➔ General Groundwater Flow Direction

2 - 20



SS 009 - FIRE VALVE AREA
 GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI

Figure 4-9: Temporal Trends of COCs in Groundwater at SS 009, MW-003



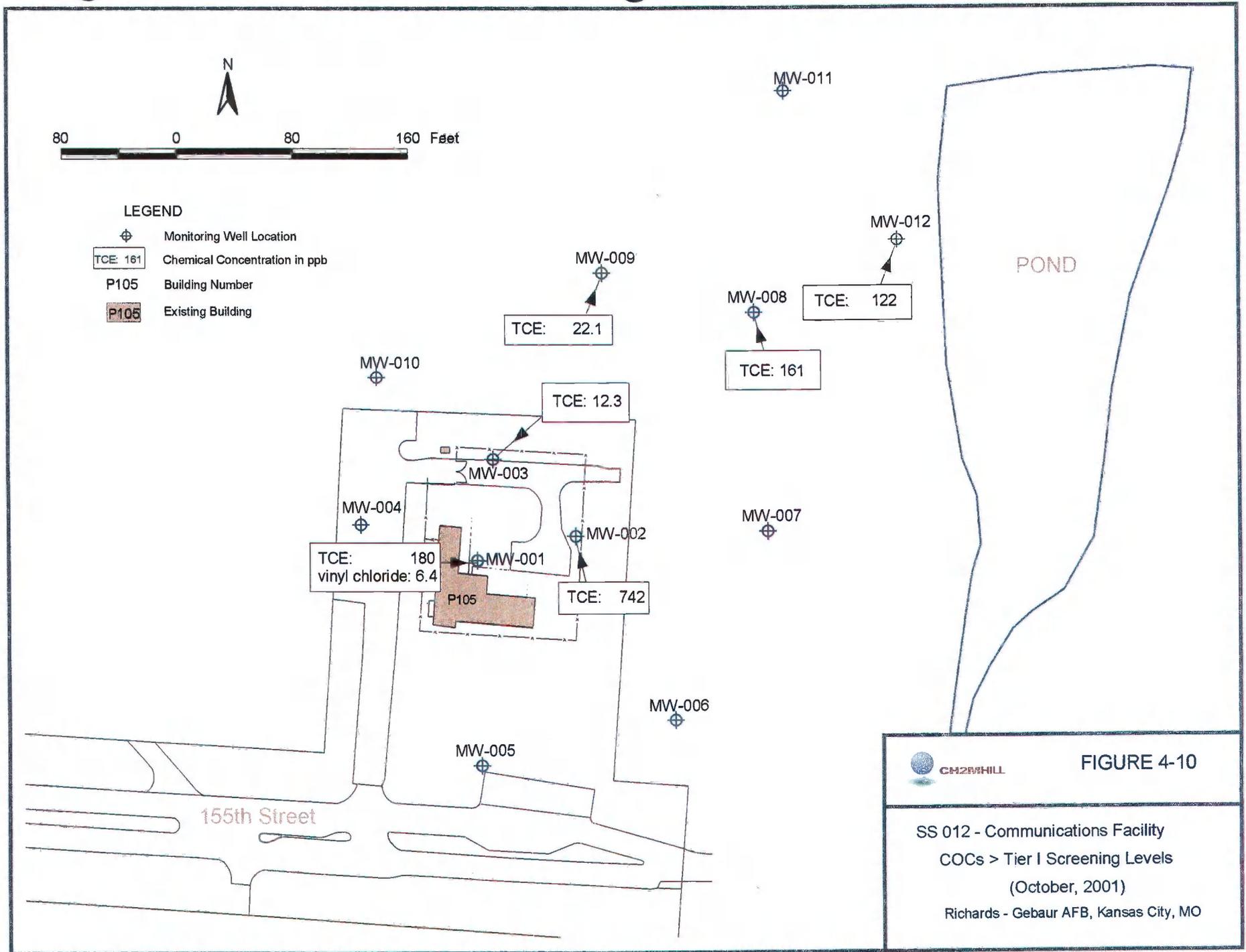
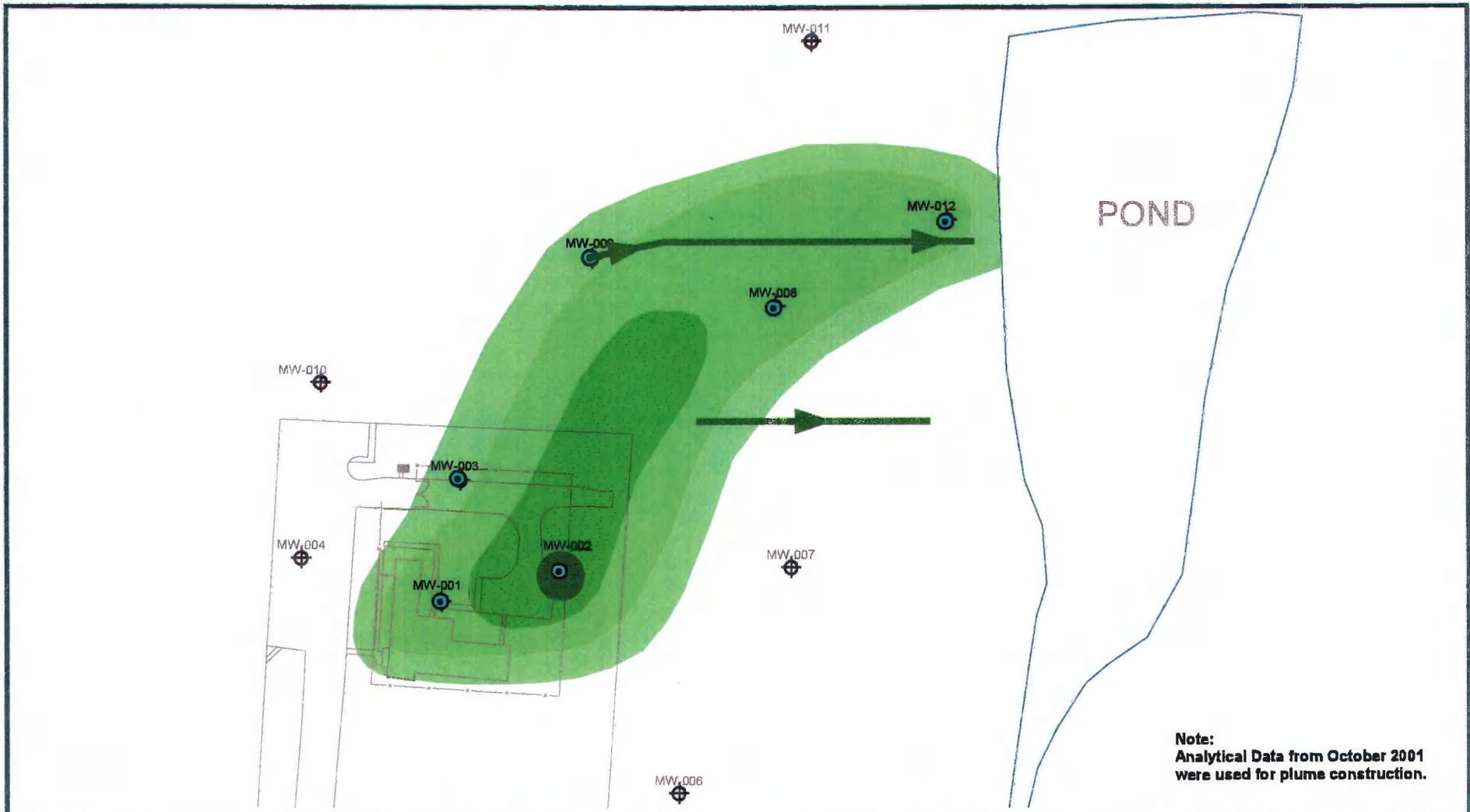


FIGURE 4-10

SS 012 - Communications Facility
 COCs > Tier I Screening Levels
 (October, 2001)
 Richards - Gebaur AFB, Kansas City, MO



Note:
Analytical Data from October 2001
were used for plume construction.

TCE Concentration (ppb)

FIGURE 4-11A

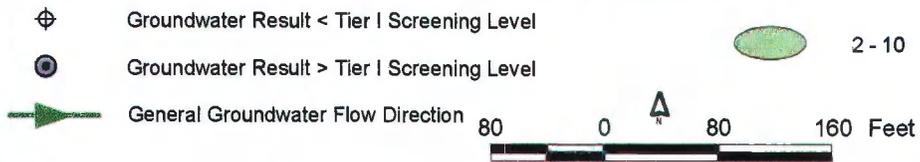
⊕	Groundwater Result < Tier I Screening Level	○	5 - 50
⊙	Groundwater Result > Tier I Screening Level	○	50 - 200
→	General Groundwater Flow Direction	○	200 - 400
		○	>400

SS 012 - COMMUNICATIONS FACILITY AT BUILDING 105
GROUNDWATER TIER I EXCEEDENCE
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI



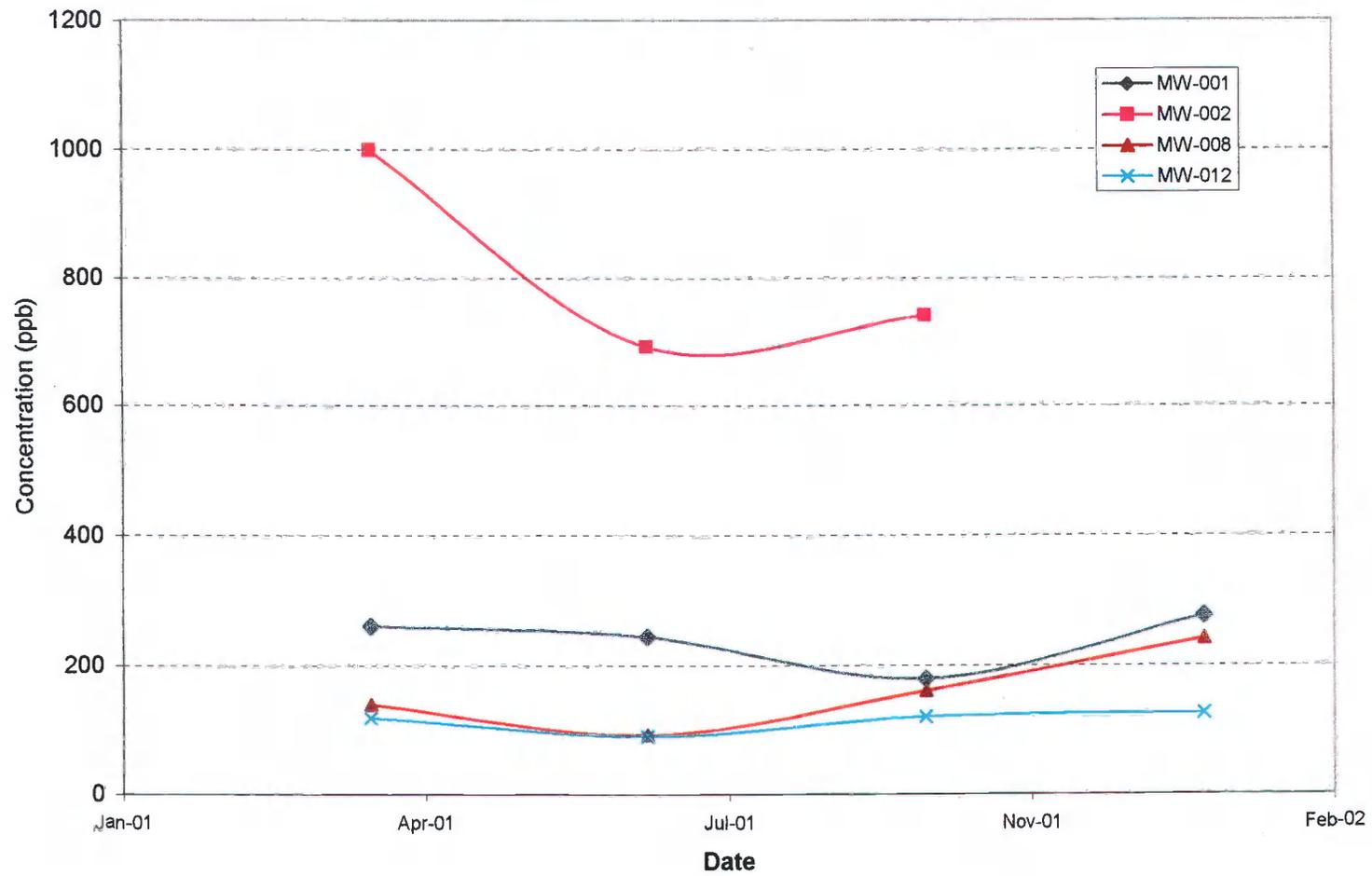
Vinyl Chloride Concentration (ppb)

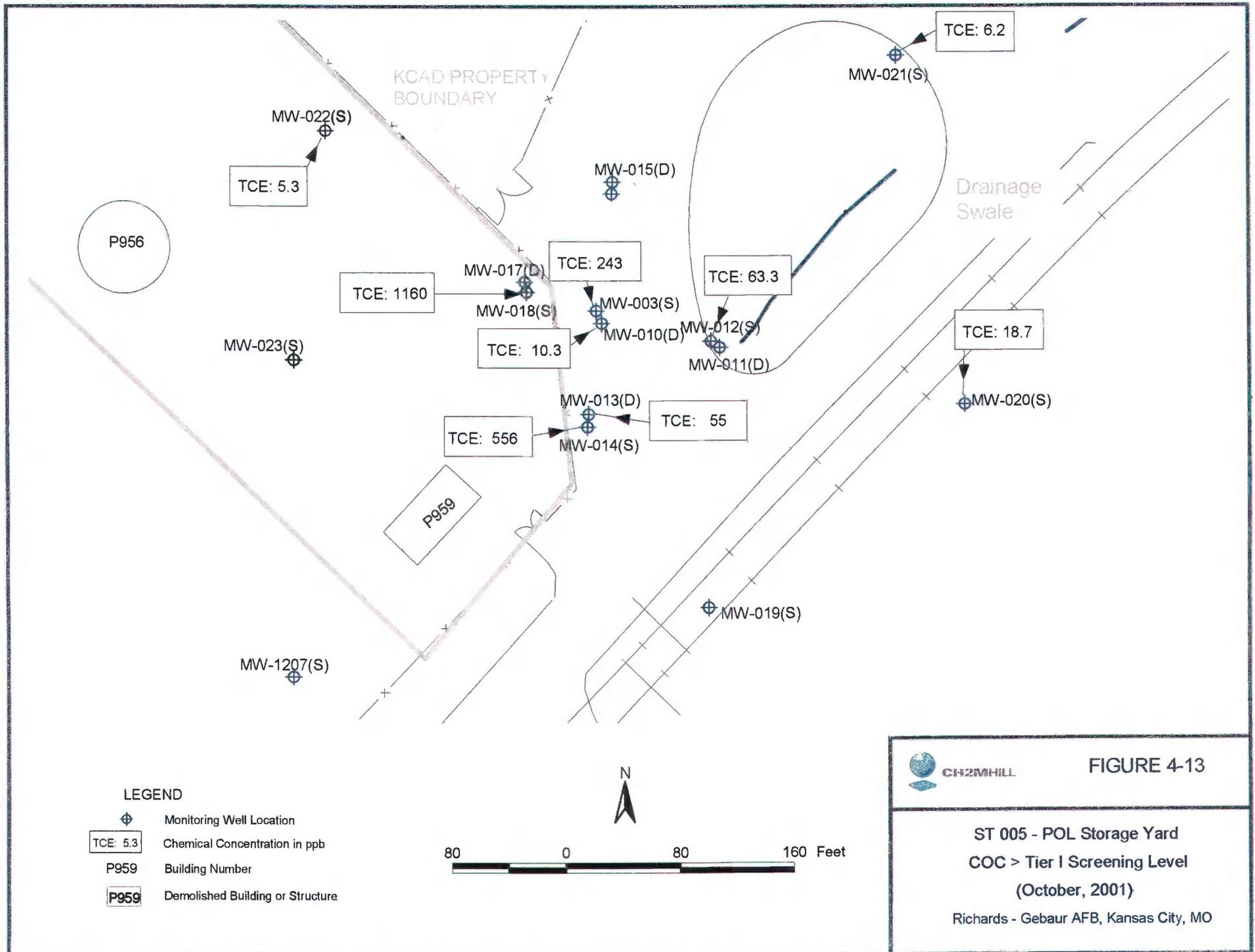
FIGURE 4-11B



SS 012 - COMMUNICATIONS FACILITY AT BUILDING 105
 GROUNDWATER TIER I EXCEEDENCE
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI

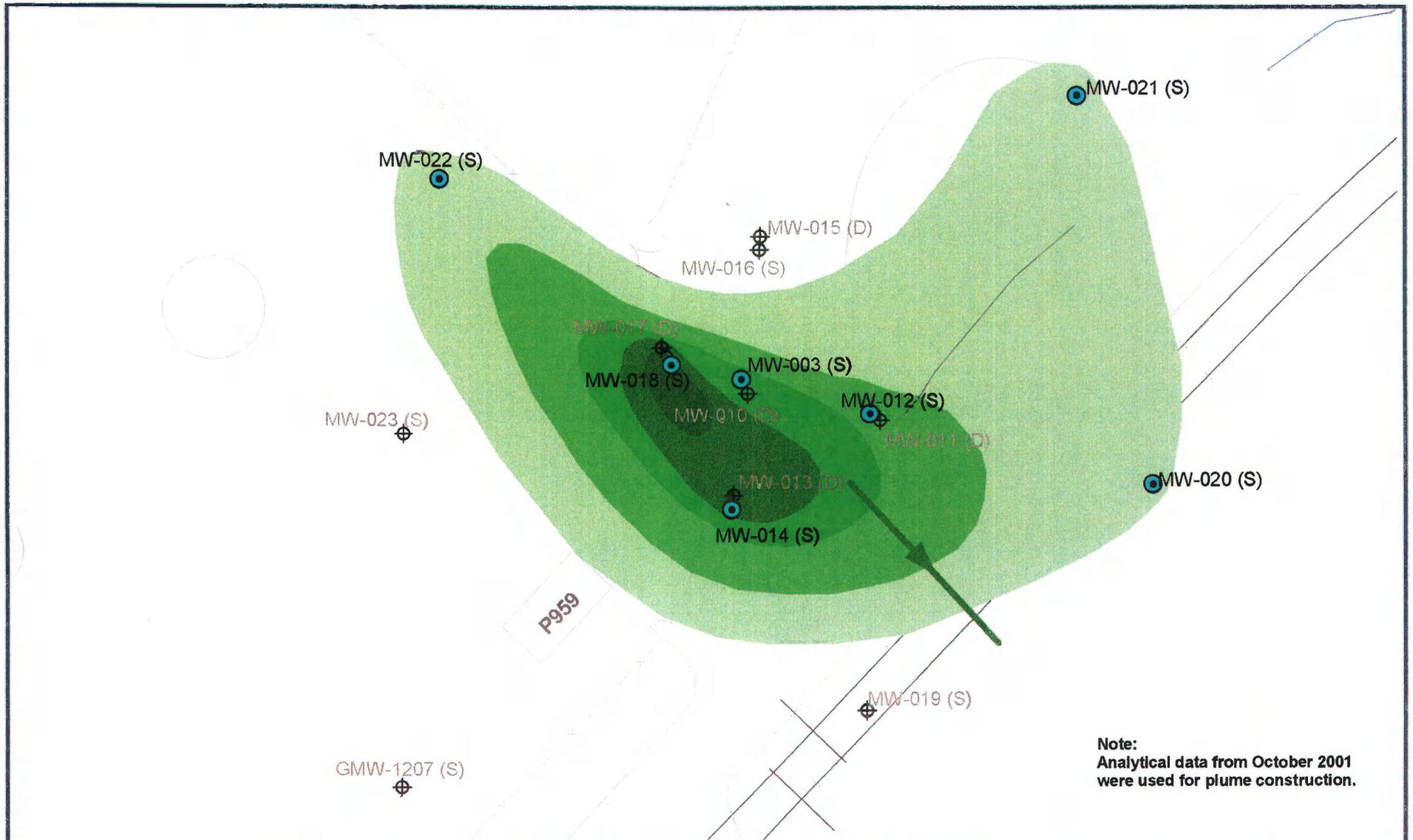
Figure 4-12: Temporal Trend of TCE in Groundwater at SS 012





CH2MHILL **FIGURE 4-13**

ST 005 - POL Storage Yard
COC > Tier I Screening Level
(October, 2001)
 Richards - Gebaur AFB, Kansas City, MO



TCE Concentration (ppb)

FIGURE 4-14

<p>⊕ Groundwater Result < Tier I Screening Level</p> <p>● Groundwater Result > Tier I Screening Level</p> <p>➔ General Groundwater Flow Direction</p>	<p>5 - 50</p> <p>50 - 200</p> <p>200 - 400</p> <p>400 - 1000</p> <p>> 1000</p>
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ST 005 - POL STORAGE YARD
 GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
 RICHARDS-GEBAUR AFB
 KANSAS CITY, MISSOURI

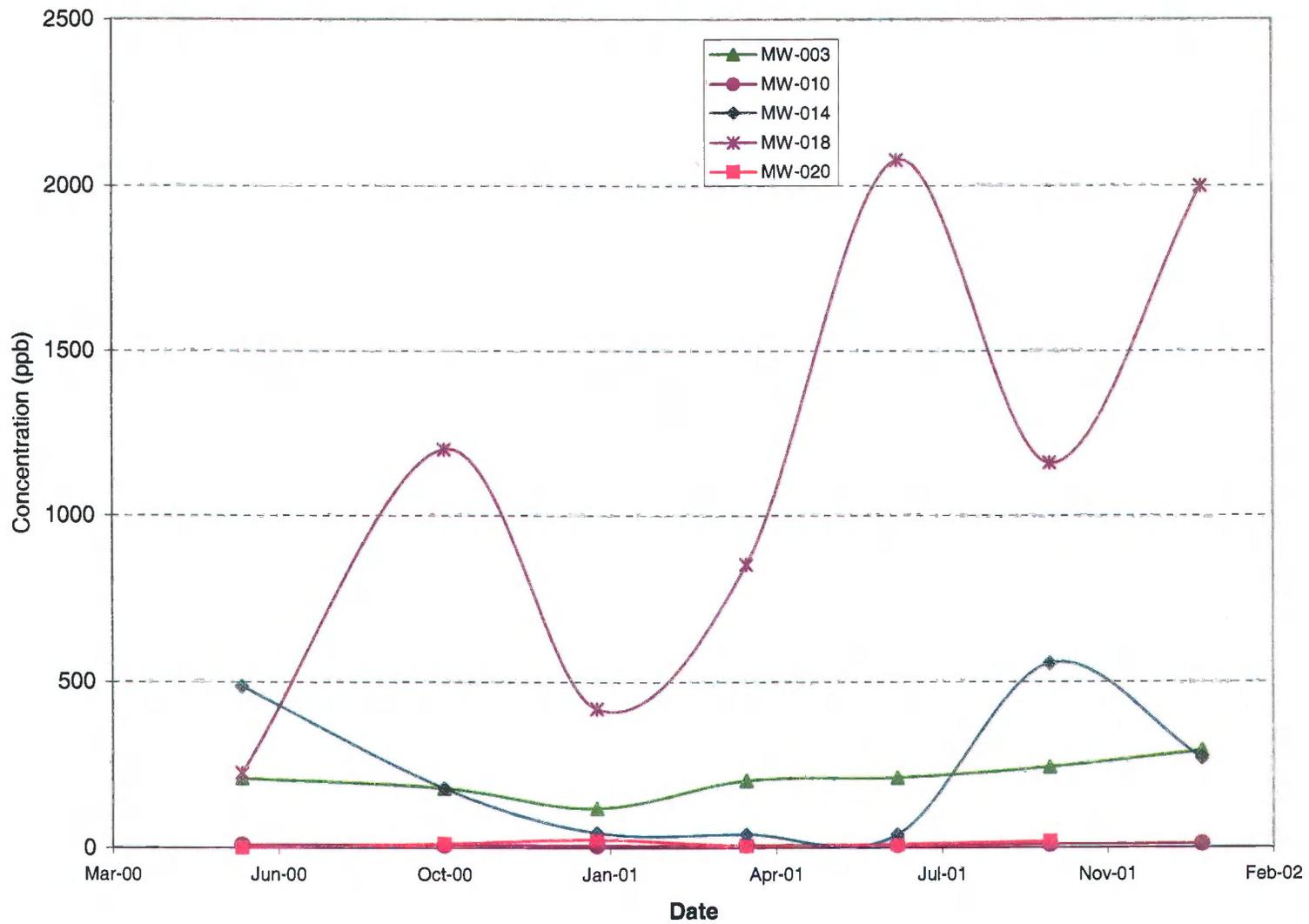


Figure 4-15: Temporal Trends of TCE in Groundwater at ST 005

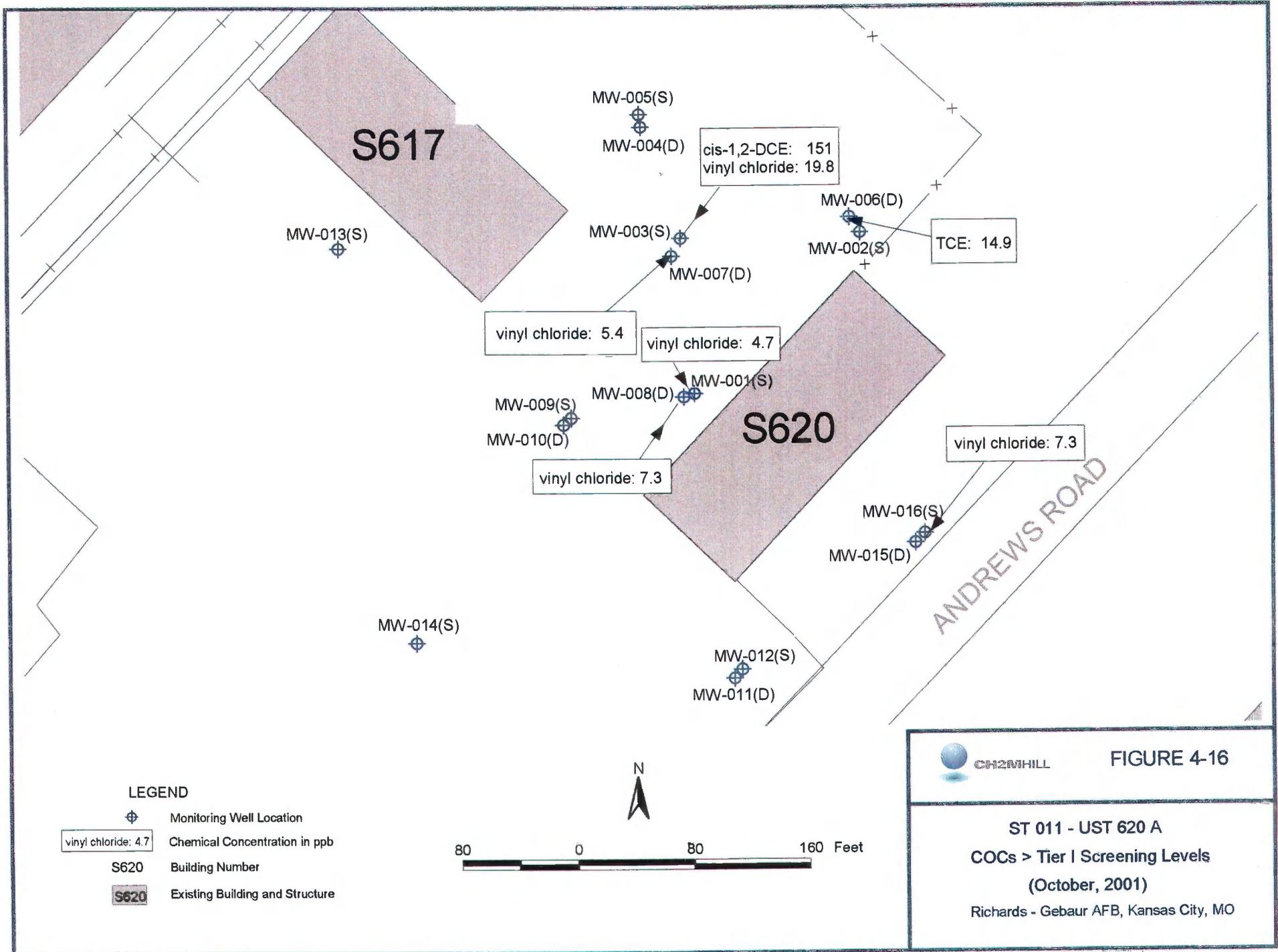
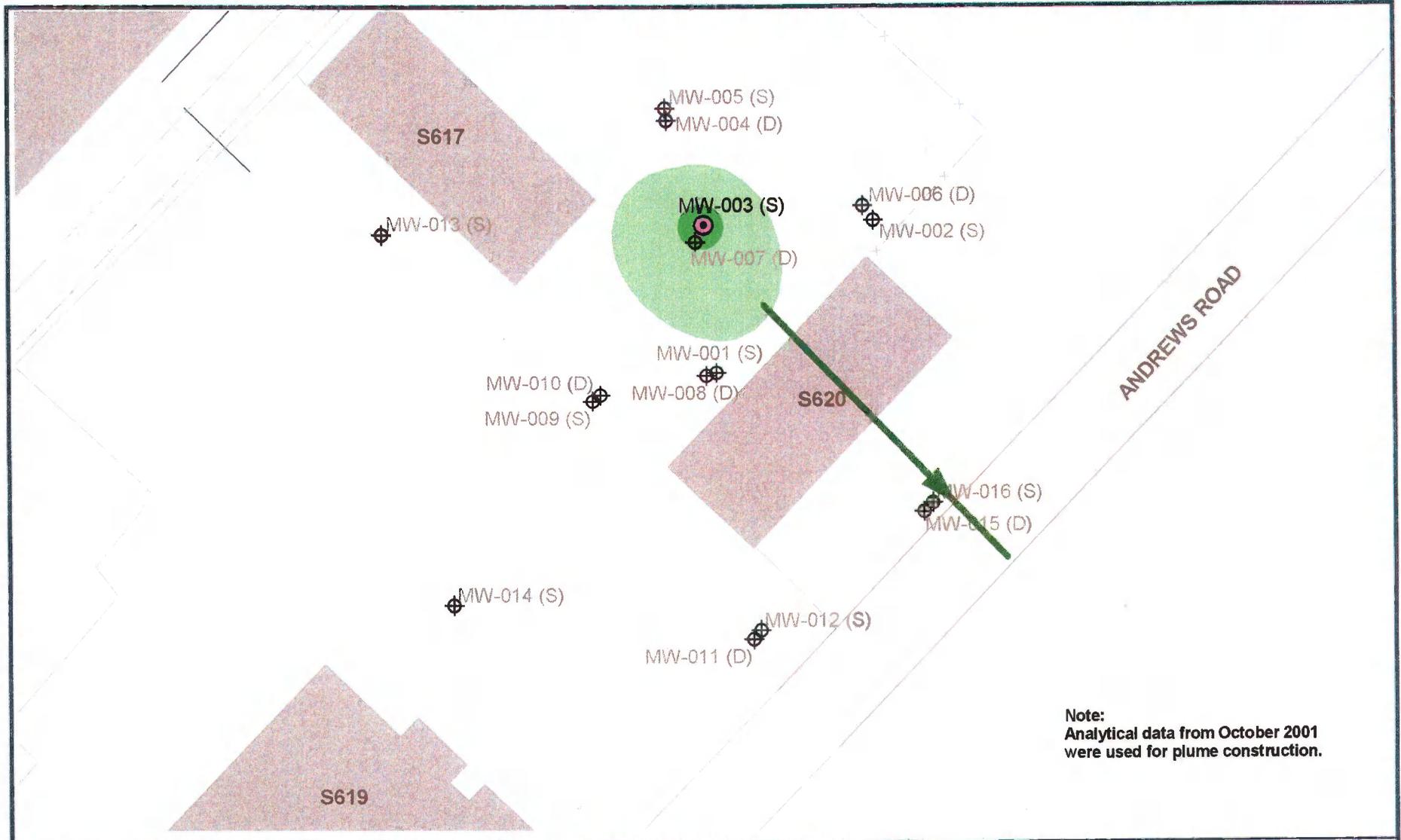


FIGURE 4-16

ST 011 - UST 620 A
 COCs > Tier I Screening Levels
 (October, 2001)
 Richards - Gebaur AFB, Kansas City, MO



Note:
Analytical data from October 2001
were used for plume construction.

cis-1,2-DCE Concentration (ppb)

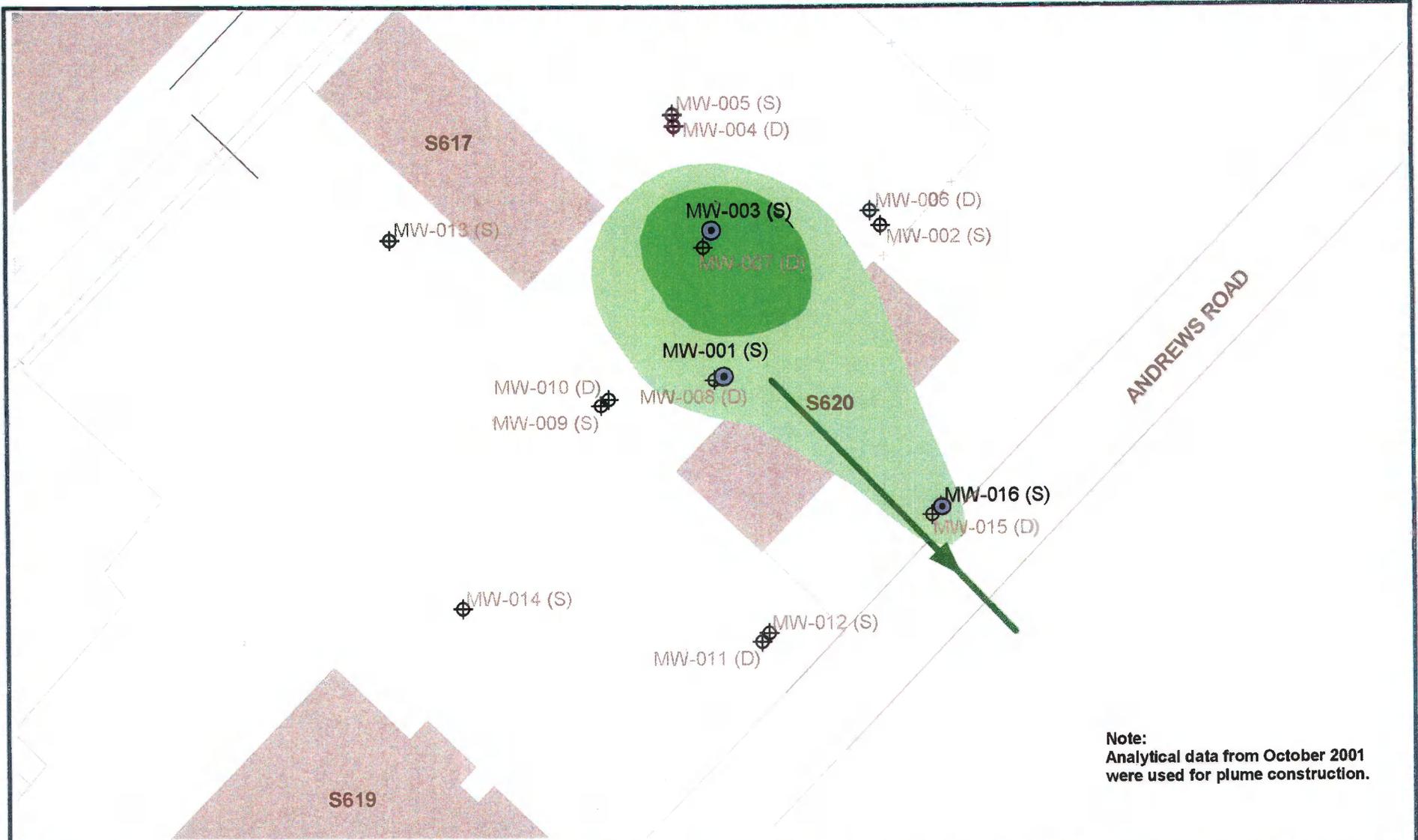
FIGURE 4-17A

- ⊕ Groundwater Result < Tier I Screening Level
- ⊙ Groundwater Result > Tier I Screening Level
- ➔ General Groundwater Flow Direction

- 70 - 140
- 140 - 210



ST 011 - UST 620A
GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI



Note:
Analytical data from October 2001
were used for plume construction.

Vinyl Chloride Concentration (ppb)

FIGURE 4-17B

⊕	Groundwater Result < Tier I Screening Level		2 - 10
⊙	Groundwater Result > Tier I Screening Level		10 - 20
	General Groundwater Flow Direction		

ST 011 - UST 620A
GROUNDWATER TIER I EXCEEDENCE - SHALLOW WELLS
RICHARDS-GEBAUR AFB
KANSAS CITY, MISSOURI

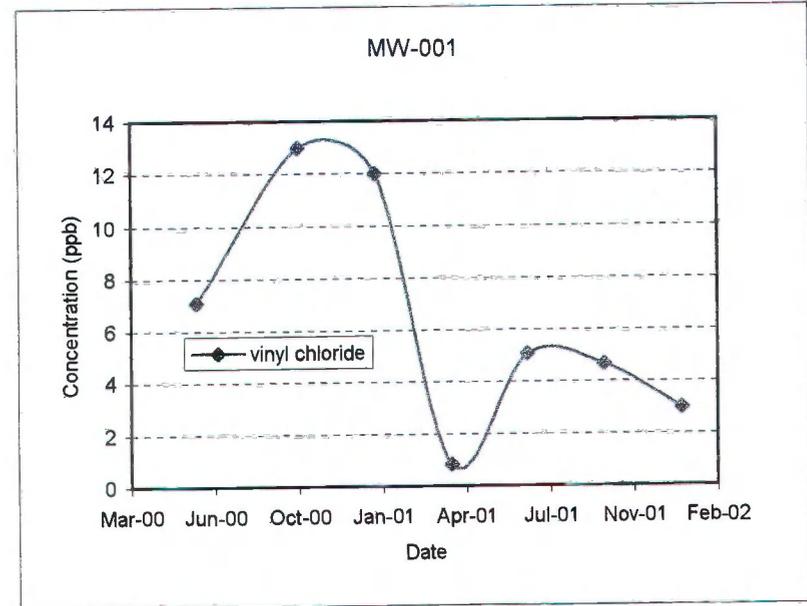
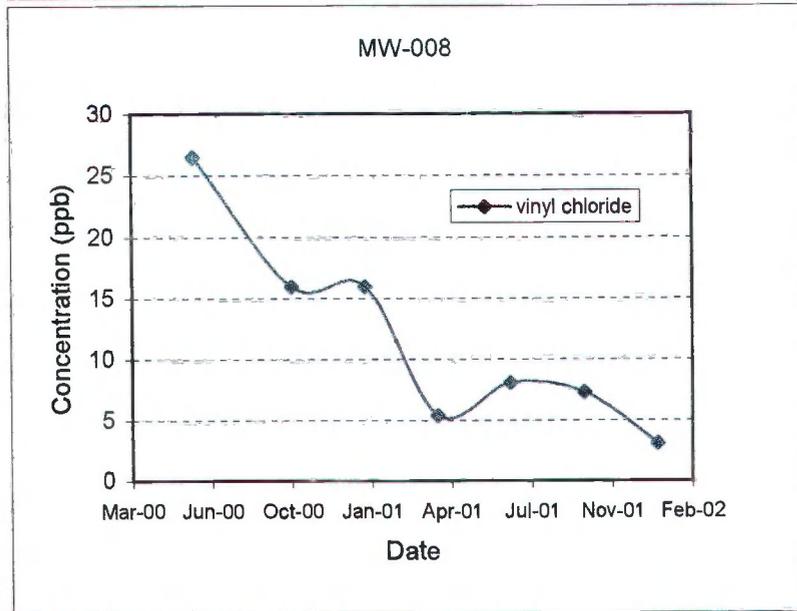
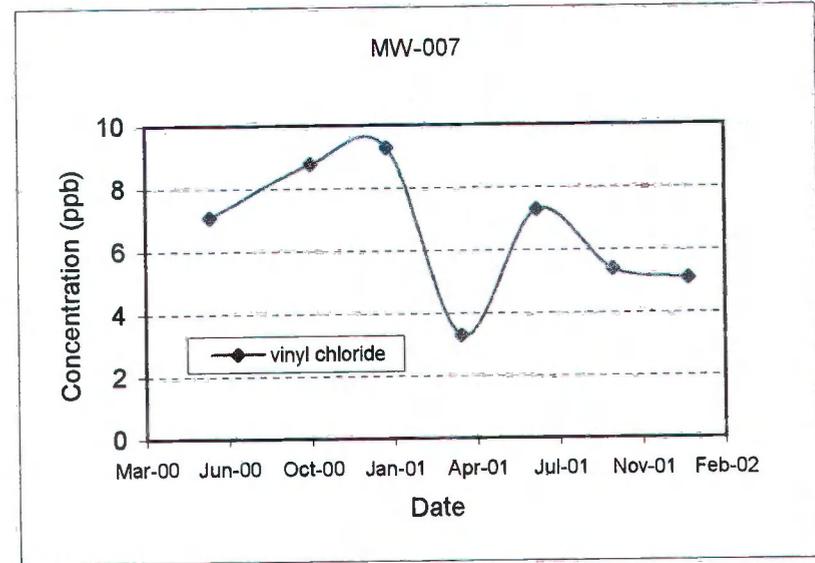
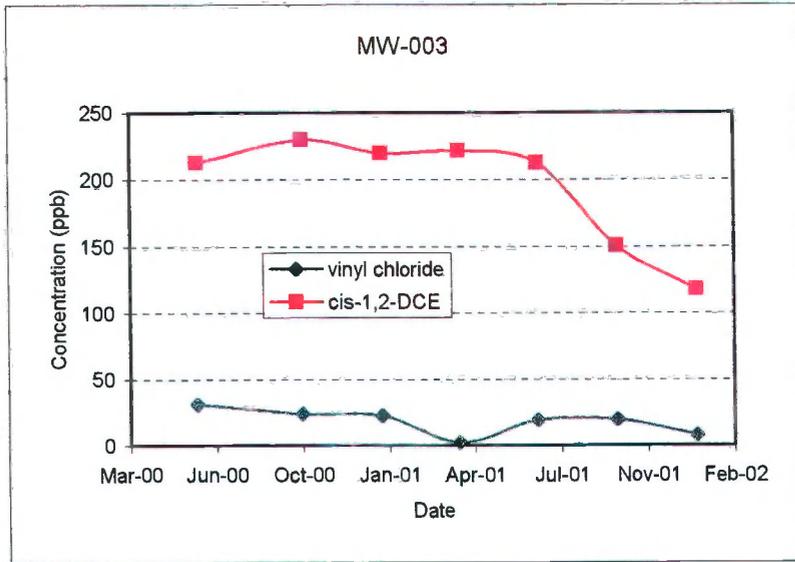


Figure 4-18: Temporal Trends of COCs in Groundwater at ST 011 (Former CS 004)

5. Development of RAOs and PRGs

Based on the *Remedial Investigation/Feasibility Study* guidance document (USEPA, 1988) and the USEPA 1990 *National Oil and Hazardous Substances Contingency Plan*, the FS consisted of three phases: (1) developing remedial alternatives; (2) screening of alternatives; and (3) detailed analysis of selected alternatives. The following steps were used in developing the remedial alternatives for Richards-Gebaur AFB.

1. Identify ARARs.
2. Develop RAOs.
3. Identify preliminary remediation goals (PRGs) using chemical-specific ARARs and human health and ecological- based risk levels.
4. Develop general response actions.
5. Identify and screen remedial technologies and process options (including innovative technologies).
6. Assemble remaining technologies and process options into remedial alternatives.

This section presents steps 1 through 3. Section 6 develops general response actions for groundwater contamination and identifies and screens a variety of remedial technologies and associated process options. Section 7 assembles the remaining technologies and process options into remedial alternatives and provides a detailed analysis of each alternative, and presents a comparative analysis of the remedial alternatives.

5.1 Summary of ARARs

ARARs may originate in federal government or, if promulgated, legally enforceable, identified in a timely manner, consistently applied, and more stringent than federal requirements, in state government. Where the state of Missouri is authorized to implement a program in lieu of a federal agency (for example National Pollution Discharge Elimination System concentration limits under the Clean Water Act), state laws arising out of that program should be the ARARs complied with, not the federal authorizing legislation. A stringency comparison is not required in this case, because state regulations under federally authorized programs are considered to be federal requirements.

There are three kinds of ARARs. *Location-specific ARARs* restrict the occurrence of chemicals in certain sensitive environments, such as wetlands (e.g., the Endangered Species Act). *Action-specific ARARs* are activity-based or technology-based, and typically control remedial activities that generate hazardous wastes (e.g., RCRA). *Chemical-specific ARARs* are health-based or risk management-based numbers that provide concentration limits for the occurrence of a chemical in the environment (e.g., target concentrations in CALM).

ARARs are the standards to be met during remediation to assure protection of human health and the environment. Section 121 of the 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 and state 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" (TBC). TBCs in remedy selection may include guidance and other limitations, but the TBCs are not evaluated pursuant to the formal ARARs process. Instead, they are used if needed to ensure that the selected remedy is protective of human health and the environment. ARARs must be complied with during implementation of the selected remedial actions, or a specific ARAR waiver must be requested per the NCP.

Applicable requirements are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances at the site.

Relevant and appropriate requirements are cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that are well suited to the particular site. While not necessarily "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstances of the site, relevant and appropriate requirements address problems or situations sufficiently similar to those encountered at the site to justify their use.

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.

TBCs are nonpromulgated advisories or guidance issued by federal or state government that are not legally binding and do not have the status of potential ARARs. However, in many circumstances TBCs will be considered along with ARARs in determining the necessary level of cleanup for protection of human health and the environment.

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

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

The ARARs for the FS are summarized in Table 5-1 and briefly described in the sections that follow.

5.2 ARARs for Groundwater Remediation

The following statutes and regulations contain requirements that are deemed to be probable ARARs at Richards-Gebaur AFB. By probable, it is meant that the requirements are commonly encountered during routine groundwater cleanups.

Table 5-1

List of ARARs for Richards-Gebaur AFB FS

Media	Requirement	Requirement Synopsis
Location-Specific ARARs		
Surface Water and Wetlands	Federal	
	Fish and Wildlife Coordination Act (16 USC 661 et seq.)	This act provides protection and consultation with the US Fish and Wildlife Service and state counterpart for actions that would affect streams, wetlands, other water bodies, or protected habitats. Action taken should protect fish or wildlife, and measures developed to prevent, mitigate, or compensate for project-related losses to fish and wildlife.
Wetland Sediment and Surface Water	Federal	
	Protection of Wetlands— Executive Order 11990 (40 CFR 6, Appendix A)	Appendix A of 40 CFR 6 sets forth policy for carrying out provisions of the Protection of Wetlands Executive Order. Under this order, federal agencies are required to minimize the degradation, loss, or destruction of wetlands, and to preserve the natural and beneficial values of wetlands. Appendix A requires that no remedial alternatives adversely affect a wetland if another practicable alternative is available. If no alternative is available, effects from implementing the chosen alternative must be mitigated. Public notice and review of activities involving wetlands is required.
	Endangered Species Act (16 U.S.C. 460 et seq.)	Passed in 1973. It establishes a program for the conservation of endangered and threatened plants and animal, and the habitats that support them. The Act is administered by the National Marine Fisheries Services and the U.S. Fish and Wildlife Service. The Fish and Wildlife Service maintains a list of 632 endangered species and 190 threatened species. The law prohibits any action, administrative or substantive, that results in a "taking" of a listed species or adversely effects its habitat.
	Clean Water Act (Section 404 (b)(1), 40 CFR 230) Guidelines for Specification of Disposal Sites for Dredged or Fill Material	Restores and maintains the chemical, physical, and biological integrity of waters of the US through the control of discharges of dredged or fill material. Dredged or fill material should not be discharged into the aquatic ecosystem unless it can be demonstrated that such a discharge will not have an unacceptable adverse impact either individually or in combination with known or probable impacts of other activities affecting the ecosystems of concern. Public notice is required.
	State	
Missouri Clean Water Law (Sect. 644 RSMo)	Enacted 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 waters of the state.	

Table 5-1		
List of ARARs for Richards-Gebaur AFB FS		
Media	Requirement	Requirement Synopsis
Action-Specific ARARs		
Surface Water	Federal	
	Clean Water Act, National Pollutant Discharge Elimination System (40 CFR 122-125 and 131), Clean Water Act	Establishes discharge limitations, monitoring requirements and best management practices for any direct discharge from a point source into surface water.
	State	
	Missouri Clean Water Law (Sect. 644 RSMo)	Enacted 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 waters of the state.
Groudwater	Federal	
	Underground Injection Control Program (40 CFR 146 Subpart F)	Passed in 1980, and amended in 1982, the regulation establishes criteria and standards for underground injection control programs that place non-hazardous fluids into aquifers.
	State	
	Class III Mineral Resources Injection / Production Well Operating Permits (10 CSR 20-6.090)	This regulation, established in 1984, provides the mechanism for the State to issue Class V underground injection permits through its Department of Environmental Quality – Water Pollution Control Program.
USTs and Associated Soil and Groundwater Cleanups	Missouri Water Well Drillers Act (Sect. 319.100 RSMo)	Passed in 1994. Administered by the State Division of Geology and Land Survey. It provides standards for subsurface drilling, including construction of water wells, monitoring wells, and test holes. This law also stipulates methods for abandoning wells and boreholes, and sets permit fees for owners and standards for contractors who do such work.
	State	
	Missouri UST Act (Sect. 644 RSMo)	The original UST Law was passed in 1989. Technical requirements are incorporated within the mandate of the Missouri Clean Water Act.
	Rules of (Missouri) Department of Natural Resources, Division 20, Clean Water Commission, Chapter 10, Underground Storage Tanks, Technical Regulations (10 CSR 20.10)	Contains the technical standards for underground storage tanks. Designed specifically to protect the quality of groundwater in the state as well as to protect human health and the overall quality of the environment.
	MDNR UST Closure Guidance Document, Division of Environmental Quality, Hazardous Waste Program, March 1996	Provides sections on UST closure checklist, UST closure requirements, UST registration and fees, notification requirements for UST closure, UST closure using Industry Standards, Sampling and Analysis, Treatment and Disposal, UST Closure Report, and references.

Table 5-1		
List of ARARs for Richards-Gebaur AFB FS		
Media	Requirement	Requirement Synopsis
Hazardous Materials	Federal	
	Toxic Substances Control Act (15 U.S.C. 2601 et seq.)	Created in 1976, TSCA institutes a range of control measures, primarily record-keeping and reporting requirements, intended to document the production and use of hazardous chemicals.
	Hazardous Materials Transportation Act (49 U.S.C. 1801 et seq.)	Provides regulations governing the transportation of hazardous materials and hazardous waste. The regulations include record-keeping and reporting requirements; labeling and packaging requirements; and detailed handling requirements for each mode of transportation (rail, air, waterway, or road).
	Occupational Safety and Health Act (29 U.S.C. 61 et seq.)	Passed in 1970, OSHA was created to ensure worker safety on the job. The U.S. Department of Labor oversees the act. Worker safety at hazardous waste sites is specifically addressed under 29 CFR 1910.120: <i>Hazardous Waste Operations and Emergency Response</i> ; general worker safety is covered elsewhere within the law.
Waste	Federal	
	Resource Conservation and Recovery Act (42 U.S.C. 321 et seq.)	Passed in 1976, RCRA amended the Solid Waste Disposal Act by including provisions for hazardous waste management. Its goals are to promote conservation of natural resources while protecting human health and the environment. The statute sets out to control the management of hazardous waste from its inception to its ultimate disposal.
	Occupational Safety and Health Act (29 U.S.C. 61 et seq.)	Passed in 1970, OSHA was created to ensure worker safety on the job. The U.S. Department of Labor oversees the act. Worker safety at hazardous waste sites is specifically addressed under 29 CFR 1910.120: <i>Hazardous Waste Operations and Emergency Response</i> ; general worker safety is covered elsewhere within the law.
	State	
	Missouri Solid Waste Management Law (Sect. 260.200 RSMo)	The Missouri Solid Waste Management Law was promulgated in 1986. In it, the MDNR was authorized to administer the state Solid Waste Management Program. The program establishes permit requirements for landfill operations and sets standards for the disposal of nonhazardous waste in landfills. The regulations recognize a waste category called "special waste" that, though nonhazardous, may require special handling.
Missouri Hazardous Waste Management Law (Sect. 260.365 RSMo)	This law was promulgated in 1986 and established standards and rules governing management of hazardous waste consistent with Federal RCRA requirements. The program is supervised and administered by the MDNR through the Hazardous Waste Program, Division of Environmental Quality.	
Air	State	
	Missouri Air Conservation Law	The Missouri Air Conservation Law in its present form was passed in 1986. It assigned the Missouri Air Conservation Commission to the authority of the MDNR, Division of Environmental Quality.

Table 5-1 List of ARARs for Richards-Gebaur AFB FS		
Media	Requirement	Requirement Synopsis
Chemical-Specific ARARs		
Groundwater	Federal	
	Federal Safe Drinking Water Act MCLs (40 CFR 141.11-141.16)	This act consists of promulgated standards or levels (concentrations) for a broad range of COCs in public drinking water supplies. It may be considered relevant and appropriate for groundwater aquifers used for drinking water. The site groundwater is not used and will not likely be used as a drinking water source in the future.
	State	
	Missouri Safe Drinking Water Act (Sect. 643 RSMo)	Passed in 1979, but its original authority dates back to 1939. It is implemented by the MDNR's Division of Environmental Quality as the Public Drinking Water Program. The law parallels its federal equivalent and stipulates maximum and secondary contaminant levels and monitoring requirements for public drinking water systems.
	MDNR, UST Closure Guidance Document, Division of Environmental Quality, Hazardous Waste Program, March 1996	Provides sections on UST closure checklist, UST closure requirements, UST registration and fees, notification requirements for UST closure, UST closure using Industry Standards, Sampling and Analysis, Treatment and Disposal, UST Closure Report, and references.
MDNR, CALM, Division of Environmental Quality, Hazardous Waste Program, September 1998	The CALM guidance document outlines a process for determining cleanup goals at sites with known or suspected hazardous substance contamination. The CALM process was developed for hazardous substance contamination which is remediated under Missouri's Voluntary Cleanup Program laws and regulations (10 CAR 25-15.010).	
ARARs = Applicable or relevant and appropriate requirements CFR = Code of Federal Regulations		CSR = Code of State Regulations USC = United States Code

Clean Water Act (33 U.S.C. 1251 et seq.)

The Clean Water Act, a major amendment of the original 1972 Federal Water Pollution Control Act, was passed in 1977. Its chief purpose is to restore and maintain surface water quality by controlling discharges of chemicals (priority toxic pollutants) to surface water.

Underground Injection Control Program (40 CFR 146 Subpart F)

Passed in 1980, and amended in 1982, the regulation establishes criteria and standards for underground injection control programs that place non-hazardous fluids into aquifers.

Resource Conservation and Recovery Act (RCRA) (42 U.S.C. 321 et seq.)

RCRA was passed in 1976. It amended the Solid Waste Disposal Act by including provisions for hazardous waste management. The statute sets out to control the management of hazardous waste from its inception to its ultimate disposal.

Toxic Substances Control Act (TSCA) (15 U.S.C. 2601 et seq.)

TSCA was created in 1976. It institutes a range of control measures, primarily record-keeping and reporting requirements, intended to document the production and use of hazardous chemicals, and includes requirements for remediation and disposal of PCBs.

Hazardous Materials Transportation Act (49 U.S.C. 1801 et seq.)

The Hazardous Materials Transportation Act provides regulations governing the transportation of hazardous materials and hazardous waste. The regulations include record-keeping and reporting requirements; labeling and packaging requirements; and detailed handling requirements for each mode of transport (rail, air, waterway, or road).

Occupational Safety and Health Act (29 U.S.C. 61 et seq.)

OSHA was created in 1970 to ensure worker safety on the job. The U.S. Department of Labor oversees the act. Worker safety at hazardous waste sites is specifically addressed under 29 CFR 1910. 120: *Hazardous Waste Operations and Emergency Response*; general worker safety is covered elsewhere within the law.

Clean Air Act (42 U.S.C. 7401 et seq.)

The Clean Air Act is intended to protect the quality of air and promote public health. Title I of the Act directed the USEPA to publish national ambient air quality standards for "criteria pollutants." Emission standards are potential ARARs if selected remedial technologies (such as incinerators or air strippers) produce air emissions of regulated Hazardous Air Pollutants.

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, USEPA developed chemical concentration limits and management standards for public drinking water supplies known as MCLs and maximum contaminant level goals. The drinking water standards are potential ARARs at the AFB.

Endangered Species Act (16 U.S.C. 460 et seq.)

The Endangered Species Act was passed in 1973. It establishes a program for the conservation of endangered and threatened plants and animals, and the habitats that support them. The Act is administered by the National Marine Fisheries Service and the U.S. Fish and Wildlife Service. The Fish and Wildlife Service maintains a list of 632 endangered species and 190 threatened species. The law prohibits any action, administrative or substantive, that results in "taking" a listed species or adversely affecting its habitat.

5.2.1 State ARARs for Richards-Gebaur AFB

Several laws and regulations of the state of Missouri are probable ARARs for Richards-Gebaur AFB. In essence, the state statutes are similar in scope to their federal counterparts but contain certain requirements specific to Missouri. Where state laws, under federal authority to the state, implement a federal program, state laws constitute ARARs.

Missouri Clean Water Law (Sect. 644 RSMo)

The Missouri Clean Water Law was enacted in 1986. The law, under Title 10, Division 20 of the Code of State Regulations, 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.

Missouri Underground Storage Tank Act (Sect. 319.100 RSMo)

The original UST law was passed in 1989. Technical requirements are incorporated within the mandate of the Missouri Clean Water Law.

Class III Mineral Resources Injection/Production Well Operating Permits (10 CSR 20-6.090)

This regulation, established in 1984, provides the mechanism for the State to issue Class V underground injection permits through its Water Pollution Control Program.

Missouri Water Well Drillers Act (Sect. 256.600 RSMo)

The Missouri Water Well Drillers Act, passed in 1994, is administered by the State Division of Geology and Land Survey. It provides standards for subsurface drilling, including construction and abandonment of water wells, monitoring wells, and test holes.

Missouri Hazardous Waste Management Law (Sect. 260.365 RSMo)

The Missouri Hazardous Waste Management Law was promulgated in 1986 and established standards and rules governing the management of hazardous waste consistent with Federal RCRA requirements. The program is supervised and administered by the MDNR through the Hazardous Waste Program, Division of Environmental Quality.

Missouri Air Conservation Law (Sect. 643 RSMo)

The state Air Conservation Law was passed in 1986. It assigned the Missouri Air Conservation Commission to the authority of MDNR's Division of Environmental Quality.

Missouri Safe Drinking Water Act (Sect. 640.100 RSMo)

The Missouri Safe Drinking Water Act was passed in 1979, but its original authority dates to 1939. It is implemented by the MDNR's Division of Environmental Quality as the Public Drinking Water Program. The law parallels its federal equivalent and stipulates maximum and secondary contaminant levels and monitoring requirements for public drinking water systems.

Missouri Solid Waste Management Law (Sect. 260.200 RSMo)

The Missouri Solid Waste Management Law was promulgated in 1986 and gives MDNR authority to administer the state's Solid Waste Management Program. The program establishes permit requirements for landfill operations and sets standards for the disposal of nonhazardous waste in landfills. The regulations recognize a waste category called "special waste" that, though nonhazardous, may require special handling.

5.3 RAOs

According to the USEPA Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites (USEPA, 1988) and the NCP, RAOs are site-specific goals that are established on the basis of the nature and extent of the contamination, the resources that are currently and potentially threatened, and the potential for human and environment exposure. The RAOs specify contaminants and media of concern, potential exposure pathways, and identify PRGs. Remediation goals are site-specific, quantitative goals that define the extent of cleanup required to achieve the RAOs. These goals are PRGs in the FS, and they will be finalized in the ROD for the site.

In this section, RAOs are identified for VOCs in groundwater at Richards-Gebaur AFB. RAOs are based on the exposure pathways found to present potentially unacceptable risks, based on the results of the HHRA as summarized in Section 4.3. Because there are no exposed populations, the identified risks are associated with potential future exposures to contaminated groundwater.

The HHRA found the following potential future exposure pathways exceeding the "point of departure" risk of 1×10^{-6} (carcinogens) or a hazard index of 1 (noncarcinogens) for the reasonable maximum exposure scenario:

- Ingestion of drinking water
- Inhalation of VOCs emitted from domestic-use water

Risks associated with inhalation of VOCs potentially resulting through migration from groundwater to indoor air were found to be lower than 1×10^{-6} or a hazard index of 1, as shown in the supplemental groundwater risk assessment presented in Appendix B.

For the purposes of the FS, RAOs, remediation goals, and remediation strategies developed assume that the future land use at Richards-Gebaur AFB will be residential, that the underlying groundwater is potable (i.e., of good quality and good yield), and that residents will install domestic wells to access groundwater as a preferred drinking source rather than using the available municipal supply from Kansas City.

The following RAOs for contaminated groundwater at the Base have been identified:

- Reducing concentrations of COCs to regulatory-acceptable levels
- Preventing human exposure to contaminated groundwater that has concentrations of COCs exceeding the risk range of 1×10^{-4} to 1×10^{-6} (carcinogens) or a hazard index of 1 (noncarcinogens) for the reasonable maximum exposure scenario
- Preventing discharge of contaminated groundwater to surface water at concentrations that result in exceedances of surface water quality standards

The RAOs are discussed further below.

5.3.1 Reducing Concentrations of COCs to Regulatory-Acceptable Levels

Environmental professionals regard the presence of chlorinated hydrocarbons in groundwater as one of the most difficult and intractable remediation problems in the industry. Nonetheless, it is incumbent upon the USAF to attempt to restore groundwater resources to acceptable quality, as represented by applicable risk-based standards set forth in MDNR's CALM guidance.

5.3.2 Preventing Human Exposure to Contaminated Groundwater

There are no complete exposure pathways to contaminated groundwater beneath the six FS sites because no known domestic wells are in use within 5 miles of Richards-Gebaur AFB. Nonetheless, if contaminated groundwater were used as a future source of domestic water, unacceptable health risks would arise. Therefore, remedial actions must mitigate the potential for human exposure to contaminated groundwater.

5.3.3 Preventing Discharges of Contaminated Groundwater to Surface Water

The nearest surface water body (with the exception of the small pond east of SS 012) to the six contaminated sites is Scope Creek, which lies several hundred feet from any of the contaminated groundwater sites. A third RAO, therefore, is to mitigate potential discharges of contaminated groundwater to surface water at concentrations that would adversely affect the ambient surface water quality.

5.4 PRGs

To meet the RAOs defined in Section 5.2, it is necessary to estimate the extent of groundwater contamination that does not satisfy RAOs. To do this, PRGs are developed to help define the extent of contaminated groundwater requiring remedial action. In general, PRGs correspond to ARARs and other applicable guidance that provides risk-based concentrations for COCs. This section presents the PRGs for contaminated groundwater at Richards-Gebaur AFB and delineates the areas of affected groundwater exceeding PRGs at each site that will be addressed in the FS.

In general, PRGs establish concentrations of COCs judged to pose no unacceptable risk to human health and the environment. Typically, PRGs are developed considering these factors:

- An acceptable USEPA-approved risk range equivalent to an excess cancer risk between 1×10^{-4} and 1×10^{-6} ; a chronic health risk defined by a hazard quotient of 1; or a significant ecological risk
- Chemical-specific ARARs
- Technical limitations, uncertainties, and other pertinent information

A number of the above factors have been discussed in the summary of site-related risks and RAO development. For the purposes of the FS, and consistent with the RI, RAOs for VOC-contaminated groundwater correspond to the chemical-specific Tier 1 Screening Levels developed for the Basewide RI/FS. In general, drinking water MCLs were used as Tier 1 Screening Levels for chemicals in groundwater. In cases where MCLs were not available, USEPA Region 9 PRGs for drinking water were used as the screening levels.

The area of contaminated groundwater is defined by the area over which concentrations of one or more of the COCs exceed their corresponding PRGs for groundwater. The most widespread contaminants are TCE and its daughter products cis-1,2-DCE and vinyl chloride.

The areas exceeding PRGs for groundwater at the six sites are summarized in Table 5-2 and depicted in Figures 5-1 through 5-6. The total area is estimated to be 9 acres. The volume of groundwater with VOC concentrations exceeding PRGs is estimated to be 15 million gallons, assuming an effective porosity of 25 percent and an average saturated thickness of 20 feet. Note that this is a conservative estimate that, in all probability, overstates the extent of contaminated groundwater at Richards-Gebaur AFB.

Site ID	Area of Contaminated GW (acre)	Volume of Contaminated GW (million gallons)
SS 003	0.23	0.37
SS 006	4.70	7.66
SS 009	0.08	0.13
SS 012	3.44	5.60
ST 005	0.41	0.67
ST 011	0.23	0.37
Total	9.09	14.80

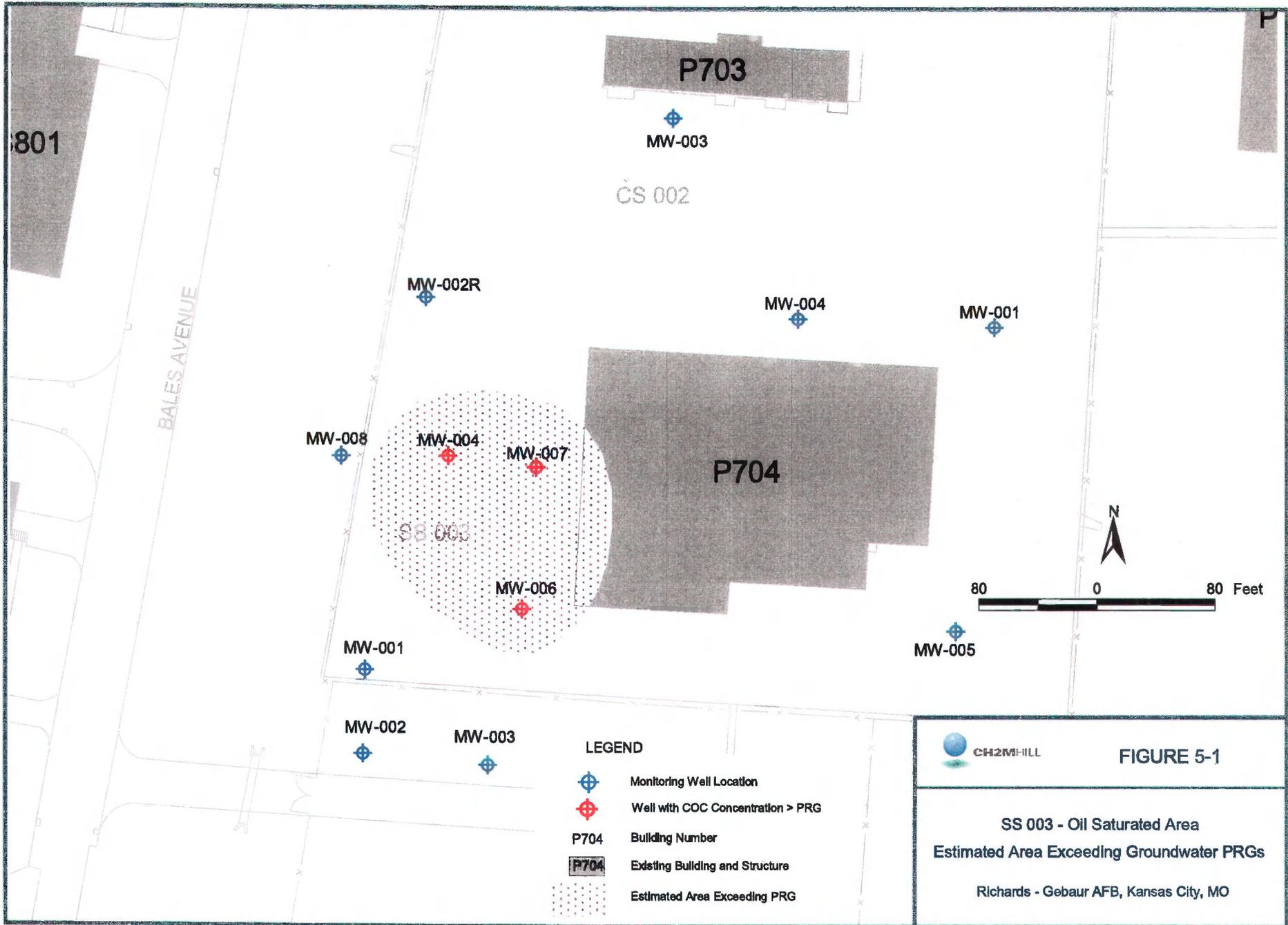
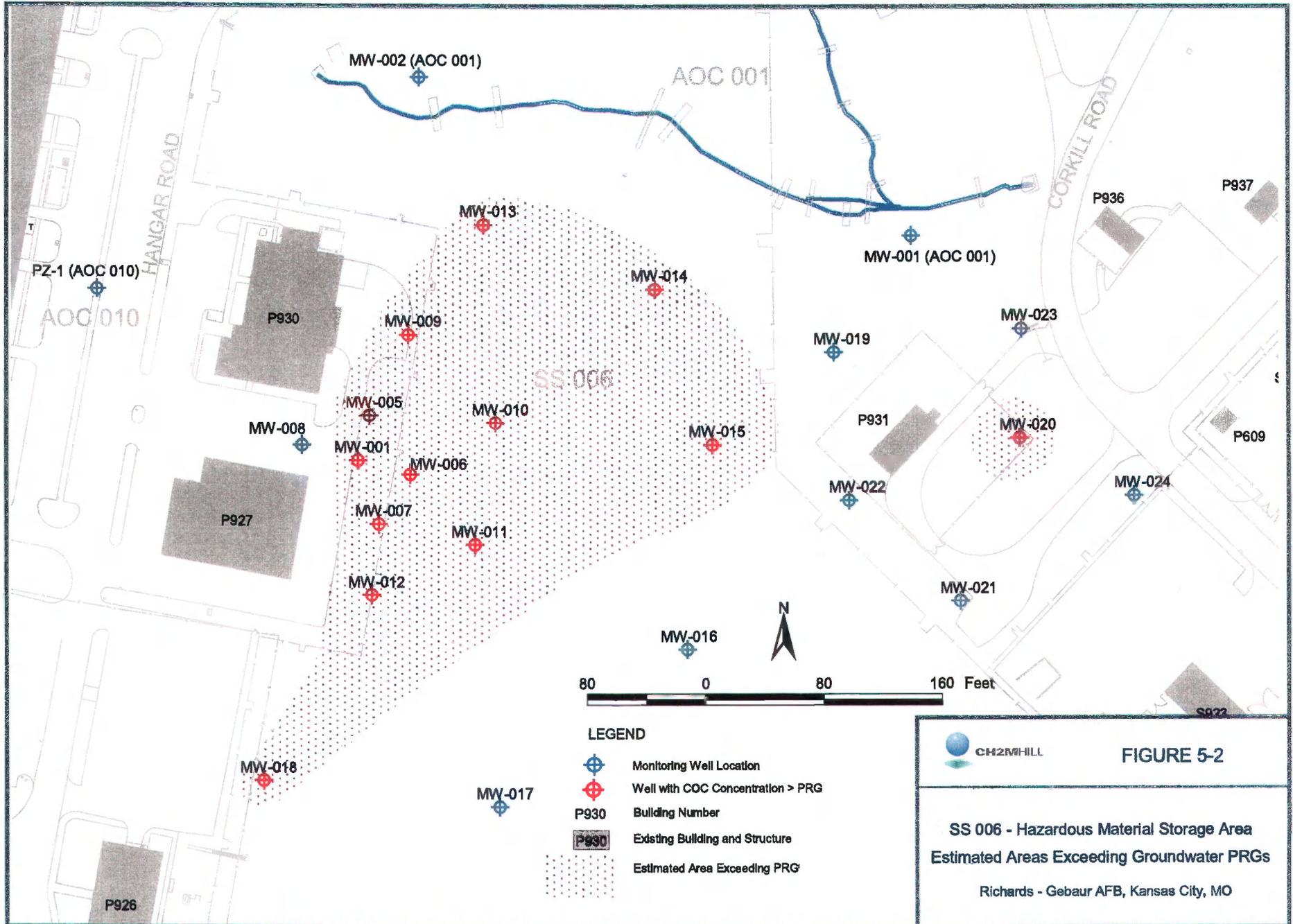
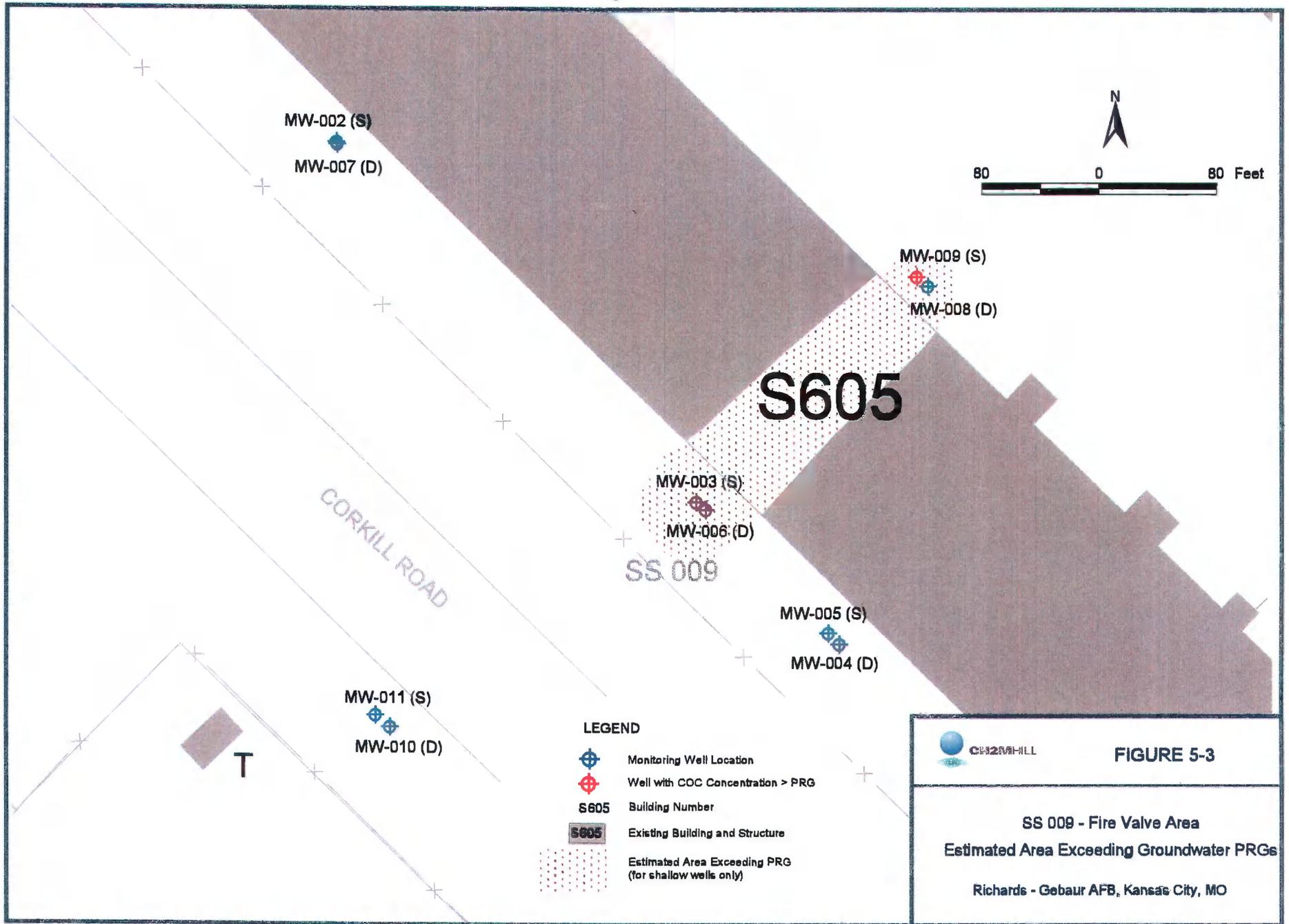


FIGURE 5-1

SS 003 - Oil Saturated Area
Estimated Area Exceeding Groundwater PRGs

Richards - Gebaur AFB, Kansas City, MO





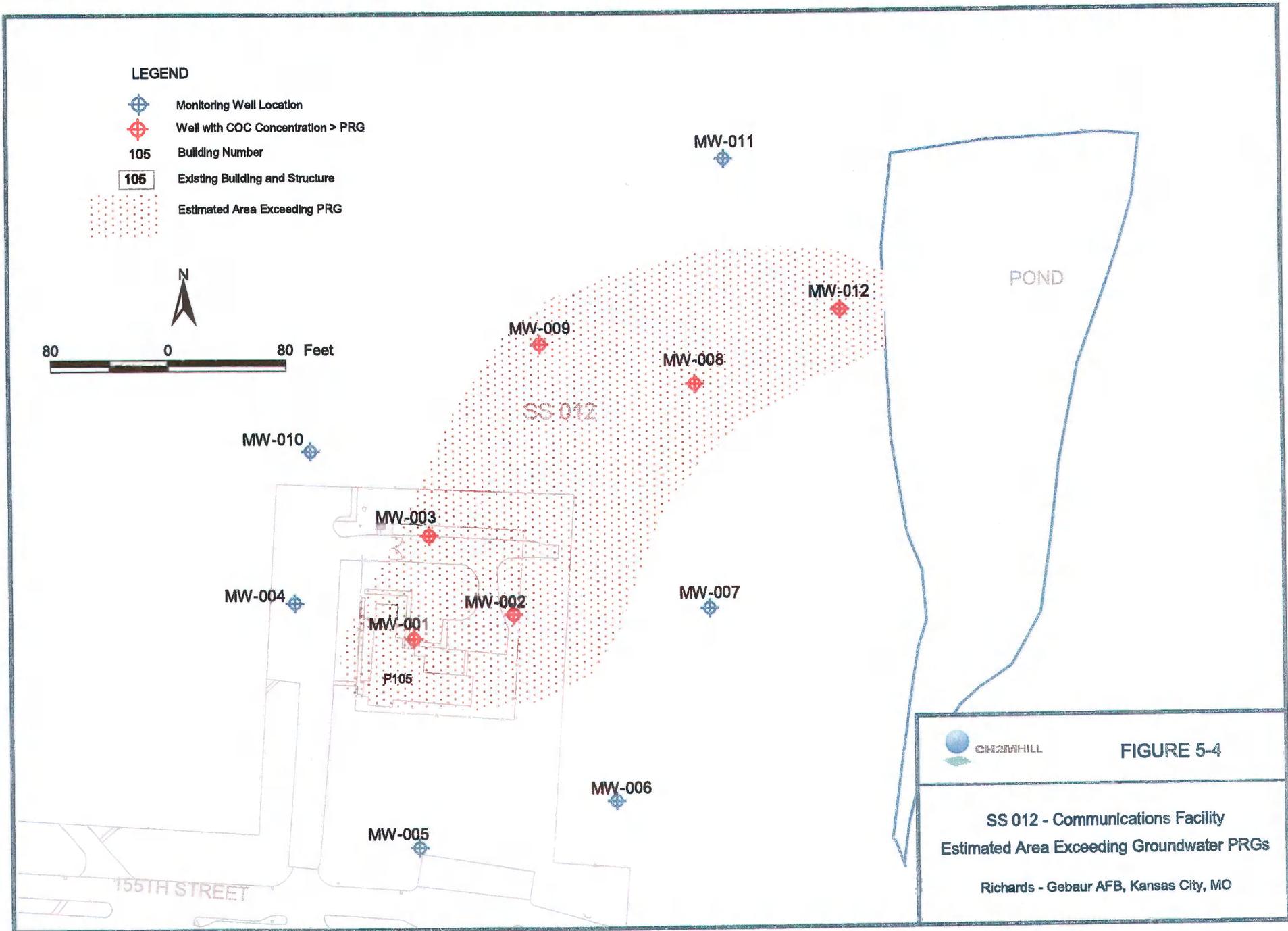
LEGEND

-  Monitoring Well Location
-  Well with COC Concentration > PRG
-  Building Number
-  Existing Building and Structure
-  Estimated Area Exceeding PRG (for shallow wells only)

 **FIGURE 5-3**

SS 009 - Fire Valve Area
Estimated Area Exceeding Groundwater PRGs

Richards - Gebaur AFB, Kansas City, MO



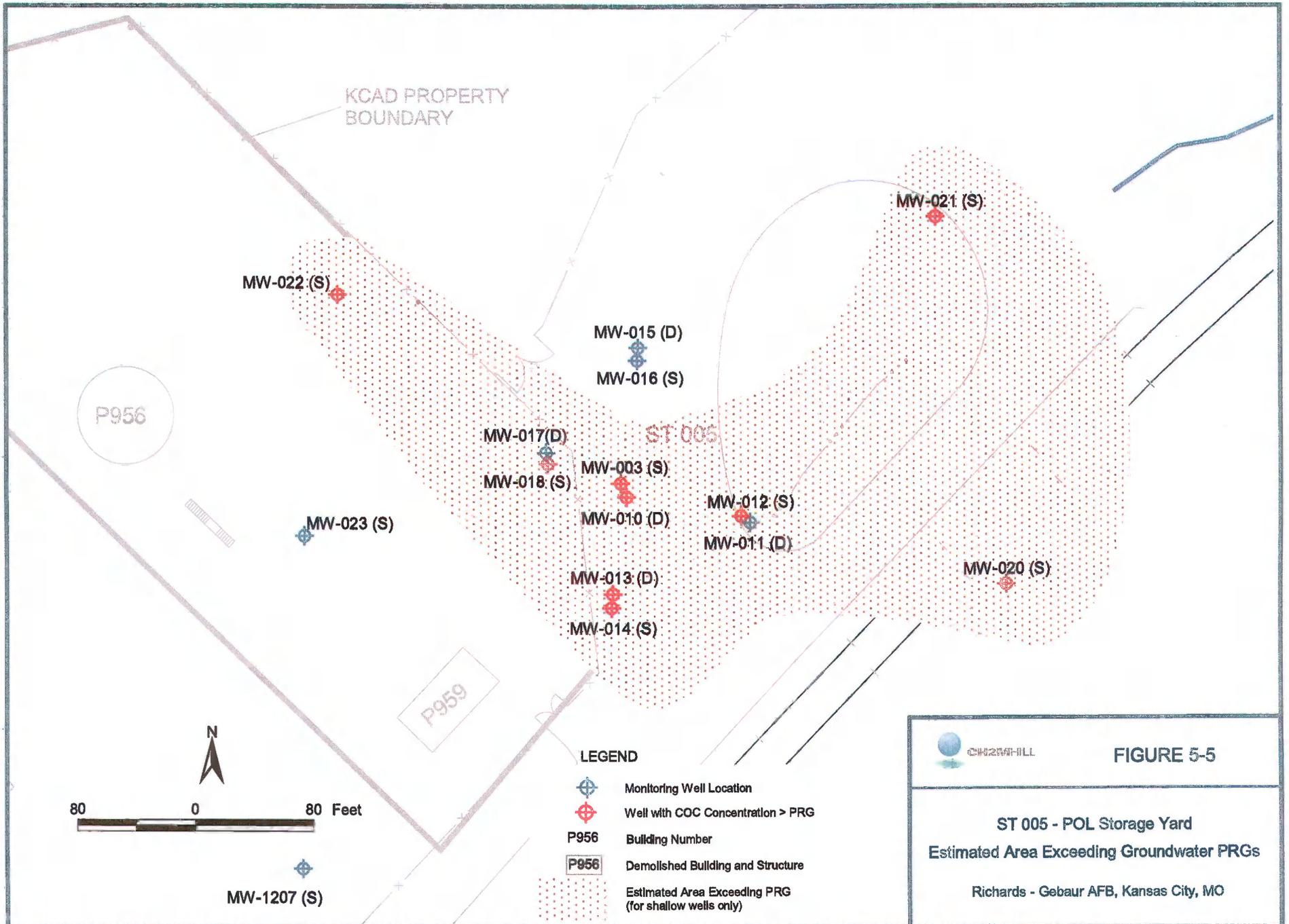
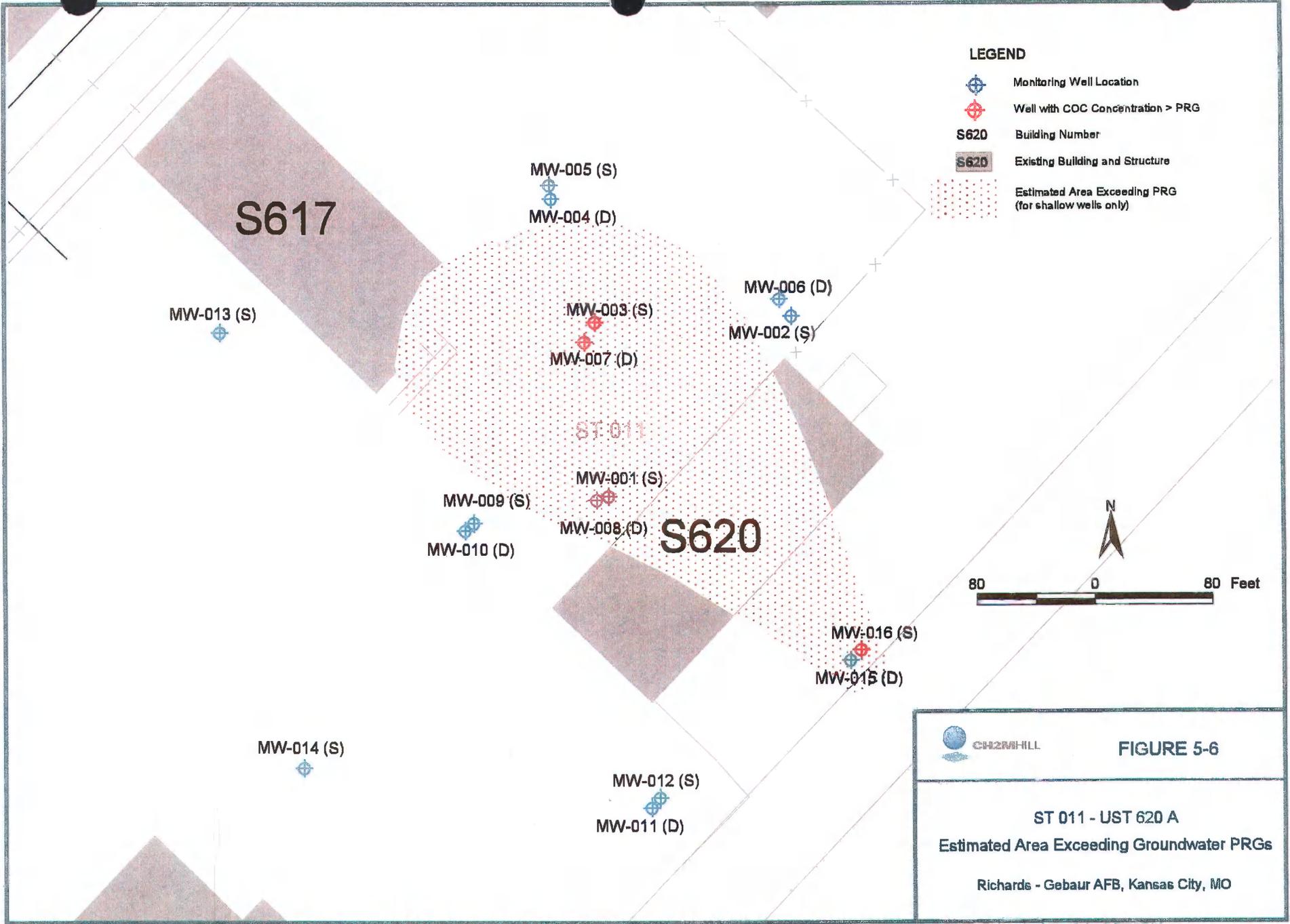


FIGURE 5-5

ST 005 - POL Storage Yard
Estimated Area Exceeding Groundwater PRGs

Richards - Gebaur AFB, Kansas City, MO



6. Identification and Screening of Remedial Technologies and Process Options

This section describes the process used to reduce the lengthy list of potential remedial technologies and process options to a short list of remedial candidates. The methodology used follows standard USAF and USEPA guidance and is consistent with the NCP.

6.1 General Response Actions

As defined in the USEPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*, Interim Final, October 1988 (USEPA, 1988), general response actions are media-specific actions that satisfy the RAOs. The media of concern at Richards-Gebaur AFB are soil and groundwater. Soil contamination at the Base is being addressed separately, through an EE/CA and a soil removal action, informally referred to as the Big Dig program. Accordingly, groundwater is the only medium of concern for the FS.

After the RAOs and PRGs for groundwater were developed, four general response actions consistent with these objectives and goals were identified. These actions for mitigating risks posed by contaminated groundwater may be applied individually or in combination. In addition, no further action was also considered to meet CERCLA requirement for comparison as a baseline. The general response actions for groundwater at Richards-Gebaur AFB are:

1. No Further Action
2. Land Use Controls (LUCs)
3. Long-Term Monitoring (LTM)
4. Monitored Natural Attenuation (MNA)
5. Groundwater Treatment

Once the general response actions have been identified, a list of feasible remedial technologies and process options was developed based primarily on their implementability.

6.2 Potential Remedial Technologies and Process Options

To help select the most promising remedial action alternatives, a list of potentially applicable remedial technologies and process options that satisfy the general response actions for contaminated groundwater was developed (Table 6-1). The list is based on professional experience, published sources, and other relevant documentation. The technologies and process options in Table 6-1 were first qualitatively screened according to technical implementability. The evaluation considered the state of technology development, site conditions, waste characteristics, the nature and extent of contamination, and the presence of constituents that could limit the effectiveness of the technology.

The technologies and process options remaining are described below and further screened using a qualitative comparison based on effectiveness, implementability, and cost.

Effectiveness pertains to the capability of a remedial technology to treat the estimated volumes of contaminated groundwater and/or to prevent or minimize the migration of the groundwater; the degree of protection afforded to human health and the environment during construction and implementation of the remedial technology; and/or the reliability and performance of the remedial technology with respect to the site conditions.

Implementability refers to the availability and capacity of onsite or offsite treatment, storage, and disposal services; the constructability of the remedial technology under site conditions; and the time needed to implement the remedial technology to achieve beneficial results and to satisfy the RAOs.

Cost considers both capital and operation and maintenance (O&M) costs of the proposed technology, and compares costs between technologies and cost of the technology to the outcome benefits. During the screening process, detailed, site-specific cost estimates were not developed—these will be provided during the detailed analysis of remedial alternatives.

The relative cost was considered only if the cost of a technology was believed to be significantly higher than the cost of the other technologies that are comparably effective or implementable. Therefore, the emphasis was placed on the overall effectiveness and implementability while comparing the potential remedial technologies and process options.

Following the qualitative screening, only the remedial technologies and process options considered most feasible for achieving RAOs for contaminated groundwater at Richards-Gebaur AFB are carried forward, assembled into remedial alternatives, and subjected to the detailed analysis described in Section 7.

6.3 Screening of Remedial Technologies and Process Options

The remedial technologies and process options provided in Table 6-1 are described below and are screened further using the three qualitative criteria identified above in Section 6.2.

6.3.1 No Further Action

The NCP requires that the no further action alternative be retained throughout the FS process as a basis of comparison for other approaches.

6.3.1.1 Description

No further action means that nothing will be done at Richard-Gebaur AFB to change the current contaminated groundwater conditions. For example, under this scenario, ongoing quarterly groundwater monitoring would cease and the monitoring well network would become dormant. The alternative provides a base condition against which the remaining alternatives can be evaluated.

6.3.1.2 Effectiveness

This alternative will not effectively mitigate human health and ecological risks posed by residual VOCs in groundwater at Richards-Gebaur AFB. Although the site groundwater is not used for human consumption, this alternative has no provisions to ensure that groundwater contaminated with VOCs will not be used for human consumption in the future. In addition, this alternative does not prevent or control potential exposure of construction workers to contaminated groundwater if excavation and subsurface construction occur.

Table 6-1
Implementability Screening Summary, Richards-Gebaur AFB

General Response Action	Remedial Technology	Process Option	Description	Implementability	Screening Comments
No Further Action	None	None	No action provided.	Easy	Retained for comparison.
Institutional Controls	Land Use Controls	Deed restrictions	Deed restriction issued for property, source area, or downgradient exceeding MCLs to restrict groundwater and land use.	Easy	Retained.
		Fences	Security fences installed and maintained around property, source area, and/or downgradient area exceeding MCLs.	Easy	Retained.
		Permits	Regulations promulgated to require a permit for various activities (i.e., excavation, installation of wells, etc)	Easy	Retained.
Long-Term Monitoring	Monitoring	None	Short- or long-term routine monitoring is implemented to record site conditions and concentration levels.	Easy	Retained.
Monitored Natural Attenuation	Monitoring	None	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.	Easy	Retained.
Groundwater Treatment (in situ)	Physical treatment	Air sparging	Air injected into groundwater through a system of wells or horizontal perforated pipes to remove volatile compounds. May be combined with soil vapor extraction to collect chlorinated VOCs.	Difficult	Rejected because the low permeability would prohibit the adequate and even distribution of injected air.
		Hot water or steam flushing/stripping	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 by six phase soil heating (SPSH), radio frequency, etc.	Moderate to Difficult	Rejected because the low permeability would prohibit the adequate and even distribution of hot water or steam.

Table 6-1
Implementability Screening Summary, Richards-Gebaur AFB

General Response Action	Remedial Technology	Process Option	Description	Implementability	Screening Comments
		In-well air stripping (circulating wells)	Groundwater is aerated and lifted within a well bore, reinfilters a different strata of the formation, and creates groundwater circulation.	Difficult	Rejected because it is inefficient in sites with strong flow patterns (e.g., bedrock fractures). Requires close well spacing.
		Dual phase extraction (DPE)	Use of groundwater collection system to lower water table to expose soil. Soil vapor extraction is then used to remove absorbed or trapped contaminants.	Moderate	Retained. DPE is a full-scale technology and commercially available.
		Hydraulic fracturing	High-pressure injection of fluids, followed by granular slurry, to create subsurface fracture patterns that minimize COC travel time via diffusion. Complements vapor or fluid extraction technologies.	Moderate	Retained in combination with enhanced reductive dechlorination (i.e. HRC). Hydraulic fracturing is a pilot-scale technology.
		Pneumatic fracturing	High-pressure injection of air to create self-propped subsurface fracture patterns that minimize COC travel time by diffusion. Complements vapor and fluid extraction technologies. The fracturing extends and enlarges existing fissures and introduces new fractures, primarily in the horizontal direction.	Moderate	Rejected because the pressures used are very high and might drive the groundwater plumes away from the injection site. In addition, pneumatic fracturing has been protected by patents owned by the New Jersey Institute of Technology (NJIT).
	Chemical treatment	Chemical oxidation	Oxidant such as hydrogen peroxide is injected, which chemically oxidizes organic contaminants to less harmful or totally harmless compounds such as CO ₂ and H ₂ O.	Difficult	Rejected because it is difficult to achieve good mixing in situ and because handling of highly concentrated oxidants may induce safety concerns in areas where human activities are high.
		Chemical reduction	Aqueous injection of reducing agents (zero-valent iron, hydrogen) to promote abiotic in situ reduction of chlorinated organic compounds.	Difficult	Rejected because the low permeability media prohibits the chemical injection. Besides, it is still a rather innovative technology with considerable uncertainty on fundamental design parameters.

Table 6-1
Implementability Screening Summary, Richards-Gebaur AFB

General Response Action	Remedial Technology	Process Option	Description	Implementability	Screening Comments
		Permeable reactive barriers (passive treatment walls)	Permeable treatment units are installed across the flow path of an impacted plume. As groundwater moves through the treatment wall, chlorinated VOCs are passively removed in the treatment zones by physical, chemical, and/or biological processes.	Moderate	Retained.
	Biological treatment	Bioaugmentation	The injection of chemical-specific nonindigenous engineered microorganisms to the subsurface to promote biodegradation.	Difficult	Rejected because augmented microbes are very likely to be out-competed by the indigenous microbes. Requires site-specific bench and/or pilot-scale testing.
		Enhanced Reductive Dechlorination (i.e. HRC)	Use of an organic substrate to promote chlorinated compound degradation via dechlorination mechanism where the chlorine molecular is replaced by hydrogen.	Moderate	Retained. Requires site-specific bench and/or pilot-scale testing.
		Phytoremediation	Use of plants to remove, stabilize, or destroy contaminants in soil or groundwater.	Difficult	Rejected because it requires sufficient space above plume to plant enough trees to remove the groundwater. Building or parking lots may need to be relocated for tree planting.
Groundwater Treatment (ex situ)	Physical treatment	Air stripping	Large volumes of air mixed with water in a packed column to promote transfer of chlorinated VOCs to air.	Moderate	Retained in combination with soil vapor extraction, pump and treat, and SPSH to collect chlorinated VOCs from extracted water.
		Carbon adsorption	Contaminants adsorbed onto activated carbon by passing contaminated water or air through a carbon column.	Moderate	Retained in combination with soil vapor extraction, pump and treat, and SPSH to collect chlorinated VOCs from extracted water.

Table 6-1
Implementability Screening Summary, Richards-Gebaur AFB

General Response Action	Remedial Technology	Process Option	Description	Implementability	Screening Comments
		Pump and treat	Series of wells to extract contaminated groundwater.	Moderate	Retained to extract contaminated water while creating a hydraulic barrier to prevent lateral migration of plume.
	Chemical treatment	Chemical oxidation	Contaminated water mixed with an oxidant, such as hydrogen peroxide, ozone, UV light, etc., to destroy the organic compounds.	Moderate	Rejected because chlorinated VOCs are more easily treated with air stripping and carbon adsorption.
		Solar detoxification	A process destroying contaminants by strong-oxidizing free radicals. Contaminated water is mixed with a semiconductor catalyst such (e.g., titanium dioxide), and fed through a reactor, which is illuminated by sunlight.	Difficult	Rejected because not well documented.
	Biological treatment	Activated sludge	Contaminants are biodegraded through contact with microorganisms, which are either in an attached or suspended culture.	Difficult	Rejected because of the low yield aquifer and the insufficient substrate concentrations to promote biological growth. Besides aerobic degradation of chlorinated VOCs is less effective than anaerobic.
		Anaerobic reactor	Organics degraded by microorganisms in an anaerobic environment.	Difficult	Rejected because of the low yield aquifer and the insufficient substrate concentrations to promote biological growth.
		Fluidized bed biological treatment	Contaminated water flow through fluidized media (sand, coal, GAC, etc.) on which a microbial film has developed. Active biomass biologically degrades contaminants in water.	Difficult	Rejected because of the low yield aquifer.

6.3.1.3 Implementability

The no further action alternative is easily implemented.

6.3.1.4 Cost

There are no capital or O&M costs for the no further action alternative. However, the NCP requires 5-year site reviews as long as hazardous substances remain at the site above levels that allow unlimited use and unrestricted exposure.

6.3.1.5 Conclusions

This alternative will not meet the RAOs because contaminated groundwater will continue to exist at the six sites without any monitoring or other controls to prevent exposure through future water well drilling or subsurface construction. Although some reduction in volume and toxicity of organic contaminants most likely would be achieved over time through natural attenuation, the rate of biodegradation would be slow. The no further action alternative is retained as a remedial alternative in the FS, as required by the NCP, to serve as a baseline for comparison to other remedial alternatives.

6.3.2 Land Use Controls

Land use controls (LUCs) are legal, administrative, or physical constraints that restrict or control access to property. They include institutional controls and site controls. Institutional controls are nonengineering, nontechnical mechanisms used to prevent or control exposure to contaminants and are commonly applied to property titles. Site controls are physical means to control site access, such as fences, warning signs, and other security features.

6.3.2.1 Description

Several types of LUCs can be used to mitigate potential risk of exposure to contaminated groundwater at Richards-Gebaur AFB. The two most common are governmental (including zoning restrictions or permit requirements) and real property-based (including title notifications and restrictive covenants). At Richards-Gebaur AFB, for example, LUCs could entail placing a restrictive covenant (deed restriction) on the property deed. The deed restriction would notify the public that residual groundwater contamination is present and would either prohibit or limit certain activities that would introduce unacceptable risks, such as excavating below a nominal depth, and well installation restrictions in zone of groundwater contamination. Such a restriction would be necessary if residual contamination concentrations exceeded applicable unrestricted land use (MDNR CALM Scenario A levels) chemical concentrations. A restrictive covenant can prescribe certain activities, such as annual groundwater monitoring or periodic site inspections, to ensure the continued integrity of monitoring wells or other remedial action components.

6.3.2.2 Effectiveness

LUCs cannot change the magnitude of contamination present, but they can be effective in preventing human or ecological exposure to residual chemicals at a site. At Richards-Gebaur AFB, appropriate LUCs such as deed restrictions can inform the public that residual contamination exceeding applicable MDNR unrestricted land use guidelines is present. In addition, a prohibition on excavation or water well construction could be added to better protect public health and the environment. Specific provisions for monitoring and enforcing LUCs formally would be established with the acting property owners to ensure that the overall

remedial strategy is not compromised by damaged equipment (such as monitoring wells) or unanticipated changes in site use.

6.3.2.3 Implementability

LUCs are easily implemented, and specific guidance is available from the USAF and from USEPA. The state of Missouri's CALM guidance contains a detailed discussion of institutional controls and provides models of restrictive covenants for applicants to use. Because of the range of LUCs available, it is beneficial to develop a layering strategy of the various options that best apply to a given situation. The USAF has developed a detailed layering strategy for mitigating potential risk posed by VOCs in groundwater at Richards-Gebaur AFB. This strategy details the various components of LUCs that are currently available, and also indicates the parties responsible for administration of the various LUC vehicles (see Appendix D).

6.3.2.4 Cost

There are minimal capital costs associated with this alternative. The O&M cost would depend on the duration of any LUC monitoring program and other applicable regulatory requirements. LUCs could remain in place until groundwater concentrations meet the remedial goals, on the order of 50 years or more at some of the sites. Nonetheless, monitoring costs should be relatively low in comparison with remedial system performance monitoring, which typically involves sample collection and analysis.

6.3.2.5 Conclusions

LUCs can be effective tools for mitigating potential risks posed by the presence of residual concentrations of VOCs in groundwater. By preventing potential exposure to contaminated groundwater, LUCs represent a key element of the risk-based remediation and site closure process, and will be retained for further detailed analysis in the FS.

6.3.3 Long-Term Monitoring

LTM is used to evaluate changes in site conditions or process performance over time. It usually begins upon the completion of remedial construction or initiation of the selected remedy for a site. At Richards-Gebaur AFB, an LTM program could be used regularly and consistently to assess groundwater conditions each year following implementation of the preferred remedial alternative.

6.3.3.1 Description

LTM is a program of consistent evaluation that monitors the performance of the selected remedial approach. For sites with groundwater contamination, a LTM program would involve regular, periodic measurements of groundwater conditions. Parameters such as groundwater depth, flow direction, and flow rates can be tracked by regularly measuring water levels in site monitoring wells. Water quality, particularly the concentrations of residual VOCs, can be evaluated by routinely scheduled groundwater sampling events. A quarterly groundwater monitoring program has been in existence at each of the six sites with groundwater contamination at Richards-Gebaur AFB since October 2000.

6.3.3.2 Effectiveness

LTM has proven effective for documenting the progress of remedial actions over time. It most often is used in combination with other remedial action components and can

demonstrate that a remedial system is operating successfully, or, conversely, indicate that remedial system operation is failing to achieve performance targets.

6.3.3.3 Implementability

LTM is a straightforward, commonly-accepted site management technique and is therefore easily implemented. At Richards-Gebaur AFB, an extensive monitoring well network is in place, and groundwater depth and quality are being evaluated quarterly the six sites with VOCs in groundwater. As a result, any LTM program could use the established monitoring protocols and reporting schemes. LTM typically is used as a component of a broader-based final remediation strategy, particularly at sites with residual groundwater contamination.

6.3.3.4 Cost

There are no capital costs associated with this technology because the monitoring well network is established. O&M costs would depend on the duration of the monitoring program and applicable regulatory requirements. Monitoring costs would be relatively low because the slow rate of groundwater movement allows longer intervals between sampling events—for example, annual monitoring as opposed to quarterly. Also, the USEPA-mandated 5-year review would permit reevaluation of the efficacy of the LTM program and, if contaminant plumes are demonstrably stable or shrinking, could permit the cessation of LTM at that time.

6.3.3.5 Conclusions

LTM is a common component of groundwater remedial actions. Because groundwater monitoring has been taking place each quarter since July 2000, little additional effort would be required to translate the existing QGM program into a LTM program. Accordingly, LTM is easily implemented and very cost-effective in comparison with other technologies. Consequently, LTM will be retained for detailed evaluation.

6.3.4 Monitored Natural Attenuation

Natural attenuation is the process by which contaminant concentrations are reduced by various natural occurring physical, chemical, and biological processes. Monitored natural attenuation (MNA) is a systematic process through which the natural reactions are evaluated quantitatively over time through a formal monitoring program replete with sampling protocols, target analytical parameters, and a schedule for regular implementation.

6.3.4.1 Description

MNA is a plume management strategy that relies on in situ physical, chemical, or biological processes to attenuate groundwater contamination to acceptable levels. Natural attenuation of contaminants in groundwater is the combined effect of several naturally occurring mechanisms—dispersion, dilution, sorption, abiotic oxidation, hydrolysis, volatilization, and biodegradation—that reduce the concentration of dissolved-phase contaminants. These mechanisms include both destructive and nondestructive processes, with biodegradation being the most important destructive process. MNA can be implemented as a final remedial component at sites where the contaminant sources have been removed and only dissolved-phase contamination persists.

The most common process in anaerobic groundwater environments is for the chlorinated hydrocarbon to be used as an electron acceptor through reductive dechlorination. When the chlorinated hydrocarbon is used as an electron acceptor, an electron donor such as native organic carbon or anthropogenic carbon from fuel spills, landfill leachate, or other sources

must be present for the reaction to take place. Reductive dechlorination of chlorinated solvents yields an accumulation of daughter products such as cis-1,2- DCE, and vinyl chloride, and increased levels of chloride in the plume.

6.3.4.2 Effectiveness

MNA has proven effective for observing and documenting the natural attenuation of chlorinated VOCs in contaminated groundwater over time. In general, the effectiveness of natural attenuation is highly dependent on site characteristics and available time. According to the results of 14 natural attenuation treatability studies conducted at 14 USAF sites, the estimated length of time required for natural attenuation alone to achieve federal or state groundwater quality standards for chlorinated VOCs ranged from 17 years to more than 200 years (AFCEE, 1999). A screening tool for assessing whether site conditions are favorable for natural attenuation has been developed by AFCEE and was applied to the six FS sites. The results are contained in Appendix C.

During the past 2 years, 7 QGM events have taken place at Richards-Gebaur AFB, and specific natural attenuation parameters were collected twice in that time. While some evidence of natural attenuation of VOCs is apparent at certain sites, in general the ambient subsurface conditions do not appear to be ideally conducive for reductive dechlorination. Appendix C contains an assessment of the potential for natural attenuation to remediate groundwater effectively at each site.

6.3.4.3 Implementability

MNA is an easy remedial component to implement. Because a comprehensive monitoring well network has been established at the six sites with groundwater contamination, there should be no need to install additional monitoring wells. The necessary chemical and biological analytical parameters have been agreed to by the BCT as part of the QGM program, and the field methodologies and analytical protocols are well understood. However, although MNA has become widely accepted by regulators as a potential groundwater remedial alternative, more extensive outreach efforts may be required to gain public acceptance.

6.3.4.4 Cost

There are no capital costs for this technology. Monitoring costs would be relatively low because the slow rate of groundwater movement allows longer intervals between sampling events—annual monitoring as opposed to quarterly. The annual costs would be relatively low, but the total cost of the alternative might be relatively high depending on the number of years required to reach the target concentrations in the groundwater. If the plumes are stable and shrinking, the frequency of monitoring may be reduced significantly, but the total cessation of monitoring under MNA is usually not permitted until PRGs are met.

Under this alternative, the USEPA-mandated 5-year review would permit reevaluation of the efficacy of the MNA program and, if contaminant plumes are demonstrably stable or shrinking, could permit the cessation of MNA at that time.

6.3.4.5 Conclusions

MNA is a relatively low-cost remedial strategy that is relatively straightforward to implement at the Base because the monitoring network and methodologies are established and agreed to. However, analysis of the available data (Appendix C) indicates that site conditions at the Base are not conducive to natural attenuation. Consequently, the ability for residual

contaminants to naturally degrade within a reasonable timeframe remains uncertain. For these reasons, this technology was not retained for detailed evaluation.

6.3.5 Groundwater Treatment

Groundwater treatment can be achieved by applying physical, chemical, biological, or thermal techniques. The selected treatment can be accomplished in situ or ex situ. In situ treatment of groundwater entails treating groundwater while it remains in the subsurface, usually by introducing a change to the subsurface environment. By contrast, ex situ treatment requires subsurface groundwater to be removed so that treatment can be performed aboveground.

Possible approaches to in situ treatment of VOCs in groundwater include chemical oxidation, permeable treatment beds, air sparging, and biological treatment technologies. Ex situ treatment usually involves groundwater extraction using pumping wells. The contaminants would then be removed from the water by physical, chemical, or biological treatment, either onsite or offsite at an appropriately permitted treatment facility.

There are numerous treatment options for VOCs in groundwater, assuming that site conditions are compatible with the process under evaluation. However, because of the ubiquitous low flow rates and presence of shallow weathered bedrock, many of the technologies that rely on moving fluids through the subsurface are at a technical disadvantage and unlikely to be effective at Richards-Gebaur AFB and thus were screened out based on technical implementability (see Table 6-1).

Accordingly, four groundwater treatment technologies were considered implementable given the constraining site conditions at Richards-Gebaur AFB: accelerated natural attenuation (ANA) using substrate addition (specifically HRC); permeable reactive subsurface barrier; dual phase extraction (DPE); and six phase subsurface heating (SPSH). These four options are discussed below.

6.3.5.1 ANA Using HRC

As noted, natural attenuation processes can act in the subsurface to reduce concentrations of organic chemicals such as VOCs in groundwater. However, such transformations can take an unreasonably long time, particularly if there is a need to close and transfer a given parcel of land. One solution to this problem is to enhance or accelerate the naturally occurring processes by introducing a chemical substrate to the subsurface to help stimulate the needed chemical transformations.

Substrates being used to speed up reductive dechlorination include vegetable oil, molasses, and HRC. A method currently favored involves injecting HRC into the subsurface to enhance ongoing natural attenuation processes. This approach is discussed in detail below.

Description. HRC is an injectable fluid that helps promote reductive dechlorination of VOCs in the subsurface. The compound slowly releases over time into the contaminated groundwater and migrates away from its injection point primarily through chemical diffusion as opposed to advection. HRC placement can be accomplished through three techniques, all of which rely on injecting the HRC into the contaminated groundwater through direct-push steel rods.

One approach uses a grid design to inject the HRC into the subsurface. This approach is tailored for smaller sites with a well-delineated groundwater plume. Another approach is to install a line of injection points that effectively creates a linear barrier of HRC at the

downgradient boundary of a plume. The third approach modifies either of the other two by using hydraulic fracturing techniques to increase the subsurface permeability. However, hydraulic fracturing is difficult to implement, and, to our knowledge, has not been used in combination with HRC placement to remediate a groundwater plume. Using conventional drilling as a mechanism for HRC placement was not considered because of the cost to dispose of investigation-derived waste from drilling.

Option 1: HRC Placement in a Grid. Direct push technologies consist of the use of hydraulic rams or rotation or vibration to advance a hollow drill rod into the subsurface. Few to no drill cuttings are brought to the surface, and the process is rapid compared to conventional drilling. For HRC placement, the direct push rig will advance a drill rod to a predetermined depth, and the HRC will be pumped down the rod under pressure. According to the manufacturer, because of the inherent low hydraulic conductivities of the clay soils and bedrock, HRC movement will be primarily through diffusion as opposed to advection. Therefore, to get HRC to spread evenly throughout the zone of groundwater contamination, numerous injection holes are required.

Drawbacks to placing HRC using a grid of injection points appear to be limited to the small amount of HRC that can be placed in each hole and the slow rate of material dispersal out of the injection holes and into the groundwater. This means that grid spacings must be small (10 feet or less), which may become a limiting factor for sites larger than 1 acre.

Option 2: HRC Placement in a Treatment Barrier. In some instances, especially where contaminant plumes are large, the high number of HRC grid placement points results in excessive material delivery costs. It may then be more effective to excavate a trench perpendicular to the groundwater flow direction across the leading edge of the plume and to place the HRC inside the trench, creating a subsurface groundwater treatment barrier. Conceptually, the contaminated groundwater would flow into and through the HRC barrier, thereby increasing biological activity and the release of hydrogen ions that would react with dissolved VOCs. This method does not, however, reduce the amount of time for the plume area upgradient of the barrier to attain PRGs.

To use this technology to place HRC in contact with most of the contaminated groundwater, multiple treatment barriers are needed, thereby reducing the cost savings relative to placement using other methods. If the approach were to place a single downgradient barrier of HRC and to assume all groundwater would eventually flow through it, then multiple barriers would not be required. However, the HRC would have to be replenished or replaced every few years and would necessarily require long-term groundwater monitoring.

Option 3: HRC Placement by Hydraulic Fracturing. Hydraulic fracturing, or hydrofracturing, involves the creation of fractures by the injection of fluid into subsurface materials under extreme pressures. A borehole is drilled and cased into the contaminated target zone, and large pumps are used to force liquid down the borehole. The pressures increase until the rock or soil matrix material breaks apart or fractures. Technologies developed and routinely used in the petroleum industry have been modified for shallow environmental applications. Ideally, at shallow depths the pressures caused by overburden are much less than the pressures caused by lateral support and the artificially produced fractures will tend to be subhorizontal in orientation; i.e. like a pancake. A hard granular material like quartz sand is injected with the fluid during the pumping and pressurization process, and the material rushes into the fracture with the fluid when the crack opens. This material is called a *propping agent* since its purpose is to prop the fracture open after the pressure dissipates.

For HRC injection, HRC is mixed into the hydrofracturing fluid and thus is spread throughout the fracture when it opens. Since this would be a sand filled zone within the shale bedrock, it would be a preferential flow zone for any groundwater due to its relatively much higher hydraulic conductivity. The contaminated groundwater within the subsurface would be directed to the flow zone containing the HRC material, resulting in stimulation and acceleration of in situ degradation.

Effectiveness. HRC-accelerated natural attenuation has been effective in addressing dissolved-phase chlorinated VOCs. Its success in restoring low concentrations of contaminants to drinking water quality is not well documented, although the preliminary results of many pilot studies have been promising. Repeated applications of HRC may be necessary to achieve RAOs at a given site. Before implementing this alternative full scale, a pilot-scale test would need to be run to determine the optimum design of a full-scale treatment program.

Based on the sites' geology and hydrogeology, the main drawbacks to using this alternative appear to be the small amount of HRC that can be placed in the subsurface and the slow rate of material dispersal and mixing with the local groundwater. Under this alternative, the monitoring well network would have to be augmented during the pilot study to document accurately the effectiveness of the remedy. Another disadvantage is that the strongly reducing environment created mobilizes naturally occurring iron and manganese. If the treated groundwater is near a surface water discharge location such as Scope Creek, the mobilized iron would precipitate, potentially raising aesthetic concerns along the creek bank.

Implementability. Given the site conditions, HRC-accelerated natural attenuation using a treatment grid or a treatment barrier to reduce VOC concentrations would be implementable at Richards-Gebaur AFB. Hydraulic fracturing is considered the least implementable of the three placement techniques.

Cost. The capital costs of HRC-accelerated natural attenuation are moderate to high, depending on the volume of groundwater being treated. Placement of HRC with grid patterns in contact with most of the contaminated groundwater at a site could be expensive. Should multiple injections of HRC be required, then barrier treatment costs may become similar to those expected for full-scale grid treatment.

O&M costs associated with HRC would be low. Similarly, monitoring costs would be low and comparable to those of other monitoring alternatives. Also, 5-year site reviews would be required as long as hazardous substances remain at the site above levels that allow for unlimited use and unrestricted exposures.

Conclusions. HRC-accelerated natural attenuation has the potential to reduce the toxicity and volume of contaminants and may be able to overcome the problems caused by low yield formations, like those beneath Richards-Gebaur AFB. Although somewhat expensive, the technology may prove effective and easily implemented, and may be able to achieve RAOs in a reasonable time. Therefore, this technology will be retained for detailed evaluation as a potential remedial alternative component.

6.3.5.2 Permeable Reactive Barrier

Another in situ option for groundwater treatment would be to place a permeable barrier of reactive materials in the subsurface to intercept a contaminant plume. As the groundwater flows through the wall, it reacts with the wall material, thereby transforming the contaminants into forms and concentrations that are more likely to attain RAOs at the downstream side of

the barrier. This technology relies on groundwater flushing to transport contaminants to the reactive media and thus may not shorten the time to achieve remedial goals appreciably from no further action. Reactive barriers most often are used where the remedial goal is to protect surface water from discharge of contaminated groundwater, to prevent further release of groundwater contaminants from a site, or to minimize further offsite migration.

Description. Permeable reactive subsurface barriers are formed by placing a reactive substrate (i.e., zero-valent iron [Fe^0]) in the subsurface to intercept a contaminant plume, to provide a preferential flow path through the reactive media, and to transform the contaminant into environmentally acceptable forms to attain PRGs at the discharge or downgradient side of the barrier. The reactive subsurface barrier is designed to provide sufficient contaminant residence time for intermediate products, such as cis-1,2-DCE and vinyl chloride, to fully degrade to ethene and ethane.

Two basic designs have been used thus far. One consists of a funnel-and-gate system in which the contaminant plume is captured and directed toward a permeable section of the barrier containing the reactive iron. The other technique employs a continuously permeable trench wherein the entire trench contains the reactive iron.

The funnel-and-gate system consists of low hydraulic conductivity (e.g., 1×10^{-6} cm/s) cutoff walls (the funnel) with a gate that contains in situ reaction zones through which the groundwater flows. The types of cutoff walls commonly used are slurry walls or sheet piles. Innovative methods such as deep soil mixing and jet grouting also are available for funnel wall construction.

A continuous trench provides a barrier of reactive substrate at the downgradient edge of the contaminant plume to provide in situ treatment of VOCs. Typical reactive substrates include iron granules or other iron-bearing minerals. As the iron is oxidized, chlorine atoms will be removed from the contaminants by one or more reductive dechlorination mechanisms, using electrons provided by the oxidation of iron. Because the iron granules dissolve so slowly, it is not unreasonable to expect the reactive barriers to remain effective for many years, although chemical precipitates can form and reduce performance with time.

With this technology, a long-term groundwater sampling and analysis program would be needed to verify the reduction in volume of the contaminated groundwater and the ongoing containment of the groundwater contaminant plumes.

Effectiveness. To evaluate the effectiveness of the permeable reactive subsurface barrier technology under site conditions, it is likely that site-and treatment-specific pilot studies would need to be conducted. Data required to support evaluation of a permeable reactive subsurface barrier alternative would include degradation rates; groundwater flow rates through the barrier; and an assessment of the barrier's ability to plug or lose reactivity quickly. The data also would be used to calculate required residence time in the treatment zone and, therefore, the required thickness of the reactive zone.

This alternative alone is probably not viable in areas where groundwater is encountered within the fractured limestone unit, which is typical at three of the six sites being addressed. In addition, treatment of groundwater will be slow due to the low hydraulic conductivities and flow rates found at the Base.

Implementability. Installation of permeable reactive subsurface barrier has a moderate level of difficulty for implementation. This alternative involves trenching and would be particularly

difficult to implement in areas where groundwater contaminants reside within fractured limestone.

Cost. The capital costs of this technology are moderate. O&M cost would be low because little or no energy input is required once construction is complete. Monitoring costs would be relatively low. Also, 5-year site reviews would be required as long as hazardous substances remain at the site above levels that allow for unlimited use and unrestricted exposure.

Conclusions. This technology alone has the potential to provide active control and treatment of the contaminant plume and thus to reduce the toxicity and volume of contaminants. However, the site geology and hydrogeology are such that its effectiveness would be compromised because of fractured bedrock. Also the time to achieve RAOs would be unacceptably long because of the ubiquitous low groundwater flow rates. The technology does not reduce the time for achievement of remedial goals from that required under no action for areas upgradient of the wall, which would be most of the area currently exceeding the PRGs. For these reasons, this technology was not retained for detailed evaluation.

6.3.5.3 Groundwater Extraction and Treatment

A typical groundwater pump-and-treat system would consist of installing groundwater extraction wells, equipping the wells with pumps to extract the groundwater, and providing aboveground storage tanks to hold and treat the contaminated groundwater prior to final disposal. In most cases where VOCs are the main contaminants, the pumped water would be sent through an air stripping unit or granular activated carbon unit, or both.

Description. Groundwater extraction and treatment involves pumping contaminated groundwater to the surface for treatment. The extraction-and-treat systems are used primarily to accomplish two objectives: (1) hydraulic containment, typically along the downgradient edge of the plume, to control the movement of contaminated groundwater thus to prevent the expansion of the contaminant plume; and (2) groundwater collection throughout the entire plume to flush contaminants out of the aquifer at the fastest possible rate. In either case, treatment of the extracted groundwater is needed to reduce the dissolved contaminant concentrations prior to discharge to surface water or reinjection to groundwater.

Active withdrawal, or pumping and treating the contaminated groundwater would require the installation of some form of pumping well, or wells, to remove the contaminated groundwater from the subsurface and construction of a system to treat it. Additionally, active pumping and groundwater recovery requires piping or other conveyance, storage, treatment facilities and discharge permitting and monitoring—all of which add significantly to the cost. Actual treatment may include the design of a train of processes such as air strippers and carbon adsorption systems tailored to remove the specific contaminants.

In addition to constructing extraction wells and treatment systems, a groundwater monitoring program also will be required to verify the effectiveness of the systems. The system may need to be adjusted in response to changes in subsurface conditions caused by remediation.

In general, pumping wells work best in aquifers where the amount of groundwater production is adequate to keep the wells from alternately pumping dry and then slowly refilling. When the wells alternately pump dry and then refill, the aquifer immediately adjacent to the well is subjected to a wide range of conditions, which tends to make the aquifer materials break down. The breakdown of the aquifer materials produces silt and also

stimulates bacterial growth, both of which interfere with the performance of the pumping system. This results in an increased maintenance effort required to keep the wells working, and lowers overall efficiency and benefit of the system.

Based on the aquifer test results during the Basewide RI (see Section 3.4), even without pumping, groundwater will not flow far at any site, thereby rendering one of the few benefits of a pump and treat alternative moot. In addition, because of the low hydraulic conductivities of soils and bedrock units and the resulting poor groundwater yields, adequate amounts of groundwater do not exist at the sites to justify the costs associated with the installation of pumping systems.

Effectiveness. The effectiveness of this technology in remediating groundwater at Richards-Gebaur AFB is questionable. As noted, the hydraulic conductivity of the subsurface materials at Richards-Gebaur AFB is so low that active pumping rates of more than a few tenths of a gallon per minute, at most, cannot be sustained by the aquifers.

Implementability. This technology is relatively easy to implement but unlikely to perform well because of the low-flow groundwater conditions that predominate at Richards-Gebaur AFB. An O&M program for groundwater extraction and treatment system would be easily implemented.

Cost. The cost for groundwater extraction and treatment is cost prohibitive, especially when the low production rates to pumping wells are combined with the natural slow groundwater flow rates. Annual O&M costs would be moderate but would be incurred for a relatively long time. Depending on the treatment required for the extracted water, additional cost may be attributed to the disposal of spent carbon and other treatment residuals and wastes. Monitoring costs would be relatively low. In addition, 5-year reviews would be required as long as hazardous substances remain at the site above levels that allow for unlimited use and unrestricted exposure.

Conclusions. An active groundwater pump-and-treat system is not considered feasible for the groundwater sites because of the low flow producing conditions of the affected groundwater zones and the increased cost and operational constraints associated with this alternative. Therefore, this alternative was not retained for detailed analysis.

6.3.5.4 DPE

DPE uses a high vacuum system to remove contaminated groundwater, separate phase liquids, and soil vapors from the subsurface simultaneously. The extracted vapors and liquids are then separated and treated before disposal.

Description. DPE, also known as multi-phase extraction, uses a high vacuum system to remove contaminated groundwater and soil vapor. It may also be used to remove separate-phase petroleum products. The groundwater and soil vapor extracted from the well is treated, collected, and either disposed of or reinjected into the ground (where permissible under applicable state laws).

A high vacuum extraction well is constructed so that the screened interval encompasses both the contaminated soils and the groundwater in the subsurface. The vacuum creates a vapor-phase pressure gradient towards the vacuum well. Greater vapor-phase pressure gradients are created with stronger vacuums yielding greater vapor and liquid recovery rates. Larger amounts of the formation are exposed as the water table is lowered during operation. As the water table is lowered, vapors in the exposed capillary fringe are removed.

There are two types of pump systems associated with DPE: single pump and dual pump. The single pump DPE system removes contaminated groundwater and soil vapor together, and they are not separated. Single pump systems are most effective in low-permeability conditions where groundwater levels do not fluctuate significantly. Dual pump DPE systems use one pump to extract the contaminated groundwater and another surface pump to remove the soil vapor. In general, dual pump DPE systems are more applicable with a wider range of site conditions than single pump DPE systems.

Under this alternative, a groundwater sampling and analysis program would be implemented to verify the reduction in volume of the contaminated groundwater and the apparent natural containment of the contaminant plumes.

Effectiveness. To evaluate the effectiveness of the DPE alternative under site conditions, it is likely that site- and treatment-specific pilot studies would need to be conducted. A DPE pilot study would require the following data: grain-size analysis, vacuum pressures, fluid flow rates, and contaminant removal capacity. This data would be used to configure well spacing, blower sizes, and offgas treatment options.

In general, DPE technology is more effective than soil vapor extraction (SVE) for heterogeneous clays and fine sands. Minimal site disturbance, short treatment times (6 months to 2 years), and the separation of the soil vapor from the groundwater are all benefits. However, subsurface characteristics such as permeability, substantially fluctuating groundwater tables, and grain size all serve as limiting factors towards overall effectiveness. Due to the tight soils at Richards-Gebaur AFB, it is likely that DPE systems will have low radius of influence and a tighter well spacing will be required. Similarly, the tight clayey nature of the soils will not allow vapor-based technologies to move the large volumes of gas through the subsurface to be effective in rapidly reducing contaminant levels.

Implementability. DPE is complicated and relatively difficult to implement. In addition to the well and vacuum system, DPE requires installation of water and off gas treatment units. Accordingly, it requires piping, blowers, vacuum pumps, and flowmeters. Onsite water treatments, such as gravity segregation, air strippers, and carbon adsorption, and offgas treatment systems, such as carbon adsorption, incineration, or catalytic oxidation, also may be required. When recovered water must be treated, discharge permits usually are necessary. An O&M program for DPE system would be easily implemented. Health and safety measures, including use of personal protective equipment, would be required to prevent field worker's exposure to contaminants. Monitoring technologies are reliable and readily available.

Cost. Capital costs for this technology would be moderate to high. Annual O&M costs would be moderate but would be incurred for a relatively long time. Depending on the treatment required for the extracted fluid, additional cost may be attributed to the disposal of spent carbon and other treatment residuals and wastes. Monitoring costs would be low. In addition, 5-year reviews would be required as long as hazardous substances remain at the site above levels that allow for unlimited use and unrestricted exposure.

Conclusions. While DPE has the potential to reduce the toxicity and volume of contaminants, the effectiveness of this alternative will be limited by the tight soils at Richards-Gebaur AFB. It is difficult to implement and requires longer time to achieve the RAOs. The total cost for capital and long-term O&M would be high. Therefore, this alternative was not retained for detailed analysis.

6.3.5.5 SPSH

SPSH uses an electric current to increase ambient temperatures in the subsurface groundwater contamination zone. By heating the subsurface, it is possible to increase the rates of volatilization of the chlorinated VOCs. The increased rate of contaminant removal is in turn related to the temperature dependency of the physicochemical properties of the contaminants present in groundwater.

Description. SPSH is a technology engineered to enhance and stimulate SVE of volatile compounds. Six-phase electrical current is used to heat the subsurface to enhance volatilization of contaminants present in the groundwater and soil.

To implement the technology, electrodes are placed in the ground in the contaminated region and a voltage is applied. Electrical current conducts through the soil, heating the soil resistively. The technology can be controlled to heat and maintain any temperature below the boiling point of water. Heating to 20°C to 40°C enhances biodegradation and volatilization. Heating to 100°C volatilizes contaminants and water (producing steam) in the soil, effectively steam-stripping contaminants in situ. The volatilized contaminants and steam then are removed by soil venting and treated above ground as necessary.

A unique aspect of SPSH is the patented use of multiphase 60-Hertz electricity to create an even heating distribution. Although 60-Hertz systems generally are desirable because of their low capital cost and the availability of robust, large-scale systems, 60 Hz typically has not been used because of the tendency to prematurely dry the soil adjacent to the electrode. When the soil dries, it becomes very resistive, preventing dissipation of the power into the bulk soil region to be treated.

With the SPSH system, standard three-phase electricity is converted to six electrical phases, with each phase being applied to a separate electrode placed in a hexagonal pattern. Because each phase is 60 degrees out of phase with the adjacent phase, every electrode fires to every other electrode and to a central neutral electrode, creating a more uniform heating pattern that enables larger volumes of soil to be treated with fewer electrodes.

Under this alternative, a groundwater sampling and analysis program would be implemented to verify the reduction in volume of the contaminated groundwater and the apparent natural containment of the contaminant plumes.

Effectiveness. SPSH has proven effective in enhancing the removal of less volatile contaminants from the subsurface with low permeability and heterogeneous soils. It is specially suited to sites where contaminants are tightly bound to clays and thus difficult to remove using SVE alone.

To fully evaluate the effectiveness of these technologies under site conditions, it is likely that site- and treatment-specific pilot studies would need to be conducted. Data collected during the SPSH pilot test would include grain-size analysis, heating capabilities, vacuum pressures, flow rates, and enhanced volatilization and biodegradation rates. These data would be used to configure well and electrode spacing, optimal operating temperatures, blower sizes, offgas treatment options, and health and safety issues.

Because of the low concentrations of COCs in groundwater at Richards-Gebaur AFB, operation of a SPSH system is unlikely to be cost-effective. Furthermore, the effective influence of the technology is likely to be limited because of the low hydraulic conductivities of the subsurface materials.

Implementability. Installation of an SPSH system would be difficult. In addition to installing heating and SVE systems, SPSH requires offgas treatment units. Accordingly, it requires electrodes, piping, blowers, vacuum pumps, flowmeters, voltage control system and transformers, and an offgas treatment system, such as carbon adsorption, incineration, or catalytic oxidation. Health and safety measures, including the use of personal protective equipment, would be required to prevent exposure of field workers to contaminants. An O&M program for SPSH system would be easily implemented. Monitoring technologies are readily available.

Cost. The capital costs for this technology are relatively high. Annual O&M costs would be moderate but would be incurred for a relatively long time. O&M costs would also depend on treatment required for vapor removal. Monitoring costs would be low. In addition, 5-year reviews would be required as long as hazardous substances remain at the site above levels that allow for unlimited use and unrestricted exposure.

Conclusion. While SPSH has the potential to reduce the toxicity and volume of contaminants, its effectiveness will be limited by the low concentrations of COCs in groundwater and the fact that fractured limestone is present at Richards-Gebaur AFB. It is difficult to implement and probably requires longer time to achieve RAOs. In addition, the total cost of long-term O&M would be high. Therefore, this alternative not retained for detailed analysis.

6.4 Development of Remedial Alternatives

Remedial technologies remaining following screening are:

1. LUCs
2. LTM
3. ANA

These technologies were assembled into two remedial alternatives:

1. LTM and LUCs
2. ANA, LTM, and LUCs

The two assembled alternatives, together with the No Action alternative, will be described and evaluated in detail in Section 7.

7. Analysis of Remedial Alternatives

The detailed analysis of alternatives presents the relevant information needed to compare the alternatives assembled for the groundwater sites at Richards-Gebaur AFB. The extent to which alternatives are evaluated during the detailed analysis is influenced by the available data and the number and types of alternatives being analyzed. In this section, the alternatives retained after the qualitative screening are further evaluated against the seven standard CERCLA feasibility evaluation criteria. The alternatives selected for detailed analysis are:

1. No Further Action
2. LTM and LUCs
3. ANA, LTM, and LUCs

Following the detailed analysis, a comparative analysis of the alternatives' ability to satisfy the CERCLA evaluation criteria is presented.

The evaluation criteria are described below. The ability of each alternative to meet each criterion is discussed and summarized in a table for ease of reference.

7.1 Evaluation Criteria

The remedial alternative discussed in this section were designed to address threats posed by the contaminated groundwater exceeding PRGs. The alternatives are evaluated against seven criteria as defined in the NCP (40 CFR 300). Those criteria permit comparison of the relative performance of the alternatives and provide a means for identifying their relative advantages and disadvantages. The seven criteria are:

1. Overall protection of human health and the environment
2. Compliance with ARARs
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, and volume
5. Short-term effectiveness
6. Implementability
7. Cost

Two additional criteria—state acceptance and community acceptance—are evaluated in the ROD following public comment on the selected remedy that will be described in the Proposed Plan for addressing contaminated groundwater at Richards-Gebaur AFB.

The evaluation criteria can be classified into three groups: threshold, balancing, and modifying criteria.

Threshold criteria are standards that must be met by a alternative for it 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. Two of the nine criteria—overall protection

of human health and the environment and compliance with ARARs—are considered threshold criteria. If ARARs cannot be met, a waiver may be obtained in situations where one or more site exceptions defined in the NCP occur.

Balancing criteria weigh the tradeoffs between alternatives. Five of the nine criteria belong to balancing criteria: long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost. These criteria represent the standards upon which the detailed evaluation and comparative analysis of alternatives are based. In general, a high rating on one can offset a low rating on another balancing criterion.

Modifying criteria are community and state acceptance. These are evaluated following the public comment and are used to modify the selection of the recommended alternative.

7.1.1 Overall Protection of Human Health and the Environment

Protectiveness is the primary requirement that remedial actions must meet under CERCLA. This evaluation criterion is an assessment of whether each alternative achieves and maintains adequate protection of human health and the environment. A remedy is protective if it adequately eliminates, reduces, or controls all current and potential risks posed by the site through each exposure pathway.

7.1.2 Compliance with ARARs

Compliance with ARARs is one of the statutory requirements of remedy selection. This evaluation criterion is used to determine whether an alternative would meet the federal, state, and local ARARs identified in Section 5. Significant ARARs are identified for each alternative, and a description whether they are met is given. A discussion of the compliance of each alternative with chemical-, location-, and action-specific ARARs is included. ARARs identified for the sites are listed in Section 5, Table 5-1.

7.1.3 Long-Term Reliability and Effectiveness

Long-term reliability and effectiveness reflects CERCLA's emphasis on implementing remedies that will ensure protection of human health and the environment in the long term. Under this evaluation 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 this 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 the site.

7.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This evaluation criterion addresses the statutory preference for remedies that employ treatment to reduce the toxicity, mobility, or volume of the hazardous substances. This preference is satisfied when treatment is used to reduce the principal threats at a site through destruction of toxic contaminants, reduction of the total mass or total volume of contaminated media. This criterion is specific to evaluating only how the treatment reduces toxicity, mobility, and volume. It does not address containment actions, such as capping.

7.1.5 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. This evaluation criterion addresses the effects of the alternative during the construction and implementation phase until remedial action objectives are met.

7.1.6 Implementability

The implementability criterion addresses the technical and administrative feasibility of executing an alternative and the availability of various services and materials required during its implementation. Technical feasibility includes construction, operation, reliability of technology, ease of undertaking additional remedial action, and monitoring. Administrative feasibility refers to the activities needed to coordinate with other offices and agencies (local permits, for example). Availability of services and materials includes availability of adequate off-facility treatment, storage capacity, and disposal services; necessary equipment and specialists; services and materials; and prospective technologies.

7.1.7 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-value calculation for each alternative can be calculated for comparison.

Capital costs consist of direct and indirect costs. *Direct costs* include the cost of construction, equipment, land and site development, treatment, transportation, and disposal. *Indirect costs* include engineering expenses, license or permit costs, and contingency allowances. Annual O&M costs are the post-construction costs required to ensure the continued effectiveness of the remedial action. Annual O&M cost consists of the cost of operating labor, maintenance materials and labor, auxiliary materials and energy, residue disposal, purchased services, administration, insurance, taxes, licensing, maintenance reserve and contingency funds, rehabilitation, monitoring, and periodic site reviews.

Expenditures that occur over different time periods were analyzed using present-value analysis, which discounts all future costs to a common base year. Present value analysis is performed to allow the cost of remedial action alternatives to be compared on the basis of a single figure representing the amount of money that, if invested in the base year and disbursed as needed, would be sufficient to cover all costs associated over the life of the remedial project.

Assumptions associated with the present-value calculations include a discount rate of 3.9 percent before taxes and after inflation, cost estimates in the planning years in constant dollars, and a period of performance that would vary depending on the activity but, per USEPA guidance, would not exceed 100 years. For the purpose of the FS, two performance periods were used (30 years and 50 years) for estimating costs.

The cost estimates in this section provide an accuracy of -30 percent to +50 percent. The alternative cost estimates are in 2002 dollars and are based on conceptual design from information available at the time of this study. The actual cost of the project will depend on the final scope and design of the selected remedial action, the implementation schedule, competitive market conditions, and other variables. Most of these factors are not expected to affect the relative cost differences between alternatives.

7.1.8 State Acceptance

This criterion evaluates the technical and administrative issues and concerns the state may have regarding each of the alternatives. This criterion is not discussed in this report but will be addressed in the ROD once comments on the FS and Proposed Plan are received.

7.1.9 Community Acceptance

This criterion evaluates the issues and concerns the public may have regarding each of the alternatives. This criterion is not discussed in this report but will be addressed in the ROD once comments on the FS report and Proposed Plan are received.

7.2 Detailed Analysis of Remedial Alternatives

To provide for the necessary detailed analysis, the alternatives retained were evaluated against the standard criteria described in Section 7.1. The results of the analysis are documented in Table 7-1. The key elements of each alternative also are presented in Table 7-1 and evaluated. Key elements are those critical to determining the success of a remedial alternative in meeting the RAOs for contaminated groundwater at Richards-Gebaur AFB or that have the greatest influence on the cost of the alternative.

The assembled alternatives are described briefly below.

7.2.1 Alternative 1—No Further Action

Alternative 1, No Further Action, is required by CERCLA. The alternative is used to provide a baseline reference for remaining remedial alternatives.

7.2.2 Alternative 2—LTM and LUCs

Alternative 2 involves establishing an LTM program for groundwater at each of the six FS sites. This is considered reasonable and feasible because a comprehensive network of monitoring wells is established at each FS site. Protectiveness of human health and the environment is further protected by augmenting LTM with appropriate and enforceable LUCs. It is envisioned that a layered system of LUCs would be used to prohibit extraction and subsequent use of groundwater from any of the six sites.

An LTM program will allow systematic evaluation of site groundwater quality and allow risk managers to respond to any changes in chemical concentration or distribution. LUCs provide a means by which the LTM program can be maintained and supervised by the relevant authority, and ensure protectiveness of human health by precluding extraction and use of site groundwater. Details of the LUC/IC layering strategy for Richards-Gebaur AFB are presented in Appendix D.

Table-7-1

Detailed Analysis of Remedial Alternatives

Evaluation Criteria	Alternative 1 No Further Action	Alternative 2 LTM and LUCs	Alternative 3 HRC-Accelerated Natural Attenuation and LTM and Institutional Controls
Overall Protection of Human Health and the Environment			
<p>Potential human exposure to contaminated groundwater</p> <p>Discharge of contaminated groundwater to surface water resources</p>	<p>No protection from present levels described in baseline risk assessment.</p> <p>With the exception of SS 012, contamination would continue to migrate at present rates but would not be expected to reach surface water within 100 years.</p>	<p>LUCs will preclude drilling groundwater wells and thus ensure that groundwater at the Base will not be used. As a result, the potential groundwater exposure pathway will remain incomplete. In addition, a long-term groundwater monitoring program will track any changes in groundwater contaminant concentrations, allowing risk managers to respond to changing site conditions in a timely manner.</p> <p>A long-term groundwater monitoring program will track changes in groundwater contaminant concentrations, allowing risk managers to respond to changing site conditions in a timely manner.</p>	<p>HRC-accelerated natural attenuation will speed up reductions in contaminant mass. LUCs will preclude drilling groundwater wells and thus ensure that groundwater at the Base will not be used. As a result, the potential groundwater exposure pathway will remain incomplete. A long-term groundwater monitoring program will track changes in groundwater contaminant concentrations to verify that application of HRC is effective, and to allow risk managers to respond to changing site conditions in a timely manner.</p> <p>A long-term groundwater monitoring program will track changes in groundwater contaminant concentrations, allowing risk managers to respond to changing site conditions in a timely manner.</p>
Compliance with ARARs			
<p>Chemical-Specific ARARs</p> <p>Location-Specific ARARs</p> <p>Action-Specific ARARs</p>	<p>Does not meet any chemical-specific ARARs.</p> <p>If no action is taken, location-specific ARARs are not applicable.</p> <p>If no action is taken, action-specific ARARs are not applicable.</p>	<p>Chemical-specific ARARs would be met but may require several decades.</p> <p>Location-specific ARARs would be met.</p> <p>Action-specific ARARs would be met.</p>	<p>Chemical-specific ARARs would be met within 5 to 10 years.</p> <p>Location-specific ARARs would be met.</p> <p>Action-specific ARARs would be met.</p>

Table-7-1

Detailed Analysis of Remedial Alternatives

Evaluation Criteria	Alternative 1 No Further Action	Alternative 2 LTM and LUCs	Alternative 3 HRC-Accelerated Natural Attenuation and LTM and Institutional Controls
Long-Term Effectiveness and Permanence			
Magnitude of residual risk	Long-term risk would remain at current levels as defined in RI risk assessment.	Long-term risk would diminish as a result of natural attenuation and plume stabilization. In addition, long-term risk will be reduced through LUCs as extraction and subsequent exposure to groundwater will be prohibited.	HRC treatment would reduce long-term risk by decreasing the mass of contaminants in groundwater
Adequacy and reliability of controls	No action would exercise no control over potential site risks.	LUCs would ensure that potential risk through exposure to contaminated groundwater is eliminated. LTM would ensure that site conditions regularly are monitored to allow risk managers to respond in a timely manner to changes in site conditions.	LUCs would ensure that potential risk through exposure to contaminated groundwater is eliminated. LTM would ensure that site conditions regularly are monitored to allow risk managers to respond in a timely manner to changes in site conditions.
Need for 5-Year Review	5-year review would not be required.	Because contaminated material would remain onsite, review would be required until levels allow unlimited and unrestricted exposure to ensure adequate protection of human health and the environment.	Because contaminated material remains onsite, review would be required until levels allow unlimited and unrestricted exposure to ensure adequate protection of human health and the environment.
Reduction of Toxicity, Mobility, or Volume Through Treatment			
Degree of expected reduction in toxicity, mobility, or volume of the waste	None.	Natural attenuation would slowly reduce the contaminant mass.	HRC-accelerated natural attenuation would reduce the contaminant mass.
Irreversibility of treatment	Not applicable.	Not applicable.	Irreversible.
Type and quantity of residuals that will remain after treatment	None.	None.	None.

Table-7-1			
Detailed Analysis of Remedial Alternatives			
Evaluation Criteria	Alternative 1 No Further Action	Alternative 2 LTM and LUCs	Alternative 3 HRC-Accelerated Natural Attenuation and LTM and Institutional Controls
Statutory preference for treatment	Does not satisfy.	Does not satisfy.	Satisfies.
Short-Term Effectiveness			
Short-term risk that might be posed to the community during implementation	None.	None.	Injection of material into groundwater would affect groundwater quality.
Potential impacts to workers during remedial action and effectiveness and reliability of protective measures	None.	None.	Construction workers would be required to follow appropriate safety procedures. Personnel protective level D likely would be sufficient. No unusual precautions would be necessary.
Potential environmental impacts of remedial action and effectiveness and reliability of mitigative measure during implementation	None.	None.	Treatment would require injecting HRC, a food-grade material. Degradation of groundwater not anticipated due to injection.
Time until protection is achieved	Not applicable.	Immediate.	5 to 10 years, depending on the amount of HRC required to treat the known mass of contaminants.

Table-7-1

Detailed Analysis of Remedial Alternatives

Evaluation Criteria	Alternative 1 No Further Action	Alternative 2 LTM and LUCs	Alternative 3 HRC-Accelerated Natural Attenuation and LTM and Institutional Controls
Implementability			
Technical feasibility	Not applicable.	Very feasible, because a basewide groundwater monitoring network and monitoring protocols have already been approved and established.	Feasible, although the presence of fractured limestone at upland sites would complicate delivery of HRC to the contaminated groundwater zone. Additional groundwater analytical parameters would need to be measured to evaluate effectiveness of HRC application. LTM network would likewise have to be augmented to properly track HRC effects.
Administrative feasibility	Not applicable.	Moderate to high, providing the federal, state, and local agencies involved can agree on appropriate enforcement mechanisms for LUCs.	Low because the state of Missouri requires the USAF to obtain an underground injection permit prior to injecting HRC into the subsurface. USAF does not agree with the state requirement for permitting HRC injection.
Availability of services, equipment, and materials	Not applicable.	LTM network exists at Base, and local contractors are readily available to undertake groundwater monitoring and design and enforcement of LUCs.	LTM network exists at Base, and local contractors are readily available to undertake HRC injection, groundwater monitoring, and design and enforcement of LUCs.
Cost (in thousands)			
Capital Cost	\$0	\$0	\$5,121
Total O&M Cost	\$0	\$739	\$1,782
Periodic Cost	\$0	\$100	\$122
Period of Analysis (yr)	30	30	30
Total Costs	\$0	\$839	\$7,025
Present Value at 3.9%	\$0	\$648	\$6,872

7.2.3 Alternative 3—ANA, LTM, and LUCs

Alternative 3 assembles three technologies: groundwater treatment, groundwater monitoring, and land use control. Natural attenuation processes, if shown to exist, would be accelerated by adding a reactive substrate to the subsurface to promote in situ reductive dechlorination. The reactive substrate evaluated for this study was HRC. To verify the effectiveness of ANA, it is recommended that an LTM program be established using the networks of monitoring wells at the six sites to monitor the progress of contaminant destruction through natural attenuation. To ensure protectiveness of human health and the environment, LUCs will be used to prevent extraction of and exposure to contaminated groundwater.

7.3 Comparative Analysis of Remedial Alternatives

Following the detailed analysis of each of the retained alternatives, it is necessary to compare how well each satisfied the seven evaluation criteria. The following subsections describe the relative abilities of the three remedial alternatives to meet the required criteria. Table 7-2 presents the results of the comparative analysis.

Table 7-2				
Comparative Analysis Results				
Criteria	Alternative 1	Alternative 2	Alternative 3	
Overall Protection of Human Health and the Environment	1	4	4	
Compliance with ARARs	1	3	3	
Long-Term Effectiveness and Permanence	1	3	4	
Reduction of Toxicity, Mobility, or Volume Through Treatment	1	1	4	
Subtotal	4	11	15	
Short-Term Effectiveness	1	4	2	
Implementability	4	4	1	
Cost	4	3	1	
Subtotal	9	11	4	
Total Score	13	22	19	

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

7.3.1 Overall Protection of Human Health and the Environment

Alternative 1 is not considered protective because it does not include groundwater monitoring or institutional controls to prevent access to contaminated groundwater. The alternative would not protect human health and the environment, in that the risk posed from contaminated groundwater would not be reduced. The risk of potential exposure would continue from the contaminated groundwater. Future exposure to onsite groundwater would result in unacceptable risks.

The two remedial alternatives are considered protective in that they include restrictive covenants on the property deed to prevent groundwater use and potential exposure to residual VOCs. Also, each includes groundwater monitoring to ensure that changes in groundwater conditions are recorded and evaluated.

7.3.2 Compliance with ARARs

Alternative 1 does not comply with chemical-specific ARARs. There are no location- or action-specific ARARs applicable to Alternative 1. The two remedial alternatives would meet applicable ARARs. Also, it is expected that the HRC-accelerated natural attenuation alternative would meet chemical-specific ARARs in less time than the MNA or LTM alternative, typically within 5 years.

7.3.3 Long-Term Effectiveness and Permanence

Alternative 1 does not provide long-term effectiveness and permanence. The risk associated with the groundwater would not be reduced and might be increased through additional migration of contaminants until a steady-state condition is achieved.

For the alternative of LTM and LUCs, although the magnitude of residual risks will not be reduced in the short term, institutional controls would provide adequate and reliable risk management by prohibiting potential groundwater use, thereby mitigating potential exposures and consequent risk.

The long-term reliability and permanence of HRC-accelerated natural attenuation, LTM, and LUCs is better than that for the other remedial alternative because the technology actively reduces contaminant mass and breaks down contaminants into nonhazardous products, thereby more quickly reducing the magnitude of residual risk over time.

The effectiveness of substrate addition in low permeability aquifers has not been good because of the difficulty in achieving good distribution throughout the contaminated zone. The most likely outcome is incomplete destruction that would still require long-term monitoring until MCLs are met.

7.3.4 Reduction of Toxicity, Mobility, and Volume

Alternative 1 would not provide any reduction of toxicity, mobility, and volume and does not meet the statutory preference for treatment.

Alternative 2 is incapable on its own of reducing the toxicity, mobility, and volume of the residual VOCs in groundwater because they do not involve active treatment. (Note that natural attenuation processes are not considered treatment in the context of this evaluation criterion.) Alternative 3, however, would provide a more timely reduction in the toxicity, mobility, and volume of contaminants under suitable geochemical conditions.

7.3.5 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. This evaluation criterion addresses the effects of the alternative during the construction and implementation phase until remedial action objectives are met.

Because active remediation of groundwater would not be undertaken under Alternatives 1 and 2, the potential risks to human health and the environment as a result of implementing

them would be negligible. In other words, they would pose no increased risk to the surrounding community in the short term.

Alternative 3 could present additional risks to workers or other surrounding populations during remedial construction. However, those risks can be controlled or mitigated providing standard health and safety protocols are established and followed during execution of the remedial alternative.

7.3.6 Implementability

Alternative 1 does not have a monitoring or construction component associated with it, so it is easily implemented.

Implementation of Alternative 2 would be routine because a comprehensive groundwater monitoring network exists at the Base and has been in use for more than 18 months. Consequently, appropriate monitoring protocols and methodologies have been established and approved by the BCT.

The technical implementability of Alternative 3 is relatively straightforward and services and materials are readily available. However, administratively it is more problematic because the state of Missouri requires that USAF obtain an underground injection permit for application. At this time, USAF and MDNR have been unable to reach consensus regarding the nature and applicability of the permit. Therefore, the alternative is regarded difficult to implement.

7.3.7 Cost

Table 7-1 breaks down the estimated capital, annual O&M, and present net worth costs associated with the alternatives. Details of the cost analysis performed for the FS are presented in Appendix D.

Taking no action would require no expenditure of money at this time. Therefore, no cost would be associated with Alternative 1. The costs for the two active remedial alternatives range between \$0.7 million to \$6.9 million, with HRC-accelerated natural attenuation, LTM, and LUCs being the greater cost alternative.

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Appendix A
Aquifer Test Technical Memorandum

Evaluation of Aquifer Tests Performed at Five Sites at the Richards-Gebaur Air Force Base

December 15, 2000

Introduction

Aquifer tests were performed at several sites at Richards-Gebaur Air Force Base in order to determine the transmissive properties of the underlying water-bearing units. This technical memorandum provides a discussion of the implementation of the tests and the analysis of the test results.

The formations underlying the facility comprise (in sequence downward): a soil horizon of silty clay and weathered shale, a fractured and transmissive limestone formation, a shale that forms a relatively impermeable boundary to vertical flow, a less-fractured and less-transmissive limestone, and a claystone and shale. The wells in which the tests were performed are screened predominantly in silty clay and limestone, with some wells screened in weathered shale.

The geologic materials underlying the sites could be characterized by a wide range of transmissive capability. Silty clay and shale typically have low hydraulic conductivities except in fractures and along some bedding planes. On the other hand, fractured limestone can have high hydraulic conductivities, particularly when the fractures have been enhanced by solution of the rock, but it has a very-low hydraulic conductivity in the rock in between the fractures. Reportedly, wells at the base typically bail dry, suggesting that low hydraulic conductivities predominate.

The tests were performed by removing water from each test well with a bailer or low-discharge pumping device as quickly as possible. In some cases, water removal was continued for several minutes, which maintained the drawdown in the well at a certain level or within a limited range of levels for the period of purging. In other cases, a volume of water was quickly removed and then the test well was allowed to recover.

In summary, the subsurface materials at the sites exhibit low hydraulic conductivities, with values on the order of those that characterize silt and other fine-grained materials. There are hydraulic connections between some areas at some of the sites, as demonstrated by observable drawdown in wells up to about 65 feet away from test wells. However, the connections appear to be limited because typically the tests in the wells produce only small, if any, drawdown in observation wells.

The following sections describe the rationale for selecting tests for analysis and the results of the analyses.

Hydrogeologic Conditions at Test Sites

The information on geology and hydrogeology for each site provided by the Final ECS Report (March 1999) and by CH2M HILL (June 2000) and was used to develop a simple conceptual site model of the hydrogeology at each site. The models are described below for each site.

Site CS004

The site has an elevation on the order of 1005 feet above mean sea level (msl). Silty clay was encountered from the surface to a depth of about 18 feet below ground surface (bgs). Below that is approximately 3 feet of limestone. The contact between the limestone and the underlying

impermeable shale layer is at a depth of about 21 feet bgs. The depth to the water table was on the order of 8 feet bgs during the period of testing. Therefore, the saturated thickness of the water-bearing unit overlying the impermeable shale is estimated to be 13 feet, the upper 10 feet of which is silty clay and the lower 3 feet of which is limestone.

Site SS003

The site has an elevation on the order of 1030 feet above msl. Silty clay and weathered shale were encountered from the surface to a depth of about 30 feet bgs, below which is a limestone unit. Some of the deep wells appear to be screened across the interface between the shale and the underlying limestone while most of the wells appear to be screened across the interface between the silty clay and the underlying shale. The assumption is that the water-bearing unit comprising the silty clay and the weathered shale is 30 feet thick. The depth to the water table was on the order of 7 feet bgs during the period of testing. Therefore, the saturated thickness of the water-bearing unit is estimated to be 23 feet and consists entirely of weathered shale.

Site SS006

The site has an elevation on the order of 1050 feet above msl. Silty clay, limestone, and shale were encountered from the surface to the greatest depth drilled, at about 16 feet bgs. It appears that the wells at the site straddle the contact between the limestone and the impermeable shale detected at all other sites. The assumption was made that the impermeable shale is at a depth of about 16 feet bgs, based on the drilling data. The depth to the water table was on the order of 6 feet bgs during the period of testing. Therefore, the saturated thickness of the water-bearing unit overlying the impermeable shale is estimated to be 10 feet, all of which is assumed to be limestone.

Site SS009

The site has an elevation on the order of 1010 feet above msl. Silty clay was encountered from the surface to a depth of about 15 feet bgs. Below that is approximately 7 feet of limestone. The contact between the limestone and the underlying impermeable shale layer is at a depth of about 22 feet bgs. The depth to the water table was on the order of 7 feet bgs during the period of testing. Therefore, the saturated thickness of the water-bearing unit overlying the impermeable shale is estimated to be 15 feet, the upper 8 feet of which is silty clay and the lower 7 feet of which is limestone.

Site ST005

The site has an elevation on the order of 1008 feet above msl. Silty clay was encountered from the surface to a depth of about 14 feet bgs. Below that is approximately 8 feet of limestone. The contact between the limestone and the underlying impermeable shale layer is at a depth of about 22 feet bgs. The depth to the water table was on the order of 4 feet bgs during the period of testing. Therefore, the saturated thickness of the water-bearing unit overlying the impermeable shale is estimated to be 18 feet, the upper 10 feet of which is silty clay and the lower 8 feet of which is limestone.

Selecting Well Tests for Analysis

Aquifer tests were performed at five sites and in eight different wells. Thirty-seven sets of water-level measurements were collected during the tests. The sets of water levels measured in all wells were plotted in figures 1 through 8 and were reviewed to determine which tests potentially provided usable data. In some cases, there was too little drawdown in an observation well for analysis. In other cases, the water levels collected during the monitoring period clearly indicated that the local water levels were changing during the test period for reasons other than the test (e.g., recharge or barometric-pressure changes.) At times, these ambient changes interfered with

the possible drawdowns due to the test to the point that the drawdown data were not usable for analysis.

The results of evaluating the potential usability of the test data are provided in Table 1. The table contains a brief statement as to the potential usability of the data and any reservations as to the applicability of the analytical results. The table also contains the depths of the wells to show which wells are screened in a depth interval other than that of the tested well.

At least one set of test data was determined to be usable at each site. Optimum data sets were those with significant drawdowns in observation wells screened in the same interval as the tested well and in which there were no ambient water-level changes to interfere with the drawdown from the test. However, most useful data were obtained from the test wells themselves.

Analytical Methods Used

Table 1 includes what general analytical methods were usable for analysis. When the period of time during which the well was pumped was short compared to the duration of the test, the data from the test well were best analyzed using an instantaneous-injection or instantaneous-withdrawal (i.e., slug) test approach. When the period during which the well was pumped was long compared to the duration of the test, the recovery data in the well were analyzed using a different method. In some cases, the discharge period was moderate compared to the duration of the test; in these cases, both slug-test and recovery-test methods were applied for comparative results. In one case, the drawdown data from an observation well (well SS009-MW008) when pumping a test well (SS009-MW006) could be analyzed using a time-drawdown method. The specific analytical methods are discussed in the following section.

HydroSolve's AQTESOLV™ computer-aided aquifer-test solver was used for the test analyses. AQTESOLV™ contains a number of analytical methods that were useful for analyzing the tests at Richards-Gebaur AFB. The following specific analytical methods were used:

- Slug-test analysis using the Bouwer and Rice method (1976), which can be used under both confined and unconfined conditions.
- Confined-aquifer analysis using the Theis method (1935), which assumes non-equilibrium conditions.
- Confined-aquifer analysis using the Theis recovery method (1935), which can be applied to the recovery of water levels from pumping. Although the method is strictly applicable to confined conditions, it can be applied to situations where the changes in the elevation of the water table are small (the case encountered during the tests discussed).
- Leaky-aquifer analysis using the Hantush-Jacob method (1955), assuming that there is no storage of groundwater in the confining layers.

The specific method used for each test analysis and the reason for the selections are discussed in the section on results later in this technical memorandum.

It should be noted that only test methods appropriate for tests performed in uniform porous media were used. The fact that the geologic materials in which some of the test wells are screened are limestone or shale may appear to violate the typical assumption of aquifer-test analysis that the porous media be isotropic and homogeneous, like a uniform sand deposit. Some of the data curves exhibit unusual inflections that may be attributed to fracture flow. On the other hand, it is likely that the limestone and shale underlying the sites has sufficient fracturing and other interconnections to closely approximate a porous media. Therefore, the test methods applied are expected to provide estimates of transmissive properties that are at least sufficient to make conclusions about the relative ability of the limestone and shale to transmit groundwater and, potentially, groundwater contaminants. Although analysis methods are available for tests performed in fractured rock, they require an understanding of the geology (particularly with respect to the distribution of fractures) that is beyond the scope of the present investigation.

Adjustments to Water-Level Data

The only adjustment made to water-level data was for partial penetration. In most cases, the screened intervals of the test and observation wells at each site only partially penetrate the saturated thickness of the water-bearing unit. The water levels were adjusted for partial penetration for all applications of the Theis method and the Hantush-Jacob method. Partial-penetration corrections are not available for the Theis recovery method and no adjustments of water-level results when applying the Bouwer and Rice method are needed.

For the partial-penetration adjustments, the following guidelines on the anisotropy of the hydraulic conductivity were used:

- In the silty clay and weathered shale, the ratio of vertical to horizontal hydraulic conductivity is specified at 0.1 to account for the fact that the vertical hydraulic conductivity typically is smaller than the horizontal hydraulic conductivity in these types of subsurface materials.
- In the limestone, the ratio of vertical to horizontal hydraulic conductivity is specified at 1.0, under the assumption that fractures are distributed uniformly in all directions through the subsurface.

Precipitation occurred periodically during some of the tests. The effects of this can be seen in many of the data plots shown in figures 1 through 8, where there are small fluctuations of the water levels in the wells. However, these fluctuations were too small and short-term to interfere with analyzing the test data.

Results of the Analyses

In this section, the results of the analyses are provided and discussed.

Table 2 contains information needed for the analytical methods. The table includes the distances between test and observation wells, the total depth and the depth to water in each well, the height of the water column in each well, and the time over which the well was purged. The total volume of water removed and the time to purge the water were used to calculate the effective pumping rate in gallons per minute (gpm).

Table 3 summarizes the analysis results and the results are discussed in detail by site below. The time-displacement plots for all tests discussed are provided in figures at the end of the technical memorandum.

Site CS004

The recovery in shallow well MW003 was analyzed as a slug test using the Bouwer and Rice method and with the Theis recovery method. The plot of recovery vs. time is shown in Figure 9. Water was not removed from the well instantaneously, as specified for a slug test, and this may contribute to the unusual shape to the curve. In a typical slug test, the water level is changed over a very short time, preventing a cone of depression from developing significantly around the well. The water then returns to the well at a steady rate. In the test in well MW003, a cone of depression likely developed around the well. The change in water level in the well then reflected the filling of the cone of depression and the well at different rates.

This situation complicates analyzing the test data. However, it is clear that the recovery of water levels in the well is controlled by the transmissive capabilities of the water-bearing unit. Therefore, the test was analyzed using the two primary segments of the curve. The test results from using the early data are shown in Figure 9 and the test results from using the later data are shown in Figure 10. The two results (0.047 feet per day (ft/day) and 0.10 ft/day) provide a rough estimate

of the hydraulic conductivity of the silty clay at this location. The Theis recovery method (Figure 11) yielded a transmissivity of 0.32 square feet per day (sq. ft/day), which yields a hydraulic-conductivity value of 0.032 ft/day. The saturated thickness of the silty clay was assumed to be 10 feet.

There was very little drawdown in any of the observation wells, and the water levels in all wells apparently were affected by an upward trend in local water levels. The drawdown and early recovery data obtained from well MW001, located about 51 feet away from test well MW003 and screened in the same depth interval, appeared suitable for analysis when reviewed in Figure 1. However, analytical curves could not be fit to the data, which are shown plotted in Figure 12. Therefore, no value of hydraulic conductivity could be obtained from these data.

The recovery in deep well MW007 was analyzed with the Theis recovery method (Figure 13). The well is screened in the limestone near the limestone/shale interface. The transmissivity was estimated to be 12.8 sq. ft/day and the hydraulic conductivity was estimated at 4.3 ft/day. This was the highest of any hydraulic conductivity measured at any of the sites. In part, the high value is caused by assuming that it is applicable only to the interval that is limestone, which is only 3 feet thick.

The test in deep well MW007 produced a significant response in shallow well MW003 (Figure 1). This suggests that there is a vertical hydraulic connection between the two wells, which are only about 6 feet apart horizontally. It is likely that the hydraulic connection is through the boreholes of the wells. Well MW003 is screened from 11 to 16 feet bgs and well MW007 is screened from 20.5 to 23.5 feet bgs. However, the sand pack in well MW007 is only about 18 feet bgs, placing the two wells close to one another vertically.

Drawdowns in other wells at Site CS004 were too small to be suitable for analysis. This suggests that the overall hydraulic conductivity of the subsurface materials at the site is low.

Site SS003

The recovery in shallow well MW007 was analyzed using the Theis recovery method. Two values of hydraulic conductivity were generated because of the uncertainty about which part of the recovery curve to use. Figure 14 illustrates the results of using the larger values of t/t' and Figure 15 illustrates the results of using the smaller values of t/t' . The test produced transmissivities of 0.29 sq. ft/day and 0.93 sq. ft/day and hydraulic conductivities of 0.013 ft/day and 0.040 ft/day, respectively. The saturated thickness of the weathered shale was assumed to be 23 feet.

Drawdowns in other wells at Site SS003 were too small to be suitable for analysis. This suggests that the overall hydraulic conductivity of the subsurface materials at the site is low.

Site SS006

The recovery in shallow well MW001 was analyzed both as a recovery test using the Theis recovery method and as a slug test using the Bouwer and Rice method, the latter method applied to both early and late time data. The data curve for the slug test shows some unusual displacements, with a steady rate of recovery during the first 100 minutes or so, then an inflection that indicates a more-rapid rate of recovery (figures 16 and 17.) As with well MW003 at Site CS004, these displacements likely are due to the fact that the well was pumped for a period of time before being allowed to recover. In order to provide a rough estimate of the hydraulic conductivity, both of the primary segments of the curve were analyzed, yielding hydraulic conductivities of 0.058 ft/day (Figure 16 for the early data) and 0.20 ft/day (Figure 17 for the later data.) The Theis recovery method generated a transmissivity of 2.71 sq. ft/day and a hydraulic conductivity of 0.27 ft/day (Figure 18.) The saturated thickness of the limestone was assumed to be 10 feet.

Drawdowns in other wells at Site SS006 were too small to be suitable for analysis. This suggests that the overall hydraulic conductivity of the subsurface materials at the site is low. Although several wells exhibit a general downward trend in water levels over time, these are attributed to a decline in the elevation of the local water table independent of the test. The drawdown in shallow well MW007 is shown in Figure 19 to indicate that the decline does not follow a curvilinear trend expected from drawdown attributed to the test well.

Site SS009

The recovery in shallow well MW003 was analyzed as a slug test using the Bouwer and Rice method. The data curve shows an early rapid recovery, likely due to water draining from the sand pack around the screen, then a steady, very slow recovery (Figure 20.) The data were used to provide an estimate of the hydraulic conductivity at 0.00074 ft/day. Unlike most of the other tests, the water level was drawn down rapidly in the well and then allowed to recover after only a short time, so that these test data are more suitable for analysis as a slug test.

The test in deep well MW006 was analyzed both as slug test using the Bouwer and Rice Method. The slug-test analysis produced a hydraulic conductivity of 0.00062 ft/day assuming that the full 5 feet of the screen is open to the water-bearing unit (Figure 21.) However, it is likely that the screen is set about 1.7 feet into the underlying shale, based on the depth of the well and the estimated depth to the limestone/shale interface. Therefore, the test was reanalyzed assuming that the screen is open only 3.3 feet to the water-bearing unit (Figure 22.) This analysis produced a hydraulic conductivity of 0.0011 ft/day.

There was very little drawdown in any of the observation wells. However, the drawdown and early recovery data obtained from deep well MW008, located about 66 feet away from test well MW006 and screened in the same depth interval, were analyzed using the Theis method (Figure 23) and the Hantush-Jacob leaky aquifer method (Figure 24). Transmissivity values of 0.050 sq. ft/day and 0.51 sq. ft/day were calculated from the analyses. Assuming a thickness of the water-bearing unit of 7 feet, then the hydraulic conductivity is 0.0071 ft/day and 0.0073 ft/day, respectively.

Drawdowns in other wells at Site SS009 were either erratic or were too small to be suitable for analysis. This suggests that the overall hydraulic conductivity of the subsurface materials at the site is low.

Site ST005

The recovery in shallow well MW003 was analyzed as a slug test. The data curve (Figure 25) shows an early rapid recovery, likely due to water draining from the sand pack around the screen, then a steady, very slow recovery. The data were used to provide an estimate of the hydraulic conductivity at 0.00068 ft/day.

Figure 26 shows the drawdown in shallow well MW012. Although all shallow wells at the site exhibited gradual declines in water level during the test, the lack of a curvilinear nature to the curves suggests that the drawdown is due to a local long-term decline in water levels rather than a result of the test.

The test in deep well MW010 was analyzed as a recovery test using the Theis recovery method (Figure 27.) The analysis produced a transmissivity of 0.25 sq. ft/day and a hydraulic conductivity of 0.031 ft/day. The saturated thickness of the limestone was assumed to be 8 feet.

There was observable drawdown in several of the observation wells. However, it appears that the drawdowns are in response to a local longer-term change in the elevation of the water table that is not attributable to the test.

General Observations

There appears to be limited hydraulic connection between locations at some of the sites, both laterally and vertically. The following observations were made:

- At Site SS009, pumping the deep well (MW006) clearly caused drawdown in deep well MW008, located about 66 feet away. A slight effect was observed in shallow well MW009, also located about 66 feet away and next to deep well MW008. This suggests that there is some hydraulic connection between the areas where wells MW006 and MW008 are located. No obvious drawdown was observed in other wells at the site, which are about 100 feet away.
- At Site CS004 there was slight effect of pumping the shallow well (MW003) on shallow well MW001 and deep wells MW007 and MW008. Well MW007 is located next to MW003. The other wells are about 50 feet away from the test well. No obvious drawdown was observed in other wells at the site, which are slightly further away.

Although there appears to be hydraulic connection across some of the sites, the connection is limited, primarily constrained by the fine-grained nature of the silty clay and weathered shale and what likely is fracture filling by silt and clay in the limestone. It is not possible to say for sure whether there is hydraulic connection between sites, but the limited connection within sites argues for only very limited, if any, connection between them.

Summary and Conclusions

Aquifer tests were performed in several wells in both the shallow and deep intervals at five sites. The results of analyzing all usable tests are provided in Table 3. Hydraulic conductivities ranged from 0.00062 ft/day to 4.3 ft/day, with most values less than about 0.3 ft/day. These results indicate that the transmissive capabilities of the water-bearing units at the five sites are very low. The estimated hydraulic conductivities from the tests conform to those estimated for silt and other low-permeability materials described in the literature (Domenico and Schwarz, 1998).

There was very little drawdown observed in most observation wells, some being as close as 50 feet to a test well. Although this may be due to the low discharge rates achieved during the tests, it should be kept in mind that these low discharge rates were all that could be achieved from the tested wells, again indicating the low transmissive capabilities of the subsurface materials. Most wells went dry when purged for groundwater sampling, again indicating the generally low hydraulic conductivity of the water-bearing units. This argues for only a limited hydraulic connection between locations at an individual site.

The hydraulic conductivities were divided up by lithologic unit to see if a distinct range of conductivities could be assigned to each unit. These are provided in Table 4. Although the hydraulic conductivity of the silty clay may be lower than that of the limestone, there is a wide range of overlap in their values and the two units appear to have similar transmissive capabilities.

Some of the test wells are screened in limestone, which may be characterized by flow in fractures. On face value, this condition might preclude analyzing aquifer-test data using the methods applied in this technical memorandum. However, it is reasonable to conclude from the results that the transmissive capabilities of the limestone are very low and that there is not extensive interconnection within the limestone between the wells at the sites.

The results of the aquifer testing, combined with the fine-grained nature observed in much of the subsurface materials and the fact that wells typically purge dry during groundwater sampling, suggest that the groundwater contamination occurring at the site would not be easily remediated using an approach such as pump and treat. It may be of value to extract groundwater from

selected wells exhibiting elevated levels of contamination. However, the approach will not efficiently remediate large volumes of the subsurface.

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Table 1
Assessment of Potential Usability of Aquifer Tests
Richards-Gebaur AFB Basewide RI/FS Aquifer Testing

Site	Well	Well Use	Screen Depth (ft bgs)	Assessment of Data	Analytical Methods
CS004 (shallow test well)	MW003	Test	11 - 16	Usable	Slug-test analysis, Theis Recovery
	MW001	Observation	11 - 16	Unusable - drawdown affected by upward trend in local water levels and data not acceptable to type-curve fitting	
	MW006	Observation	20 - 23	Unusable - water level went up	
	MW007	Observation	20.5 - 23.5	Unusable - drawdown affected by upward trend in local water levels and data not acceptable to type-curve fitting	
	MW008	Observation	20 - 23	Unusable - drawdown affected by upward trend in local water levels, data not acceptable to type-curve fitting, and drawdown too small for analysis	
CS004 (deep test well)	MW007	Test	20.5 - 23.5	Usable	Theis Recovery
	MW001	Observation	11 - 16	Unusable - too little drawdown	
	MW002	Observation	11 - 16	Unusable - too little drawdown	
	MW003	Observation	11 - 16	Unusable	
	MW006	Observation	20 - 23	Unusable - too little drawdown	
SS003/CS002	MW008	Observation	20 - 23	Unusable - too little drawdown	
	MW007	Test	13 - 23	Usable	Theis Recovery
	MW004	Observation	14 - 24	Unusable - too little drawdown	
	MW006	Observation	11.5 - 21.5	Unusable - too little drawdown	
	MW002	Observation	12.5 - 22.5	Unusable - too little drawdown	
SS006	MW004	Observation	14.7 - 24.2	Unusable - too little drawdown	
	MW001	Test	5.8 - 15.8	Usable	Slug-test analysis, Theis Recovery
	MW005	Observation	7.2 - 12.2	Unusable - too little drawdown	
	MW006	Observation	7.2 - 12.2	Unusable - too little drawdown	
	MW007	Observation	6.7 - 11.7	Unusable - too little drawdown	
	MW008	Observation	5.7 - 10.7	Unusable - too little drawdown	

Table 1
Assessment of Potential Usability of Aquifer Tests
Richards-Gebaur AFB Basewide RI/FS Aquifer Testing

Site	Well	Well Use	Screen Depth (ft bgs)	Assessment of Data	Analytical Methods
SS009 (shallow test well)	MW003	Test	8.5 - 13.5	Usable	Slug-test analysis
	MW002	Observation	8.5 - 13.5	Unusable - unusual behavior	
	MW006	Observation	18.7 - 23.7	Unusable - unusual behavior	
	MW007	Observation	19.2 - 24.2	Unusable - unusual behavior	
	MW008	Observation	18.7 - 23.7	Unusable - unusual behavior	
	MW009	Observation	11.2 - 16.2	Unusable - unusual behavior	
SS009 (deep test well)	MW006	Test	18.7 - 23.7	Usable	Slug-test analysis
	MW002	Observation	8.5 - 13.5	Unusable - downward trend of local water level	
	MW003	Observation	8.5 - 13.5	Unusable - downward trend of local water level	Theis and Hantush-Jacob analysis
	MW007	Observation	19.2 - 24.2	Unusable - downward trend of local water level	
	MW008	Observation	18.7 - 23.7	Usable	
	MW009	Observation	11.2 - 16.2	Unusable - downward trend of local water level	
ST005 (shallow test well)	MW003	Test	5.0 - 12.5	Usable	Theis Recovery
	MW010	Observation	17.2 - 22.2	Unusable - affected by downward trend in local water level	
	MW011	Observation	17.2 - 22.2	Unusable - affected by downward trend in local water level	
	MW012	Observation	6.2 - 11.2	Unusable - affected by downward trend in local water level	
	MW015	Observation	19.7 - 24.7	Unusable - affected by downward trend in local water level	
	MW016	Observation	9.2 - 14.2	Unusable - affected by downward trend in local water level	
ST005 (deep test well)	MW010	Test	17.2 - 22.2	Usable	Slug-test analysis
	MW003	Observation	5.0 - 12.5	Unusable - no response	
	MW011	Observation	17.2 - 22.2	Unusable - no response	
	MW012	Observation	6.2 - 11.2	Unusable - affected by downward trend in local water level	
	MW015	Observation	19.7 - 24.7	Unusable - affected by downward trend in local water level	
	MW016	Observation	9.2 - 14.2	Unusable - affected by downward trend in local water level	

ft bgs = feet below ground surface

Table 2
 Aquifer-Testing Information
 Richards-Gebaur Basewide R/FS Aquifer Testing

Site	Well ID	Northing	Easting	Elevation (ft above msl)	Distance to Shallow Test Well (ft)	Distance to Deep Test Well (ft)	Total Depth (ft below toc)	Static Water Level (ft below toc)	Initial Water Column (ft)	Purge Time (min)	Pumping rate (gpm)
CS004	CS004-MW001	975871.729	2774958.223	1005.393	51.38	45.90	16.19	8.07	8.12	NA	0.234 for MW003 and 0.295 for MW007
	CS004-MW003	975922.949	2774954.151	1005.275	-	6.64	16.20	7.61	8.59	32	
	CS004-MW002	975924.537	2775012.915	1004.940	58.79	62.30	16.20	7.13	9.07	NA	
	CS004-MW006	975929.573	2775009.375	1004.850	55.62	59.63	23.20	7.11	16.09	NA	
	CS004-MW007	975917.066	2774951.069	1005.110	6.64	-	23.50	7.50	16.00	168	
	CS004-MW008	975870.670	2774954.747	1005.490	52.28	46.54	22.40	8.21	14.19	NA	
SS003	SS003-MW007	974647.747	2773374.440	1030.160	-	ND	23.00	6.10	16.90	153	0.15
	SS003-MW006	974585.078	2773367.979	1030.610	63.00	ND	21.60	7.40	14.20	NA	
	SS003-MW004	974652.774	2773334.404	1029.797	40.35	ND	23.82	6.49	17.33	NA	
	CS002-MW002R	974724.664	2773324.175	1029.710	91.88	ND	22.70	3.66	19.04	NA	
	CS002-MW004	974715.242	2773492.944	1030.614	136.38	ND	24.32	7.43	16.89	NA	
SS006	SS006-MW001	975730.310	2773411.860	1049.690	-	ND	18.50	9.46	9.04	52	0.14
	SS006-MW005	975772.682	2773422.840	1053.170	43.77	ND	18.66	10.96	7.70	NA	
	SS006-MW006	975716.696	2773462.551	1046.630	52.49	ND	15.33	9.28	6.05	NA	
	SS006-MW007	975669.579	2773432.218	1049.560	64.05	ND	14.95	9.83	5.12	NA	
	SS006-MW008	975744.565	2773358.205	1050.960	55.52	ND	10.45	7.05	3.40	NA	
SS009	SS009-MW003	975569.211	2774443.661	1010.095	-	2.55	14.02	7.28	6.74	10	0.35 for MW003 and 0.294 for MW006
	SS009-MW002	975643.764	2774368.222	1009.161	106.06	108.61	13.80	5.92	7.88	NA	
	SS009-MW009	975616.071	2774489.838	1012.390	65.79	65.64	15.45	9.92	5.53	NA	
	SS009-MW006	975567.564	2774445.610	1012.830	2.55	-	23.62	8.26	15.36	17	
	SS009-MW007	975643.300	2774368.391	1012.160	105.62	108.16	23.56	6.44	17.12	NA	
	SS009-MW008	975614.088	2774492.177	1012.710	66.09	65.83	25.25	5.28	19.97	NA	
ST005	ST005-MW015	977443.478	2775996.404	1009.680	51.19	56.01	28.20	7.28	20.92	NA	0.42 for MW003 and 0.210 for MW010
	ST005-MW016	977438.718	2775996.063	1009.520	46.43	51.24	17.40	6.80	10.60	NA	
	ST005-MW010	977387.651	2775991.891	1008.650	5.51	-	25.50	6.87	18.63	59	
	ST005-MW011	977378.119	2776038.768	1007.820	51.16	47.84	25.50	8.49	17.01	NA	
	ST005-MW012	977380.527	2776035.289	1007.920	47.15	43.98	14.65	5.61	9.04	NA	
ST005-MW003	977392.720	2775989.740	1007.300	-	5.51	14.12	9.18	4.94	6		

Notes:

ft = feet

msl = mean sea level

toc = top of casing

min = minutes

gpm = gallons per minute

Bold well designations indicate those wells pumped for testing

ND = No deep well available

NA = Not applicable; well not pumped

Table 3
Aquifer-Test Results
Richards-Gebaur AFB Basewide RI/FS Aquifer Testing

Site	Test Well	Observation Well	Figure Number	Geologic Material	Test Type	Transmissivity (ft ² /day)	Unit Thickness (ft)	Hydraulic Conductivity	
								(ft/day)	(m/sec)
CS004	MW003	MW003	9	Silty clay	Slug test on early data (Bouwer and Rice - unconfined)	NA	10	4.70E-02	1.66E-07
		MW003	10	Silty clay	Slug test on later data (Bouwer and Rice - unconfined)	NA	10	1.00E-01	3.53E-07
		MW003	11	Silty clay	Theis Recovery	0.32	10	3.20E-02	1.13E-07
	MW007	MW007	13	Limestone	Theis Recovery	12.8	3	4.30E+00	1.52E-05
SS003	MW007	MW007	14	Weathered shale	Theis Recovery on large t/t'	0.29	23	1.30E-02	4.59E-08
		MW007	15	Weathered shale	Theis Recovery on small t/t'	0.93	23	4.00E-02	1.41E-07
SS006	MW001	MW001	16	Limestone	Slug test on early data (Bouwer and Rice - unconfined)	NA	10	5.80E-02	2.05E-07
		MW001	17	Limestone	Slug test on later data (Bouwer and Rice - unconfined)	NA	10	2.00E-01	7.06E-07
		MW001	18	Limestone	Theis Recovery	2.71	10	2.70E-01	9.52E-07
SS009	MW003	MW003	20	Silty clay	Slug test (Bouwer and Rice - unconfined)	NA	8	7.40E-04	2.61E-09
	MW006	MW006	21	Limestone	Slug test (Bouwer and Rice - confined with 5-ft. screen)	NA	7	6.20E-04	2.19E-09
		MW006	22	Limestone	Slug test (Bouwer and Rice - confined with 3.3-ft. screen)	NA	7	1.10E-03	3.88E-09
		MW008	23	Limestone	Theis (drawdown and recovery)	0.050	7	7.14E-03	2.52E-08
		MW008	24	Limestone	Hantush-Jacob Leaky (drawdown and recovery)	0.051	7	7.29E-03	2.57E-08
ST005	MW003	MW003	25	Silty clay	Slug test (Bouwer and Rice - unconfined)	NA	10	6.80E-04	2.40E-09
	MW010	MW010	27	Limestone	Theis Recovery	0.25	8	3.10E-02	1.09E-07

NA = Not available (i.e., not generated by the analytical method)

ft = feet

ft²/day = square feet per day

ft/day = feet per day

m/sec = meters per second

Table 4
 Aquifer-Test Results Sorted by Lithology
 Richards-Gebaur AFB Basewide RI/FS Aquifer Testing

Site	Test Well	Observation Well	Figure Number	Geologic Material	Test Type	Transmissivity (ft ² /day)	Unit Thickness (ft)	Hydraulic Conductivity	
								(ft/day)	(m/sec)
CS004	MW003	MW003	9	Silty clay	Slug test on early data (Bouwer and Rice - unconfined)	NA	10	4.70E-02	1.66E-07
		MW003	10	Silty clay	Slug test on later data (Bouwer and Rice - unconfined)	NA	10	1.00E-01	3.53E-07
		MW003	11	Silty clay	Theis Recovery	0.32	10	3.20E-02	1.13E-07
SS009	MW003	MW003	20	Silty clay	Slug test (Bouwer and Rice - unconfined)	NA	8	7.40E-04	2.61E-09
ST005	MW003	MW003	25	Silty clay	Slug test (Bouwer and Rice - unconfined)	NA	10	6.80E-04	2.40E-09
SS003	MW007	MW007	14	Weathered shale	Theis Recovery on large t/t'	0.29	23	1.30E-02	4.59E-08
		MW007	15	Weathered shale	Theis Recovery on small t/t'	0.93	23	4.00E-02	1.41E-07
CS004	MW007	MW007	13	Limestone	Theis Recovery	12.8	3	4.30E+00	1.52E-05
SS006	MW001	MW001	16	Limestone	Slug test on early data (Bouwer and Rice - unconfined)	NA	10	5.80E-02	2.05E-07
		MW001	17	Limestone	Slug test on later data (Bouwer and Rice - unconfined)	NA	10	2.00E-01	7.06E-07
		MW001	18	Limestone	Theis Recovery	2.71	10	2.70E-01	9.52E-07
SS009	MW006	MW006	21	Limestone	Slug test (Bouwer and Rice - confined with 5-ft. screen)	NA	7	6.20E-04	2.19E-09
		MW006	22	Limestone	Slug test (Bouwer and Rice - confined with 3.3-ft. screen)	NA	7	1.10E-03	3.88E-09
		MW008	23	Limestone	Theis (drawdown and recovery)	0.050	7	7.14E-03	2.52E-08
		MW008	24	Limestone	Hantush-Jacob Leaky (drawdown and recovery)	0.051	7	7.29E-03	2.57E-08
ST005	MW010	MW010	27	Limestone	Theis Recovery	0.25	8	3.10E-02	1.09E-07

NA = Not available (i.e., not generated by the analytical method)

ft = feet

ft²/day = square feet per day

ft/day = feet per day

m/sec = meters per second

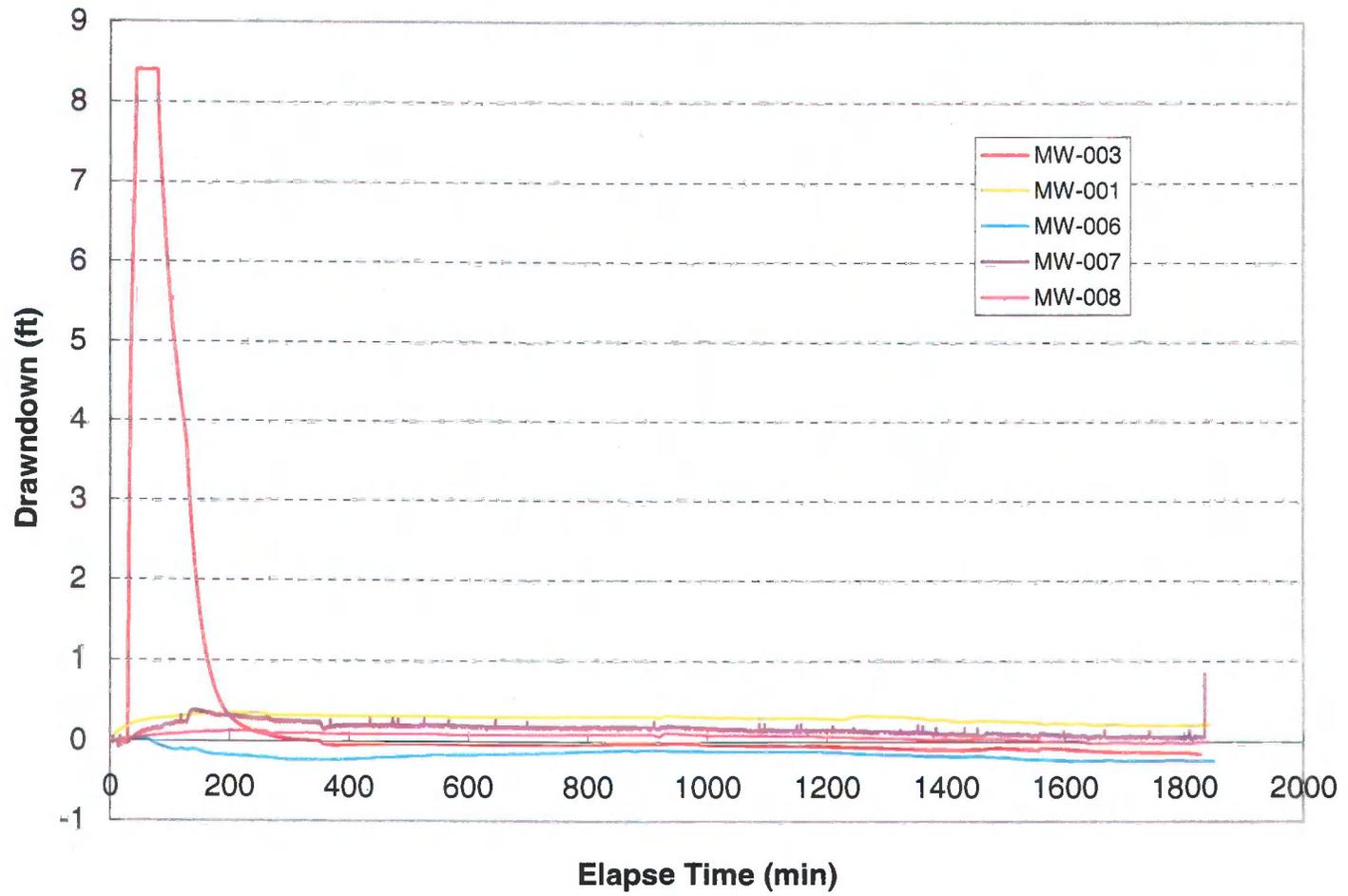


Figure 1. Aquifer Test at CS 004 with MW003(Shallow) as Test Well

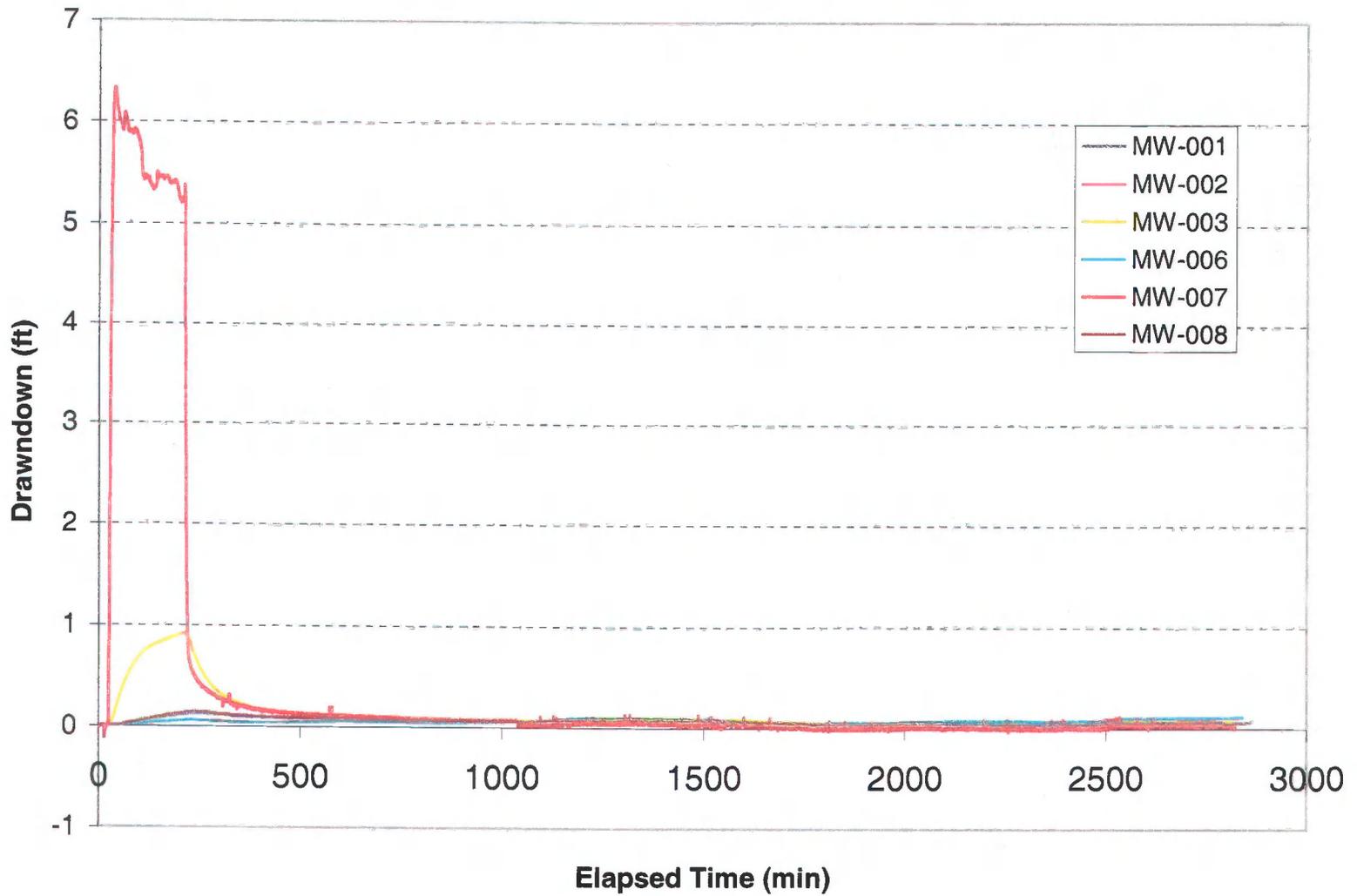


Figure 2. Aquifer Test at CS 004 with MW-007 (Deep) as Test Well

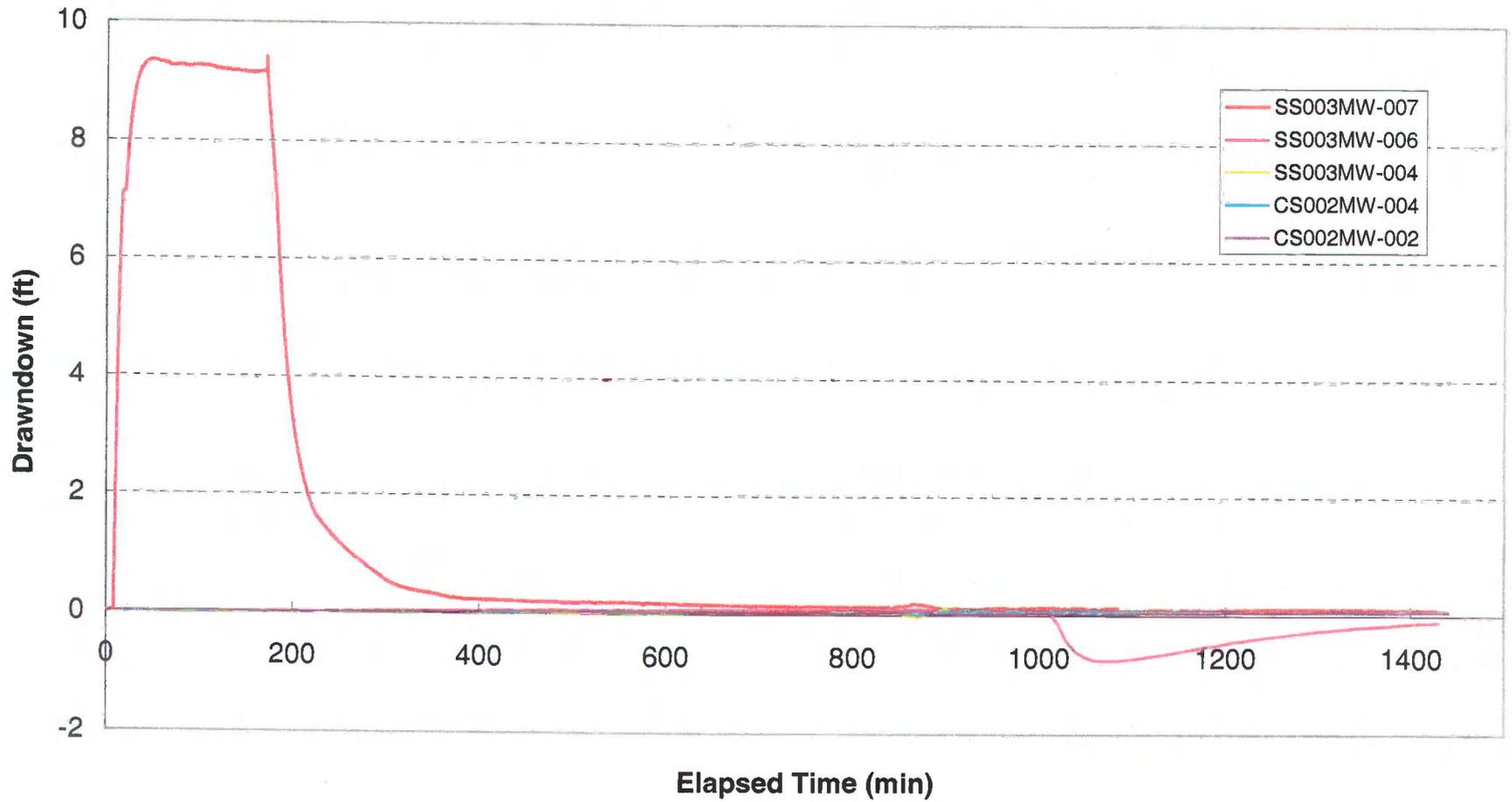


Figure 3. Aquifer Test at SS 003 with SS003-MW007 as Test Well

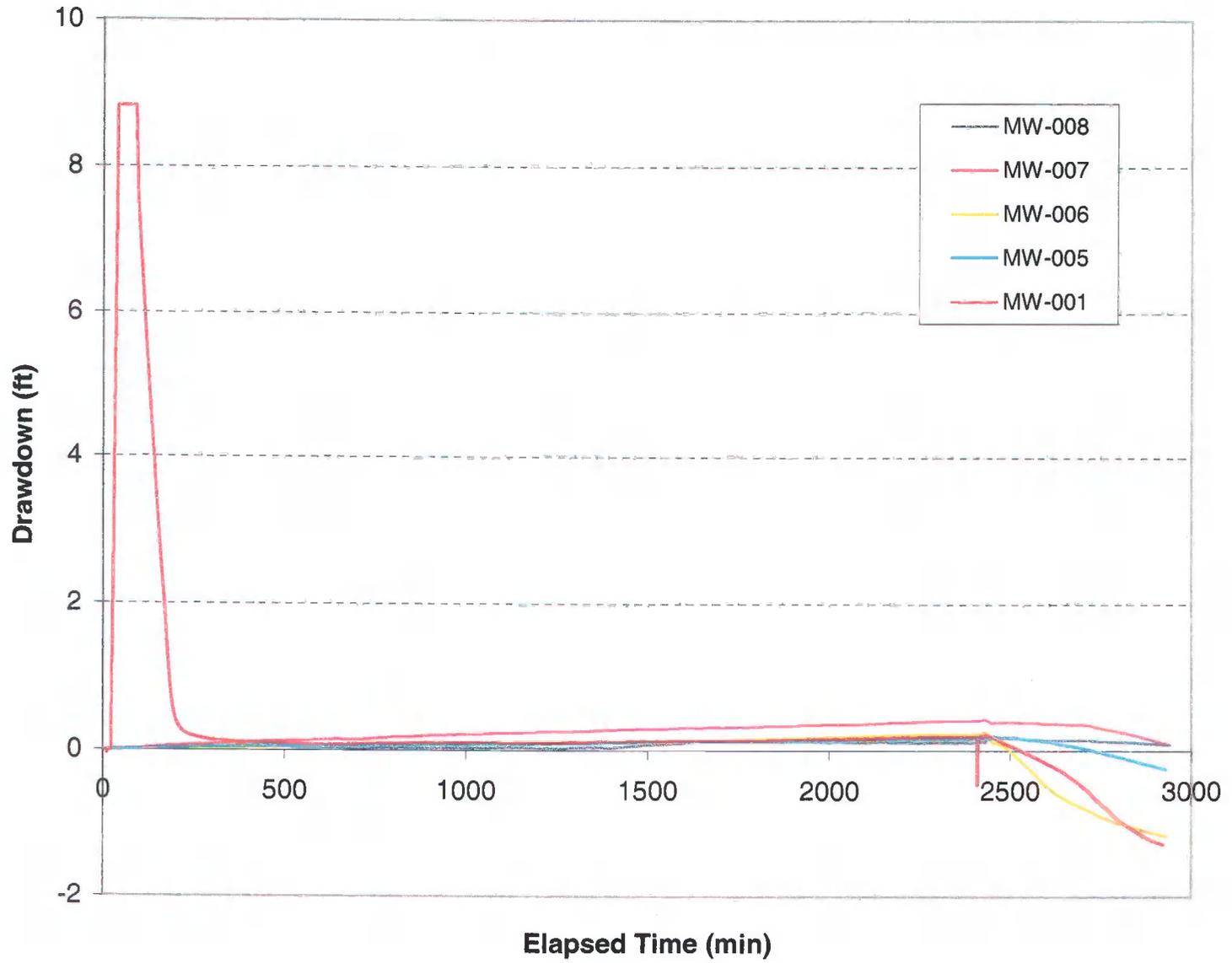


Figure 4. Aquifer Test at SS 006 with MW001 as Pumping Well

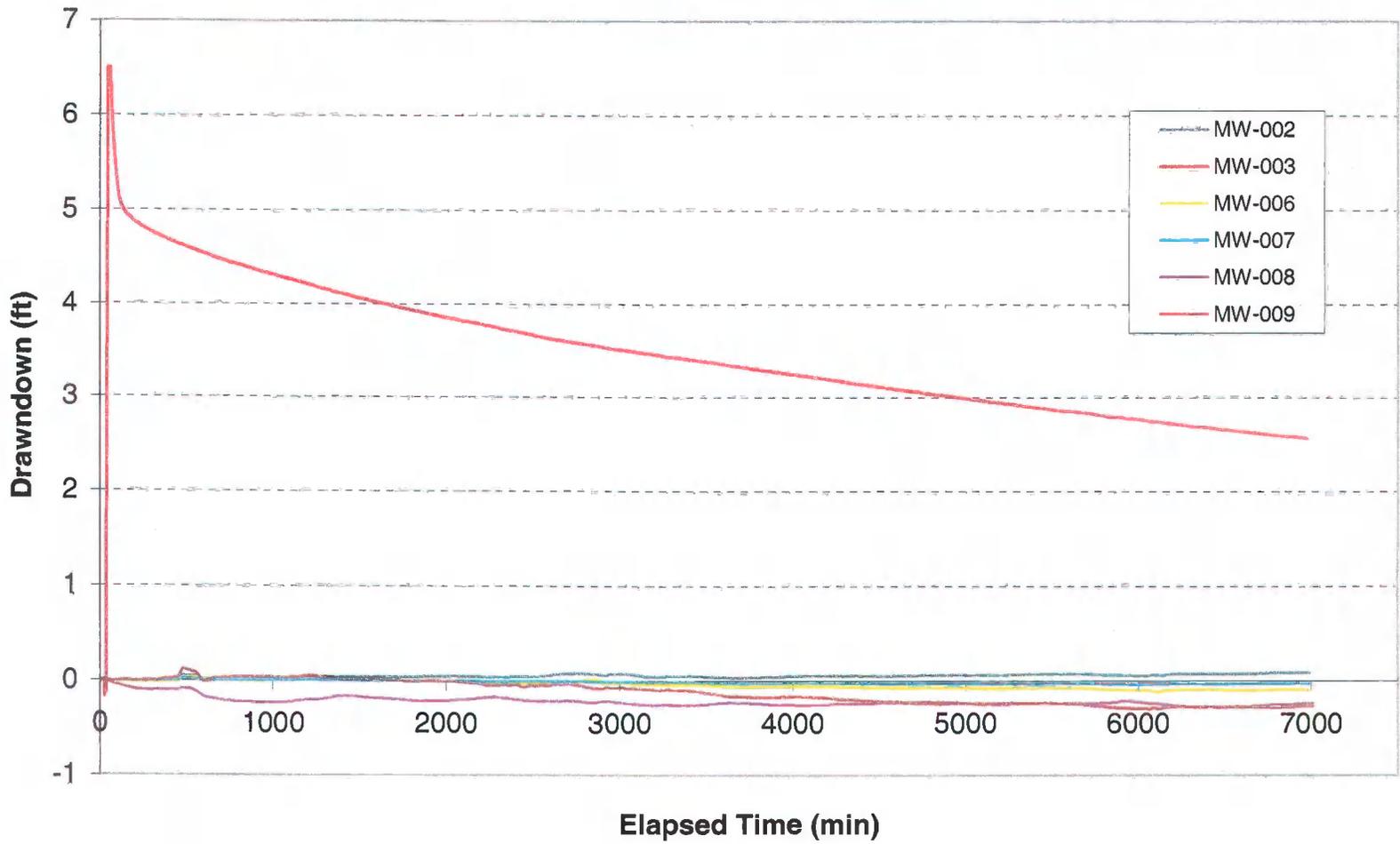


Figure 5. Aquifer Test at SS 009 with MW003 as Pumping Well

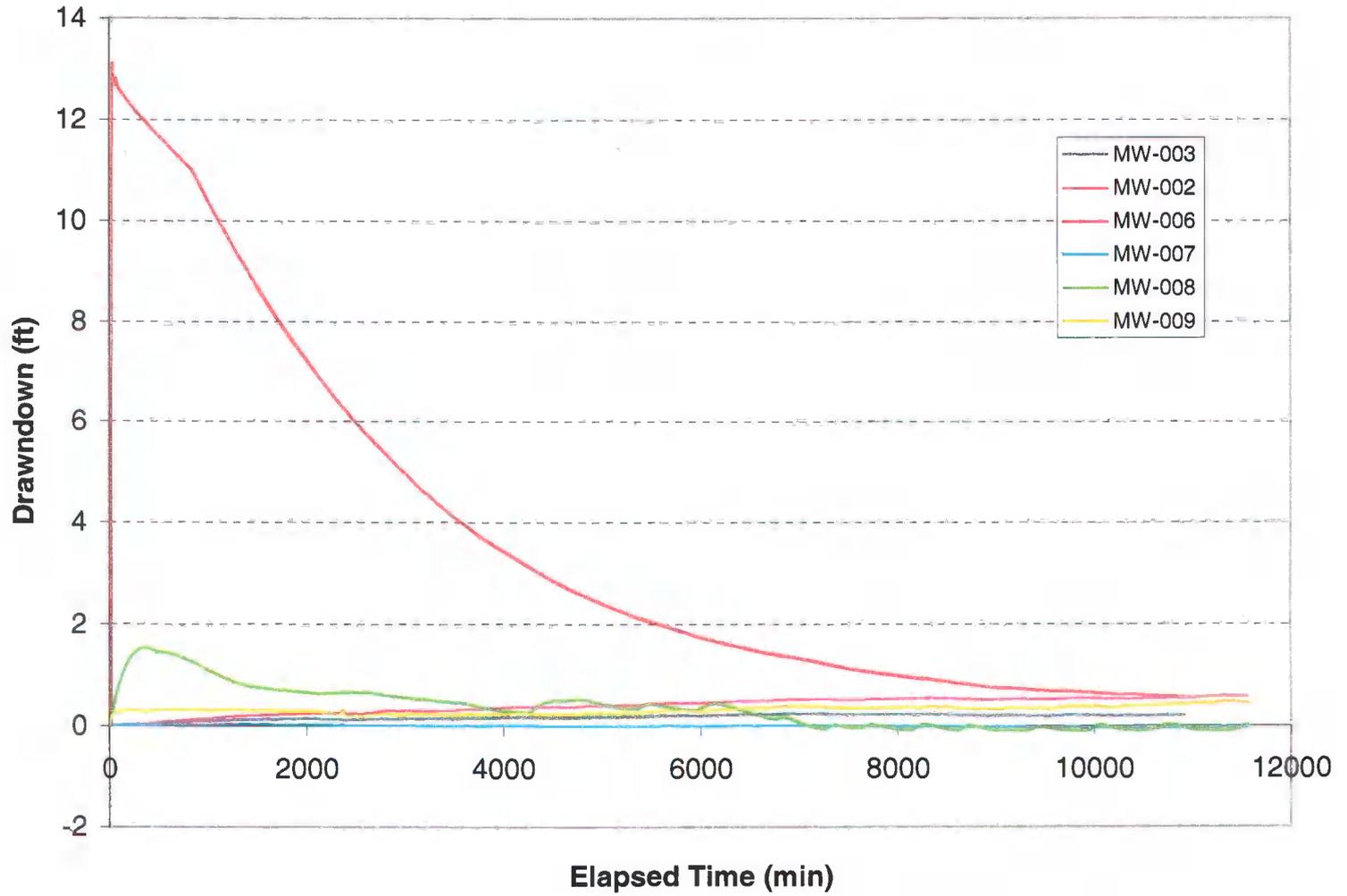


Figure 6. Aquifer Test at SS 009 with MW006 (Deep) as Test Well

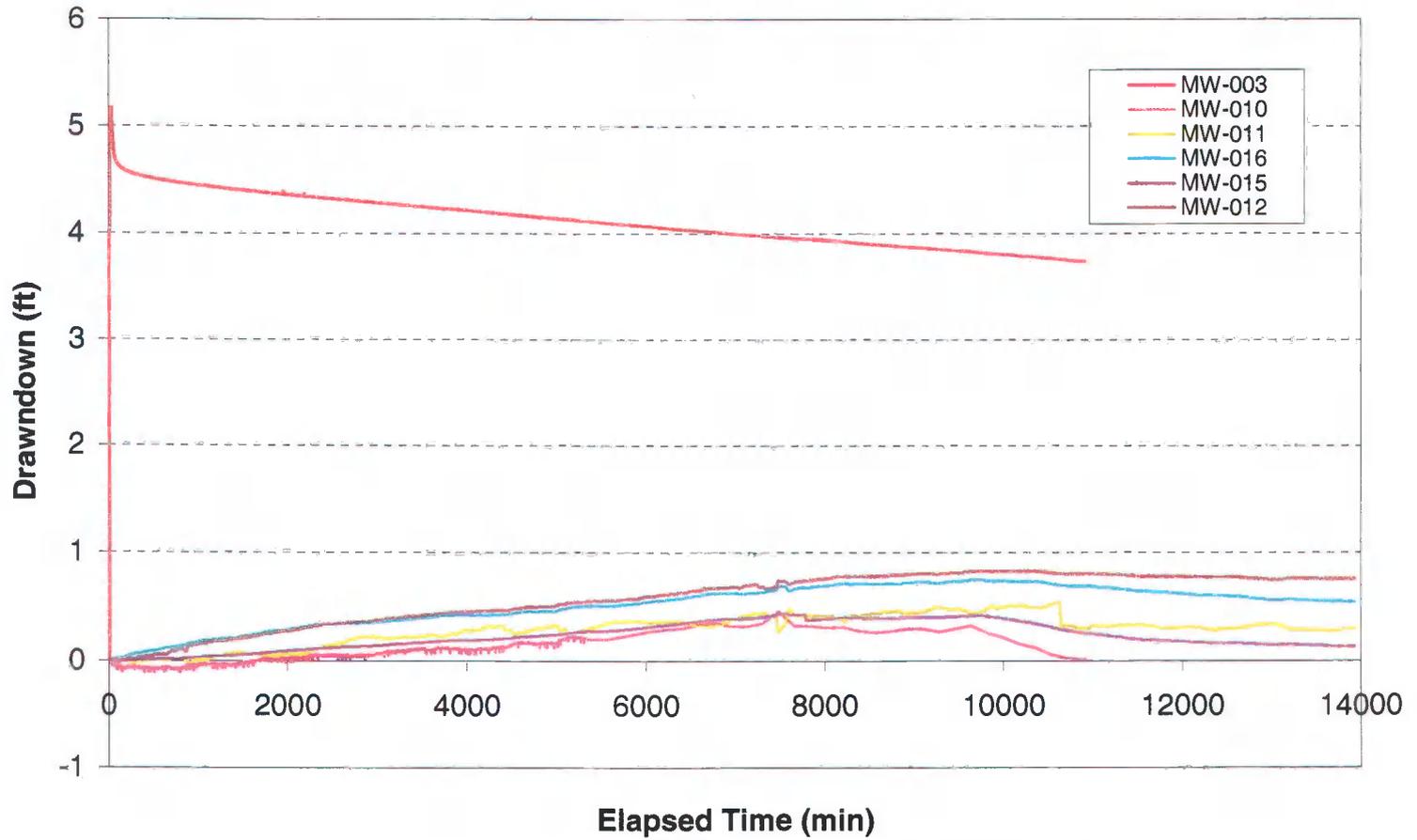


Figure 7. Aquifer Test at ST 005 with MW003 (Shallow) as Test Well

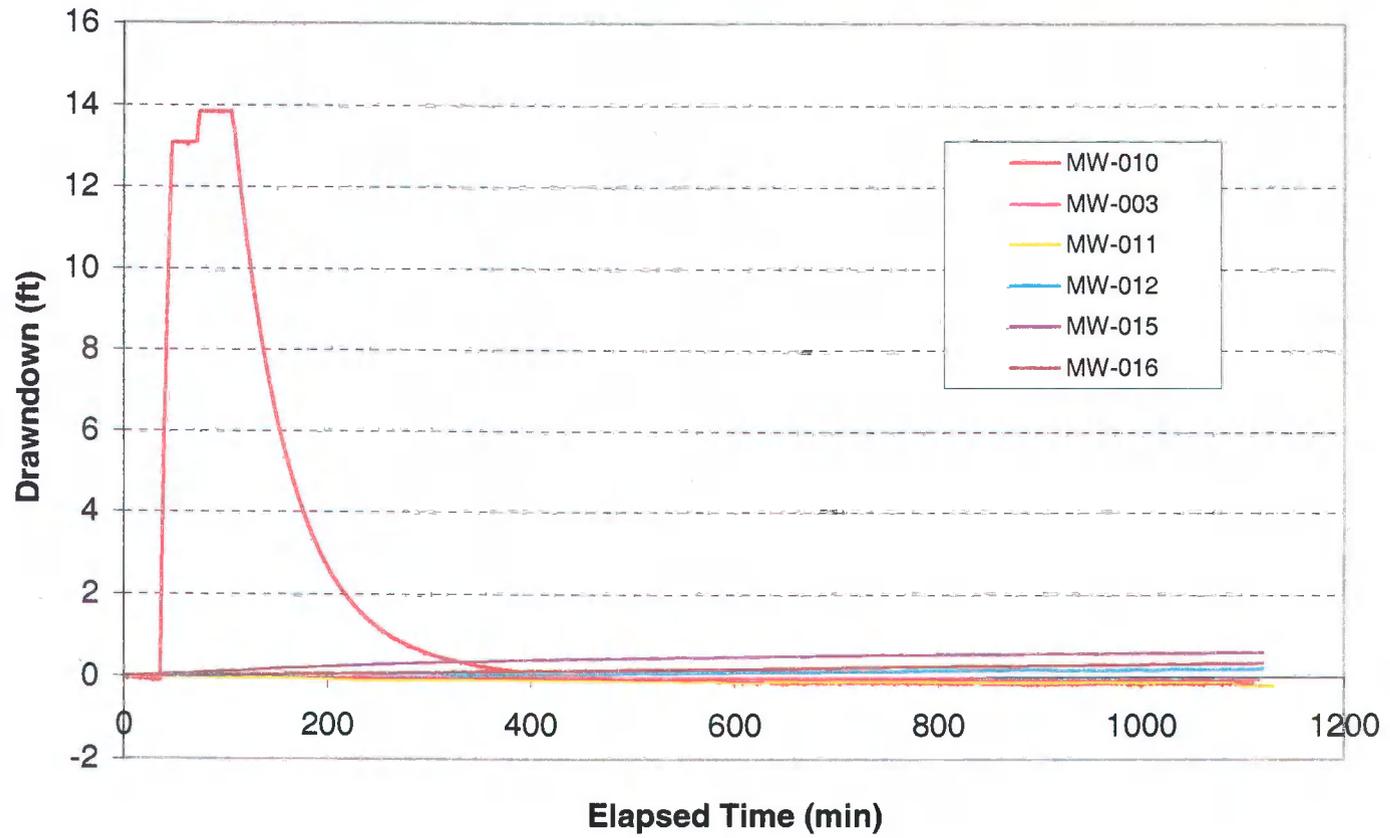
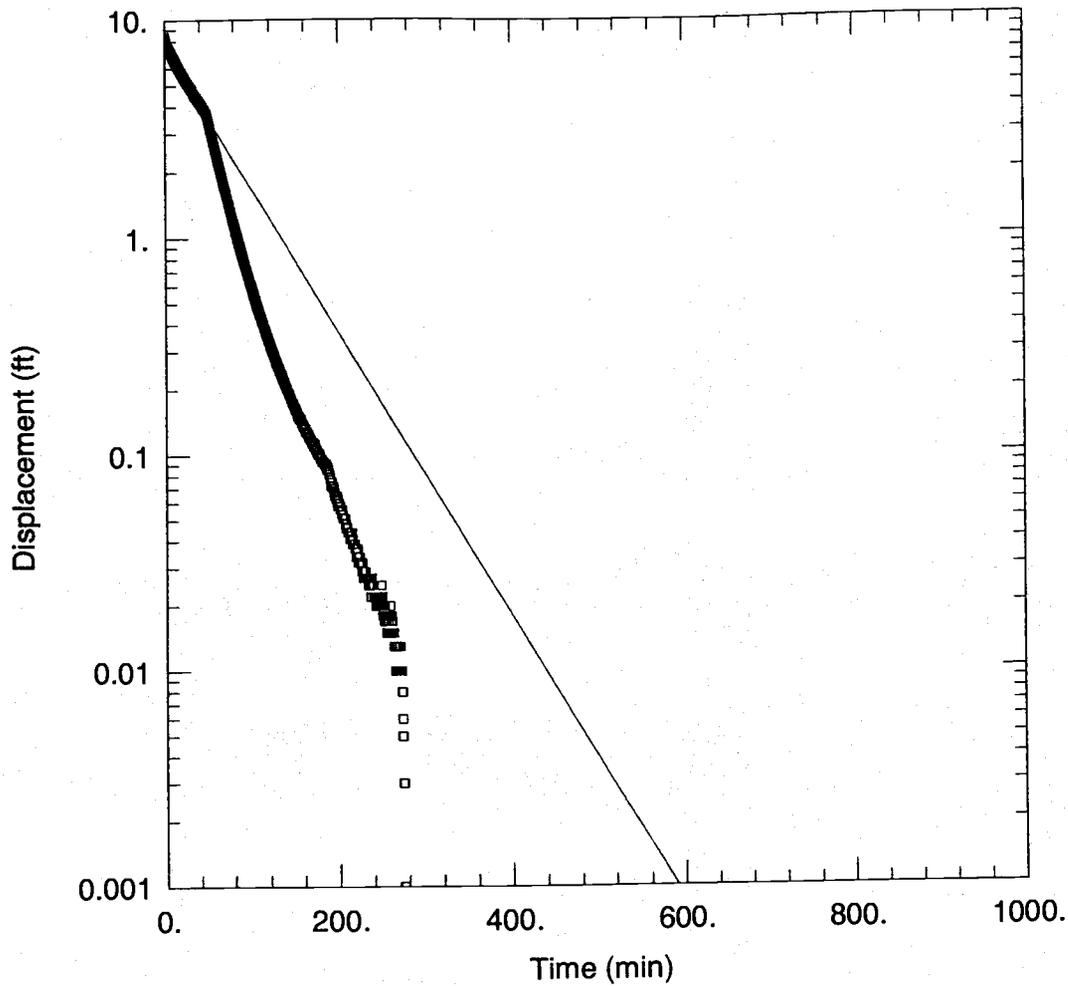
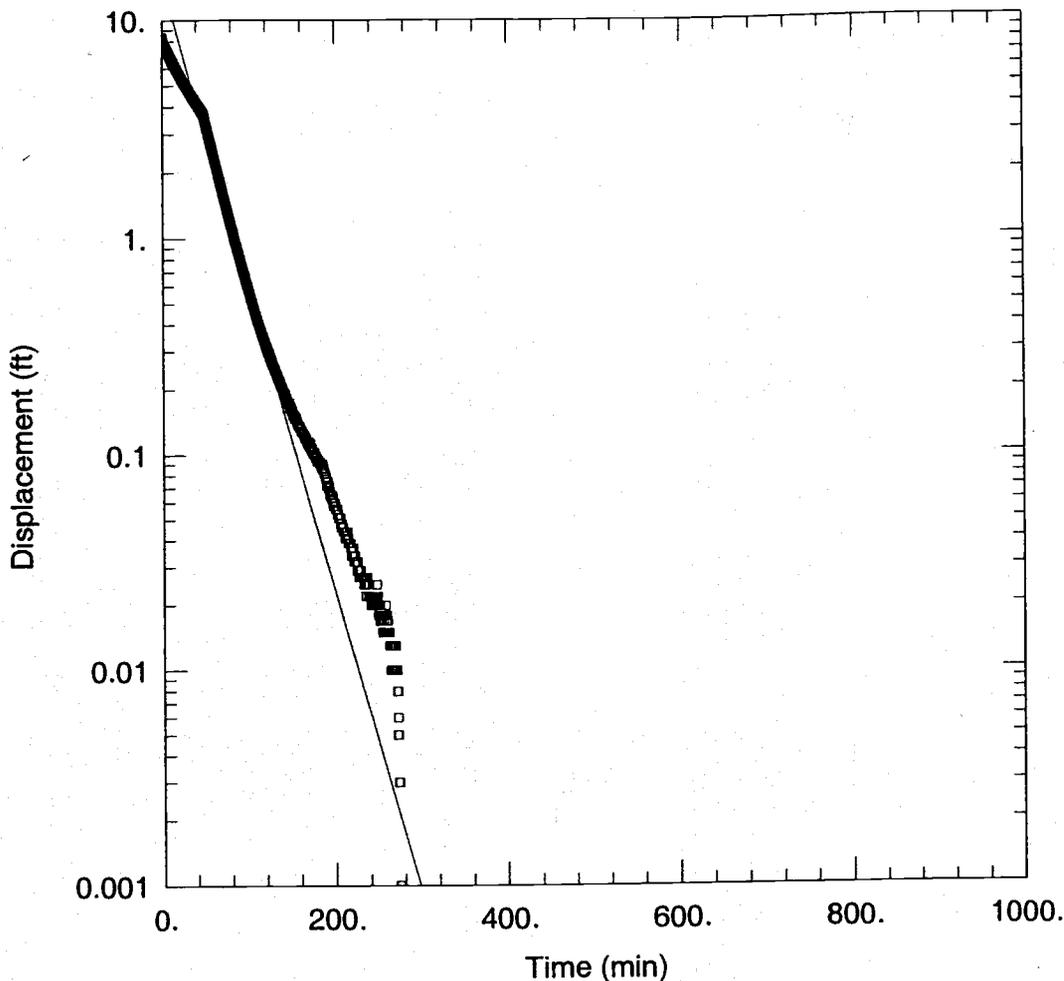


Figure 8. Aquifer Test at ST 005 with MW010 (Deep) as Test Well



SLUG TEST IN WELL MW003 AT CS004	
Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\4_3_3_SL.AQT	
Date: <u>12/12/00</u>	Time: <u>11:17:04</u>
AQUIFER DATA	
Saturated Thickness: <u>10. ft</u>	Anisotropy Ratio (Kz/Kr): <u>0.1</u>
WELL DATA	
Initial Displacement: <u>8.4 ft</u>	Water Column Height: <u>8.4 ft</u>
Casing Radius: <u>0.083 ft</u>	Wellbore Radius: <u>0.25 ft</u>
Screen Length: <u>5. ft</u>	
SOLUTION	
Aquifer Model: <u>Unconfined</u>	K = <u>0.04746 ft/day</u>
Solution Method: <u>Bowser-Rice</u>	y0 = <u>7.699 ft</u>

Figure 9



SLUG TEST IN WELL MW003 AT CS004

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\4_3_3_SL.AQT
 Date: 12/12/00 Time: 11:17:38

AQUIFER DATA

Saturated Thickness: 10. ft Anisotropy Ratio (K_z/K_r): 0.1

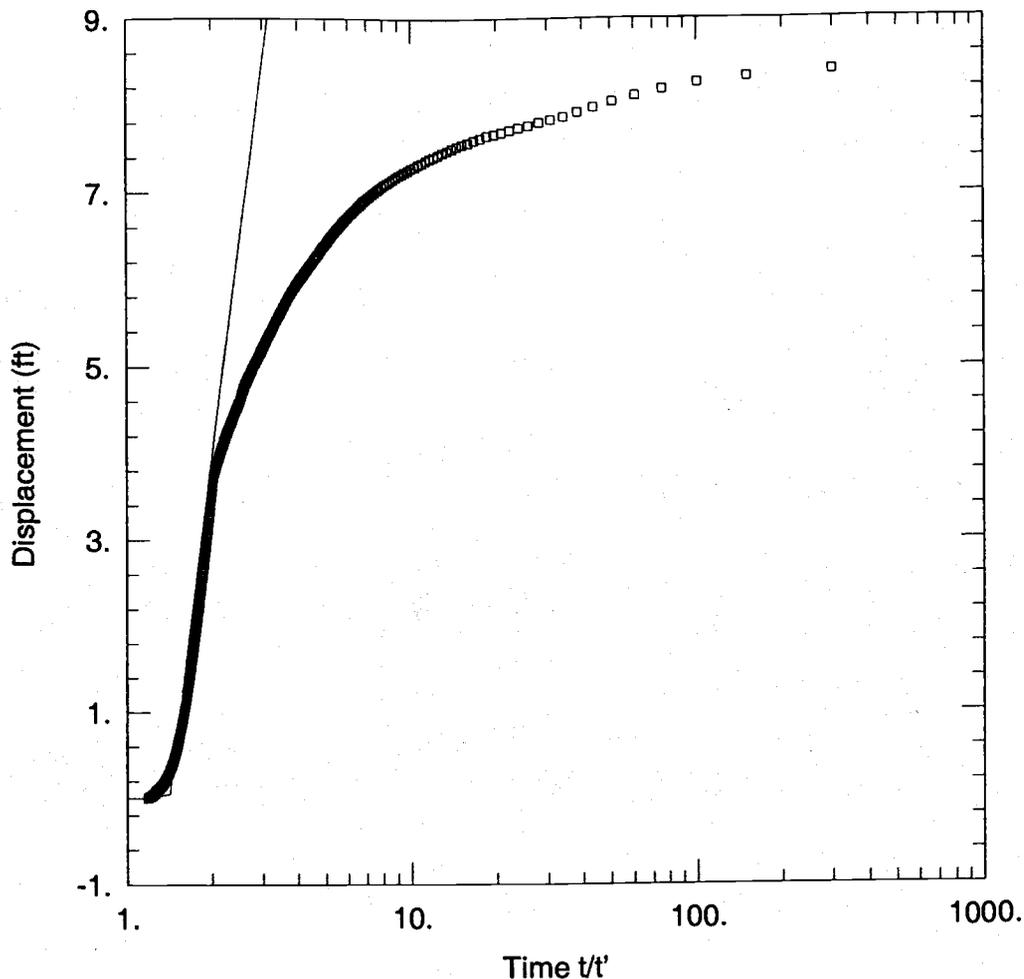
WELL DATA

Initial Displacement: 8.4 ft Water Column Height: 8.4 ft
 Casing Radius: 0.083 ft Wellbore Radius: 0.25 ft
 Screen Length: 5. ft

SOLUTION

Aquifer Model: Unconfined $K = 0.1013$ ft/day
 Solution Method: Bouwer-Rice $y_0 = 15.31$ ft

Figure 10



RECOVERY IN MW3 - PUMPING MW3 AT CS4

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\4_3_3_RC.AQT
 Date: 12/12/00 Time: 11:19:03

AQUIFER DATA

Saturated Thickness: 10. ft Anisotropy Ratio (Kz/Kr): 0.1

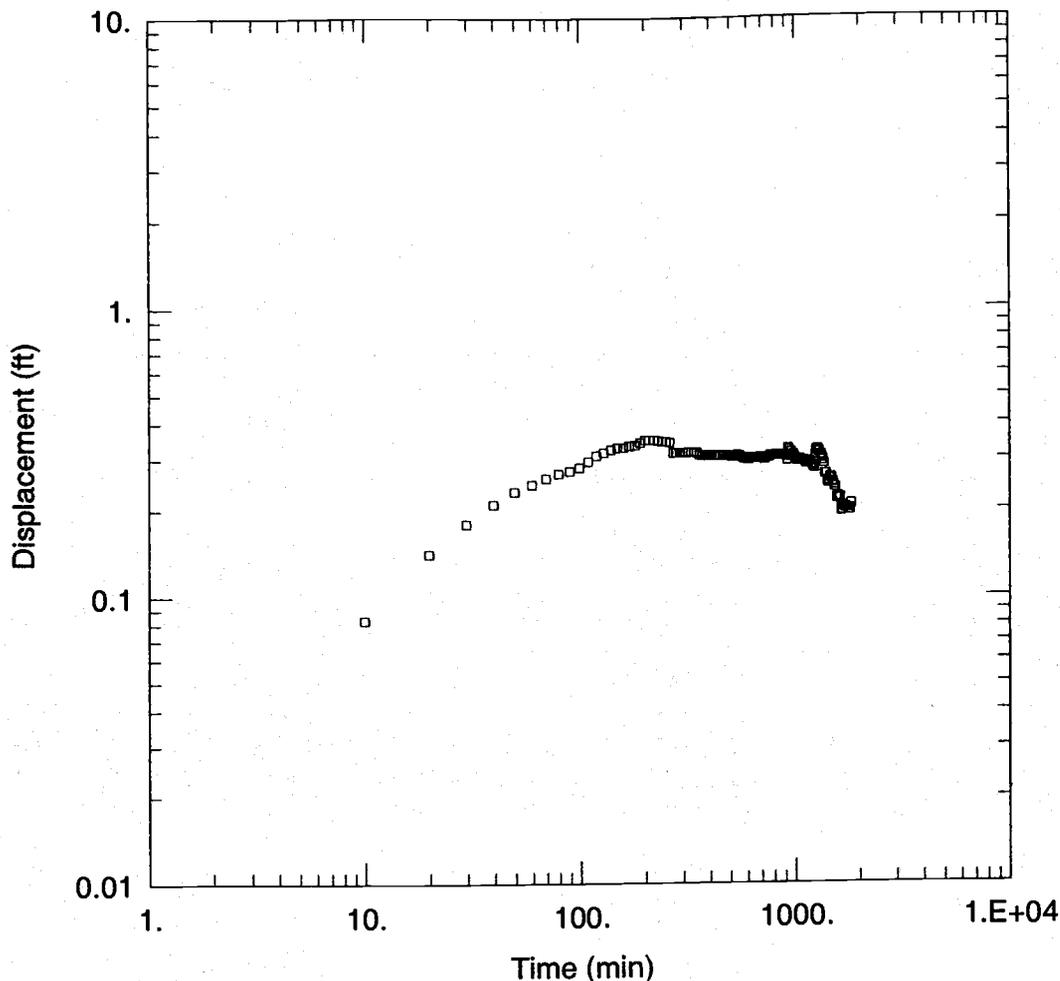
WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
CS004-MW003	2.775E+006	9.759E+005	CS004-MW003	2.775E+006	9.759E+005

SOLUTION

Aquifer Model: Confined T = 0.3206 ft²/day
 Solution Method: Theis Recovery S' = 1.406

Figure 11



D'D/RECOV IN MW1 - PUMPING MW3 AT CS4

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\4_3_1_DR.AQT
 Date: 09/21/00 Time: 15:51:16

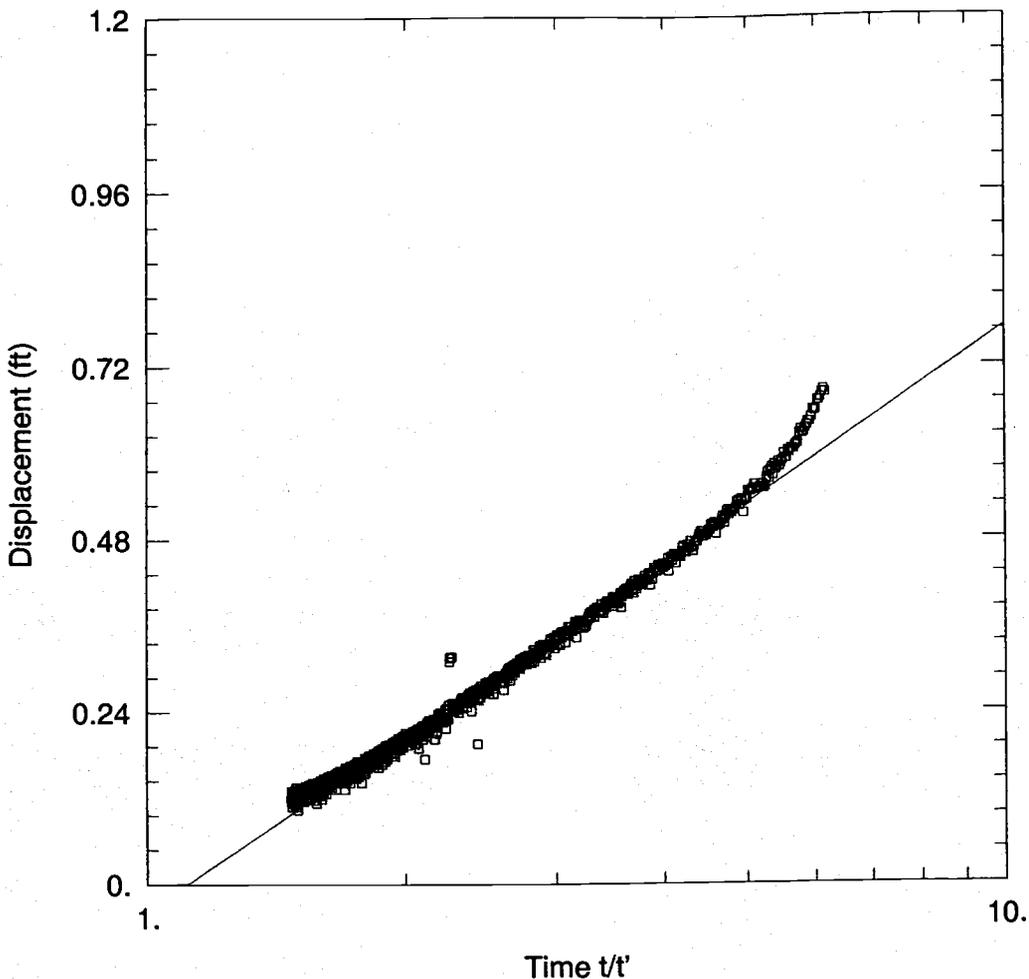
AQUIFER DATA

Saturated Thickness: 13. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
CS004-MW003	2.775E+006	9.759E+005	CS04-MW001	2.775E+006	9.759E+005

Figure 12



RECOVERY IN MW7 - PUMPING MW7 AT CS4

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\4_7_7_RC.AQT
 Date: 12/12/00 Time: 11:27:18

PROJECT INFORMATION

Test Well: CS004-MW07

AQUIFER DATA

Saturated Thickness: 3. ft Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

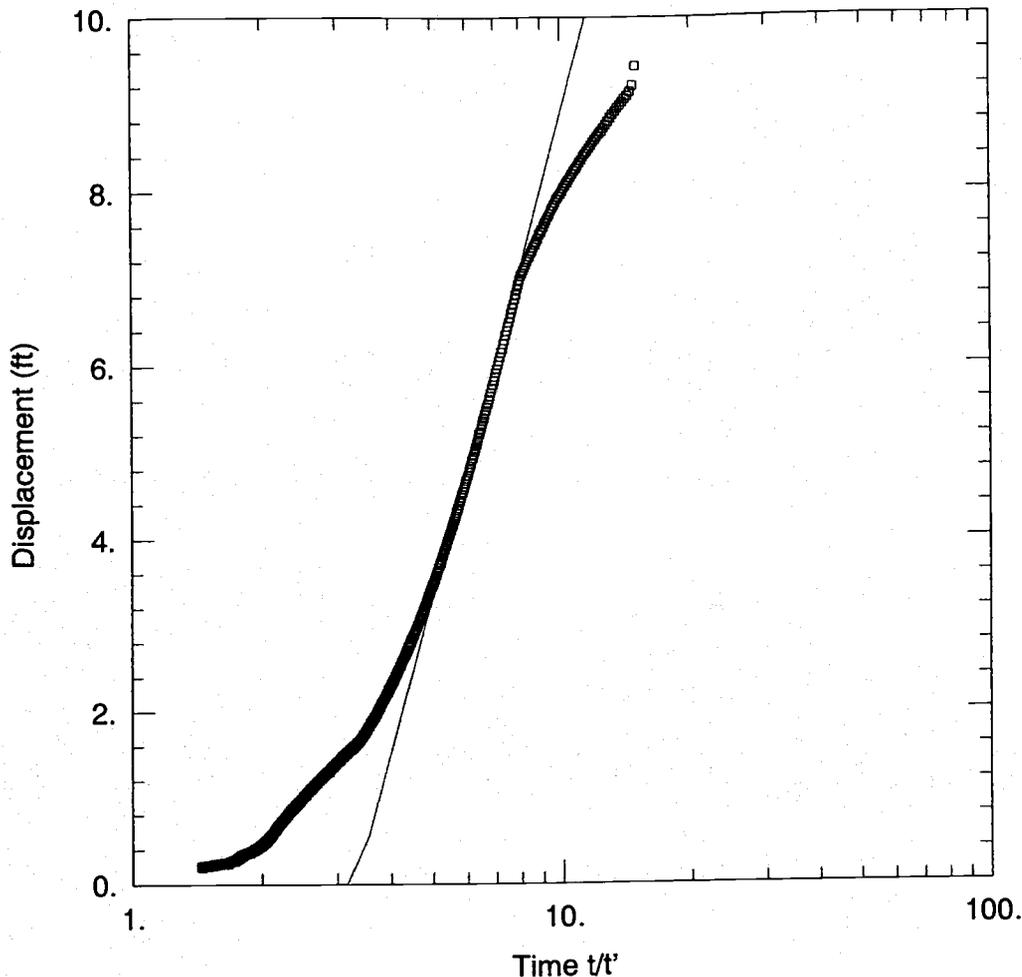
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
CS004-MW007	2.775E+006	9.759E+005	□ CS004-MW007	2.775E+006	9.759E+005

SOLUTION

Aquifer Model: Confined
 Solution Method: Theis Recovery

T = 12.83 ft²/day
 S' = 1.116

Figure 13



RECOVERY TEST IN WELL MW007 AT SS003

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\3_7_7_RC.AQT
 Date: 12/05/00 Time: 10:52:35

AQUIFER DATA

Saturated Thickness: 23. ft Anisotropy Ratio (Kz/Kr): 0.1

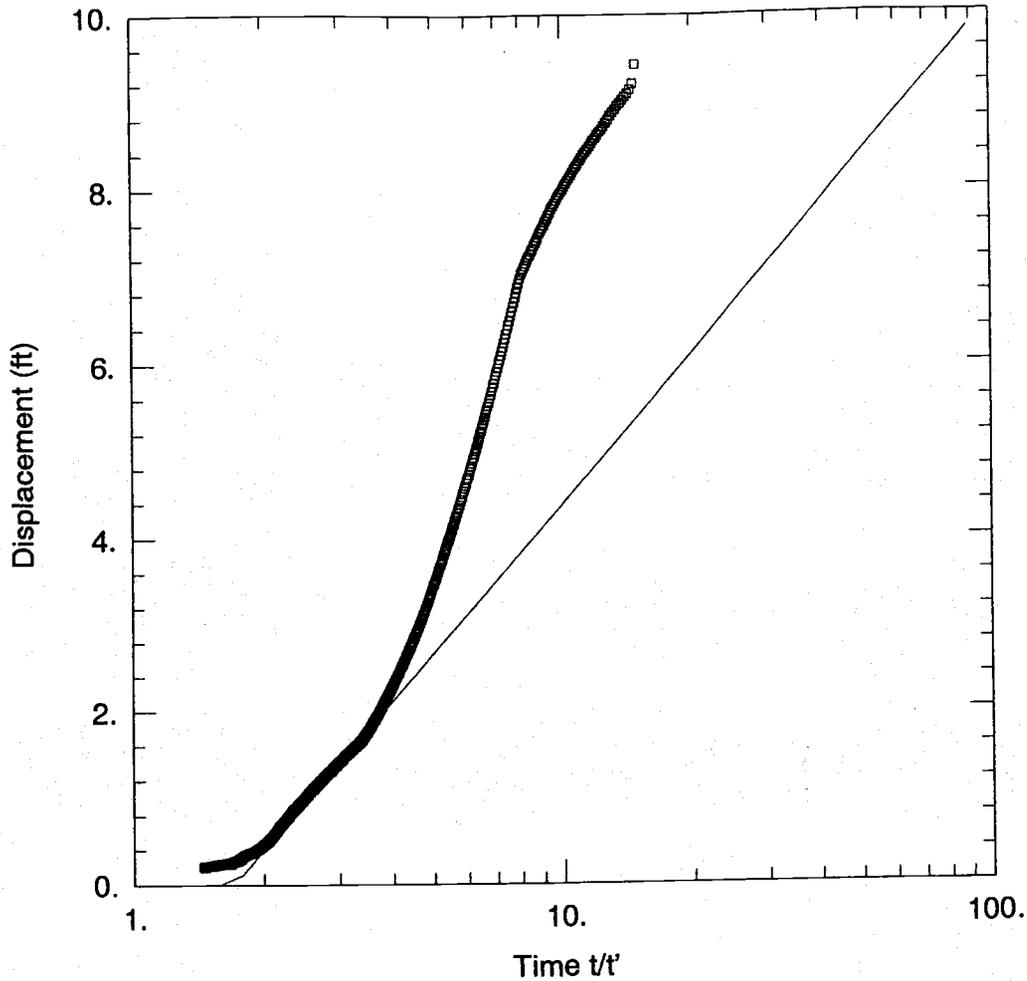
WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS003-MW007	2.773E+006	9.746E+005	□ SS003-MW007	2.773E+006	9.746E+005

SOLUTION

Aquifer Model: Confined T = 0.2859 ft²/day
 Solution Method: This Recovery S' = 3.31

Figure 14



RECOVERY TEST IN WELL MW007 AT SS003

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\3_7_7_RC.AQT
 Date: 12/05/00 Time: 10:52:55

AQUIFER DATA

Saturated Thickness: 23. ft Anisotropy Ratio (Kz/Kr): 0.1

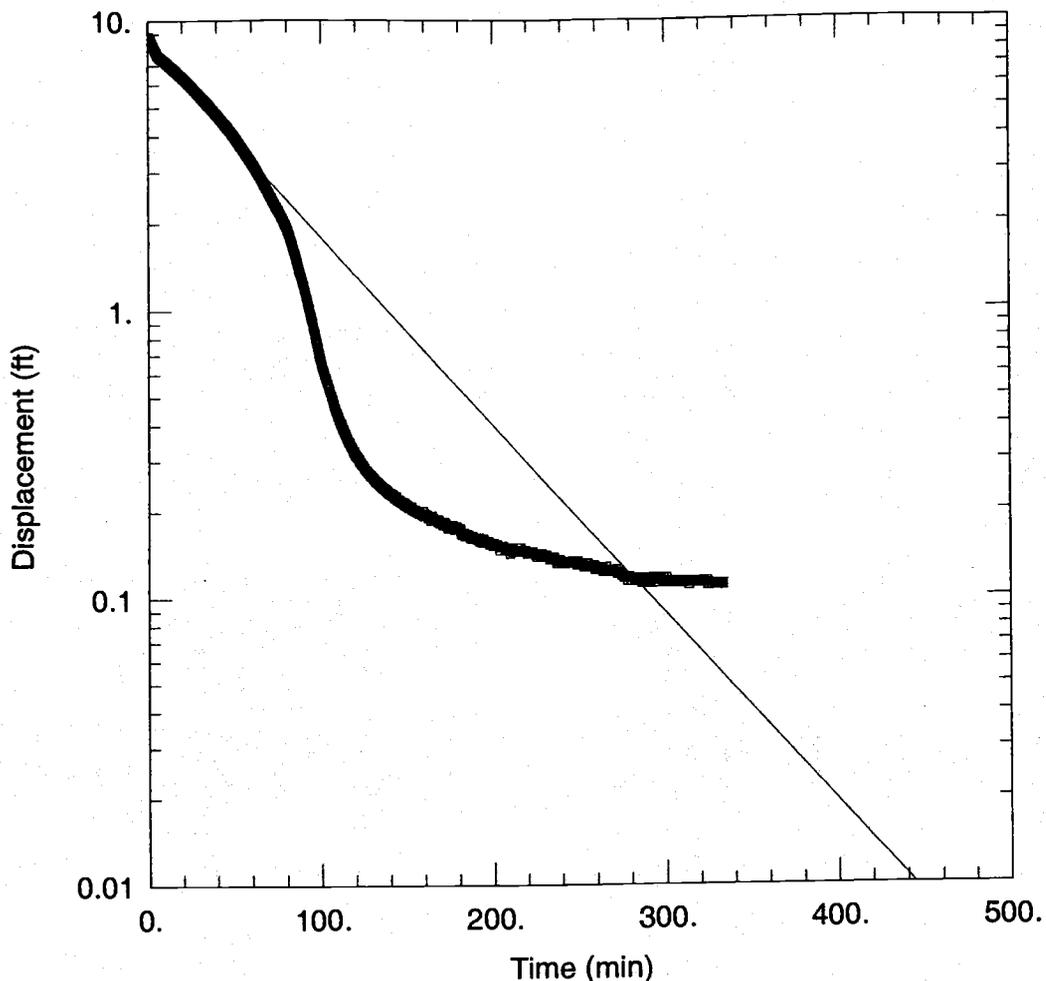
WELL DATA

Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS003-MW007	2.773E+006	9.746E+005	SS003-MW007	2.773E+006	9.746E+005

SOLUTION

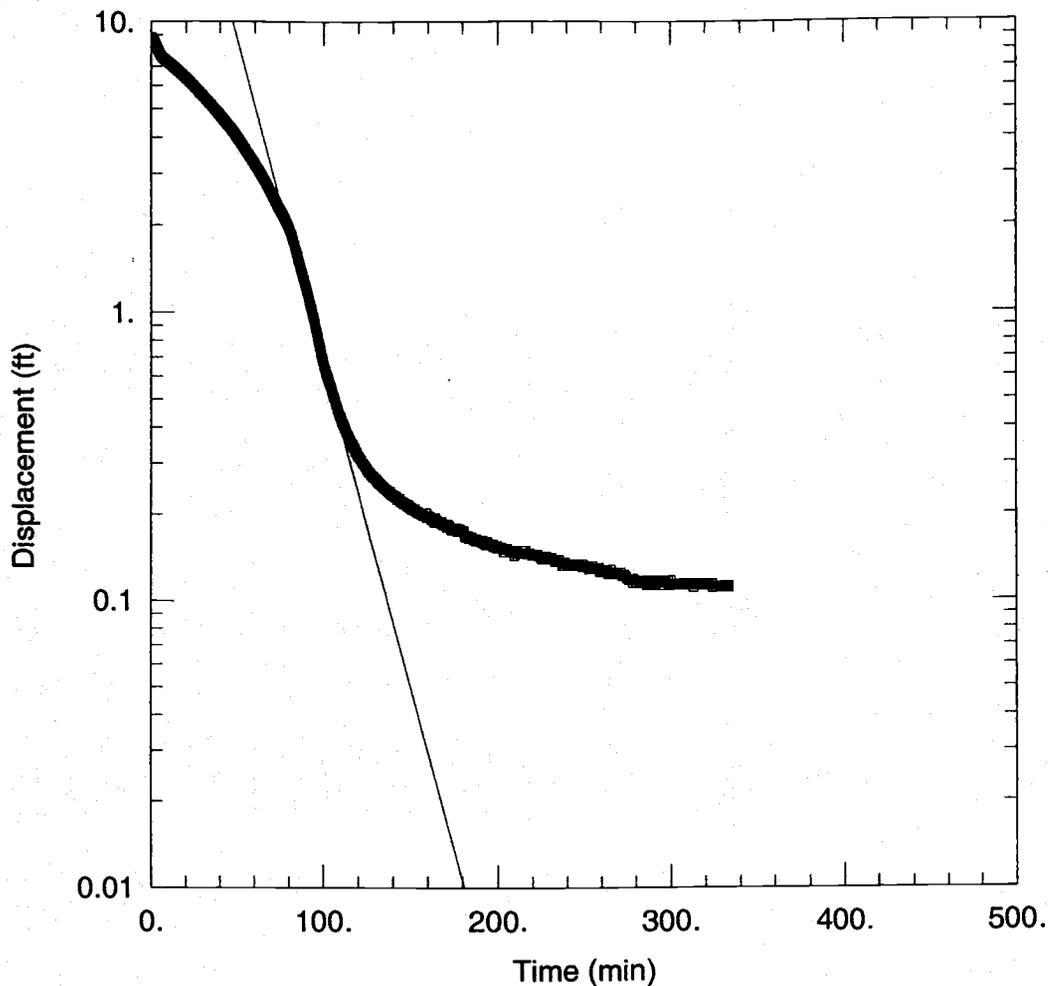
Aquifer Model: Confined T = 0.927 ft²/day
 Solution Method: Theis Recovery S' = 1.702

Figure 15



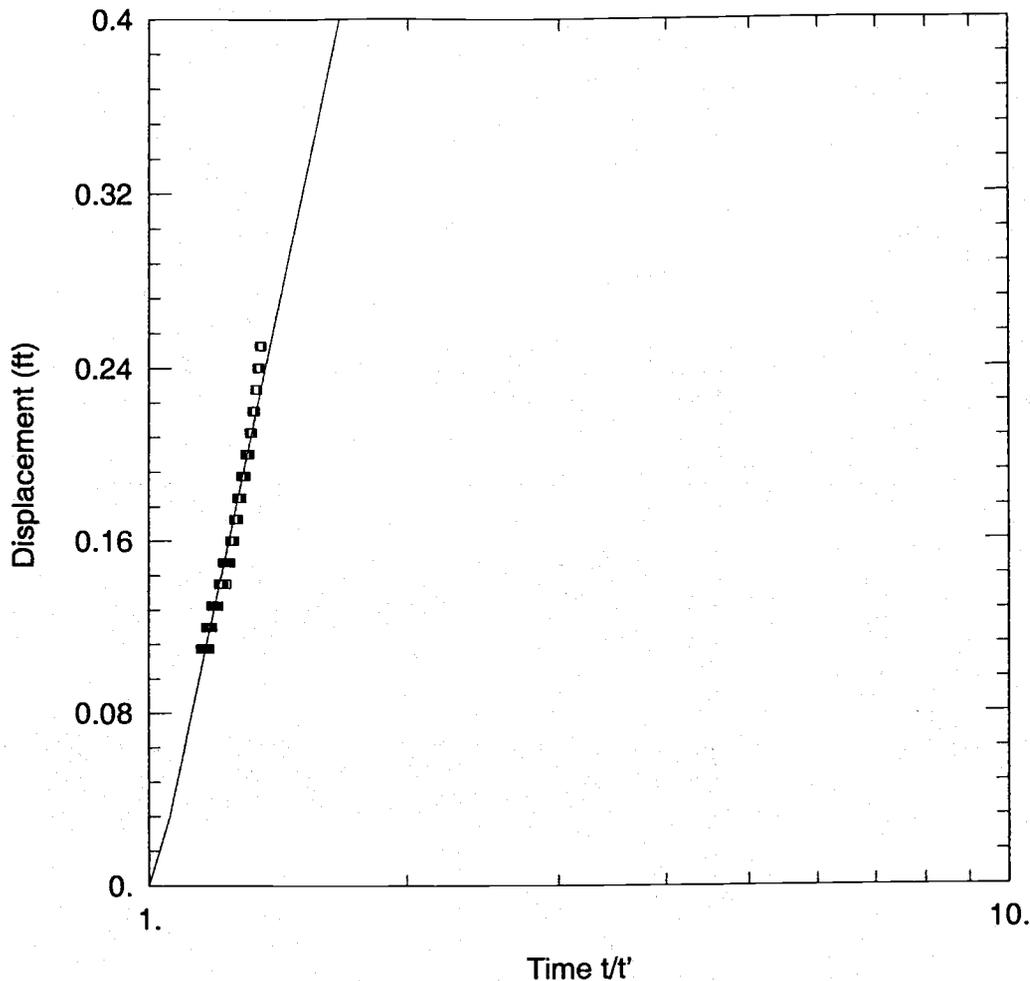
SLUG TEST IN MW001 AT SS006	
Data Set: <u>H:\BSC\STC38D~1.LOU\DATAFI~1\6_1_1_SL.AQT</u>	Time: <u>17:48:30</u>
Date: <u>09/21/00</u>	
AQUIFER DATA	
Saturated Thickness: <u>10. ft</u>	Anisotropy Ratio (Kz/Kr): <u>0.1</u>
WELL DATA	
Initial Displacement: <u>8.83 ft</u>	Water Column Height: <u>9.04 ft</u>
Casing Radius: <u>0.083 ft</u>	Wellbore Radius: <u>0.25 ft</u>
Screen Length: <u>10. ft</u>	Gravel Pack Porosity: <u>0.25</u>
SOLUTION	
Aquifer Model: <u>Unconfined</u>	K = <u>0.05782 ft/day</u>
Solution Method: <u>Bouwer-Rice</u>	y0 = <u>8.126 ft</u>

Figure 16



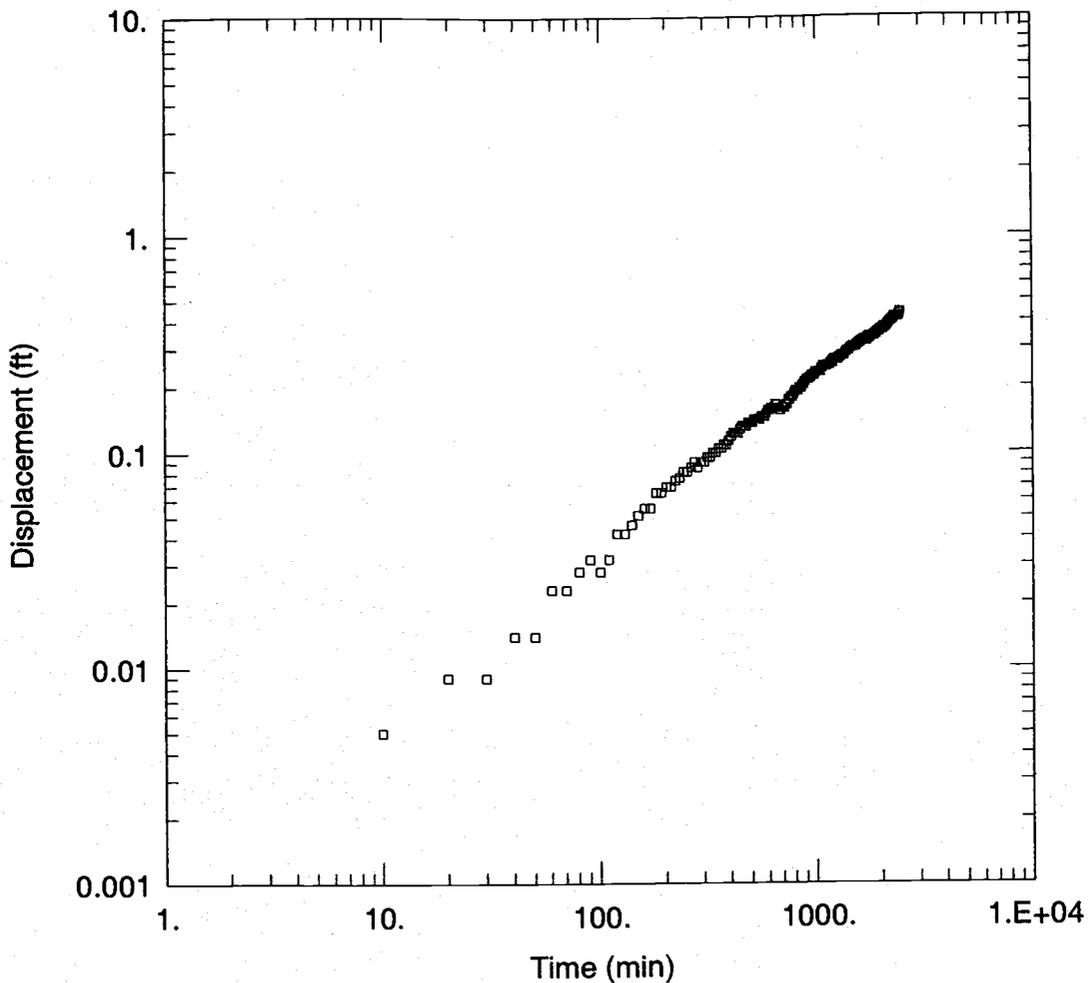
SLUG TEST IN MW001 AT SS006	
Data Set: <u>H:\BSC\STC38D~1.LOU\DATAFI~1\6_1_1_SL.AQT</u>	
Date: <u>09/21/00</u>	Time: <u>17:48:09</u>
AQUIFER DATA	
Saturated Thickness: <u>10. ft</u>	Anisotropy Ratio (Kz/Kr): <u>0.1</u>
WELL DATA	
Initial Displacement: <u>8.83 ft</u>	Water Column Height: <u>9.04 ft</u>
Casing Radius: <u>0.083 ft</u>	Wellbore Radius: <u>0.25 ft</u>
Screen Length: <u>10. ft</u>	Gravel Pack Porosity: <u>0.25</u>
SOLUTION	
Aquifer Model: <u>Unconfined</u>	K = <u>0.1979 ft/day</u>
Solution Method: <u>Bower-Rice</u>	y0 = <u>114.9 ft</u>

Figure 17



RECOVERY IN MW1 - PUMPING MW1 AT SS006					
Data Set: <u>H:\BSC\STC38D~1\LOU\DATAFI~1\6_1_1_RC.AQT</u>					
Date: <u>12/05/00</u>			Time: <u>10:53:28</u>		
AQUIFER DATA					
Saturated Thickness: <u>10. ft</u>			Anisotropy Ratio (Kz/Kr): <u>0.1</u>		
WELL DATA					
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS006-MW001	2.773E+006	9.757E+005	□ SS006-MW001	2.773E+006	9.757E+005
SOLUTION					
Aquifer Model: <u>Confined</u>			T = <u>2.711</u> ft ² /day		
Solution Method: <u>This Recovery</u>			S' = <u>1.018</u>		

Figure 18



D'D IN MW7 - PUMPING MW1 AT SS006

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\6_1_7_DD.AQT
 Date: 09/21/00 Time: 17:56:12

AQUIFER DATA

Saturated Thickness: 10. ft Anisotropy Ratio (Kz/Kr): 0.1

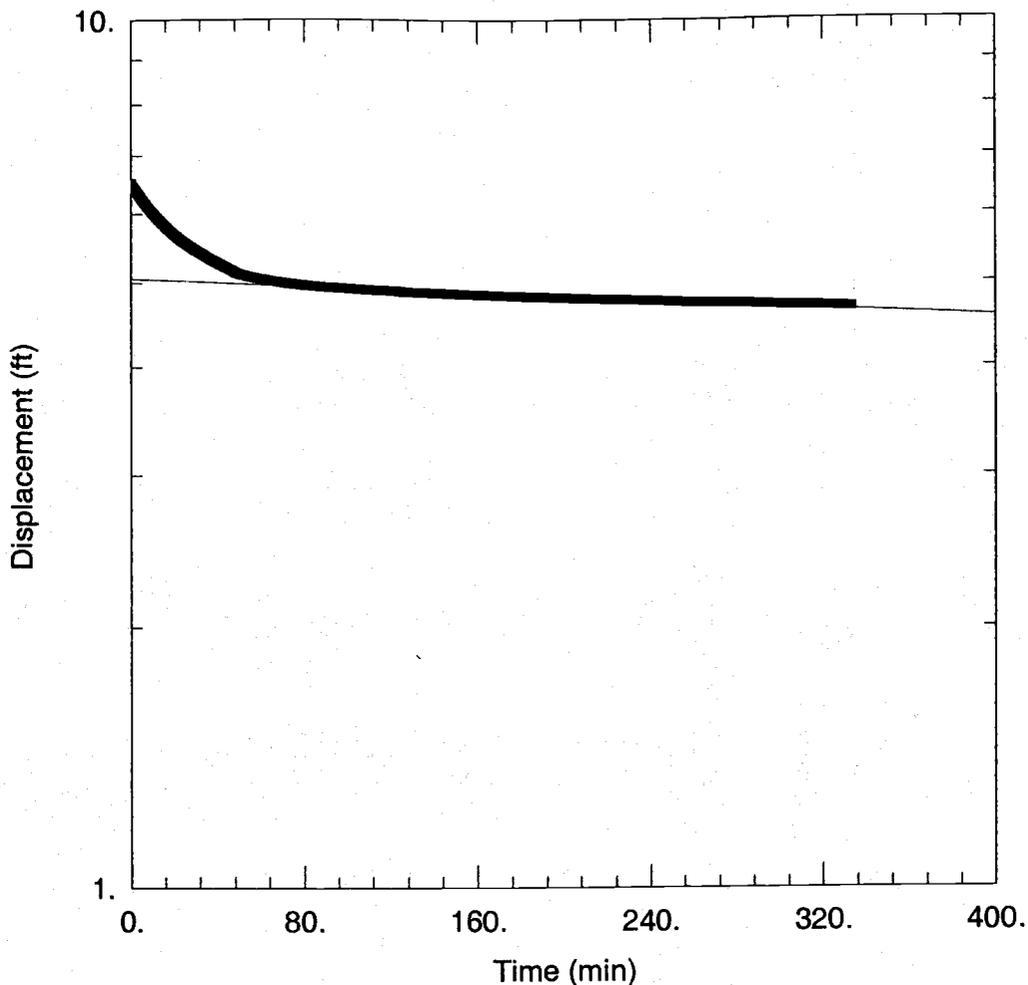
WELL DATA

Pumping Wells

Observation Wells

Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS006-MW001	2.773E+006	9.757E+005	□ SS006-MW007	2.773E+006	9.757E+005

Figure 19



SLUG TEST IN WELL MW003 AT SS009

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\9_3_3_SL.AQT

Date: 12/07/00

Time: 10:43:32

AQUIFER DATA

Saturated Thickness: 15. ft

Anisotropy Ratio (Kz/Kr): 0.1

WELL DATA

Initial Displacement: 6.504 ft

Water Column Height: 6.74 ft

Casing Radius: 0.083 ft

Wellbore Radius: 0.25 ft

Screen Length: 5. ft

SOLUTION

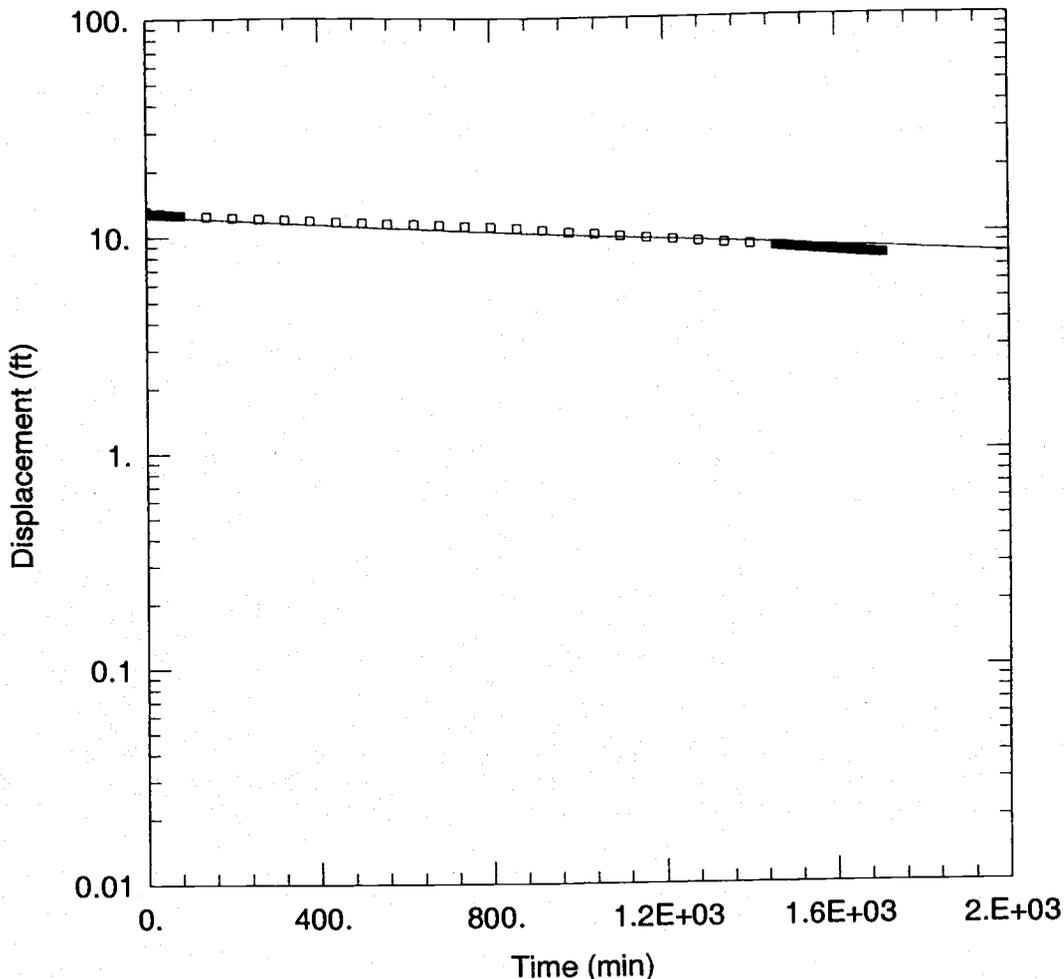
Aquifer Model: Unconfined

K = 0.000741 ft/day

Solution Method: Bouwer-Rice

y0 = 5.06 ft

Figure 20



SLUG TEST IN WELL MW006 AT SS009

Data Set: H:\BSC\STC38D-1.LOU\DATAFI-1\9_6_6_SL.AQT
 Date: 12/07/00 Time: 13:02:18

AQUIFER DATA

Saturated Thickness: 15. ft Anisotropy Ratio (Kz/Kr): 1.

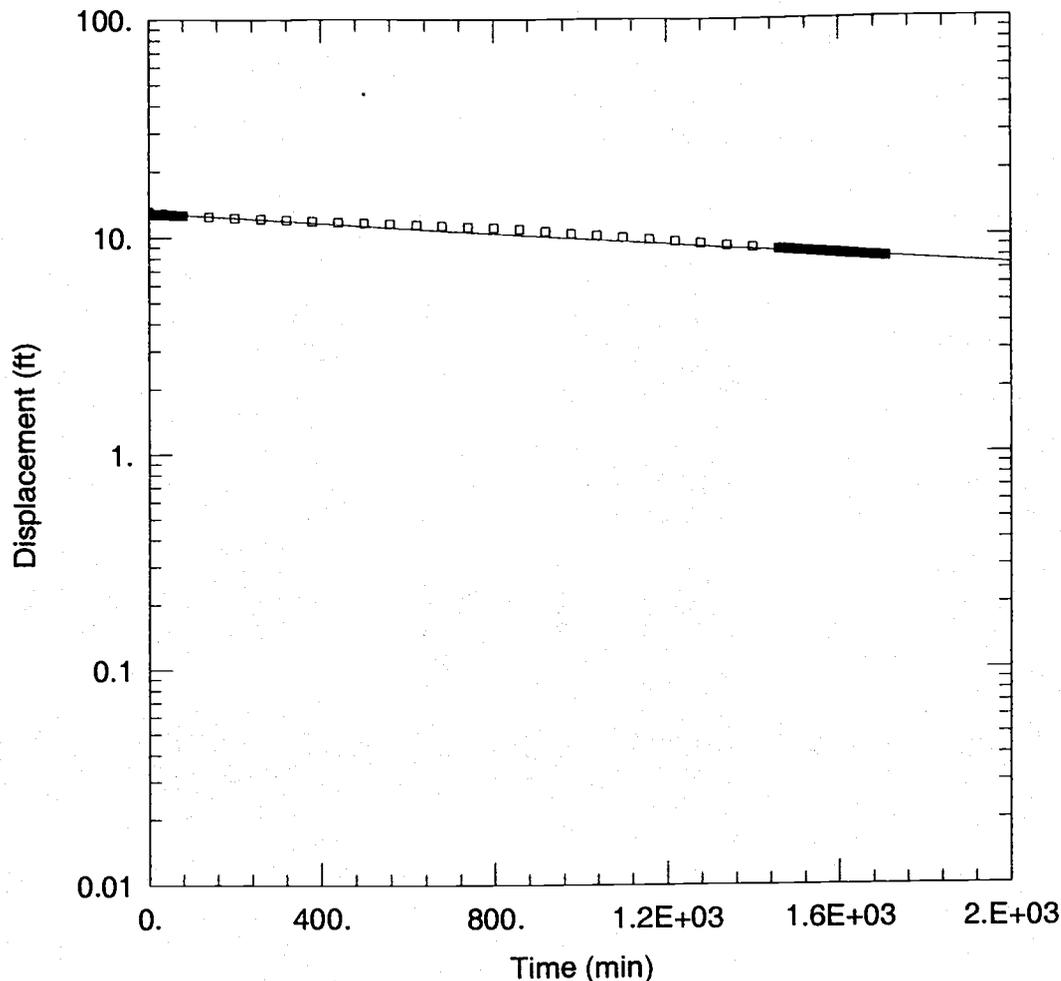
WELL DATA

Initial Displacement: 13.13 ft Water Column Height: 15.36 ft
 Casing Radius: 0.083 ft Wellbore Radius: 0.25 ft
 Screen Length: 5. ft

SOLUTION

Aquifer Model: Confined K = 0.0006183 ft/day
 Solution Method: Bouwer-Rice y0 = 12.44 ft

Figure 21



SLUG TEST IN WELL MW006 AT SS009

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\9_6_6_SL.AQT

Date: 12/07/00

Time: 11:08:07

AQUIFER DATA

Saturated Thickness: 15. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 13.13 ft

Water Column Height: 15.36 ft

Casing Radius: 0.083 ft

Wellbore Radius: 0.25 ft

Screen Length: 3.3 ft

SOLUTION

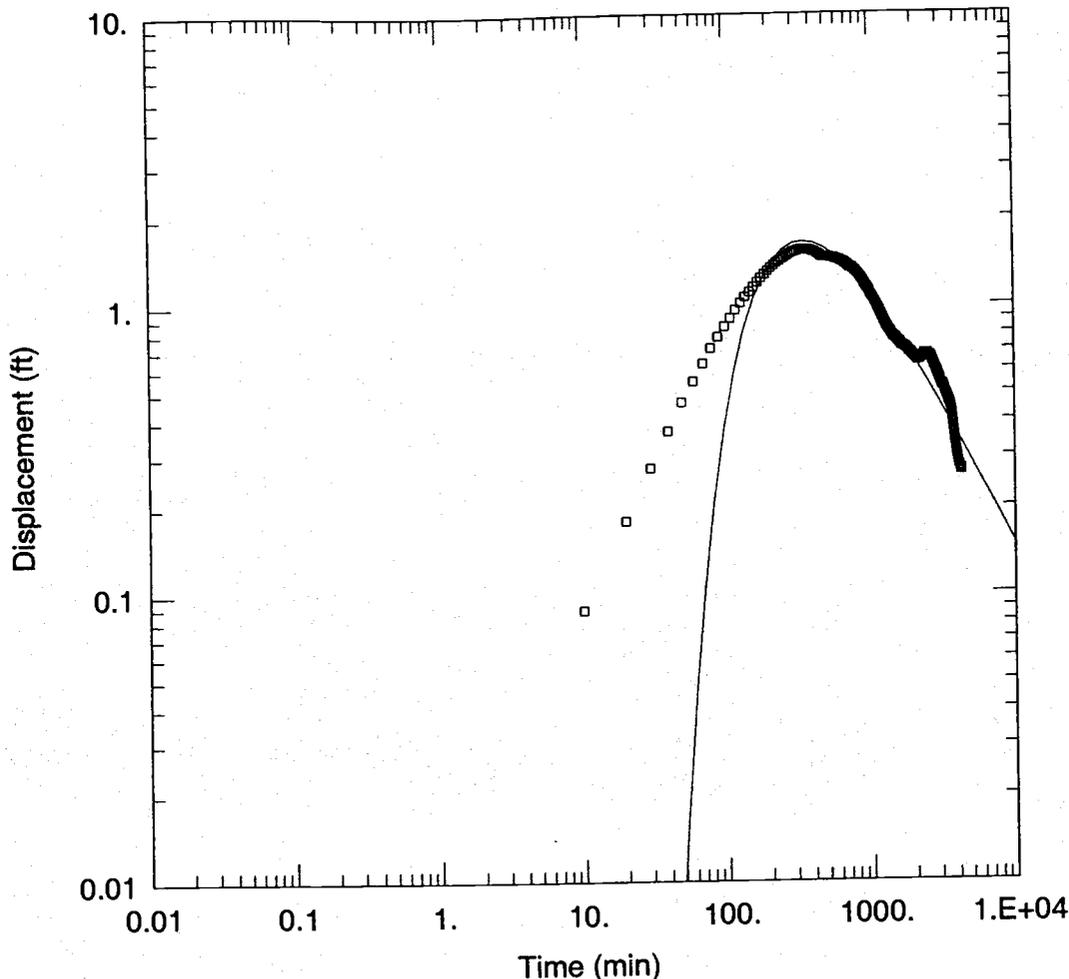
Aquifer Model: Confined

K = 0.001128 ft/day

Solution Method: Bouwer-Rice

y0 = 12.97 ft

Figure 22



D'D/RECOVERY IN MW8 - PUMPING MW6 AT SS9

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\9_6_8_DR.AQT
 Date: 09/21/00 Time: 23:11:31

AQUIFER DATA

Saturated Thickness: 15. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

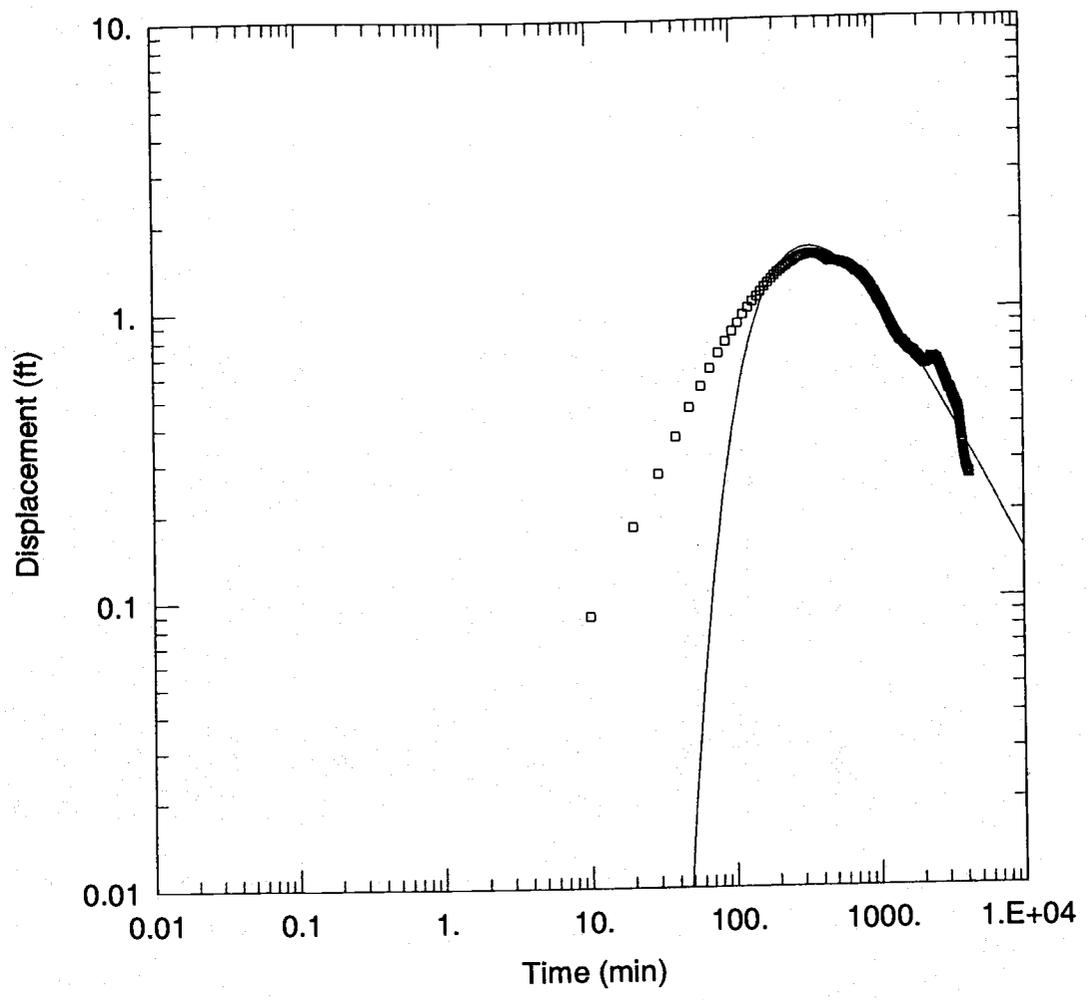
Pumping Wells			Observation Wells		
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS009-MW006	2.774E+006	9.756E+005	SS009-MW008	2.774E+006	9.756E+005

SOLUTION

Aquifer Model: Confined
 Solution Method: Theis

T = 0.04987 ft²/day
 S = 1.123E-05

Figure 23



D'D/RECOVERY IN MW8 - PUMPING MW6 AT SS9

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\9_6_8_DR.AQT

Date: 09/21/00

Time: 23:08:55

AQUIFER DATA

Saturated Thickness: 15. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Observation Wells

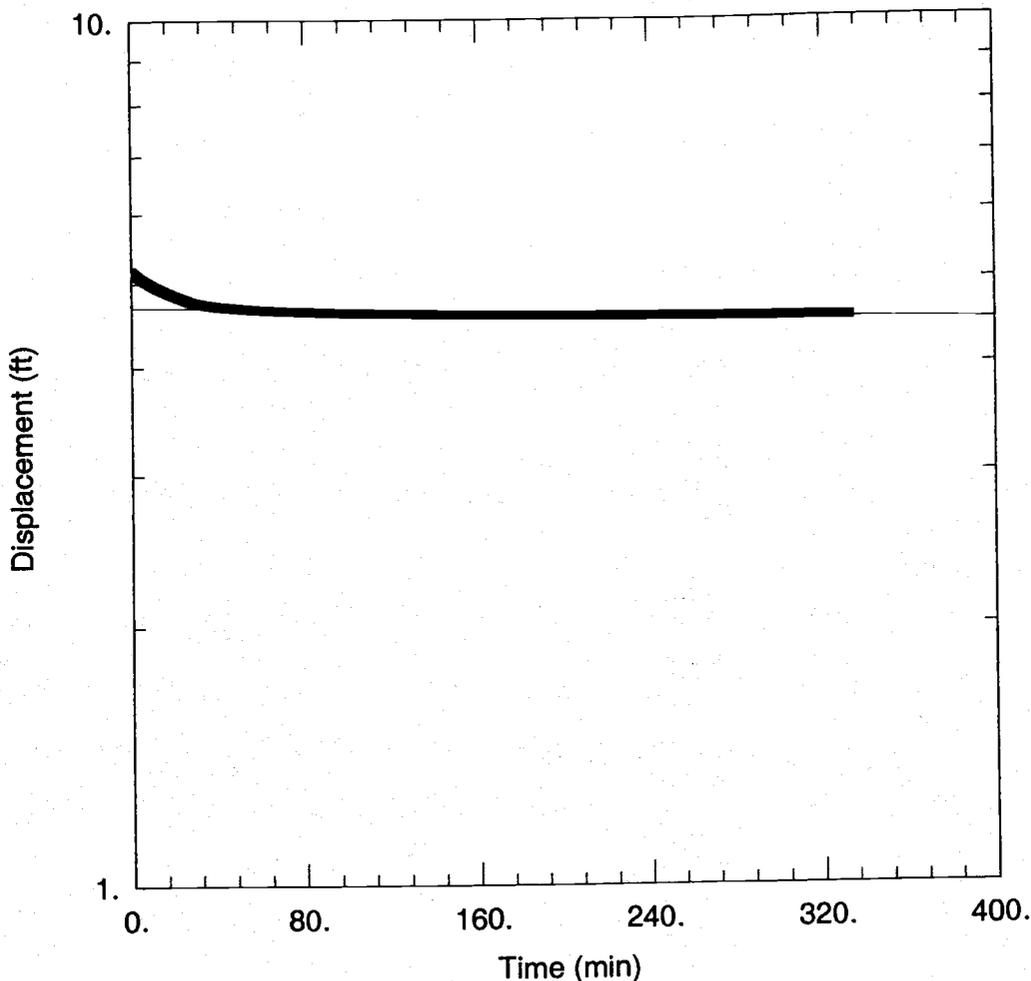
Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
SS009-MW006	2.774E+006	9.756E+005	SS009-MW008	2.774E+006	9.756E+005

SOLUTION

Aquifer Model: Leaky
 Solution Method: Hantush-Jacob

T = 0.05073 ft²/day
 S = 1.126E-05
 r/B = 1.E-05

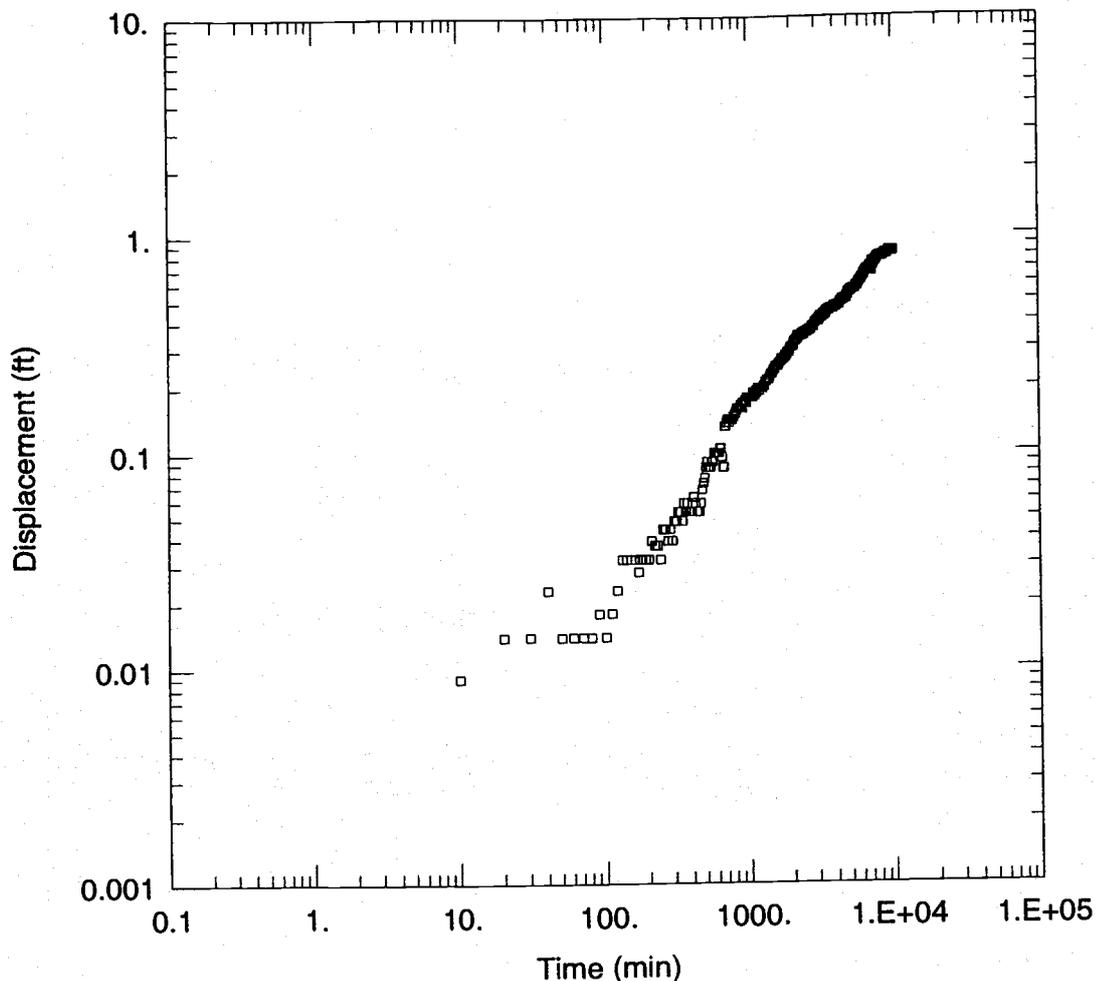
Figure 24



SLUG TEST IN MW003 AT ST005	
Data Set: <u>H:\BSC\STC38D~1.LOU\DATAFI~1\5_3_3_SL.AQT</u>	Time: <u>11:45:33</u>
Date: <u>12/12/00</u>	
AQUIFER DATA	
Saturated Thickness: <u>10. ft</u>	Anisotropy Ratio (Kz/Kr): <u>0.1</u>
WELL DATA	
Initial Displacement: <u>5.17 ft</u>	Water Column Height: <u>5.2 ft</u>
Casing Radius: <u>0.083 ft</u>	Wellbore Radius: <u>0.25 ft</u>
Screen Length: <u>7.5 ft</u>	Gravel Pack Porosity: <u>0.25</u>
SOLUTION	
Aquifer Model: <u>Unconfined</u>	K = <u>0.0006779 ft/day</u>
Solution Method: <u>Bouwer-Rice</u>	y0 = <u>4.693 ft</u>

Figure 25

26



D'D IN MW12 - PUMPING MW3 AT ST005

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\5_3_12_D.AQT

Date: 09/19/00

Time: 17:43:58

AQUIFER DATA

Saturated Thickness: 15. ft

Anisotropy Ratio (Kz/Kr): 0.1

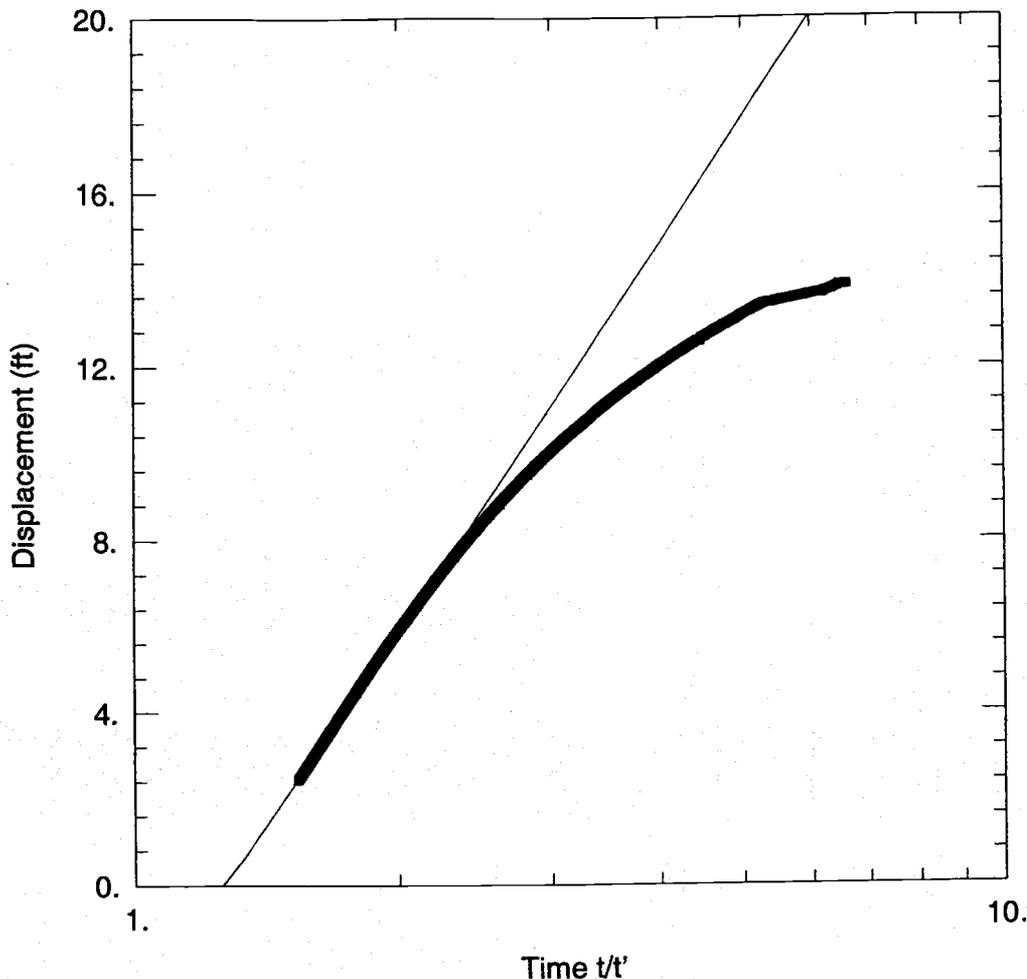
WELL DATA

Pumping Wells

Observation Wells

Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
ST005-MW003	2.776E+006	9.774E+005	□ ST005-MW012	2.776E+006	9.774E+005

Figure 26



RECOVERY IN MW10 - PUMPING MW10 AT ST005

Data Set: H:\BSC\STC38D~1.LOU\DATAFI~1\5_1010_R.AQT

Date: 12/12/00

Time: 11:52:22

AQUIFER DATA

Saturated Thickness: 8. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Observation Wells

Well Name	X (ft)	Y (ft)	Well Name	X (ft)	Y (ft)
ST005-MW010	2.776E+006	9.774E+005	ST005-MW010	2.776E+006	9.774E+005

SOLUTION

Aquifer Model: Confined
 Solution Method: Theis Recovery

T = 0.2498 ft²/day
 S' = 1.267

Figure 27

Appendix B
Supplemental Groundwater Risk Assessment

APPENDIX B

Supplemental Groundwater Risk Assessment

Purpose and Objectives

This supplemental risk assessment component of the Feasibility Study (FS) evaluates potential risks to human health from selected contaminants in groundwater detected at Richards-Gebaur Air Force Base (AFB) using data generated by the Quarterly Groundwater Monitoring Program. The primary purpose of this risk assessment is to assess the residual risk from other relevant pathways if groundwater use is prohibited through institutional controls under certain remedial alternatives, but contaminated groundwater is allowed to remain in place.

This supplemental risk assessment that follows was conducted based on the methods documented in the Basewide Remedial Investigation (RI) Report (CH2M HILL, 2001). These methods have been reviewed and accepted both by Air Force Center for Environmental Excellence (AFCEE) and the Missouri Department of Natural Resources (MDNR). Issues that have been resolved satisfactorily with these stakeholders include selection of the target risk levels for making site decisions, selection of screening levels for risk-based evaluation of sampling and analytical data, process for identifying chemicals of potential concern, selection of exposure factors and toxicity values for assessing health risk, and selection of potential receptors and exposure pathways. The risk assessment approach documented in the Basewide RI Report reflects the resolutions obtained through discussions with these stakeholders. Specific methodologies not published in the Basewide RI Report are documented in this appendix.

Background

The RI risk assessment approach for contaminants in groundwater involved assessing potential risks assuming that residents could use groundwater as a drinking water supply. As described in the Basewide RI, shallow groundwater underneath the Base is not likely to be used as a drinking water supply.

The Basewide RI also qualitatively examined the potential for two additional complete exposure pathways to exist for workers exposed to in-situ groundwater. The first scenario considered workers inhaling volatile organic compounds (VOCs) that have volatilized from groundwater and migrated upward through soil to enter a structure and contaminate indoor air. While the groundwater to indoor air pathway could be complete, this scenario is unlikely to result in significant exposures because groundwater under the Base generally occurs at depths of 10 feet or more, and the Base is overlain by low-porosity silt or silty clay loam soils. The second scenario considers workers entering deep excavations and encountering ponded groundwater that has seeped into the excavation. This scenario is not significant because the frequency and duration of worker contact with groundwater via this pathway is very low.

In its comments on the Basewide RI report, MDNR acknowledged that residential scenarios involving extraction and use of groundwater are most conservative; however, MDNR stated that the Air Force would need to calculate the risks for a worker at the sites with

groundwater contamination to determine if no action (i.e., no active treatment of groundwater) is an acceptable remedial component.

The following supplemental risk assessment addresses MDNR's concerns regarding risks for residuals and workers at sites with underlying residual groundwater contamination.

Conceptual Model of Exposure Pathways

Sources of Chemicals in Groundwater

- Concentrations of VOCs in groundwater exceed the conservative Tier 1 Screening Levels that were set forth in the RI (generally equivalent to federal maximum contaminant levels) in six sites: SS 003, Oil Saturated Area
- SS 006, Hazardous Material Storage Area
- SS 009, Fire Valve Area
- SS 012, Communications Facility at Building 105 (formerly referred to as Building 105)
- ST 005, POL Storage Yard
- ST 011, UST 620 A (formerly referred to as CS 004)

Five groundwater sites were identified during the RI. In 2001, an additional site SS 012, formerly referred to as Building 105, was also investigated to assess the presence of VOCs in the site groundwater.

The primary contaminants at the sites, as identified from the Basewide RI, are chlorinated VOCs, specifically tetrachloroethene (PCE), trichloroethene (TCE), cis-1,2-dichloroethene (DCE), 1,1-dichloroethene (1,1-DCE), and vinyl chloride.

Potential Receptors

Three groups of potential receptors have been identified.

Future Indoor Workers

Workers in buildings that are located over groundwater containing VOCs could potentially be exposed through migration of VOCs from groundwater to indoor air, followed by inhalation. For this pathway to be considered potentially complete, it is assumed that volatile constituents in groundwater could partition into soil gas and transport through soil gas into overlying structures. These constituents could then mix with indoor air, potentially resulting in inhalation exposure by the structure's inhabitants.

Future Residents

It is assumed that land use controls would prevent the extraction and use of groundwater by residents, thus preventing exposure through ingestion, direct skin contact, or VOC inhalation during indoor water use. However, as with workers, individuals who are in buildings that are located over groundwater contaminated with VOCs could potentially be exposed through migration of VOCs from groundwater to indoor air, followed by inhalation exposure.

Construction Workers

Construction workers may excavate soils for utility installation, maintenance, or other purposes. Shallow groundwater may seep into the excavation, and VOCs could volatilize directly from groundwater during excavation. Construction workers also could experience direct skin contact with groundwater under these conditions. Therefore, it is assumed that, for construction workers, potential complete exposure routes for contaminated groundwater are dermal (skin) contact and inhalation of VOCs emitted from groundwater.

Potential Exposure Pathways

The conceptual model of exposure pathways is presented in Figure B-1. Discussion of the potential exposure pathways and identification of the potentially complete pathways are presented below.

Vapor Intrusion to Indoor Air from Groundwater

VOCs dissolved in groundwater will partition into overlying soil gas. The tendency for a VOC to migrate from groundwater to soil gas is reflected by its Henry's Law coefficient. The larger the Henry's Law coefficient, the more likely it is that a chemical will migrate into soil gas from groundwater. Next, the VOCs must diffuse through a capillary zone immediately above the water table. In the lower part of the capillary zone, the soil pores are saturated with water, but the water is under tension and essentially immobile (except during recharge events). Contaminants in groundwater move across the saturated portion of the capillary zone by liquid diffusion, rather than by convective transport with water flux or by vapor diffusion. Therefore, the capillary zone limits the migration of VOCs dissolved in groundwater into soil gas in the unsaturated zone.

The tendency for a VOC to migrate by vapor diffusion is reflected by its air diffusion coefficient. Air-filled porosity in soil influences VOC vapor migration; air-filled porosity is, in turn, affected by soil properties, such as total porosity, clay or silt content, and moisture content. Vapor diffusion of a VOC in soil decreases with low air-filled porosity and high moisture content and a low air diffusion coefficient.

Molecular diffusion moves the VOC towards the soil surface until it reaches the zone of influence of the building/residence. Convective air movement within the soil column transports the vapors through cracks between the foundation and the building slab floor. This convective sweep effect is induced by a negative pressure within the structure caused by a combination of wind and stack effects due to building heating and mechanical ventilation. The concentration in indoor air resulting from VOC intrusion into a structure resulting from pressure-driven air flow is related to the building volume (length, width, and height) and the building ventilation rate (numbers of air changes per hour).

These transport processes are evaluated using the Johnson and Ettinger (1991) model, which estimates the concentration in indoor air from a vapor source located some distance below the floor of an enclosed building. The Johnson and Ettinger (1991) model incorporates both convective and diffusive mechanisms for estimating the transport of chemical vapors emanating from either subsurface soils or groundwater into indoor spaces located directly above or in close proximity to the location of contamination.

This exposure pathway is considered to be potentially complete and is evaluated quantitatively in this supplemental risk assessment.

Construction Worker Exposure Pathways

During excavation work, a worker may excavate a trench for utility installation or maintenance. Shallow groundwater may seep into the excavation and VOCs could volatilize directly from groundwater during excavation. Therefore, potentially complete exposure pathways may exist from groundwater to construction workers who perform intrusive work in locations where VOCs have been detected in groundwater. These pathways include inhalation of VOC emissions from groundwater that could be ponded in excavations, and dermal exposure to VOCs entrained in the water.

However, the likelihood is small that construction workers would routinely work near the deep excavations that are in proximity to contaminated groundwater, limiting the potential frequency of contact with VOCs in groundwater. Also, the Basewide RI has shows that groundwater is often trapped within clay-filled, solution-widened limestone fractures above impermeable shale layers, resulting in limited groundwater yields and discontinuous, low flow characteristics. Examples of low yields and flows include frequent occurrence of dry wells and open excavations, up to 18 feet deep and into bedrock, that remain dry. Finally, construction activities that could bring workers into potential contact with contaminated groundwater would be limited both in frequency and duration. The combination of the limited exposure potential and hydrogeological limitations indicates that construction workers are likely to have little inhalation or dermal contact with contaminated groundwater.

While these exposure pathways are considered to be potentially complete, the available information indicates that potential exposures would be very small as a result of infrequent exposure episodes and limited exposure durations, and do not warrant quantitative evaluation in this supplemental risk assessment.

Identification of Chemicals of Concern

Chlorinated VOCs detected in groundwater during the most recent Quarterly Groundwater Monitoring event (October 2001) represent the chemicals of potential concern addressed in this supplemental risk assessment. The Basewide RI concluded that these chlorinated VOCs were detected at concentrations above Tier I screening levels. These chlorinated VOCs also are being addressed through development of remedial alternatives in the FS. Therefore, selection of the chemicals of concern (COCs) is consistent with the findings of the Basewide RI, and the objectives of the FS. The COCs evaluated in this supplemental risk assessment are:

- PCE
- TCE
- Cis-1,2-DCE
- 1,1-DCE
- Vinyl chloride

Exposure Assessment

The exposure assessment involves the following steps:

- Identification of potentially exposed populations

- Identification of potential exposure pathways and selection of complete exposure pathways
- Evaluation of the environmental fate and transport of chemicals in groundwater
- Estimation of exposure point concentrations used to quantify chemical intakes
- Quantification of chemical intakes for each exposure pathway

The information developed through the conceptual model of exposure pathways together with the COCs identified were used to develop an exposure scenario. An exposure scenario describes the sources of the chemical substances that could come into contact with the subject population, the exposure pathways through which contact could occur, and the characteristics of that population that affect the resulting levels of exposure. The exposure scenario evaluated in this supplemental risk assessment was the reasonable maximum exposure (RME) scenario. This scenario is defined as the highest exposure that is reasonably expected to occur at a site. The intent of the RME is to develop a conservative estimate of exposure (i.e., well above the average case) that is still within the range of plausible exposures (USEPA, 1989).

Identification of Potentially Exposed Population

The potentially exposed population considered in this supplemental risk assessment was workers located in buildings overlying groundwater contamination.

Identification of Potentially Complete Exposure Pathways

The potentially complete exposure pathway that is quantitatively evaluated in this risk assessment is inhalation of VOCs that have migrated to indoor air from groundwater.

Fate and Transport Evaluation

Estimates of VOC concentrations in indoor air from VOC concentrations in groundwater were evaluated using the Johnson and Ettinger (1991) screening-level model. This model incorporates both convective and diffusive mechanisms for estimating the transport of contaminant vapors emanating from either subsurface soils or groundwater into indoor spaces located directly above or in close proximity to the source of contamination. Figure B-2 presents a simplified conceptual diagram of the exposure scenario that is evaluated using the Johnson and Ettinger (1991) model (USEPA, 2000).

Parameters required for implementing the model include soil properties (such as soil texture, porosity, moisture content, and heterogeneity), building properties (dimensions, air exchange rate, soil-building pressure difference, and surface area available for soil gas intrusion) and chemical and groundwater properties (VOC concentrations in groundwater and depth from surface to groundwater). Key assumptions are discussed below in further detail. The parameter values, data sources, and assumptions used in their development are documented in Table B-1 (for a worker scenario) and Table B-2 (for a residential scenario). Chemical-specific parameters used in modeling vapor intrusion from groundwater to indoor air are presented in Table B-3.

Soil Texture

U.S. Soil Conservation Service soil texture classification is used to estimate soil vapor permeability, which in turn is used to calculate soil vapor flow indoors. The unconsolidated surficial materials at Richards-Gebaur AFB consist of red-brown residual clays containing

abundant chert fragments derived from in-situ weathering of the near-surface limestone bedrock. At higher elevations, the residual clays are sometimes in turn overlain by wind-blown silt deposits. The unconsolidated materials overlying the bedrock range in thickness from 0 to 20 feet. The soils belong to the Macksburg-Urban Series and are characterized as poorly drained silt and silt-clay loam. For purposes of modeling, soils underlying structures are assumed to be clay loam.

Depth of Contamination (Source - Building Separation or L_T)

This parameter represents the separation between the contaminant source and the structure. It is based on the assumed depth to groundwater. While the depth to groundwater will vary from location to location at the Base, available information indicates that the depth to groundwater at Site SS 012 could be as little as 5 to 7 feet below ground surface. Therefore, a conservative assumption of the depth to groundwater, and therefore the source-building separation, is 5 feet.

Effective Soil Vapor Permeability

Soil vapor permeability is used to calculate soil vapor flow into a structure, and is a highly sensitive model parameter, according to the user's guide (USEPA, 2000). It is calculated within the Johnson and Ettinger model as a function of soil texture classification directly underneath the foundation. For purposes of this model, the conservative assumption is made that the soil underneath the foundation resembles clay loam.

Capillary Fringe Thickness

The capillary zone is located directly above the water table. Within the capillary zone, groundwater is held within the soil pores at less than atmospheric pressure, and moisture content varies with changes in water level. VOCs in groundwater must diffuse through a capillary zone immediately above the water table and through the subsequent unsaturated or vadose zone before convection transports the vapors into the structure. Air diffusion coefficient is almost 0 in the water saturated portions of the capillary zone. As the air-filled porosity increased, however, air-diffusion coefficient increases. A thick capillary zone with low air-filled porosity reduces the effective diffusion coefficient of a VOC. The assumption that the soil column is clay loam provides a relatively thin capillary fringe with higher air-filled porosity, compared with the tighter soils found at the base. Therefore, use of a clay loam soil type results in conservative properties for the capillary fringe and a conservative estimate of the effective diffusion coefficient.

Building Dimensions and Indoor Air Exchange Rate

The building dimensions and indoor air exchange rate affect the VOC concentrations in indoor air resulting from vapor intrusion. The building dimensions for the residential exposure scenario are the default values recommended in the user's guide (USEPA, 2000) and represent a 1,000-square-foot, two-story residence. The indoor air exchange rate for the residential exposure scenario is the default value recommended in the user's guide (USEPA, 2000) and represents the median value obtained from nationwide studies. The building dimensions for the commercial (worker) exposure scenario represent the median floorspace for commercial buildings, based on national surveys (MDEQ, 1998). The indoor air exchange rate for the commercial building is based on supply rates for an office building provided by the American Society for Heating, Refrigeration and Air Conditioning Engineering (ASHRAE) (MDEQ, 1998).

The output from the Johnson and Ettinger model is an attenuation coefficient (α). The attenuation coefficient is the ratio of indoor air concentration/soil gas concentration. With a calculated value for α , the vapor concentration in the building (C_{building}) is:

$$C_{building} = \alpha C_{source}$$

where C_{source} is the concentration in soil gas. The soil gas concentration is calculated from the groundwater concentration using Henry's Law. The attenuation coefficients are presented in Table B-4 (worker exposure scenario) and Table B-5 (residential exposure scenario).

Estimation of Exposure Point Concentrations

Potential exposure via the groundwater to indoor air pathway (which is based on the assumption that VOCs diffuse vertically from soil into buildings) are influenced by the spatial distribution of chemicals in soil, both laterally and vertically. Potential risks via this pathway also are influenced by the composition of VOCs across a site. The risk characterization approach typically used for risk assessments has assumed that exposures can occur simultaneously to all chemicals detected over a specified geographic area. Under this approach, exposure point concentrations for an RME scenario are assumed to be the 95 percent Upper Confidence Level (UCL) on the arithmetic mean concentrations (USEPA, 1989). The result of such an assessment is a boiled-down point estimate of risk for the predefined area over which concentrations were averaged. However, this approach yields no information about the spatial distribution of risks within the predefined area.

Rather than generating a single point estimate of exposure or risk, VOCs detected in groundwater were evaluated on a sample-by-sample basis, in which each sample location in the Phase II investigation represented an exposure point. This approach retained information on the spatial distribution of risk across the site. Sample specific risk or hazard index calculations used the same equations, exposure factors, and toxicity values to risks as defined in U.S. Environmental Protection Agency (USEPA) guidance. The only difference in calculating sample-specific versus sitewide risks lies in the concentration values used. Where the sitewide approach uses the 95 percent UCL of the mean concentration (or the mean concentration) for all chemicals of potential concern (COPCs), sample-specific risk calculations use concentrations reported from each individual sample.

The concentration data used to estimate exposure point concentrations are the values measured during the October 2001 Quarterly Monitoring Program that are higher than screening levels. These analytical data are summarized in Table B-6. These values were used to calculate well-specific risks; the well-specific risk estimates were based on the assumption that there could be vapor intrusion into a structure from the concentrations measured in a specific well. These concentrations were also compared with risk-based screening levels in groundwater based on a vapor intrusion exposure pathway and inhalation exposure. These levels are based on an excess lifetime cancer risk of 1×10^{-5} or a noncancer hazard quotient of 1. These risk-based levels were calculated from these target risks using the exposure factors (Tables B-1 and B-2, attenuation factors (Tables B-4 and B-5) and toxicity values (Table B-7) presented in this supplemental risk assessment.

Quantification of Intakes

Quantification of chemical intakes from inhalation and associated health risks were calculated as follows:

For carcinogenic effects:

$$Risk = \frac{URF \times EF \times ED \times C_{building}}{AT_c \times 365 \text{ days / yr}}$$

For non-carcinogenic effects:

$$HQ = \frac{EF \times ED \times \frac{1}{RfC} \times C_{building}}{AT_{NC} \times 365 \text{ days/yr}}$$

Where:

Risk = Excess lifetime cancer risk

HQ = Noncancer hazard quotient

URF = Unit risk factor ($\mu\text{g}/\text{m}^3$)⁻¹

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

RfC = Reference concentration ($\mu\text{g}/\text{m}^3$)

C_{building} = Building (indoor) air concentration ($\mu\text{g}/\text{m}^3$)

AT = Averaging time (years)

The values for exposure frequency, exposure duration, and averaging time for worker and residential exposure scenarios are presented in Tables B-1 and B-2. The toxicity values used in these calculations are presented in Table B-7. The summary of the exposure and health risk estimates for each well are presented in Tables B-8.

Toxicity Assessment

The toxicity assessment describes the relationship between the magnitude of exposure to a chemical and adverse health effects. This assessment provides, where possible, a numerical estimate of the increased likelihood and/or severity of adverse effects associated with chemical exposure (USEPA, 1989). This section describes the adverse effects and toxicity values used to calculate total site risks.

For purposes of the toxicity assessment, the COPCs have been classified into two broad categories, noncarcinogens and carcinogens, because health risks are calculated quite differently for carcinogenic and noncarcinogenic effects. The USEPA developed separate toxicity values for carcinogenic and noncarcinogenic effects. These values represent the potential magnitude of adverse health effects associated with exposure to chemicals. Toxicity studies with laboratory animals or epidemiological studies of human populations provide the data used to develop these toxicity values. These values represent allowable levels of exposure based upon the results of toxicity studies or epidemiological studies. The toxicity values are then combined with the exposure estimates (as presented in the previous section) to develop the numerical estimates of carcinogenic risk and noncancer health risks. These numerical estimates are used in the risk characterization process to estimate adverse effects from chemicals in groundwater at these sites.

Toxicity values (cancer slope factors and reference doses) used to develop the screening levels in this risk assessment were obtained from these sources:

- The Integrated Risk Information System (IRIS), a database available through by the National Center for Environmental Assessment in Cincinnati, Ohio. IRIS, prepared and maintained by USEPA, is a web site containing health risk and USEPA regulatory information on specific chemicals.
- The Health Effects Assessment Summary Tables (HEAST), provided by the USEPA Office of Solid Waste and Emergency Response (OSWER) (USEPA, 1997). HEAST is a compilation of toxicity values published in various health effects documents issued by USEPA.

Toxicity values for 1,1-dichloroethylene are being updated. The proposed values and the sources for those values are presented in Table B-7.

Toxicity profiles for the chlorinated VOCs identified as COPCs are attached to this appendix. Key issues with the toxicity of these chemicals include:

- Uncertainties in cancer potency for TCE. The toxicity values for TCE have been withdrawn from IRIS and are undergoing reevaluation. A "state-of-the-science" review of the toxicology and epidemiology of TCE was published in the journal *Environmental Health Perspectives* in May 2000 (Volume 108, Supplement 2). The USEPA released for public comment a risk characterization report in August 2001, which included proposed revised toxicity factors for assessing carcinogenic risks and noncancer effects (USEPA, 2001). Comments on the risk characterization document, including comments from the Department of Defense (AFIERA, 2001), have raised concerns that USEPA's evaluation of the existing data is inadequate to support its revised assessment of cancer and noncancer risks for TCE. Pending resolution of the comments, health risk characterizations associated with TCE in groundwater were based on the available toxicity values. The available toxicity values are based on the health assessment document for TCE (USEPA, 1985; 1987).
- Revised carcinogenicity weight of evidence for 1,1-dichloroethene. USEPA proposes to classify 1,1-dichloroethylene as not carcinogenic by ingestion. USEPA has concluded that inhalation carcinogenicity evidence from laboratory animal studies is inconclusive, and that an inhalation cancer potency value cannot be calculated. These proposed values are used to assess health risks from 1,1-dichloroethylene.

Risk Characterization

The numerical risk estimates are summarized in Table B-10. These results are based on the most recent groundwater monitoring data collected during October 2001, and are based on the assumption that the concentrations in the groundwater monitoring wells are underneath a structure. The future land uses assumed for these sites are commercial or industrial land use where risks from inhalation of concentrations in indoor air are based on worker exposure assumptions, or residential land use. Future residential land use was evaluated because it represents the most conservative land use assumption that would place the fewest restrictions on future land use. The concentrations monitored during the October 2001 quarterly monitoring event indicate future concentrations (hence future risks) associated with the chlorinated VOCs in groundwater. Natural attenuation in groundwater could result in TCE concentrations being reduced over time, with corresponding increases in cis-1,2-DCE and vinyl chloride concentrations.

As shown in Tables B-8 and B-9, excess lifetime cancer risks are less than 1×10^{-5} at all monitoring well locations, based on either a worker or residential exposure scenario. Noncancer hazard indexes fell below 1 at all monitoring well locations based on either a worker or residential exposure scenario.

The risk estimates presented in this appendix are limited by uncertainties inherent in the models used to estimate risk, and in the data used in those models. The risk assessment approach attempted to minimize these uncertainties by developing assumptions that overstate the potential for VOCs to migrate from groundwater to indoor air. The uncertainties associated with these risk estimates are discussed below.

Uncertainties in Site Characterization and Conceptual Model of Exposure Pathways

The site characterization data used to estimate exposure point concentrations provides uncertainties in the risk estimates, because using these data implies that concentrations in groundwater will not change over the exposure duration (25 to 30 years). While the concentrations in groundwater could change through natural attenuation, analysis of the natural attenuation potential indicates that there is either inadequate or limited evidence of anaerobic biodegradation of chlorinated organics at the six groundwater sites (see Appendix C of the FS).

Uncertainties in Identifying Chemicals of Potential Concern

The COPCs addressed in this risk assessment are selected chlorinated VOCs that were detected at concentrations higher than screening levels. Other VOCs were detected at lower concentrations (i.e., less than screening levels) and less frequently than the chlorinated VOCs. In most cases, these other VOCs were detected at concentrations below analytical reporting limits, and were reported as qualified values. It is unlikely that health risks have been understated by not including chemicals other than the chlorinated VOCs.

Uncertainties in Exposure Assessment

The principal uncertainties in the exposure assessment are with the selection of exposure point concentrations in groundwater, the modeling of VOC concentrations from groundwater to indoor air, and with the exposure factors used to estimate chemical intakes from VOC concentrations in indoor air. The relative uncertainties associated with the different assumptions used in the Johnson and Ettinger model are summarized in Table B-11.

Key assumptions made in developing the model for this site were:

- It was assumed that VOCs in groundwater were at a depth of 5 feet below grade directly underneath a building foundation. Depths to groundwater vary across Richards-Gebaur AFB, but generally are 10 feet or greater. The attenuation between groundwater and indoor air concentration increases slightly with larger separation between contamination and the building foundation. A sensitivity analysis shows that the attenuation between groundwater and indoor air concentrations increases by a factor of 1.4 when depth to groundwater in the model is increased from 5 to 20 feet. Therefore, it is a conservative assumption that the contamination is directly beneath the foundation is at a depth of 5 feet.
- The soil underlying the building foundation is assumed to be clay loam, which provides a conservative estimate of the attenuation between groundwater and indoor air concentrations. As described in the FS report (Section 3.1), the soils are characterized as poorly-drained silts and silt-clay loams. When used in the model, the site-specific soil types (either a silt or silty-clay loam) increase attenuation between groundwater and

indoor air concentrations by a factor of 2.4 to 3.6 compared to the baseline assumption of a clay loam soil. Therefore, it is a conservative assumption for the site conditions at Richards-Gebaur AFB that the soil type underlying the building is a clay loam.

A key parameter used to evaluate the Johnson and Ettinger model is the soil gas flow to building ventilation ratio. This parameter is affected by several soil and building characteristics, and a wide range of values for this parameter can be found in the literature. The range of values based on the available field studies has recently been reviewed (Johnson, 2002). Published values for this parameter range from 0.00006 (Olson and Corsi, 2001) to 0.02 (Mose and Mushrush, 1999). The calculated site-specific values for a commercial building and a residence in this supplemental groundwater risk assessment were 0.0000086 and 0.000019, respectively. While these values fall below the lower end of the literature range, the review of the available literature (Johnson, 2002) noted that the data set for field studies is limited. Also, it is not known if there are field studies of structures in relatively tight soils, or field studies of commercial buildings (commercial buildings will be larger and will have higher air exchange rates, producing higher building ventilation rates).

A key parameter for evaluating how well the model reflects inhalation exposure from vapor intrusion is the attenuation coefficient. This is the ratio of indoor air concentration/soil gas concentration. The attenuation coefficient provided by the worker and residential scenarios fall within the range of values estimated from field studies (Johnson et al., 2001).

The exposure factors (exposure frequency and duration, and inhalation rates) are likely to result in an overstatement of potential exposures and health risks. The exposure frequency (250 days/year for a worker scenario or 350 days/year for a residential scenario) assumes that an individual stays inside a workplace or residence nearly continuously. In particular, the USEPA states that the worker exposure duration is an upper bound value, likely to be applicable to only 5 percent of the working population (USEPA, 1991).

Uncertainties in Toxicity Assessment

The principal uncertainty in the toxicity assessment is the cancer potency value for TCE. TCE is detected more frequently and at higher concentrations compared with the chlorinated VOCs. Therefore, changes in toxicity values for TCE would have a greater influence on the risk assessment results. While USEPA's draft risk characterization has proposed higher cancer slope factors for TCE than used in this risk assessment, it is uncertain if these values are technically appropriate for use in risk assessments.

Summary of Uncertainties

The principal uncertainties and their influences on the risk assessment are:

- Reasonably conservative assumptions have been used to model vapor intrusion from groundwater to indoor air.
- Upper-bound exposure factors have been used to estimate inhalation exposure that overstate potential exposure for most individuals.

Conclusions

Under assumed commercial/industrial and residential land uses, there are no excess lifetime cancer risks or noncancer health effects higher than the regulatory levels of concern (an excess lifetime cancer risk of 1×10^{-5} and a noncancer hazard index of 1) associated with VOCs in groundwater. This conclusion is based on the assumption that the potential pathway of exposure is vapor intrusion to indoor spaces from VOCs in groundwater.

Because the risk assessment is conservative, actual risks and exposures are likely to be less than the estimated risk and exposures.

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TABLE B-1

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Worker Assumptions
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
T _s	Average Soil/Groundwater Temperature		13.9	°C	Based on groundwater temperature contours in the User's Guide (USEPA, 2000).
L _F	Depth Below Grade to Bottom of Enclosed Space Floor	This is the depth from soil surface to the bottom of the floor in contact with soil	15	cm	Default value in User's Guide for slab-on-grade construction (USEPA, 2000). Represents 6 inch thick concrete slab.
L _{WT}	Depth Below Grade to Water Table		152.4	cm	Conservative estimate that the assumed depth to groundwater (5 feet). Based on information on the depth to groundwater at Site SS 012 (5-7 ft bgs).
h _A	Thickness of Soil Stratum A		152.4	cm	Thickness of soil stratum A is assumed to be consistent with average depth to groundwater.
h _B	Thickness of Soil Stratum B		NA	cm	Not used
h _C	Thickness of Soil Stratum C		NA	cm	Not used
	Soil Stratum Directly Above Water Table		A	unitless	Consistent with the deepest stratum with a specified thickness (h _A).
	SCS Soil Texture Type Above Water Table		CL	unitless	Soil is assumed to be a clay loam, based on information presented in the Basewide RI, as modified to provide a conservative estimate of vapor intrusion. This parameter is used to estimate the thickness of the capillary zone.
	Soil Stratum A SCS Soil Type	Used to estimate soil vapor permeability	CL	unitless	
k _v	User-defined Soil Vapor Permeability	A parameter associated with convective transport of vapors within the zone of influence of a building. It is related to the size and shape of connected soil pores	NA	Cm ²	Not used, calculated within the model for a clay loam as described above.

TABLE B-1

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Worker Assumptions
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
ρ_b^A	Stratum A Soil Dry Bulk Density		1.5	g/cm ³	Default value provided in User's Guide.
n^A	Stratum A Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	0.43	unitless	Default value provided in User's Guide.
θ_w^A	Stratum A Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	0.3	cm ³ /cm ³	Default value provided in User's Guide.
ρ_b^B	Stratum B Soil Dry Bulk Density		NA	g/cm ³	Not used
n^B	Stratum B Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	NA	unitless	Not used
θ_w^B	Stratum B Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	NA	cm ³ /cm ³	Not used
ρ_b^C	Stratum C Soil Dry Bulk Density		NA	g/cm ³	Not used
n^C	Stratum C Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	NA	unitless	Not used
θ_w^C	Stratum C Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	NA	cm ³ /cm ³	Not used
L_{crack}	Enclosed Space Floor Thickness		15	cm	Same as L_f shown above in this table.
ΔP	Soil-Building Pressure Differential		40	g/cm-s ²	Default in the User's Guide (USEPA, 2000). Considered to be range of depressurization under ambient conditions (Fischer et al., 1996).
L_B	Enclosed Space Floor Length		1928	cm	Typical size of a commercial building – 4000 ft ² (MDEQ, 1998).
W_B	Enclosed Space Floor Width		1928	cm	Typical size of a commercial building – 4000 ft ² (MDEQ, 1998).

TABLE B-1

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Worker Assumptions
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
H _B	Enclosed Space Height		244	cm	Building is assumed to be single-story (8 feet ceiling).
w	Floor-Wall Seam Crack Width	Represents a gap assumed to exist at the junction between the floor and the foundation perimeter. This gap is due to building design or concrete shrinkage. It represents the only route for soil gas intrusion into a building	1	cm	Value provides a total crack to total floor area ration of 0.002. This is consistent with range of values evaluated previously for the J&E model.
ER	Indoor air exchange rate	Building ventilation rate, expressed in units of air changes per hour (ACH)	1	(1/h)	Average residential air exchange rate is 0.45 ACH. Commercial/industrial air exchange rate cited in literature is up to 2 ACH (Michigan DEQ, 1998). Little data existing evaluating range of commercial ACH values.
AT _C	Averaging Time for Carcinogens		70	yrs	
AT _{NC}	Averaging Time for Noncarcinogens		25	yrs	
ED	Exposure Duration		25	yrs	Source: USEPA, 1991
EF	Exposure Frequency		250	days/yr	Source: USEPA, 1991
TR	Target Risk for Carcinogens	Used to calculate risk-based groundwater concentration	1.00E-05	unitless	
THQ	Target Hazard Quotient for Noncarcinogens	Used to calculate risk-based groundwater concentration	1	Days/yr	

TABLE B-2

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Residential Assumptions
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
T _S	Average Soil/Groundwater Temperature		13.9	°C	Based on groundwater temperature contours in the User's Guide (USEPA, 2000).
L _F	Depth Below Grade to Bottom of Enclosed Space Floor	This is the depth from soil surface to the bottom of the floor in contact with soil	15	cm	Default value in User's Guide for slab-on-grade construction (USEPA, 2000). Represents 6 inch thick concrete slab.
L _{WT}	Depth Below Grade to Water Table		152.4	cm	Conservative estimate that the assumed depth to groundwater (5 feet). Based on information on the depth to groundwater at Site SS 012 (5-7 ft bgs).
h _A	Thickness of Soil Stratum A		152.4	cm	Thickness of soil stratum A is assumed to be consistent with average depth to groundwater.
h _B	Thickness of Soil Stratum B		NA	cm	Not used
h _C	Thickness of Soil Stratum C		NA	cm	Not used
	Soil Stratum Directly Above Water Table		A	unitless	Consistent with the deepest stratum with a specified thickness (h _A).
	SCS Soil Texture Type Above Water Table		CL	unitless	Soil is assumed to be a clay loam, based on information presented in the Basewide RI, as modified to provide a conservative estimate of vapor intrusion. This parameter is used to estimate the thickness of the capillary zone.
	Soil Stratum A SCS Soil Type	Used to estimate soil vapor permeability	CL	unitless	
k _v	User-defined Soil Vapor Permeability	A parameter associated with convective transport of vapors within the zone of influence of a building. It is related to the size and shape of connected soil pores	NA	cm ²	Not used, calculated within the model for a clay loam as described above.

TABLE B-2

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Residential Assumptions
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
ρ_b^A	Stratum A Soil Dry Bulk Density		1.5	g/cm ³	Default value provided in User's Guide.
n^A	Stratum A Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	0.43	unitless	Default value provided in User's Guide.
θ_w^A	Stratum A Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	0.3	cm ³ /cm ³	Default value provided in User's Guide.
ρ_b^B	Stratum B Soil Dry Bulk Density		NA	g/cm ³	Not used
n^B	Stratum B Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	NA	unitless	Not used
θ_w^B	Stratum B Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	NA	cm ³ /cm ³	Not used
ρ_b^C	Stratum C Soil Dry Bulk Density		NA	g/cm ³	Not used
n^C	Stratum C Total Soil Porosity	Used with water-filled porosity to calculate air-filled porosity (see below)	NA	unitless	Not used
θ_w^C	Stratum C Soil Water-filled porosity	Used with total porosity to calculate air-filled porosity (see below)	NA	cm ³ /cm ³	Not used
L_{crack}	Enclosed Space Floor Thickness		15	cm	Same as L_F shown above in this table.
Δ_P	Soil-Building Pressure Differential		40	g/cm-s ²	Default in the User's Guide (USEPA, 2000). Considered to be range of depressurization under ambient conditions (Fischer et al., 1996).
L_B	Enclosed Space Floor Length		961	cm	Default value provided in User's Guide.
W_B	Enclosed Space Floor Width		961	cm	Default value provided in User's Guide.
H_B	Enclosed Space Height		488	cm	Default value provided in User's Guide.

TABLE B-2

Groundwater to Indoor Air Parameters Used in the Johnson and Ettinger (1991) Model - Reasonable Maximum Exposure Scenario with Residential Assumptions
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

Symbol	Parameter	Description	Selected Value	Units	Sources
w	Floor-Wall Seam Crack Width	Represents a gap assumed to exist at the junction between the floor and the foundation perimeter. This gap is due to building design or concrete shrinkage. It represents the only route for soil gas intrusion into a building	1	cm	Value provides a total crack to total floor area ration of 0.0042. This is consistent with range of values evaluated previously for the J&E model.
ER	Indoor air exchange rate	Building ventilation rate, expressed in units of air changes per hour (ACH)	0.45	(1/h)	Default value provided in User's Guide.
AT _C	Averaging Time for Carcinogens		70	yrs	
AT _{NC}	Averaging Time for Noncarcinogens		30	yrs	
ED	Exposure Duration		30	yrs	Source: USEPA, 1991
EF	Exposure Frequency		350	days/yr	Source: USEPA, 1991
TR	Target Risk for Carcinogens	Used to calculate risk-based groundwater concentration	1.00E-05	unitless	
THQ	Target Hazard Quotient for Noncarcinogens	Used to calculate risk-based groundwater concentration	1	days/yr	

TABLE B-3
Fate and Transport Parameters Used In the Supplemental Groundwater Risk Assessment
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

CAS No.	Chemical	Organic Carbon Partition Coefficient, K_{oc} (cm ³ /g)	Diffusivity in Air, D_a (cm ² /s)	Diffusivity in Water, D_w (cm ² /s)	Pure Component Water Solubility, S (mg/L)	Henry's Law Constant H' (unitless)	Henry's Law Constant at Reference Temperature, H (atm-m ³ /mol)	Henry's Law Constant Reference Temperature, T_R (°C)	Normal Boiling Point, T_B (°K)	Critical Temperature, T_c (°K)	Enthalpy of Vaporization at the Normal Boiling Point, $\Delta H_{v,b}$ (cal/mol)	Henry's Law Constant Groundwater Temperature,
75014	Vinyl Chloride	1.86E+01	1.06E-01	1.23E-05	2.76E+03	1.11E+00	2.71E-02	25	259.25	432.00	5,250	8.33E-01
75014	Vinyl Chloride (res)	1.86E+01	1.06E-01	1.23E-05	2.76E+03	1.11E+00	2.71E-02	25	259.25	432.00	5,250	8.33E-01
75354	1,1-Dichloroethylene	5.89E+01	9.00E-02	1.04E-05	2.25E+03	1.07E+00	2.61E-02	25	304.75	576.05	6,247	7.31E-01
79016	Trichloroethylene	1.66E+02	7.90E-02	9.10E-06	1.10E+03	4.22E-01	1.03E-02	25	360.36	544.20	7,505	2.51E-01
127184	Tetrachloroethylene	1.55E+02	7.20E-02	8.20E-06	2.00E+02	7.54E-01	1.84E-02	25	394.40	620.20	8,288	4.20E-01
156592	cis-1,2-Dichloroethylene	3.55E+01	7.36E-02	1.13E-05	3.50E+03	1.67E-01	4.07E-03	25	333.65	544.00	7,192	1.05E-01
156605	trans-1,2-Dichloroethylene	5.25E+01	7.07E-02	1.19E-05	6.30E+03	3.85E-01	9.39E-03	25	320.85	516.50	6,717	2.51E-01

TABLE B-4

Groundwater to Indoor Air Attenuation Factors Used In the Supplemental Groundwater Risk Assessment -
 Worker Exposure Scenario
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

CAS No.	Chemical	Attenuation Factor
75014	Vinyl Chloride	4.86E-06
75354	1,1-Dichloroethylene	4.52E-06
79016	Trichloroethylene	4.54E-06
127184	Tetrachloroethylene	4.16E-06
156592	cis-1,2-Dichloroethylene	5.10E-06
156605	trans-1,2-Dichloroethylene	4.48E-06

TABLE B-5

Groundwater to Indoor Air Attenuation Factors Used In the Supplemental Groundwater Risk Assessment -
 Residential Exposure Scenario
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

CAS No.	Chemical	Attenuation Factor
75014	Vinyl Chloride (res)	7.52E-06
75354	1,1-Dichloroethylene	6.82E-06
79016	Trichloroethylene	6.84E-06
127184	Tetrachloroethylene	6.09E-06
156592	cis-1,2-Dichloroethylene	8.05E-06
156605	trans-1,2-Dichloroethylene	6.72E-06

TABLE B-6
 Exposure Point Concentrations (Concentrations in Groundwater Above Tier 1 Screening Levels)
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Units	Analyte	Concentration Detected	Tier 1 Screening Level	Groundwater to Indoor Air Pathway Screening Level		Date	QA/QC Type
					Worker Scenario	Residential Scenario		
SS 012 (Former Building 105)								
BLDG105-MW001	µg/L	Trichloroethylene	199	5	21,126	8,333	10/05/2001	FD
BLDG105-MW001	µg/L	Trichloroethylene	180	5	21,126	8,333	10/05/2001	N
BLDG105-MW001	µg/L	Vinyl Chloride	7.3	2	2,298	442	10/05/2001	FD
BLDG105-MW001	µg/L	Vinyl Chloride	6.4	2	2,298	442	10/05/2001	N
BLDG105-MW002	µg/L	cis-1,2-Dichloroethylene	79.7	70	95,841	43,351	10/05/2001	N
BLDG105-MW002	µg/L	Trichloroethylene	742	5	21,126	8,333	10/05/2001	N
BLDG105-MW003	µg/L	Trichloroethylene	12.3	5	21,126	8,333	10/05/2001	N
BLDG105-MW008	µg/L	Trichloroethylene	161	5	21,126	8,333	10/05/2001	N
BLDG105-MW009	µg/L	Trichloroethylene	22.1	5	21,126	8,333	10/05/2001	N
BLDG105-MW012	µg/L	Trichloroethylene	122	5	21,126	8,333	10/05/2001	N
ST 011 (Former CS 004)								
CS04-MW01	µg/L	Vinyl Chloride	4.7	2	2,298	442	10/06/2001	N
CS04-MW01	µg/L	Vinyl Chloride	4.3	2	2,298	442	10/06/2001	FD
CS04-MW03	µg/L	cis-1,2-Dichloroethylene	151	70	95,841	43,351	10/06/2001	N
CS04-MW03	µg/L	Vinyl Chloride	19.8	2	2,298	442	10/06/2001	N
CS04-MW06	µg/L	Trichloroethylene	14.9	5	21,126	8,333	10/06/2001	N
CS04-MW07	µg/L	Trichloroethylene	5.2	5	21,126	8,333	10/06/2001	N
CS04-MW07	µg/L	Vinyl Chloride	5.4	2	2,298	442	10/06/2001	N

TABLE B-6
 Exposure Point Concentrations (Concentrations in Groundwater Above Tier 1 Screening Levels)
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Units	Analyte	Concentration Detected	Tier 1 Screening Level	Groundwater to Indoor Air Pathway Screening Level		Date	QA/QC Type
					Worker Scenario	Residential Scenario		
CS04-MW08	µg/L	Vinyl Chloride	7.3	2	2,298	442	10/06/2001	N
CS04-MW16	µg/L	Vinyl Chloride	7.3	2	2,298	442	10/09/2001	N
SS-003								
SS03-MW04	µg/L	Trichloroethylene	57.6	5	21,126	8,333	10/03/2001	FD
SS03-MW04	µg/L	Trichloroethylene	55.2	5	21,126	8,333	10/03/2001	N
SS03-MW07	µg/L	Trichloroethylene	11	5	21,126	8,333	10/03/2001	N
SS03-MW06	µg/L	Trichloroethylene	9.6	5	21,126	8,333	10/03/2001	N
SS-006								
SS06-MW05	µg/L	Trichloroethylene	271	5	21,126	8,333	10/01/2001	N
SS06-MW05	µg/L	Vinyl Chloride	3.7	2	2,298	442	10/01/2001	N
SS06-MW09	µg/L	Trichloroethylene	30.3	5	21,126	8,333	10/01/2001	N
SS06-MW09	µg/L	Trichloroethylene	25.9	5	21,126	8,333	10/01/2001	FD
SS06-MW10	µg/L	cis-1,2-Dichloroethylene	97.2	70	95,841	43,351	10/01/2001	N
SS06-MW10	µg/L	Trichloroethylene	166	5	21,126	8,333	10/01/2001	N
SS06-MW10	µg/L	Vinyl Chloride	3.2	2	2,298	442	10/01/2001	N
SS06-MW11	µg/L	cis-1,2-Dichloroethylene	73.7	70	95,841	43,351	10/01/2001	N
SS06-MW11	µg/L	Trichloroethylene	141	5	21,126	8,333	10/01/2001	N
SS06-MW12	µg/L	cis-1,2-Dichloroethylene	78.1	70	95,841	43,351	10/01/2001	N
SS06-MW12	µg/L	Trichloroethylene	86	5	21,126	8,333	10/01/2001	N

TABLE B-6
 Exposure Point Concentrations (Concentrations in Groundwater Above Tier 1 Screening Levels)
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Units	Analyte	Concentration Detected	Tier 1 Screening Level	Groundwater to Indoor Air Pathway Screening Level		Date	QA/QC Type
					Worker Scenario	Residential Scenario		
SS06-MW13	µg/L	Trichloroethylene	18	5	21,126	8,333	10/01/2001	N
SS06-MW14	µg/L	Trichloroethylene	70.2	5	21,126	8,333	10/01/2001	N
SS06-MW15	µg/L	Trichloroethylene	128	5	21,126	8,333	10/01/2001	N
SS06-MW18	µg/L	Trichloroethylene	16.9	5	21,126	8,333	10/01/2001	N
SS06-MW20	µg/L	cis-1,2-Dichloroethylene	132	70	95,841	43,351	10/02/2001	N
SS06-MW20	µg/L	cis-1,2-Dichloroethylene	125	70	95,841	43,351	10/02/2001	FD
SS06-MW20	µg/L	Trichloroethylene	930	5	21,126	8,333	10/02/2001	N
SS06-MW20	µg/L	Trichloroethylene	859	5	21,126	8,333	10/02/2001	FD
SS06-MW20	µg/L	Vinyl Chloride	18.1	2	2,298	442	10/02/2001	N
SS06-MW20	µg/L	Vinyl Chloride	17	2	2,298	442	10/02/2001	FD
SS-009								
SS09-MW03	µg/L	1,1-Dichloroethylene	42.9	7	88,259	41,822	10/03/2001	N
SS09-MW03	µg/L	1,1-Dichloroethylene	41.7	7	88,259	41,822	10/03/2001	FD
SS09-MW03	µg/L	cis-1,2-Dichloroethylene	171	70	95,841	43,351	10/03/2001	N
SS09-MW03	µg/L	cis-1,2-Dichloroethylene	167	70	95,841	43,351	10/03/2001	FD
SS09-MW03	µg/L	Tetrachloroethylene	15.8	5	40,371	16,399	10/03/2001	N
SS09-MW03	µg/L	Tetrachloroethylene	14.8	5	40,371	16,399	10/03/2001	FD
SS09-MW03	µg/L	Trichloroethylene	19.2	5	21,126	8,333	10/03/2001	FD
SS09-MW03	µg/L	Trichloroethylene	18.8	5	21,126	8,333	10/03/2001	N

TABLE B-6
 Exposure Point Concentrations (Concentrations in Groundwater Above Tier 1 Screening Levels)
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Units	Analyte	Concentration Detected	Tier 1 Screening Level	Groundwater to Indoor Air Pathway Screening Level		Date	QA/QC Type
					Worker Scenario	Residential Scenario		
SS09-MW03	µg/L	Vinyl Chloride	6	2 J	2,298	442	10/03/2001	N
SS09-MW03	µg/L	Vinyl Chloride	4.8	2 J	2,298	442	10/03/2001	FD
SS09-MW09	µg/L	Vinyl Chloride	3.4	2	2,298	442	10/03/2001	N
ST-005								
ST05-MW03	µg/L	Trichloroethylene	278	5	21,126	8,333	10/09/2001	FD
ST05-MW03	µg/L	Trichloroethylene	243	5	21,126	8,333	10/09/2001	N
ST05-MW10	µg/L	Trichloroethylene	10.3	5	21,126	8,333	10/09/2001	N
ST05-MW10	µg/L	Trichloroethylene	9.9	5	21,126	8,333	10/09/2001	FD
ST05-MW12	µg/L	Trichloroethylene	63.3	5	21,126	8,333	10/09/2001	N
ST05-MW13	µg/L	Trichloroethylene	55	5	21,126	8,333	10/09/2001	N
ST05-MW14	µg/L	Trichloroethylene	556	5	21,126	8,333	10/09/2001	N
ST05-MW18	µg/L	Trichloroethylene	1160	5	21,126	8,333	10/09/2001	N
ST05-MW20	µg/L	Trichloroethylene	18.7	5	21,126	8,333	10/09/2001	N
ST05-MW21	µg/L	Trichloroethylene	6.2	5	21,126	8,333	10/09/2001	N
ST05-MW22	µg/L	Trichloroethylene	5.3	5	21,126	8,333	10/09/2001	N

TABLE B-7

Toxicity Values Used In the Supplemental Groundwater Risk Assessment
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

CAS No.	Chemical	Unit Risk Factor, URF ($\mu\text{g}/\text{m}^3$) ⁻¹	Reference Conc., RfC ($\mu\text{g}/\text{m}^3$)	Notes
75014	Vinyl chloride	4.4E-06	1.0E+02	Values updated in IRIS, August 2000
	Vinyl chloride (res)	8.8E-06	1.0E+02	Vinyl chloride unit risk factor for lifetime exposure was used to evaluate risks under the residential land use scenario.
75354	1,1-Dichloroethylene	0.0E+00	2.0E+02	Proposed toxicity values, scheduled for publication on IRIS in 2002.
79016	Trichloroethylene	1.7E-06	2.1E+01	Withdrawn unit risk factor; inhalation RfD converted to an RfC. Source: USEPA Region 9 PRG Table.
127184	Tetrachloroethylene	5.8E-07	3.5E+02	Withdrawn unit risk factor; inhalation RfD converted to an RfC. Source: USEPA Region 9 PRG Table.
156592	cis-1,2-Dichloroethylene	0.0E+00	3.5E+01	Derived from provisional RfD published in HEAST (USEPA, 1997).
156605	trans-1,2-Dichloroethylene	0.0E+00	7.0E+01	Source: IRIS

IRIS - Integrated Risk Information System

PRG - Preliminary Remediation Goal

HEAST - Health Effects Assessment Summary Table

RfC - Reference Concentration

RfD - Reference Dose

TABLE B-8

Exposure and Health Risk Assessment Results - Worker Exposure Scenario
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater (µg/L)	Date	QA/QC Type	Source Concentration in Soil Gas (µg/m ³)	Indoor Air Concentration (µg/m ³)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
BLDG-105 (Site SS-011)								
BLDG105-MW001	Trichloroethylene	199	10/05/2001	FD	4.99E+04	2.27E-01	9.4E-08	7.4E-03
BLDG105-MW001	Vinyl Chloride	7.3	10/05/2001	FD	6.08E+03	2.95E-02	3.2E-08	2.0E-04
BLDG105-MW002	cis-1,2-Dichloroethylene	79.7	10/05/2001	N	8.33E+03	4.25E-02		8.3E-04
BLDG105-MW002	Trichloroethylene	742	10/05/2001	N	1.86E+05	8.45E-01	3.5E-07	2.8E-02
BLDG105-MW003	Trichloroethylene	12.3	10/05/2001	N	3.09E+03	1.40E-02	5.8E-09	4.6E-04
BLDG105-MW008	Trichloroethylene	161	10/05/2001	N	4.04E+04	1.83E-01	7.6E-08	6.0E-03
BLDG105-MW009	Trichloroethylene	22.1	10/05/2001	N	5.55E+03	2.52E-02	1.0E-08	8.2E-04
BLDG105-MW012	Trichloroethylene	122	10/05/2001	N	3.06E+04	1.39E-01	5.8E-08	4.5E-03
CS-004								
CS04-MW01	Vinyl Chloride	4.7	10/06/2001	N	3.91E+03	1.90E-02	2.0E-08	1.3E-04
CS04-MW03	cis-1,2-Dichloroethylene	151	10/06/2001	N	1.58E+04	8.05E-02		1.6E-03
CS04-MW03	Vinyl Chloride	19.8	10/06/2001	N	1.65E+04	8.01E-02	8.6E-08	5.5E-04
CS04-MW06	Trichloroethylene	14.9	10/06/2001	N	3.74E+03	1.70E-02	7.1E-09	5.5E-04
CS04-MW07	Trichloroethylene	5.2	10/06/2001	N	1.30E+03	5.92E-03	2.5E-09	1.9E-04
CS04-MW07	Vinyl Chloride	5.4	10/06/2001	N	4.50E+03	2.18E-02	2.4E-08	1.5E-04
CS04-MW08	Vinyl Chloride	7.3	10/06/2001	N	6.08E+03	2.95E-02	3.2E-08	2.0E-04
CS04-MW16	Vinyl Chloride	7.3	10/09/2001	N	6.08E+03	2.95E-02	3.2E-08	2.0E-04

TABLE B-8
 Exposure and Health Risk Assessment Results - Worker Exposure Scenario
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater (µg/L)	Date	QA/QC Type	Source Concentration in Soil Gas (µg/m ³)	Indoor Air Concentration (µg/m ³)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
SS-003								
SS03-MW04	Trichloroethylene	57.6	10/03/2001	FD	1.45E+04	6.56E-02	2.7E-08	2.1E-03
SS03-MW04	Trichloroethylene	55.2	10/03/2001	N	1.39E+04	6.28E-02	2.6E-08	2.0E-03
SS03-MW07	Trichloroethylene	11	10/03/2001	N	2.76E+03	1.25E-02	5.2E-09	4.1E-04
SS03-MW06	Trichloroethylene	9.6	10/03/2001	N	2.41E+03	1.09E-02	4.5E-09	3.6E-04
SS-006								
SS06-MW05	Trichloroethylene	271	10/01/2001	N	6.80E+04	3.08E-01	1.3E-07	1.0E-02
SS06-MW05	Vinyl Chloride	3.7	10/01/2001	N	3.08E+03	1.50E-02	1.6E-08	1.0E-04
SS06-MW09	Trichloroethylene	30.3	10/01/2001	N	7.60E+03	3.45E-02	1.4E-08	1.1E-03
SS06-MW10	cis-1,2-Dichloroethylene	97.2	10/01/2001	N	1.02E+04	5.18E-02		1.0E-03
SS06-MW10	Trichloroethylene	166	10/01/2001	N	4.17E+04	1.89E-01	7.9E-08	6.2E-03
SS06-MW10	Vinyl Chloride	3.2	10/01/2001	N	2.66E+03	1.29E-02	1.4E-08	8.9E-05
SS06-MW11	cis-1,2-Dichloroethylene	73.7	10/01/2001	N	7.71E+03	3.93E-02		7.7E-04
SS06-MW11	Trichloroethylene	141	10/01/2001	N	3.54E+04	1.60E-01	6.7E-08	5.2E-03
SS06-MW12	cis-1,2-Dichloroethylene	78.1	10/01/2001	N	8.17E+03	4.16E-02		8.1E-04
SS06-MW12	Trichloroethylene	86	10/01/2001	N	2.16E+04	9.79E-02	4.1E-08	3.2E-03
SS06-MW13	Trichloroethylene	18	10/01/2001	N	4.52E+03	2.05E-02	8.5E-09	6.7E-04
SS06-MW14	Trichloroethylene	70.2	10/01/2001	N	1.76E+04	7.99E-02	3.3E-08	2.6E-03
SS06-MW15	Trichloroethylene	128	10/01/2001	N	3.21E+04	1.46E-01	6.1E-08	4.8E-03
SS06-MW18	Trichloroethylene	16.9	10/01/2001	N	4.24E+03	1.92E-02	8.0E-09	6.3E-04

TABLE B-8

Exposure and Health Risk Assessment Results - Worker Exposure Scenario
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater (µg/L)	Date	QA/QC Type	Source Concentration in Soil Gas (µg/m ³)	Indoor Air Concentration (µg/m ³)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
SS06-MW20	cis-1,2-Dichloroethylene	132	10/02/2001	N	1.38E+04	7.04E-02		1.4E-03
SS06-MW20	Trichloroethylene	930	10/02/2001	N	2.33E+05	1.06E+00	4.4E-07	3.5E-02
SS06-MW20	Vinyl Chloride	18.1	10/02/2001	N	1.51E+04	7.32E-02	7.9E-08	5.0E-04
SS-009								
SS09-MW03	1,1-Dichloroethylene	42.9	10/03/2001	N	3.14E+04	1.42E-01		4.9E-04
SS09-MW03	cis-1,2-Dichloroethylene	171	10/03/2001	N	1.79E+04	9.12E-02		1.8E-03
SS09-MW03	Tetrachloroethylene	15.8	10/03/2001	N	6.63E+03	2.76E-02	3.9E-09	5.4E-05
SS09-MW03	Trichloroethylene	19.2	10/03/2001	FD	4.82E+03	2.19E-02	9.1E-09	7.1E-04
SS09-MW03	Vinyl Chloride	6	10/03/2001	N	5.00E+03	2.43E-02	2.6E-08	1.7E-04
ST-005								
ST05-MW03	Trichloroethylene	278	10/09/2001	FD	6.98E+04	3.16E-01	1.3E-07	1.0E-02
ST05-MW10	Trichloroethylene	10.3	10/09/2001	N	2.58E+03	1.17E-02	4.9E-09	3.8E-04
ST05-MW12	Trichloroethylene	63.3	10/09/2001	N	1.59E+04	7.21E-02	3.0E-08	2.4E-03
ST05-MW13	Trichloroethylene	55	10/09/2001	N	1.38E+04	6.26E-02	2.6E-08	2.0E-03
ST05-MW14	Trichloroethylene	556	10/09/2001	N	1.40E+05	6.33E-01	2.6E-07	2.1E-02
ST05-MW18	Trichloroethylene	1160	10/09/2001	N	2.91E+05	1.32E+00	5.5E-07	4.3E-02
ST05-MW20	Trichloroethylene	18.7	10/09/2001	N	4.69E+03	2.13E-02	8.9E-09	6.9E-04
ST05-MW21	Trichloroethylene	6.2	10/09/2001	N	1.56E+03	7.06E-03	2.9E-09	2.3E-04
ST05-MW22	Trichloroethylene	5.3	10/09/2001	N	1.33E+03	6.03E-03	2.5E-09	2.0E-04

TABLE B-9
 Exposure and Health Risk Assessment Results - Residential Exposure Scenario
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater ($\mu\text{g/L}$)	Date	QA/QC Type	Source Concentration in Soil Gas ($\mu\text{g/m}^3$)	Indoor Air Concentration ($\mu\text{g/m}^3$)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
BLDG-105 (Site SS-011)								
BLDG105-MW001	Trichloroethylene	199	10/05/2001	FD	4.99E+04	3.42E-01	1.4E-07	1.6E-02
BLDG105-MW001	Vinyl Chloride (res)	7.3	10/05/2001	FD	6.08E+03	4.57E-02	9.8E-08	4.4E-04
BLDG105-MW002	cis-1,2-Dichloroethylene	79.7	10/05/2001	N	8.33E+03	6.71E-02		1.8E-03
BLDG105-MW002	Trichloroethylene	742	10/05/2001	N	1.86E+05	1.27E+00	5.3E-07	5.8E-02
BLDG105-MW003	Trichloroethylene	12.3	10/05/2001	N	3.09E+03	2.11E-02	8.8E-09	9.6E-04
BLDG105-MW008	Trichloroethylene	161	10/05/2001	N	4.04E+04	2.77E-01	1.1E-07	1.3E-02
BLDG105-MW009	Trichloroethylene	22.1	10/05/2001	N	5.55E+03	3.80E-02	1.6E-08	1.7E-03
BLDG105-MW012	Trichloroethylene	122	10/05/2001	N	3.06E+04	2.10E-01	8.7E-08	9.6E-03
CS-004								
CS04-MW01	Vinyl Chloride (res)	4.7	10/06/2001	N	3.91E+03	2.94E-02	6.3E-08	2.8E-04
CS04-MW03	cis-1,2-Dichloroethylene	151	10/06/2001	N	1.58E+04	1.27E-01		3.5E-03
CS04-MW03	Vinyl Chloride (res)	19.8	10/06/2001	N	1.65E+04	1.24E-01	2.7E-07	1.2E-03
CS04-MW06	Trichloroethylene	14.9	10/06/2001	N	3.74E+03	2.56E-02	1.1E-08	1.2E-03
CS04-MW07	Trichloroethylene	5.2	10/06/2001	N	1.30E+03	8.93E-03	3.7E-09	4.1E-04
CS04-MW07	Vinyl Chloride (res)	5.4	10/06/2001	N	4.50E+03	3.38E-02	7.3E-08	3.2E-04
CS04-MW08	Vinyl Chloride (res)	7.3	10/06/2001	N	6.08E+03	4.57E-02	9.8E-08	4.4E-04
CS04-MW16	Vinyl Chloride (res)	7.3	10/09/2001	N	6.08E+03	4.57E-02	9.8E-08	4.4E-04

TABLE B-9
 Exposure and Health Risk Assessment Results - Residential Exposure Scenario
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater (µg/L)	Date	QA/QC Type	Source Concentration in Soil Gas (µg/m ³)	Indoor Air Concentration (µg/m ³)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
SS-003								
SS03-MW04	Trichloroethylene	57.6	10/03/2001	FD	1.45E+04	9.89E-02	4.1E-08	4.5E-03
SS03-MW04	Trichloroethylene	55.2	10/03/2001	N	1.39E+04	9.48E-02	3.9E-08	4.3E-03
SS03-MW07	Trichloroethylene	11	10/03/2001	N	2.76E+03	1.89E-02	7.9E-09	8.6E-04
SS03-MW06	Trichloroethylene	9.6	10/03/2001	N	2.41E+03	1.65E-02	6.9E-09	7.5E-04
SS-006								
SS06-MW05	Trichloroethylene	271	10/01/2001	N	6.80E+04	4.65E-01	1.9E-07	2.1E-02
SS06-MW05	Vinyl Chloride (res)	3.7	10/01/2001	N	3.08E+03	2.32E-02	5.0E-08	2.2E-04
SS06-MW09	Trichloroethylene	30.3	10/01/2001	N	7.60E+03	5.20E-02	2.2E-08	2.4E-03
SS06-MW10	cis-1,2-Dichloroethylene	97.2	10/01/2001	N	1.02E+04	8.18E-02		2.2E-03
SS06-MW10	Trichloroethylene	166	10/01/2001	N	4.17E+04	2.85E-01	1.2E-07	1.3E-02
SS06-MW10	Vinyl Chloride (res)	3.2	10/01/2001	N	2.66E+03	2.00E-02	4.3E-08	1.9E-04
SS06-MW11	cis-1,2-Dichloroethylene	73.7	10/01/2001	N	7.71E+03	6.21E-02		1.7E-03
SS06-MW11	Trichloroethylene	141	10/01/2001	N	3.54E+04	2.42E-01	1.0E-07	1.1E-02
SS06-MW12	cis-1,2-Dichloroethylene	78.1	10/01/2001	N	8.17E+03	6.58E-02		1.8E-03
SS06-MW12	Trichloroethylene	86	10/01/2001	N	2.16E+04	1.48E-01	6.1E-08	6.7E-03
SS06-MW13	Trichloroethylene	18	10/01/2001	N	4.52E+03	3.09E-02	1.3E-08	1.4E-03
SS06-MW14	Trichloroethylene	70.2	10/01/2001	N	1.76E+04	1.21E-01	5.0E-08	5.5E-03
SS06-MW15	Trichloroethylene	128	10/01/2001	N	3.21E+04	2.20E-01	9.1E-08	1.0E-02
SS06-MW18	Trichloroethylene	16.9	10/01/2001	N	4.24E+03	2.90E-02	1.2E-08	1.3E-03

TABLE B-9
 Exposure and Health Risk Assessment Results - Residential Exposure Scenario
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Analyte	Concentration Detected in Groundwater ($\mu\text{g/L}$)	Date	QA/QC Type	Source Concentration in Soil Gas ($\mu\text{g/m}^3$)	Indoor Air Concentration ($\mu\text{g/m}^3$)	Excess Lifetime Cancer Risk	Noncancer Hazard Quotient
SS06-MW20	cis-1,2-Dichloroethylene	132	10/02/2001	N	1.38E+04	1.11E-01		3.0E-03
SS06-MW20	Trichloroethylene	930	10/02/2001	N	2.33E+05	1.60E+00	6.6E-07	7.3E-02
SS06-MW20	Vinyl Chloride (res)	18.1	10/02/2001	N	1.51E+04	1.13E-01	2.4E-07	1.1E-03
SS-009								
SS09-MW03	1,1-Dichloroethylene	42.9	10/03/2001	N	3.14E+04	2.14E-01		1.0E-03
SS09-MW03	cis-1,2-Dichloroethylene	171	10/03/2001	N	1.79E+04	1.44E-01		3.9E-03
SS09-MW03	Tetrachloroethylene	15.8	10/03/2001	N	6.63E+03	4.04E-02	5.7E-09	1.1E-04
SS09-MW03	Trichloroethylene	19.2	10/03/2001	FD	4.82E+03	3.30E-02	1.4E-08	1.5E-03
SS09-MW03	Vinyl Chloride (res)	6	10/03/2001	N	5.00E+03	3.75E-02	8.1E-08	3.6E-04
ST-005								
ST05-MW03	Trichloroethylene	278	10/09/2001	FD	6.98E+04	4.78E-01	2.0E-07	2.2E-02
ST05-MW10	Trichloroethylene	10.3	10/09/2001	N	2.58E+03	1.77E-02	7.4E-09	8.1E-04
ST05-MW12	Trichloroethylene	63.3	10/09/2001	N	1.59E+04	1.09E-01	4.5E-08	5.0E-03
ST05-MW13	Trichloroethylene	55	10/09/2001	N	1.38E+04	9.45E-02	3.9E-08	4.3E-03
ST05-MW14	Trichloroethylene	556	10/09/2001	N	1.40E+05	9.55E-01	4.0E-07	4.4E-02
ST05-MW18	Trichloroethylene	1160	10/09/2001	N	2.91E+05	1.99E+00	8.3E-07	9.1E-02
ST05-MW20	Trichloroethylene	18.7	10/09/2001	N	4.69E+03	3.21E-02	1.3E-08	1.5E-03
ST05-MW21	Trichloroethylene	6.2	10/09/2001	N	1.56E+03	1.06E-02	4.4E-09	4.9E-04
ST05-MW22	Trichloroethylene	5.3	10/09/2001	N	1.33E+03	9.10E-03	3.8E-09	4.2E-04

TABLE B-10
 Health Risk Assessment Summary Results
 Supplemental Groundwater Risk Assessment
 Richards-Gebaur AFB Feasibility Study

Monitoring Well	Total Well-Specific Excess Lifetime Cancer Risk		Total Well-Specific Noncancer Hazard Index	
	Worker Scenario	Residential Scenario	Worker Scenario	Residential Scenario
BLDG-105 (Site SS 012)				
BLDG105-MW001	1.3E-07	2.4E-07	0.01	0.02
BLDG105-MW002	3.5E-07	5.3E-07	0.03	0.06
BLDG105-MW003	5.8E-09	8.8E-09	0.0005	0.0010
BLDG105-MW008	7.6E-08	1.1E-07	0.01	0.01
BLDG105-MW009	1.0E-08	1.6E-08	0.0008	0.0017
BLDG105-MW012	5.8E-08	8.7E-08	0.005	0.01
CS-004 (Site ST 011)				
CS04-MW01	2.0E-08	6.3E-08	0.0001	0.0003
CS04-MW03	8.6E-08	2.7E-07	0.0021	0.0047
CS04-MW06	7.1E-09	1.1E-08	0.0006	0.0012
CS04-MW07	2.6E-08	7.6E-08	0.0003	0.0007
CS04-MW08	3.2E-08	9.8E-08	0.0002	0.0004
CS04-MW16	3.2E-08	9.8E-08	0.0002	0.0004
SS-003				
SS03-MW04	5.3E-08	8.1E-08	0.004	0.01
SS03-MW07	5.2E-09	7.9E-09	0.0004	0.001
SS03-MW06	4.5E-09	6.9E-09	0.0004	0.001
SS-006				
SS06-MW05	1.4E-07	2.4E-07	0.01	0.02
SS06-MW09	1.4E-08	2.2E-08	0.001	0.002
SS06-MW10	9.3E-08	1.6E-07	0.01	0.02
SS06-MW11	6.7E-08	1.0E-07	0.01	0.01
SS06-MW12	4.1E-08	6.1E-08	0.004	0.01
SS06-MW13	8.5E-09	1.3E-08	0.0007	0.0014
SS06-MW14	3.3E-08	5.0E-08	0.003	0.01
SS06-MW15	6.1E-08	9.1E-08	0.005	0.01
SS06-MW18	8.0E-09	1.2E-08	0.0006	0.0013
SS06-MW20	5.2E-07	9.1E-07	0.04	0.08
SS-009				
SS09-MW03	3.9E-08	1.0E-07	0.003	0.01

TABLE B-10
 Health Risk Assessment Summary Results
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

Monitoring Well	Total Well-Specific Excess Lifetime Cancer Risk		Total Well-Specific Noncancer Hazard Index	
	Worker Scenario	Residential Scenario	Worker Scenario	Residential Scenario
ST-005				
ST05-MW03	1.3E-07	2.0E-07	0.01	0.02
ST05-MW10	4.9E-09	7.4E-09	0.0004	0.0008
ST05-MW12	3.0E-08	4.5E-08	0.002	0.005
ST05-MW13	2.6E-08	3.9E-08	0.002	0.004
ST05-MW14	2.6E-07	4.0E-07	0.02	0.04
ST05-MW18	5.5E-07	8.3E-07	0.04	0.09
ST05-MW20	8.9E-09	1.3E-08	0.001	0.001
ST05-MW21	2.9E-09	4.4E-09	0.0002	0.0005
ST05-MW22	2.5E-09	3.8E-09	0.0002	0.0004

TABLE B-11
 Relative Uncertainties in the Johnson and Ettinger Model Used for Groundwater to Indoor Air Pathway Analysis
Supplemental Groundwater Risk Assessment
Richards-Gebaur AFB Feasibility Study

Input Parameter	Default or Site-specific value?	Relative Uncertainty
Soil water-filled porosity	Default	High
Soil vapor permeability	Site-specific	High
Soil-building pressure differential	Default	High
Depth to top of contamination	Site-specific	Low
Fraction of floor surface area with permeable cracks	Conservative assumed value	Moderate
Building air exchange rate	Default	Moderate
Building volume	Default	Low
Soil texture type (determines the capillary fringe thickness)	Conservative assumed value	High

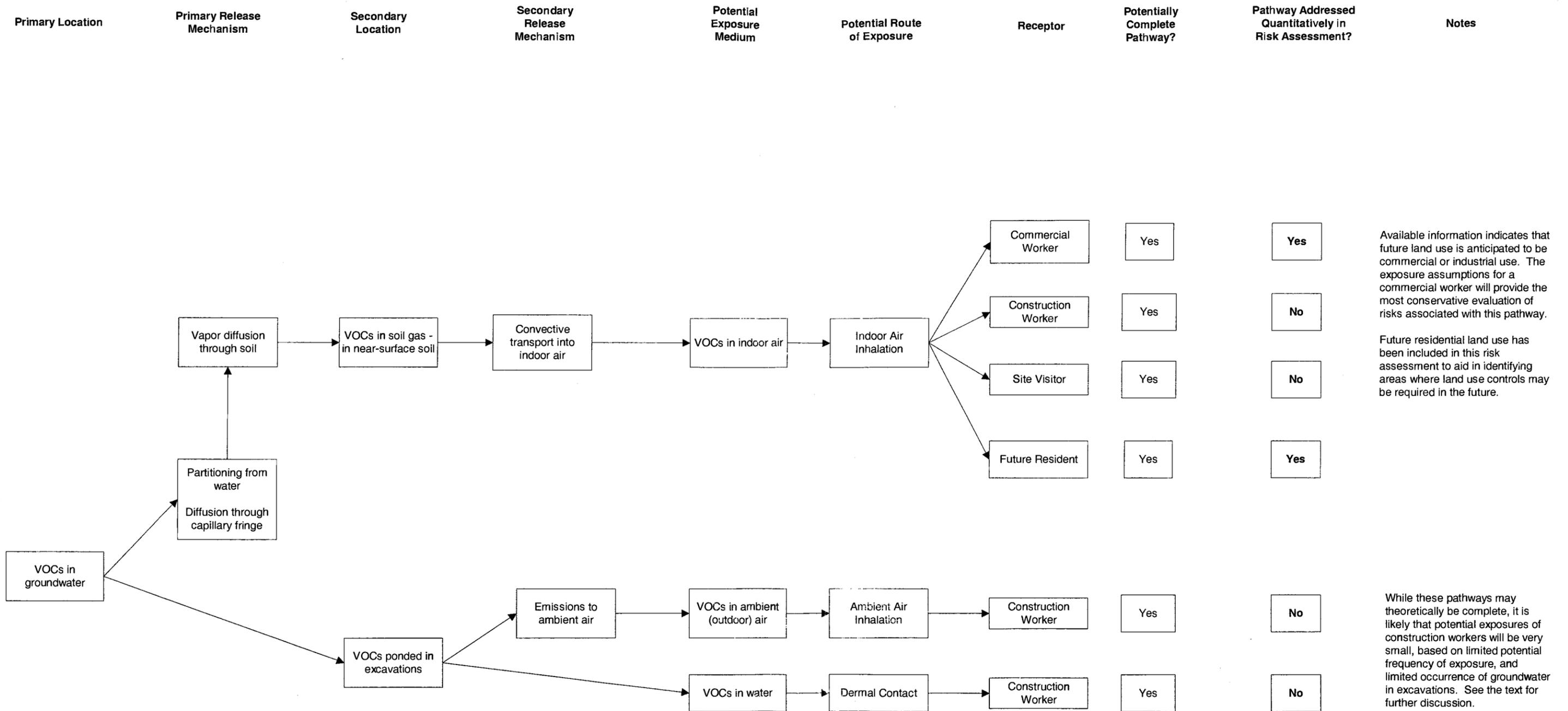


FIGURE B-1
Conceptual Site Model - Identification of Potentially Complete Exposure Pathways in Groundwater
Richards-Gebaur AFB Feasibility Study
Kansas City, MO

Notes:
 X = Pathway broken at this point.
 Shaded boxes indicate exposure pathway is not complete at this point.

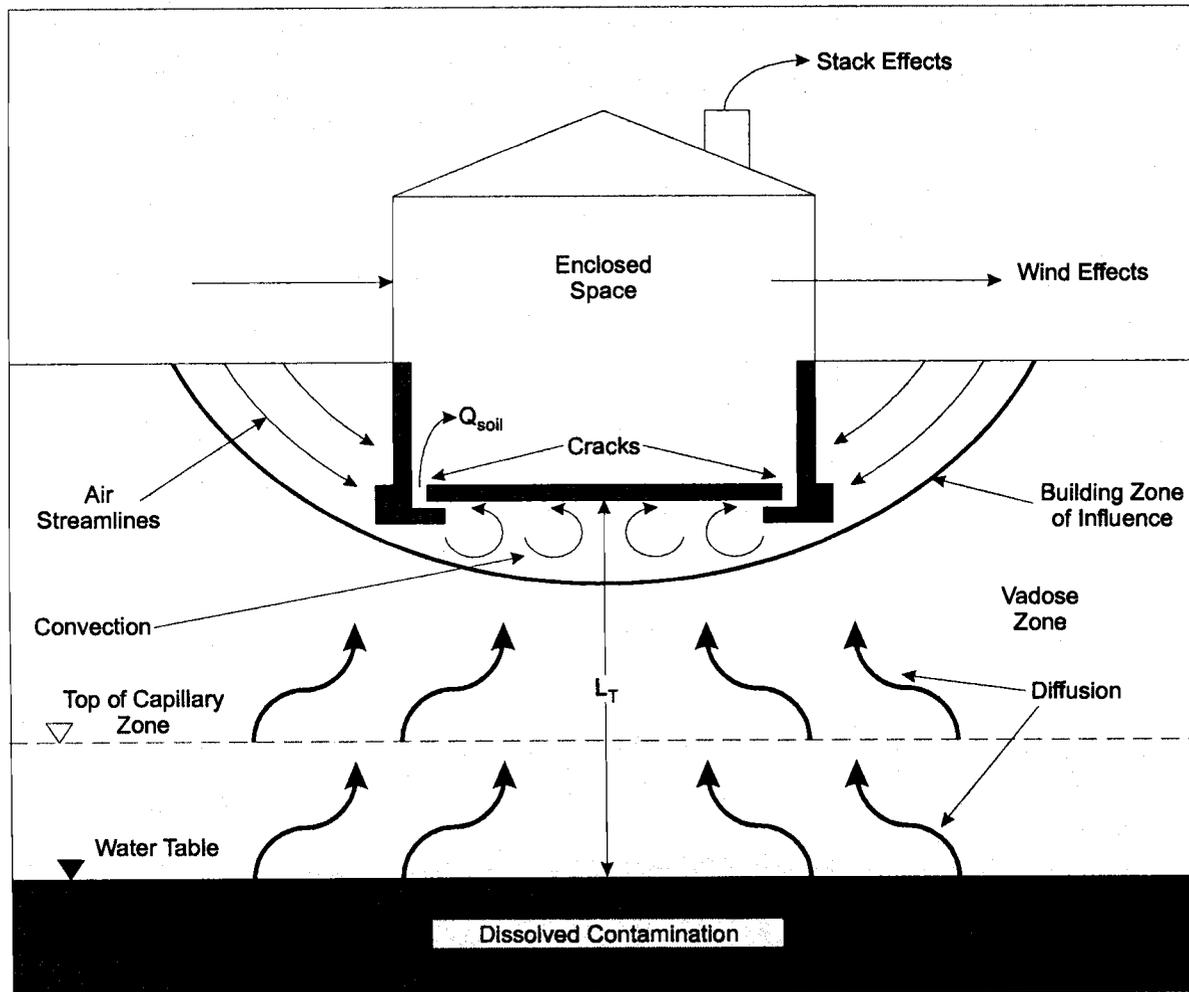


FIGURE B-2
Conceptual Model of Groundwater to Indoor Air Pathway
 (Source: USEPA, 2000)
 Richards-Gebaur AFB Feasibility Study
 Kansas City, MO

ATTACHMENT

Toxicity Profiles for Selected Groundwater Contaminants

Trichloroethylene

This summary of the toxicology of trichloroethylene (TCE) has been drawn from the Agency for Toxic Substances and Disease Registry (ATSDR) toxicological profile (ATSDR, 1997a), and from the recent state-of-the-science review of TCE health risks (Scott and Cogliano, 2000).

TCE is a nonflammable, colorless liquid at room temperature with a sweet odor and a sweet, burning taste. TCE principally was used as a solvent to remove grease from metal parts. It is also has been used as a solvent in some household products, including typewriter correction fluid, paint removers, adhesives, and spot removers. TCE in air has an odor threshold of approximately 100 parts per million (ppm). Sources of potential exposure, beyond contamination in soil and groundwater, formerly included inhalation of TCE emitted from the use in household products and inhalation of TCE emitted to ambient air from industrial facilities.

Exposure can occur via the inhalation, oral, and dermal routes in people living near hazardous waste sites if TCE volatilizes from contaminated soils, or if contaminated water is ingested or used in bathing. Workers in industries that use TCE may experience inhalation exposure or skin contact. The group with the greatest likelihood for substantial exposure to TCE consists of those exposed to substances in the workplace. In the past, TCE was used as an anesthetic in surgery, and has also been inhaled intentionally for its narcotic properties. Therefore, most of the information regarding the effects of TCE in humans comes from case studies and experiments describing effects after inhalation exposure.

The primary effect of exposure to TCE is on the central nervous system. Effects include headache, vertigo, fatigue, short-term memory loss, decreased word associations, central nervous system depression, and anesthesia. Acute high-level inhalation of TCE has been reported to produce death through cardiac arrhythmias. Studies in laboratory animals have indicated that TCE-induced cardiac sensitization to catecholamines may explain the arrhythmias that have been documented in humans. There is some evidence for TCE-induced hepatic effects in humans. This evidence is primarily from case reports of accidental or intentional exposure to relatively high levels in air, though chronic occupational exposure has also been reported in some cases to produce liver enlargement and alteration of hepatic function. Liver enlargement is the primary hepatic effect seen in laboratory animals after oral or inhalation exposure. While considered hepatotoxic in laboratory animals, the available studies indicate that TCE is not as potent a liver toxin as are a number of other chlorinated hydrocarbons (such as carbon tetrachloride).

Humans exposed to TCE in contaminated groundwater have not shown adverse reproductive effects, though TCE has shown some potential for causing reproductive toxic effects in laboratory animals. There is limited evidence that oral exposure to TCE in drinking water, or inhalation exposure in the workplace may be associated with developmental toxic effects (i.e., birth defects). Reports have recently emerged of TCE-induced effects on human sex hormones and their binding proteins, principally affecting male reproductive systems.

TCE is known to be carcinogenic in laboratory animals, producing cancers in the liver, lung, and kidney. The U.S. Environmental Protection Agency (USEPA) concluded in its draft risk characterization that there is a small but consistent relationship between TCE exposure and human cancers in multiple organs (USEPA, 2001a), though questions have been raised regarding the reliability of USEPA's conclusions drawn from its review of the epidemiological data (AFIERA, 2001).

1,1-Dichloroethene

This summary of the toxicology of 1,1-dichloroethene (1,1-DCE) has been drawn from the ATSDR toxicological profile (ATSDR, 1994), and from the recent draft toxicological review conducted by the USEPA (USEPA, 2001b). Based on its toxicological profile, the USEPA has proposed revisions to the toxicity classification for 1,1-DCE.

1,1-DCE is used to make certain plastics (such as packaging materials and flexible films like SARAN wrap) and flame retardant coatings for fiber and carpet backing. It is a colorless liquid with a mild sweet odor, and evaporates quickly at room temperature. 1,1-DCE is emitted into the air from industrial facilities. 1,1-DCE is also formed in groundwater from the degradation of chlorinated solvents that are groundwater contaminants.

Exposure can occur via the inhalation, oral, and dermal routes in people living near hazardous waste sites if 1,1-DCE volatilizes from contaminated soils, or if contaminated water is ingested or used in bathing. Workers in industries that use 1,1-DCE may experience inhalation or dermal exposure. The group with the greatest likelihood for substantial exposure to 1,1-DCE consists of those exposed to substances in the workplace.

The available information on the human health effects following exposure to 1,1-DCE comes primarily from case reports of acute exposures and epidemiological studies. The epidemiological studies are of limited usefulness because of small exposed populations or lack of information about the magnitude and duration of exposure to 1,1-DCE. Relatively high concentrations of inhaled 1,1-DCE can induce adverse neurological effects after acute-duration exposure. 1,1-DCE is associated with liver and kidney toxicity in humans after repeated, low-level exposure.

The systemic toxicity of 1,1-DCE has been demonstrated in numerous studies with laboratory animals, with the liver, kidney, and lungs being the primary target organs. Liver toxicity in animals has occurred from both inhalation and oral exposures. Signs of liver toxicity include biochemical changes (increases in serum enzyme level that indicate liver injury), microscopic cellular changes, and necrosis at higher exposure levels. Liver injury is thought to be related to the depletion of reduced glutathione (GSH) levels (GSH is a peptide that exerts a protective effect against certain toxic substances). For example, 1,1-DCE liver toxicity is more severe in fasted animals. Kidney toxicity (e.g., enzyme changes, hemoglobinuria, increases in organ weight, and tubular swelling, degeneration, and necrosis) has been observed following both inhalation and oral exposure to 1,1-DCE in animals. As with liver toxicity, kidney toxicity is greater in fasted animals.

1,1-DCE does not appear to produce reproductive toxicity in laboratory animals or humans. 1,1-DCE produces developmental toxicity only at maternally toxic levels. The results from animals' studies indicate that reproductive or developmental toxicity is not a critical effect for 1,1-DCE exposure.

There is inadequate evidence for evaluating carcinogenicity of 1,1-DCE in humans, and limited evidence of carcinogenicity in laboratory animals. There is one epidemiological study following occupational exposure, based on a population of 138 people. The USEPA considers the study too limited to draw useful conclusions about the carcinogenicity of 1,1-DCE in humans. Out of numerous cancer bioassays (both oral and inhalation) conducted in laboratory animals, only one inhalation study has shown evidence of carcinogenicity. USEPA recently reevaluated this study and concluded that while there was evidence suggesting that 1,1-DCE could be carcinogenic in humans by inhalation, there was inadequate evidence to develop a quantitative estimate of cancer risks. 1,1-DCE is not considered to be carcinogenic by the oral or dermal routes of exposure.

Vinyl Chloride

This summary of the toxicology of vinyl chloride has been drawn from the ATSDR toxicological profile (ATSDR, 1997b), and from the recent draft toxicological review conducted by the USEPA (USEPA, 2000). Based on its toxicological profile, the USEPA has proposed revisions to the toxicity values for vinyl chloride.

Vinyl chloride is a colorless gas at room temperature. Vinyl chloride exists in liquid form only under high pressure or at low temperatures (less than -13.4°C). Vinyl chloride has a mild, sweet odor, with an odor threshold in the air at 3,000 ppm. Odor is of no value in preventing excess exposure. The principal use of vinyl chloride is to manufacture polyvinyl chloride (PVC). Prior to the 1970s, vinyl chloride was also used as a coolant and as a propellant in spray cans. Vinyl chloride is also formed in groundwater from the degradation of chlorinated solvents that are groundwater contaminants.

Exposure can occur via the inhalation or oral routes in people living near hazardous waste sites if vinyl chloride volatilizes from contaminated soils, or if contaminated water is ingested or used in bathing. Workers in industries that use vinyl chloride may experience inhalation exposure, and in the past, dermal exposures. The group with the greatest likelihood for substantial exposure to vinyl chloride consists of those exposed to substances in the workplace.

The available information on the human health effects following exposure to vinyl chloride comes primarily from case reports of acute exposures, and epidemiological studies in the late 1960s in the workplace. Vinyl chloride is judged to be a human carcinogen based on these workplace epidemiological studies. The association between occupational exposure to vinyl chloride and the development of liver angiosarcomas is one of the best characterized cases of chemical-induced carcinogenicity in humans. The association of vinyl chloride with angiosarcoma has been supported by findings in laboratory animals administered vinyl chloride via oral and inhalation routes.

Studies in laboratory animals show that the liver is the primary target of vinyl chloride toxicity. Pathological effects observed in laboratory animals include necrosis, liver cell polymorphism, and cysts as well as alterations in liver function.

Other effects reported in some occupational studies are associated with exposure levels much higher than those that cause liver injury. Acroosteolysis, or resorption of the terminal phalanges of the fingers, was observed in workers occupationally exposed to high levels of vinyl chloride, often preceded by clinical signs of Raynaud's phenomenon (cold sensitivity and numbness of fingers). This was most often seen in tank cleaners and is apparently associated with dermal exposure. Occupational exposures at high concentrations may induce headaches, drowsiness, dizziness, ataxia, and loss of consciousness.

The most significant effect of vinyl chloride observed in human epidemiologic studies is liver cancer. The observation that the cancer effects of vinyl chloride dominate at high human exposure concentrations, coupled with the fact that vinyl chloride is a genotoxic carcinogen for which linear low-dose extrapolation is appropriate, suggests that the noncancer effects of vinyl chloride are not likely to be as important a concern for chronic human exposure.

1,2-Dichloroethene (Total)

This summary of the toxicology of 1,2-dichloroethene (total) (1,2-DCE) has been drawn from the ATSDR toxicological profile (ATSDR, 1996).

1,2-DCE is a colorless liquid with a sharp, harsh odor. The odor threshold is approximately 17 ppm in air. There are two forms of 1,2-DCE; one form is called cis-1,2-DCE and the other is called trans-1,2-DCE. Sometimes both forms are present as a mixture. 1,2-DCE is used most often to produce solvents. 1,2-DCE is also formed in groundwater from the degradation of chlorinated solvents that are groundwater contaminants.

Exposure can occur via the inhalation or oral routes in people living near hazardous waste sites if 1,2-DCE volatilizes from contaminated soils, or if contaminated water is ingested or used in bathing. Workers in industries that use 1,2-DCE may experience inhalation exposure and dermal exposures. The group with the greatest likelihood for substantial exposure to 1,2-DCE consists of those exposed to substances in the workplace.

The most significant effects of 1,2-dichloroethene exposure are to blood-forming organs and the liver. At high levels of exposure in air, symptoms that have been reported in humans include nausea, drowsiness, fatigue, and eye irritation. No information is available on oral toxicity of 1,2-DCE in humans. No information is available on the relative toxicities of the cis and trans isomers in humans.

Adverse effects in the heart and liver have been reported in rats exposed to trans-1,2-DCE in air. High levels of exposure produce swelling of heart muscle tissue. Liver effects in animals include fatty degeneration of liver lobules. Higher exposure levels produced changes in liver function enzymes. There is no evidence of significant reproductive or developmental toxicity in laboratory animals associated with exposure to 1,2-DCE.

A variety of genotoxicity tests have been performed for 1,2-dichloroethene. The predominant results are negative, and no carcinogenicity studies were found in the literature. The USEPA considers 1,2-DCE to be "not classifiable for carcinogenicity".

Perchloroethene

This summary of the toxicology of perchloroethene (PCE) has been drawn from the ATSDR toxicological profile (ATSDR, 1997c).

PCE is widely used for dry cleaning of fabrics and for metal-degreasing operations. It is also used manufacturing other chemicals and has been used in some consumer products. It is a nonflammable liquid at room temperature. It evaporates easily into the air and has a sharp, sweet odor. Most people can smell PCE when it is present in the air at a level of 1 ppm.

Exposure can occur via the inhalation or oral routes in people living near hazardous waste sites if PCE volatilizes from contaminated soils, or if contaminated water is ingested or used in bathing. Workers in industries that use PCE may experience inhalation exposure and

dermal exposures. The group with the greatest likelihood for substantial exposure to PCE consists of those exposed to substances in the workplace.

Inhalation and oral routes are the major routes of human exposure to PCE. Inhalation exposure may occur near hazardous waste sites as well as in urban and industrial areas. Occupational exposure to PCE (dry cleaners, chemical workers) is generally by inhalation. Oral exposure to PCE is primarily through drinking contaminated groundwater. Because PCE readily volatilizes from water, contaminated water is also a source of inhalation exposure to PCE.

Central nervous system effects are the most predominant and sensitive effects of PCE in humans. Low-level occupational exposure has been associated with dizziness, forgetfulness, difficulty in concentration, and degradation of hand-eye coordination. Occupational exposure to PCE has also been associated with mild physiological changes in the kidney. Kidney effects, including cancer, following PCE exposure have also been noted in laboratory animals, predominantly male rats. The mechanism for the development of kidney effects in rats may differ from that in humans, and observed kidney toxicity in male rats may not be applicable to human exposure settings. Liver effects including enlarged liver, fatty changes, and elevated levels of liver function enzymes have been reported in humans exposed to high levels of PCE. PCE produces liver toxicity in laboratory animals, particularly rodents (rats and mice). The mechanism for the development of liver effects in rodents may differ from that in humans, and observed liver toxicity in rodents may not be applicable to human exposure settings.

Some studies have indicated reproductive disorders in women associated with occupational exposure to PCE. Overall, the available studies are inconclusive regarding reproductive effects in humans. Developmental toxicity from PCE exposure to laboratory animals occurs only at maternally toxic doses.

PCE by itself is not genotoxic, but can be biotransformed to genotoxic metabolites. Epidemiological studies of cancer incidence in dry cleaners and populations exposed to PCE are inconclusive. PCE is carcinogenic in laboratory animals; however the carcinogenic effects may occur through mechanisms not present in humans. Therefore, the relevance of animal carcinogenicity data to human risk remains unclear.

References

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Appendix C
Screening of Natural Attenuation Potential at
Richards-Gebaur AFB, MO

APPENDIX C

Screening of Natural Attenuation Potential at Richards-Gebaur Air Force Base, Missouri

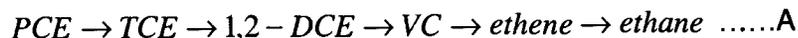
This appendix presents the preliminary screening results for the use of natural attenuation to remediate the chlorinated VOCs-contaminated groundwater at the former Richards-Gebaur Air Force Base (AFB) using a scoring system set up by the Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division (ERT) (USEPA, 1998). The screening process determined whether biodegradation is occurring at the six feasibility study (FS) sites to support the selection of monitored natural attenuation (MNA) as a remedial alternative component at Richards-Gebaur AFB.

Background

Natural attenuation is the process in which contaminant concentrations are passively, but continually, reduced by various naturally occurring *in situ* mechanisms, without active remedial actions.

At chlorinated volatile organic compound- (VOC-) contaminated sites where natural attenuation is well documented, biodegradation by indigenous, subsurface microbes appears to be the primary attenuation mechanism for VOCs. This attenuation mechanism is important in terms of limiting migration of the aqueous phase contaminants. Recently, it has been recognized that natural attenuation will be protective of human health and the environment for approximately 20 percent of chlorinated aliphatic hydrocarbon spills at federal facilities (Wiedemier et al., 1996). With time, the source area is depleted to the point that the rate of natural attenuation exceeds the rate of contaminant loading in the source area, and the plume begins to decrease in concentration and eventually shrink in size. This conceptual model of plume migration from chlorinated VOC-contaminated sites has been validated in a number of studies (AFCEE, 1999).

Most chlorinated VOCs can be transformed into less toxic compounds under anaerobic conditions. Sequential reductive dechlorination is one of the predominant mechanisms for transformation of chlorinated VOCs. The pathways of anaerobic sequential reductive dechlorination are shown as follows:



or



In these processes, hydrogen atoms are sequentially substituted for a chlorine atom in the contaminant molecules. Therefore, an increase in the concentration of chloride ions in groundwater is expected if reductive dechlorination is occurring. Through the above process, perchloroethylene (PCE) turns to trichloroethylene (TCE), TCE to dichloroethene (DCE), DCE to vinyl chloride, and vinyl chloride to ethene or ethane (see pathway A). The more chlorinated a compound is, the more oxidized the compound will be, and the more

susceptible it is to reduction. However, vinyl chloride is relatively resistant to reductive dechlorination. Once it is formed, the process may change, with vinyl chloride becoming the primary food source for different bacteria. In this case, complete mineralization of vinyl chloride to carbon dioxide and water is possible through pathway B.

During the reductive dechlorination, the chlorinated compounds serve as the electron acceptors. Therefore, the availability of other electron acceptors in anaerobic conditions will affect the reductive dechlorination process by competing with the chlorinated compounds for reducing potential. For example, sulfate and nitrate can inhibit the dechlorination. In general, reductive dechlorination rates were found to be the highest under highly reducing conditions associated with methanogenic reactions. More discussions on the interpretation of these factors is presented below. The major requirement for reductive dechlorination is the presence of other carbon sources. Potential carbon sources include organic compounds such as fuel hydrocarbons or other natural organic matter.

To determine whether natural attenuation is a viable remedial alternative component for a specific site, representative chemical and geochemical data from the site are screened and scored using a standard process (USEPA, 1998). The analytical parameters and weighting for preliminary screening are shown in Table C-1. The fundamental rule of the scoring process is that natural attenuation of chlorinated VOCs will cause predictable changes in groundwater chemistry. The general interpretation of the total score is shown in Table C-2.

If adequate evidence of biotransformation is indicated or the score totals 15 or more points, it is likely that biodegradation is occurring at the site. In this case, a screening model such as BIOCHLOR may be used to determine if the residence time along the flow path is long enough to allow attenuation to occur sufficiently to be protective of human health and the environment. Otherwise, engineered remediation systems may be required to mitigate contamination.

Analytical Results

The analytical results for natural attenuation parameters in site groundwater at Richards-Gebaur AFB are presented in Table C-3. The data were collected in April 2001 as part of the quarterly groundwater monitoring (QGM). Field sampling procedures and laboratory analytical methods follow those specified in the Basewide Remedial Investigation/Feasibility Study Work Plan (CH2M HILL, 1999).

The available natural attenuation data include parent and daughter chlorinated VOCs, electron acceptors, methane, ethane, ethene, total organic carbon (TOC), chloride, oxidation-reduction potential (ORP), dissolved oxygen (DO), alkalinity, temperature, and pH. Interpretations of natural attenuation parameters are provided follow.

Dissolved Oxygen

DO is the most thermodynamically first-choice electron acceptor used by microbes. However, anaerobic bacteria are unable to function properly in an environment with DO concentrations above 0.5 mg/L (USEPA, 1998).

Based on Table C-3, the majority of the DO readings obtained from groundwater at Richards-Gebaur AFB were above 0.5 mg/L, the tolerated DO threshold for reductive dechlorination. The only exception is well MW-001 at SS 012, which had a detected DO concentration of 0.48 mg/L. This indicates the subsurface conditions may not be favorable for reductive dechlorination of most chemicals of concern, except vinyl chloride.

Nitrate

After oxygen is depleted, nitrate is the most thermodynamically favored electron acceptor. In order for reductive dechlorination to occur, nitrate concentrations in the contaminated groundwater must be less than 1.0 mg/L because nitrate ions can outcompete the chlorinate VOCs as electron acceptors (USEPA, 1998).

Groundwater analytical data collected from Richards-Gebaur AFB show that seven out of 30 wells had nitrate detected at a concentration above 1.0 mg/L. Among the remaining 23 wells, 16 wells had a nitrate concentration between 0.1 and 1 mg/L, and seven wells were detected with a nitrate concentration less than 0.1 mg/L. Each of the seven wells with 0.1 mg/L or less nitrate is located at or near the boundary of a plume, relatively favorable conditions for reductive dechlorination at these locations. Therefore, the nitrate data tend to support the notion of ongoing dechlorination.

Ferrous Iron

After the more readily used electron acceptors are consumed, anaerobic bacteria can use ferric iron as electron acceptor for biodegradation. In this process, relatively insoluble ferric iron is reduced to the more water soluble ferrous iron. Thus, increasing concentrations of dissolved ferrous iron across the site can be used as an indicator of anaerobic biodegradation via the process of iron reduction.

It is noted that an elevated ferrous iron concentration of 4.6 mg/L was detected in groundwater at one well at Site ST 011. At Richards-Gebaur AFB, low ferrous iron concentrations were observed in nearly all the other wells, both along the site perimeter and within the site interior. This absence of ferrous iron in groundwater indicates that reductive dechlorination conditions in groundwater are relatively unfavorable at Richards-Gebaur AFB.

Sulfate

After depletion of the more readily used electron acceptors, sulfate can also be used as an electron acceptor by anaerobic bacteria. However, higher concentrations of sulfate may prohibit reductive dechlorination. Particularly, a sulfate concentration greater than 20 mg/L can exclude dechlorination (USEPA, 1998).

Based on the data collected at Richards-Gebaur AFB, 27 out of 30 wells showed relatively high sulfate concentration (i.e., greater than 20 mg/L) in groundwater. The remaining three wells, with two wells at ST 011 and one well at SS 009, had relatively low sulfate concentrations. The presence of high sulfate concentrations indicates that groundwater conditions are not favorable for natural attenuation via reductive dechlorination.

Methane

Methane is one of the metabolic byproducts resulting from the microbial degradation of VOCs, generally referred to as methanogenesis. Although it is unclear if methane in groundwater originates from chlorinated VOCs or from other native dissolved organic carbon, the presence of methane in groundwater at elevated concentrations indicates strongly reducing conditions.

According to the groundwater analytical data at Richards-Gebaur AFB, 14 out of 30 monitoring wells were detected with methane. The highest methane concentration of 1.57 mg/L was found in well MW-012 at ST 011 (i.e., MW-012) and the second highest methane concentration of 0.55 mg/L was found in well MW-009 at Site SS 009, suggesting strong

anaerobic conditions at and adjacent to these well locations. However, methane was not seen at significant levels in the other 16 wells. The methane data, therefore, is inconclusive.

Alkalinity

Concentrations of alkalinity increase as a result of biodegradation. For example, complete oxidation of organic contaminants results in production of carbon dioxide. The production of carbon dioxide results in elevated alkalinity concentrations, which can therefore be another indicator of chlorinated hydrocarbon biodegradation.

Interpreting trends in alkalinity at the groundwater sites is complicated because background concentrations of this parameter are not easily determined. It appears that alkalinity values in groundwater at Sites SS 009 and ST 011 are almost twice as high as those concentrations detected in groundwater at other sites. The data indicate that biodegradation of chlorinated VOCs may have occurred at SS 009 and ST 011, but is unlikely to be a major transformation process at the majority of contaminated groundwater sites at Richards-Gebaur AFB.

Ethane and Ethene

Both chemicals are daughter products of chlorinated solvents under anaerobic conditions. When these chemicals are present in groundwater at a concentration above 0.01 mg/L, biodegradation of vinyl chloride may have occurred in the past (Wiedemeier et al., 1996).

In general, the groundwater samples collected from Richards-Gebaur AFB (with the exception of four wells) had no evidence of ethane and ethene. However, a conclusion cannot be drawn because the laboratory detection limits were generally 20 times higher than 0.01 mg/L, the threshold concentration mentioned above. The four wells with relative high ethane/ethene concentrations were MW-001 at SS 012, MW-012 at ST 011, MW-009 at SS 009, and MW-001 at AOC 001, suggesting reductive dechlorination may have occurred at these locations, but was largely absent elsewhere.

Total Organic Carbon

As explained above, a proper source of carbon other than chlorinated VOCs for microbial growth has to be provided in order for reductive dechlorination to occur. TOC content in groundwater indicates whether sufficient carbon sources are available to propel the dechlorination processes. A concentration of 20 mg/L is considered acceptable for the desired dechlorination.

Based on Table C-3, TOC concentrations in groundwater at Richards-Gebaur AFB ranged from approximately 1 to 9 mg/L. Therefore, the TOC levels in site groundwater do not support reductive dechlorination.

Oxidation-Reduction Potential

The ORP of groundwater is a measure of the tendency of a solution to accept or transfer electrons. If an ORP reading less of than 50 millivolts (mV) is measured in groundwater, reductive dechlorination processes are possible.

At Richards-Gebaur AFB, the range of the ORP readings in groundwater were from 69 to 293 mV, exceeding the desired ORP threshold for reductive dechlorination.

Temperature and pH

Temperature and pH are indicators of favorable biodegradation conditions. If the temperature is higher than 20°C, accelerated biodegradation is possible. A range of pH values from 5 to 9 suggests optimal condition for reductive dechlorination.

Based on data collected from the six sites, it appears both pH and temperature conditions in groundwater were favorable for reductive dechlorination to occur.

Chloride

If chloride is present in groundwater at twice the background groundwater concentration, it could be the daughter product of chlorinated VOCs. Although no background wells were sampled for this parameter, it appears that the background chloride concentration is approximately 10 mg/L, based on groundwater data from ST 005 at which very limited biodegradation has occurred in the past. However, chloride is a characteristic of the groundwater in the area of the Base, and has been classified by the state as a sodium chloride type groundwater (MDNR, 1987).

Chloride concentrations at most wells generally ranged from 40 to about 200 mg/L, indicating limited reductive dechlorination has occurred at the sites.

Preliminary Screening Results

Using the scoring system described above, the available site-specific data were analyzed to determine if biodegradation of chlorinated VOCs in groundwater is likely. The results of the analysis are presented in Tables C-4 through C-10.

Based on the scores, it appears that three out of the six FS sites (SS 003, SS 012, and ST 005) show inadequate evidence. The remaining three FS sites (SS 006, SS 009, and ST 011) show very limited evidence for anaerobic biodegradation of chlorinated organics.

In accordance with the screening process presented in *Technical Protocol for Natural Attenuation of Chlorinated Solvents in Groundwater* (USEPA, 1998), natural attenuation is not considered to be a viable remedial alternative for Richards-Gebaur AFB because the total score for each site is less than 15 points. Accordingly, no further detailed study of natural attenuation should be made on the groundwater sites at Richards-Gebaur AFB.

References

AFCEE. *Natural Attenuation of Chlorinated Solvents Performance and Cost Results from Multiple Air Force Demonstration Sites*. 1999.

CH2M HILL. *Basewide Remedial Investigation/Feasibility Study (RI/FS) Work Plan, Richards-Gebaur Air Force Base*. 1999.

MDNR, 1987. *Missouri State Water Plan Series, Volume III, Missouri Water Quality Assessment*.

USEPA. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Ground Water*. 1998.

Wiedemeier, T.H., et al. *Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater*. Draft – Revision 1: Air Force Center for Environmental Excellence. San Antonio, Texas. 1996.

Natural Attenuation Screening Protocol		Interpretation	Score	Score: 0	
The following is taken from the USEPA protocol (USEPA, 1990). The results of this scoring process have no regulatory significance.		Inadequate evidence for anaerobic biodegradation* of chlorinated organics	0 to 5	Scroll to End of Table	
		Limited evidence for anaerobic biodegradation* of chlorinated organics	6 to 14		
		Adequate evidence for anaerobic biodegradation* of chlorinated organics	15 to 20		
		Strong evidence for anaerobic biodegradation* of chlorinated organics	>20		
Analysis	Concentration in Most Contam. Zone	Interpretation	Yes	No	Points Awarded
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input type="radio"/>	<input type="radio"/>	0
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input type="radio"/>	0
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
	5 > pH > 9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input type="radio"/>	<input type="radio"/>	0
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input type="radio"/>	<input type="radio"/>	0
Chloride*	>2x background	Daughter product of organic chlorine	<input type="radio"/>	<input type="radio"/>	0
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} ; 1,1-DCE can be a chem. reaction product of TCA	<input type="radio"/>	<input type="radio"/>	0
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.

a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE

Reset

Table C-2	
Interpretation of Points Awarded (USEPA, 1998)	
Score	Interpretation
0 to 5	Inadequate evidence for biodegradation of chlorinated organics
6 to 14	Limited evidence for biodegradation of chlorinated organics
15 to 20	Adequate evidence for biodegradation of chlorinated organics
> 20	Strong evidence for biodegradation of chlorinated organics

Table C-3

Natural Attenuation Indicator Parameters in Groundwater at Richards-Gebaur AFB - April 2001 QGM

Site	Well ID	Chloride (mg/L)	Nitrate (mg/L)	Alkalinity (mg/L as CaCO ₃)	Sulfate (mg/L)	Iron, Ferrous (mg/L)	Methane (µg/L)	Ethane (µg/L)	Ethene (µg/L)	DO (mg/L)	ORP (mV)	pH	TOC (ppm)
SS 012	MW-001	163	0.62	310	56.8	< 0.1	0.23 U	0.65 F	0.29 F	0.48	151	7.66	1.7
	MW-002	63.7	1.67	302	74.3	< 0.1	0.12 U	0.26 U	0.22 U	5.70	169	8.02	1.7
	MW-005	61.9	0.68	270	40.1	< 0.1	0.14 U	0.21 U	0.24 U	6.75	173	7.78	1.8
	MW-008	26.7	0.28	190	21.8	< 0.1	0.11 U	0.23 U	0.24 U	7.68	159	8.19	1
	MW-011	8.38	0.08 F	205	21.6	< 0.1	0.2 F	0.23 U	0.23 U	7.87	204	8.63	6.2
	MW-012	125	0.21	256	45.2	< 0.1	0.11 U	0.12 U	0.23 U	5.06	173	8.26	1.7
ST 011	MW-001	125	0.11	452	16.8	0.4	7.45 J	0.23 U	0.22 U	0.61	247	7.67	3.7
	MW-003	23.3	0.058 F	376	35.8	< 0.1	1.13	0.23 U	0.23 U	1.63	200	7.60	2.2
	MW-005	9.25	1.05	368	38.2	< 0.1	0.9	0.23 U	0.23 U	3.31	206	7.95	0.93 F
	MW-012	192	0.13	498	1.54	4.6	1570	0.94	0.24 U	0.61	69	7.67	8.9
SS 003	MW-002R (CS 002)	98.2	1.21	218	80.4	< 0.1	0.11 U	0.22 U	0.22 U	8.97	171	7.46	2
	MW-003	15.9	0.09 F	328	72.1	0.2	0.11 U	0.18 U	0.22 U	4.62	181	8.07	6.5
	MW-004	43.4	2.2	306	29.9	< 0.1	0.09 U	0.21 U	0.19 U	9.56	167	7.91	0.88 F
	MW-006	111	0.2	255	44.7	0.2	0.11 U	0.22 U	0.22 U	6.72	182	7.40	2.3
SS 006	MW-001 (AOC 001)	11.4	0.004	244	36	0.2	2.13	0.23 U	0.22 J	1.63	183	7.62	2.3
	MW-005	147	0.87	310	92.9	< 0.1	0.36 F	0.22 U	0.24 U	7.19	150	8.13	1.4
	MW-008	53.1	0.24	324	239	0.1	0.13 U	0.25 U	0.25 U	1.55	219	7.94	1.9
	MW-010	107	0.34	282	81.1	< 0.1	0.11 U	0.2 U	0.21 U	5.76	169	8.08	1.7
	MW-011	152	1.32	264	101	< 0.1	0.12 U	0.23 U	0.23 U	6.99	179	8.11	1.5
	MW-012	174	1.98	300	72.4	< 0.1	0.14 F	0.23 U	0.24 U	8.49	187	7.96	1.5
SS 009	MW-002	214	0.15	431	17.2	< 0.1	0.25 F	0.23 U	0.23 U	1.65	262	7.44	2.9
	MW-003	98.4	0.004 U	600	78.6	< 0.1	0.95	0.22 U	0.22 U	4.52	270	8.28	4.2
	MW-005	129	0.2	500	64.5	< 0.1	0.12 U	0.22 U	0.23 U	2.31	159	8.16	2.6
	MW-009	97.9	0.16	332	29.5	0.4	551	0.41 F	0.21 U	1.65	129	7.57	3
ST 005	MW-003	11	3.53	214	58.5	< 0.1	0.11 U	0.21 U	0.22 U	7.81	251	8.13	1
	MW-018	8.56	0.97	224	59.6	< 0.1	0.18 F	0.24 U	0.24 U	5.50	269	7.83	2.2
	MW-020	10.4	0.27	406	38.7	< 0.1	0.2 F	0.22 U	0.23 U	2.56	245	8.46	3.9
	MW-022	7.55	0.09 F	305	37.2	< 0.1	0.22 F	0.24 U	0.25 U	2.95	293	8.26	2

Note: J =The analyte was positively identified, the quantitation is an estimate.
 F =The analyte was positively identified but the associated numerical value is below the reporting limit (RL).
 U =The analyte was not detected above the method detection limit (M)

Natural Attenuation Screening Protocol	Interpretation		Score
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics		0 to 5
	Limited evidence for anaerobic biodegradation* of chlorinated organics		6 to 14
	Adequate evidence for anaerobic biodegradation* of chlorinated organics		15 to 20
Strong evidence for anaerobic biodegradation* of chlorinated organics		>20	Scroll to End of Table

Score: 2

The following is taken from the USEPA protocol (USEPA, 1999). The results of this scoring process have no regulatory significance.

Analysis	Concentration in Most Contam. Zone	Interpretation	reductive dechlorination		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input checked="" type="radio"/>	<input type="radio"/>	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH >9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloride*	>2x background	Daughter product of organic chlorine	<input checked="" type="radio"/>	<input type="radio"/>	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} ; 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.

^{a/} Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE

Reset

End of Form

Natural Attenuation Screening Protocol	Interpretation		Score
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics		0 to 5
	Limited evidence for anaerobic biodegradation* of chlorinated organics		6 to 14
	Adequate evidence for anaerobic biodegradation* of chlorinated organics		15 to 20
Strong evidence for anaerobic biodegradation* of chlorinated organics		>20	Score: 12

The following is taken from the USEPA protocol (USEPA, 1998). The results of this scoring process have no regulatory significance.

* reductive dechlorination

Scroll to End of Table

Analysis	Concentration in Most Contam. Zone	Interpretation	Interpretation		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input type="radio"/>	<input checked="" type="radio"/>	0
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH >9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input checked="" type="radio"/>	<input type="radio"/>	1
Chloride*	>2x background	Daughter product of organic chlorine	<input checked="" type="radio"/>	<input type="radio"/>	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input checked="" type="radio"/>	<input type="radio"/>	2
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} . 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input checked="" type="radio"/>	<input type="radio"/>	2
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.

^{a/} Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE

Reset

Natural Attenuation Screening Protocol	Interpretation	Score	Score: 6 <i>Scroll to End of Table</i>
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics	0 to 5	
	Limited evidence for anaerobic biodegradation* of chlorinated organics	6 to 14	
	Adequate evidence for anaerobic biodegradation* of chlorinated organics	15 to 20	
Strong evidence for anaerobic biodegradation* of chlorinated organics		>20	

The following is taken from the USEPA protocol (USEPA, 1999). The results of this scoring process have no regulatory significance.

Analysis	Concentration in Most Contam. Zone	Interpretation	reductive dechlorination		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input checked="" type="radio"/>	<input type="radio"/>	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH >9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloride*	>2x background	Daughter product of organic chlorine	<input checked="" type="radio"/>	<input type="radio"/>	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} ; 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input checked="" type="radio"/>	<input type="radio"/>	2
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.
a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE Reset

Natural Attenuation Screening Protocol <small>The following is taken from the USEPA protocol (USEPA, 1998). The results of this scoring process have no regulatory significance.</small>	Interpretation		Score	Score: 4 <small>Scroll to End of Table</small>
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics		0 to 5	
	Limited evidence for anaerobic biodegradation* of chlorinated organics		6 to 14	
	Adequate evidence for anaerobic biodegradation* of chlorinated organics		15 to 20	
	Strong evidence for anaerobic biodegradation* of chlorinated organics		>20	

Analysis	Concentration in Most Contam. Zone	Interpretation	Interpretation		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input checked="" type="radio"/>	<input type="radio"/>	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH >9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloride*	>2x background	Daughter product of organic chlorine	<input checked="" type="radio"/>	<input type="radio"/>	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} ; 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis
 a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE Reset

Natural Attenuation Screening Protocol <small>The following is taken from the USEPA protocol (USEPA, 1998). The results of this scoring process have no regulatory significance.</small>	Interpretation		Score	Score: 2 <i>Scroll to End of Table</i>
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics		0 to 5	
	Limited evidence for anaerobic biodegradation* of chlorinated organics		6 to 14	
	Adequate evidence for anaerobic biodegradation* of chlorinated organics		15 to 20	
	Strong evidence for anaerobic biodegradation* of chlorinated organics		>20	

Analysis	Concentration in Most Contam. Zone	Interpretation	reductive dechlorination		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input checked="" type="radio"/>	<input type="radio"/>	-3
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(III)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH >9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic.	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloride*	>2x background	Daughter product of organic chlorine	<input type="radio"/>	<input checked="" type="radio"/>	0
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^w	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^w ; 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^w	<input type="radio"/>	<input type="radio"/>	0
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.

^w Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE

Reset

Natural Attenuation Screening Protocol <small>The following is taken from the USEPA protocol (USEPA, 1996). The results of this scoring process have no regulatory significance.</small>	Interpretation	Score	Score: 10 <i>Scroll to End of Table</i>
	Inadequate evidence for anaerobic biodegradation* of chlorinated organics	0 to 5	
	Limited evidence for anaerobic biodegradation* of chlorinated organics	6 to 14	
	Adequate evidence for anaerobic biodegradation* of chlorinated organics	15 to 20	
	Strong evidence for anaerobic biodegradation* of chlorinated organics	>20	

Analysis	Concentration in Most Contam. Zone	Interpretation	*reductive dechlorination		Points Awarded
			Yes	No	
Oxygen*	<0.5 mg/L	Tolerated, suppresses the reductive pathway at higher concentrations	<input type="radio"/>	<input checked="" type="radio"/>	0
	>5mg/L	Not tolerated; however, VC may be oxidized aerobically	<input type="radio"/>	<input checked="" type="radio"/>	0
Nitrate*	<1 mg/L	At higher concentrations may compete with reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	2
Iron II*	>1 mg/L	Reductive pathway possible; VC may be oxidized under Fe(II)-reducing conditions	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfate*	<20 mg/L	At higher concentrations may compete with reductive pathway	<input type="radio"/>	<input checked="" type="radio"/>	0
Sulfide*	>1 mg/L	Reductive pathway possible	<input type="radio"/>	<input type="radio"/>	0
Methane*	<0.5 mg/L	VC oxidizes	<input checked="" type="radio"/>	<input type="radio"/>	0
	>0.5 mg/L	Ultimate reductive daughter product, VC Accumulates	<input type="radio"/>	<input type="radio"/>	0
Oxidation Reduction Potential* (ORP)	<50 millivolts (mV)	Reductive pathway possible	<input type="radio"/>	<input checked="" type="radio"/>	0
	<-100mV	Reductive pathway likely	<input type="radio"/>	<input checked="" type="radio"/>	0
pH*	5 < pH < 9	Optimal range for reductive pathway	<input checked="" type="radio"/>	<input type="radio"/>	0
	5 > pH > 9	Outside optimal range for reductive pathway	<input type="radio"/>	<input type="radio"/>	0
TOC	>20 mg/L	Carbon and energy source; drives dechlorination; can be natural or anthropogenic	<input type="radio"/>	<input checked="" type="radio"/>	0
Temperature*	>20°C	At T >20°C biochemical process is accelerated	<input checked="" type="radio"/>	<input type="radio"/>	1
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	<input type="radio"/>	<input type="radio"/>	0
Alkalinity	>2x background	Results from interaction of carbon dioxide with aquifer minerals	<input checked="" type="radio"/>	<input type="radio"/>	1
Chloride*	>2x background	Daughter product of organic chlorine	<input checked="" type="radio"/>	<input type="radio"/>	2
Hydrogen	>1 nM	Reductive pathway possible, VC may accumulate	<input type="radio"/>	<input type="radio"/>	0
	<1 nM	VC oxidized	<input type="radio"/>	<input type="radio"/>	0
Volatile Fatty Acids	>0.1 mg/L	Intermediates resulting from biodegradation of aromatic compounds; carbon and energy source	<input type="radio"/>	<input type="radio"/>	0
BTEX*	>0.1 mg/L	Carbon and energy source; drives dechlorination	<input type="radio"/>	<input type="radio"/>	0
PCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
TCE*		Material released	<input checked="" type="radio"/>	<input type="radio"/>	0
		Daughter product of PCE ^{a/}	<input type="radio"/>	<input type="radio"/>	0
DCE*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of TCE. If cis is greater than 80% of total DCE it is likely a daughter product of TCE ^{a/} ; 1,1-DCE can be a chem. reaction product of TCA	<input checked="" type="radio"/>	<input type="radio"/>	2
VC*		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of DCE ^{a/}	<input checked="" type="radio"/>	<input type="radio"/>	2
1,1,1-Trichloroethane*		Material released	<input type="radio"/>	<input type="radio"/>	0
DCA		Daughter product of TCA under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Carbon Tetrachloride		Material released	<input type="radio"/>	<input type="radio"/>	0
Chloroethane*		Daughter product of DCA or VC under reducing conditions	<input type="radio"/>	<input type="radio"/>	0
Ethene/Ethane	>0.01 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
	>0.1 mg/L	Daughter product of VC/ethene	<input type="radio"/>	<input checked="" type="radio"/>	0
Chloroform		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Carbon Tetrachloride	<input type="radio"/>	<input type="radio"/>	0
Dichloromethane		Material released	<input type="radio"/>	<input type="radio"/>	0
		Daughter product of Chloroform	<input type="radio"/>	<input type="radio"/>	0

* required analysis.
a/ Points awarded only if it can be shown that the compound is a daughter product (i.e., not a constituent of the source NAPL).

SCORE Reset

Appendix D
LUC/IC Layering Strategy

APPENDIX D

Land Use Control/Institutional Control Layering Strategy for Sites at Richards-Gebaur AFB with Residual Groundwater Contamination

Purpose

The environmental cleanup documents for the former Richards-Gebaur Air Force Base (AFB) have identified land use controls/institutional controls (LUC/ICs) that support the remedial action. The goal of the LUC/ICs is to either protect the integrity of the remedial action or to prevent or manage exposure to the contamination by establishing use restrictions or controls on the property.

This layering strategy worksheet will identify the combination of mutually reinforcing mechanisms used to implement and establish the LUC/ICs needed to ensure that residual contamination at the sites under consideration does not present an unreasonable threat to human health and the environment until unrestricted use is appropriate. Identifying the layers of overlapping mechanisms or vehicles that implement or establish the LUC/ICs can increase the number of parties involved, strengthen the network that maintains the remedy, strengthen the overall integrity of the system of the controls, and, ultimately, ensure the protectiveness of the remedy. Once documented, the Air Force will use this information to develop the LUC/IC Management Plan for the former Richards-Gebaur AFB.

This worksheet will identify planned reuses and characterize residual contamination above levels enabling unrestricted use as a first step in determining the risk factors that need to be specifically controlled (e.g., exposure to contaminated soil). Once the risk factors have been identified, a strategy of mutually reinforcing mechanisms to establish the LUC/ICs for each parcel at the installation (e.g., a combination of use restrictions in deeds, physical barriers, and notice to interested parties) will be designed and described. The selected mechanisms will be incorporated into an LUC/IC Management Plan, which will summarize the implementation, monitoring, and enforcement needed for each control.

This Layering Strategy Worksheet is a living document that should be reevaluated periodically when information indicates the existing controls are not effective or changes in site conditions would lead to new or different controls.

Planned Reuses

Richards-Gebaur AFB originally encompassed approximately 2,400 acres. In 1980, about 80 percent of the installation property was declared excess to Air Force needs and transferred to the General Services Administration. Most of this property was transferred to the cities of Kansas City and Belton in August 1985, via a public benefit conveyance. Environmental issues resulting from past Air Force activity are addressed under the Formerly Used Defense Sites (FUDS) Program, which is implemented by the U.S. Army Corps of Engineers.

The installation officially closed on September 30, 1994. At that time, 428 acres of the original installation property remained under Air Force control. Environmental restoration and transfer of this property is addressed under the Base Realignment and Closure (BRAC) program by the Air Force Base Conversion Agency. Most of this property has been transferred to the control of the U.S. Army Reserves and U.S. Marine Corps; however, a Memoranda of Agreement requires that the Air Force complete restoration of known contamination sites on this property.

Approximately 184 acres of the former installation are currently leased to and will be transferred to the city of Kansas City, Missouri. Until January 2000, this property was used to support aviation activities at the civilian airport. However, in November 1999, a referendum was passed by Kansas City to allow use of the airfield as an intermodal transportation facility. The airport runway was officially deactivated by the Kansas City Aviation Department (KCAD) in January 2000. All aircraft operations have ceased, and the airfield is currently used to stage and load new automobiles on to trucks and railcars for distribution.

The affected BRAC property was previously and is expected to continue to be used for industrial and commercial purposes. Most of the buildings are vacant and have not been used since the closure of the airfield. The U.S. Marine Corps maintains recreational and housing facilities on part of their property. However, none of the affected property is currently or expected to be used for residential or recreational purposes. The Local Reuse Authority's reuse plan includes a mixture of commercial and light industrial land use. Table D-1 identifies the planned reuses of the installation.

Site Description

Groundwater at six sites (i.e., SS 003, SS 006, SS 009, SS 012, ST 005, and ST 011) is contaminated with one or more of the following chlorinated volatile organic compounds (VOCs) at a concentration in excess of the Maximum Contaminant Level (MCL) for drinking water: tetrachloroethene (PCE), trichloroethene (TCE), cis 1,2-dichloroethene (DCE), 1,1-DCE, and vinyl chloride. Residential use and consumption of this water poses a potential health risk. LUC/ICs will be required at these sites to prevent exposure to contaminated groundwater.

Table D-2 identifies the sites with groundwater contamination remaining at the former Richards-Gebaur AFB and the LUC/IC goals and objectives that must be achieved to prevent potential exposure to the contaminated groundwater. A map showing the parcel locations is presented in Figure 1.

Layering Strategy Components

There are three principal forms of LUCs that may be included in a layering strategy: property law/proprietary controls, governmental controls, and site controls. Other individual LUC mechanisms are also potentially available. Each LUC can have numerous components, as described in Table D-3.

Column A is a list of potential vehicles for establishing or implementing the LUC/ICs. Column B identifies those that are potentially available at Richards-Gebaur AFB given the site's environmental condition. Column C identifies those that can actually be implemented at Richards-Gebaur AFB. (Mechanisms establishing or implementing LUC/ICs identified in Column C will be carried forward to Table D-4). Column D identifies detailed point of contact

Table D-1		
Reuse Selection for Richards-Gebaur AFB		
Planned Reuse	YES/NO	Responsible Agency
Residential	YES	
Housing	YES	U.S. Marine Corps
Daycare	NO	
Hospitals	NO	
Schools	NO	
Other		
Commercial	YES	City of Kansas City, Missouri, U.S. Marine Corps
Industrial	YES	City of Kansas City, Missouri
Recreation	YES	U.S. Marine Corps
Agriculture	NO	
Airport	NO	
Other		

Table D-2			
LUC/IC Objectives for Sites with Residual Groundwater Contamination			
Site(s)/AOC(s)	Affected Parcel(s)	Residual Contamination	LUC/IC Objective
SS 003	B-1	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater
SS 006	B	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater
SS 009	O	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater
ST 011	B	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater
SS 012	E	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater
ST 005	B	VOCs in shallow groundwater	Prevent exposure to contaminated groundwater

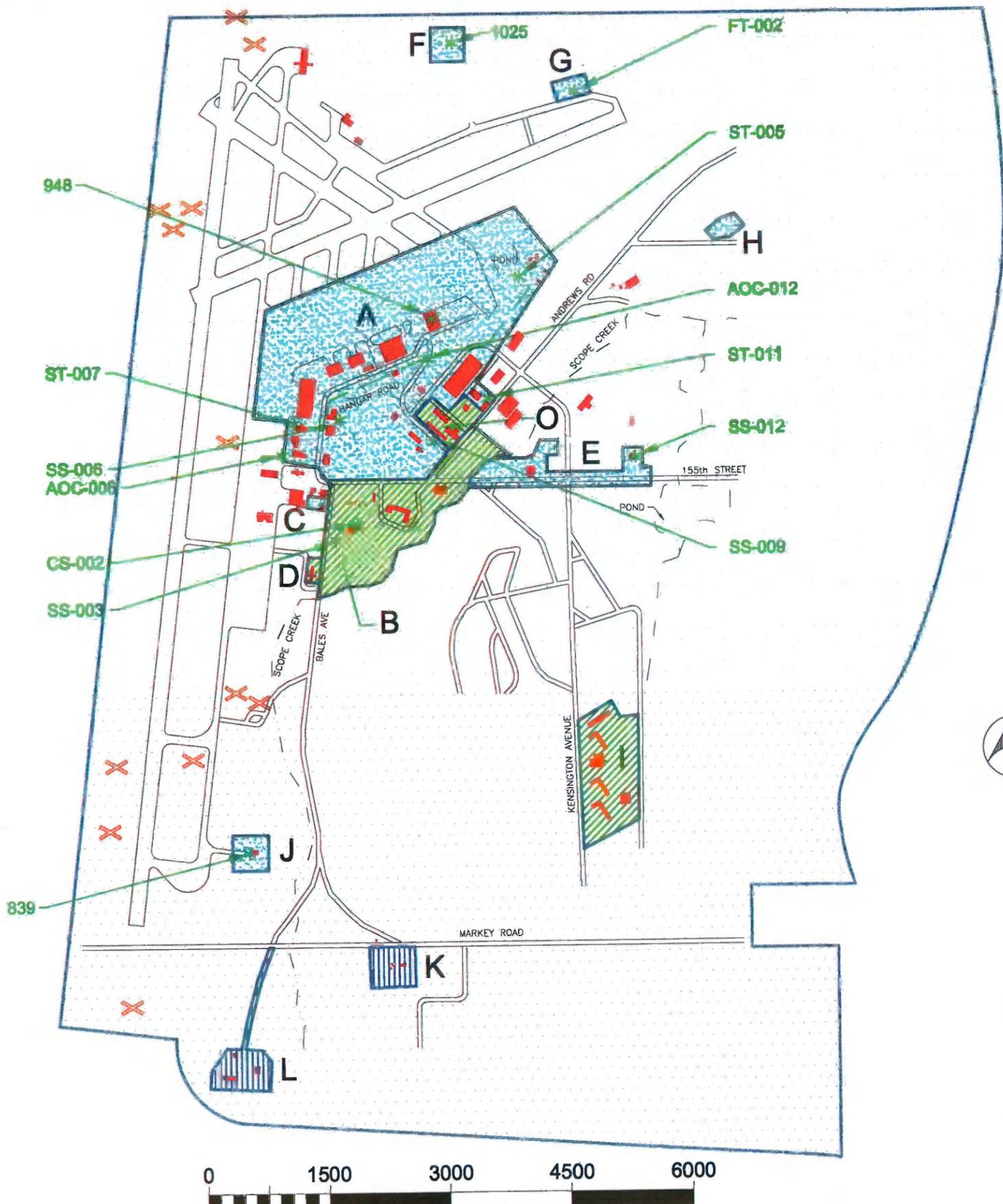
Table D-3			
Richards-Gebaur AFB LUC/IC Layering Strategy Checklist			
Column A	B Potential	C Confirmed	D Points of Contact (Organization, Personnel, Phone Number)
Property Law /Proprietary Controls			
Use restrictions in deed - Easements - covenants Reversionary Interests (e.g., public benefit conveyance for parks, education, airports, etc.)	X	X	AFBCA (800) 655-7200 Kansas City Aviation Department, Director's Office P.O. Box 20047, 601 Brasilia Avenue Kansas City, MO 64195 (816) 243-3100 Jackson County Records Recorder of Deeds 1st Floor, Jackson County Courthouse 415 East 12th Street Kansas City, MO 64106 (816) 881-3192
Lease Restrictions	X	X	AFBCA (800) 655-7200 Kansas City Aviation Department, Director's Office, P.O. Box 20047, 601 Brasilia Avenue, Kansas City, MO 64195 (816) 243-3100
Other			
Governmental Controls			
Zoning restrictions/ requirements	X	X	City of Kansas City, Missouri Codes Administration, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-1500
Local ordinances/master plans restricting use	X	X	Kansas City Aviation Department, Director's Office P.O. Box 20047, 601 Brasilia Avenue Kansas City, MO 64195 (816) 243-3100 City of Kansas City, Missouri Codes Administration, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-1500
State environmental land use restriction covenants	X	X	Missouri Department of Natural Resources Division of Environmental Quality P.O. Box 176 Jefferson City, MO 65102-0176 (573) 751-3907
State NEPA laws (e.g., CEQA)			
Groundwater use restrictions	X	X	Missouri Department of Natural Resources Geological Survey and Resource Assessment Division P.O. Box 250 Rolla, MO 65402-0250 (573) 368-2165 Missouri Department of Natural Resources Division of Environmental Quality P.O. Box 176 Jefferson City, MO 65102-0176 (573) 751-3907

Table D-3			
Richards-Gebaur AFB LUC/IC Layering Strategy Checklist			
Column A	B Potential	C Confirmed	D Points of Contact (Organization, Personnel, Phone Number)
Well installation restrictions in zone of contamination	X	X	Missouri Department of Natural Resources Geological Survey and Resource Assessment Division P.O. Box 250 Rolla, MO 65402-0250 (573) 368-2165
Well installation restrictions in areas that may influence the remedial system	NA		
Water use restrictions (e.g., irrigation, watering, livestock, recreational uses, including fishing)	NA		
Permitting to ensure proper disposal of excavated soil resulting from excavation, construction, drilling, or disturbance of soil in impacted areas; may consider depth depending on residual contamination	X	X	City of Kansas City, Missouri Codes Administration, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-1500
Permitting to prevent reuse of impacted soil.	X	X	City of Kansas City, Missouri Codes Administration, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-1500
Local/state ordinances requiring notice before disturbance of surface cover			
Permitting to prevent construction activities (i.e., utility lines, sewers, etc) in areas of contaminated groundwater that may impact the remedial strategy	X	X	City of Kansas City, Missouri Codes Administration, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-1500 City of Kansas City, Missouri Water Services Division, City Hall 414 E 12th Street Kansas City, MO 64106 (816) 513-2103/2171
Restrictions to protect wildlife or wetlands (e.g., Conservation Management Plan)	NA		
Site Controls			
Install fence or other physical barriers to restrict site access	X		
Maintain security (guards, monitoring/surveillance system) to restrict site access	X		
Install signage and warnings regarding residual contamination	X		
Install cover (i.e., asphalt, concrete, clean fill) over impacted areas	X		

Table D-3			
Richards-Gebaur AFB LUC/IC Layering Strategy Checklist			
Column A	B Potential	C Confirmed	D Points of Contact (Organization, Personnel, Phone Number)
Monitor natural/existing surface cover over impacted areas	X	X	AFBCA (800) 655-7200
Vapor barriers/ ventilation systems	NA		
Monitor and inspect wells in impacted area regularly	X	X	AFBCA (800) 655-7200
Inspect and monitor remedial systems (i.e., water treatment systems, SVE systems, etc.)	NA		
Install and monitor locking caps on wells	X	X	AFBCA (800) 655-7200
Other			
Deed notices	X	X	AFBCA (800) 655-7200 Kansas City Aviation Department, Director's Office P.O. Box 20047, 601 Brasilia Avenue Kansas City, MO 64195 (816) 243-3100 Jackson County Records Recorder of Deeds 1st Floor, Jackson County Courthouse 415 East 12th Street Kansas City, MO 64106 (816) 881-3192
Incorporate use restrictions into Airport Layout Plan	NA		
Health and safety program, PPE for any construction activities	X		
State hazardous waste site registries and other registry databases			
Provide public notices/advisories (e.g., fishing advisories)			
Maintain administrative record	X	X	AFBCA (800) 655-7200
Maintain Information Repositories	X	X	AFBCA (800) 655-7200
Notify utility purveyors and join "Dig-Safe" type programs	X	X	AFBCA (800) 655-7200 Missouri DIG RITE: (800) DIG-RITE Utility System Purveyors
Conduct public meetings			
Co-op, condo association, and homeowner association use restrictions	NA		

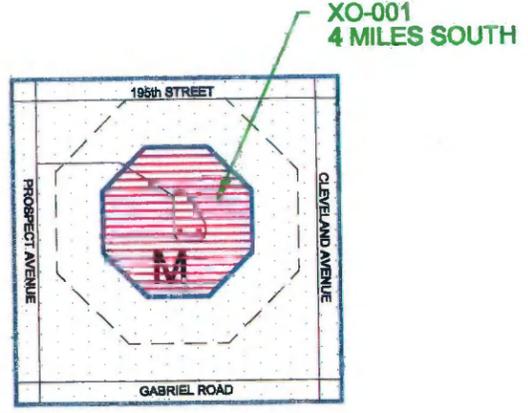
Table D-4
Richards-Gebaur AFB Site Layering Table

A Affected Parcel(s)	B Site(s)/ AOC(s)	C Media	D Residual Contamination	E Goals/ Objectives of LUC/IC	F Use Restriction(s)/IC Classification (s)	LUC/IC LAYERS / PRIORITY RANKING			
						1 Real Property/ Legal	2 Governmental/ Administrative	3 Site Controls	4 Other
B, B-1, E and O	SS003 SS006 SS009 SS012 ST005 ST011	Groundwater	Chlorinated solvents in shallow groundwater	Prevent use of/exposure to contaminated groundwater	No extraction and subsequent use of onsite groundwater. Class 1	Use Restrictions in Deed Priority 1	Permit program to prevent well installation in contaminated zone Priority 1 Restrict potable water use Priority 1 Missouri Environmental Restriction Land Use Covenant Priority 3	Monitor and inspect wells Priority 2 Install locking caps on wells Priority 2	All Priority 3 Implement Communication Plan Maintain administrative record File Deed Notice Maintain information repositories Notify utility purveyors and Underground Alert
				Protect monitoring wells	No interference with, or damage to, the groundwater monitoring wells. Class 2	Use Restrictions in Deed Priority 1	Permit program to prohibit excavation and or surface activities in the areas of monitoring wells Priority 1	Monitor and inspect wells Priority 2 Install locking caps on wells Priority 2	

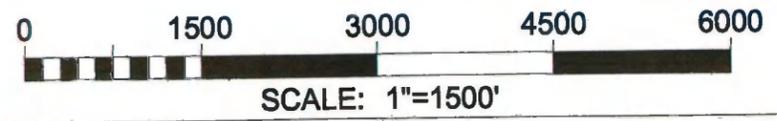


LEGEND

- CURRENT AIR FORCE PROPERTY (PARCELS A, C, E, F, G, H, AND J)
- FEDERAL TRANSFER (U.S. MARINE CORPS) (PARCELS B, D, I, AND O)
- NEGOTIATED SALE (CITY OF BELTON, MO) (PARCELS K AND L)
- FEDERAL TRANSFER (DEPARTMENT OF THE ARMY) (PARCEL M)
- PREVIOUSLY CONVEYED RICHARDS-GEBAUR AFB PROPERTY
- FORMER NAVIGATIONAL AID EQUIPMENT SITE
- BELTON TRAINING COMPLEX PROPERTY EASEMENT BOUNDARY (TO BE CONVEYED WITH PARCEL)
- PARCEL LABEL
- FACILITY



NOT TO SCALE



Parcelization of
 Richards-Gebaur AFB
 Richards-Gebaur AFB, Missouri
 October 2002



Appendix E
Remedial Alternatives Cost Estimate:
Summaries and Assumptions

**Alternative 2 - Long Term Monitoring and Institutional Controls
Cost Worksheet**

Site: Former Richards-Gebaur AFB, Missouri	Prepared By: NL
Phase: Feasibility Study (-30% to 50%)	Date: 7/25/02
Base Year: 2002	

Descriptions:

Conduct semi-annual groundwater sampling for two years (Year 1 through Year 2) and annual groundwater sampling for 3 years at the six FS sites. A total of 84 wells will be sampled and groundwater samples will be analyzed for VOCs only. In addition, institutional controls and 5-year site reviews are assumed. After the initial 5-year review, the monitoring will be reduced to once every 5 years.

Capital Costs

Not Applicable.

\$0

O & M Costs**1. Institutional Controls**

Institutional Controls Plan	1	EA	\$5,000	\$5,000	Describe controls/implementation.
Groundwater Use Restriction	1	LS	\$3,200	\$3,200	Legal fees.
Site Information Database	1	LS	\$4,800	\$4,800	Setup data management system.
Subtotal (including 10% PM & administrative and 20% contingency)				\$16,900	
Present Worth of ICs				\$16,900	

2. Semi-annual Groundwater Monitoring and Reporting

Annual Groundwater Monitoring & Reporting	1	LS	\$88,048	\$88,048	
Subtotal (including 10% PM & administrative and 20% contingency)				\$114,462	
Discount Rate				3.90%	
Number of Years				2	
Present Worth of Semi-annual Monitoring & Annual Reporting				\$220,493	

3. Annual Groundwater Monitoring and Reporting

Annual Groundwater Monitoring & Reporting	1	LS	\$47,430	\$47,430	
Subtotal (including 10% PM & administrative and 20% contingency)				\$61,659	
Discount Rate				3.90%	
Number of Years				8	
Present Worth of Annual Monitoring & Reporting				\$357,179	

Present Worth of O&M Costs**\$594,572****Periodic Costs****1. 5-Year Site Reviews**

5-Year Site Reviews	1	LS	\$12,773	\$12,773	
Subtotal (including 10% PM & administrative and 20% contingency)				\$16,604	
Discount Rate				3.90%	
Present Worth of 5-Year Site Reviews				\$53,767	

Present Worth of Periodic Costs**\$53,767****Total Present Worth Project Cost for 30 Years****\$648,000****Total Present Worth Project Cost for 50 Years****\$662,000****Assumptions:**

Current discount rate is: 3.90%

Cost for institutional control was estimated using quotes from the 2000 USEPA "A Guide to developing and documenting cost the estimates during Feasibility Study"

Unit prices for laboratory analysis were provided by CH2M HILL Applied Science Lab, Corvallis, Oregon.

Unit prices for IDW disposal were provided by Geotechnical Service, Inc., Kansas City, Kansas.

Alternative 3 - HRC-Accerelated Naurtal Attenuation and Institutional Controls Cost Worksheet

Site:	Former Richards-Gebaur AFB, Missouri				Prepared By:	NL	
Phase:	Feasibility Study (-30% to 50%)				Date:	7/25/02	
Base Year:	2002						
Descriptions:							
<p>This alternative consists of full-scale HRC treatment at the six FS sites. Based on the plume dimensions, aquifer transport parameters, and contaminant concentrations, the required costs for HRC materials and geoprobe installation were estimated using the standard worksheet provided by Regenesis. The injection point spacing is set for 10 feet for each site, based on the base geology and hydrogeology. Under this alternative, two applications of HRC injection are assumed for each site.</p> <p>Annual groundwater sampling events will be conducted for 5 years. Institutional Controls and 5-year site reviews are also assumed.</p>							
Capital Costs							
1. HRC Injection							
Year 1	Full-Scale Treatment at 6 Sites						
	HRC Injection with Geoprobe	1	EA	\$429,000			\$429,000
	HRC Material Costs	1	EA	\$1,540,646			\$1,540,646
	Subtotal (including 10% PM & administrative and 20% contingency)						\$2,560,540
Year 2	Reapplication of HRC at 6 Sites						
	HRC Injection with Geoprobe	1	EA	\$429,000			\$429,000
	HRC Material Costs	1	EA	\$1,540,646			\$1,540,646
	Subtotal (including 10% PM & administrative and 20% contingency)						\$2,560,540
	Discount Rate						3.90%
Present Worth of Capital Costs							\$5,121,080
O & M Costs							
1. Institutional Controls							
	Institutional Controls Plan	1	EA	\$5,000			\$5,000
	Groundwater Use Restriction	1	LS	\$3,200			\$3,200
	Site Information Database	1	LS	\$4,800			\$4,800
	Subtotal (including 10% PM & administrative and 20% contingency)						\$16,900
	Number of Years						1
Present Worth of ICs							\$16,900
2. Monitoring Costs for HRC Injections							
HRC Injection Oversight, Pre-and Post-injection Sampling							
Year 1	Full-Scale Treatment at 6 Sites						
	Laboratory Analysis	1	EA	\$60,556			\$60,556
	Labor & Expenses (Oversight and Sampling)	1	EA	\$491,602			\$491,602
	IDW Disposal	1	EA	\$8,040			\$8,040
	Subtotal (including 10% PM & administrative and 20% contingency)						\$728,257
Year 2	Reapplication of HRC at 6 Sites						
	Laboratory Analysis	1	EA	\$60,556			\$60,556
	Labor & Expenses (Oversight and Sampling)	1	EA	\$491,602			\$491,602
	IDW Disposal	1	EA	\$8,040			\$8,040
	Subtotal (including 10% PM & administrative and 20% contingency)						\$728,257
	Discount Rate						3.90%
Present Worth O&M and Monitoring Costs							\$1,456,514
3. Annual Groundwater Monitoring and Reporting							
	Annual Groundwater Monitoring & Reporting	1	LS	\$47,430			\$47,430
	Subtotal (including 10% PM & administrative and 20% contingency)						\$61,659
	Discount Rate						3.90%
	Number of Years						5
Present Worth of Annual Monitoring & Reporting							\$226,659
Present Worth of O&M Costs							\$1,700,072
Periodic Costs							
1. 5-Year Site Reviews							
	5-Year Site Reviews	1	LS	\$12,773			\$12,773
	Subtotal (including 10% PM & administrative and 20% contingency)						\$16,604
	Discount Rate						3.90%
Present Worth of 5-Year Site Reviews							\$30,227
2. Remediation Action Reporting (Year 2)							
	Remediation Action Reporting	1	LS	\$17,030			\$17,030
	Subtotal (including 10% PM & administrative and 20% contingency)						\$22,139
	Discount Rate						3.90%
	Number of Years						1
Present Worth of Remediation Action Reporting							\$20,508

Alternative 3 - HRC-Accerelated Naurtal Attenuation and Institutional Controls Cost Worksheet

Site: Former Richards-Gebaur AFB, Missouri	Prepared By: NL
Phase: Feasibility Study (-30% to 50%)	Date: 7/25/02
Base Year: 2002	
Present Worth of Periodic Costs	\$50,736
Total Present Worth Project Cost for 30 Years	\$6,872,000
Total Present Worth Project Cost for 50 Years	\$8,030,000
Assumptions:	
Current discount rate is: 3.90%	
Cost for Institutional control was estimated using quotes from the 2000 USEPA "A Guide to developing and documenting cost the estimates during Feasibility Study"	
Unit prices for laboratory analysis were provided by CH2M HILL Applied Science Lab, Corvallis, Oregon.	
Unit prices for IDW disposal were provided by Geotechnical Service, Inc., Kansas City, Kansas.	

Attachment A – Cost Details for Alternative Elements

Cost Estimates for 5-Year Site Review

5-Year Site Review				
Labor	150	HR	\$78	\$11,700
Computers	150	HR	\$4.20	\$630
Communication	150	HR	\$1.20	\$180
Health and Safety	150	HR	\$1.75	\$263
Subtotal				\$12,773

Total**\$12,773**

Note:

Assume 120 hours of report preparation.

Including senior review and administrative support.

Cost Estimates for Long Term Monitoring

Semi-Annual Groundwater Monitoring and Reporting

	QTY	Unit	Unit Cost	Total
Labor & Expenses for Field Sampling				
Labor	400	HR	\$78	\$31,200
Computers	400	HR	\$4.20	\$1,680
Communication	400	HR	\$1.20	\$480
Health and Safety	400	HR	\$1.75	\$700
Travel	40	EA	\$183	\$7,320
Equipment	20	EA	\$500	\$10,000
Subtotal				\$51,380

Note:
 Assume 10 working days/person/sampling event for 2-person team.
 Assume 10 hours per person per working day. Including mob/demob.

Laboratory Cost				
VOCs	210	EA	\$110	\$23,100
Subtotal				\$23,100

Assume 84 monitoring wells/event.
 1 duplicate every 10 samples per site.
 1 MS/MSD every 20 samples per site.
 1 trip blank every shipment.
 1 equipment rinsate blank per day.

IDW Disposal				
55-gallon drums	10	EA	\$35	\$350
Purged Water	10	EA	\$300	\$3,000
Subtotal				\$3,350

Assume 5 drums for each event.

Annual Reporting				
Labor	120	HR	\$78	\$9,360
Computers	120	HR	\$4.20	\$504
Communication	120	HR	\$1.20	\$144
Health and Safety	120	HR	\$1.75	\$210
Subtotal				\$10,218

Assume 120 hours for report preparation.

Total **\$88,048**

Annual Groundwater Monitoring and Reporting

Labor & Expenses for Field Sampling				
Labor	200	HR	\$78	\$15,600
Computers	200	HR	\$4.20	\$840
Communication	200	HR	\$1.20	\$240
Health and Safety	200	HR	\$1.75	\$350
Travel	20	EA	\$183	\$3,660
Equipment	10	EA	\$500	\$5,000
Subtotal				\$25,690

Assume 10 working days/person/sampling event for 2-person team.
 Assume 10 hours per person per working day. Including mob/demob.

Laboratory Cost				
VOCs	105	EA	\$110	\$11,550
Subtotal				\$11,550

Assume 84 monitoring wells/event.
 1 duplicate every 10 samples per site.
 1 MS/MSD every 20 samples per site.
 1 trip blank every shipment.
 1 equipment rinsate blank per day.

IDW Disposal				
55-gallon drums	5	EA	\$35	\$175
Purged Water	5	EA	\$300	\$1,500
Subtotal				\$1,675

Assume 5 drums for each event.

Annual Reporting				
Labor	100	HR	\$78	\$7,800
Computers	100	HR	\$4.20	\$420
Communication	100	HR	\$1.20	\$120
Health and Safety	100	HR	\$1.75	\$175
Subtotal				\$8,515

Assume 100 hours for report preparation.

Total **\$47,430**

Cost Estimate for Annual Groundwater Monitoring and Reporting

Annual Groundwater Monitoring

Labor & Expenses for Sampling

Labor	200	HR	\$78	\$15,600	
Computers	200	HR	\$4.20	\$840	Assume 10 working days/person/sampling event.
Communication	200	HR	\$1.20	\$240	for 2-person team.
Health and Safety	200	HR	\$1.75	\$350	Assume 10 hours per person per working day.
Travel	20	DAY	\$183	\$3,660	Including mob/demob.
Equipment	10	DAY	\$500	\$5,000	
Subtotal				\$25,690	

Assume 84 monitoring wells/event.

1 duplicate every 10 samples per site.

1MS/MSD every 20 samples per site.

1 trip blank every shipment.

1 equipment rinsate blank per day.

Laboratory Cost

VOCs	105	EA	\$110	\$11,550
Subtotal				\$11,550

IDW Disposal

55-gallon drums	5	EA	\$35	\$175	Assume 5 drums for each event.
Purged Water	5	EA	\$300	\$1,500	
Subtotal				\$1,675	

Subtotal of Annual Groundwater Sampling \$38,915

Annual Monitoring Report

Labor

Labor	100	HR	\$78	\$7,800	
Computers	100	HR	\$4.20	\$420	Assume 100 hours of report preparation.
Communication	100	HR	\$1.20	\$120	
Health and Safety	100	HR	\$1.75	\$175	
Subtotal				\$8,515	

Subtotal of Annual Groundwater Report \$8,515**Total \$47,430**

Cost Estimates for HRC-accelerated Natural Attenuation

Full-Scale HRC Injection (One Application Only)

SS 003 - Grid Injection
Geoprobe for HRC Injection
Subtotal

\$15,000
 \$15,000

7 days injection required.
 See Table 1 in Attachment B for details.

HRC Material Costs
Subtotal

\$42,926
 \$42,926

See Table 1 in Attachment B for details.

Labor & Expense (HRC Injection Oversight)

Labor (1 person for oversight)	80	HR	\$78	\$6,240
Computers	80	HR	\$4.20	\$336
Communication	80	HR	\$1.20	\$96
Health and Safety	80	HR	\$1.75	\$140
Travel	8	DAY	\$183	\$1,464
Equipment	8	DAY	\$50	\$400
Subtotal				\$8,676

Including 1 day of mob/demob.
 Assume 10 hours/day.

Laboratory Analysis

VOCs by EPA8260	32	EA	\$70	\$2,240
Permant Gases by ASTM D1945	28	EA	\$70	\$1,960
Metabolic Acids by HPLC/UV	28	EA	\$75	\$2,100
Metals and Nutrients	28	EA	\$144	\$4,032
Subtotal				\$10,332

Assume 6 wells/per sampling events.
 Assume 4 sampling events
 1 trip blank per event will be collected for VOCs analysis.
 1 duplicate & 1 rinsate blank per event will be collected for all analysis.

Labor & Expense (Post-treatment Groundwater Monitoring)

Labor (2 persons for sampling)	160	HR	\$78	\$12,480
Computers	160	HR	\$4.20	\$672
Communication	160	HR	\$1.20	\$192
Health and Safety	160	HR	\$1.75	\$280
Travel	16	DAY	\$183	\$2,928
Equipment	8	DAY	\$100	\$800
Subtotal				\$17,352

Assume 10 hrs per day.
 Assume 2 days for each sampling event.
 Including mob/demob.

IDW Disposal

55-gal Drum	4	EA	\$35	\$140
Purged Water	4	EA	\$300	\$1,200
Subtotal				\$1,340

One 55-gal drum of purged water per sampling event.

Total Cost of SS 003

\$95,600

SS 006 - Grid Injection
Geoprobe for HRC Injection
Subtotal

\$228,000
 \$228,000

113 days injection required.
 See Tables 2 & 3 in Attachment B for details.

HRC Material Costs
Subtotal

\$ 1,087,970
 \$1,087,970

See Tables 2 & 3 in Attachment B for details.

Labor & Expense (HRC Injection Oversight)

Labor (1 person for oversight)	1330	HR	\$78	\$103,740
Computers	1330	HR	\$4.20	\$5,586
Communication	1330	HR	\$1.20	\$1,596
Health and Safety	1330	HR	\$1.75	\$2,328
Travel	665	DAY	\$183	\$121,695
Equipment	665	DAY	\$50	\$33,250
Subtotal				\$268,195

Including 20 days of mob/demob.
 Assume 10 hours/day.

Laboratory Analysis

VOCs by EPA8260	36	EA	\$70	\$2,520
Permant Gases by ASTM D1945	32	EA	\$70	\$2,240
Metabolic Acids by HPLC/UV	32	EA	\$75	\$2,400
Metals and Nutrients	32	EA	\$144	\$4,608
Subtotal				\$11,768

Assume 6 well /per sampling events.
 Assume 4 sampling events
 1 trip blank per event will be collected for VOCs analysis.
 1 duplicate & 1 rinsate blank per event will be collected for all analysis.

Labor & Expense (Post-treatment Groundwater Monitoring)

Labor (2 persons for sampling)	160	HR	\$78	\$12,480
Computers	160	HR	\$4.20	\$672
Communication	160	HR	\$1.20	\$192
Health and Safety	160	HR	\$1.75	\$280
Travel	16	DAY	\$183	\$2,928
Equipment	8	DAY	\$100	\$800
Subtotal				\$17,352

Assume 10 hrs per day.
 Assume 2 day for each sampling event.
 Including mob/demob.
 Assume 4 sampling events

IDW Disposal
 55-gal Drum

4	EA	\$35	\$140
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Purged Water	4	EA	\$300	\$1,200	One 55-gal drum of purged water per sampling event.
Subtotal				\$1,340	

Total Cost of SS 006 **\$1,614,600**

SS 009 - Grid Injection				\$7,000	9 days injection required.
Geoprobe for HRC Injection				\$7,000	
Subtotal				\$7,000	

HRC Material Costs				\$15,980	See Table 4 in Attachment B for details.
Subtotal				\$15,980	

Labor & Expense (Oversight)					
Labor (1 person for oversight)	100	HR	\$78	\$7,800	
Computers	100	HR	\$4.20	\$420	
Communication	100	HR	\$1.20	\$120	
Health and Safety	100	HR	\$1.75	\$175	Including 1 day of mob/demob.
Travel	10	DAY	\$183	\$1,830	Assume 10 hours/day.
Equipment	10	DAY	\$50	\$500	
Subtotal				\$10,845	

Laboratory Analysis					
VOCs by EPA8260	20	EA	\$70	\$1,400	Assume 2 wells/per sampling event.
Permant Gases by ASTM D1945	16	EA	\$70	\$1,120	Assume 4 sampling events
Metabolic Acids by HPLC/UV	16	EA	\$75	\$1,200	1 trip blank per event will be collected for VOCs analysis.
Metals and Nutrients	16	EA	\$144	\$2,304	1 duplicate & 1 rinsate blank per event will be collected for all analysis.
Subtotal				\$6,024	

Labor & Expense (Post-treatment Groundwater Monitoring)					
Labor (2 persons for sampling)	80	HR	\$78	\$6,240	Assume 10 hrs per day.
Computers	80	HR	\$4.20	\$336	Assume 1 day for each sampling event.
Communication	80	HR	\$1.20	\$96	Including mob/demob.
Health and Safety	80	HR	\$1.75	\$140	Assume 4 sampling events
Travel	8	DAY	\$183	\$1,464	
Equipment	4	DAY	\$100	\$400	
Subtotal				\$8,676	

IDW Disposal					
55-gal Drum	4	EA	\$35	\$140	
Purged Water	4	EA	\$300	\$1,200	One 55-gal drum of purged water per sampling event.
Subtotal				\$1,340	

Total Cost of SS 009 **\$49,900**

SS 012 - Grid Injection				\$151,000	75 days injection required.
Geoprobe for HRC Injection				\$151,000	See Table 5 in Attachment B for details.
Subtotal				\$151,000	

HRC Material Costs				\$346,122	See Table 5 in Attachment B for details.
Subtotal				\$346,122	

Labor & Expense (Oversight)					
Labor (1 person for oversight)	850	HR	\$78	\$66,300	
Computers	850	HR	\$4.20	\$3,570	
Communication	850	HR	\$1.20	\$1,020	Including 10 day of mob/demob.
Health and Safety	850	HR	\$1.75	\$1,488	Assume 10 hours/day.
Travel	85	DAY	\$183	\$15,555	
Equipment	85	DAY	\$50	\$4,250	
Subtotal				\$92,183	

Laboratory Analysis					
VOCs by EPA8260	36	EA	\$70	\$2,520	Assume 6 wells/per sampling events.
Permant Gases by ASTM D1945	32	EA	\$70	\$2,240	Assume 4 sampling events
Metabolic Acids by HPLC/UV	32	EA	\$75	\$2,400	1 trip blank per event will be collected for VOCs analysis.
Metals and Nutrients	32	EA	\$144	\$4,608	1 duplicate & 1 rinsate blank per event will be collected for all analysis.
Subtotal				\$11,768	

Labor & Expense (Post-treatment Groundwater Monitoring)					
Labor (2 persons for sampling)	160	HR	\$78	\$12,480	Assume 10 hrs per day.
Computers	160	HR	\$4.20	\$672	Assume 2 days for each sampling event.
Communication	160	HR	\$1.20	\$192	Including mob/demob.
Health and Safety	160	HR	\$1.75	\$280	Assume 4 sampling events
Travel	16	DAY	\$183	\$2,928	
Equipment	8	DAY	\$100	\$800	
Subtotal				\$17,352	

IDW Disposal					
55-gal Drum	4	EA	\$35	\$140	
Purged Water	4	EA	\$300	\$1,200	One 55-gal drum of purged water per sampling event.
Subtotal				\$1,340	

Total Cost of SS012 **\$619,800**

ST 005 - Grid Injection					
Geoprobe for HRC Injection				\$17,000	8 days injection required.
Subtotal				\$17,000	See Table 6 in Attachment B for details.

HRC Material Costs					See Table 6 in Attachment B for details.
Subtotal				\$32,880	

Labor & Expense (Oversight)					
Labor (1 person for oversight)	90	HR	\$78	\$7,020	Including 1 day of mob/demob.
Computers	90	HR	\$4.20	\$378	Assume 10 hours/day.
Communication	90	HR	\$1.20	\$108	
Health and Safety	90	HR	\$1.75	\$158	
Travel	9	DAY	\$183	\$1,647	
Equipment	9	DAY	\$50	\$450	
Subtotal				\$9,761	

Laboratory Analysis					
VOCs by EPA8260	32	EA	\$70	\$2,240	Assume 5 wells/per sampling events.
Permant Gases by ASTM D1945	28	EA	\$70	\$1,960	Assume 4 sampling events
Metabolic Acids by HPLC/UV	28	EA	\$75	\$2,100	1 trip blank per event will be collected for VOCs analysis.
Metals and Nutrients	28	EA	\$144	\$4,032	1 duplicate & 1 rinsate blank per event will be collected for all analysis.
Subtotal				\$10,332	

Labor & Expense (Post-treatment Groundwater Monitoring)					
Labor (2 persons for sampling)	160	HR	\$78	\$12,480	
Computers	160	HR	\$4.20	\$672	Assume 10 hrs per day.
Communication	160	HR	\$1.20	\$192	Assume 2 days for each sampling event.
Health and Safety	160	HR	\$1.75	\$280	Including mob/demob.
Travel	16	DAY	\$183	\$2,928	
Equipment	8	DAY	\$100	\$800	
Subtotal				\$17,352	

IDW Disposal					
55-gal Drum	4	EA	\$35	\$140	
Purged Water	4	EA	\$300	\$1,200	One 55-gal drum of purged water per sampling event.
Subtotal				\$1,340	

Total Cost of ST 005 **\$88,700**

ST 011 - Grid Injection					
Geoprobe for HRC Injection				\$11,000	5 days injection required.
Subtotal				\$11,000	See Table 9 in Attachment B for details.

HRC Material Costs					See Table 3 in Attachment B for details.
Subtotal				\$14,768	

Labor & Expense (HRC Injection Oversight)					
Labor (1 person for oversight)	60	HR	\$78	\$4,680	
Computers	60	HR	\$4.20	\$252	
Communication	60	HR	\$1.20	\$72	Including 1 day of mob/demob.
Health and Safety	60	HR	\$1.75	\$105	Assume 10 hours/day.
Travel	6	DAY	\$183	\$1,098	
Equipment	6	DAY	\$50	\$300	
Subtotal				\$6,507	

Laboratory Analysis					
VOCs by EPA8260	32	EA	\$70	\$2,240	Assume 5 wells/per sampling events.
Permant Gases by ASTM D1945	28	EA	\$70	\$1,960	Assume 4 sampling events
Metabolic Acids by HPLC/UV	28	EA	\$75	\$2,100	1 trip blank per event will be collected for VOCs analysis.
Metals and Nutrients	28	EA	\$144	\$4,032	1 duplicate & 1 rinsate blank per event will be collected for all analysis.
Subtotal				\$10,332	

Labor & Expense (Post-treatment Groundwater Monitoring)					
Labor (2 persons for sampling)	160	HR	\$78	\$12,480	Assume 10 hrs per day.
Computers	160	HR	\$4.20	\$672	Assume 2 days for each sampling event.
Communication	160	HR	\$1.20	\$192	Including mob/demob.
Health and Safety	160	HR	\$1.75	\$280	
Travel	16	DAY	\$183	\$2,928	

Equipment	8	DAY	\$100	\$800	
Subtotal				\$17,352	

IDW Disposal					
55-gal Drum	4	EA	\$35	\$140	
Purged Water	4	EA	\$300	\$1,200	One 55-gal drum of purged water per sampling event.
Subtotal				\$1,340	

Total Cost of ST 011 **\$61,300**

Subtotal of Capital Costs **\$1,969,646**

Subtotal of O&M Costs **\$560,198**

Remediation Action Report

Labor & Expense

Labor	200	HR	\$78	\$15,600	Assume 200 hours for report preparation.
Computers	200	HR	\$4.20	\$840	
Communication	200	HR	\$1.20	\$240	
Health and Safety	200	HR	\$1.75	\$350	
Subtotal				\$17,030	

Total Cost **\$17,030**

Annual Groundwater Monitoring

Labor & Expenses for Field Sampling

Labor	200	HR	\$78	\$15,600	Assume 10 working days/person/sampling event for 2-person team.
Computers	200	HR	\$4.20	\$840	
Communication	200	HR	\$1.20	\$240	Assume 10 hours per person per working day.
Health and Safety	200	HR	\$1.75	\$350	Including mob/demob.
Travel	20	EA	\$183	\$3,660	
Equipment	10	EA	\$100	\$1,000	
Subtotal				\$21,690	

Laboratory Cost					
VOCs	105	EA	\$110	\$11,550	Assume 84 monitoring wells/event. 1 duplicate every 10 samples per site. 1MS/MSD every 20 samples per site. 1 trip blank every shipment. 1 equipment rinsate blank per day.
Subtotal				\$11,550	

IDW Disposal					
55-gallon drums	5	EA	\$35	\$175	
Purged Water	5	EA	\$300	\$1,500	Assume 5 drums for each event.
Subtotal				\$1,675	

Annual Reporting					
Labor	100	HR	\$78	\$7,800	
Computers	100	HR	\$4.20	\$420	Assume 100 hours for report preparation.
Communication	100	HR	\$1.20	\$120	
Health and Safety	100	HR	\$1.75	\$175	
Subtotal				\$8,515	

Total **\$43,430**

Attachment B – HRC Grid Design Work Sheets

Basic Site Characteristics

Width of plume (intersecting flow)	100	ft
Length of plume	100	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	16	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.027	ft/day
Hydraulic gradient	0.043	ft/ft
Seepage velocity	0.003	ft/day = 1.1 ft/yr
Treatment Zone Pore Volume (cu. ft.)	64,000	ft ³

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.00
TCE	0.05
DCE	0.02
VC	0.00
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	

(Values are estimated using Soil Conc=foc*Koc*Cgw)
(Adjust Koc as nec. to provide realistic estimates)

	Koc (L/kg)	Soil Conc. (mg/kg)
PCE	263	0.00
TCE	107	0.06
DCE	80	0.03
VC	2.5	0.00
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

	(mg/L)
Oxygen	7.47
Nitrate	0.93
Manganese reduction potential	50.00
Iron reduction (potential amount of Fe2+ that can be formed)	0.50
Sulfate reduction	56.78

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

Nominal injection spacing (ft)
points in row(w/desired spacing)
Actual spacing between columns (ft)
rows (w/desired spacing)
Actual spacing between rows (ft)
Advective travel time bet. rows (days)
Number of points in grid

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	10	20	7
Actual spacing between columns (ft)	10.0	5.0	14.3
# rows (w/desired spacing)	10	20	7
Actual spacing between rows (ft)	10.0	5.0	14.3
Advective travel time bet. rows (days)	3445	1723	4922
Number of points in grid	100	400	49

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)
Feasibility of above HRC per foot:

5.2	2.0	10.5
(ok)	(ok)	(high)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	100
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	5.2
Corresponding amount of HRC per point (lbs)	83
Buckets per injection point	2.8
Total Buckets	276
Total Amt of HRC (lbs)	8,255
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 41,275
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate) cost per lb: 0.2	\$ 1,651
Sales tax (call for exact rate) rate: 0%	\$ -
Total Regenesys Material Cost	\$ 42,926

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	26
Total vertical feet for project (feet)	2,600
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	1.9
Time per day spent pushing/drilling (hrs)	8
Required number of days	7
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 15,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 57,926

Basic Site Characteristics

Width of plume (intersecting flow)	500	ft
Length of plume	400	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	12	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.164	ft/day
Hydraulic gradient	0.11	ft/ft
Seepage velocity	0.045	ft/day =
Treatment Zone Pore Volume (cu. ft.)	960,000	ft ³

*****Consider use of a number of individual barriers*****

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.00
TCE	0.46
DCE	0.15
VC	0.00
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw)		
(Adjust Koc as nec. to provide realistic estimates)		
	Koc	Soil Conc.
	(L/kg)	(mg/kg)
PCE	263	0.00
TCE	107	0.00
DCE	80	0.23
VC	2.5	0.02
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

Oxygen	6.00	(mg/L)
Nitrate	0.95	
Manganese reduction potential	50.00	
Iron reduction (potential amount of Fe2+ that can be formed)	0.50	
Sulfate reduction	117.28	

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

Nominal injection spacing (ft)
 # points in row(w/desired spacing)
 Actual spacing between columns (ft)
 # rows (w/desired spacing)
 Actual spacing between rows (ft)
 Advective travel time bet. rows (days)
 Number of points in grid

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	50	100	33
Actual spacing between columns (ft)	10.0	5.0	15.2
# rows (w/desired spacing)	40	80	27
Actual spacing between rows (ft)	10.0	5.0	14.8
Advective travel time bet. rows (days)	222	111	328
Number of points in grid	2000	8000	891

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)
 Feasibility of above HRC per foot:

8.6	2.1	19.3
(ok)	(ok)	(high)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	2000
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	8.6
Corresponding amount of HRC per point (lbs)	103
Buckets per injection point	3.4
Total Buckets	6876
Total Amt of HRC (lbs)	206,349
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 1,031,745
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate)	cost per lb: 0.2 \$ 41,270
Sales tax (call for exact rate)	rate: 0% \$ -
Total Regenesis Material Cost	\$ 1,073,015

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	22
Total vertical feet for project (feet)	44,000
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	2.3
Time per day spent pushing/drilling (hrs)	8
Required number of days	110
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 221,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 1,294,015

Basic Site Characteristics

Width of plume (intersecting flow)	70	ft
Length of plume	70	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	12	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.027	ft/day
Hydraulic gradient	0.021	ft/ft
Seepage velocity	0.001	ft/day =
Treatment Zone Pore Volume (cu. ft.)	23,520	ft ³

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.00
TCE	0.93
DCE	0.13
VC	0.02
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw) (Adjust Koc as nec. to provide realistic estimates)		
Koc	Soil Conc.	
(L/kg)	(mg/kg)	
PCE	283	0.00
TCE	107	0.00
DCE	80	0.23
VC	2.5	0.02
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

Oxygen	6.00	(mg/L)
Nitrate	0.95	
Manganese reduction potential	50.00	
Iron reduction (potential amount of Fe ²⁺ that can be formed)	0.50	
Sulfate reduction	50.00	

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	7	14	5
Actual spacing between columns (ft)	10.0	5.0	14.0
# rows (w/desired spacing)	7	14	5
Actual spacing between rows (ft)	10.0	5.0	14.0
Advective travel time bet. rows (days)	7055	3527	9877
Number of points in grid	49	196	25

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)	4.9	2.0	9.6
Feasibility of above HRC per foot:	(ok)	(ok)	(ok)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	49
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	4.9
Corresponding amount of HRC per point (lbs)	59
Buckets per injection point	2.0
Total Buckets	96
Total Amt of HRC (lbs)	2,876
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 14,380
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate) cost per lb: 0.2	\$ 575
Sales tax (call for exact rate) rate: 0%	\$ -
Total Regensis Material Cost	\$ 14,955

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	22
Total vertical feet for project (feet)	1,078
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	2.3
Time per day spent pushing/drilling (hrs)	8
Required number of days	3
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 7,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 21,955

Basic Site Characteristics

Width of plume (intersecting flow)	60	ft
Length of plume	60	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	20	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.004	ft/day
Hydraulic gradient	0.0365	ft/ft
Seepage velocity	0.0004	ft/day = 0.1 ft/yr
Treatment Zone Pore Volume (cu. ft.)	28,800	ft ³

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.02
TCE	0.02
DCE	0.20
VC	0.01
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw)		
(Adjust Koc as nec. to provide realistic estimates)		
	Koc	Soil Conc.
	(L/kg)	(mg/kg)
PCE	263	0.11
TCE	107	0.06
DCE	80	0.03
VC	2.5	0.00
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

	(mg/L)
Oxygen	2.53
Nitrate	0.13
Manganese reduction potential	50.00
Iron reduction (potential amount of Fe2+ that can be formed)	0.50
Sulfate reduction	47.45

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	6	12	4
Actual spacing between columns (ft)	10.0	5.0	15.0
# rows (w/desired spacing)	6	12	4
Actual spacing between rows (ft)	10.0	5.0	15.0
Advective travel time bet. rows (days)	27397	13699	41096
Number of points in grid	36	144	16

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)	4.3	2.0	9.6
Feasibility of above HRC per foot:	(ok)	(ok)	(ok)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	36
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	4.3
Corresponding amount of HRC per point (lbs)	85
Buckets per injection point	2.8
Total Buckets	103
Total Amt of HRC (lbs)	3,073
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 15,365
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate) cost per lb: 0.2	\$ 615
Sales tax (call for exact rate) rate: 0%	\$ -
Total Regensis Material Cost	\$ 15,980

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	30
Total vertical feet for project (feet)	1,080
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	1.7
Time per day spent pushing/drilling (hrs)	8
Required number of days	3
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 7,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 22,980



HRC Grid Design

Version 1

Technical Support (949) 366-8000

Site Name: Richards-Gebaur AFB

Location: SS 012

Consultant: CH2M HILL

Basic Site Characteristics

Width of plume (intersecting flow)	750	ft
Length of plume	200	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	10	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.164	ft/day
Hydraulic gradient	0.027	ft/ft
Seepage velocity	0.045	ft/day =
Treatment Zone Pore Volume (cu. ft.)	600,000	ft ³

Microbial Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	75	150	50
Actual spacing between columns (ft)	10.0	5.0	15.0
# rows (w/desired spacing)	20	40	13
Actual spacing between rows (ft)	10.0	5.0	15.4
Advective travel time bet. rows (days)	222	111	341
Number of points in grid	1500	6000	650

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)	4.4	2.0	10.2
Feasibility of above HRC per foot:	(ok)	(ok)	(high)

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.00
TCE	0.89
DCE	0.02
VC	0.01
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw)		
(Adjust Koc as nec. to provide realistic estimates)		
Koc (L/kg)	Soil Conc. (mg/kg)	
PCE	263	0.00
TCE	107	0.00
DCE	80	0.23
VC	2.5	0.02
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	1500
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	4.4
Corresponding amount of HRC per point (lbs)	44
Buckets per injection point	1.5
Total Buckets	2218
Total Amt of HRC (lbs)	66,562
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 332,810

Shipping and/or Tax Estimate

HRC (\$0.1 to \$0.4/lb, call for exact rate)	cost per lb: 0.2	\$ 13,312
Sales tax (call for exact rate)	rate: 0%	\$ -
Total Regensis Material Cost		\$ 346,122

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	20
Total vertical feet for project (feet)	30,000
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	2.5
Time per day spent pushing/drilling (hrs)	8
Required number of days	75
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 151,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 497,122

Competing Electron Acceptor (CEA) Concentrations:

Oxygen	5.59	(mg/L)
Nitrate	0.59	
Manganese reduction potential	50.00	
Iron reduction (potential amount of Fe ₂₊ that can be formed)	0.50	
Sulfate reduction	43.30	

Basic Site Characteristics

Width of plume (intersecting flow)	150	ft
Length of plume	120	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	7.5	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	0.0158	ft/day
Hydraulic gradient	0.085	ft/ft
Seepage velocity	0.003	ft/day = 1.2 ft/yr
Treatment Zone Pore Volume (cu. ft.)	54,000	ft ³

Dissolved Phase Groundwater VOC Concentrations: Cgw in mg/L

PCE	0.00
TCE	0.85
DCE	0.02
VC	0.00
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw) (Adjust Koc as nec. to provide realistic estimates)		
	Koc	Soil Conc.
	(L/kg)	(mg/kg)
PCE	263	0.00
TCE	107	0.00
DCE	80	0.23
VC	2.5	0.02
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

	(mg/L)
Oxygen	4.71
Nitrate	1.22
Manganese reduction potential	50.00
Iron reduction (potential amount of Fe2+ that can be formed)	0.50
Sulfate reduction	48.50

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	15	30	10
Actual spacing between columns (ft)	10.0	5.0	15.0
# rows (w/desired spacing)	12	24	8
Actual spacing between rows (ft)	10.0	5.0	15.0
Advective travel time bet. rows (days)	2978	1489	4468
Number of points in grid	180	720	80

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)	4.7	2.0	10.5
Feasibility of above HRC per foot:	(ok)	(ok)	(high)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	180
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	4.7
Corresponding amount of HRC per point (lbs)	35
Buckets per injection point	1.2
Total Buckets	211
Total Amt of HRC (lbs)	6,323
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 31,615
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate) cost per lb: 0.2	\$ 1,265
Sales tax (call for exact rate) rate: 0%	\$ -
Total Regenesys Material Cost	\$ 32,880

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	18
Total vertical feet for project (feet)	3,150
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	2.9
Time per day spent pushing/drilling (hrs)	8
Required number of days	8
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 17,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 49,880

Basic Site Characteristics

Width of plume (intersecting flow)	100	ft
Length of plume	100	ft
Depth to contaminated zone	10	ft
Thickness of contaminated saturated zone	10	ft
Nominal aquifer soil (gravel, sand, silty sand, silt, clay)	clay	
Porosity	0.1	
Hydraulic conductivity, Kh	2.1	ft/day
Hydraulic gradient	0.014	ft/ft
Seepage velocity	0.074	ft/day = 26.8 ft/yr
Treatment Zone Pore Volume (cu. ft.)	40,000	ft ³

Dissolved Phase Groundwater VOC Concentrations: Cgw In mg/L

PCE	0.00
TCE	0.01
DCE	0.22
VC	0.00
Carbon tetrachloride	0.00
Chloroform	0.00
TCA	0.00
DCA	0.00

Sorbed Phase VOC Mass:

Soil bulk density	1.5	kg/L
Fraction of organic carbon: foc	0.02	
(Values are estimated using Soil Conc=foc*Koc*Cgw) (Adjust Koc as nec. to provide realistic estimates)		
	Koc	Soil Conc.
	(L/kg)	(mg/kg)
PCE	263	0.00
TCE	107	0.00
DCE	80	0.23
VC	2.5	0.02
Carbon tetrachloride	110	0.00
Chloroform	34	0.00
TCA	183	0.00
DCA	40	0.00

Competing Electron Acceptor (CEA) Concentrations:

	(mg/L)
Oxygen	1.54
Nitrate	0.34
Manganese reduction potential	50.00
Iron reduction (potential amount of Fe2+ that can be formed)	0.50
Sulfate reduction	23.09

Microbial Demand Factor
Additional Demand Factor

4	Recommend 3-4x
3	Recommend 2-3x

Injection Point Spacing

	Rec.	Min.	Max.
Nominal injection spacing (ft)	10.0	5	15
# points in row(w/desired spacing)	10	20	7
Actual spacing between columns (ft)	10.0	5.0	14.3
# rows (w/desired spacing)	10	20	7
Actual spacing between rows (ft)	10.0	5.0	14.3
Advective travel time bet. rows (days)	136	68	194
Number of points in grid	100	400	49

HRC Injection Amount

Minimum req. HRC per foot (lbs/ft)	2.8	2.0	5.8
Feasibility of above HRC per foot:	(ok)	(ok)	(ok)

Proposed HRC Grid Specifications

Proposed number of HRC delivery points (adjust as nec. for site)	100
Proposed HRC applic. rate lbs/foot (adjust as nec. for site)	2.8
Corresponding amount of HRC per point (lbs)	28
Buckets per injection point	0.9
Total Buckets	95
Total Amt of HRC (lbs)	2,840
Unit cost of HRC	\$ 5.00
Total Material Cost	\$ 14,200
Shipping and/or Tax Estimate	
HRC (\$0.1 to \$0.4/lb, call for exact rate) cost per lb: 0.2	\$ 568
Sales tax (call for exact rate) rate: 0%	\$ -
Total Regenesys Material Cost	\$ 14,768

HRC Installation Cost Estimate (responsibility of customer to contract work)

Footage for each inj. point = uncontaminated + HRC inj. interval (feet)	20
Total vertical feet for project (feet)	2,000
Estimated production rate (feet per hour: 50 for push, 25 for drilling)	50
Estimated hole completion rate (holes per hour)	2.5
Time per day spent pushing/drilling (hrs)	8
Required number of days	5
Mob/demob cost for injection subcontractor	\$ 1,000
Daily rate for inj. Sub. (\$1-2K for geoprobe or \$3-4K for drill rig)	\$ 2,000
Total injection subcontractor cost for application	\$ 11,000
Total Project Cost(not including consultant oversight, GWM, etc.)	\$ 25,768