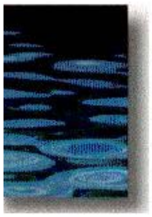

Engineering Evaluation/ Cost Analysis
Revised and Updated 2010

Twins Inn Site
Arvada, Colorado

August 2010

FINAL

TWINS INN SITE
ENGINEERING EVALUATION/COST ANALYSIS
REVISED AND UPDATED 2010

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Table of Contents

Page

List of Tables

List of Figures

List of Appendices

List of Acronyms

°F	degrees Fahrenheit
µg/L	micrograms per liter
µg/kg	micrograms per kilogram
$\mu g/m^3$	micrograms per cubic meter
ARAR	Applicable or Relevant and Appropriate Requirement
AOC	Administrative Order on Consent
AST	aboveground storage tank
bgs	below ground surface
CCR	Code of Colorado Regulations
Cl	chloride iron
CAA	Clean Air Act
CBSG	Colorado Basic Standard for Groundwater
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability
CFR	Code of Federal Regulations
cis-1,2-DCE	*cis*-1,2-dichloroethene
cm/sec	centimeters per second
CO_2	carbon dioxide
COC	contaminant of concern
CRS	Colorado Revised Statutes
CWA	Clean Water Act
DCA	dichloroethane
DCE	dichloroethene
DCP	dichloropropane
EDD	electronic data deliverable
EDR	Environmental Data Resources, Inc.
EE/CA	Engineering Evaluation/Cost Analysis
EPA	U.S. Environmental Protection Agency
ft	foot or feet
ft/min	foot or feet per minute
ft^2	square foot or feet
ft^3	cubic foot or feet
FR	Federal Register

List of Acronyms (continued)

FS	Feasibility Study
g/L	grams per liter
gpm	gallons per minute
GRA	General Response Action
GW	groundwater
H_2O	water
HA	hand auger
HAZWOPER	Hazardous Waste Operations and Emergency Response
HCl	hydrochloric acid
HDPE	High density polyethylene
Hg	mercury
HI	hazard index
HQ	hazard quotient
HRC®	Hydrogen Release Compound®
HTTD	high-temperature thermal desorption
ID	identification
iSOC/iMOX™	In Situ Submerged Oxygen Curtain/In Situ Cometabolic Oxidation
LTM	Long-Term Monitoring
LTTD	low-temperature thermal desorption
LUST	leaking underground storage tank
M	million
MCL	Maximum Contaminant Level
MEK	2-butanone or methyl ethyl ketone
mg/L	milligrams per liter
MIBK	4-methyl-2-pentanone or methyl isobutyl ketone
mm	millimeter
MNA	monitored natural attenuation
MW	monitoring well
NAAQS	National Ambient Air Quality Standards
NaOH	sodium hydroxide
NAPL	Non-aqueous Phase Liquid
NCP	National Oil and Hazardous Substances Contingency Plan
ND	not detected
NFRAP	no further remedial action planned
NPDES	National Pollutant Discharge Elimination System

List of Acronyms (continued)

NPL	National Priority List
NPV	net present value
O&M	Operation and Maintenance
O_2	oxygen
OH•	hydroxyl free radical
ORC®	Oxygen Releasing Compound®
OSHA	Occupational Safety and Health Administration
PA/SI	Preliminary Assessment/Site Inspection
PCE	tetrachloroethene
PID	Photoionization Detector
POC	point of compliance
POTW	publicly owned treatment works
PRB	permeable reactive barrier
PRP	Potentially Responsible Party
psi	pounds per square inch
PVC	polyvinyl chloride
RA	remedial action
RACER™	Remedial Action Cost Engineering and Requirements
RAGS	Risk Assessment Guidance for Superfund
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RI	Remedial Investigation
RME HI	reasonable maximum exposure hazard index
ROI	radius of influence
scfm	standard cubic feet per minute
SDWA	Safe Drinking Water Act
Site	Twins Inn Site
SO	soil
SO_4^{-0}	persulfate radicals
SOD	soil oxidant demand
SSL	soil screening level
SVE	soil vapor extraction
SW	EPA publication SW-846, entitled *Test Methods for Evaluation Solid Waste, Physical/Chemical Methods*

List of Acronyms (continued)

TBC	to be considered
TCA	trichloroethane
TCE	trichloroethene
Thoro	Thoro Product Company, Inc.
TS	Treatability Study
TSCA	Toxic Substances Control Act
UIC	Underground Injection Control
URS	URS Corporation
USC	United States Code
UST	underground storage tank
UV	ultraviolet
VOC	volatile organic compound
yd^3	cubic yard
ZVI	zero-valent iron

Executive Summary

This report presents the proposed Engineering Evaluation/Cost Analysis (EE/CA) conducted by URS Corporation for the Twins Inn Site in Arvada, Colorado. The EE/CA was conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), and U.S. Environmental Protection Agency (EPA) guidance for conducting feasibility studies (EPA 1988) and/or Conducting Non-Time-Critical Actions Under CERCLA (EPA 1993) for the purpose of evaluating potential remedial options for soil and groundwater contamination.

As required by the Administrative Order on Consent (AOC) dated May 13, 2009, this is a proposed revision to the previously-approved EE/CA for the Twins Inn Site. This proposed revision amends the EE/CA to include a new remedial alternative for groundwater (GW8 – Alternate Water Supply). In addition, soil alternative SO2 (Institutional Controls) has been retained in the updated analysis. With the exception of adding GW8 and retaining SO2, no changes have been made to the other remedial alternatives (including costs). This proposed revision to the EE/CA does incorporate updated information from the Final Risk Evaluation Report (URS 2009), including updated Remedial Action Objectives (RAOs) that have been approved for the Site (EPA 2009b).

The Twins Inn Site is defined as the area affected by a dissolved contaminant plume and areas of contaminated soil originating near West 58th Avenue and Nolan Street in the city of Arvada and unincorporated Jefferson County, Colorado. The groundwater plume extends approximately 5,000 feet to the east-southeast almost to Sheridan Boulevard. The EPA discovered the Site in the spring of 1995 during a preliminary assessment/site inspection for a nearby historical landfill. The agency conducted an emergency response field investigation and traced the contamination westward to the property and facility located at 6611 West 58th Place, which is owned and was operated by Thoro Products Company, Inc.

The principal source area for the groundwater plume at the Site is believed to be contaminated soil and/or residual non-aqueous phase liquid (NAPL) in soil near the water table in the North Tank source area on the Thoro property. There is also a localized area of soil contamination on the southern end of the Thoro property that is referred to as the South Pit area. This area does not appear to be a principal source for the groundwater contaminant plume. Soil and groundwater contamination are present in the North Tank source area and South Pit area; only groundwater contamination is present in the downgradient contaminant plume.

The main contaminants of concern (COCs) in groundwater at the Site, based on their prevalence in the plume and exceedances of EPA Maximum Contaminant Levels (MCLs) and/or the Colorado Basic Standards for Groundwater (CBSGs), are 1,1,1-trichloroethane; trichloroethene; tetrachloroethene; 1,2-dichloropropane; and their associated breakdown products including 1,1-dichloroethene and vinyl chloride. These and other volatile organic compounds are also present in the soil at the North Tank source area and South Pit area.

Remedial Action Objectives (RAOs) identified for this EE/CA for soil and groundwater at the Site are as follows:

Soil

- Decrease, eliminate, or control risk to human health – Prevent ingestion and direct contact with contaminated soil in the North Tank source area and South Pit area by preventing disturbance of subsurface soils in these areas.

Groundwater

- Decrease, eliminate, or control risk to human health – Prevent ingestion of water containing potential chemical risk drivers in excess of MCLs and maintain groundwater in the shallow aquifer to below risk-based concentrations for an excavation worker based on a hazard index (HI) of 1 and an excess cancer risk of 10^{-5}.

For this EE/CA, the Point of Compliance (POC) for contaminated groundwater is assumed to be at the eastern edge of the Vintage Sales and Leasing property along Lamar Street. The Vintage Sales and Leasing property is located adjacent to and directly downgradient of the Thoro property.

To identify a remedial alternative that can achieve the RAOs, remedial technologies and process options corresponding to general response actions for soil and groundwater at the Site were identified and then screened to refine the number considered for the remedial alternative development. This initial screening was based on three general criteria: effectiveness, implementability, and cost. Data from the Treatability Study (URS 2004b) contributed to the evaluation of technology effectiveness. The retained technologies and process options were further assembled into alternatives. Additionally, preliminary groundwater modeling simulations were performed to refine the remedial alternatives to be carried forward for further development.

The development of alternatives included a process description, conceptual design, and performance monitoring plan. Developed alternatives were then further screened to retain or reject alternatives to be carried forward for a detailed analysis and comparison. The screening again included evaluations for effectiveness, implementability, and cost.

The detailed analysis evaluated the alternatives according to overall protection of human health and the environment, compliance with applicable or relevant and appropriate requirements (ARARs), long-term effectiveness, reduction in toxicity, mobility, and volume, short-term effectiveness, technical and administrative implementability, and capital and operation and maintenance costs. Two scenarios were considered in the screening and detailed analysis of groundwater alternatives. In one scenario, it was assumed that there is no soil removal, and therefore a continuing source of groundwater contamination remains in place. In the second scenario, it was assumed that soil from the North Tank source area will be removed such that there is little to no continuing source of groundwater contamination. Concern about future access to the Thoro property for implementation of remedial activities was also a factor in the analysis and comparison of alternatives.

The preferred approach for cleanup at this Site is to provide an alternate water supply to properties where shallow groundwater wells are used to obtain drinking water along with placing institutional controls (in the form of environmental covenants and/or restrictions) on the source area parcel (Thoro Products property). Institutional controls would restrict the use or disturbance of subsurface soil and groundwater. This alternative eliminates direct exposure to groundwater and reduces the risk to human health from soil and groundwater at the source area.

1.0 Introduction

This report presents the Engineering Evaluation (EE/CA) conducted by URS Corporation (URS) for the Twins Inn Site (Site) in Arvada, Colorado. This EE/CA was conducted in conformance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended (commonly known as Superfund) the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), and U.S. Environmental Protection Agency (EPA) CERCLA policies and guidance. URS was retained by the Twins Inn Potentially Responsibility Party (PRP) Group to prepare the EE/CA report as required by an Administrative Order on Consent (EPA 2000) from Region VIII of the EPA for the Site (EPA Docket No. CERCLA-8-2000-15). Currently, the Site is not listed on the CERCLA National Priority List (NPL).

1.1 Purpose and Organization of the Report

The purpose of this EE/CA is to evaluate potential remedial options for soil and groundwater contamination at the Site so that EPA may select a remedy that is protective of human health and the environment. This EE/CA was originally prepared as a Feasibility Study (FS). This EE/CA report has been organized into the following sections that are consistent with EPA's Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (EPA 1988) and/or Conducting Non-Time-Critical Actions Under CERCLA (EPA 1993):

1 – Introduction
2 – Site-Specific Remedial Requirements and Objectives
3 – Identification and Screening of Remedial Technologies and Process Options
4 – Development of Alternatives for Soil
5 – Development of Alternatives for Groundwater
6 – Alternative Screening
7 – Detailed Analysis of Alternatives for Soil
8 – Detailed Analysis of Alternatives for Groundwater
9 – Comparison of Alternatives
10 – Preferred Alternatives
11 – References

Section 1 presents background information including the site description and history, summaries of the nature and extent of contamination, contaminant fate and transport, risk assessment, results of the Treatability Study (TS), and indoor air sampling. Section 2 discusses the areas and types of contaminated media, the Applicable or Relevant and Appropriate Requirements (ARARs), and the Remedial Action Objectives (RAOs). Section 3 presents the General Response Actions (GRAs), the identification and screening of technology types and process options, the retained technologies and process options, and assembled alternatives. Sections 4 and 5 provide the development of soil and groundwater alternatives, respectively, including process description, conceptual design, and performance monitoring. Section 6 describes the alternative screening. Sections 7 and 8 include a detailed analysis of the alternatives for soil and groundwater, respectively, according to the seven threshold and balancing evaluation criteria. Section 9 compares alternatives and Section 10 presents the preferred soil and groundwater alternatives. Section 11 lists the references used in writing this document.

1.2 Background Information

This subsection presents an overview of the Site, including its location, description, history, physical characteristics, nature and extent of contamination, and contamination fate and transport.

1.2.1 Site Location and Description

The Site is defined as the area affected by a dissolved contaminant plume in groundwater and areas of contaminated soil originating near West 58th Avenue and Nolan Street in the city of Arvada in Jefferson County, Colorado. The groundwater plume extends east southeastward almost to Sheridan Boulevard. The general location of the Site is shown in Figure 1-1. Previous investigations (URS 2001a) have shown that groundwater at the Site generally flows to the east-southeast. The extent of the Site is shown in Figure 1-2.

The EPA discovered the contamination associated with the Twins Inn Site in the spring of 1995 during a preliminary assessment/site inspection (PA/SI) for a nearby historical landfill. EPA conducted an emergency response field investigation in 1995 and traced the contamination westward to the property and facility located at 6611 West 58th Place, owned and (formerly) operated by Thoro Products Company, Inc. (Thoro). Soil and groundwater contaminated with chlorinated solvents and other chemicals were detected at this property. Low concentrations of chemicals were also detected in the sediment and surface water from Ralston Creek downstream from the Thoro property during 1998. Chlorinated solvents were not detected in the former Goralnick-Rudden Pond (pond is displayed on Figure 1-2) water or sediment (UOS 1999a); therefore, it appears that the plume terminates upgradient (west) of the pond. Note that this pond was filled in during late 2005.

1.2.2 Site History

The Thoro facility in Arvada was built in 1960. Thoro produced spot removers, bleach, and other cleaning products at its Arvada location from approximately the late 1960s to the early 1990s. Thoro also acted as a local distributor of certain bulk chemicals during that time. During the late 1960s and 1970s, solvent reclamation and drum recycling operations were reportedly conducted at the Arvada facility. In this process, drums containing waste solvents from various industrial facilities in the greater metropolitan Denver area were allegedly brought to the Thoro facility. The solvent waste was recycled in stills located inside the building at the Site, and the drums were washed and reconditioned. Still bottoms allegedly were disposed in the South pit area on the southern end of the Thoro property.

Past chemical management practices at the Thoro facility have reportedly included direct pouring of solvent recycling residues as well as drum washing liquids directly onto the ground. In addition, allegedly leaking valves on solvent storage tanks was reported. These events resulted in the release of chemicals into the environment, including 1,1,1-trichloroethane (1,1,1-TCA), trichloroethene (TCE), and tetrachloroethene (PCE). Chemicals apparently seeped into the soil and reached the groundwater, where they migrated in the direction of groundwater flow to the east-southeast, forming a plume of contaminated groundwater nearly 1 mile in length. Low concentrations of chemicals have also been detected in the sediment and surface water from Ralston Creek near the Thoro property.

EPA discovered the groundwater contamination associated with the Site in May 1995 when water from a shallow domestic drinking water well near the Twins Inn Bar on West 56th Avenue was sampled and analyzed as part of the PA/SI process for the Sheridan Dump. The Site was named the Twins Inn Site because chlorinated solvents were first detected near the bar of that name. The principal source of contamination has since been found to be at the Thoro property, but the Site remains known as the Twins Inn Site.

The following contaminants were detected in the drinking water well sample in May 1995 at concentrations exceeding the Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs): TCE; PCE; 1,1-dichloroethene (1,1-DCE); *cis*-1,2-dichloroethene (*cis*-1,2-DCE); 1,1,1-TCA; and 1,1-dichloroethane (1,1-DCA). Following discovery of this contamination in the shallow groundwater aquifer, a carbon filtration water treatment system was installed to treat the shallow groundwater extracted from the well that provides drinking water to two residences and one commercial establishment in the area to ensure that the drinking water at these locations meets appropriate standards. EPA initiated monthly water sampling to ensure that the people using treated water from these shallow wells were not being exposed to unsafe levels of contaminants in their drinking water. The sampling frequency has since been reduced to every four months.

1.3 Previous Investigations

Six field investigation and sampling efforts were conducted at the Site between 1995 and 2001. The results of the investigations conducted to date are documented in the following reports, which are maintained at the EPA Region VIII Superfund Record Center:

- Sampling and Activities Report, Twins Inn Site, Arvada, Colorado (E&E 1995)
- Sampling Activities Report, Twins Inn Tanks, Arvada, Colorado (UOS 1996)
- Field Screening Investigation Report, Twins Inn Site, Arvada, Colorado (Radian 1998)
- Sampling Activities Report for Expanded Site Inspection—Phase I, Twins Inn Site, Arvada, Colorado (UOS 1999a)
- Sampling Activities Report for Ambient Air Sampling, Twins Inn Site, Arvada, Colorado (UOS 1999b)
- Risk Assessment Report (Final), Twins Inn Arvada, Colorado (UOS 1999c)
- Remedial Investigation Report, Twins Inn Site, Arvada, Colorado (URS 2001a)

Additional indoor air, groundwater, and soil data were collected during 2001 through 2010 and reported in the following documents:

- Final Indoor Air Sampling Activities Technical Memorandum, Twins Inn Site, Arvada, Colorado (URS 2002)
- Remedial Investigation Phase I Preliminary Data Submittal, Twins Inn Site, Arvada, Colorado (URS 2001b)
- Remedial Investigation Phase II, III, and IV Preliminary Data Submittal, Twins Inn Site, Arvada, Colorado (URS 2001c)
- Data Submittal for the August 2003 Site-wide Groundwater Sampling Event, Twins Inn Site, Arvada, Colorado (URS 2004a)
- Final Treatability Study Evaluation Report, Twins Inn Site, Arvada, Colorado (URS 2004b) (Note: This document includes additional investigation of the South Pit source area.)
- Baseline Indoor Air Sampling Results and Indoor Air Mitigation Plan, Twins Inn Site, Arvada, Colorado (URS 2005)
- Addendum to Baseline Indoor Air Sampling Results and Indoor Air Mitigation Plan, Twins Inn Site, Arvada, Colorado (URS 2006a)

- Groundwater Data Submittal for Fall 2005 Site-wide Groundwater Sampling Event, Twins Inn Site, Arvada, Colorado (URS 2006b)
- Groundwater Monitoring Results, 1st Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006c)
- Final Twins Inn Site Human Health Risk Assessment (URS 2006d)
- Groundwater Monitoring Results, Second Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006e)
- Indoor Air Mitigation and Post-Installation Indoor Air Sampling Results, Twins Inn Site, Arvada, Colorado (URS 2006g)
- Groundwater Monitoring Results, Third Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006h)
- Indoor Air Sampling Results, Third Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006i)
- Groundwater Monitoring Results, Fourth Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006j)
- Indoor Air Sampling Results, Fourth Quarter 2006, Twins Inn Site, Arvada, Colorado (URS 2006k)
- Groundwater Monitoring Results, First Quarter 2007, Twins, Inn Site, Arvada, Colorado (URS 2007a)
- Groundwater Monitoring Results, Second Quarter 2007, Twins, Inn Site, Arvada, Colorado (URS 2007b)
- Groundwater Monitoring Results, Third Quarter 2007, Twins, Inn Site, Arvada, Colorado (URS 2007c)
- Groundwater Monitoring Results, Fourth Quarter 2007, Twins, Inn Site, Arvada, Colorado (URS 2008a)
- Groundwater Monitoring Results, First Quarter 2008, Twins, Inn Site, Arvada, Colorado (URS 2008b)
- Groundwater Monitoring Results, Second Quarter 2008, Twins, Inn Site, Arvada, Colorado (URS 2008c)
- Groundwater Monitoring Results, Third Quarter 2008, Twins, Inn Site, Arvada, Colorado (URS 2008d)
- Groundwater Monitoring Results, Fourth Quarter 2008, Twins, Inn Site, Arvada, Colorado (URS 2008e)
- Groundwater Monitoring Results, First Quarter 2009, Twins, Inn Site, Arvada, Colorado (URS 2009a)
- Groundwater Monitoring Results, Second Quarter 2009, Twins, Inn Site, Arvada, Colorado (URS 2009b)

- Risk Evaluation, Twins Inn Site, Arvada, Colorado (URS 2009c)
- Groundwater Monitoring Results, Third Quarter 2009, Twins, Inn Site, Arvada, Colorado (URS 2009d)
- Groundwater Monitoring Results, Fourth Quarter 2009, Twins, Inn Site, Arvada, Colorado (URS 2010a)
- New Remedial Alternative, Twins Inn Site, Arvada, Colorado (URS 2010b)
- Groundwater Monitoring Results, First Quarter 2010, Twins, Inn Site, Arvada, Colorado (URS 2010c)

1.4 Site Characteristics

This section describes the physical characteristics of the Site, including its geology, hydrology, hydrogeology, meteorology, demographics, neighboring features, ecology, and cultural resources.

1.4.1 Site Geology, Hydrology, and Hydrogeology

The subsurface lithology of the Site consists of fine-grained sand, silt, and silty clay with some gravel in the top 14 to 16 feet below ground surface (bgs), underlain by a coarse, gravelly sand unit in the interval from approximately 16 feet bgs to the top of a bedrock aquitard. This sand unit is thought to be a shallow alluvial aquifer. Bedrock at the Site is the Denver Formation, which has a distinctive bluish-gray color and varies from firm, low-permeability claystone to highly weathered siltstone with some sand. The Denver Formation is typically encountered at approximately 18 to 30 feet bgs. Bedrock slopes to the south-southeast at approximately 0.02 foot/foot (2-foot change in elevation over a 100-foot horizontal distance).

The water table is typically encountered at approximately 10 to 16 feet bgs, and the saturated thickness of the alluvial aquifer is approximately 8 to 14 feet across the Site. The horizontal groundwater flow direction is to the southeast. This flow direction is consistent with the south-southeastern downward slope of the bedrock at the Site, and with the southeastern flow direction of Ralston Creek. The horizontal hydraulic gradient across the Site is 0.008 foot/foot. The vertical hydraulic gradient is minimal.

Hydraulic conductivity values at the Site range from 1.9 to 30.8 feet/day. The geometric mean of the hydraulic conductivity values at the Site is 13.6 feet/day (8.82×10^{-3} feet per minute [ft/min] or 4.48×10^{-3} centimeters per second [cm/sec]). The average linear velocity of groundwater is calculated to be 0.55 feet/day.

1.4.2 Site Meteorology

The climate in Arvada, Colorado, is characteristic of high plains and is classified as dry continental. Because it is situated a great distance from any moisture source and is separated from the Pacific Ocean by several mountain barriers, the area experiences relatively low humidity, low average precipitation, and abundant sun. Average wind speed is highest in the spring at 10 miles per hour (USDA 1980).

The temperatures in the area are relatively mild considering the latitude and high elevation (approximately 5,280 feet above mean sea level). The average annual temperature is approximately 50 degrees Fahrenheit (°F) with the average monthly temperature ranging from 16°F during December to 88°F during July (Colorado Climate Center 2001). Extremely warm or cold weather is usually of short duration. During the summer, afternoon temperatures of 90°F or over are reached on an average of only 35 days a year and seldom exceed 100°F. During the winter, weather can be quite severe, but generally the severity does not continue for long periods of time. Spring is the wettest, cloudiest, and windiest season. Stormy periods in winter and spring are often interspersed by stretches of mild sunny weather that remove previous snow cover (Colorado Climate Center 2001).

Precipitation in the area is relatively sparse with the average annual rainfall of 19.5 inches. Over 75% of the precipitation falls between March and September, and monthly average precipitation ranges from 0.62 inches in January to 2.72 inches in May. The average annual snowfall in the area is 8.7 inches. On average, at least 1 inch of snow is on the ground for 57 days out of the year (Colorado Climate Center 2001). The number of such days varies greatly from year to year. The average annual evaporation rate is approximately 45 inches per year.

1.4.3 Site Demographics and Neighboring Features

The majority of the Site is in the city of Arvada, Colorado. Arvada is a suburban municipality with a population of around 102,000, located within the Denver metropolitan area northwest of Denver in Jefferson County, Colorado. The Site is near the southeastern edge of Arvada. The southeastern end of the plume is partially located in unincorporated Jefferson County. The Site groundwater plume is in the area bounded approximately by Nolan Street to the west, Ralston Creek to the south, and Sheridan Boulevard to the east. It is slightly north of and parallel to the Union Pacific railroad on the north, as shown on Figure 1-2.

The Twins Inn groundwater plume extends under several properties primarily used for industrial and commercial purposes, including a gasoline station, gymnastics school, equipment manufacturer, bar, city wastewater treatment plant, and a rental car company. A few isolated residential properties also exist within the plume area. The majority of the plume area is zoned for light and heavy industrial purposes or commercial use. The residential properties in the Site were “grandfathered” in and allowed to remain in this industrial/commercial area. However, the city of Arvada land use plan restricts further residential development in this part of Arvada (City of Arvada 1994). The groundwater plume appears to terminate just west of Sheridan Boulevard. One area near the Site is currently used for public recreation: a public bike trail located alongside Ralston Creek south of the Site. Figure 1-3 shows the general land use in the vicinity of the Site and highlights key features of the area.

A search of environmental databases was conducted by Environmental Data Resources, Inc., (EDR) in November 1998 for a 1-mile radius around the approximate center of the plume area. The CERCLA Information System (CERCLIS) database search indicated two sites designated as *CERCLIS – No Further Remedial Action Planned* (CERCLIS-NFRAP) sites in the vicinity of the Site: (1) the Sheridan Dump located at 52nd Avenue and Sheridan Boulevard, south of the Twins Inn plume, and (2) the Layton Denver Drum Company located west of the Thoro property at 6725 West 58th Place. Figure 1-3 shows these locations. Fuel compounds, including benzene, have been detected in the Twins Inn plume in the vicinity of a leaking underground storage tank (LUST) on the Vintage Sales property, as shown on Figure 1-3. Other LUST sites are also present in the downgradient plume area.

1.4.4 Site Ecology

The ecology of the Site has been significantly modified by human activities. The terrestrial habitat consists of isolated areas of cultivated grass, trees, and shrubs situated among the commercial/industrial development, roads, railroad right-of-way, and scattered residences. The aquatic habitat in Ralston Creek has been severely modified during the process of channeling the stream around recent changes in road alignment of Lamar Street and Ralston Road (UOS 1999c).

1.4.5 Site Cultural Resources

Six recorded cultural resources are located within the Site. These resources include a segment of what once was the Colorado and Southern Railroad, which has been determined to be eligible for the National Register of Historic Places and is now part of the Burlington Northern Santa Fe railroad; a segment of the Union Pacific railroad, which was formerly the Denver and Rio

Grande Western railroad; and four standing residential structures located at 5201 West 56th Avenue, 5820 Lamar Street, 5875 Lamar Street, and 5607 Sheridan Boulevard (URS 2000).

1.5 Nature and Extent of Contamination

This section provides a brief description of the nature and extent of contamination at the Site. In general, the Site can be categorized into the following three main areas:

- North Tank source area on the Thoro property
- South Pit area on the Thoro property
- Downgradient Plume area (refers to the plume – transition and downgradient plume areas that are east of the North Tank and South Pit areas)

The main contaminants at the Site, based on their prevalence in the plume and exceedances of the MCLs and/or Colorado Basic Standards for Groundwater (CBSGs), are 1,1,1-TCA, TCE, PCE, and 1,2-dichloropropane (1,2-DCP), and their associated breakdown products including 1,1-DCE and vinyl chloride (refer to Remedial Investigation Figures 6-6 through 6-13 [URS 2001a]). Updated plume maps from the Fall 2006 site-wide groundwater sampling event were prepared for PCE, TCE, and 1,1,1-TCA and are included as Figures 1-4, 1-5, and 1-6, respectively.

Two main areas of soil contamination have been identified on the Thoro property: the North Tank source area and the South Pit area. It is believed that the release of contaminants from the Thoro property may have begun in the late 1960s to early 1970s, when Thoro conducted chlorinated solvent transfer, reclamation, and drum recycling activities.

The groundwater contaminant plume associated with the Site extends approximately 5,000 feet from the Thoro property to Sheridan Boulevard, as shown in Figure 1-2. Additional source(s) may also exist; however, to date, no others have been located.

1.5.1 North Tank Source Area

The North Tank source area, located on the north end of the Thoro property, is shown on Figure 1-7. The outline shown on Figure 1-7 is approximate based on soil sampling data from the RI. In the future, if the tanks are removed from this area and additional soil sampling is completed (for example, no soil testing has been done beneath the Thoro building), the boundaries of this source area could be better defined. In this area of the Site, 1,1,1-TCA, TCE, and PCE were routinely delivered to three aboveground storage tanks (AST) via railcar and then transferred to trucks for distribution throughout the Denver area. Drum washing also allegedly occurred in this area on the north side of the Thoro building. The North Tank source area includes the railroad spur area and the area on the north side of the Thoro building around the three ASTs.

Based on the soil and groundwater sampling conducted during the RI and other investigations at the Site listed in Section 1.3, the main source of the Twins Inn Site groundwater contamination plume is located in this North Tank area. Soil sampling data have shown that the same contaminants in groundwater are also detected in the soil in this area. The highest concentrations detected in groundwater were from samples collected close to the water table in the northeastern corner of the Thoro property. In some cases, the concentrations were greater than 10% of the aqueous solubility for the compounds detected (e.g., PCE, TCE). As a general rule of thumb, if concentrations in groundwater are close to or greater than 10% of the solubility for a chlorinated solvent, it is reasonable to assume a non-aqueous phase liquid (NAPL) may be present (Pankow and Cherry 1996). Based on the concentrations in the shallow groundwater in the North Tank source area, it is assumed that residual NAPL may be present in the soil near the water table and therefore may be acting as the main source of chlorinated solvent compounds to the downgradient groundwater plume. Although the main constituents detected in groundwater at the Site (i.e., 1,1,1-TCA, TCE, and PCE) have specific gravity values greater than 1 (i.e., they are heavier than water), it is assumed that residual NAPL is primarily present in the finer-grained, shallower soils rather than as a “pool” of NAPL at the base of the aquifer. In the remainder of this EE/CA, the term “source area” refers to the contaminated soil and/or residual NAPL in soil above and slightly below the water table in the North Tank source area. Further discussion of the source area is provided in Appendix A.

1.5.1.1 North Tank Source Area Soil

The main contaminants detected in soil in the North Tank source area were 1,1,1-TCA, TCE, and PCE. This is consistent with the contaminants detected in groundwater. In addition to these contaminants, other compounds detected included chlorobenzene, toluene, 2-butanone (MEK), acetone, and methylene chloride, but these were relatively limited in horizontal extent. The areas with the highest levels of detected soil contaminant concentrations on the north end of the Thoro property were between the three inactive ASTs and between the main building and two small sheds, one of which was reportedly used as a test laboratory. During the Remedial Investigation (RI), maximum soil contaminant concentrations in the North Tank source area of 16,000, 19,000 and 300,000 micrograms per kilogram (µg/kg) for 1,1,1-TCA, TCE, and PCE, respectively, were detected between the inactive tanks at 0 to 0.5 feet bgs (URS 2001a).

1.5.1.2 North Tank Source Area Groundwater

The primary contaminants detected in groundwater in the North Tank source area were 1,1,1-TCA, TCE, and PCE. The concentrations of 1,1,1-TCA, TCE, and PCE in the upper portion of the aquifer (i.e., near the water table or capillary fringe), where the lithology is comprised of typically finer-grained materials such as clays and silts, were generally three or more orders-of-magnitude higher than the levels detected downgradient during the RI. Groundwater concentrations of these three compounds were each typically on the order of 100,000 to 200,000 µg/L near the water table and within the capillary fringe above the water table. Concentrations in the sand to gravelly-sand portion of the aquifer from approximately 15 feet bgs to the top of the Denver Formation bedrock were generally lower, typically around 1,000 µg/L.

Other compounds detected in the North Tank source area were the degradation products of 1,1,1-TCA, TCE, and PCE, specifically 1,1-DCA, 1,1-DCE, *cis*-1,2-DCE, and vinyl chloride. Acetone, xylenes, and 4-methyl-2-pentanone (MIBK) were also detected to a lesser extent in groundwater from the North Tank source area.

Because groundwater contaminant concentrations near the water table were often substantially higher than concentrations in the sands and gravels, this may be indicative of localized areas of vadose-zone soil contamination or NAPL pockets trapped in the lower permeability clay and silt soils near the water table. As noted in Section 1.5.1, the term “source area” refers to these localized areas of soil contamination and/or residual NAPL in soil near the water table in the North Tank source area. Additional discussion on the source area interpretation is provided in Appendix A.

1.5.2 South Pit Area

The South Pit area is located on the southern end of the Thoro property, as shown on Figure 1-7. In the RI report (URS 2001a), the South Pit area was referred to as a source area because it was an area with high concentrations of contaminants in soil and groundwater. However, the current understanding of the Site data indicates that the South Pit is not a significant source for the Site groundwater plume, but instead is a localized “hot spot” area. The South Pit area is a topographic depression between the former Telone (a soil fumigant containing 1,3-dichloropropene) tank and Ralston Creek. Still bottoms from solvent recycling operations on the Thoro property were allegedly dumped in this area.

1.5.2.1 South Pit Area Soil

The South Pit area is unlined, and during the RI, a black rubbery substance containing approximately 6% toluene, 1% chlorinated solvents, and relatively smaller proportions of MEK and MIBK were observed in the soil at approximately 4.5 feet below the base of the pit, a few feet above the water table. The main contaminants detected in soil during the RI were toluene, TCE, PCE, 1,1,1-TCA, methylene chloride, *cis*-1,2-DCE, MIBK, MEK, and total xylenes (refer to RI Figure 6-2 [URS 2001a]).

Additional soil sampling was conducted during the TS and consisted of 5 soil borings drilled in the center and four corners of the South Pit area. Contaminants detected were similar to those observed during the RI, with maximum concentrations observed in samples from the soil boring location in the southwestern corner (TS007) (URS 2004b). Concentrations in soil samples approximately 2 feet above the water table were higher than those observed below the water table by one to two orders of magnitude, suggesting the main source of soil contamination is present above the water table in this area of the Site. Additionally, the black, rubbery substance observed in the RI was also observed during the TS and appeared to be localized in the center and southwestern corner of the pit.

1.5.2.2 South Pit Area Groundwater

The main contaminants detected in groundwater in the South Pit area were toluene, 1,1,1-TCA, TCE, PCE, *cis*-1,2-DCE, 1,2-DCP, and vinyl chloride. Acetone, methylene chloride, MEK, and MIBK were also detected in this area. Of these chemicals, the only ones with widespread distribution outside the source area were 1,1,1-TCA, PCE, TCE, and *cis*-1,2-DCE. Also, the compound with the highest concentration in groundwater in the South Pit area was toluene, and toluene only exceeded the MCL at the Site in the South Pit area (URS 2001a).

Groundwater contaminant concentrations from shallower samples were considerably higher than concentrations in the deeper samples in this area, suggesting that the tar-like substance above the water table is acting as a continuing source of contamination to the groundwater.

1.5.3 Downgradient Plume Area

The primary contaminants detected in the Downgradient Plume were 1,1,1-TCA, PCE, TCE, *cis*-1,2-DCE, and 1,1-DCE. During the RI, groundwater samples collected from downgradient locations generally contained similar contaminant concentrations in shallow and deep samples, suggesting good vertical mixing within the aquifer (URS 2001a). However, in three downgradient locations (listed as DP036 [MW016 location], DP037 [MW017 location], and

DP039 [MW018 location] in the Final RI Report [URS 2001a]), concentrations in the deeper samples were higher than in the shallow samples by one order-of-magnitude or less. The conceptual understanding of the site assumes that contaminants in the downgradient area are most likely transported by groundwater flow. In general, the preferential flow may favor the deeper, coarse gravel unit near the base of the shallow aquifer rather than the fine to medium-grained sand unit near the top, possibly creating a slight vertical gradient in contaminant concentrations.

Figures 1-4, 1-5, and 1-6 show the downgradient extent of dissolved PCE, TCE and 1,1,1-TCA, respectively, as of Fall 2006.

Soil contaminant concentrations in the downgradient plume area were generally non-detect or below screening levels (URS 2001a).

1.6 Contaminant Fate and Transport

The following section discusses the potential fate and transport of contaminants at the Site including potential migration routes, natural attenuation conditions, and RI modeling results.

1.6.1 Potential Migration Routes

Data collected during the RI and subsequent sampling at the Site suggest that, for the majority of the Site, the primary route of contaminant migration in groundwater appears to be through horizontal groundwater flow. However, at the North Tank source area and South Pit area, it appears that vertical migration from the vadose zone to the groundwater may also be an important contaminant migration route. In the North Tank source area, contaminant concentrations measured in shallow groundwater samples were generally higher than the deeper groundwater samples, which indicates that vertical migration in groundwater may also be an important migration route at the source area. In the downgradient areas of the plume, the concentrations are generally the same between the shallow and deep groundwater samples. Soil vapor data from samples collected across the Site during the RI (URS 2001a) and in the South Pit area during the Treatability Study (URS 2004b), shows that the vertical movement of contaminants through the vadose zone may also be a potential migration route. High concentrations of contaminants were detected in soil vapor samples collected above areas of high contaminant concentrations in groundwater in the vicinity of the North Tank and South Pit areas.

1.6.2 Natural Attenuation Conditions

During the RI, an evaluation of natural attenuation processes causing contaminant mass loss, including biodegradation processes, abiotic degradation, advection, dilution, sorption and retardation, and volatilization was performed. Conclusions from this evaluation were as follows:

- Aerobic co-metabolic and anaerobic biological degradation is likely to have occurred in the downgradient groundwater plume from 1995 to 2001.
- Although some uncertainty exists as to the exact mechanism that caused the decline in groundwater plume concentrations from 1995 to 2001, there is evidence suggesting aerobic co-metabolic degradation of contaminants in the presence of toluene may have occurred.
- Advection and adsorption appear to be affecting the transport and behavior of contaminants in groundwater.
- Despite the decreases in downgradient groundwater contaminant concentrations from 1995 to 2001, there appear to be continuing sources of dissolved groundwater contaminants in the North Tank source area on the Thoro property.

1.6.3 Modeling Results from the RI

Groundwater modeling was performed during the RI to further improve the understanding of the fate and transport of contaminants at the Site. The modeling results were presented in detail in the RI report (URS 2001a) and provide a description of the modeling objectives and the model development, parameters, and results. The following three models were used:

- MODFLOW — a numerical flow model
- MT3DMS — a numerical solute transport model
- BIOCHLOR — an analytical fate and transport package

Groundwater contaminant fate and transport was simulated in three time periods as listed below.

- Historical plume development from 1970 to 1995
- Plume concentration decreases from 1995 to 2000
- Potential for natural attenuation processes to continue in the future

The modeling results indicate that from 1970 to 1995, advection and retardation appear to be the dominant processes for plume migration, driving the plume extent to approximately 1 mile from the source area. If the assumptions used in the model are correct, then biodegradation in this first time period appears to be weak. However, in the period from 1995 to 2000, biodegradation appears to dominate the fate of the plume, causing concentration reductions by more than one order-of-magnitude during this time. Note that the modeling was updated for this EE/CA and updated modeling results are presented in Appendix A.

1.7 Risk Assessment

A baseline risk assessment was conducted for the Site in 1999, prior to the RI, using the Site data available at that time (UOS 1999c). Following the RI, the human health risk assessment was updated using data through 2005 (URS 2006d). The Site risk assessment was updated in 2009 because there were changes in land use and groundwater contaminant concentrations since the 2006 risk assessment. The risk assessments are summarized below.

1.7.1 1999 Baseline Risk Assessment

The baseline risk assessment was conducted in 1999 (UOS 1999c). The human health portion of the risk assessment determined that exposure to surface soil or subsurface soil at the Thoro property or exposure to surface water and sediments along Ralston Creek, Clear Creek, or Goralnick-Rudden Pond would likely not pose a risk to human health for the receptors evaluated (UOS 1999c). However, several groundwater exposure scenarios identified a potential risk to human health. These include groundwater ingestion, dermal contact with groundwater, and inhalation exposure to contaminated groundwater by residential receptors. However, it is important to note that the shallow groundwater being used for domestic purposes has been treated (there is an activated carbon filter on the well supplying water) and monitored by EPA since 1995 to ensure that it does not exceed MCLs. The risk assessment also identified residential and industrial indoor air in the vicinity of the groundwater plume as well as outdoor air in excavated trenches as other pathways that potentially pose a risk to human health. Further data collection associated with these pathways was recommended, since there were insufficient data to make a determination about these potential risks during the risk assessment (UOS 1999c).

An ecological risk screening evaluation was conducted as part of the 1999 risk assessment (UOS 1999c). The screening involved comparing maximum concentrations of chemicals in surface soils, sediment, and surface water to available conservative benchmarks. Based on this screening, the soil was considered unlikely to adversely affect mammals or birds. Likewise, the contaminants in sediments and surface water do not appear to present an unacceptable risk to aquatic life.

1.7.2 Updated Human Health Risk Assessment - 2006

The Human Health Risk Assessment for the Site was updated (URS 2006d) (Updated Risk Assessment) using the 2005 sampling results for surface soil, subsurface soil, groundwater, and indoor air and current toxicity data. Previous sampling results were used with current toxicity data to calculate risk from exposure to chemicals in surface water and sediments (no surface water or sediment samples have been collected since the 1999 risk assessment). The Updated Risk Assessment results did not take into account the fact that one or more exposure pathways had already been eliminated or mitigated (e.g., installation of indoor air mitigation systems and treatment of groundwater from drinking water wells).

The updated groundwater risk assessment results were generally similar to the 1999 Baseline Risk Assessment. However, with the addition of more soil characterization data from the source areas and additional indoor air data, the updated risk assessment provided a more complete assessment of risk at the Site. For the updated report, the groundwater risk assessment considered the plume area as a whole, while the soil risk assessment considered two distinct areas: the North Tank source area and the South Pit area.

The Human Health Risk Assessment estimated non-cancer and cancer risk for several potential receptors, including industrial workers, excavation workers, commercial workers, and adult and children residents. The main findings and conclusions of the Updated Human Health Risk Assessment are summarized below:

- Other than groundwater, exposure to environmental media at the Site (i.e., surface soil, subsurface soil, surface water, or indoor air) does not pose a risk of non-cancer effects for any receptors.
- Cancer risk does not exceed 10^{-6} (i.e., estimated excess cancer risk of 1 in 1,000,000) for subsurface soil in the North Tank area, surface soil in the South Pit area, surface water, or sediments for any receptors. Therefore, these media do not pose an unacceptable excess cancer risk to human health.
- Cancer risks for surface soil in the North Tank area; subsurface soil in the South Pit area; and indoor air in the gymnastics school, Gold Creek Complex (5812 Lamar Street), and 5820 Lamar Street residence are within EPA's target cancer risk management range of 10^{-6} to 10^{-4}. (As noted above, these results do not take into account the installation of indoor air mitigation systems at the gymnastics school and the Gold Creek complex.)

Only the intentional use (including ingestion) of untreated groundwater at the Site would pose an unacceptable risk of non-cancer and cancer effects for industrial workers and residents. (Note that these risk assessment results do not consider the installation of treatment systems on the drinking water wells within the Site.)

1.7.3 2009 Risk Evaluation

The evaluation of risk for the Site was updated because there were changes in land use and groundwater contaminant concentrations since the URS (2006) risk assessment report. The primary change in land use was the demolition of two residences in the area of unincorporated Jefferson County. The residences had previously used shallow, treated groundwater as their drinking water source. Because of this change, there are no residential receptors for groundwater at the Site. In addition, the concentrations of volatile organic compounds (VOCs) in groundwater in that location now meet MCLs and no longer require treatment.

The 2009 Risk Evaluation (URS 2009c) report did not reevaluate risks from exposure to surface soil, subsurface soil, VOCs and soil particulates from soil in ambient air, or surface water/sediments in Ralston Creek. Current and future risks for these pathways are assumed to be the same as reported in the URS (2006) risk assessment.

Residents are not directly exposed to groundwater via ingestion, dermal contact, and inhalation of VOCs (there is no household use of groundwater); therefore, those pathways are incomplete and there is no risk. In addition, risks are currently considered negligible for residents inhaling VOCs in indoor air impacted by vapor intrusion from groundwater because measured indoor air concentrations have been below risk-based levels and sub-slab depressurization systems have been installed and are operating at 5840 Lamar Street (gymnastics school) and 5820 Lamar Street (residence), as a precautionary measure.

East of Lamar Street, risks are considered negligible for commercial/industrial workers inhaling VOCs in indoor air impacted by vapor intrusion from groundwater because measured indoor air concentrations have been below risk-based levels.

For commercial/industrial workers ingesting groundwater, the reasonable maximum exposure hazard index (RME HI) is less than 1 and the RME cancer risk is less than 10^{-5}. These risks are much lower than reported in URS (2006) for commercial/industrial workers ingesting groundwater, because concentrations of chemical risk drivers in groundwater are low in the only area of the plume where commercial facilities are not currently using city provided water.

For excavation workers exposed to VOCs in air and groundwater in a potential excavation trench, the RME HI is less than 1 and the RME cancer risk is less than 10^{-5}. The current HI is lower than that reported in URS (2006), whereas the current cancer risk is similar to that reported in URS (2006).

In the most recent sampling (2006) of indoor air at 5889 Lamar Street located west of Lamar Street, maximum detected concentrations of VOCs in indoor air were less than EPA screening levels for industrial air (adjusted to a target cancer risk of 10^{-5} and hazard quotient [HQ] of 1). Indoor air has not been sampled at the Thoro property.

1.8 Treatability Study

A TS was conducted in 2002 to 2003 to evaluate several groundwater treatment technologies through laboratory bench-scale testing. During the TS, anaerobic bioremediation, aerobic bioremediation, chemical oxidation using Fenton's reagent, and zero-valent iron (ZVI) were evaluated for treatment of Site contaminants. Field samples were collected from the North Tank source area and South Pit area and the downgradient plume during July 2002. An additional investigation of these areas was also conducted, as well as a site-wide groundwater monitoring event. Results of the TS are presented in the Final Treatability Study Evaluation Report (URS 2004b), and are summarized below.

Bioremediation: Native anaerobic bacteria from the North Tank source, South Pit, and downgradient plume areas amended with electron donors were capable of degrading PCE, TCE, and 1,1,1-TCA. The fastest and most effective degradation was observed in the North Tank microcosm amended with lactate only. The observed biodegradation half-lives for PCE, TCE, and 1,1,1-TCA were 20, 22, and 41 days, respectively. The anaerobic bacteria were also capable of degrading the *cis*-1,2-DCE produced from PCE and TCE degradation. Further degradation of the 1,1-DCA and 1,2-DCP was limited. Results from the aerobic degradation showed that native aerobic bacteria in the presence of oxygen were capable of degrading the lesser chlorinated compounds, namely *cis*-1,2-DCE and vinyl chloride.

Chemical Oxidation: Removal of 99% of PCE, TCE, 1,1,1-TCA, and 1,2-DCP in groundwater was observed using a 60:1:1 ratio of hydrogen peroxide to ferrous sulfate to sodium citrate chelate-modified Fenton's reagent (10% hydrogen peroxide).

Zero-valent Iron: The percent removal of PCE, TCE, 1,1,1-TCA, and 1,2-DCP in batch reactors were 98%, 99%, 99%, and 11%, respectively. Complete dechlorination of PCE and TCE to ethene was achieved; only partial dechlorination of 1,1,1-TCA to 1,1-DCA and chloroethane was observed. Dechlorination of 1,2-DCP, 1,1-DCA, and chloroethane was minimal.

1.9 Indoor Air

Indoor air sampling was performed in March of 2002 to evaluate whether the Twins Inn Site groundwater plume and associated soil vapors were affecting indoor air quality, and if so, to estimate the potential risk and make recommendations for reducing risk. VOCs (including several of the chlorinated compounds associated with the groundwater plume) were detected in indoor air samples collected at locations over the plume, and generally not in samples collected from areas outside of the plume (URS 2002).

To estimate the potential human health risk from indoor air exposure, risk assessment calculations were performed following EPA’s Risk Assessment Guidance for Superfund (RAGS) and considered both a typical average (central tendency) and worst-case (reasonable maximum exposure) scenario for each of the locations sampled.

The risk assessment calculations considered the current land use scenario for each location sampled. If the location was a residence, then a residential scenario was considered in the risk assessment. One location sampled was a gymnastics school. The risk evaluation for this location included both an adult gymnastics school worker scenario and a child gymnast scenario. For two residences near the gymnastics school where access to collect indoor air samples was denied, a hypothetical residential scenario was evaluated using data collected from the gymnastics school.

Based on the indoor air sampling results and the risk assessment calculations, indoor air concentrations of Site-related compounds did not pose an unacceptable risk to human health at the Twins Inn Site. Also, by inference, the Site does not pose an unacceptable risk to commercial or industrial workers from indoor air exposure (URS 2002).

Additional indoor air sampling was performed in 2005 (URS 2005, 2006a), and sub-slab depressurization systems were installed at the gymnastics school and an adjacent residence in early 2006. Baseline concentrations of chlorinated solvent compounds in indoor air prior to system installation did not pose an unacceptable risk, and the concentrations have further decreased since startup of the systems (URS 2006g 2006i, 2006k).

Indoor air sampling was also conducted inside the office portion of the Vintage Sales building at 5889 Lamar Street in 2006. This building is situated directly over the Twins Inn plume on the property directly to the east of the Thoro Products Company property, as shown on Figure 1-3. URS collected indoor air samples in April 2006 (URS 2006e) and ERO Resources Corporation collected indoor air samples in August 2006 (ERO 2006). VOCs (including several of the chlorinated compounds associated with the groundwater plume) were detected in the indoor air samples.

1.9.1 Discontinuation of Indoor Air Sampling

In a letter dated June 23, 2008, a request was made to EPA from the Twins Inn PRP Group to discontinue indoor air monitoring at 5840 Lamar Street (Denver School of Gymnastics), 5810 Lamar Street (Gold Creek Complex), and 5820 Lamar Street (residence) and to continue operating the existing sub-slab depressurization systems at 5840 Lamar and 5820 Lamar Street.

The points below summarize the rationale for discontinuing the indoor air monitoring:

1. The Baseline Indoor Air Sampling Results and Indoor Air Mitigation Plan (November 30, 2005) recommended collection of quarterly indoor air samples from the Denver School of Gymnastics and the Gold Creek Complex on a quarterly basis for one year. Quarterly indoor air monitoring was conducted at these locations for two years; therefore the initial obligation to monitor for one year was fulfilled.
2. Concentrations of TCE and PCE in indoor air at 5840 Lamar Street and 5820 Lamar Street remained below the Colorado Department of Public Health and Environment (CDPHE) interim action levels of 1.6 micrograms per cubic meter of air ($\mu g/m^3$) for TCE and 31 $\mu g/m^3$ for PCE since the sub-slab depressurization systems were installed.
3. Even without a sub-slab depressurization system at 5810 Lamar Street, concentrations of TCE and PCE in indoor air at the Gold Creek Complex have remained below the CDPHE interim action levels, with the following exceptions:
    a. There was a one-time spike in PCE concentration at Unit #12 (Wyoming Analytical Laboratory) in January 2007, with elevated detections in Unit #4 and Unit #5. These PCE results appear to be unrelated to the Twins Inn plume since PCE was the only chemical with unusual analytical results. If the increase in PCE concentration had been due to vapor intrusion related to groundwater, similar increases in other volatile compounds detected in indoor air would be likely. Concentration increases for other volatile compounds were not observed.
    b. There have been two other times (February 2006 and October 2006), when the TCE concentration in indoor air at Unit #12 was above the CDPHE action level. There is no noticeable pattern to these results, and the concentrations were only slightly above the action level (2.9 $\mu g/m^3$ and 2.5 $\mu g/m^3$ compared to the action level of 1.6 $\mu g/m^3$).

4. Routine groundwater monitoring will continue at the Site, and if PCE or TCE groundwater concentrations in MW032 are equal to or greater than 2003 concentrations (when concentrations were highest), then indoor air monitoring will be conducted at the Denver School of Gymnastics quarterly, until groundwater concentrations remain below 2003 levels for at least two consecutive quarters and indoor air concentrations remain below CDPHE indoor air risk levels. A flow chart for this decision making process is included as Figure 1-8.

EPA approved the June 23, 2008 request to discontinue air monitoring in a letter dated July 17, 2008 sent to the Twins Inn PRP Group.

2.0 Site-Specific Remedial Requirements and Objectives

This section identifies the point of compliance (POC) requirement for the Site in addition to the areas and types of contaminated media, and contaminants of concern (COCs) for soil and groundwater specified in this EE/CA. It also presents the ARARs and RAOs for the Site. Prior to screening remedial technologies and evaluating options, it is important to understand these key factors and underlying objectives for the Site.

2.1 Point of Compliance

A POC is defined as a vertical surface that is located hydrologically downgradient of the activity being monitored for compliance. Under CERCLA, the POC is generally beyond the downgradient extent of contamination, where the migration or potential migration of contaminants can be monitored effectively. Likewise, under the Colorado Basic Standards for Groundwater (5 CCR 1002-41), the POC may be defined as the downgradient limit of the area in which contamination existed as of September 30, 1989. For the Twins Inn Site, this would be approximately at Sheridan Boulevard, where contaminant concentrations in groundwater meet standards.

Relatively high groundwater contaminant concentrations have been observed beyond the Thoro property boundary. These concentrations appear to migrate from the North Tank source area and travel across the neighboring Vintage Sales and Leasing property in the direction of groundwater flow (Figures 1-4, 1-5, and 1-6). Therefore, for the purposes of the EE/CA, the recommended POC location is at the eastern edge of the Vintage Sales property, or more specifically, the 5000 block of Lamar Street. Reasons for this POC recommendation are:

- Contaminated groundwater from the North Tank source area appears to have migrated past the Thoro property boundary.
- Historically, high contaminant concentrations in groundwater have been observed in wells on the Vintage Sales and Leasing property, west of Lamar Street.
- Historically, distinctly lower contaminant concentrations have been observed in wells east of Lamar Street. The “slug” of higher concentrations on the 2006 plume maps east of Lamar Street is believed to be a temporary effect (e.g. MW033; Figure 1-6). Refer to Appendix A for further discussion of the slug.
- The area directly adjacent to Lamar Street provides an open corridor (no buildings present) allowing for potential construction access to the north/south width of the plume, if determined to be necessary.

2.2 Areas and Types of Contaminated Media

The Twins Inn Site is comprised of several distinct areas of soil and groundwater contamination. To evaluate remedial technologies and process options, the Site is divided into areas based on the general location in relation to the POC (5000 Block of Lamar Street), type of media (unsaturated or saturated soil and groundwater), contaminants detected, and level of concentrations. These distinct areas are used throughout the remainder of this EE/CA.

The plume is first divided into two main areas: the area to the west of the POC (Lamar Street) and the area to the east of the POC. The area west of the POC is further divided into three areas: (1) the North Tank source area, (2) the South Pit area, and (3) the plume-transition area, which generally includes the Vintage Sales and Leasing property. The area to the east of the POC includes the remainder of the downgradient plume. Figure 2-1 displays the locations of the POC and the four separate plume areas.

The type of contaminated media present can make further distinction between the four plume areas. Soil contamination, including unsaturated and saturated, exists in the North Tank source area and South Pit area. Groundwater contamination exists in all of the four plume areas. Table 2-1 provides a summary of the plume areas and the contaminated media evaluated for treatment in this study.

Table 2-1. Plume Areas and Types of Media Evaluated for Treatment

Media	Plume Area Location
Soil – vadose zone	North Tank source area South Pit area
Soil – saturated zone	North Tank source area South Pit area
Groundwater	North Tank source area South Pit area Plume-transition area Downgradient plume

2.3 Contaminants of Concern

The Final RI report (URS 2001a) listed the maximum levels of contaminants detected in soil and groundwater, and highlighted those that exceeded regulatory screening levels (for soil) or standards (for groundwater). Since the preparation of the RI report, additional soil sampling and groundwater monitoring have occurred. Therefore, to reassess the contaminants of concern

(COCs) for the site, more recent data (URS 2004b) are compared to regulatory standards in this EE/CA.

2.3.1 Soil COCs

The majority of the contaminants and their highest concentrations were detected in the South Pit area during the 2000 RI sampling event. During this event, samples were collected from shallow depths using direct push methods and a hand auger. Soil screening levels have remained the same as those reported in Table 6-1 of the RI report (URS 2001a). However, an additional comparison was completed using data from soil samples collected during the Treatability Study Sampling (URS 2004b). Tables 2-2 through 2-5 list the soil contaminants with concentrations exceeding screening levels for the North Tank, South Pit, plume-transition area, and downgradient plume.

In the North Tank source area the highest levels of contamination are within the first foot of soil below ground surface. However, high concentrations (> 1,000 µg/kg) were also observed near the top of the water table between approximately 8 to 12 feet bgs. Degradation products such as 1,1-DCE and vinyl chloride are found at depths below the water table (> 12 feet).

The highest levels of soil contamination in the South Pit area appear to be above the water table at approximately 4 to 8 feet bgs, at the interval where the black, rubbery substance was observed (URS 2001a). The topographic relief of the pit combined with the soil sampling depths are important considerations when evaluating the thickness of the contaminated zone.

The sampling locations in the plume-transition area include those upgradient of Lamar Street, and in the middle of the Thoro property, between the North Tank source area and South Pit area. Exceedances of soil screening levels were found for PCE, TCE, and 1,2-DCP in the area directly upgradient and adjacent to the South Pit. An exceedance of the methylene chloride screening level was found in the location between the North Tank and South Pit, although this area does not appear to be a contributing source of groundwater contamination.

One exceedance of soil screening levels was found in the downgradient plume. PCE exceeded screening levels at a location directly downgradient of the North Tank source area.

In summary, the soil COCs for the Site are listed in Table 2-6 according to location. The North Tank and South Pit include the areas of the Site with the highest levels of soil contamination and are the two areas of the Site where active treatment of soil is being considered in this EE/CA.

2.3.2 Groundwater COCs

Groundwater data collected from the Site through the Fall 2009 sampling event were evaluated against the CBSGs and EPA MCLs. The groundwater contaminants with concentrations exceeding regulatory standards for the North Tank source area, South Pit area, plume-transition area, and downgradient plume are listed in Tables 2-7 through 2-10, respectively.

In the North Tank source area, 1,1,2-TCA and chlorobenzene are not considered COCs since they exceeded standards during only one sampling event and, historically, have not been detected at any of the other three areas of the plume. Methylene chloride appears to be localized to this source area since it was not detected downgradient. Because the North Tank source area appears to be the principal source of the groundwater plume that extends to Sheridan Boulevard, this area will be addressed as such in this EE/CA.

In this EE/CA, the contaminants listed in Table 2-8 are considered to be localized to the South Pit area, with the exception of 1,2-DCP. Groundwater samples collected from downgradient monitoring wells adjacent to the South Pit area during more recent sampling events (2001, 2002, 2003, 2005, and 2006) did not contain a majority of the contaminants nor the high concentrations observed during the RI. With the exception of 1,2-DCP, the contaminants listed in the table appear to be localized to the shallow depths of the South Pit area. Therefore, it appears that the South Pit is not a major contributing source of the downgradient groundwater plume. However, fluctuations in groundwater levels could change the steady-state conditions within the South Pit area. Methylene chloride and toluene appear to be localized to this area since they were either not detected or detected at low concentrations downgradient.

For the plume-transition area (Table 2-9), 1,4-dioxane, benzene, and chloroform are not considered to be COCs. 1,4-Dioxane was not detected in the North Tank source area or the South Pit area; however it was detected at 120 µg/L in MW004 in August 2003. This well is located on the Thoro property between the North Tank source area and the South Pit area and is therefore considered part of the plume-transition area. In addition, a 1,4-dioxane concentration of 57 µg/L was detected during the RI at a direct push location upgradient of the plume, and considered to be a background location (DP011-GW-16 (Figure 4-1 in the RI; URS 2001a). Therefore, 1,4-dioxane concentrations do not appear to be related to the North Tank source area or South Pit area. Benzene is also not considered to be a COC since the exceedances in the plume-transition area were localized near a former LUST on the Vintage Sales and Leasing property (MW029). Finally, chloroform is not considered a COC since one detection in the entire plume slightly exceeded the CBSG. Chloroform is a well-known degradation product from the addition of chlorine to municipal drinking water.

For the downgradient plume exceedances, 1,4-dioxane is not considered to be a COC since it was detected during one sampling event and also because of the background detection as described in the previous paragraph.

The groundwater COCs for the site are summarized in Table 2-6 according to plume area. A notable result is that the COCs for the plume-transition area upgradient of the POC are the same as those for the downgradient plume.

2.4 Applicable or Relevant and Appropriate Requirements

A review of the potentially applicable or relevant and appropriate Federal and state of Colorado requirements was conducted, as required under CERCLA. The preliminary list of ARARs considered the actions anticipated through the completion of the RI. An additional evaluation of ARARs was conducted for the EE/CA to consider potential remedial alternatives for the Site.

Federal regulations reviewed include those promulgated under the Clean Air Act (CAA), Clean Water Act (CWA), Safe Drinking Water Act (SDWA), Toxic Substances Control Act (TSCA), Resource Conservation and Recovery Act (RCRA), and Endangered Species Act, and by the Occupational Safety and Health Administration (OSHA). The U.S. Fish and Wildlife Service and the Colorado Division of Wildlife were contacted regarding possible endangered or threatened species in the RI area, but none were identified. State regulations reviewed include those regulating visible and odor emissions; ambient air quality standards; volatile organic and hazardous air pollutant emissions; effluent discharge; standards for drinking, surface, and groundwater; solid waste disposal; and hazardous waste generation, transport, storage, and disposal. Jefferson and Adams counties and the city of Arvada were contacted to identify potential ARARs for the Site. No local regulations (above and beyond federal and state) pertaining to environmental issues were identified. Individual regulations were reviewed and categorized as applicable, relevant, and appropriate, or not an ARAR. Guidance, advisories, and non-regulatory criteria were also evaluated for applicability.

The potentially applicable ARARs for the Site RI were updated for this EE/CA and are presented in Tables 2-11 through 2-16. The tables include federal and state chemical-specific ARARs, location-specific ARARs, and action-specific ARARs.

Applicable requirements are those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that directly apply and specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. A promulgated requirement is one that is legally enforceable and of general applicability. “Legally enforceable” means that the law or standard must be issued in accordance with state or federal procedural requirements and contain specific enforcement provisions.

Relevant and appropriate requirements are defined as “cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that, while not specifically applicable to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is appropriate to the particular site” (NCP 55 FR 8817).

A requirement may not meet the definition of ARAR as defined above but may still be useful in determining whether to take action at a site or to what degree action is necessary. Such requirements are called “To Be Considered” (TBC). The TBC requirements are advisories or guidance issued by federal or state government that are not legally binding but may provide useful information or recommended procedures for remedial action. Although TBCs do not have the status of ARARs, they are considered along with ARARs as part of the preliminary ARAR evaluation to establish the required level of cleanup for protection of health or the environment.

2.5 Remedial Action Objectives

RAOs have been defined for the Site soil and groundwater. RAOs identify the media specific goals for protecting human health and the environment. The following RAOs, approved by EPA (EPA 2009b), have been identified for soil and groundwater at the Site:

Soil

- Decrease, eliminate, or control risk to human health – Prevent ingestion and direct contact with contaminated soil in the North Tank source area and South Pit area by preventing disturbance of subsurface soils in these areas.

Groundwater

- Decrease, eliminate, or control risk to human health – Prevent ingestion of water containing potential chemical risk drivers in excess of MCLs and maintain groundwater in the shallow aquifer to below risk-based concentrations for an excavation worker based on a HI of 1 and an excess cancer risk of 10^{-5}.

3.0 Identification and Screening of Remedial Technologies and Process Options

This section presents GRAs for soil and groundwater that will satisfy the RAOs, followed by identification and screening of potentially applicable remedial technologies and process options. Technologies and process options retained from the screening are further described in this section, and then assembled to establish remedial alternatives.

3.1 General Response Actions

GRAs have been developed to satisfy the RAOs established for soil and groundwater at the Site and are listed below.

Soil

- No Action
- Institutional Controls
- Removal
- Treatment
- Containment
- Stabilization
- Disposal

Groundwater

- No Action
- Institutional Controls
- *In situ* Treatment
- Containment
- Removal
- *Ex situ* Treatment
- Disposal
- Alternate Water Supply

A summary of the GRAs for Site soil and groundwater in addition to remedial technologies and process options is provided in Tables 3-1 and 3-2, respectively.

3.2 Identification and Screening of Technologies and Processes

Remedial technologies and process options corresponding to GRAs for soil and groundwater at the Site that were identified as feasible are presented in Tables 3-1 and 3-2. Within these general categories, a number of technologies and process options were identified for treatment of contaminated soil and groundwater. Remedial technologies are the methods by which a GRA may be undertaken. Process options are the specific implementation processes within a technology type. An initial screening of the technologies and process options was performed to refine the number to be considered in the development of remedial alternatives. Results of the initial screening for soil and groundwater are included in Tables 3-3 and 3-4, respectively.

Remedial technologies and process options were evaluated and eliminated from further consideration based on three general criteria: effectiveness, implementability, and cost. A description of these criteria is provided below.

Effectiveness addresses whether the technology would achieve the RAOs for contaminants at the Site. Data and information to evaluate effectiveness is derived from current literature, historical case studies, similar ongoing projects, hands-on technology experience, vendor/subcontractor data, and the bench-scale treatability studies.

Implementability (technical and administrative) addresses the degree of difficulty in carrying out the proposed technology or process option. Data and information to evaluate implementability are derived from historical case studies, similar ongoing projects, hands-on technology experience, vendor/subcontractor data, and pilot studies. At the Twins Inn Site, a key implementability factor is access to conduct remedial activities at the Thoro property. Restrictions on access will limit the implementability of many technologies, in particular, for soil at the Thoro property, and is likely to extend the time for achieving ARARs for the groundwater plume.

Cost (capital and operation and maintenance [O&M]) was considered in relative terms for this screening. Technologies and process options can involve little to no capital and O&M cost, or significant capital (construction, equipment, materials) and O&M costs for ongoing operation of a system. Data and information to evaluate cost is derived from historical case studies, similar ongoing projects, hands-on technology experience, and vendor/subcontractor data.

Technologies or process options were evaluated relative to each other and those determined to be the most effective, implementable, and cost effective are retained for assembly into alternatives.

3.2.1 Retained Soil and Groundwater Technologies and Process Options

Based on the initial screening, process options and technologies that address the RAOs are retained for soil and groundwater. The retained process options are listed in Tables 3-3 and 3-4 and are summarized below:

Soil

- No action
- Institutional controls
- Excavation
- Excavation by Auger Drilling
- On-site Thermal Desorption
- Off-site Treatment and Disposal

Groundwater

- No action
- Institutional controls
- Monitored natural attenuation (MNA)
- Anaerobic biostimulation using electron donors
- Anaerobic biostimulation using HRC®
- Anaerobic bioaugmentation
- Anaerobic biorecirculation system
- *In situ* chemical oxidation using Fenton's reagent
- *In situ* chemical oxidation using sodium persulfate
- Zero-valent iron permeable reactive barrier (PRB) by trenching
- Alternate water supply

3.2.2 Assembling Alternatives

The alternatives assembled for further evaluation through the remedial alternative development and screening process were identified through a review of ARARs, current literature, historical case studies, similar ongoing projects, hands-on technology experience, vendor/subcontractor data, the bench-scale treatability studies, and groundwater modeling (as discussed in the previous section). The "No action" and "institutional control" alternatives were evaluated to serve as a baseline for comparison purposes. The assembled alternatives for the Site that are further evaluated in this EE/CA are listed in Table 3-5.

Alternatives for soil and groundwater are considered based on whether access to the Thoro property is obtained. Although some alternatives do not require access to Thoro, implementation would be enhanced if access were available. Further discussion on the implementability of alternatives is provided throughout the sections that follow.

The listed soil and groundwater alternatives can be combined to produce alternatives that address both contaminated media at the Site. Because of the number of alternatives for each media as well as the distinction between whether access to the Thoro property is or is not required, soil and groundwater alternatives were considered separately during alternative development. Combinations of alternatives for the two types of media will be discussed further in Section 10.0 of this document.

3.2.3 Groundwater Modeling

Groundwater modeling for the Twins Inn Site was originally conducted in 2001 as part of the Remedial Investigation (RI) effort (URS 2001, Appendix N). The model includes both flow and fate and transport using MODFLOW (McDonald and Harbaugh 1988) and MT3DMS (Zheng and Wang 1998). The model was calibrated to both groundwater flow and fate and transport conditions observed at the Site. To support the EE/CA, additional evaluation of the Site conditions and groundwater modeling were conducted in 2006, as described in more detail in Appendix A. Modeling simulations are provided for each of the assembled alternatives for groundwater.

The results of the modeling are summarized below:

- Unless the soil source is removed, the groundwater will remain contaminated indefinitely.
- If the source is contained via a PRB or hydraulic controls (i.e., biorecirculation system), then the downgradient portion of the plume is expected to meet MCLs within approximately 20 years through MNA.
- If the vadose zone/capillary fringe source area soils are removed, and the residual DNAPL in the vadose zone/capillary fringe soils in North Tank source area is the only source of contamination to groundwater, then the groundwater plume is expected to meet MCLs within about 20 years through MNA.
- If the vadose zone/capillary fringe source area soils are removed, but there is a remaining source (residual DNAPL) in the saturated zone that is not removed, then the time to reach MCLs throughout the plume is uncertain, although the downgradient area is still expected to reach MCLs within about 20 years.

The modeling results in Appendix A estimate the performance of the selected treatment technologies and process options that are simulated in the five scenarios. These results were used to further assemble and develop the remedial alternatives for the Site.

4.0 Development of Alternatives for Soil

This section includes process descriptions and conceptual designs for the development of soil alternatives. The alternatives are further screened in Section 6.0 to develop a final list of remedial alternatives for detailed analysis.

The alternatives presented in this section are identified by their respective number previously assigned in Table 3-5. The naming convention consists of a media identification, "SO" for soil; an alternative number 1 through 5; and an access identifier, "A" indicates access to the Thoro property is required for implementation. Although the institutional controls alternative does not require access for work on the Thoro property, it does require cooperation from the property owner for implementation. The soil alternatives to be developed further in this section are listed below.

- SO1 – No Action
- SO2 – Institutional Controls
- SO3A – Soil Excavation with Off-site Treatment and Disposal
- SO4A – Soil Excavation with On-Site Thermal Desorption
- SO5A – Soil Vapor Extraction

4.1 Alternative SO1 - No Action

The no action alternative assumes no further action will be taken to address soil contamination. Because remedial activities or monitoring would not be implemented, long-term human health and environmental risks for the Site are essentially the same as those identified during the risk assessment (URS 2006d). This alternative is included for baseline comparison purposes and does not take into account natural attenuation over time.

4.2 Alternative SO2 – Institutional Controls

Institutional controls can be used to prevent and/or limit potential exposure to contaminants in soil. Legal and/or management controls and physical access restrictions can be applied to the Site to control or prevent present and future use and access to soil. This alternative would require implementation of institutional controls, most likely in the form of an environmental covenant or a similar restriction on property within the Site in which ARARs apply to contaminated soil. Institutional controls might be a component of other alternatives even if it is not a "stand-alone" alternative.

4.3 Alternative SO3A – Soil Excavation with Off-site Treatment and Disposal

Soil excavation physically removes the contaminated media. This alternative combines physical soil removal with disposal at a permitted waste facility. Removing the North Tank source area discontinues the supply of contaminants to the downgradient groundwater plume. As noted in Section 1.5.1, the term “source area” refers to the contaminated soil and/or residual NAPL in soil near the water table in the North Tank source area. Excavation areas presented in this alternative are located in the North Tank source area and South Pit area.

This alternative assumes that the main Thoro building would be left in place, but the sheds, aboveground tanks and associated concrete pads would be demolished and removed prior to soil excavation. Historically, samples have not been collected from under the building; however, it is suspected that contaminated soil could be present, particularly under the northern end of the building near the bulk storage tanks. This alternative assumes there is no significant soil contamination beneath the building.

4.3.1 Process Description

In this alternative, contaminated soil is removed using heavy equipment and transported to an off-site permitted disposal facility. Pre-disposal treatment (pretreatment) of the contaminated media is usually required in order to meet Land Disposal Restrictions. A hazardous waste disposal contractor conducts soil pretreatment at an off-site facility.

4.3.2 Conceptual Design

Contaminated soil above and below the water table would be excavated from the North Tank source area. The excavation would continue below the water table to the bottom of the finer-grained silts and sands at the top of the sand unit, at a depth of approximately 16 feet bgs. Contaminated soil above the water table in the South Pit area of the Thoro property would also be excavated to a depth of approximately 10 feet bgs. Based on the data from the RI and TS sampling events (URS 2001a and URS 2004b), it is estimated that about 2,850 cubic yards (yd^3) would be removed from the North Tank source area and about 800 yd^3 from the South Pit area. The areas to be excavated are divided into individual 10 feet (ft) by 10 ft cells and are shown on Figure 4-1.

Empty aboveground storage tanks and concrete pads in both the North Tank source area and South Pit area would be removed before excavation begins. The empty storage tanks would be disassembled in place, cleaned, and removed from the site as scrap metal. Concrete pads would be lifted and broken using a loader and a track hoe excavator with a concrete breaker attachment and removed from the Site by the waste disposal contractor. Additional soil sampling would be performed in these previously covered areas. Sampling would be performed to confirm whether NAPL is present in the basal sand unit. Furthermore, a pre-design investigation of soil under the building would be conducted (i.e., drilling through the building floor and sampling soil beneath the building) to evaluate whether soil contamination is present under the building, and whether the Thoro building should be demolished to remove contaminated soil and meet ARARs. Note that the cost estimate for this alternative assumes that the building will be left in place.

After the tanks and concrete are demolished and removed, excavation and hauling equipment would be used to complete the soil removal. Additionally, auger drilling could be used in areas where excavation access is limited (e.g., near building foundations or utilities), although this is not currently assumed in the cost estimate. Excavation near buildings or structures would be conducted in a manner that protects structure foundations, such as the use of sheet piling. Excavation areas would be sprayed with water as necessary to suppress dust using a hose and a nozzle connected to an on-site water source. Water would be applied in sufficient quantity to control dust, but not to puddle or form muddy areas.

During the excavation activities, soil samples would be collected from the excavation sidewalls and bottom to confirm that the soil exceeding ARARs has been removed, and excavation would continue until the confirmation results indicate that the remaining soil in place meets ARARs or until it is impractical to continue excavation. Some contaminated soil may have to be left in place if it is not safe or practical to remove it (e.g., would require excavation too close to building foundation, railroad tracks, creek, etc.).

Excavated soil would be staged temporarily on the Thoro property until sampling and analysis is completed to determine its waste status. A composite sample would be collected from each 100 yd^3 of excavated soil and analyzed to determine if the soil could be disposed as hazardous or non-hazardous waste. The solid waste characterization methods and analyses to be performed on excavated soil are listed in Table 4-1.

It is expected that the temporary soil staging area would be located to the north and west of the South Pit. Excavated soil would be placed on plastic sheeting. Soil piles would be covered with plastic to control dust and VOC emissions, and to shield the soil from precipitation. A berm would be constructed around the staging area to prevent run-on and runoff.

For evaluating this alternative, it is assumed that all of the excavated soil would be classified as a hazardous waste. Therefore, the excavated soil would need to be hauled by truck to a landfill permitted to treat and dispose of such waste. One such facility is the Grassy Mountain Landfill operated by Clean Harbors in Knolls, Utah, at a distance of approximately 600 miles from the site. Haul trucks typically hold approximately 20 yd^3 of soil. About 283 truckloads (assuming 1.55 tons per yd^3 and 20 tons per truck load) would be required to remove the estimated 3,650 yd^3 of soil excavated from the Thoro Property.

Following excavation, clean soil from off-Site would be used to backfill the impacted areas. Fill materials would be placed in the excavations in 1-foot lifts and compacted with a vibratory plate compactor.

4.4 Alternative SO4A – Soil Excavation with On-site Thermal Desorption

As stated in the description for Alternative SO3A, soil excavation physically removes the contaminated media. This alternative combines physical removal with on-site treatment using thermal desorption. On-site thermal desorption destroys contaminants; producing clean soil that can be returned to the excavated area. Removing the source area soil removes the supply of contaminants to the downgradient groundwater plume. Excavation areas presented in this alternative are positioned in the North Tank source area and South Pit area, identical to the areas assumed in alternative SO3A

This alternative assumes that the sheds, aboveground tanks and associated concrete pads would be demolished and removed prior to soil excavation. It also assumes that the main Thoro building will be demolished and removed so that there is sufficient space for the on-site thermal desorption unit during soil treatment.

4.4.1 Process Description

Thermal desorption is an *ex situ* process used to separate contaminants from excavated soil. Heat from the combustion of fuel (typically propane or natural gas) is used to raise the temperature of the excavated soil so that contaminants volatilize into a waste gas stream. It is not an incineration process. The waste gas containing the volatile contaminants is generally routed through a thermal or catalytic oxidizer to destroy the contaminants. Emissions from the oxidizer are primarily carbon dioxide (CO_2) and water vapor (H_2O). However, since chlorinated compounds are being treated, hydrochloric acid (HCl) would also form in the off-gas and require further treatment using a caustic scrubber.

The basic thermal desorption process was once limited to contaminants with relatively low boiling points (i.e., below 600°F) in a process referred to as low-temperature thermal desorption (LTTD). Later, thermal desorption evolved to treat contaminants with boiling points higher than 600°F. These systems are referred to as high-temperature thermal desorption (HTTD) and are able to heat soil to temperatures within the range of 600°F to 1,200°F. The physical properties of the soil are retained using either heating method. The boiling points of the contaminants (chlorinated solvents) in soil at the Twins Inn Site are below 600°F, the maximum temperature used during LTTD. However, to combust and therefore destroy such contaminants, higher temperatures more representative of HTTD, may be required.

Thermal desorption systems use either direct or indirect heating configurations, and are designed for various combinations of temperature, residence time, and mixing processes depending on soil characteristics and contaminant properties. The primary types of thermal desorbers in use today include:

- Indirect-Fired Rotary
- Direct-Fired Rotary
- Heated Screw
- Infrared
- Microwave

Direct-fired rotary desorbers are the most commonly used for petroleum contaminated soils and soils contaminated with RCRA hazardous wastes. The majority of these systems utilize a secondary combustion chamber (afterburner) or catalytic oxidizer to thermally destroy the volatilized organics. Some systems also have a quench and scrubber after the oxidizer that allows them to treat soils containing chlorinated organics such as solvents and pesticides. The desorbing cylinder for full-scale transportable systems is typically 4 to 10 feet in diameter with heated lengths ranging from 20 to 50 feet. The maximum practical solids temperature for these systems is around 750 to 900ºF depending on the material of construction of the cylinder. Total residence time in this type of desorber normally ranges from 3 to 15 minutes. Treatment capacities can range from 6 to over 100 tons per hour for transportable units.

4.4.2 Conceptual Design

A mobile thermal desorption unit and secondary off-gas treatment system would be mobilized at the Thoro property. The unit would likely be delivered on two tractor trailers – one trailer for the soil desorber unit and a second trailer for the off-gas treatment oxidizer/scrubber. A typical footprint for such a system is approximately 75 x 50 feet, and requires 3 days to set up. As noted above, on-site soil treatment requires that the main Thoro building be demolished and removed to allow sufficient space for the thermal desorption treatment equipment and operations.

During field operations, excavated contaminated soil is placed into a feed hopper by means of a front-end loader. If an excess of cobbles/boulders are present, the soil may be sent through a shaker screen prior to feeding to the desorber. The soil is conveyed over a weigh scale and enters the "cool end" of the rotary drum. As the contaminated soil travels through the drum it comes in contact with hot combustion gases flowing in the opposite direction. This counter-current flow of soil and hot combustion gases heats the soil and reduces the gas temperature to approximately 500ºF. As the soil is heated, contaminants in the soil are volatilized and enter the gas stream. The rotary drum is generally equipped with speed, slope, and temperature controls to provide a variable soil retention time of 6 to 12 minutes. Most units can achieve soil discharge temperatures as high as 900ºF.

The contaminated and dust-laden air stream exiting the desorber would be routed to a baghouse. Dust fines collected in the baghouse would be conveyed to the rotary discharge auger. The particulate-free gases exiting the baghouse would then be routed to the air pollution control system housed on a second skid. A booster fan draws the gas stream into a thermal oxidizer where the combination of high temperature and residence time converts virtually all of the organic contaminants to CO_2, H_2O, and HCl. Such oxidizers typically provide a 2-second residence time at an oxidizer discharge temperature of 1,800ºF.

Because of the presence of chlorinated compounds, exhaust gases from the oxidizer would be routed to a quench duct that reduces the gas temperature to below 400º F. This rapid quench (milliseconds) minimizes the potential for dioxin formation. The cooled gas flows into a packed-bed scrubber where any HCl formed in the oxidizer would be removed. Usually caustic sodium hydroxide (NaOH) is used to neutralize the acid gases. Spent scrubber water containing mainly neutralized salts can be used for dust control on processed soil, thereby minimizing waste discharges.

The hot soils exiting the thermal desorber pass into the discharge auger where they are mixed with dust fines removed in the baghouse. This auger typically includes water spray nozzles that cool and re-hydrate the soil using the water described above. The treated soil would be stockpiled using a front-end loader.

A typical process flow diagram for thermal desorption is shown in Figure 4-2. The throughput for the on-site thermal desorption system is approximately 15 tons per hour, depending upon the water content of the soil being treated. Assuming that approximately 5,584 tons[1] of soil would

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[1] This assumes 2,738 yd^3 with a volume to weight conversion of 1.50 tons/yd^3 for unsaturated soils and 912 yd^3 with a volume to weight conversion of 1.62 tons/yd^3 for saturated soils.

be treated on site, about 62 working days would be required to treat the soil (assuming an average of 6 hours per day of treatment time). A drawing displaying a typical thermal desorption equipment layout is included in Figure 4-3.

Contaminated soil above and below the water table would be excavated from the North Tank source area. Soil from above the water table would be excavated in the South Pit area of the Thoro property. Tank and concrete removal and soil excavation are discussed above in Section 4.3.2, Conceptual Design for the Excavation and Disposal alternative. The treated soil would be used to backfill the excavations. Backfilling would be conducted as described in Section 4.3.2.

Compliance with substantive requirements of air control regulations may be required for the on-site treatment. Sampling and analyses of the gas discharge would be necessary to show compliance.

Additionally, approximately 75 yd^3 of soil containing a rubbery substance historically found in the South Pit area will be segregated from the staged soil to receive on-site treatment. This substance is not anticipated to respond to treatment by thermal desorption and will therefore be removed for off-site treatment and disposal.

4.4.3 Performance Monitoring

As the treated soil exits the desorber, it would be staged in 100 yd^3 piles to await confirmation sampling and analysis. A composite sample of the treated soil would be collected from each pile and analyzed to determine that it meets the soil cleanup criteria. Treated soil would be used for backfill in the excavation. Soil that does not meet the cleanup criteria based on the analyses can be retreated in the thermal desorber. Air emissions from the off-gas oxidizer/scrubber may need to be monitored as well. The system may be required to meet air emission limits for VOCs. Depending upon the discharge criteria, this monitoring may be accomplished with either a real time instrument such as a photoionization detector (PID), or through the use of sample collection and laboratory analyses. The system would be equipped with sample ports so that the VOC destruction efficiency of the unit can be monitored.

4.5 Alternative SO5A – Soil Vapor Extraction

Soil vapor extraction (SVE) physically removes the contaminants from the unsaturated soil. Further treatment of the waste stream is applied *ex situ*. Removing contaminants from the unsaturated North Tank source area soils would decrease the supply of contaminants to the downgradient groundwater plume. In this alternative for soil, SVE areas are positioned in the North Tank source area and South Pit area.

4.5.1 Process Description

SVE, also known as soil venting or vacuum extraction, is an *in situ* remedial technology that removes volatile constituents present in soil pore spaces and adsorbed to soils in the unsaturated (vadose) zone. In this technology, a vacuum is applied through wells near the source of contamination in the soil. Volatile constituents of the contaminant mass “evaporate” and the vapors are drawn toward the extraction wells. Extracted vapor is then treated as necessary (commonly with carbon adsorption) before being released to the atmosphere. The increased airflow through the subsurface can also stimulate biodegradation of some of the contaminants, especially those that are less volatile. Wells may be either vertical or horizontal.

Vertical vapor extraction wells are typically installed at depths of 5 feet bgs or greater. Horizontal vapor extraction, installed as a trench or horizontal well, can be used if necessary and depends on site-specific factors such as contaminant zone geometry, building footprints, and drill rig access. Geomembrane covers are often placed over the impacted soil surface to prevent vapor short-circuiting and to increase the radius of influence of the wells (USACE 2002).

In situ SVE is applicable to the removal of VOCs and some fuels (volatile compounds with a Henry's law constant greater than 0.01 or a vapor pressure greater than 0.5 millimeters of mercury [mm Hg]). Other factors such as moisture content, soil structure and stratification, organic content, and air permeability of the soil, can increase or decrease its effectiveness. *In situ* SVE would not remove heavy oils or solid material such as the rubbery substance found in the South Pit.

In areas with a shallow water table, ground water depression pumps can be used to reduce groundwater upwelling induced by the vacuum or to increase the depth of the vadose zone. The water table in the South Pit area has been measured at approximately 6 feet bgs (URS 2001a and URS 2004b). Therefore, groundwater in this area should be depressed in conjunction with the use of SVE.

4.5.2 Conceptual Design

The most critical design consideration for the application of SVE is radius of influence (ROI). The ROI is defined as the greatest distance from an extraction well at which a sufficient vacuum and vapor flow can be induced to adequately enhance volatilization and extraction of the contaminants in the soil. Extraction wells should be placed so that the overlap in their radii of influence covers the area of contamination.

Fluctuations in the groundwater table should also be considered when designing an SVE system. Significant seasonal or daily (precipitation-related) fluctuations may, at times, submerge some of the contaminated soil or a portion of the extraction well screen, making it unavailable for airflow. This is an important consideration for horizontal extraction wells, where the screen is parallel to the water table surface.

Pilot studies play an important role with respect to determining the ROI, the vacuum levels necessary to induce adequate flow of soil gas, and the equipment necessary to treat the extracted vapors. For the purposes of this conceptual design, the following assumptions have been made:

- North Area ‘A’ is 60 x 80 feet for a total area of 4,800 ft^2
- South Area ‘B’ is 40 x 50 feet for a total area of 2,000 ft^2
- Each SVE well would have an effective ROI of 15 feet
- Seven SVE wells would be required for Area A
- Three SVE wells would be required for Area B
- Each well would generate 50 standard cubic feet per minute (scfm) of vapor flow
- A single vacuum blower/treatment system would be installed in a centralized location and serve both Area A and B.
- Approximately 500 scfm of total vapor flow would be generated at a vacuum of approximately 8 inches of Hg. The anticipated horsepower requirements for the vacuum blower are 15 – 20.
- Vapor phase activated carbon would be suitable for treating the extracted soil vapors.

The piping system would likely be buried in shallow trenches to provide insulation and keep it from interfering with surface operations. The blower system would be enclosed in either an existing building or in a stand-alone shed-type building. Electrical power would be required from either existing sources or brought onto the Thoro property. It is anticipated that the system would operate for a year or less before reaching the limits of its effectiveness.

A process schematic of a typical SVE system is shown in Figure 4-4. Some liquid is expected to accumulate which would require disposal as possible hazardous waste. An air discharge permit or compliance with the substantive requirements of air pollution control regulations may also be required for the vapor treatment device. As the concentration of contaminants in the extracted vapor decrease with time, it may be more efficient to operate the system in a “pulse” mode that allows extraction to be conducted from certain wells on an intermittent basis.

An additional element of the SVE conceptual design includes a small-scale site preparation stage and excavation. In the South Pit area, the currently existing soil berm would be pushed into the pit to level the area for vapor extraction well installation. During the infilling, approximately 75 yd^3 of soil containing a rubbery substance historically found in the South Pit area would be excavated during SVE site preparation and well installation. This substance is not anticipated to respond to treatment by SVE and would therefore be removed for off-site treatment and disposal.

4.5.3 Performance Monitoring

Monitoring of the SVE system would be accomplished by installing direct-push subsurface vacuum probes at selected locations between the SVE wells. These small diameter probes would allow for the measurement of vacuum in the subsurface, and provide a means to check the ROI of each well.

To track the mass of contamination extracted, samples of the vacuum blower discharge (prior to treatment) would be collected and analyzed for VOCs on a periodic basis. Multiplying these VOC concentrations by the volume of air extracted with time, would allow calculation of the mass of contamination removed. Monthly samples of the discharge from the vapor treatment unit would also be necessary to assess the effectiveness of the treatment, and evaluate compliance with any discharge parameters. Numerous other performance parameters would also be recorded regularly including vacuum and flow from each SVE well, total flow at the blower, blower vacuum and temperature, and discharge pressure.

5.0 Development of Alternatives for Groundwater

This section includes process descriptions and conceptual designs for the development of groundwater alternatives. Once the alternatives are developed they will be further screened in Section 6 to develop a list of final remedial alternatives for detailed analysis. The alternatives presented in this section are identified by their respective numbers previously assigned in Table 3-5. The naming convention consists of a medium identification, “GW” for groundwater; an alternative number 1 through 7; and an access identifier, “A” indicates physical access to the Thoro property is required for implementation. The groundwater alternatives to be developed further in this section are listed below.

- GW1 – No Action
- GW2 – Institutional Controls
- GW3 – Monitored Natural Attenuation (MNA)
- GW4 – Anaerobic Biorecirculation and MNA
- GW5 – Zero-valent Iron PRB by Trenching and MNA
- GW6A – Anaerobic Bioremediation and MNA
- GW7A – *In situ* Chemical Oxidation and MNA
- GW8 – Alternate Water Supply and Institutional Controls

The North Tank source area soils are considered the main source of the downgradient groundwater plume; therefore, without removal of this source material, active treatment or containment of groundwater in this area is appropriate for achieving RAOs. Active treatment of groundwater in the South Pit area is not included based on historical data indicating that the area is not currently a significant contributing source to the downgradient plume. Contamination in the South Pit area would be better addressed through implementation of a remedial alternative for soil, as presented in the previous section. Required monitoring and five-year reviews will indicate if this is valid.

5.1 Alternative GW1 - No Action

The no action alternative assumes no further action would be taken to address groundwater contamination. Because no remedial activities or monitoring would be implemented, long-term human health and environmental risks for the Site are essentially the same as those identified during the risk assessment (URS 2006d). This alternative is included for baseline comparison purposes and does not take into account natural attenuation of the groundwater over time.

5.2 Alternative GW2 – Institutional Controls

Institutional controls can be used to prevent and/or limit potential exposure to contaminants in groundwater. Legal and/or management controls and physical access restrictions can be applied to the Site to control or prevent present and future use and access to groundwater. This alternative would require implementation of institutional controls, most likely in the form of an environmental covenant, local ordinance imposing appropriate use restrictions, or other restriction on properties within the Site contaminated groundwater above ARARs. It should be noted that institutional controls might be a component of other alternatives.

5.3 Alternative GW3 – Monitored Natural Attenuation

MNA relies on natural processes and chemical reactions with subsurface materials to reduce contaminant concentrations at the Site to acceptable levels. Long-term monitoring (LTM) is performed throughout the MNA process to confirm that the decrease in contaminant concentrations is proceeding at rates consistent with the timeline established for meeting cleanup objectives.

According to the *EPA Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater* (EPA 1998), the most important factors for assessing whether MNA is a suitable remedy include:

- Whether the contaminants are likely to be effectively addressed by natural attenuation processes.
- The stability of the groundwater contaminant plume and its potential migration.
- The potential for unacceptable risks to human health or environmental resources by contamination.

The guidance also indicates that MNA should not be used where such an approach would result in either contaminant migration or impacts to environmental resources that would be unacceptable to regulatory agencies. Therefore, sites where the contaminant plumes have stabilized (no longer increasing in extent) or are shrinking are the most appropriate candidates for MNA remedies (EPA 1998).

5.3.1 Process Description

In this alternative, MNA would be implemented in the North Tank source area, South Pit area, and the downgradient areas of the plume. No additional engineered technologies would be used to reach groundwater cleanup goals.

Natural attenuation is comprised of biological, chemical, and physical processes that reduce mass, toxicity, mobility, volume, or concentration of contaminants *in situ*, without actively engineered remediation techniques. Processes of attenuation include biodegradation, advection, dispersion, diffusion, adsorption, and volatilization.

Biodegradation is a destructive natural attenuation process that results in the transformation of contaminants to other by-products (EPA 1998) and directly affects the persistence of some chemicals, particularly VOCs, such as PCE. Other natural attenuation processes are considered to be nondestructive and indirectly affect contaminant persistence by influencing the migration of chemicals.

Advection is the process by which dissolved contaminants in groundwater are transported by the bulk motion of groundwater flow (Freeze and Cherry 1979). Groundwater flow and advective transport occur in the direction of maximum hydraulic gradient. Dissolved contaminants migrating with groundwater tend to spread out from the path that would be expected solely from advective transport. This spreading phenomenon is known as hydrodynamic dispersion, which is caused primarily by mechanical mixing.

Dispersion is the physical process by which contaminants in groundwater are mixed with uncontaminated water, decreasing the overall level of contamination. This process is caused by differences in the velocity and rate at which groundwater flows through the flow path in an aquifer (Fetter 1994).

Diffusion is the process by which contaminant molecules dissolved in groundwater move from areas of higher concentration to lower concentration.

Adsorption is a process by which dissolved contaminants partition from the liquid to the solid phase, and is considered to be a key process affecting the rate of migration of certain contaminants in groundwater. Contaminants that are adsorbed onto the solid matrix (soil or other geologic material) in the saturated zone migrate at a slower rate than the advective transport rate, i.e., their rate is retarded to some degree.

Volatilization is a process by which organic chemicals are transferred from a liquid (dissolved phase in water) or solid (adsorbed onto soil grains) into a gas (vapor) phase. In general, the tendency of a chemical to volatilize depends on its physical properties such as vapor pressure and Henry's Law constant and environmental factors such as temperature and pressure.

5.3.2 Conceptual Design

Design for the MNA alternative consists of an LTM plan. Groundwater modeling was performed to estimate the period of time required for groundwater contaminants to reach cleanup goals with and without source removal. If there is no source removal, the results of the groundwater modeling estimate that the plume will continue to exist at levels above EPA MCLs for an extensive number of years that cannot be quantified. If there is a source removal (e.g., soil excavation), then the estimated time to reach RAOs through MNA is about 20 years. Modeling results are included in Appendix A.

The MNA LTM program would be reviewed and modified as needed on the basis of new data obtained during the monitoring period. The main components of the LTM program are listed below.

- Validate the conclusions of the RI and modeling predictions.
- Monitor increases or decreases in contaminant concentrations.
- Monitor contaminant migration or lack thereof.
- Track changes in the shape, size, or position of the groundwater contaminant plume over time.
- Assess the degree to which site-specific remediation goals are being met, and evaluate the need for additional remediation.
- Assess the degree to which potential receptors are at risk to exposure.

5.3.3 Performance Monitoring

The 29 existing groundwater monitoring wells at the Site would serve as the MNA monitoring well network as shown in Figure 5-1. Groundwater from these wells would be collected and analyzed for VOCs using EPA Method SW8260.

Quarterly LTM is planned to verify that the downgradient edge of the plume has stabilized. The MNA alternative assumes that quarterly monitoring would continue for 5 years, then annual monitoring every year for 10 years followed by monitoring every 5 years for the remainder of the LTM program. The LTM plan would be reviewed and revised as necessary to optimize the program. Groundwater data collected during the sampling events would be used as the basis for plan revisions.

The existing Twins Inn database and electronic data deliverables (EDDs) would be used to manage LTM data for the project. LTM reports would be generated in accordance with guidelines specified in the approved LTM plan for the Site. Reporting is assumed to occur annually during the first 15 years of the monitoring period and then every 5 years for the remainder of the LTM program.

The performance of the MNA program would be reviewed annually to evaluate the performance of this alternative. The review would include evaluation of statistical trends and overall effectiveness to determine whether or not RAOs have been achieved. The evaluation would use the following general guidelines:

- If contaminant concentrations are above the cleanup levels, but concentrations in the LTM wells show a decreasing trend, monitoring would continue.
- If contaminant concentrations in groundwater were less than the cleanup levels, then groundwater monitoring would continue until four quarterly sampling rounds show concentrations in the LTM wells to be below the required levels.
- If contaminant concentrations in the LTM wells at the Site remain below cleanup levels for an additional four quarterly sampling rounds, the Site would be proposed for closure with no further action.

5.4 Alternative GW4 – Anaerobic Biorecirculation and MNA

Anaerobic biodegradation removes contaminants through reductive dehalogenation, an effective process when reducing conditions are present. Recirculating groundwater in a subsurface treatment cell can assist in establishing strong reducing conditions. Anaerobic biorecirculation consists of anaerobic biodegradation occurring in a recirculation cell.

This alternative addresses groundwater contamination in the North Tank source area. Two functions are provided by this alternative: (1) treatment and (2) containment of contaminants in the North Tank source area. Contaminants would be treated through anaerobic biodegradation in a closed-loop treatment cell positioned around the source area in or nearby the northern portion of the Thoro property. Therefore, containment of this area would essentially discontinue the supply of contaminants to the downgradient plume and isolate the source area for treatment. This alternative may have some influence on the source area soils in the capillary fringe just above the water table, depending on the localized groundwater mounding effect, but is not expected to be effective for long-term soil source treatment due to the low permeability of soils near the water table.

In addition, MNA would be implemented throughout the plume during and after the biorecirculation phase is complete. The process description and conceptual design for MNA is provided in Section 5.3.

5.4.1 Process Description

Biostimulation, and possibly bioaugmentation, are used in this alternative. Biostimulation involves the addition of electron donors to the aquifer for the purpose of stimulating indigenous bacteria to degrade contaminants. Bioaugmentation is the addition of laboratory-grown microbial cultures to the groundwater system for the purpose of degrading contaminants when indigenous microbes at the Site are stressed, non-existent, or not effective at degrading contaminants. Further technical description of these two processes is provided in Section 5.6, Alternative GW6A – Anaerobic Bioremediation and MNA.

Anaerobic biorecirculation is a closed-loop groundwater extraction and reinjection system that creates a biotreatment cell in the subsurface. Groundwater is pumped from extraction wells downgradient of the source area and re-injected through infiltration wells or trenches slightly upgradient of the source area, to create a containment area around the source. As water is pumped, electron donor is pulsed into the extracted groundwater stream. This nutrient laden groundwater is then returned to the aquifer to be carried through the contaminated regions requiring treatment.

The purpose of adding electron donor is to stimulate the indigenous anaerobic bacteria to degrade contaminants and to create a localized reducing environment within the aquifer that promotes anaerobic growth. Because the electron donor supply is constant and artificially distributed through the closed-loop system, full distribution within the aquifer is expected. Therefore, contamination present in saturated soil and groundwater can be treated.

Additionally, contamination in the capillary fringe, slightly above the water table, may also be treated due to localized groundwater mounding, created and based on extraction and re-injection rates. Mounding the groundwater can raise the water table to release sorbed-phase contamination from the soil into the groundwater, and therefore the biorecirculation cell, while providing electron donor to anaerobic bacteria previously in the unsaturated zone. Although the biorecirculation system may allow for some very limited treatment of soils in the capillary fringe, it is not expected to address soil and/or residual NAPL in the vadose zone.

If determined to be necessary, bioaugmentation can be included in the biorecirculation system, where dechlorinating microbes are pulsed in with the electron donor. This application is necessary if the indigenous bacteria in the aquifer are not capable of completely removing contaminants within acceptable time fame.

5.4.2 Conceptual Design

Before the final remedial design of the biorecirculation system is completed, microcosm studies, groundwater modeling, and a pilot test would be performed to collect site-specific parameters for system performance operation. In the absence of site-specific design parameters, assumptions are made in this conceptual design.

Based on the results of pumping tests, 1 to 2 extraction and 1 to 2 injection wells would be installed to create the closed-loop recirculation system. The wells would be positioned upgradient and downgradient of the North Tank source area as shown on Figure 5-2. Assuming no access issues, the extraction wells would be located on the Vintage Sales property, and the injection wells would be located either on the Thoro property or on the property immediately to the west of the Thoro property. Well screens would extend from approximately 13 feet bgs (approximately 1.5 feet above the water table) to 27 feet bgs (above dry Denver Formation). Preferably, piping for the system would be installed across the Thoro property. However, if necessary, the piping could be routed to the north of the Thoro property. This would make the system less efficient, but is a design option.

A drawing of the biorecirculation concept is provided in Figure 5-3 and a process flow diagram is provided in Figure 5-4. Groundwater would be pumped from each of the extraction wells at an approximate rate of 0.5 gallons per minute (gpm). The extracted water would be pumped through an aboveground nutrient delivery system where electron donor is pulse-pumped into the groundwater stream. Sodium lactate is selected as the electron donor for the system based on the results of the TS (URS 2004b). The desired sodium lactate concentration (approximately 200 milligrams per liter [mg/L]) would be maintained in the groundwater using the pulsing system. However, it is anticipated that the lactate concentration would be refined after system start-up and initial operation.

The lactate-charged stream would continue through the aboveground piping and pass through the monitoring station where groundwater samples and field measurements can be collected. The parameters to be measured during system start-up and operation are listed in Table 5-1. The stream is then pumped to the injection wells where the groundwater is re-infiltrated by gravity feed or with slight pressure.

Equipment for the biorecirculation system would be installed both underground and aboveground. High density polyethylene (HDPE) piping used to transport the groundwater stream would be installed underground at approximately 40 inches bgs, to avoid damage from frost and potential vehicle traffic. Equipment used at the electron donor delivery station would be installed aboveground and consists of a delivery pump, holding tank, backflow preventer, flow meter, water filter, and polyvinyl chloride (PVC) piping. Monitoring station equipment would also be installed aboveground and consists of sampling ports, monitoring electrodes, and a data-logger. The delivery station would be housed in an enclosed, locked shed to avoid tampering. Preferably, the delivery station would be installed on the Thoro property, as close as possible to the injection wells.

The system equipment would be designed and installed to allow it to be retrofitted to accommodate for injection and extraction of reagents other than those used for bioremediation, such as chemical oxidants.

The conceptual design provided for the MNA Alternative (GW3) Section 5.3.2, would serve as the design for the MNA portion of this alternative. If the soil source is removed, then groundwater modeling estimates that the groundwater within the recirculation cell will meet EPA MCLs within about 3 to 5 years of operation, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source remains in place, then the length of time to reach MCLs within the recirculation cell is uncertain, and likewise the time frame to achieve MCLs downgradient of the POC through MNA is uncertain. For the purposes of this EE/CA, it was assumed that the recirculation system would operate for 20 years, followed by an additional 30 years of MNA. Modeling results are presented in Appendix A.

5.4.3 Performance Monitoring

Two new monitoring wells would be installed in the vicinity of the biorecirculation system: 1 upgradient of the treatment cell and 1 inside the cell located on the Vintage Sales and Leasing property. Monitoring well locations are displayed on Figure 5-2. The two new wells, along with existing wells MW003 and MW028 would be included in the performance monitoring. The existing well MW003 would also be used for monitoring, as it is currently located inside the proposed treatment cell. Well MW028 would be used for monitoring directly downgradient from the treatment cell.

Before system start-up, groundwater samples would be collected from the 4 cell monitoring wells to establish baseline contaminant concentrations. Groundwater sampling in these wells would then be conducted quarterly during operation of the recirculation system, estimated to be 5 years. Table 5-1 lists the groundwater parameters to be monitored as well as the number of wells and frequency of sample collection.

After the North Tank source has been sufficiently treated, MNA would be implemented for treatment of the remaining groundwater plume. Therefore, further performance monitoring would be conducted as part of the MNA program. The MNA portion of the performance monitoring for this alternative would begin with annual rather than quarterly monitoring, since quarterly monitoring would be accomplished during the active remediation phase. Please refer to Section 5.3.3 for MNA performance monitoring.

For purposes of this study, the source of the groundwater plume in the North Tank source area is assumed to be removed after 3 to 5 years of system operation, based on modeling. The performance of the biorecirculation alternative would be evaluated throughout system operation. This performance evaluation would use the two following general guidelines:

1. If the samples collected in the treatment cell indicate that contaminant concentrations in groundwater meet the cleanup goals, then groundwater monitoring through the original MNA LTM program would begin.
2. If the samples collected in the treatment cell indicate that contaminant concentrations in groundwater remain above the cleanup goals, then:
    - additional groundwater modeling would be performed to provide an updated estimate of the duration of the MNA LTM program and groundwater monitoring through the updated program would begin, or
    - biorecirculation operation would continue and/or different remedial actions for the Site would be considered.

5.5 Alternative GW5 – Zero-valent Iron PRB by Trenching and MNA

Treatment of chlorinated organics using ZVI is a chemical process referred to as reductive dehalogenation where iron is oxidized and the contaminant is reduced through the loss of chlorine atoms. By utilizing this chemical process in the form of a permeable barrier, contaminant source areas can effectively be contained, removing the supply of contaminants to the downgradient groundwater plume. In this alternative, an iron PRB would be installed perpendicular to the flow of contaminated groundwater from the North Tank source area and South Pit area. In addition, MNA would be implemented throughout the plume. The process description for MNA is discussed in Section 5.3.1.

5.5.1 Process Description

When properly designed, the placement of a PRB in the subsurface to intercept a contaminant plume provides a flow path through reactive treatment media with relatively small impact on the natural groundwater flow conditions. As groundwater and chlorinated organics enter the reactive zone established by the iron, oxidation/reduction reactions occur such that electrons from iron oxidation are used to reduce contaminant molecules through the sequential release of chlorine atoms.

The reaction between the ZVI and the contaminant occurs primarily on the surface of the iron granules, slowly reducing the reactivity of the granules over time. Recent studies have shown that even in challenging environments, granular iron PRBs have a projected longevity of at least 30 years where longevity is defined as the period of time over which reactivity of the iron decreases by 50% (ESTCP 2003). By serving as a type of containment technology, groundwater exiting the reactive zone and entering the downgradient plume would have been treated; eliminating the supply of contaminants from the source area to the downgradient plume.

PRBs have traditionally been designed and installed as a simple trench, excavated and backfilled with granular iron, requiring heavy construction equipment and a relatively large staging area. More recently, installation depths of approximately 30 feet bgs have been achieved with smaller construction equipment modified specifically for trenching (e.g., extended reach backhoe). Additional methods used to form continuous PRBs include single- or multi-pass trenching, and injection by hydraulic fracturing. Maximum depths range from 35 feet bgs with single or multi-pass trenching to over 100 feet bgs with injected technologies. At the Site, a continuous trenched style PRB using smaller construction or single-pass trenching equipment is most applicable. An injected PRB is cost prohibitive for the size, depth, and thickness required at the Site.

Plume capture and residence time are two important design considerations for a reactive wall. To design for adequate plume capture, the site must be thoroughly characterized, and a column test performed to understand the contaminant presence, groundwater flow patterns, and site soil and groundwater interactions with the ZVI. Residence time is the time required for contact of the contaminants and the iron granules for complete dehalogenation. This parameter determines the necessary thickness of the wall based on the contaminant concentrations and horizontal velocity of groundwater at the site based on actual subcontractor bids received for the Site.

Trenched PRBs are constructed of ZVI granules and a filler material, such as sand, used to balance the required amount of iron and the thickness of the barrier as determined by the dimensions of the trenching equipment. To optimize the reactivity of the iron granules, the maximum ratio of sand to iron is 5:1. With common construction equipment, such as a backhoe, the trench thickness is determined by the width of the excavation bucket, ranging from approximately 12 to 36 inches wide. Single- or one-pass trenching equipment also ranges from

12 to 36 inches. Multi-pass trenching equipment increases the overall thickness by excavating multiple single-pass widths in parallel, perpendicular to groundwater flow direction.

To overcome the installation challenge of potential wall collapse during trenching, a guar stabilizer can be used in a trenched PRB. Guar is a non-toxic natural polymer derived from guar beans, with the ability to suspend the granular iron and filler material (e.g., sand) creating highly viscous slurry during installation. The increased viscosity during installation exerts hydraulic pressure against the trench walls and acts as shoring to prevent trench wall collapse. When mixed with the appropriate natural “breaker” enzyme, the stabilizing guar material degrades after PRB installation into water-soluble compounds that have minimal impact on the reactivity and/or porosity of the completed PRB.

5.5.2 Conceptual Design

Before preparation of the final remedial design, a laboratory column test would be performed using soil borings and groundwater collected from the Site. This test lasts approximately 3 to 4 months and can determine the appropriate type of iron for the Site, quantify specific contaminant degradation rates and required residence times, and identify site-specific interactions that may affect iron longevity. For purposes of this study, assumptions are made where site-specific data are not available.

After evaluating the column test data to determine the site-specific iron requirements, a trenched continuous iron PRB extending approximately 200 feet across the width of the plume would be installed on the east side of Lamar Street at the POC, as displayed in Figure 5-5. The area along Lamar Street provides more complete access to the entire width of the plume in the closest proximity to the source area. In addition, the property to the east of Lamar Street is open for staging installation equipment and materials.

The PRB would be installed beginning slightly above the water table at the bottom of the confining clay layer (approximately 16 ft bgs), down to the underlying impermeable dry Denver Formation (approximately 26 ft bgs). Based on these assumptions, the calculated thickness of the iron and sand barrier required to intercept and remove contaminants at the Site is approximately 12 inches, using a 1:1 iron to sand ratio. This calculated thickness corresponds to approximately 74 yd^3 made up of 50% iron filings and 50% sand, for a PRB 200 feet in length and 2,000 square feet (ft^2) in cross-sectional area.

Prior to installation, iron filings and sand would be carefully mixed to obtain the desired ratio, density, and permeability. The iron/sand mixture would be pre-loaded into a dust-free hopper system and then fed into a slurry mixing tank in measured quantities. The guar stabilizer would then be added and mixed until the desired viscosity (similar to glycol) is reached. Immediately before trenching and PRB installation, the enzyme breaker would be added and thoroughly mixed. Once mixed with the enzyme, the iron sand slurry must be installed within 2 hours before the guar begins to degrade into water and sugars.

It may be possible that water can be used in place of the guar when using single-pass trenching. Recent field applications have demonstrated that single-pass can rapidly place the iron in the trench, eliminating the need for a viscosity stabilizer.

The PRB would be installed by single-pass trenching, which incorporates a rotary mechanism that temporarily shores trenched material behind the cutter while simultaneously placing the iron sand slurry backfill into the trench. The trencher would excavate a 12-inch wide, 26-foot bgs deep trench, while filling the zone from 16 to 26 feet bgs with the iron/sand/guar slurry. Cuttings from the trench would be placed into 40 yd^3 roll-off bins for disposal. Samples for waste characterization would be collected and analyzed as described in Section 4.3, Alternative SO3A, Soil Excavation with Off-site Treatment and Disposal.

A geomembrane would be installed on top of the iron once it is placed into the trench. Clean backfill would be used to fill the remainder of the trench from the top of the iron layer (approximately 16 feet bgs) to 6 to 12 inches bgs, and would be compacted in 1-foot lifts. A bentonite cap would be placed in the remainder of the trench to further seal the excavation at the ground surface. The portions of the backfilled trench that are exposed to heavy traffic (e.g., driveways, etc.) would be covered with asphalt or concrete, as appropriate. Other areas, away from heavy traffic, would be covered with appropriate vegetation.

The conceptual design provided for the MNA Alternative (GW3) Section 5.3.2, would serve as the design for the MNA portion of this alternative. If the soil source is removed, then modeling indicates that the groundwater downgradient of the PRB (i.e., east of Lamar Street) would achieve MCLs in about 20 years through MNA. If the soil source remains in place, then the PRB provides long-term source containment upgradient (i.e., west) of Lamar Street, and groundwater downgradient of the PRB is expected to achieve MCLs within about 20 years as long as the PRB remains effective. For the purposes of this EE/CA, it was assumed that the PRB would need to be replaced in 30 years if the source is not removed, and long-term monitoring would be conducted for 100 years. Modeling results are presented in Appendix A.

This alternative will require authorization by the property owner for staging equipment and materials and implementation of institutional controls for the PRB location, most likely in the form of an environmental covenant or other land and/or groundwater use restrictions.

5.5.3 Performance Monitoring

In addition to the existing wells at the Twins Inn Site, up to 6 monitoring wells would be installed to serve as the monitoring well network for this alternative. Monitoring wells located immediately up and downgradient of the PRB are required to effectively monitor the PRB performance as shown in Figure 5-5. To better characterize the presence of contamination upgradient of the barrier, two additional wells (B_1 and B_2) are recommended to be installed parallel to the PRB. Two wells (A_1 and A_2) are proposed at each end of the PRB, approximately 10 feet off the horizontal extent of the barrier. These two wells would monitor the groundwater flow to ensure that the plume is not passing around the horizontal extent of the PRB. The remaining two wells (C_1 and C_2) would be installed downgradient and parallel to the barrier.

Baseline groundwater parameters and samples would be collected before and after PRB construction. Groundwater parameters would be monitored in the field on a monthly basis for up to 1 year to monitor the geochemical effects of the PRB. Groundwater parameters include pH, dissolved oxygen, oxidation-reduction potential, conductivity, and temperature. In conjunction with the monitoring of groundwater parameters, groundwater samples would be collected on a quarterly basis to monitor the effectiveness of the reactive wall and analyzed for VOCs (by EPA Method SW8260B), calcium, total iron, total manganese, alkalinity (total, bicarbonate, and carbonate), and chloride. Groundwater monitoring and sample collection would then continue on a quarterly basis.

In addition to performance monitoring for the PRB, MNA would be implemented downgradient of the PRB throughout the groundwater plume. Therefore, performance monitoring outside the PRB installation area would be conducted as part of the MNA program. Please refer to Section 5.3.3 for MNA performance monitoring.

The performance of the ZVI PRB and MNA alternative would be determined after construction is complete and contaminant concentrations downgradient of the barrier have been established. This performance evaluation would use the two following general guidelines:

1. If the samples collected from monitoring wells immediately downgradient of the PRB 1 year after the construction indicate that contaminant concentrations in groundwater meet the cleanup goals, then groundwater monitoring through the original MNA LTM program would continue.

2. If the samples collected from monitoring wells immediately downgradient of the PRB 1 year after the construction indicate that contaminant concentrations in groundwater remain above the cleanup goals, then:
    - additional groundwater modeling would be performed to provide an updated estimate of the duration of the MNA LTM program and groundwater monitoring through the updated program would begin, or
    - PRB modifications and/or different remedial actions for the Site would be considered.

5.6 Alternative GW6A – Anaerobic Bioremediation and MNA

This alternative combines the use of biostimulation and bioaugmentation. Biostimulation involves the addition of electron donors to the aquifer for the purpose of stimulating indigenous bacteria capable of degrading contaminants and can be an effective treatment method when a limited quantity of a food substrate required for microbial growth is present in the natural environment. Bioaugmentation is the addition of electron donors plus laboratory-grown microbial cultures to the groundwater system for the purpose of degrading contaminants and can be an effective treatment method when indigenous microbes at the Site are stressed, non-existent, or not effective at degrading site contaminants.

In this alternative, a combination of biostimulation and bioaugmentation would be implemented in the North Tank source area, the major contributing source of the plume. In addition, MNA would be implemented throughout the plume during and after the bioremediation treatment phase is complete. The process description for MNA is discussed in Section 5.3.1.

5.6.1 Process Description

Biostimulation: Anaerobic biostimulation consists of the addition of electron donors to stimulate the growth of indigenous anaerobic microorganisms within their native environment, therefore increasing anaerobic biodegradation of contaminants. Anaerobic bacteria can degrade chlorinated hydrocarbons through reductive dehalogenation, where a hydrogen atom, reducing the compound to a lesser chlorinated species, replaces a chlorine atom in the contaminant. An example of this process is where PCE is sequentially reduced to TCE, to a DCE isomer, to vinyl chloride, and finally to ethene. This process is not always complete and may only occur in segments resulting in a build up of degradation products such as *cis*-1,2-DCE. In addition, the rates of reduction for PCE and TCE are higher than for DCE and vinyl chloride.

To facilitate cell development and reproduction, anaerobic bacteria require a growth substrate (food source), which is the electron donor. As the food substrate is added to the subsurface, the indigenous microbes grow and reproduce faster and more efficiently than under natural conditions. This increase in microbial growth stimulates the anaerobic reductive dehalogenation biodegradation process, and therefore, the rate of contaminant destruction.

Several anaerobic substrates were tested during the bench-scale treatability study and include lactate, edible oil, propylene glycol, and molasses (URS 2004b). Of the four substrates tested, lactate + theralin and molasses + nutrient media most effectively removed contaminants and are therefore included in this alternative. In addition, Hydrogen Release Compound (HRC®) is a proprietary, slow release, food grade, polylactate ester and can be used as an electron donor. Although the performance of HRC® is well documented, the cost is higher than non-proprietary electron donors.

Bioaugmentation: In many cases, indigenous microorganisms even after biostimulation do not have the ability to completely degrade a specific contaminant. Bioaugmentation can establish a consortium of microorganisms to destroy contaminants by introducing effective species for complete contaminant degradation, increasing population densities, or accelerating biodegradation rates to meet treatment goals. As anaerobic microorganisms are added to the subsurface, an electron donor reagent consisting of electron donors (lactate or HRC®), vitamins, an oxygen scavenger (such as methanol), and reducing agents (such as ferrous iron) may also be added to help establish the reducing conditions in the aquifer, creating the necessary environment for the anaerobic bacteria to live.

The anaerobic bacterium *Dehalococcoides ethenogenes* is currently the only known organism that can completely dechlorinate PCE and TCE to ethene via dehalorespiration (Magnuson et al. 2000; Maymó-Gatell et al. 1997; Damborsky 1999; Duhamel et al. 2002). For other organisms that have demonstrated the ability to reductively dechlorinate PCE and TCE, the dechlorination is incomplete with the end product being *cis*-1,2-DCE (Maymó-Gatell et al. 1997; Suyama et al. 2001; Wild et al. 1997; Damborsky 1999; Magnuson et al. 2000; Duhamel et al. 2002).

During the field sampling for the TS, groundwater samples were collected from 4 monitoring wells to detect native *Dehalococcoides* at the Site. Results of the sampling and analysis showed that low to non-detect levels were observed in samples collected from the South Pit and the downgradient portions of the plume. Therefore, dechlorinators in these areas are either poorly distributed and/or exist at very low densities. In contrast, a high detection of the bacteria was observed in the sample collected from the North Tank source area. Due to the high concentration levels of *cis*-1,2-DCE, it is not known whether the species of *Dehalococcoides* present is capable of degrading the higher chlorinated hydrocarbons (i.e., PCE and TCE) to ethene. Therefore, the addition of a more effective dechlorinator strain may be appropriate.

5.6.2 Conceptual Design

Liquid reagents consisting of an electron donor such as lactate + theralin, molasses + nutrient media, or HRC®, and a *Dehalococcoides* microbial culture, if determined to be necessary, would be injected directly into the aquifer to address contamination in the saturated zone. Approximately 32 injection locations would be established within and downgradient of the North Tank source area as displayed on Figure 5-6. It is assumed that two applications of electron donor reagent and one application of microbial culture would be delivered to complete the bioremediation treatment.

The electron donor reagent applications would stimulate indigenous microbes to degrade contaminants (biostimulation) and are required to condition the aquifer before the addition of a laboratory-grown *Dehalococcoides* culture (bioaugmentation). It may be possible that electron donor amendments are all that is required to decrease contaminant concentrations to acceptable levels and bioaugmentation is not necessary. After each application of electron donor reagent, groundwater samples would be collected and the results would be evaluated to determine if additional applications of electron donor reagent or microbial culture are necessary. The flowchart in Figure 5-7 displays the decision process to evaluate and implement the components of the bioremediation alternative.

Injection locations in the 0.5-acre treatment area would be spaced on a 50 x 50-foot grid and staggered to allow for the most effective distribution of liquid reagents. This spacing is based on an estimated hydraulic conductivity of 15.9 feet/day (URS 2001a) and the assumption that stimulated or augmented microbes would not flow with groundwater. The staggered injection locations would spot treat the initial injection areas, intercept the influx of contaminated groundwater, and grow beyond their initial injection areas to cover a majority of the planned injection zone.

The actual number and placement of injection locations may vary depending on access agreements with property owners and impediments such as structures, railroads, easements, underground utilities, etc.

For the injection points, a direct push drill rig would be used to install injection rods and screens to predetermined depths. The direct push injection system is designed to allow for pressure injection and introduction of reagents directly into the aquifer. Initially, drill rods consisting of a 1.25-inch outer diameter stainless steel casing with a fixed tip would be driven into the subsurface via the drill rig. These rods would be advanced to create the injection borehole. Once the desired depth is reached, the rods would be pulled back 4 feet to reveal a stainless steel screen. This screened section of rod is typically used for groundwater sampling; however, it can also be used to support the walls of the borehole to avoid collapse during injections.

The screened interval of the injection boreholes would be positioned to deliver electron donor reagents and microbial culture to the saturated zone between the confining clay layer at the top of the aquifer and the low permeability bedrock (Denver Formation) at the bottom. This saturated zone is estimated to be a 10-foot interval, approximately 16 to 26 feet bgs.

Two temporary boreholes would be drilled within 1 foot of each other at each injection location. One borehole would be used to deliver shallow injections and the second to deliver deeper injections. The deeper borehole would be drilled to the bottom of the aquifer, the actual depth to be determined in the field based on drilling refusal. The shallow borehole would be drilled to a depth that is 5 feet above the bottom of the deeper borehole. This configuration allows for two 4-foot injection intervals and two 1-foot blank intervals that are expected to be addressed by slight mounding from injection, therefore covering the 10-foot interval. A bioremediation injection location schematic is shown in Figure 5-8.

To inject the reagents, the top of the well casing would be fitted with an injection hose adapter to transfer solutions from the mixing tanks into the ground. Material may be heated to limit viscosity, and then pumped into the boreholes at each injection location using a diaphragm pump. Low injection rates and pressures of approximately 10 gpm and 10 to 50 pounds per square inch (psi), respectively, would be used to limit mounding effects and establish the greatest lateral ROI. Approximately 20,000 to 30,000 pounds of electron donor reagent and 300 liters microbial culture would be delivered to the site over multiple applications to complete the bioremediation treatment.

The conceptual design provided for the MNA Alternative (GW3) Section 5.3.2, would serve as the design for the MNA portion of this alternative. If the soil source is removed, then groundwater modeling estimates that the groundwater within the 0.5-acre treatment area will meet EPA MCLs within about 6 years, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source is left in place, then this alternative becomes impractical with an indefinite time frame to meet MCLs. Modeling results are presented in Appendix A.

5.6.3 Performance Monitoring

In conjunction with the existing wells at the Site, 2 new wells would serve as the monitoring well network for this alternative. The 2 new wells would be installed in the plume transition area, (downgradient of the North Tank source area and upgradient of the POC), and are shown on Figure 5-6. These new wells and 7 existing wells would be used to monitor the performance of the bioremediation treatment. The remainder of the existing wells shown on Figure 5-1 would be included in the MNA monitoring plan. The MNA portion of the performance monitoring for this alternative would begin with annual rather than quarterly monitoring. Please refer to Section 5.3.3 for MNA performance monitoring.

Before the initial injection, groundwater samples would be collected to establish baseline contaminant concentrations. After each injection event, groundwater samples would be collected on a quarterly basis to evaluate the number of electron donor reagent applications required and if an application of microbial culture is necessary (refer to flowchart in Figure 5-7). It is estimated that 12 quarters of monitoring would be required to effectively monitor the performance of the bioremediation alternative. Table 5-1 lists the groundwater parameters to be monitored as well as the number of wells and frequency of sample collection.

The performance of the bioremediation + MNA alternative would be determined after injections are complete and a new baseline for contaminant concentrations has been established. This performance evaluation would use the two following general guidelines:

1. If the samples collected 1 year after the final injection event indicate that contaminant concentrations in groundwater meet the cleanup goals, then groundwater monitoring through the original MNA LTM program would begin.
2. If the samples collected 1 year after the final injection indicate that contaminant concentrations in groundwater remain above the cleanup goals, then:
    - additional groundwater modeling would be performed to provide an updated estimate of the duration of the MNA LTM program and groundwater monitoring through the updated program would begin, or
    - additional injections and/or different remedial actions for the Site would be considered.

5.7 Alternative GW7A – *In Situ* Chemical Oxidation and MNA

In situ chemical oxidation is based on the delivery of a chemical oxidant to contaminated media to destroy the contaminants or to convert them to innocuous compounds commonly found in nature. In this alternative, chemical oxidation would be implemented in the North Tank source area, the major contributing source of the groundwater plume. In addition, MNA would be implemented throughout the plume during and after the chemical oxidation treatment phase. The process description for MNA is discussed in Section 5.3.1.

5.7.1 Process Description

Oxidants attack the carbon-carbon bonds in chlorinated hydrocarbons, and the final breakdown products are CO_2, H_2O, and chloride. An oxidant typically applied in this process is Fenton's reagent, which is hydrogen peroxide combined with soluble iron. In addition, another oxidant, sodium persulfate (persulfate) has just recently joined the list of oxidants that are effective for treating chlorinated hydrocarbon contaminants.

Fenton's Reagent: Fenton's reagent is a chemical oxidant that can be injected into the subsurface to treat contamination in the saturated zone. Conventional Fenton's chemistry reactions are produced when hydrogen peroxide is applied with an iron catalyst, creating a hydroxyl free radical ($OH\bullet$) capable of oxidizing complex organic compounds such as TCA, PCE, TCE, DCE, and vinyl chloride. The fundamental Fenton's reaction involving the addition of dilute hydrogen peroxide to a degassed solution of ferrous iron is as follows,

$$H_2O_2 + Fe^{2+} \rightarrow OH\bullet + OH^- + Fe^{3+} \qquad \textit{Equation 1}$$

where H_2O_2 is hydrogen peroxide, Fe^{2+} is ferrous iron, Fe^{3+} is ferric iron, $OH\bullet$ is the hydroxyl free radical, and OH^- is the hydroxide ion. Residual hydrogen peroxide decomposes into water and oxygen in the subsurface and any remaining iron precipitates out of groundwater as ferric iron. In addition, the hydroxyl radical reacts to form CO_2, and the chloride ion (Cl^-).

The hydroxyl free radical is a strong oxidizer and is capable of treating sorbed-phase as well as dissolved-phase contamination. In addition, minor agitation produced during the reaction between hydrogen peroxide and ferrous iron can assist in transferring sorbed or immobile contamination into the dissolved phase, where it can be treated more effectively.

Because Fenton's reagent is capable of releasing sorbed contamination from saturated soil particles into the dissolved phase, a dramatic increase in contaminant concentrations is typical following an injection; however, the increase is temporary. Over a short period of time (days to weeks), the dissolved-phase contaminant is treated with the excess reagent or reabsorbed to soil particles, resulting in decreases in contaminant concentrations.

The reaction between hydrogen peroxide and ferrous iron is vigorous and can produce significant amounts of off-gassing, causing injected material to force its way up and onto the ground surface. Because of this tendency for the material to surface, modified iron catalysts have been created to slow down the reaction between hydrogen peroxide and ferrous iron to a more controlled pace. Slowing down the reaction controls the off-gassing process, creating more favorable conditions for the injected material to remain below ground. In addition to a slower, more controlled reaction, the modified Fenton's reagent does not require pH adjustments, as with conventional Fenton's reagent where acidic conditions are necessary to maintain ferrous iron concentrations. In contrast to Fenton's reagent reactions, oxidation with persulfate produces minimal off-gassing.

Sodium Persulfate: Activated persulfate has been widely used in industry to initiate polymerization reactions, etch and clean printed circuit boards, remove dyes, and enhance hair bleaches. Recent laboratory testing has shown that persulfate can also oxidize a wide range of environmental contaminants including PCE and TCE, though the reaction conditions continue to be optimized at this time.

Persulfate salts, such as sodium persulfate, are water-soluble, crystalline solids that when activated react to form persulfate radicals ($SO_4^{-\bullet}$). These radicals are strong oxidants that react with chlorinated hydrocarbons as well as non-target compounds such as natural organic matter and other reduced soil species. The end product is sulfate, as shown below in Equations 2 and 3. (The electron, e^-, in Equation 2 is supplied by the oxidized contaminant.)

$$S_2O_8^{2-} \xrightarrow{\text{catalyst}} 2SO_4^{-}\bullet \qquad \textit{Equation 2}$$

$$SO_4^{-}\bullet + e^- \rightarrow SO_4^{2-} \qquad \textit{Equation 3}$$

Activation of persulfate may be accomplished with a transition metal-based catalyst, such as chelated iron. Persulfate is effective at near-neutral pH, so acidification of the treatment solution is not necessary. In addition, no significant heat or off-gassing is generated during the oxidation reaction with chlorinated hydrocarbons. However, depending on facility conditions, the addition of persulfate could result in a slight decrease in pH and an increase in sulfate concentrations in groundwater.

Depending upon the change in pH, secondary effects with persulfate, as well as Fenton's reagent, such as mobilization of metals could occur. It is likely however, that these effects would be transitory since pH should eventually return to pre-treatment levels as untreated groundwater enters the treatment zone and metals would re-precipitate upon contact with untreated soil downgradient of the injection zone. The volume of oxygen (O_2) generated is low, approximately 0.3 liters of O_2 gas per 1 liter of 5 grams per liter (g/L) $S_2O_8^{2-}$. In comparison, Fenton's reagent oxidation generates approximately 3 to 4 liters of O_2 gas per liter of 1% hydrogen peroxide solution.

5.7.2 Conceptual Design

Liquid chemical oxidant would be injected directly into the aquifer to address dissolved and sorbed-phase contamination in the saturated zone. Initially, saturated soil samples would be collected from two areas of the North Tank source area to perform pre-design soil oxidant demand (SOD) tests to estimate the quantity of oxidant required to reach cleanup goals. The injection locations would be established within and directly downgradient of the North Tank source area as displayed on Figure 5-9. Three separate injection events are estimated to be required to remove contamination dissolved in groundwater and sorbed to soil particles. It is assumed that the first two injection events would cover the entire areas as outlined in Figure 5-9. The third application is assumed to cover half of the injection areas and is intended to be a "polishing" application where any areas of remaining contamination would be addressed. Based on the groundwater monitoring results after the first and second injection, it may be possible that a third injection event is not necessary. To establish a relative cost of this alternative, 2.5 applications are assumed.

The injection locations would be spaced on a 30 x 50-foot grid and staggered to allow for the most effective oxidant distribution. This spacing is based on an estimated hydraulic conductivity of 15.9 feet/day and an assumed oxidant persistence of 3 days. The actual number and placement of injection locations may vary depending on access agreements with property owners and impediments such as structures, railroads, easements, underground utilities, etc.

For the injection points that are not located under buildings, a direct push drill rig would be used to install injection rods and screens to predetermined depths at injection locations at the Site. The direct push injection system is designed to allow for pressure injection and introduction of oxidants directly into the aquifer. Initially, drill rods consisting of a 1.25-inch outer diameter stainless steel casing with a fixed tip would be driven into the subsurface via the drill rig. These rods would be advanced to create the injection borehole and would be removed upon reaching the desired injection depth. Next, an injection rod consisting of a 1.5-inch diameter stainless steel fixed tip attached to a 1.25-inch diameter screen would be pushed into the borehole. Solid sections of 1.5-inch diameter casing would be added behind the initial drive rod, and advanced until the desired injection depth is reached.

Two temporary boreholes would be drilled within 1 foot of each other at each injection location. One borehole would be used to deliver shallow injections and the second to deliver deeper injections. The vertical injection zone is estimated to be approximately 16 to 26 feet bgs in the North Tank source area and directly downgradient; however, actual injection depths would be determined in the field based on drilling refusal. A conceptual injection point design diagram is shown in Figure 5-8.

Injection screens installed in the boreholes would be 3 to 6 feet in length, allowing oxidant to be delivered over 3- to 6-foot intervals within the borehole. The screened interval would be positioned to deliver reagent to the saturated zone between the confining clay layer at the top of the aquifer and the impermeable bedrock (Denver Formation) at the bottom. Specifically, injection screens would be driven to the depths necessary to cover the 16- to 26-foot interval.

Before injection, the exposed top of the drill rods would be fitted with an injection hose adapter to transfer the oxidant solution from the mixing tank into the ground. The solution would be pumped into the boreholes at each injection location using an air diaphragm pump at an injection rate of approximately 10 gpm and pressures of 10 to 50 psi. Approximately 200 to 300 gallons of oxidant solution would be pumped into each injection location for a total of 16,600 to 24,900 gallons for the first and second site-wide injection event, and 8,300 to 12,450 for the third event.

The conceptual design provided for the MNA Alternative (GW3) Section 5.3.2, would serve as the design for the MNA portion of this alternative. If the soil source is removed, then groundwater modeling estimates that the groundwater within the 0.5-acre treatment area will meet EPA MCLs within about 5 years, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source is left in place, then this alternative becomes impractical with an indefinite time frame to meet MCLs. Modeling results are presented in Appendix A.

5.7.3 Performance Monitoring

In conjunction with the existing wells at the Site, 2 new wells would serve as the monitoring well network for this alternative. The 2 new wells would be installed in the plume transition area, downgradient of the North Tank source area, and are shown on Figure 5-9. These new wells and 7 existing wells would be used to monitor the performance of the chemical oxidation treatment.

The remainder of the existing wells also shown on Figure 5-1 would be included in the MNA monitoring plan. The MNA portion of the performance monitoring for this alternative would begin with annual rather than quarterly monitoring. Please refer to Section 5.3.3 for MNA performance monitoring.

Before the initial injection, groundwater samples would be collected to establish baseline contaminant concentrations. After each injection event, groundwater samples would be collected on a quarterly basis to evaluate the amount of oxidant still required. It is estimated that six quarters of monitoring would be required to effectively monitor the performance of the chemical oxidation alternative. Table 5-1 lists the groundwater parameters to be monitored as well as the number of wells and frequency of sample collection.

The performance of the *in situ* chemical oxidation + MNA alternative would be determined after injections are complete and a new baseline for contaminant concentrations has been established. This performance evaluation would use the two following general guidelines:

1. If the analyses of samples collected 1 year after the third injection event indicate that contaminant concentrations in groundwater meet the cleanup goals, then groundwater monitoring through the original MNA LTM program would begin.
2. If the analyses of samples collected 1 year after the third injection indicate that contaminant concentrations in groundwater remain above the cleanup goals, then:
    - Additional groundwater modeling would be performed to provide an updated estimate of the duration of the MNA LTM program and groundwater monitoring through the updated program would begin, or
    - Additional injections and/or different remedial actions for the Site would be considered.

5.8 GW8 – Alternate Water Supply and Institutional Controls

5.8.1 Process Description

This remedial alternative provides a permanent alternative water supply for commercial properties where shallow groundwater wells are used to obtain drinking water. It also includes institutional controls/environmental covenants for shallow groundwater at the source area. No engineered technologies would be used to achieve groundwater cleanup goals. This alternative removes the point of exposure to groundwater by plugging and abandoning two existing shallow wells used for potable water and arranging for City of Arvada water for the affected properties.

The properties proposed for the alternate water supply are located in unincorporated Jefferson County northwest of the intersection of Sheridan Boulevard and Ralston Road where concentrations of Site COCs in shallow groundwater exceed MCLs and shallow wells are present nearby. (Note that the water in the two shallow wells used for drinking water in this area already meet MCLs and as of December 11, 2008 EPA no longer required treatment of this water). These properties would be annexed by the City of Arvada and then several taps and associated water supply lines would be installed to provide these properties with water from the City of Arvada system. After the City of Arvada water connections are in place, the shallow groundwater supply wells would be permanently plugged and abandoned. With the exception of this area of unincorporated Jefferson County, the rest of the Twins Inn plume area properties are already supplied potable water through the City of Arvada water system. An alternate water supply is not necessary for these properties that are already within the City of Arvada.

Institutional controls would be implemented to restrict use of the shallow groundwater to prevent and/or limit potential exposure to contaminants in groundwater. Institutional controls would consist of environmental covenants and/or environmental restrictions on the source area parcel (Thoro Products property).

5.8.2 Conceptual Design

The alternate water supply alternative consists of the following steps:

- Annexing the subject commercial business properties into the City of Arvada.
- Designing the piping and selecting the tap locations.
- Connecting the commercial businesses to the City of Arvada water system.
- Abandoning the existing known shallow groundwater supply wells within the plume area.
- Placing institutional controls (in the form of environmental covenants and/or environmental restrictions) on the source area parcel (Thoro Products property) to restrict the use of subsurface soil and groundwater, and to prohibit uncontrolled disturbance of contaminated soil and sources of contamination. Such a covenant or use restriction would be created under 25-15-317 et seq., CRS.

City of Arvada water system connections require service pipe line installation to distribute water to the properties. The pipe installation would involve clearing surface materials, such as asphalt and vegetation, from the planned pipe excavation area, excavating shallow soil to install the pipe, and connecting the pipe to the main water distribution line and property water tap. For this remedial alternative, the conceptual design assumes that four service lines would be installed in the annexed area. Based upon potential water service requirements, the conceptual design also assumes that three water service lines would be ¾” and one would be a 1” diameter. The pipe excavations would be backfilled with soil and surface materials would be replaced. The existing water lines connected to the existing groundwater wells would be disconnected from the wells and connected to the City of Arvada water system.

After the connections to the City of Arvada water system are in place, the shallow drinking water wells would be abandoned (closed or removed) in accordance with the Colorado water well abandonment rules (2 CCR 402-2, State Rule 16).

5.8.3 Performance Monitoring

The existing groundwater monitoring wells at the Site would serve as the monitoring well network. Groundwater from these wells would be collected and analyzed for VOCs using EPA Method SW8260.

Annual long-term monitoring (LTM) would be used to verify that the downgradient edge of the plume remains stable. This alternative assumes that annual monitoring would continue for 5 years, then the monitoring frequency would be reduced to every 5 years. The LTM program length would be dependent upon the monitoring results. The LTM plan would be reviewed and revised, as necessary, to optimize the program with respect to the number of wells sampled and the sampling frequency.

6.0 Alternative Screening

The soil and groundwater alternatives developed in Sections 4.0 and 5.0 were evaluated for effectiveness, implementability, and cost. “Effectiveness” includes evaluations for four screening criteria (overall protection of human health and the environment; long-term effectiveness; reduction in toxicity, mobility, and volume; and short-term effectiveness). Therefore, alternatives were essentially screened using six of the screening criteria. An evaluation of the alternatives with respect to compliance with ARARs is provided in the detailed analysis of alternatives in Sections 7.0 and 8.0. Table 6-1 presents the screening of alternatives for soil. Tables 6-2a and 6-2b present the screening of alternatives for groundwater. Table 6-2a assumes that the soil source has not been removed and Table 6-2b assumes that it has been removed. The screening step was used to evaluate whether alternatives should be further retained or rejected for detailed analysis.

6.1 Effectiveness

Each alternative was evaluated for effectiveness in providing protection of human health and the environment and the reduction in toxicity, mobility, or volume that it would achieve. Reduction in toxicity, mobility, or volume refers to changes in one or more characteristics of the contaminant or contaminated media by the use of treatment that decreases the inherent threats or risks associated with the hazardous material (EPA 1988). In addition, both short- and long-term components of effectiveness were evaluated.

6.2 Implementability

Implementability consists of the technical feasibility of constructing, operating, and maintaining a remedial action alternative, and the administrative feasibility of obtaining approvals from agencies, access from property owners, treatment equipment and material, and disposal services. Implementability for alternative screening is used to evaluate the combinations of process options with respect to conditions specific to the Site.

6.3 Cost

Comparative cost estimates for alternatives were made using the Remedial Action Cost Engineering and Requirements (RACER™) cost estimating program. Estimates were made with relative accuracy to within +50 to –30%. Both capital and O&M costs are included for the life of the remedial action. Tables 6-1, 6-2a and 6-2b include the total estimated alternative cost, and a more detailed cost summary including net present value for capital, O&M, and periodic costs is provided in Table 6-3. The data and assumptions used for cost estimating, and the RACER backup reports are included in Appendix B.

6.4 Retained Alternatives

The screening was first completed on the soil alternatives, as shown in Table 6-1. The following alternatives for soil are retained for the detailed analysis presented in Section 7.

Soil

1. SO1 – No Action
2. SO2 – Institutional Controls
3. SO3A – Soil Excavation with Off-site Treatment and Disposal
4. SO4A – Soil Excavation with On-site Thermal Desorption

The uncertainty of access to the Thoro property affects the results of the alternative screening. The no action alternative is retained for comparison to other alternatives, although it is not effective at addressing the soil contamination. Institutional controls are retained to restrict the disturbance of subsurface soil. If access is obtained, the soil excavation with off-site treatment and disposal and the soil excavation with thermal desorption alternatives are retained. The soil excavation with off-site treatment and disposal alternative (SO3A) could be performed with or without demolition of the Thoro building. The soil excavation with on-site thermal desorption alternative (SO4A) can only be implemented if the Thoro building is demolished so that there is sufficient space for an on-site thermal treatment unit. The SVE alternative was rejected primarily because the dense, low permeability clay that is present in the vadose zone will present difficulties for vapor removal.

The groundwater alternatives were screened based on two scenarios. In the first scenario, the soil source is left in place, where it continues to be a source of groundwater contamination. Table 6-2a presents the screening based on this scenario. In the second scenario, the soil source is removed, resulting in an anticipated decrease in groundwater concentrations over time. Table 6-2b presents the screening based on this scenario. Based on the screening completed in Tables 6-2a and 6-2b, the following alternatives for groundwater are retained for the detailed analysis presented in Section 8.

Groundwater without Soil Source Removal

1. GW1 – No Action
2. GW4 - Anaerobic Biorecirculation with MNA

3. GW5 - Zero-valent Iron PRB with MNA
4. GW8 – Alternate Water Supply and Institutional Controls

Groundwater with Soil Source Removal

1. GW1 – No Action
2. GW3 – Monitored Natural Attenuation (MNA)
3. GW4 – Anaerobic Biorecirculation with MNA
4. GW5 – Zero-valent Iron PRB with MNA
5. GW6 – Anaerobic Bioremediation with MNA
6. GW7A – In Situ Chemical Oxidation with MNA

For groundwater, assuming that the soil source is not removed, anaerobic biorecirculation and the ZVI PRB alternatives were retained since both do not necessarily require access to the Thoro property and are effective and implementable. It is important to note, however, that although the biorecirculation alternative can be implemented without access to the Thoro property, it would be easier to implement with access to the Thoro property for installation of piping and periodic monitoring. Both the anaerobic biorecirculation and ZVI PRB alternatives contain the source and are expected to achieve ARARs downgradient of the POC, but they do not address the source area soils. The anaerobic biorecirculation system would address source area groundwater on the Thoro and Vintage Sales properties, but the system would have to be operated indefinitely to ensure effectiveness in the long-term if the soil source remains in place. The MNA, anaerobic bioremediation, and *in situ* chemical oxidation alternatives would not be effective at meeting RAOs in the long-term if the source of groundwater contamination were left in place and untreated, and therefore these alternatives were not retained for the scenario with the source area soil left in place. An alternate water supply and institutional controls would address the RAOs and restrict the use of groundwater on the source area parcel.

For groundwater, assuming that the soil source is removed, MNA, anaerobic bioremediation, and *in situ* chemical oxidation were retained in addition to anaerobic biorecirculation and the ZVI PRB alternatives. These alternatives would achieve RAOs, meet ARARs downgradient of the POC, be protective, and are implementable. However, the anaerobic bioremediation and *in situ* chemical oxidation alternatives both require access to the Thoro property and adjacent Vintage Sales and Leasing property for implementation (e.g., drilling boreholes to inject nutrients or oxidant compounds). As mentioned above, the anaerobic biorecirculation and ZVI PRB alternatives do not necessarily require access to the Thoro property for implementation.

7.0 Detailed Analysis of Alternatives for Soil

The detailed analysis of alternatives provides a further assessment of the remedial alternatives to develop the rationale for remedy selection. Consistent with CERCLA and the NCP, nine evaluation criteria have been determined to be appropriate for a thorough alternative evaluation, and are categorized as threshold, balancing, and modifying, as listed below:

1. Threshold Criteria: Overall Protection of Human Health and the Environment; Compliance with ARARs
2. Primary Balancing Criteria: Long-term Effectiveness and Permanence; Reduction of Toxicity, Mobility, and Volume; Short-term Effectiveness; Implementability; and Cost
3. Modifying Criteria: State Acceptance; Community Acceptance

The seven evaluation criteria for soil that are considered to be threshold or balancing are presented in this section. It is assumed that the two modifying criteria, State Acceptance and Community Acceptance, will be factored into EPA's decision regarding cleanup at this Site. The detailed analysis of groundwater alternatives is presented in Section 8.0.

7.1 Alternative SO1 – No Action

The no action alternative assumes no further action will be taken to address soil contamination. Because no remedial activities or monitoring would be implemented, the long-term human health and environmental risks for the Site are essentially the same as those identified during the risk assessment (URS 2006d). This alternative is included for baseline comparison purposes.

7.2 Alternative SO2 – Institutional Controls

Institutional controls would be used to prevent and/or limit potential exposure to contaminants in the soil. Environmental covenants or restrictions would be applied to the source area parcel to restrict present and future use of the subsurface soil to prohibit uncontrolled disturbance of contaminated soil.

7.2.1 Overall Protection of Human Health and the Environment

Overall, this alternative provides a moderate degree of protection of human health and the environment. Institutional controls, in the form of environmental covenants, provide near-term and long-term protection of human health and the environment by preventing exposure. The contaminated soil does not leave the Site, but the use or disturbance of the soil at the source area parcel would be prohibited. Risks to human health would be controlled by preventing ingestion and direct contact with the subsurface soils in the source area.

7.2.2 Compliance With ARARs

This alternative complies with ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

7.2.3 Long-Term Effectiveness

Institutional controls manage the risk of soil contact and therefore have a high long-term effectiveness. Assuming the institutional controls are in place as long as the contamination exists, exposure to the contamination is low and the alternative is effective in the long-term.

7.2.4 Reduction of Toxicity, Mobility, and Volume

There is no reduction of toxicity or volume for this alternative, but the mobility of the soil is reduced. Because the soil remains in place, there is no soil contamination being moved and exposure to the subsurface soil would not occur. Although there is no reduction in toxicity or volume of the soil contamination, it is not expected to increase.

7.2.5 Short-Term Effectiveness

The short-term effectiveness of institutional controls on the source area parcel would be similar to the present exposure. As soon as institutional controls are finalized, this alternative would be effective.

7.2.6 Implementability

Institutional controls are implementable. The owner of the Thoro property must agree to institutional controls/environmental covenants for this alternative to be effective.

7.2.7 Cost

The total present value cost of institutional controls for soil is estimated to be $0.1 million (M). A summary of the alternative costs is provided in Table 6-3.

7.3 Alternative SO3A – Soil Excavation with Off-site Treatment and Disposal

Soil excavation with off-site treatment and disposal would remove contaminated soil from the North Tank source area and South Pit area. Access to the Thoro property is required to implement this alternative. Before excavation, the existing tanks and concrete pad at the North Tank source area would be disassembled and removed from the Site. Afterwards, soil would be excavated from the North Tank source area and South Pit area and removed from the Site. An appropriate waste contractor would manage off-site treatment and disposal.

7.3.1 Overall Protection of Human Health and the Environment

Overall, this alternative provides a high degree of protection of human health and the environment. The risks posed through soil exposure pathways are expected to be greatly reduced or eliminated long term, the main source of the groundwater plume is removed, and compliance with ARARs is anticipated. This technology is expected to remove soil contaminants from the North Tank source area and South Pit area in a relatively short amount of time. Limited short-term risks are anticipated during the short-term implementation due to engineering controls (dust suppression) and worker protection. Institutional controls will be needed to assure long-term protectiveness.

7.3.2 Compliance with ARARs

The soil excavation with off-site treatment and disposal alternative for soil is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

Applicable and/or relevant and appropriate requirements may include the following:

1. Under the Code of Federal Regulations (CFR):
    - Intergovernmental Review of EPA Programs and Activities (Executive Order 12372)
    - Clean Air Act
    - RCRA subtitle C:
        - Standards Applicable to Generators of Hazardous Waste
        - Standards Applicable to Transporters of Hazardous Waste
        - Floodplain Restriction
    - Land Disposal Restrictions
    - Hazardous Materials Permitting Program

  - Hazardous Materials Transportation Regulations

2. Under the Code of Colorado Regulations (CCR)
   - Particulates, Smokes, Carbon Monoxide, and Sulfur Oxides
   - Odor Emissions
   - Stationary Source Permitting
   - Standards of Performance for New Stationary Sources
   - Emissions of VOCs
   - Hazardous Waste Act:
     - Hazardous Waste Permitting Regulations
     - EPA Identification Numbers
     - The Manifest
     - Pre-Transport Requirements
     - Floodplain Restrictions
     - General Operational Standards for Hazardous Waste Treatment and Storage Disposal Facilities
     - Standards for Groundwater Protection and Closure and Post-Closure at Hazardous Waste Treatment, Storage, and Disposal Facilities
3. Under the United States Code (USC):
   - Fish and Wildlife Coordination Act
   - Occupational Safety and Health Administration (OSHA)

Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

7.3.3 Long-Term Effectiveness

Assuming that the main Thoro building is left in place and the soil beneath the building is not acting as a continuing source of groundwater contamination, the residual risk to human health and environment that remains after completing remedial activities is expected to be low. The excavation and off-Site treatment and disposal alternative is intended to remove contaminated soil from the North Tank source area and South Pit area at the Thoro property, along with the risk posed by exposure pathways.

Institutional controls to direct future land use, and therefore manage risk, may be appropriate. The adequacy and reliability of such additional controls is affected by the cooperation of the Thoro property owner. If that cooperation is not achieved, it is unknown whether controls can be implemented to manage exposure to human and environmental receptors long-term, to appropriate levels.

7.3.4 Reduction of Toxicity, Mobility, and Volume

A high degree or percentage of reduction of toxicity, mobility, and volume is expected for the planned excavation areas. The GRA for this soil alternative is removal and is therefore irreversible.

7.3.5 Short-Term Effectiveness

Risk to human health and the environment resulting from remedial action implementation is expected to be effectively managed during soil excavation to limit risk to the lowest possible level. Dust suppression would be initiated, transportation would be conducted in accordance with applicable regulatory requirements, and potential environmental impacts resulting from remedial activities would be minimized. Additionally, protective measures for workers would be implemented, along with air monitoring during the excavation activities.

The time to achieve the remedial response objectives is anticipated to be relatively short for this alternative.

7.3.6 Implementability

This alternative is technically implementable based on the ready availability of the appropriate and necessary equipment, reliability of the technology (few technical problems associated), and ease of performance monitoring. However, equipment and excavation logistics will pose technical difficulties, particularly in the North Tank source area between the main Thoro building and the active railroad tracks to the north of the Thoro property.

The small and confined nature of the property could hinder equipment maneuverability and possibly limit the size and depth of excavations in some areas. For example, maintaining an appropriate distance from nearby structures and shoring for excavations adjacent to buildings could reduce the volume of contaminated soil that is removed and result in ARARs not being achieved.

Administratively, this alternative is implementable with respect to agency coordination. However, access to the Thoro property is required for implementation. Therefore, the implementability of this alternative is likely to be dependent upon the level of owner cooperation.

7.3.7 Cost

The total present value cost of the soil excavation and off-site treatment and disposal alternative (SO3A), which includes removal of the sheds, aboveground tanks, and associated concrete pads, is estimated to be about $2.2M, all in capital cost. A summary of the alternative costs is provided in Table 6-3.

7.4 Alternative SO4A – Soil Excavation with On-site Thermal Desorption

Soil excavation with on-site thermal desorption would temporarily remove contaminated soil from the North Tank source area and South Pit area, treat the soil on site with a thermal desorption unit, and then return the treated soil back into the excavation areas. Access to the Thoro property is required to implement this alternative, and this alternative is only retained if the Thoro building is demolished. If the Thoro building is left in place, there is insufficient space on the Thoro property to stage the necessary thermal desorption equipment for this alternative.

Before excavation, the existing tanks and concrete pad at the North Tank source area would be disassembled and removed from the Site and the Thoro building would be removed. Afterwards, soil would be excavated from the North Tank source area and South Pit area and treated on site. Compliance with air emission limitations would likely be required for the on-site treatment operations.

7.4.1 Overall Protection of Human Health and the Environment

Overall, this alternative provides a high degree of protection of human health and the environment. The contaminated soil does not leave the Site, but is treated *ex situ* and then returned to the excavation areas. The risks posed through soil exposure pathways are expected to be greatly reduced or eliminated long term, the main source of the groundwater plume is removed, and compliance with ARARs is anticipated. This technology is expected to remove soil contaminants from the North Tank source area and South Pit area in a relatively short amount of time. Because implementation of this alternative requires demolition of the Thoro building, if there is contaminated soil beneath it, that soil can also be removed, and so little to no waste residuals would be expected, eliminating the need for long-term protective controls of the source areas. Additionally, limited short-term risks are anticipated during the short-term implementation due to engineering controls (dust suppression, fences around excavations, emission controls) and worker protection.

7.4.2 Compliance with ARARs

The soil excavation with on-site thermal desorption alternative is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

Applicable and/or relevant and appropriate requirements may include the following:

1. Under the Code of Federal Regulations (CFR):
   - Intergovernmental Review of EPA Programs and Activities (Executive Order 12372)
   - Clean Air Act
   - RCRA subtitle C:
     - Standards Applicable to Generators of Hazardous Waste
     - Standards Applicable to Transporters of Hazardous Waste
     - Floodplain Restriction
   - Land Disposal Restrictions
   - Hazardous Materials Permitting Program
   - Hazardous Materials Transportation Regulations
2. Under the Code of Colorado Regulations (CCR)
   - Particulates, Smokes, Carbon Monoxide, and Sulfur Oxides
   - Odor Emissions
   - Stationary Source Permitting
   - Standards of Performance for New Stationary Sources
   - Emissions of VOCs
   - Hazardous Waste Act:
     - Hazardous Waste Permitting Regulations
     - EPA Identification Numbers
     - The Manifest
     - Pre-Transport Requirements
     - Floodplain Restrictions
     - General Operational Standards for Hazardous Waste Treatment and Storage Disposal Facilities
     - Standards for Groundwater Protection and Closure and Post-Closure at Hazardous Waste Treatment, Storage, and Disposal Facilities

3. Under the United States Code (USC):
    - Fish and Wildlife Coordination Act
    - Occupational Safety and Health Administration (OSHA)

Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

7.4.3 Long-Term Effectiveness

The residual risk to human health and environment that remains after completing remedial activities is expected to be low. The excavation and on-site thermal desorption alternative is intended to treat contaminated soil from the North Tank source area, the South Pit area and contaminated soil beneath the Thoro building at the Thoro property, along with the risk posed by exposure pathways. The treated soil would not act as a source of groundwater contamination.

7.4.4 Reduction of Toxicity, Mobility, and Volume

A high degree or percentage of reduction of toxicity, mobility, and volume is expected for the planned excavation areas. The GRA for this soil alternative is treatment and is therefore irreversible.

7.4.5 Short-Term Effectiveness

Risk to human health and the environment resulting from remedial action implementation is expected to be effectively managed during soil excavation to limit risk to the lowest possible level. Dust suppression would be initiated, transportation would be conducted in accordance with applicable regulatory requirements, and potential environmental impacts resulting from remedial activities would be minimized. Additionally, protective measures for workers would be implemented, along with air monitoring during the excavation activities and appropriate air emission controls associated with the on-site thermal desorption unit.

The time to achieve the remedial response objectives is anticipated to be relatively short for this alternative.

7.4.6 Implementability

This alternative is technically implementable based on the ready availability of the appropriate and necessary equipment, reliability of the technology (few technical problems associated), and ease of performance monitoring. This alternative assumes that the Thoro building will be removed prior to the soil excavation; therefore, contaminated soil (if any) beneath the building would be excavated and treated. The main logistical issue for this alternative would be safety issues due to the proximity of the active railroad north of the Thoro property.

Administratively, this alternative is implementable with respect to agency coordination, although compliance with substantive requirements of air control regulations may be required for the on-site treatment. Access to the Thoro property is required for implementation. Implementability of this alternative is likely to be dependent upon the level of owner cooperation.

7.4.7 Cost

The total present value cost of the soil excavation and on-site thermal desorption alternative (SO4A), which includes demolition and removal of the main Thoro building and removal of the sheds, aboveground tanks, and associated concrete pads, is estimated to be about $2.9M, all in capital cost. A summary of the alternative costs is provided in Table 6-3.

8.0 Detailed Analysis of Alternatives for Groundwater

As explained in Section 7.0 for soil, the seven evaluation criteria for groundwater that are considered to be threshold or balancing are presented in this section. It is assumed that the two modifying criteria, State Acceptance and Community Acceptance, will be addressed as part of EPA’s decision regarding cleanup at this Site.

8.1 GW1 – No Action

The no action alternative assumes no further action will be taken to address groundwater contamination. Because no remedial activities or monitoring would be implemented, the long-term human health and environmental risks for the Site are essentially the same as the current risk presented in the risk assessment (URS 2006d). This alternative is included for baseline comparison purposes and does not take into account natural attenuation of the groundwater over time.

8.2 GW3 – Monitored Natural Attenuation

The MNA alternative assumes that natural attenuation processes will be sufficient to address groundwater contamination. The MNA alternative would only be retained if the soil source is removed so that there is no longer a continuing source of contamination to groundwater. If the source remains, then MNA is no longer a viable alternative because the time to reach RAOs cannot be determined. If the source is removed, then MNA is retained and the detailed analysis below applies.

The MNA alternative consists of periodic groundwater monitoring to assess the reduction in groundwater contaminants over time. There is no intervention in the form of additional groundwater treatment. Natural processes are assumed to be sufficient to restore the groundwater to levels that meet RAOs.

8.2.1 Overall Protection of Human Health and the Environment

Assuming removal of the soil source, this alternative provides a moderate degree of protection of human health and the environment. There is little short-term risk because the MNA occurs *in situ*. The risks posed through exposure pathways are anticipated to be reduced or eliminated long term.

8.2.2 Compliance with ARARs

Assuming there is soil source removal prior to implementation of MNA, the MNA alternative for groundwater is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

General applicable and/or relevant and appropriate requirements may include the following:

1. Under the CFR:
    - Intergovernmental Review of EPA Programs and Activities (Executive Order 12372):
    - Safe Drinking Water Act:
        - National Primary Drinking Water Standards
        - Maximum Contaminant Level Goals
        - Maximum Contaminant Levels
        - National Secondary Drinking Water Standards
    - Clean Water Act:
        - Executive Order on Floodplain Management
        - National Pollutant Discharge Elimination System (NPDES)
    - RCRA Subtitle C:
        - Standards Applicable to Generators of Hazardous Waste
        - Standards Applicable to Transporters of Hazardous Waste
        - Floodplain Restriction
    - Hazardous Materials Permitting Program:
    - Effluent Guidelines and Standards for Organic Chemicals
    - Hazardous Materials Transportation Regulations
2. Under the CCR:
    - Odor Emissions
    - Basic Standards and Methodologies for Surface Water
    - Classification and Numeric Standards for the South Platte River Basin, Laramie River Basin, Republican River Basin, Smoky Hill River Basin
    - Basic Standards for Groundwater
    - Primary Drinking Water Regulations
    - Hazardous Waste Act:
        - Hazardous Waste Permitting Regulation;

    - EPA Identification Numbers
    - The Manifest
    - Pre-Transport Requirements
    - Floodplain Restrictions
    - General Operational Standards for Hazardous Waste Treatment and Storage Disposal Facilities
    - Standards for Groundwater Protection and Closure and Post-Closure at Hazardous Waste Treatment, Storage, and Disposal Facilities
3. OSHA under the United States Code (USC) guidelines

Applicable and/or relevant and appropriate requirements specific to this alternative include the following:

4. CCR Water Well Construction Rules including:
    - Well Permit Requirements

Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

8.2.3 Long-Term Effectiveness

Upon completion of soil source removal, the magnitude of residual risk remaining from untreated waste or waste residuals in groundwater in the North Tank source area is anticipated to be low. Assuming soil source removal prior to MNA implementation, this alternative is expected to reduce groundwater contamination to levels below required regulatory standards in about 20 years.

Untreated waste or waste residuals in groundwater in the South Pit area, upgradient of the POC, will remain and would be addressed through MNA processes. During the MNA program, management and/or institutional controls can be implemented to provide continued protection from untreated waste. While this alternative assumes the owner's cooperation with respect to soil removal, it is not known whether that cooperation will extend to such management and/or institutional controls.

8.2.4 Reduction of Toxicity, Mobility, and Volume

A moderate degree of reduction in toxicity, mobility, and volume is expected for the North Tank source area and therefore, the downgradient plume. Because there is no containment in this alternative, there will be some mobility during the period of MNA, but this will be slowed by the natural attenuation processes of retardation and degradation. Based on the groundwater data for the Site, it is anticipated that natural biodegradation will reduce the toxicity of many of the contaminants over time, resulting in less toxic breakdown products.

8.2.5 Short-Term Effectiveness

Risk to human health and the environment resulting from remedial action implementation is expected to be low. The MNA alternative involves no intrusive activities other than possible well drilling. Treatment of contaminants would occur *in situ*.

Off-Site transportation of purge water from the groundwater sampling by the waste disposal contractor would be conducted in accordance with applicable regulatory requirements. Additionally, protective measures for groundwater sampling workers would be implemented.

8.2.6 Implementability

This alternative is highly implementable based on the fact that the monitoring well network is already in place and the simplicity of performance monitoring. Administratively, this alternative is expected to be implementable with respect to agency coordination.

8.2.7 Cost

The total present value cost of the MNA alternative is estimated to be $1.2M. A summary of the alternative costs is provided in Table 6-3.

8.3 Alternative GW4 – Anaerobic Biorecirculation with MNA

Anaerobic biorecirculation has the potential to treat and contain contaminated groundwater in the North Tank source area without requiring access to the Thoro property. However, access to the neighboring properties to the east (downgradient) and west (upgradient) is required for well and circulation equipment installation. MNA would be implemented throughout the remainder of the plume. The anaerobic biorecirculation with MNA alternative can be implemented with or without soil source removal. If the soil source is removed, the anticipated time to reach RAOs is reduced as so is the cost. See Section 8.3.7 for estimated costs.

The system would be comprised of groundwater extraction and injection wells, along with an aboveground mixing and inoculation station. Groundwater would be extracted from the aquifer downgradient of the North Tank source area, piped to the mixing and inoculation station where it would be charged with a biostimulation media (electron donor and possibly bioaugmented with a *Dehalococcoides* culture), then injected back into the aquifer upgradient of the North Tank source area. Extraction and injection rates would be regulated so that slight mounding of groundwater occurs at the water table to force water up into the capillary fringe, and therefore, deliver treatment to this saturated/unsaturated zone transition area.

The anaerobic biorecirculation alternative includes treatment for groundwater in the North Tank source area and does not include treatment of groundwater other than natural attenuation for the South Pit area. This design criterion is based on the interpretation of historical plume data, which indicates that the principal source of the downgradient groundwater plume is the North Tank source area.

8.3.1 Overall Protection of Human Health and the Environment

Overall, this alternative provides a high degree of protection of human health and the environment. The risks posed through exposure pathways are anticipated to be greatly reduced in the long term. The implemented technology is expected to remove groundwater contaminants *in situ* in the North Tank source area. Also, contaminated groundwater would be contained in the source area. Little to no waste residuals are expected eliminating long-term protection management of the North Tank source area.

Additionally, limited short-term risks are anticipated during the short-term implementation and operation of the recirculation system. Engineered controls would be necessary to avoid tampering with system equipment during operation. If such controls are reliable, additional exposure caused by extracted groundwater can be eliminated.

8.3.2 Compliance with ARARs

The anaerobic biorecirculation and MNA alternative for groundwater is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

General applicable and/or relevant and appropriate requirements may include the following:

1. Under the CFR:
    - Intergovernmental Review of EPA Programs and Activities (Executive Order 12372):
    - Safe Drinking Water Act:
        - National Primary Drinking Water Standards
        - Maximum Contaminant Level Goals
        - Maximum Contaminant Levels
        - National Secondary Drinking Water Standards

- Clean Water Act:
  - Executive Order on Floodplain Management
  - National Pollutant Discharge Elimination System (NPDES)
- RCRA Subtitle C:
  - Standards Applicable to Generators of Hazardous Waste
  - Standards Applicable to Transporters of Hazardous Waste
  - Floodplain Restriction
- Hazardous Materials Permitting Program:
- Effluent Guidelines and Standards for Organic Chemicals
- Hazardous Materials Transportation Regulations

2. Under the CCR:
   - Odor Emissions
   - Basic Standards and Methodologies for Surface Water
   - Classification and Numeric Standards for the South Platte River Basin, Laramie River Basin, Republican River Basin, Smoky Hill River Basin
   - Basic Standards for Groundwater
   - Regulations for the State Discharge System:
     - Permit Requirements for Discharge
     - Definition of Effluent Limitations
     - Stormwater Discharges
   - Regulations for Effluent Limitations:
   - Regulations Controlling Discharges to Storm Sewers
   - Primary Drinking Water Regulations
   - Hazardous Waste Act:
     - Hazardous Waste Permitting Regulation;
     - EPA Identification Numbers
     - The Manifest
     - Pre-Transport Requirements
     - Floodplain Restrictions
     - General Operational Standards for Hazardous Waste Treatment and Storage Disposal Facilities
     - Standards for Groundwater Protection and Closure and Post-Closure at Hazardous Waste Treatment, Storage, and Disposal Facilities

3. OSHA under the United States Code (USC) guidelines

Applicable and/or relevant and appropriate requirements specific to this alternative include the following:

4. CFR Underground Injection Control Regulations
5. CCR Water Well Construction Rules including:
    - Well Permit Requirements
    - Remediation Project Recovery Wells

Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

8.3.3 Long-Term Effectiveness

The magnitude of residual risk remaining from untreated waste or waste residuals in groundwater in the North Tank source area (the suspected source of the groundwater plume) is anticipated to be low as long as the soil source is removed. This alternative is expected to reduce groundwater contamination at the POC to levels below required regulatory standards. Little to no untreated waste or waste residuals are anticipated for this alternative, eliminating or greatly reducing the long-term risk. If the soil source remains in place, then the system may need to be operated for a long period of time to maintain long-term effectiveness.

Untreated waste or waste residuals in groundwater in the South Pit area, upgradient of the POC, will remain and would be addressed through MNA processes. During the MNA program, management and/or institutional controls can be implemented to provide continued protection from untreated waste. However, the adequacy and reliability of such controls is unknown considering the current uncertainty regarding future access to the Thoro property.

If the soil source is removed, then groundwater modeling estimates that the groundwater within the recirculation cell will meet EPA MCLs within about 3 to 5 years of operation, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source remains in place, then the length of time to reach MCLs within the recirculation cell is uncertain, and likewise the time frame to achieve MCLs downgradient of the POC through MNA is uncertain. For the purposes of this EE/CA, it was assumed that the recirculation system would operate for 20 years, followed by an additional 30 years of MNA.

8.3.4 Reduction of Toxicity, Mobility, and Volume

A high degree of reduction in toxicity, mobility, and volume is expected for the North Tank source area and therefore, the downgradient plume. Dissolved- and sorbed-phase contamination beneath the water table within the capillary fringe would be treated. In addition, groundwater would be contained in the source area eliminating the downgradient migration of contaminants. Treatment is expected to be irreversible, with limited to no treatment residuals.

8.3.5 Short-Term Effectiveness

Risk to human health and the environment resulting from remedial action implementation is expected to be low. Intrusive activities in this alternative consist of well drilling, and treatment of contaminants would occur *in situ*. Engineering controls consisting of a locked shed and/or fencing would be constructed to avoid tampering with system components, and eliminate potential exposure to extracted groundwater.

Off-Site transportation of waste by the waste disposal contractor would be conducted in accordance with applicable regulatory requirements. Additionally, protective measures for workers would be implemented.

8.3.6 Implementability

This alternative is highly implementable based on the ease of system installation, availability of experienced contractors, reliability of the technology (few technical problems associated), and simplicity of performance monitoring. Although some technical aspects of this alternative are innovative (biostimulation and bioaugmentation), the basic system design, which includes well installation, groundwater pumping, and fluid mixing, is based on conventional hydrogeologic techniques.

Administratively, this alternative is expected to be implementable with respect to agency coordination. However compliance with substantive underground injection control requirements (even if a permit is not required) would be necessary to allow reinjection of extracted groundwater, charged with nutrients.

The main implementability issue for this alternative is access, either to the Thoro property or to the adjacent properties to the east and west of the Thoro property. If access to the Thoro property is not granted, this alternative is still implementable, but access to the adjacent properties would be necessary. During the groundwater recirculation treatment duration, institutional controls on the treatment area would also be needed. It is uncertain whether the property owners would agree to such controls.

8.3.7 Cost

The total present value cost of the anaerobic biorecirculation and MNA alternative (GW4) is estimated to be about $2.5M if the soil source is not removed, and about $1.7M if the soil source is removed. Note that there is more uncertainty in the cost estimate for the scenario without soil source removal because the system may need to be operated for an indefinite amount of time to contain the source. A summary of the alternative costs is provided in Table 6-3.

8.4 Alternative GW5 – Zero Valent Iron PRB by Trenching with MNA

The installation of a ZVI PRB has the potential to treat and contain contaminated groundwater at the POC without requiring access to the Thoro property. Access to city of Arvada property and potentially the adjacent property to the east (Gold Creek Complex) is required. The PRB does not address groundwater contamination directly in the source locations since treatment relies on dissolved-phase downgradient interception. The ZVI PRB with MNA alternative can be implemented with or without soil source removal. If the soil source is removed, the anticipated time to reach RAOs is reduced and so is the cost. If the source of the plume remains, this alternative would contain it. MNA would be implemented for the area upgradient of the PRB, including the source areas, in addition to the downgradient plume.

The PRB would be installed by trenching and would extend vertically from the bottom of the aquifer (dry bedrock) to slightly above the water table. Horizontally, the PRB would extend north to south from the northern Union Pacific railroad right-of-way (northern edge of plume) to the vicinity of Ralston Creek (southern edge of plume).

8.4.1 Overall Protection of Human Health and the Environment

Overall, at the POC and downgradient of the POC, this alternative provides a high degree of protection of human health and the environment. The risks posed through exposure pathways are anticipated to be greatly reduced or eliminated long term. The implemented technology is expected to remove groundwater contaminants *in situ* at the POC with little to no waste residuals remaining downgradient. However, limited to no protection is provided upgradient of the POC where the main source area is located. Assuming no action regarding contaminated soil in the North Tank source area and South Pit area, the risk to human health and environment for the plume upgradient of the POC is assumed to be similar to the current risk presented in the risk assessment (URS 2006d), since treatment would not be implemented in this area.

8.4.2 Compliance with ARARs

The ZVI PRB and MNA alternative for groundwater is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

In addition to the general list included Section 8.2.2, the following may also be applicable and/or relevant and appropriate requirements specific to this alternative:

1. Under the Code of Colorado Regulations (CCR)
    - Particulates, Smokes, Carbon Monoxide, and Sulfur Oxides
    - Odor Emissions
    - Stationary Source Permitting
    - Standards of Performance for New Stationary Sources
    - Emissions of VOCs

Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

8.4.3 Long-Term Effectiveness

The magnitude of residual risk remaining from untreated contaminants in the groundwater plume downgradient of the POC is expected to be low. This alternative is expected to reduce groundwater contamination at the POC to levels below required regulatory standards allowing little to no untreated waste or waste residuals to reach the downgradient plume.

The magnitude of residual risk remaining from untreated waste in the North Tank source area and South Pit area is anticipated to be similar to the current calculated risk (URS 2006d). Untreated waste in groundwater upgradient of the POC is expected to remain and would be addressed to some extent through MNA processes, but will not be substantially addressed unless the soil source is removed. During the MNA program, management and/or institutional controls can be implemented to provide continued protection from untreated waste. However, the adequacy and reliability of such controls is unknown considering the current access situation with the Thoro property owner.

If the soil source is removed, then modeling indicates that the groundwater downgradient of the PRB (i.e., east of Lamar Street) would achieve MCLs in about 20 years through MNA. If the soil source remains in place, then the PRB provides long-term source containment upgradient (i.e., west) of Lamar Street, and groundwater downgradient of the PRB is expected to achieve MCLs within about 20 years as long as the PRB remains effective. For the purposes of this

EE/CA, it was assumed that the PRB would need to be replaced in 30 years if the source is not removed, and long-term monitoring would be conducted for 100 years. Modeling results are presented in Appendix A.

8.4.4 Reduction of Toxicity, Mobility, and Volume

A high degree or percentage of reduction of toxicity, mobility, and volume is expected to occur at the POC. Dissolved-phase contamination in the aquifer will be intercepted and treated. Treatment is expected to be irreversible, with limited to no treatment residuals downgradient of the POC.

8.4.5 Short-Term Effectiveness

Risk to human health and the environment resulting from remedial action implementation is expected to be effectively managed during trenching and PRB construction to limit risk to the lowest possible level. The installation location (Lamar Street) is an active industrial, commercial, and residential area, which increases the potential for risk. However, engineered and construction management controls can be implemented to manage risk. Dust suppression would be initiated and an exclusion zone and traffic plan would be developed. Work would be conducted in accordance with applicable regulatory requirements, and potential environmental impacts resulting from remedial activities would be minimized. Additionally, protective measures for workers would be implemented. After installation, risk is expected to be minimal since treatment of groundwater contaminants occurs *in situ*.

8.4.6 Implementability

This alternative is moderately implementable based on contractor availability, iron availability, reliability of technology, access issues and ease of performance monitoring. PRB installation techniques have improved over the last decade increasing implementability. The basic system design, which includes trenching and backfilling, is based on conventional construction techniques. Property access could be an issue for this alternative because it requires installation of a long-term treatment PRB on a property other than the source area. In addition, this alternative would require institutional controls, most likely in the form of an environmental covenant for the source area and the area between the source and the PRB. It is uncertain whether the property owners would agree to such environmental covenants.

Administratively, this alternative is expected to be implementable with respect to agency coordination.

8.4.7 Cost

The total present value cost of the ZVI PRB with trenching and MNA alternative (GW5) is estimated to be $1.9M if the soil source is left in place. If the soil source is removed, then the total present value cost of the ZVI PRB (GW5) is estimated to be $1.8M. A summary of the alternative costs is provided in Table 6-3.

8.5 Alternative GW6A – Anaerobic Bioremediation with MNA

Anaerobic bioremediation can be used for *in situ* treatment of contaminated groundwater within and downgradient of the North Tank source area. The anaerobic bioremediation alternative would only be retained if the soil source is removed. If the source remains, then anaerobic bioremediation is no longer a viable alternative because the time to reach RAOs cannot be determined due to the continuing source of groundwater contamination. If the source is removed, then anaerobic bioremediation is retained and the detailed analysis below applies.

Access to the Thoro property and other properties within the Site is required to implement this alternative. A network of temporary injection points would be installed in the North Tank source area on the Thoro property and directly downgradient on the Vintage Sales and Leasing property. Points would be installed up to the POC at Lamar Street. An electron donor (i.e., food source for microbes) and/or laboratory-cultivated microbe injection and groundwater monitoring program would be implemented in phases. The electron donors are expected to stimulate biodegradation of contaminants (i.e., biostimulation), and the addition of specific microbes (i.e., bioaugmentation) is expected to provide more complete biodegradation of the contaminants, compared with using indigenous microbes alone. MNA would be implemented throughout the remainder of the plume after treatment.

8.5.1 Overall Protection of Human Health and the Environment

Assuming that the soil source is removed, this alternative provides a high degree of protection of human health and the environment. The risks posed through exposure pathways are anticipated to be greatly reduced or eliminated long term. The implemented technology is expected to treat groundwater contaminants *in situ* upgradient of the POC. Little to no waste residuals are expected, eliminating long-term protection management of the North Tank source area. Additionally, limited short-term risks are anticipated during the implementation of the electron donor and/or microbe injection program.

8.5.2 Compliance with ARARs

Assuming that the soil source is removed, the anaerobic bioremediation alternative for groundwater is expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

In addition to the general list included Section 8.2.2, applicable and/or relevant and appropriate requirements specific to this alternative may include CFR underground injection control regulations and CCR water well construction rules specific to well permit requirements. Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

8.5.3 Long-Term Effectiveness

The magnitude of residual risk remaining from untreated waste is expected to be low, assuming that the soil source is removed. This alternative is expected to biodegrade dissolved-phase contamination upgradient of the POC, shortening the time required for MNA to decrease contaminants to levels below required regulatory standards. Little to no untreated waste or waste residuals is expected; therefore, the risk would be eliminated or greatly reduced.

Untreated waste or waste residuals in groundwater in the South Pit area, upgradient of the POC, may remain and would be addressed through MNA processes. During the MNA program, management and/or institutional controls can be implemented to provide continued protection from untreated waste. While this alternative assumes the owner’s cooperation with respect to soil removal, it is not known whether that cooperation will extend to such management and/or institutional controls.

If the soil source is removed, then groundwater modeling estimates that the groundwater within the 0.5-acre treatment area will meet EPA MCLs within about 6 years, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source is left in place, then it is not effective in the long term, as this alternative becomes impractical with an indefinite time frame to meet MCLs.

8.5.4 Reduction of Toxicity, Mobility, and Volume

Assuming that the soil source is removed, a high degree or percentage of reduction of toxicity, mobility, and volume is expected to occur upgradient and downgradient of the POC. Dissolved-phase contamination in groundwater upgradient of the POC would be destroyed. Treatment is expected to be irreversible, with limited to no treatment residuals, as long as the microbes are capable of fully dechlorinating the contaminants such that only ethane or ethane remains.

8.5.5 Short-Term Effectiveness

Risk to human health and the environment resulting from the remedial action implementation is expected to be low. Intrusive activities in this alternative consist of direct push drilling and injection, and treatment of contaminants would occur *in situ*. The generation of dust or waste is not expected. Additionally, protective measures for workers due to drilling activities and electron donor and microbe handling would be implemented.

8.5.6 Implementability

This alternative is moderately implementable based on the ease of installation and performance monitoring. Conventional direct push drilling and injection, which is highly implementable, would be used in portions of the treatment area. Buildings at the Thoro property and adjacent Vintage Sales property cover several of the key areas to be treated; therefore, horizontal drilling and well installation would be used to address these areas. The logistics of horizontal drilling and well installation may be difficult considering the limited work area at the Thoro property and adjacent Vintage Sales property.

Administratively, this alternative is expected to be implementable with respect to agency coordination. Additionally, an Underground Injection Control (UIC) permit waiver from EPA would be necessary. Access to the Thoro and Vintage Sales and Leasing properties are required for implementation.

8.5.7 Cost

The total present value cost of the anaerobic bioremediation and MNA alternative (GW6A) is estimated to be $1.3M, assuming that the soil source is removed prior to implementation of this alternative. A summary of the alternative costs is provided in Table 6-3.

8.6 Alternative GW7A – *In Situ* Chemical Oxidation with MNA

In situ chemical oxidation has the potential to treat contaminated groundwater within and downgradient of the North Tank source area. Access to the Thoro property and other properties within the Site is required to implement this alternative. After the treatment phase is complete, MNA would be implemented at the Site. This alternative would only be retained with soil source removal. If the source remains, then it is no longer a viable alternative because the time to reach RAOs cannot be determined. If the soil source is removed, then the alternative is retained and the detailed analysis presented below applies.

A network of temporary injection points would be installed in the North Tank source area on the Thoro property and directly downgradient on the Vintage Sales and Leasing property. Points would be installed up to the POC at Lamar Street. A chemical injection and groundwater monitoring program would be implemented and is anticipated to include three separate injections of a chemical oxidant such as Fenton's reagent. The injected reagents are expected to treat sorbed-phase soil and dissolved-phase groundwater contamination *in situ*. MNA would be implemented throughout the remainder of the plume after treatment.

8.6.1 Overall Protection of Human Health and the Environment

Assuming that the soil source is removed, this alternative provides a moderate to high degree of protection of human health and the environment. The risks posed through exposure pathways are anticipated to be greatly reduced or eliminated long term. The implemented technology is expected to remove groundwater contaminants *in situ* upgradient of the POC, removing the main source of the groundwater plume. Little to no waste residuals are expected, eliminating long-term protection management of the North Tank source area. Additionally, limited short-term risks are anticipated during the implementation of the chemical oxidation program.

8.6.2 Compliance with ARARs

The *in situ* chemical oxidation and MNA alternative for groundwater are expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

In addition to the general list included Section 8.2.2, applicable and/or relevant and appropriate requirements specific to this alternative may include CFR underground injection control regulations and CCR water well construction rules specific to well permit requirements. Comments concerning these ARARs are provided in Tables 2-11 through 2-16.

8.6.3 Long-Term Effectiveness

The magnitude of residual risk remaining from untreated waste is expected to be low. This alternative is expected to destroy dissolved- and sorbed-phase contamination upgradient of the POC, shortening the time required for MNA to decrease contaminants to levels below required regulatory standards. Little to no untreated waste or waste residuals is expected; therefore, the risk would be eliminated or greatly reduced.

Untreated waste or waste residuals in groundwater in the South Pit area, upgradient of the POC, would remain and would be addressed through MNA processes. During the MNA program, management and/or institutional controls can be implemented to provide continued protection from untreated waste. While this alternative assumes the owner's cooperation with respect to soil removal, it is not known whether that cooperation will extend to such management and/or institutional controls.

Injection of chemical oxidants into the groundwater at and near the source area is likely to cause groundwater conditions to change from anaerobic to aerobic in the short term, but is not expected to have an impact on the long-term effectiveness of the MNA portion of this alternative for the downgradient plume.

If the soil source is removed, then groundwater within the 0.5-acre treatment area is expected to meet EPA MCLs within about 2 years, with groundwater downgradient of the POC (i.e., east of Lamar Street) achieving MCLs in about 20 years through MNA. If the soil source is left in place, then this alternative becomes impractical with an indefinite time frame to meet MCLs.

8.6.4 Reduction of Toxicity, Mobility, and Volume

Assuming soil source removal, a high degree or percentage of reduction of toxicity, mobility, and volume is expected to occur upgradient and downgradient of the POC. Dissolved- and sorbed-phase contamination in groundwater upgradient of the POC would be destroyed. Treatment is expected to be irreversible, with limited to no treatment residuals.

8.6.5 Short-Term Effectiveness

Risk to human health and the environment resulting from the remedial action implementation is expected to be low. Intrusive activities in this alternative consist of direct push drilling and injection, and treatment of contaminants would occur *in situ*. The generation of dust or waste is not expected. Additionally, protective measures for workers due to drilling activities and chemical handling would be implemented. There may be a short-term, localized reduction in natural attenuation in the 0.5-acre treatment area during the application of oxidants, as this will temporarily decrease anaerobic biodegradation while the oxidants are present. However, this effect is expected to be short-term and not impact the long-term effectiveness of this alternative.

8.6.6 Implementability

This alternative is moderately implementable based on the ease of installation and performance monitoring. Conventional direct push drilling and injection, which is highly implementable, would be used in portions of the treatment area. Buildings at the Thoro property and adjacent Vintage Sales property cover several of the key areas to be treated; therefore, horizontal drilling and well installation would be used to address these areas. The logistics of horizontal drilling and well installation may be difficult considering the limited work area at the Thoro property and adjacent Vintage Sales property.

The reliability of the technology is currently assumed, and must be evaluated through field-scale pilot testing. The success of *in situ* chemical oxidation depends on the ability to distribute injected material to the contaminated portions of the aquifer. Evaluating the distribution of chemical oxidants is currently a difficult process since delivery and treatment occurs *in situ*. Distribution can be evaluated to some degree by monitoring groundwater parameters. However, the data received may not be representative of the aquifer as a whole, and a rebound of contamination could occur once the aquifer has returned to pre-injection state.

Administratively, this alternative is expected to be implementable with respect to agency coordination. Additionally, an Underground Injection Control (UIC) permit waiver from EPA would be necessary. Access to the Thoro and Vintage Sales and Leasing properties are required for implementation.

8.6.7 Cost

The total present value cost of *in situ* chemical oxidation and MNA alternative (GW7A) is estimated to be $1.1M, assuming that the soil source is removed prior to implementation of this alternative. A summary of the alternative costs is provided in Table 6-3.

8.7 Alternative GW8 – Alternate Water Supply and Institutional Controls

An alternate water supply would remove the point of exposure to groundwater by plugging and abandoning two existing shallow wells used for drinking water and arranging for City of Arvada water for the affected commercial properties. Institutional controls would be implemented to restrict the use of the shallow groundwater to prevent and/or limit potential exposure to contaminants in groundwater. Institutional controls would consist of environmental covenants and/or environmental restrictions for shallow groundwater on the source area parcel (Thoro Products Property). Long-term monitoring would be conducted for groundwater.

8.7.1 Overall Protection of Human Health and the Environment

This alternative provides a high degree of protection of human health and the environment by providing a permanent alternate water supply for properties where shallow groundwater wells are used to provide drinking water. By providing an alternate water supply, the risk of the shallow groundwater being used as drinking water is eliminated. Institutional controls for the source area provide additional protection of human health and the environment by restricting the use of and exposure to soil and groundwater on the source area parcel (Thoro Products property).

8.7.2 Compliance with ARARs

An alternate water supply and institutional controls are expected to comply with chemical-specific, location-specific, and action-specific ARARs. The ARARs for the Site are provided in Tables 2-11 through 2-16.

8.7.3 Long-Term Effectiveness

This alternative is highly effective for the long-term. No residences use groundwater as a drinking water source. Commercial facilities that currently use shallow groundwater wells will be changed over to City water, which provides a permanent alternative water supply that meets MCLs.

Annual long-term groundwater monitoring will be used to verify that the downgradient edge of the plume remains stable.

8.7.4 Reduction of Toxicity, Mobility, and Volume

A moderate degree of reduction in toxicity, mobility, and volume is expected for the groundwater plume. Because there is no containment in this alternative, there will be some mobility during the period of long-term monitoring, but this will be slowed by the natural attenuation processes of retardation and degradation. Based on the groundwater data for the Site, the anticipated natural biodegradation will reduce the toxicity of many of the contaminants over time, resulting in less toxic breakdown products.

8.7.5 Short-Term Effectiveness

The short-term effectiveness is high. As soon as the commercial properties at the downgradient edge of the plume are connected to City water, there would be no exposure to shallow groundwater.

8.7.6 Implementability

This alternative is implementable assuming the affected property owners are amenable to having their properties annexed to the City of Arvada. Also, the monitoring well network is already in place and long-term monitoring would be conducted. Administratively, this alternative is expected to be implementable with respect to agency coordination.

8.7.7 Cost

The total present value of the Alternate Water Supply and Institutional Controls Alternative is $0.6M. A summary of the alternative costs is provided in Table 6-3.

9.0 Comparison of Alternatives

In this section, soil and groundwater remedial alternatives are compared against each other according to the seven criteria presented in Sections 7.0, and 8.0, respectively. Section 9.1 presents the comparison of soil alternatives. Two different scenarios are considered in the evaluation of alternatives for groundwater. Section 9.2 presents the comparison of groundwater alternatives retained if there is no soil removal at the Thoro property and a continuing source of groundwater contamination remains. Section 9.3 presents the comparison of groundwater alternatives retained assuming that the soil source is excavated from the Thoro property such that there is no longer a continuing source of groundwater contamination.

9.1 Comparison of Soil Alternatives

The soil alternatives retained for the detailed analysis included no action (SO1), institutional controls (SO2), soil excavation with off-site treatment and disposal (SO3A), and soil excavation with on-site thermal desorption (SO4A). These soil alternatives are compared below.

9.1.1 Overall Protection of Human Health and the Environment

Of the retained soil alternatives, institutional controls, soil excavation with off-site treatment, and disposal and soil excavation with on-site thermal desorption are highly protective of human health and the environment. Institutional controls, in the form of an environmental covenant or restriction, would prevent exposure to contaminants in soil by restricting disturbance of subsurface soil at the source area parcel, therefore protecting human health and the environment. The excavation with off-site treatment and disposal alternative permanently removes the contaminated media, eliminating or drastically reducing the potential risk of exposure. Soil excavation with on-site thermal desorption is also highly effective at overall protection of human health and the environment, returning the treated soil back to the excavation after treatment, also greatly reducing risk. Removal of the apparent source of groundwater contamination through soil excavation is also expected to significantly reduce the time period for achievement of groundwater ARARs and may eliminate the need for long-term groundwater treatment. No action presents no protection from exposure and no attempt to manage risk.

9.1.2 Compliance with ARARs

With the exception of no action, the alternatives presented are expected to be in compliance with the ARARs presented in Tables 2-11 through 2-16 and as outlined in Section 7.3.2.

9.1.3 Long-Term Effectiveness

Of the retained soil alternatives, institutional controls, soil excavation with off-site treatment and disposal and soil excavation with on-site thermal desorption would be highly effective at reducing risk in the long term because these alternatives achieve RAOs. Institutional controls restrict the disturbance of subsurface soil on the source area parcel and therefore reduce risk of exposure. Soil excavation removes the contaminated media, eliminating or drastically reducing the potential risk of exposure. The soil excavation with off-site treatment and disposal alternative (SO3A) would be somewhat more effective in the long-term because it removes the contaminated soil and replaces it with clean fill. In contrast, the soil excavation with on-site thermal desorption alternative (SO4A) would treat the soil on site and then return the treated soil to the excavation. If the treated soil meets cleanup objectives, but still contains some residual concentrations of contaminants, it may be less effective than the off-site treatment and disposal alternative.

The no action alternative provides no reduction in contaminant mass and no attempt to manage risk. It also leaves a long-term source of groundwater contamination at the Site. Soil excavation and institutional controls achieve the RAO of preventing ingestion and direct contact with contaminated soil by preventing disturbance of subsurface soils in these area.

9.1.4 Reduction of Toxicity, Mobility, and Volume

Soil excavation with off-site treatment and disposal and soil excavation with on-site thermal desorption both reduce toxicity, mobility, and volume while no action does not. Institutional controls reduce the mobility of the soil since soil is not disturbed. No action provides no reduction and no protection from exposure.

9.1.5 Short-Term Effectiveness

The no action and institutional control alternatives do not involve active treatment; therefore, the risk is the same as the current risk presented in the risk evaluation (URS 2009c). Institutional controls are effective as soon as they are in place. Soil excavation has a potential to increase short-term risk since contaminated soil would be exposed, staged, and transported from the site. With proper engineering controls, the additional short-term risk brought on by excavation can be reduced, although the potential for an increase in risk still exists. The on-site thermal desorption unit would require a longer time on site compared to the off-site treatment and disposal alternative, posing a higher short-term risk. Because the no action and institutional control alternatives do not disturb or expose the contaminated soil at the Site, they would have no impact on risk to human health and the environment in the short term.

9.1.6 Implementability

The soil alternatives considered are technically implementable. The source area property owner would have to agree to institutional controls and the State of Colorado would have to coordinate the institutional controls. The excavation alternatives would both require access to the Thoro property, and the excavation with on-site thermal desorption alternative would require demolition of the Thoro building. The excavation with off-site treatment and disposal alternative could be implemented without removing the main Thoro building, but this might result in some soil contamination remaining in place, and would make this alternative more logistically challenging to implement due to the close proximity of the main Thoro building to adjacent property buildings and an active railroad line. The no action alternative is implementable.

9.1.7 Cost

Assuming that the main Thoro building remains in place, then the soil excavation with off-site treatment alternative (SO3A) has a present value cost of about $2.2M, compared to about $2.9M for the soil excavation with on-site thermal desorption alternative (SO4A). The no action alternative consists of zero cost. The cost for the institutional controls (SO2) is combined with the cost for GW8 and is $0.6M.

9.2 Comparison of Alternatives for Groundwater Without Source Removal

If the soil source is not removed, then the groundwater alternatives retained are no action (GW1), anaerobic biorecirculation with MNA (GW4), ZVI PRB with MNA (GW5), and Alternate Water Supply and Institutional Controls (GW8). Alternatives GW4 and GW5 are retained because they contain the source, allowing for downgradient groundwater treatment through MNA. GW8 is retained because it provides a permanent alternative water supply to the shallow groundwater and restricts the use of groundwater on the source area parcel. Table 6-2a presents the screening of alternatives for this scenario.

9.2.1 Overall Protection of Human Health and the Environment

With the source of groundwater contamination remaining present, the more protective alternatives are those that contain the groundwater upgradient of the POC or remove the point of exposure to groundwater.

An alternate water supply is highly protective of human health and the environment as shallow groundwater would no longer be used for drinking water. The point of exposure to groundwater would be removed by plugging and abandoning existing shallow wells used for potable water and arranging for City water for the affected properties. The additional institutional controls for groundwater (and soil as Alternative SO2) provide additional protection of human health and the environment by restricting the disturbance of subsurface soil and groundwater on the source area parcel.

Anaerobic biorecirculation is protective of human health and the environment because it contains the higher concentration groundwater into a smaller area than the PRB. Biorecirculation would contain the groundwater at the North Tank source area, limiting the treatment cell to the north end of the Thoro property and the northwestern corner of the adjacent Vintage Sales property. While in operation, the biorecirculation system would cut off the supply of contaminants to the downgradient groundwater plume.

The ZVI PRB provides protection by intercepting and treating dissolved-phase contaminants at the POC at Lamar Street; however, groundwater in the North Tank source area, including both the Thoro property and the adjacent Vintage Sales property, remains untreated. The relative degree of protectiveness is higher with the anaerobic biorecirculation system than PRB because it contains the higher concentrations of groundwater to a smaller area and potentially offers some treatment of the source by stimulating biodegradation. No action presents no protection from exposure and no attempt to manage risk.

9.2.2 Compliance with ARARs

With the exception of no action, the alternatives are expected to be in compliance with the ARARs presented in Tables 2-11 through 2-16 and as outlined in Sections 8.2.2, 8.3.2, and 8.4.2. It is important to note that although these alternatives would meet MCLs downgradient of the POC, the PRB would not treat groundwater upgradient of the POC, while anaerobic biorecirculation would.

9.2.3 Long-Term Effectiveness

Of the groundwater alternatives, the PRB is highly effective in the long-term. This is because the PRB is a passive system that acts as a long-term treatment barrier for the plume. An alternate water supply and institutional controls is also highly effective because a permanent alternative water supply would be provided. The biorecirculation system is also effective in the long-term, but only as long as the system is actively operated. No action presents no reduction in contaminant mass and no attempt to manage risk.

9.2.4 Reduction of Toxicity, Mobility, and Volume

Anaerobic biorecirculation more effectively reduces the toxicity, mobility, and volume of contaminants compared to the PRB. Bioremediation is anticipated to be more effective on the

COCs at the Site than abiotic treatment using ZVI. The PRB reduces toxicity, mobility, and volume downgradient of the POC, although untreated waste is likely to remain in the source area and upgradient of the POC. Greater reductions would likely be achieved with anaerobic biorecirculation. An alternate water supply and institutional controls does not reduce toxicity, or volume of the contaminants, but does reduce mobility (no soil is moved) and removes the point of exposure to groundwater. No action provides no reduction to and no protection from exposure to contaminants.

9.2.5 Short-Term Effectiveness

With the use of proper engineering controls, anaerobic biorecirculation and ZVI alternatives have the potential for moderate short-term risk of exposure. The alternative that poses the greatest potential for additional risk is the ZVI PRB since installation requires a fairly large-scale trenching operation along a major street. Some contaminated media may be exposed and brought to the ground surface through the trenching operations. The anaerobic biorecirculation treatment process extracts contaminated groundwater for nutrient addition at the ground surface, therefore increasing the potential for short-term risk. An alternate water supply and institutional controls would provide short-term effectiveness as soon as the alternate water supply was available. No action does not involve active treatment; therefore the risk to exposure pathways is no greater than the current risk presented in the risk assessment (URS 2006d).

9.2.6 Implementability

Anaerobic biorecirculation system, the ZVI PRB, and an alternate water supply are highly implementable. Neither anaerobic biorecirculation or the ZVI PRB alternatives require access to the Thoro property; however, they do require access to several of the neighboring properties. The ZVI PRB would likely be easier to implement than the anaerobic biorecirculation system. This is because there is better physical access to the PRB installation location and because this alternative primarily involves a one-time PRB installation (possibly with a replacement in 30 years) with monitoring. In contrast, installation of the biorecirculation system would involve relatively difficult logistics and access issues during installation, and would require ongoing operations and maintenance for 20 years or more if the source is not removed. Biorecirculation activities would occur in a relatively isolated area of the Site where community exposure is limited and where an extensive exclusion zone and traffic plan is not necessary. Installation of the PRB would occur in a highly visible area that would require an extensive exclusion zone and traffic plan. Overall, the active operations and maintenance involved with the biorecirculation system make more difficult to implement than the PRB. An alternate water supply and institutional controls are implementable. The no action alternative is implementable.

9.2.7 Cost

The ZVI PRB alternative has the present value cost of $1.9M, followed by anaerobic biorecirculation at $2.5M. It is important to note that the $2.5M estimated cost assumes the anaerobic biorecirculation system would only need to be operated for 20 years, which is optimistic if the source is not removed. Monitoring costs for the ZVI PRB alternative were estimated out to 100 years, and monitoring costs for the biorecirculation alternative were estimated for 50 years, assuming that the biorecirculation system would possibly have some beneficial effects on the soil source. However, if the soil source is not removed, then it is suspected that monitoring could be required for longer than 50 years, so the costs could ultimately be higher. The no action alternative has a zero cost. The alternate water supply and institutional controls provides a cost of $0.6M.

9.3 Comparison of Alternatives for Groundwater with Source Removal

If North Tank source area soils are removed, thus substantially reducing or eliminating the source of groundwater contamination, six groundwater alternatives are retained. Table 6-2b presented the screening of alternatives for this scenario. The six alternatives are:

- No action (GW1)
- MNA (GW3)
- Anaerobic biorecirculation with MNA (GW4)
- ZVI PRB by trenching with MNA (GW5)
- Anaerobic bioremediation with MNA (GW6A)
- In situ chemical oxidation with MNA (GW7A)

9.3.1 Overall Protection of Human Health and the Environment

With the elimination of the soil source at the North Tank source area, the anaerobic bioremediation and anaerobic biorecirculation alternatives provide the highest level of overall protection to human health and the environment because they enhance the natural bioremediation processes that are already present at the Site. Source containment through anaerobic biorecirculation or the PRB both become unnecessary once the source is removed. Chemical oxidation may be able to quickly eliminate contaminants in groundwater near the source area, but the unknown distribution of injection reagents may limit treatment effectiveness and thus make it less protective. MNA provides overall protection of human health and the environment, but at a slower rate than the enhanced biotreatment alternatives. No action presents no protection from exposure and no attempt to manage risk.

9.3.2 Compliance with ARARs

With the exception of no action, the alternatives presented are expected to be in compliance with the ARARs presented in Tables 2-11 through 2-16 and as outlined in Section 8.

9.3.3 Long-Term Effectiveness

With the source of groundwater contamination removed, all six of the groundwater alternatives would be effective in the long term. Anaerobic biorecirculation, anaerobic bioremediation, and *in situ* chemical oxidation have the highest effectiveness because they actively treat the area upgradient of the POC, thus reducing the overall time to reach cleanup goals near the source area. However, *in situ* chemical oxidation may not be as technically reliable in the long term as the biotreatment alternatives and could have issues with concentrations rebounding after treatment. The ZVI PRB effectively contains and removes contaminants in the long term, but the treatment occurs at the POC so long-term risk management would be needed upgradient of the POC until the concentrations in this area meet cleanup goals through MNA. Because the downgradient plume is addressed through MNA in all of the alternatives, they all have similar long-term effectiveness in the downgradient plume, reaching MCLs within about 20 years. No action presents no reduction or documentation of contaminant mass and no attempt to manage risk.

9.3.4 Reduction of Toxicity, Mobility, and Volume

With the soil source removed, anaerobic bioremediation, biorecirculation, and chemical oxidation are all effective at reducing the toxicity, mobility, and volume of contaminants already present in the groundwater plume, including in the source area. Chemical oxidation would likely reduce toxicity, mobility and volume in the shortest time and would likely be the most complete at these reductions in the source area, however, it could have an impact on the effectiveness of MNA in the downgradient plume since the MNA assumes natural anaerobic conditions will remain, but chemical oxidation relies on oxidizing conditions. Anaerobic bioremediation and *in situ* chemical oxidation are more effective than anaerobic recirculation at reducing the toxicity, mobility, and volume of contaminants because they treat a larger area of the plume. The ZVI PRB provides some reduction, although untreated waste is likely to remain upgradient of the POC. MNA reduces toxicity, mobility, and volume but at a slower rate than the other treatment alternatives. No action does not reduce toxicity, mobility or volume.

9.3.5 Short-Term Effectiveness

Assuming the use of proper engineering controls, the groundwater treatment alternatives have the potential for minimal short-term risk of exposure. The alternative that poses the greatest potential for additional risk is the ZVI PRB since installation requires a fairly large-scale trenching operation along a major street. Some contaminated media may be exposed and brought to the ground surface through the trenching operations. The anaerobic biorecirculation treatment process extracts contaminated groundwater for nutrient addition at the ground surface, therefore increasing the potential for short-term risk. The anaerobic bioremediation and in situ chemical oxidation alternatives pose a short term risk on the Thoro and Vintage Sales properties during the direct push drilling and injection activities. No action does not involve active treatment; therefore the risk to exposure pathways is no greater than the current risk presented in the risk assessment (URS 2006d).

9.3.6 Implementability

Assuming the soil source is removed, MNA is the easiest groundwater alternative to implement because it only involves periodic sampling and short-term access to the properties at the Site. The anaerobic bioremediation and *in situ* chemical oxidation alternatives are relatively easy to implement technically, but would both involve some access to the Thoro property and more extensive short-term access to the Vintage Sales and Leasing property for implementation. Administrative access issues could impede the implementability of these alternatives. The ZVI PRB alternative would require access for initial PRB installation with some heavy equipment on site during construction and would occur in a highly visible area that would require an extensive exclusion zone and traffic plan. However, the PRB would require little O&M thereafter, making it moderately easy to implement long-term. The anaerobic biorecirculation alternative would involve obtaining access to the Thoro property and/or to the adjacent properties for initial installation and periodic maintenance. The anaerobic biorecirculation alternative is expected to be the most difficult groundwater alternative to implement in the long term due the multiple properties to be accessed and the ongoing operations and maintenance requirements. The no action alternative is implementable.

9.3.7 Cost

Costs for the treatment alternatives were estimated using the RACER program and are listed in Table 6-3. Cost information is included in Appendix B. The groundwater alternative present value costs are similar, ranging from about \$1.1M to \$1.8M. The lowest cost groundwater alternative, assuming the soil source is already removed, is *in situ* chemical oxidation at a present value cost of \$1.1M. The second lowest cost alternative is MNA at a present value cost of \$1.2M. Anaerobic bioremediation has a present value cost of about \$1.3M, and anaerobic biorecirculation and ZVI PRB both have a present value cost of about \$1.8M. The no action alternative has a zero cost.

10.0 Preferred Alternatives

The final remedy for the Twins Inn Site will most likely involve a combination of soil and groundwater alternatives. Table 10-1 summarizes various combinations of alternatives with comments. The preferred approach is to provide an alternate water supply and place institutional controls/environmental covenants on the soil and groundwater on the source area parcel.

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