Union Pacific Railroad

FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA

29th and Grove Site
Wichita, Kansas
Consent Order 01-E-0191

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FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas

Consent Order 01-E-0191
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Acronyms and Abbreviations

ACL                  Alternative Cleanup Level
ARAR                Applicable or Relevant and Appropriate Requirement
ART                 Accelerated Remedial Technology
AS                  air sparge
BER                 Bureau of Environmental Remediation
bgs                 below ground surface
BRA                 Baseline Risk Assessment
BTEX                benzene, toluene, ethylbenzene, and xylenes
CAD                 Corrective Action Decision
CERCLA              Comprehensive Environmental Response, Compensation, and Liability Act
cm/sec              centimeters per second
COC                 contaminant of concern
CVOC                chlorinated volatile organic compound
DCE                 dichloroethylene
DGR                 directed groundwater recirculation
DHC                 Dehalococcoides mccartyi
DOT                 U.S. Department of Transportation
DPT                 direct-push technology
EC/HPT              Electroconductivity/Hydraulic profiling tool
ERD                 enhanced reductive dechlorination
EUC                 Environmental Use Control
EVO                 emulsified vegetable oil
FFS                 Focused Feasibility Study
FRTR                Federal Remediation Technologies Roundtable
FS                  Feasibility Study
ft/yr               feet per year
ft²/day             square feet per day
GAC                 granular activated carbon
GC/MS               gas chromatography/mass spectrometry
gpm                 gallon per minute
FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
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GRA general response action
HCS hydraulic containment system
I-135 Interstate 135
IRA interim remedial action
IRZ in situ reactive zone
ISCO in situ chemical oxidation
ISSS in situ soil solidification/stabilization
K horizontal conductivity
KDHE Kansas Department of Health and Environment
µg/m³ microgram per cubic meter
µg/L microgram per liter
MCL maximum contaminant level
mg/kg milligrams per kilogram
MIP membrane interface probe
MNA monitored natural attenuation
MoPac Missouri Pacific Railroad
MPA Mid-Plume Area
MTBE methyl tertiary butyl ether
mV millivolts
NAPL non-aqueous phase liquid
NCP National Contingency Plan
NIC Northeast Industrial Corridor
NPDES National Pollutant Discharge Elimination System
O&M Operations and Maintenance
OM&M Operation, Maintenance, and Monitoring
ORP oxidation reduction potential
PCE perchloroethylene
PI Preliminary Investigation
PID photoionization detector
ppb parts per billion
PPE personal protective equipment
FEASIBILITY STUDY - SOURCE AREA AND MIO-PLUME AREA
29th and Grove Site, Wichita, Kansas

PRG  preliminary remediation goal
psi  pounds per square inch
RAO  Remedial Action Objective
RCRA Resource Conservation and Recovery Act
RI  Remedial Investigation
ROI  radius of influence
RSK  Risk-based Standards for Kansas
S  storage coefficient
SA  Source Area
SAI  Source Area Investigation
SARA Superfund Amendments and Reauthorization Act
S_s  specific storage
SSI  Site Screening Investigation
SVE  soil vapor extraction
SVOC  semi-volatile organic compound
S_y  specific yield
T  transmissivity
TBC  To Be Considered
TCE  trichloroethene
TCLP  toxicity characteristic leachate procedure
TOC  total organic carbon
TOP  The Opportunity Project
UP  Union Pacific Railroad
USEPA U.S. Environmental Protection Agency
VOC  volatile organic compound
ZVI  zero valent iron
1. INTRODUCTION

Arcadis, on behalf of Union Pacific Railroad (UP), has prepared this Focused Feasibility Study (FS) for the 29th and Grove Site (the Site) in Wichita, Kansas. This Focused FS evaluates remedial technologies and assembled alternatives to address impacted soil and groundwater in the Source Area (SA) and impacted groundwater in the Mid-Plume Area (MPA) of the Site. The SA is defined as saturated and unsaturated soils and groundwater containing trichloroethene (TCE) and its degradation byproducts. It is located in the existing rail yard east of Interstate 135 (I-135) and downgradient areas to the north of the East Fork of Chisolm Creek as shown on Figure 1-1. The MPA is defined as groundwater containing TCE and its degradation byproducts existing downgradient of the East Fork of Chisholm Creek and extending to Murdock Street, also shown on Figure 1-1.

Because the SA and the MPA comprise two distinct regions of impacted soil and groundwater, remedial actions for each area were developed and evaluated separately in this FS.

1.1 Purpose and Organization of Report

The purpose of this FS is to present an evaluation of potential remedial alternatives to address impacted soil and groundwater at the SA and impacted groundwater at the MPA. This FS was completed in accordance with guidance developed by the United States Environmental Protection Agency’s (USEPA) Guidance for Conducting Remedial Investigations and Feasibility Studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; USEPA 1988b). Cost estimates for each alternative were developed in accordance with A Guide to Developing and Documenting Cost Estimates during the Feasibility Study (USEPA 2000).

The objectives of this FS were identified in the Consent Order (Case Number 01 E 181) for the 29th and Grove Site between UP and the Kansas Department of Health and Environment (KDHE), dated September 20, 2002. The objectives of the FS are to:

- Identify, evaluate, and screen remedial technologies based on site characterization information obtained during the Remedial Investigation (RI) and during remedial activities completed to date.
- Develop, refine, and evaluate remedial alternatives to address impacts at the SA and MPA.
- Conduct treatability studies (if necessary)
- Recommend the most feasible and effective remedial alternative for each impacted area.

Remedial alternatives for the MPA were previously evaluated in an earlier FS (Forrester 2007) prepared for the 29th and Grove Site. The FS documented in this report presents additional evaluation of alternatives, incorporating operational treatability data obtained from pilot studies and interim measures implemented at the MPA subsequent to the 2007 FS. As previously mentioned, this FS addresses impacted groundwater in the MPA and impacted soil and groundwater in the SA.

This FS is organized into the following sections:

- Section 1 – Introduction – Presents the study objectives and background information, including a description of the physical setting of the Site and summaries of the historical investigations, remedial actions, pilot studies, and remedial actions conducted or implemented at the SA and MPA.
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- **Section 2 - Remedial Investigation and Risk Assessment Summary** – Presents a summary of the RI and Risk Assessment performed to support remedial actions contemplated in this FS as well as descriptions of pilot studies necessary to implement the selected remedy. This section also presents a discussion on Applicable or Relevant and Appropriate Requirements (ARARs), preliminary Remedial Action Objectives (RAOs), and Preliminary Remediation Goals (PRGs).

- **Section 3 – Source Area Feasibility Study Process** – Presents the complete evaluation of potential remedial options including:
  - **Source Area Screening of Technologies** – Presents initial screening of prospective remedial technologies to identify those applicable to the SA and contaminants of concern (COCs).
  - **Detailed Analysis of Alternatives** – Presents a detailed examination of remedial alternatives developed based on combinations of the screened technologies for the SA and each medium of concern.
  - **Comparative Analysis** - Discusses the relative advantages and disadvantages for each of the remedial alternatives developed for the SA.

- **Section 4 – Mid-Plume Area Feasibility Study Process** – repeats the evaluation of potential remedial options for the MPA, including screening of technologies, and presents detailed and comparative analysis of alternatives.

- **Section 5 – Summary** – Briefly summarizes the salient points of the SA and MPA evaluations.

- **Section 6 – References** - Provides references cited throughout this report.

1.2 **The Feasibility Study Process**

As defined by USEPA, the FS process includes the following four steps (USEPA 1988b):

- Establish RAOs.
- Identify and screen technologies.
- Assemble and screen remedial alternatives.
- Analyze the remaining alternatives in detail.

During screening of remedial technologies, the universe of potentially applicable technologies is reduced by evaluation with respect to technical implementability. Remedial technologies are defined as:

"...appropriate waste management options that ensure the protection of human health and the environment. These options may involve the complete elimination or destruction of hazardous substances at the site, the reduction of concentrations of hazardous substances to acceptable health levels, and the prevention of exposure to hazardous substances via engineering or environmental use controls, or some combination of the above" (USEPA 1988b).

Remedial alternatives are developed by assembling combinations of technologies applicable to each impacted medium. Site-specific remedial alternatives are evaluated and screened based on their effectiveness, implementability, and cost. Alternatives with the most favorable composite evaluation are
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retained for detailed analysis, in which the alternatives are examined with respect to the following nine evaluation criteria:

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

1.3 Site Background Information

This section provides an overview of the background of the Site, including a site description, site history, and site geology and hydrogeology.

1.3.1 Site Description and History

The 29th and Grove Site is located in the northeast portion of Wichita, Sedgwick County, Kansas, as shown on Figure 1-1. The rail yard facility associated with the Site was originally owned by the Missouri Pacific Railroad (MoPac). UP acquired the facility in 1982 as a result of a merger with MoPac. The SA of the Site is located in the northern portion of the UP rail yard east of I-135. The northern yard is occupied only by rail tracks with no structures present.

TCE has been detected in the SA soil and downgradient groundwater, as shown on Figure 1-1. The exact source, time frame, and incident that caused impacts to soil and groundwater are unknown.

1.4 Site Geology and Hydrogeology

Multiple rounds of investigations completed at the Site, as well as activities related to interim remediation for both the TCE-impacted SA and MPA, have fostered a detailed understanding of the geologic and hydrogeologic conditions that control TCE migration. The following discussion (primarily excerpted from the 2007 Forrester FS) summarizes these conditions as they impact the fate and transport of TCE at the Site.

1.4.1 Bedrock Geology

The Wellington Formation, Permian shale bedrock, underlies the Site at an approximate depth of 30 to 50 feet below ground surface (bgs). This bedrock unit is overlain by alluvial sediments typical of fluvial depositional environments. The base of the alluvium is channel deposits composed of sand, which constitutes a shallow alluvial aquifer. The shale bedrock unit represents the practical lower limit of the overlying alluvial aquifer. This aquifer is impacted by varying concentrations of COCs.
The Wellington Formation shale bedrock high is present upgradient of the SA. To the south of the SA (downgradient), the bedrock dips, and the basal alluvial sediments (coarse sand) thicken significantly. The bedrock high (present upgradient of the SA) continues to the east and subsequently to the south in a north-to-south trending ridge present largely east of the Site, against which the channel deposits pinch out completely and which represents the eastern limit of the shallow alluvial aquifer. Thus, the eastern edge of the impacted groundwater is limited by a stratigraphic pinch-out of sand against this shale channel margin.

The bedrock surface below most of the MPA is relatively flat, but there are several bedrock features that impact the thickness and distribution of the basal alluvial sediments (coarse sand) through which much of the site groundwater migrates.

1.4.2 Hydrogeology

This subsection describes the conceptual model hydrogeology including aquifer materials, the rate and direction of groundwater flow, and the surface water and groundwater interaction along the East Fork of Chisholm Creek.

1.4.2.1 Aquifer Materials

Throughout the Site, the sequence of unconsolidated sediments above bedrock exhibits an upward fining succession of sediment types. Over much of this area, the sequence consists of medium to coarse sands present above the shale bedrock and then grades upwards to fine sand, silt, and then to clay. This succession is evident through much of the Site south of the East Fork of Chisholm Creek and in the western portion of the rail yard SA, as evidenced by soil data collected during the Preliminary Investigation (PI; ThermoRetec 2001), RI, and John's Sludge Pond studies (a now closed neighboring Superfund site to the west). Table 1-2 summarizes groundwater and aquifer material physical properties.

The type and distribution of sediments in the Site are typical of river-dominated or fluvial sedimentary systems. Portions of the Site containing coarser and thicker sands are interpreted to represent channel deposits of the Arkansas River. While sand, silt, and clay were deposited across the river system in response to sediment supply and water energy, sediments in the main channel were more frequently reworked and finer sediments were winnowed, leaving a relatively thick accumulation of sand. Over time, the river system appears to have migrated westward (where it is presently located). Finer grained deposits consisting of fine sand, silt, and then clay were deposited on floodplains in response to progressively lower water energy.

However, massive channel sand deposits are not indicated to occur in all parts of the Site. In particular, the northeastern part of the Site, comprising the eastern portion of the SA, appears to exhibit mud-rich and/or interbedded clay, silt, and sand more typical of floodplain depositional environments. Thus, the overall axis of the channel-sand complex was farther to the west, and the SA is interpreted to occupy a channel-margin position.

Groundwater flow and chemical transport is likely more limited in the SA due to the flank position of the SA relative to the channel deposits. The close proximity of the SA to the massive channel sand deposits, located nearby to the south and west, has facilitated the migration of impacted groundwater.
1.4.2.2 Groundwater Flow Direction and Rate

A shallow aquifer is developed in alluvial sediments present above the Wellington Formation shale bedrock. The aquifer is considered to be bounded on the bottom by shale bedrock and is primarily developed in porous and permeable sand overlying bedrock. In the northern part of the Site, including the SA, the water table is also present in silt and clay overlying the sand. Geotechnical properties (especially hydraulic conductivity) of the overlying silt and clay indicate that these materials may locally confine shallow groundwater; in other words, the water level (or potentiometric surface) rises above the top of the porous sand. However, this aquifer is generally considered to be unconfined.

Locally, groundwater recharge originates from the ponds that are present directly north of the rail yard SA. These ponds represent borrow pits from which soil was removed for the construction of I-135 just to the west. Aerial photographs indicate that the borrow pits were excavated between approximately 1968 and 1974. Depth measurements from the largest pond show that the pond ranges in depth from approximately 4 to 6 feet and indicates that the borrow pits were cut into the sand layer, evident in well UP-MW-04 just to the south. Comparison of water levels in this pond and in monitoring wells indicates that the pond represents a significant constant head. Thus, surface water recharge from this pond represents a driving force for groundwater located immediately upgradient of the rail yard SA.

Water level head data in monitoring wells indicate that groundwater flow is to the south, as shown on Figure 1-2. Head contours appear to be more closely spaced near the SA and more widely spaced with increasing distance to the south. Steeper hydraulic gradients near the SA are a result of the relatively thinner channel deposits and support the conclusion that the water level in the borrow pit pond to the north is exerting an influence on groundwater head.

All other parameters held constant, groundwater will move most rapidly through sand with the highest hydraulic conductivity, a zone represented in the Site by coarse to medium sand. The rate of groundwater flow is anticipated to decrease as particle size (and hydraulic conductivity) decreases. Therefore, the highest groundwater flow rates are anticipated to occur in coarse sand present above bedrock.

Water level measurements indicate that hydraulic gradients are steeper near the rail yard (0.0103 ft/ft average) and flatten toward the south (0.0012 ft/ft average). The average hydraulic gradient, calculated between monitoring wells MW-19D and MW-21D, is flatter at 0.00055 ft/ft. Analyses performed in the December 2006 Aquifer Characterization Pumping Test (Appendix C of Forrester 2006b) developed groundwater hydraulic parameters for the MPA. The estimates of hydraulic properties for the aquifer are as follow:

- Transmissivity (T) 4,060 square feet per day (ft²/day)
- Horizontal Conductivity (K) 290 ft/day (0.102 centimeter per second [cm/sec])
- Storage Coefficient (S) 3.7 x 10⁻⁴
- Specific Storage (S₀) 2.7 x 10⁻⁵
- Specific Yield (S_y) 0.026

A groundwater flow rate of 529 feet per year (ft/yr) in the area of the pumping test was computed from test data (Forrester 2007).
1.4.2.3 Relationship between the East Fork of Chisholm Creek and Groundwater

During periods of low discharge in the East Fork of Chisholm Creek, the water level in the creek is correlative to or slightly lower than water levels in adjacent wells. Therefore, the water level in the East Fork of Chisholm Creek is considered to represent a surface expression of the shallow water-bearing zone.

Discharge to or recharge from the creek depends on the lithology through which water must move and the head differential between surface and groundwater. Review of soil boring logs for wells adjacent to the East Fork of Chisholm Creek shows that the creek is incised into the predominant silt and clay. The movement of water to and from the stream will be restricted by the fine grain size.

During periods of drought, water levels in the East Fork of Chisholm Creek and nearby wells are similar, but the creek appears to exhibit a slightly lower elevation and so likely represents a line of groundwater discharge. This discharge is anticipated to be small due to low head differentials and the low permeability of the fine-grained sediments underlying the stream bed. This is demonstrated by the low measured concentrations of volatile organic compound (VOC) constituents reported in August 2003, which were lower than 5 parts per billion (ppb) for individual constituents and lower than 8 ppb for total VOCs. At low stream levels, the depth and flow rate of water in the East Fork of Chisholm Creek are limited.

During periods of precipitation or snowmelt, upstream runoff causes the water depth and flow rate in the East Fork of Chisholm Creek to increase significantly. Increased head in the East Fork of Chisholm Creek will favor the flow of water from the stream to the aquifer. Actual flow will depend on the magnitude and duration of the head differential and the hydraulic conductivity of the aquifer materials beneath the stream. Recharge from the stream to the aquifer will tend to raise the water level in the aquifer (i.e., increase bank storage). After the stream level falls, bank storage will discharge from the aquifer to the stream until the head differential is essentially eliminated.

Thus, impact to the East Fork of Chisholm Creek from the aquifer is possible during periods of little or no runoff, but is limited by low head differential between the aquifer and the stream and by fine-grained sediments underlying the stream. Shallow water and low stream flow under fair weather conditions favor volatilization.

1.4.2.4 Current Contaminant Occurrence and Migration

As summarized in Section 1.7, multiple remedial activities (such as Accelerated Remedial Technology [ART], soil excavation, in situ chemical oxidation [ISCO], and pump-and-treat) have been implemented to eliminate source mass and address TCE at the Site. The remedies evaluated in this FS are all based on the success or failure of those efforts, and this section summarizes the occurrence and migration of the remaining contaminant mass. Additional information is contained in the MPA RI (Forrester 2006b).

TCE non-aqueous phase liquid (NAPL) has not been observed in soil or in a mobile phase in groundwater wells. However, residual NAPL may be indicated by groundwater TCE concentrations at the SA. For example, well MW-UP-01 exhibits concentrations on the order of 15 to 40 percent of the TCE solubility. Any residual TCE, if present, will slowly dissolve and will create an ongoing source to the aqueous phase plume.

Figure 1-3 illustrates the distribution of TCE in groundwater during the most recent groundwater monitoring event (November 2019). Overall, higher groundwater TCE concentrations are indicated in the deeper portion of the water-bearing zone, as indicated by both historical direct-push investigations and
monitoring well groundwater sampling results. In the SA, this is interpreted to result from non-aqueous TCE being denser than water and migrating downward by gravity, thereby impacting deeper water to a higher degree. Downgradient from the SA, this trend is interpreted to result from advective groundwater flow through coarse sand in the lower part of the sequence.

TCE transport in the SA occurs through a complex of interbedded fine sands, silts, and clays. These transport zones are not entirely understood; however, active transport is assumed to occur at the base of the alluvial sediments in the interbedded sand lenses with relatively higher conductivity profiles. Seasonal fluctuations in groundwater elevation flush TCE from the shallow SA soil impacts into the deeper saturated zone, where it is transported downgradient. This assumption is supported by a dual-concentration pattern, where higher TCE levels are observed in the rapid transport zone at the base of the formation, and moderate to low TCE levels are observed in the finer upper zone. This conceptual model is important for remedial design because the slightly elevated hydraulic conductivity profile observed at the base of the formation will be more accessible than the contaminant mass in the upper portions of the clay and silty clay alluvial deposits.

Through the MPA, TCE transport occurs in the coarse sands at the base of the formation. Seasonal fluctuations in groundwater elevation push TCE upward into the finer sands at the top of the formation, where it mixes with recharge from above. During wet years, the water table in the MPA rises to the base of the overlying silts and clays. This generates a dual-concentration pattern, with higher TCE levels in the rapid transport zone at the base of formation and moderate to low TCE levels in the finer upper zone. This conceptual model is important for remedial design because the high-flow zone at the base of formation will be more accessible than the stranded mass in the upper portions of the sand unit.

In 2011, drought conditions led to a site-wide decline in water table elevation, and the unsaturated zone at the top of the sand unit has partially unsaturated. This reduces the thickness of the finer sand zone that could retain stranded mass with limited accessibility to remedial technologies.

Other sources of chemical impact (e.g., benzene from gasoline stations and perchloroethylene [PCE] from dry cleaners) have been detected within the groundwater in the MPA, evident by the horizontal and vertical extent of impact within the water-bearing zone. In particular, local sources are indicated by chemical concentrations that occur in the upper part of the water-bearing zone, while impacts in the lower part of the water-bearing zone indicate a more distant source.

1.4.2.4.1 Conceptual Model Summary

The following points summarize the hydrogeologic conceptual model for the 29th and Grove Site as illustrated on Figure 1-4.

- A historical surface spill of TCE impacted soil and groundwater at the eastern end of the rail yard.
- The TCE migrated vertically through soil and then beneath the water table until bedrock was encountered. Free-phase TCE NAPL has not been evident at the SA, indicating that TCE does not exceed the residual saturation of SA soils. However, the majority of SA TCE impact observed during the RI is below the water table.
- Over time, TCE has dissolved and has been transported south from the rail yard by groundwater flow.
- The natural rate of biological attenuation of the plume is relatively low. Few degradation products are present in the MPA, indicating a relatively slow rate of naturally occurring reductive dechlorination.
In the MPA, the 29th and Grove plume has unassociated dissolved plumes on both the east and west sides.

- On the east side, and partially commingled with the 29th and Grove plume, the PCE drycleaner plume is present, migrating in a largely parallel manner.
- To the west, the Northeast Industrial Corridor (NIC) plume also migrates in a largely parallel manner. While there is significant separation between the plumes over most of their lengths, near the southern extent of the 29th and Grove plume near Murdock Street, the plumes are immediately adjacent.

Groundwater flow is from north to south and has been enhanced by a constant surface water head represented by borrow-pit ponds located just north of the rail yard SA.

At the SA, the permeable portion of the aquifer is relatively thin (less than 10 ft), is entirely saturated (causing semi-confined conditions), and lies atop a relatively sharply sloping bedrock surface. In the MPA, the aquifer thickens to the south in the direction of groundwater flow as the depth to bedrock increases and the overlying silt and clay unit thins.

The low-permeability silts and clays at the surface limit the rate of surface water recharge to the aquifer and provide some protection against upward migration of TCE vapors. In the northern portion of the MPA, the low-permeability strata act as a confining layer on the aquifer. In southern areas, there is unsaturated sand above the groundwater-bearing strata, and the aquifer will behave mainly as an unconfined unit.

The aquifer is very thin below the SA and in northern sectors, and hydraulic gradients are steep (0.0103 ft/ft). The aquifer thickens in the central portion areas, and the hydraulic gradients decrease (0.0012 ft/ft).

Within the sandy portion of the aquifer, materials generally coarsen and increase in hydraulic conductivity with depth.

Approximately 4,000 ft downgradient of the SA, the water table drops below the base of the silt and clay unit and, from that point, the remainder of the impacted portion of the aquifer to the south is effectively unconfined.

In the southern portion of the plume, groundwater flow directions and velocities are relatively constant, from north to south at approximately 500 ft/year. Several site characteristics have localized impact on the direction and velocity of groundwater flow and the associated dissolved plume distribution:

- The East Fork of Chisholm Creek is hydraulically connected to the water table, though the degree of connection is limited by low-permeability sediments into which the stream is incised and the low head differential between the aquifer water table and the stream water level.
- The pinch-out of the channel deposits to the east appears to have little impact for much of the plume length, but before installation and operation of the Murdock Hydraulic Control System (HCS), may have caused a westward component of flow at the downgradient margin of the plume.
- The installation of the groundwater extraction system on Murdock Street has removed any westward component of groundwater flow and has begun to draw groundwater from the west.
In the central and southern portions of the MPA, groundwater monitoring wells labeled as "shallow" are placed in moderately permeable aquifer materials, and velocities are relatively slow compared to monitoring well locations labeled as "deep," which are placed in highly permeable strata at the base of the aquifer. In these deeper wells, groundwater flow velocities are much faster.

- The depth of impacted groundwater is bounded vertically by the shale bedrock. The plume widens as the aquifer thickens to the south, at which point advective transport dominates and the plume width remains consistent as it slowly attenuates.
- Limited discharge from groundwater to surface water may result during low runoff periods; however, surface water impacts are nominally evident due to low groundwater discharge rates and shallow stream depth, favoring chemical volatilization. Impacts to stream sediment are nominally evident for the same reasons, plus limited chemical partitioning from water to soil. Downstream of the SA, impacts to Chisholm Creek surface water and sediment samples were not evident.
- TCE emissions from impacted groundwater to both outdoor and indoor air are not evident, though indoor and background sources were clearly identified.
- Sources of other chemicals are evident in groundwater, likely associated with dry cleaning (PCE) and gasoline stations (benzene, toluene, ethylbenzene, and xylenes [BTEX]). Because TCE is a breakdown product of PCE, some TCE in the plume is likely contributed by the PCE sources. Other TCE sources may be indicated by elevated detections in shallow groundwater that are locally observed.

### 1.4.3 Groundwater Flow and Solute Transport Model

In 2015, a three-dimensional numerical groundwater flow and solute transport model was developed for the Site (Arcadis 2016a). The purpose of the model was to refine the understanding of subsurface flow conditions, capture zones associated with remedial systems, and the fate and transport of TCE.

The objectives of the modeling study were to:
- Evaluate subsurface flow conditions.
- Evaluate capture zones associated with a proposed directed groundwater recirculation (DGR) remedial system.
- Evaluate the fate and transport of TCE.

The modeling report is included as Appendix A.

### 1.5 Historical Investigations

This section summarizes the investigations conducted at the SA and MPA.

#### 1.5.1 1998 KDHE Screening Site Investigation

In September 1998, KDHE issued the Site Screening Investigation (SSI) to provide data on TCE concentrations in groundwater (KDHE 1998). During the SSI, 51 direct-push probes were installed along five transects in the vicinity of the suspected SA, and groundwater samples were collected and analyzed. These results indicated the presence of TCE south of the southern edge of the UP right-of-way along
29th Street, east of I-135 and west of Grove Street. The concentrations of TCE in groundwater directly adjacent to the UP right-of-way ranged from not detected (at 0.5 microgram per liter [µg/L]) to 218,000 µg/L. TCE was not detected in groundwater probes north of the UP right-of-way.

Subsequent to the KDHE investigation, the project name was changed from “21st and Grove” to “29th and Grove” to reflect the apparent source of the affected TCE groundwater plume.

### 1.5.2 2001 UP Preliminary Investigation

At the request of KDHE, UP conducted a follow-up soil and groundwater investigation to further delineate vertical and horizontal TCE. On March 9, 2001, ThermoRetec Consulting Corporation issued the Draft Report on Preliminary Investigation (Pl Report; ThermoRetec 2001), Union Pacific Railroad, 29th and Grove Site, which identified TCE impacts to soil and/or groundwater on both the UP and adjoining properties. The results of the Pl Report indicated that TCE was present in soil and groundwater in the UP right-of-way. The area of affected soil varied with depth and was observed between land surface and the top of the shale bedrock as defined by soil borings SS-25, SS-30, SS-38, SS-41, SS-44, and SS-37.

The extent of affected groundwater was defined by monitoring wells to the north (MW UP-04S/D), to the west (MW-UP-03), and to the east (MW-UP-05). Wells to the south of the UP right-of-way (MW-UP-02S/D) confirmed results obtained during the SSI.

Surface water quality samples collected in May 2001 by the KDHE indicated that TCE, cis-1,2-dichloroethylene (cis-1,2-DCE), benzene, and naphthalene were present in the East Fork of Chisholm Creek, located west (downstream) of the 29th and Grove area.

### 1.5.3 December 2012 Indoor Air Sampling at the Boys and Girls Club and The Opportunity Project Early Learning Center

In December, air sampling was conducted at the Boys and Girls Club and The Opportunity Project (TOP).

In samples collected at the Boys & Girls Club, chemicals were not detected at concentrations above the laboratory reporting limits in any of the outdoor air samples, indicating no outdoor source of contaminants was present at the time of testing. In the indoor air samples, only one sample collected in a classroom in the northeast part of the building (BCG-04) contained a detectable concentration of a chemical. The concentration of TCE detected in sample BGC-04 was 0.32 µg/m³, which is below the KDHE standard of 2.09 µg/m³ for TCE in indoor air in a residential setting (KDHE 2013a).

For the indoor air samples collected at TOP, only one sample collected from the new building addition (TOP-04) contained a detectable concentration of a chemical. The concentration of TCE detected in sample TOP-04 was 0.26 µg/m³, which is below the KDHE standard of 2.09 µg/m³ for TCE in indoor air in a residential setting (KDHE 2013b).

### 1.5.4 March 2013 Residential Indoor Air Investigation

In March 2013, ambient and indoor air samples were collected from seven residential properties located in the 2600 block of North Madison Street and a new development south of Chisholm Creek. The KDHE requested this sampling in a letter dated October 28, 2011 to account for the new development south of Chisholm Creek, to recollect samples in the 2600 block of North Madison, and to compare results to the new KDHE Tier 2 Indoor Air Pathway value for TCE (2.09 µg/m³). Samples were collected in accordance with the Indoor Air Sampling Work Plan dated February 28, 2012.
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The ambient and indoor air samples were collected over a 24-hour period on March 12 and 13, 2013, using 6-liter stainless steel Summa canisters. At each residential structure, Arcadis collected one ambient air sample outside to measure background levels and two indoor air samples. At residences with basements, one indoor air sample was collected from the basement area and one from the first floor. In residences with crawlspaces, one indoor air sample was collected from the crawlspace and one from the first floor living area.

All indoor air sample results were below the reporting limit for all COCs except for two samples, both collected from the 2655 N Madison property. TCE was detected in samples collected from the crawlspace and living area, measuring 1.4 and 0.42 µg/m³, respectively. Both detections are below the KDHE Tier 2 Air Pathway level of 2.09 µg/m³ (Arcadis 2013b).

1.5.5 2013 Indoor Air Investigation

In December 2013, six indoor air samples and three ambient air samples were collected from the Gordon Parks Academy, and seven indoor air samples (including a duplicate) and three ambient air samples were collected from the Little Early Childhood Education Center. The samples were collected in accordance with the Indoor Air Sampling Work Plan (Arcadis 2012), and the results were transmitted in a letter report to KDHE (Arcadis 2014).

Samples had been previously collected from the Gordon Parks Academy in February 2009 to evaluate VOC impacts to indoor air. During the 2009 sampling event, indoor air concentrations of TCE, cis-1,2-DCE and trans-1,2-dichloroethene (trans-1,2-DCE) were not detected above laboratory reporting limits and were not considered a concern for the facility. The KDHE requested additional indoor air sampling in a letter dated October 28, 2011 to compare results to the new KDHE Tier 2 Indoor Air Pathway value for TCE (2.09 µg/m³). The KDHE also requested additional sampling at the Little Early Childhood Education Center.

During the 2013 sampling, all indoor air sample results were below the Tier 2 goals for all COCs. TCE was detected at concentrations above laboratory reporting limits in five of the six indoor air samples collected from the Gordon Parks Academy, and detections of TCE were well below the Tier 2 goals, ranging from 0.0760 to 0.303 µg/m³. All other sample results at the Gordon Parks Academy were below laboratory reporting limits. No COCs were detected at the Little Early Childhood Education Center. All ambient air sample results were below reporting limits for all COCs.

1.5.6 2006 UP Remedial Investigation

UP prepared a Revised RI Report (Forrester 2006b) to describe investigation activities at the Site conducted under the KDHE Remedial Investigation/Feasibility Study (RI/FS) process under a consent order (01-E-0191) between UP and KDHE issued on October 4, 2002. The objectives of this Revised RI Report included determination of the extent of groundwater impacted by chlorinated VOCs (CVOCs) and characterization of potential additional sources of VOC loading to the groundwater plume.

1.5.6.1 Remedial Investigation Activities

The following field investigations were performed as part of the RI (Forrester 2006b).

- The Phase 1 groundwater investigation employed direct-push technology groundwater sampling as a screening tool to help define the extent of affected groundwater. Based on these results, the Phase 2
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groundwater investigation involved the installation of groundwater monitoring wells to determine the plume extent and groundwater flow direction. Groundwater samples were also collected from several residential lawn and garden wells.

• Soils in the SA were initially characterized during PI activities (KDHE 1995). Additional chemical characterization of soils was not performed during the RI. A supplemental SA soil investigation was performed in April 2007 (Appendix D of Forrester 2007).
• Surface water and sediment in the East Fork of Chisholm Creek were sampled to evaluate possible impacts to the creek.
• Two phases of air pathway analysis were conducted using flux chamber technology and indoor air samples.

Finally, a human health baseline risk assessment was performed using data collected during RI field activities to define potential risks from impacted media.

1.5.6.2 Remedial Investigation Results

The RI concluded that:

• The primary COC at the Site is TCE. TCE is present in soil at the rail yard SA and in MPA groundwater downgradient from the SA. A summary of physical and chemical properties of TCE is included in Table 1-1. Other VOC chemicals are present, but at considerably lower concentrations, such that they are unlikely to drive remediation.

• The lateral and vertical extent of impacted groundwater has been determined. The lateral extent is approximately defined by Minnesota Street to the west, Grove Street to the east, Murdock Street to the south, and by unimpacted wells on the north portion of the UP rail yard. The vertical extent is defined to be within the water-bearing zone above shale bedrock, which occurs at a depth of approximately 30 to 50 feet.

• The groundwater flow direction is to the south.

A historical surface spill of TCE apparently impacted soil and groundwater at the UP rail yard. Dissolved-phase TCE then migrated with groundwater south from the SA creating a long, narrow TCE plume. The exact source, time frame, or incident that caused impacts of CVOCs to soil and groundwater is not known. Additional sources of subsurface impact were also present within the Site and were not related to the release at the rail yard. Several dry-cleaning facilities along and south of 21st Street were identified by KDHE to have released PCE to groundwater, and groundwater BTEX compounds were associated with a gasoline station on 21st Street (Forrester 2006b).

The RI was helpful in identifying the preliminary nature and distribution of TCE extending from the SA to the MPA. These findings prompted multiple rounds of supplemental investigation to add granularity to the understanding of TCE distribution within the SA and to further refine its orientation in downgradient MPA groundwater.

1.5.7 2007 UP Feasibility Study

Forrester Group prepared a Revised FS report to present an evaluation of potential remedial alternatives to address soil and groundwater impacts at the Site in 2007. A total of five remedial alternatives, combining remedial technologies for both SA and downgradient remedies, were evaluated. Three
remedial technologies, including enhanced bioremediation ART system, focused soil excavation, and combinations of these technologies, were evaluated for the SA remedy. Three remedial technologies, including enhanced bioremediation, pump-and-treat, and hydraulic containment (and their combinations), were evaluated for downgradient remediation within the MPA.

All five remedial alternatives satisfied criteria including RAOs; overall protection of human and the environment; compliance with ARARs; long-term effectiveness and performance; and reduction of toxicity, mobility, or volume through treatment, while failing equally to meet short-term effectiveness, implementability, and cost criteria. Considering all criteria, the best alternative at the time consisted of an ART system and focused soil excavation in the SA, enhanced bioremediation along transects at intervals across the groundwater plume, and hydraulic containment at the leading edge of the plume, which was anticipated to reach site-specific RAOs in an estimated period of 8 years. This FS also indicated that, based on supplemental investigations within the site vicinity, additional sources of CVOCs, most notably PCE associated with dry cleaning operations, are commingled with the 29th and Grove TCE plume.

As a part of the FS, a pilot study was conducted to evaluate the remediation of groundwater in the SA using an ART system. Operation and performance results of the ART system are summarized in Section 2.5.

### 1.5.8 2009 Source Area Investigation

A SAI report was prepared by the Forrester Group, Inc. (Forrester 2009) to summarize the characterization results of vadose and saturated zone source area sampling. A total of 14 membrane interface probe (MIP) borings were completed in November 2008 to delineate potential residual VOC source mass within the saturated zone, and a total of 27 soil borings were completed in February 2009 via direct-push technology (DPT) to further define shallow, surficial soil impacts in the area of release. Gas chromatograph/mass spectrometry (GC/MS) sampling was also performed at the MIP locations to identify specific compounds.

Vadose-zone soil data indicate that the residual source material is vertically defined to within a 5 ft depth from land surface. Toxicity Characteristic Leachate Procedure (TCLP) results for impacted soils indicate that soil excavated during future remedial activities may be disposed of as non-hazardous waste. Based on MIP, GC/MS, and soil analytical data, TCE impacts in the saturated zone are primarily located in a silt layer overlying a sequence of alternating silt lenses and clay layers. TCE impacts are also present in the underlying silt lenses. Based on soil and MIP characterization results, the saturated zone SA was identified at vertical depths up to 32 ft bgs.

### 1.5.9 2013-2015 Mid-Plume Hydraulic Testing and Long-Term Pilot Testing

In August 2013, Arcadis installed eight pilot injection wells throughout the MPA and conducted injection tests to evaluate the ability to inject water into the aquifer and to support pilot-scale reinjection testing of treated groundwater from the existing Murdock HCS currently in operation at the downgradient extent of the MPA. The HCS was installed to control downgradient migration of dissolved CVOCs, primarily TCE, in the groundwater plume. The hydraulic testing and reinjection pilot testing had two principal objectives:

- Evaluate the hydraulic capability of the alluvial sediments to accept reinjection of treated groundwater,
Determine the long-term impacts of groundwater reinjection on the aquifer and evaluate potential operational and/or maintenance issues that would affect the design, implementation, and operation of a full-scale MPA remedial action.

The hydraulic and injection testing was conducted in two phases. An initial phase of discrete short-term hydraulic and injection tests was conducted at four locations throughout the MPA. A second phase of long-term injection testing was conducted at four reinjection wells located north and west of the existing HCS extraction wells. The scope of work included the following activities:

- Geoprobe® electrical conductivity and rate of penetration profiling, collection of soil samples and grain size data to support injection well design (July 31 to August 1, 2013)
- Installation and development of injection wells and adjacent observation wells at selected locations (September 5 to 8, 2013)
- Completion of hydraulic step testing to evaluate specific pumping capacity of each injection well and associated drawdown characteristics (November 12 to 14, 2013)
- Collection of baseline groundwater samples from the injection wells (November 12 to 15, 2013)
- Completion of short-duration injection step tests to evaluate the short-term, well-specific injection capacity of each injection well (November 15 to 20, 2013)
- Evaluation of the hydraulic testing results to determine design injection rates for long-term testing
- Installation of injection piping between the HCS and the injection wells and modification of the HCS to allow partial discharge of treated effluent to the newly installed injection wells (February and March 2014)
- Completion of long-term injection testing on wells IW-1 through IW-4 including monitoring changes in injection-specific capacity (April 10, 2014 to March 27, 2015)

All activities were conducted in accordance with the Mid-Plume Reinjection Pilot Test Work Plan (Arcadis 2013), which was submitted to the KDHE on February 1, 2013 and approved by KDHE in a letter dated February 6, 2013.

The hydraulic testing and long-term injection testing indicated that long-term injection of groundwater into the shallow alluvial aquifer is a viable option. Injection rates and trends are related to variations in saturated thickness, silt content, and variations in lithology. In general, injection appear to be suitable in all areas of the aquifer within the MPA. A summary of the Mid-Plume Reinjection Pilot Test is included in Appendix B.

### 1.5.10 2013-2014 Source Area Enhanced Reductive Dechlorination Pilot Test

During 2013 and 2014, Arcadis conducted dye tracer and carbon substrate injection tests at the SA. The work was completed in accordance with the scope outline in the Source Area Enhanced Reductive Dechlorination (ERD) Pilot Test Work Plan submitted to KDHE in December 2012.

The overall objectives of the pilot study were to:

- Collect site-specific hydraulic data necessary to support the successful design and implementation of a full-scale SA injection well network.
- Collect soil lithological and geotechnical data from the unconsolidated sediments and Wellington Shale beneath the SA.
- Provide a basis for development of a comprehensive source area remedial strategy to be detailed in a Focused Feasibility Study (FFS) Report.

The results of the pilot tests were summarized in a Source Area ERO Pilot Test Summary report (Arcadis 2016b) and indicated that ERO is a viable remedy for the SA saturated soil. The Source Area ERO Pilot Test Summary is included in Appendix C.

1.5.11 2016 Source Area Pre-Design Soil and Groundwater Investigation

In 2016, Arcadis conducted additional soil and groundwater assessment at the SA as part of pre-design investigation activities, before remedial action implementation, to further define lithology and the nature and extent of impacted soil and groundwater at the SA. The primary objective of the scope of work was to provide sufficient data to support and refine the final design of an SA remedial alternative.

Key objectives of the pre-design SA investigation included:
- Further define the lithologic transition between the Wellington Uplands and the Arkansas River alluvium where sediments transition from generally low permeability uplands sediments to higher permeability alluvial sands at the base of the alluvium.
- Assess residual VOC concentrations in the vadose zone directly south of the SA to determine if in-situ soil stabilization (ISSS) bench testing was necessary and a viable remedial technology.
- Update the distribution of dissolved VOCs in the transition area from the SA into the mid-plume area.

The results of the pre-design SA investigation were summarized in a Summary Report submitted to KDHE on August 20, 2018 (Arcadis 2018a), which is included as Appendix D.

This work was completed in accordance with the revised Work Plan for Additional Source Area Soil and Groundwater Investigation dated July 10, 2016, and conditionally approved by the KDHE on August 5, 2016.

Field activities were completed from October 3 to November 2, 2016 and included:
- Five soil borings were advanced in the SA. Four of the soil borings were used to collect bulk soil samples from between 5 to 20 ft bgs for bench-scale testing of ISSS.
- One soil boring was advanced approximately 50 ft downgradient (south) of the SA to investigate depth to bedrock and lateral vadose-zone VOC concentrations extending in a southerly direction from the SA. At one location, a soil core and an electrical conductivity (EC)/hydraulic profiling tool (HPT)/MIP boring was advanced to collect lithologic data, evaluate VOC distribution, and determine the depth to the water table.
- Twelve direct-push groundwater borings were completed downgradient from the SA to 26th Street to collect groundwater samples in deep permeable zones. In each case, an EC/HPT/MIP probe was advanced and electronically logged by direct push to collect lithologic data and profile the soil and water columns. A groundwater sample was collected at each location from the deep permeable unit.
- Groundwater samples were collected from four existing groundwater piezometers located to the south of New York Street.
Bulk soil samples collected for ISSS suitability assessment were submitted to the Arcadis laboratory in Durham, North Carolina. Samples were assessed for moisture content and bulk baseline VOC concentrations.

Soil samples to be evaluated for ISSS were collected from four locations in the SA, with bulk samples collected from 5 to 20 ft bgs. Soil cuttings from each of the borings were containerized in sealed 20-liter U.S. Department of Transportation (DOT)-approved drums, packed with sufficient soil to minimized headspace, and shipped to the testing laboratory for bench-scale testing for ISSS. Upon sampling, baseline VOC concentrations indicated average TCE and cis-1,2-DCE concentrations approximately two orders of magnitude lower than the cleanup goals, and indicated that the VOC concentrations in the bulk samples were not sufficiently elevated to warrant treatment by ISSS. This conclusion was supported by the field photoionization detector (PID) measurements, which did not indicate any specific elevated VOC concentrations in the four borings advanced to collect the bulk samples, plus an additional boring advanced to further confirm the PID readings (Arcadis 2018a).

In a June 12, 2018 meeting between KDHE and UP, UP agreed to collect additional discrete soil samples in the SA vadose zone because several rounds of soil remediation have occurred in this area since 2004. The scope of the unsaturated soil investigation and results of the sampling are summarized in the following section.

1.5.12 2019 Source Area Unsaturated Soil Investigation

In April 2019, Arcadis completed an unsaturated soil investigation in the SA to collect additional discrete soil data to support the evaluation and implementation of the SA Feasibility Study alternatives and confirm the results of the previously conducted ERD pilot test (described in Section 1.7). Key objectives of the unsaturated soil investigation were to:

- Collect discrete soil samples to define the extent of TCE-impacted soil below the SA excavation fill and above the saturated zone.
- Determine if residual COCs beneath the soil excavation area and above the ERD reactive zone are present at levels that warrant additional active remediation.

All activities were conducted in accordance with the SA Unsaturated Soil Investigation Work Plan (Arcadis 2019a), which was submitted to KDHE on March 20, 2019 and approved by KDHE on March 25, 2019. The results of the SA Unsaturated Soil Investigation were summarized in a letter summary report (Arcadis 2019b) submitted to KDHE on February 4, 2020 and approved by KDHE in a letter dated April 16, 2020. The summary report is included in Appendix E.

The scope of work consisted of the collection of discrete soil samples at 15 locations using a direct-push rig. Soil samples were collected at three intervals at each location:

- Just below the limit of clean fill placed as part of the 2011 excavation (at the 6 to 6.5 ft bgs interval)
- At the 14 to 14.5 ft bgs interval, which was located approximately 1 foot above the water table
- Midway between the first two samples (at the 10 to 10.5 ft bgs interval)

The soil beneath the Waste Storage Area slab was not removed during the previous excavations, and samples collected from the sidewall edges indicated soil impacted at concentrations above remediation goals. In order to obtain data from the underlying shallow soil beneath the Waste Storage Area slab, two additional samples were collected from the boring advanced through the slab.
The 0.5 to 1 ft bgs interval immediately below the slab and any bedding aggregate.

The 3 to 3.5 ft bgs interval.

Analytical data collected from the Unsaturated Soil Investigation sampling suggested that, with minor exceptions (including the shallow soil immediately beneath the Waste Storage Area slab), soil impacted with TCE above the Source Area Soil Remediation Goals is present primarily at the deeper intervals (14 to 14.5 ft bgs). Additionally, the deeper intervals may periodically be saturated or at least within the capillary fringe of the groundwater present in this area. The TCE impacts observed at the deeper intervals are likely a result of impact from the fluctuation of deeper water below.

The Summary Report concluded that additional large-scale soil remediation is not warranted for the Rail Yard Area of the SA. However, UP proposed to conduct spot excavation at the Waste Storage Area and perform a focused direct-push ERD injection event in the Rail Yard Area. As part of the final remedial activities performed at the SA, ERD substrate would be injected into the soil using direct-push methods at the 10 to 10.5 ft interval at each of the three locations in the Rail Yard where soil was detected at concentrations above cleanup goals (SB202, SB210, and SB213) and at 10 ft step-outs in each cardinal direction at each boring. For the spot excavation, the impacted subsurface soil beneath the Waste Storage Area in the Rail Yard will be remediated by shallow excavation and off-site disposal. The fencing and concrete slab will be removed, and the soil beneath the slab footprint will be excavated to a depth of 3 ft. The excavated soil will be profiled and disposed at an appropriate facility. Clean fill will be imported to bring the excavation to grade, and a new concrete slab and fencing will be constructed.

1.6 Results of the Risk Evaluation

Baseline routes of exposure were evaluated in the Baseline Risk Assessment (BRA, CTEH 2006). The BRA concludes that, among potentially complete pathways, the only route of exposure exhibiting an unacceptable risk to human receptors is the use of groundwater for prolonged full-body contact (e.g., swimming). This is based on water quality data from monitoring wells using the 95th percent upper confidence limit of the arithmetic mean. However, only one active lawn and garden well was identified within the area of groundwater impact. The actual TCE concentration from this well did not pose an unacceptable risk.

The BRA concludes that, among hypothetical/future pathways, the primary route of exposure to human receptors is the use of site groundwater for drinking water purposes. However, no municipal or private drinking water wells were identified within the Site, and proposals to install potable wells in areas of impacted groundwater would be disapproved by the City of Wichita because of existing environmental use controls (EUCs).

No risks were identified with regard to the highest indoor air TCE concentration, which was measured at a background location. No significant routes of exposure were identified for ecological receptors.

1.7 Previous Remedial Activities

1.7.1 Source Area - Accelerated Remediation Technology

As the SA interim remedial action (IRA) to mitigate soil and groundwater impacts, an ART in-well remedial technology that combined in situ air stripping, air sparging, and soil vapor extraction was installed in the
SA. The ART system was installed with two remediation wells in August 2004 and expanded to a total of five remediation wells during December 2005 (Forrester 2005, Forrester 2006a).

During the period in which two ART wells were in operation (between December 2004 and November 2005), an estimated 57 pounds of TCE was removed from the subsurface. Mass recovery improved following system expansion during operation between November 2005 and April 2006. Based on air sampling data, an estimated total of 227 pounds of TCE was removed by April 2007 (Forrester 2007). During the period of operation, improvements in shallow groundwater quality were observed within the immediate vicinity of the ART extraction wells (specifically MW-UP-1S and OW 01S) (Forrester 2007). While positive treatment was observed within several shallow SA well locations, shallow groundwater concentrations remained elevated (at MW UP 1S, specifically) through the end of ART operation. Based on the limited ongoing effectiveness observed, the ART system was shut down during June 2010 and an alternative ISCO interim measure was selected to address both shallow and deeper TCE source material.

1.7.2 Source Area – In Situ Chemical Oxidation Remediation

An ISCO remediation program was implemented by In-Situ Oxidative Technologies, Inc. (Foth 2010, ISOTEC 2011) to address TCE concentrations in saturated soil and groundwater. Injection activities were accomplished using DPT drilling techniques to establish temporary injection points from which modified Fenton's reagent could be introduced. A total of five DPT injection events were conducted between August 2010 and July 2011, which focused on shallow and deep saturated zones between approximately 17 to 32 ft bgs over an area of approximately 24,300 ft².

During each injection event, between 21 and 55 temporary DPT injection locations were installed on a 25 ft spacing in a grid-like pattern across the treatment area. Multiple vertical intervals targeted the shallow and deep groundwater zones and were generally spaced at vertical elevations between 17 and 32 ft bgs. Injected reagents included a neutral pH, chelated iron catalyst, and dilute hydrogen peroxide. Injection flow rates encountered during the ISCO events were highly variable, and injection pressures up to 40 pounds per square inch (psi) were applied in some locations. While the target injection volumes were achieved in the majority of the injection locations, the temporary construction of the injection points (i.e., unsealed deployable screens), the elevated injection pressures applied, and the presence of abandoned injection holes within the ISCO treatment area resulted in short-circuiting of the injection fluid. This limited subsurface distribution and resulted in preferential flow paths outside of the treatment interval.

Soil samples were collected at depths of 16, 24, and 30 ft bgs before the start of injection (baseline) and following each injection event to evaluate TCE treatment effectiveness in groundwater and soil. While positive treatment benefit was observed in areas outside of the immediate SA – leading to a reduction in the overall area where soil TCE concentrations are present - the injection methodology and challenges encountered due to surfacing of the injected solution led to incomplete oxidation within portions of the SA where the highest residual TCE is observed. The details of the ISCO remediation activities are included in the In-Situ Chemical Oxidation Remediation Program Final Report (ISOTEC 2011).

1.7.3 Source Area - Shallow Excavation

As presented in the Source Area Shallow Soil Excavation Completion Report (Foth 2012), SA shallow soil excavation was completed during 2010 and 2011 to remove TCE-impacted shallow soils from the SA. Two excavation events were conducted between February 22 and March 6, 2010 and between December 12 and 23, 2011.
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A total of 714 cubic yards (1,183 tons) of material was excavated from the SA, and the area was backfilled with clean material to meet the Site-specific Tier 3 Risk-Based Standards for Kansas (RSK) soil to groundwater standard of 0.14 milligram per kilogram (mg/kg). To achieve this, soils were excavated to a total depth of approximately 6 ft bgs where necessary. KDHE has indicated that the objective of the SA shallow soil excavation had been met where obstructions to additional investigation were not present. However, residual VOCs are present at concentrations higher than remediation objectives in areas that could not be excavated (along the railroad tracks to the north of the excavation area and under the secured waste storage area). KDHE will require establishment of an EUC for this remaining impact to permit future non-residential land use.

1.7.4 Source Area – Enhanced Reductive Dechlorination Pilot Study

A Source Area ERO Pilot Study was initiated in November 2013 to evaluate the feasibility of applying an ERO within the immediate vicinity of the TCE source area. The pilot study was conducted by injecting molasses and tracer dye solutions into two discrete intervals (14 to 21 ft bgs and 22 to 29 ft bgs) under gravity in the vicinity of the point of release. The objectives of the pilot test were to determine the overall injectability of the SA and collect design parameters necessary for implementation of a full-scale ERO remedy. Geochemical and dehalogenation data were also used to evaluate changes in the groundwater geochemistry following reagent delivery and indirectly assess the activity of the microbial community following the ISCO injection events. Groundwater samples from adjacent and downgradient monitoring wells were collected during and after the injection activities were complete to evaluate distribution of the injected reagents and confirm the onset of ERO treatment (e.g., changes in groundwater geochemistry, reduction of TCE to daughter products). Those samples were analyzed for the following parameters: total organic carbon (TOC), tracer dye, dissolved gases (methane, ethane and ethene), sulfate, dissolved iron, and VOCs. These analytes were used to provide multiple lines of evidence to assess the viability of the subsurface microbial community for ERO treatment.

Review of the pilot test data yielded the following key observations:

- The injection capacity into each interval (shallow and the deep) is sufficient to allow for gravity feed injections. The observed injection capacities within the two discrete intervals were similar (within an order of magnitude). The flowrate at the start of the shallow injection test was approximately 0.41 gallon per minute (gpm), and the average flowrate over the course of the test was approximately 0.15 gpm. The flowrate at the start of the deep injection test was approximately 0.65 gpm, and the average flowrate over the course of the test was approximately 0.27 gpm.

- The radius of influence (ROI) observed during the injections was sufficient to establish a reactive zone that will allow for complete degradation of TCE. Based on the locations of wells where TOC and tracer dye response was observed, the ROIs observed during the injections were at least 5.5 and 7 feet within the shallow and deep zones, respectively.

- Degradation of TCE through reductive dechlorination pathways was enhanced by the injection of a carbon substrate. While microbial sampling was not performed during the test, evidence of TCE dechlorination was observed at multiple wells. The average concentration of TCE reported in 2013 (pre-pilot test) and 2014 (post-pilot test) decreased by 90 and 80 percent in wells OW-1D and OW-1S, respectively. The average cis-1,2-DCE concentrations observed at each of these locations increased by 1,540 and 13,453 percent, respectively, during the same monitoring period. The presence of residual TOC at the end of the pilot test monitoring period (approximately 4 months after the pilot test) indicates that dechlorination was likely still ongoing.
Microbial analyses for Dehalococcoides (DHC) species was not performed during the pilot test. Complete dechlorination of cis-1,2-DCE was not observed, but due to the magnitude of source material within the SA, complete dechlorination was not expected over the brief time period in which the pilot test was monitored.

The observation of TCE degradation to cis-1,2-DCE, declines in sulfate concentrations, and increases in methane during the limited period of the pilot test provides compelling evidence that the source area microbial community was not eradicated by the previously completed chemical oxidation injections.

The geochemical shifts observed during the pilot test were consistent with expectations in systems where organic carbon is first introduced. It is common to observe lag periods following carbon application that coincide with the consumption of background electron acceptors and development of robust anaerobic conditions (i.e., methanogenic). These lag periods can last up to 6 months, following which methane concentrations will continue to increase in the presence of available electron donor.

There are a variety of microbial genera that facilitate the initial dehalogenation step of TCE to cis-1,2-DCE, a number of which perform this mechanism under iron- or sulfate-reducing conditions consistent with those observed during the test. As conditions transition further from sulfate-reducing to methanogenic (where DHC is most prolific), more significant cis-1,2-DCE dehalogenation occurs. Even in the absence of complete transformation of TCE through end products (e.g., ethene, ethane), the pilot test provided the necessary information to support design of a source area injection program and the leading indicators to demonstrate that a TCE-dehalogenating microbial community can be established.

Any ERD treatment program performed in the SA would be completed via an adaptive approach, in which performance monitoring data would serve as a constant feedback loop to support treatment optimization (e.g., the timing and volumes of injection applications, modification of carbon substrate types, necessary pH modification amendments, bioaugmentation). The need for bioaugmentation – or other optimization techniques – would be determined following initiation of the ERD treatment program based on performance monitoring data and would be added into the injection program as necessary once the appropriate subsurface reducing conditions are established.

The ERD Pilot Test Summary Report (Arcadis 2016b) is included in Appendix C.

1.7.5 Mid-Plume Area – Murdock Hydraulic Containment System

In 2009, the HCS was installed at the leading edge of the MPA TCE plume (along Murdock Street) and has been in continuous operation since construction was completed. Until 2014, this groundwater extraction and treatment system collected TCE-impacted groundwater from six recovery wells and treated the combined influent using granular activate carbon (GAC). The treated effluent was discharged to the nearby Chisholm Creek under a National Pollutant Discharge Elimination System (NPDES) permit. In 2014, an air stripper was installed in the existing treatment building to provide primary treatment, and one of the GAC vessels was retained as a polishing treatment. In addition, a portion of the discharge is directed to the four injection wells installed to the west and north of the HCS as part of the long-term pilot test. The treated water flow is split between the injection wells and the existing NPDES outfall at Chisholm Creek.

Valuable aquifer response and treatment efficiency data have been collected during operation of the Murdock HCS. These data will be incorporated into any long-term remedy for the MPA.
1.7.6 2018 Source Area ERD Remedial Implementation

Based on the results of the ERD pilot testing at the SA (Arcadis 2015), UP began implementation of a Source Area ERD remedial strategy in late 2018. The scope of the ERD remediation was contained in a Source Area ERD Injection Work Plan (Work Plan; Arcadis 2018a) approved by the KDHE in a letter dated September 19, 2018.

The overall scope of work for the Source Area ERD implementation included:

- Installation of the SA injection and monitoring well networks
- EC/HPT logging at select injection well locations to evaluate overall treatment area transmissivity and refine the expected range of injection parameters including flow rate and injection volume
- ERD injection events conducted in December 2018 and May 2019
- Monitoring results, including baseline sampling, tracer testing, and 6 months of post-injection performance monitoring.

Injection wells were installed in three transects, and new monitoring wells were installed to delineate site impacts, evaluate the distribution and washout of the injected solution, and assess changes in groundwater geochemistry and COC concentrations following injection activities.

During the initial ERD injection event in November and December 2018, more than 56,700 gallons of an approximate 2% by volume molasses solution was injected into site injection wells. During the second injection event conducted in May 2019, more than 83,400 gallons of an approximate 2% by volume molasses solution was injected.

Post-injection performance monitoring at wells located within and downgradient of the injection area observed the following results after the first molasses injection:

- The molasses injection event supported the onset of more strongly reducing conditions and accelerated the initial stages of TCE dechlorination.
- While organic carbon distribution challenges were observed due to the low permeability conditions in Transects 1 and 2, adequate organic carbon injection was completed in all three transects to support the onset of geochemical changes.
- Where elevated TOC concentrations were observed, enhanced iron and sulfate reduction was observed. In some locations, the onset of methanogenesis was observed.
- The presence of residual elevated sulfate in some locations following previous Fenton’s reagent injection will require additional organic carbon injection to completely reduce.
- Where elevated TOC had resulted in a shift to more strongly reducing conditions, enhanced dechlorination of TCE to cis-1,2-DCE was observed. The transformation of TCE to cis-1,2-DCE is consistent with the beginning stage of ERD processes expected following a single injection event.
- The production of final end-products ethene and ethane within 6 months of the first molasses injection event was a positive indicator for the complete dechlorination of TCE and cis-1,2-DCE as the remedy progresses with subsequent injection events.

The results from the first 6 months of ERD injection and post-injection performance monitoring are summarized in a Source Area ERD Startup Report (Arcadis 2019b). The Startup Report is included as Appendix F.
Since the submittal of the ERD Startup Report in October 2019, the continued effectiveness of the Source Area ERD treatment has been monitored and documented in quarterly project reports submitted by UP to the KDHE (Arcadis 2020a, 2020b).

As presented in the Fourth Quarter 2019 Progress Report (Arcadis 2020a), post-injection data collected since the initial ERD injection event at the SA in 2018 indicate that the injection of a dilute molasses solution has supported the onset of strongly reducing conditions and accelerated the initial stages of TCE dechlorination. These results include:

- Total organic carbon has been detected at elevated concentrations in all injection area wells and most downgradient monitoring wells, indicating that the dilute molasses solution was distributed throughout the injection area, and advective transport is conveying the organic carbon to downgradient locations.
- Iron reduction, sulfate reduction, and methanogenesis have been observed throughout the SA, indicating strongly reducing conditions across the Site.
- Enhanced dechlorination of TCE has been observed throughout the SA. Before the initial injection event, TCE was the dominant CVOC throughout the SA, except near the former pilot study area. Following initiation of the injection program, cis-1,2-DCE has become the dominant CVOC, with some production of vinyl chloride. Ethene and/or ethane were also detected in some wells, indicating that complete dechlorination is occurring. Continued reductive dechlorination is expected to further reduce CVOC concentrations.
- Immediately following the initial injection event, total CVOC concentrations increased in some wells due to surfactant effects increasing desorption from the aquifer matrix to the dissolved phase where dechlorination occurs. Concentrations have since declined in most wells and were below the maximum in 10 of 13 injection area and downgradient wells sampled during the fourth quarter of 2019.

In the Fourth Quarter 2019 Progress Report, the use of emulsified vegetable oil (EVO) as an alternate carbon substrate was recommended. EVO has a lower solubility, slowing the release of organic carbon, maintaining reducing conditions for a longer period, and expanding the length of time between injections. The potential use of EVO as a carbon substrate was previously approved in the Work Plan and the Site’s Underground Injection Control permit. The fourth Source Area ERD injection event, using EVO, was performed during March/April 2020 (Arcadis 2020b). The performance of the Source Area ERD treatment is currently being monitored semi-annually, and results will be included in subsequent progress reports.

1.8 Conceptual Model Summary

The following points summarize the hydrogeologic conceptual model for the 29th and Grove Site, as illustrated on Figure 1-4.

1.8.1 Source Area near the Point of Release

A historical surface spill of TCE impacted soil and groundwater at the eastern end of the rail yard.

- The TCE migrated vertically through soil and then beneath the water table until bedrock was encountered.
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- Free-phase TCE NAPL has not been evident at the SA, indicating that TCE concentrations do not exceed the residual saturation of SA soils. However, the majority of SA TCE impact observed during the RI is below the water table.
- Over time, TCE has dissolved and has been transported south from the rail yard by groundwater flow.
- Groundwater flow is from north to south and has been enhanced by a constant surface water head, represented by borrow-pit ponds located just north of the rail yard SA.
- At the SA, the permeable portion of the aquifer is relatively thin (less than 10 ft), is entirely saturated (causing semi-confined conditions), and lies atop a relatively sharply sloping bedrock surface.
- The aquifer is very thin below the SA and in northern sectors, and hydraulic gradients are steep (0.0103 ft/ft).

1.8.2 Extended Source Area
- The East Fork of Chisholm Creek is hydraulically connected to the water table, though the degree of connection is limited by low-permeability sediments, into which the stream is incised, and the low head differential between the aquifer water table and the stream water level.
- Limited discharge from groundwater to surface water may result during low runoff periods; however, surface water impacts are nominally evident due to low groundwater discharge rates and shallow stream depth, favoring chemical volatilization. Impacts to stream sediment are nominally evident for the same reasons, plus limited chemical partitioning from water to soil. Downstream of the SA, impacts to Chisholm Creek surface water and sediment samples were not evident.

1.8.3 Mid-Plume Area
- Few degradation products are present in the MPA, indicating a relatively slow rate of naturally occurring reductive dechlorination.
- In the MPA, the 29th and Grove plume has unassociated dissolved plumes on both the east and west sides.
  - On the east side, and partially commingled with the 29th and Grove plume, the PCE dry cleaner plume is present, migrating in a largely parallel manner.
  - To the west, the NIC plume also migrates in a largely parallel manner. While there is significant separation between the plumes over most of their lengths, near the southern extent of the 29th and Grove plume near Murdock Street, the plumes are immediately adjacent.
- In the MPA, the aquifer thickens to the south in the direction of groundwater flow as the depth to bedrock increases, and the overlying silt and clay unit thins.
- The low-permeability silts and clays at the surface limit the rate of surface water recharge to the aquifer and provide some protection against upward migration of TCE vapors. In the northern portion of the MPA, the low-permeability strata act as a confining layer on the aquifer. In southern areas, there is unsaturated sand above the groundwater-bearing strata, and the aquifer will behave mainly as an unconfined unit.
• Approximately 4,000 ft downgradient of the SA, the water table drops below the base of the silt and clay unit and, from that point, the remainder of the impacted portion of the aquifer to the south is effectively unconfined.

• The aquifer thickens in the central portion areas, and the hydraulic gradients decrease (0.0012 ft/ft).

• Within the sandy portion of the aquifer, materials generally coarsen and increase in hydraulic conductivity with depth.

• In the southern portion of the plume, groundwater flow directions and velocities are relatively constant, from north to south at approximately 500 ft/year.

• Several site characteristics have localized impact on the direction and velocity of groundwater flow and the associated dissolved plume distribution:
  - The pinch-out of the channel deposits to the east appears to have little impact for much of the plume length, but before installation and operation of the Murdock HCS, may have caused a westward component of flow at the downgradient margin of the plume.
  - The installation of the groundwater extraction system on Murdock Street has removed any westward component of groundwater flow and has begun to draw groundwater from the west.
  - In the central and southern portions of the MPA, groundwater monitoring wells labeled as “shallow” are placed in moderately permeable aquifer materials, and velocities are relatively slow compared to monitoring well locations labeled “deep,” which are placed in highly permeable strata at the base of the aquifer. In these deeper wells, groundwater flow velocities are much faster. The plume widens as the aquifer thickens to the south, at which point advective transport dominates and the plume width remains consistent as it slowly attenuates.

1.8.4 Site Wide

• The natural rate of biological attenuation of the plume is relatively low.

• The depth of impacted groundwater is bounded vertically by the shale bedrock.

• TCE emissions from impacted groundwater to both outdoor and indoor air are not evident, though indoor and background sources were investigated and identified.

• Sources of other chemicals are evident in groundwater, likely associated with dry cleaning (PCE) and gasoline stations (BTEX). Because TCE is a breakdown product of PCE, some TCE in the plume is likely contributed by the PCE sources. Other TCE sources may be indicated by elevated detections in shallow groundwater that are locally observed.
2 REMEDIAL ACTION OBJECTIVES

RAOs are medium-specific and source-specific goals achieved through completion of a remedial action that is protective of human health and the environment. These objectives are typically expressed in terms of the contaminant, the exposure route, and receptor. They provide the basis for determination of whether protection of human health and the environment is achieved for a remedial alternative.

RAOs are typically developed by evaluating several sources of information, including the results of the BRA and tentatively identified ARARs. During development of the RAOs, other remedial goals expressed by various Site stakeholders may be considered. All of these inputs provide the basis for determining whether protection of human health and the environment is achieved for a remedial alternative.

PRGs are defined as the concentration of a chemical in an exposure medium associated with a target risk level such that concentrations at or lower than the PRG do not pose an unacceptable risk. Numerical remediation goals can be based on existing environmental standards or risk calculations, thus providing targets for successful remedial alternatives to meet.

The following sections present the ARARs, RAOs, and the preliminary remedial action goals identified for the SA.

2.1 Applicable or Relevant and Appropriate Requirements

The CERCLA (United States Code 42 §9621[d], 1980), as amended by the Superfund Amendments and Reauthorization Act (SARA), stipulates that the cleanup standards or controls for hazardous substances, pollutants, or contaminants be at least in accordance with any ARARs designated under state or federal law (CERCLA Section 121[d]). Applicable requirements are those cleanup standards or controls promulgated under state or federal law that specifically address a hazardous substance, pollutant or contaminant, action, location, or other situation at the site. Relevant and appropriate requirements are those cleanup standards or controls that do not specifically or fully address a hazardous substance, pollutant or contaminant, action, location, or other situation at a site, but address similar situations.

2.1.1 Definition of ARARs

ARARs are defined as chemical-, location-, or action-specific. An ARAR can be one or a combination of all three types of ARARs.

Chemical-specific requirements address chemical or physical characteristics of compounds or substances on sites. These values establish acceptable amounts or concentrations of chemicals that may be found in or discharged to the ambient environment.

Location-specific requirements are restrictions placed upon the concentration of hazardous substances or the conduct of cleanup activities because they are in specific locations. Location-specific ARARs relate to the geographical or physical positions of sites rather than the natures of contaminants at sites.

Action-specific requirements are usually technology-based requirements or limitations on actions taken with respect to hazardous substances, pollutants, or contaminants. A given remedial activity can trigger an action-specific requirement. Such requirements do not themselves determine the cleanup alternative but define how selected cleanup methods should be implemented.
2.1.2 Other Requirements to Be Considered

In addition to ARARs, To Be Considered (TBC) criteria should be evaluated and incorporated as appropriate to achieve the required level of protection of human health and the environment. The TBC criteria are non-promulgated advisories, regulations, or guidance issued by federal or state agencies that are not legally binding and are not generally enforceable but may have specific bearing on all or part of the remedial alternative. TBCs can be used to determine the appropriate level of cleanup where no specific ARARs exist for a chemical or situation, or where such ARARs are not sufficient to be protective.

2.1.3 Waivers

CERCLA authorizes that any ARAR may be waived under one of the six conditions presented in Table 2-1 if the projection of human health and environment can be ensured.

2.2 Identification of ARARs

Summaries of federal and Kansas chemical-specific, action-specific, and location-specific ARARs and TBCs were compiled using USEPA and KDHE guidance (USEPA 1988a, 1989, and 1997 and KDHE 2005), and other FSs that have been completed in the vicinity of the SA (CDM 2011 and USEPA 1992). The ARARs and TBCs are included in Table 2-2 (federal) and Table 2-3 (state), along with a designation denoting the applicability of each ARAR or TBC to the SA. The type of ARAR or TBC (chemical-, location-, or action-specific) is also noted in the tables.

2.3 Remedial Action Objectives

Site-specific RAOs for the SA are developed in this section using the results of the site-specific risk assessment performed during the RI and include discussion of contaminants and media of concern, potential exposure pathways, and remediation goals.

The RI report (Forrester 2006b) details the nature and extent of impact at the 29th and Grove Site. TCE is the primary COC associated with the SA. Other contaminants were also identified in downgradient areas at somewhat lower concentrations including PCE, BTEX, and methyl tertiary butyl ether (MTBE). These constituents are not associated with the 29th and Grove SA, and therefore are not within the scope of the remedial effort presented here. The media of concern for the source area include shallow SA soils and groundwater in the alluvial sediments.

A BRA was performed based on data collected in the RI (CTEH 2006). The BRA concluded that no current risks to human receptors are present within the area of impact, even though groundwater TCE concentrations exceed USEPA’s Maximum Contaminant Levels (MCLs) for drinking water. Although groundwater from the 29th and Grove Site is not used for potable water supply, MCLs (corresponding to KDHE’s RSK) are the only groundwater standards available at this time. The only potentially completed pathway identified was through prolonged full-body contact with impacted water (e.g., swimming). However, only one active lawn and garden well was identified within the area of groundwater impact (located in the MPA), and the concentration of TCE detected in this well does not pose an unacceptable risk to human health. This one lawn and yard well was subsequently closed in 2008. No risks to ecological receptors were identified.
2.3.1 Source Area RAOs

The overall objective of the SA remedial action is to mitigate the risk of exposure to at-risk populations, as determined by the BRA. As no at-risk populations were identified by the BRA, restoration of the environment will be the primary goal. The ultimate remediation goals are identified in the following subsection and include the general risk-based standards used by KDHE. The regulatory framework in which the remedial action will be performed is represented by the ARARs, described in subsequent sections.

The following RAOs have been developed for the SA of the 29th and Grove Site:

- Reduce or stabilize (prevent the migration of) TCE and CVOC mass in SA soils.
- Reduce concentrations of TCE and other CVOCs in groundwater to the extent practicable.
- Prevent inhalation of site-related constituents in indoor air.
- Prevent exposure to contaminated soil and groundwater.

Soil remedial actions will be performed with the ultimate goal of achieving the appropriate KDHE Bureau of Environmental Remediation (BER) soil standard in accessible areas (e.g., not below the railroad tracks). Groundwater remedial actions will be performed in the SA with the ultimate goal of achieving KDHE-BER groundwater pathway standards for dissolved-phase COCs. However, these goals may not be readily attainable due to limitations in the technical practicability of the remedial actions. If it is determined that remedial systems are not reducing COC concentrations at a sufficient rate, then the UP may propose to KDHE an alternative means to achieve remediation goals, such as use of Alternate Cleanup Levels (ACLs) or soil excavation.

2.3.2 Mid-Plume Area RAOs

Site-specific RAOs for the MPA are developed in this section using the results of the site-specific risk assessment performed during the RI and include discussion of contaminants and media of concern, potential exposure pathways, and remediation goals.

The RI report (Forrester 2006b) details the nature and extent of impact at the 29th and Grove Site. TCE is the primary COC associated with the Site. Other contaminants were identified at somewhat lower concentrations including PCE, BTEX, and MTBE. These constituents are not associated with the 29th and Grove SA, and therefore are not within the scope of the remedial effort presented here. The medium of concern for the MPA includes groundwater in the long, narrow area to the south of the SA, as shown on Figure 1-3.

A BRA was performed based on data collected in the RI (CTEH 2006). The BRA concluded that no current risks to human receptors are present within the area of impact, even though groundwater TCE concentrations exceed USEPA’s MCLs for drinking water. Although groundwater from the 29th and Grove Site is not used for potable water supply, MCLs (corresponding to KDHE’s RSK) are the only groundwater standards available at this time. The only potentially completed pathway identified was through prolonged full-body contact with impacted water (e.g., swimming). However, only one active lawn and garden well was identified within the area of groundwater impact, and the concentration of TCE detected in this well does not pose an unacceptable risk to human health. This one lawn and yard well was subsequently closed in 2008. No risks to ecological receptors were identified.
The overall objective of the MPA remedial action is to mitigate the risk of exposure to at-risk populations as determined by the BRA. As no at-risk populations were identified by the BRA, restoration of the environment will be the primary goal. The ultimate remediation goals are identified in the following subsection and include the general risk-based standards used by KDHE. The regulatory framework in which the remedial action will be performed is represented by the ARARs described in subsequent sections.

The following RAOs have been developed for the MPA of the 29th and Grove Site:

- Reduce concentrations of TCE and associated degradation compounds (cis 1,2 DCE, trans-1,2-DCE, 1,1-DCE, and vinyl chloride) in groundwater to the extent practicable.
- Prevent inhalation of site-related contaminants in indoor air.
- Prevent exposure to contaminated groundwater.
- Prevent migration of the downgradient edge of TCE-impacted groundwater.
- To the extent practicable, restore the aquifer to the most beneficial use.

Remedial actions will be performed at the Site with the ultimate goal of achieving KDHE RSK in groundwater located downgradient of the SA. However, these goals may not be readily attainable due to limitations in the technical practicability of the remedial actions. If it is determined that remedial systems are not removing mass at a rate greater than that of natural attenuation, then the UP may propose discontinuation of a remedial system and employment of MNA to achieve remediation goals.

### 2.4 Preliminary Remediation Goals

The KDHE-BER RSK values for the site COCs are included in the following tables. The soil standard shown below for TCE represents the site-specific KDHE-BER RSK Tier 3 value developed for the SA. All other soil values shown below consist of the listed KDHE-BER RSK Tier 2 value for the non-residential soil-to-groundwater pathway.

<table>
<thead>
<tr>
<th>Constituent of Concern</th>
<th>Source Area Soil Remediation Goal (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCE</td>
<td>0.14</td>
</tr>
<tr>
<td>cis-1,2-DCE</td>
<td>0.855</td>
</tr>
<tr>
<td>trans-1,2-DCE</td>
<td>1.22</td>
</tr>
<tr>
<td>1,1-DCE</td>
<td>0.0859</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0.0205</td>
</tr>
</tbody>
</table>

The KDHE-BER groundwater pathway standard for the COCs at the Site corresponds to USEPA's primary MCLs.

<table>
<thead>
<tr>
<th>Constituent of Concern</th>
<th>Groundwater Remediation Goal (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TCE</td>
<td>0.005</td>
</tr>
<tr>
<td>cis-1,2-DCE</td>
<td>0.070</td>
</tr>
<tr>
<td>trans-1,2-DCE</td>
<td>0.1</td>
</tr>
<tr>
<td>1,1-DCE</td>
<td>0.007</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0.002</td>
</tr>
</tbody>
</table>

These values are proposed as PRGs for the Site.
3 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

Remedial alternatives are developed from stand-alone technologies, process options, or combinations of technologies and process options. The purpose of technology, process option, and alternative screening is to reduce the number of remedial alternatives retained for detailed analysis.

For this FFS, a multi-phase approach is used to screen the technologies, process options, and alternatives for both the SA and the MPA. The multi-phase approach consists of the following steps:

- Identify general response actions, remedial technologies, and process options that are potentially useful to address the RAOs identified in Section 2 for TCE-impacted soil and groundwater. Preference is given to active technologies that are known to effectively address VOC impacts.
- Conduct an initial screening of general response actions (GRAs), technologies, and process options based on technical implementability and suitability to address impacted soil and groundwater. Technologies and process options that are not technically implementable relative to Site-specific objectives, or that have low effectiveness or relative high cost to implement, are eliminated from further consideration in this initial screening.
- Assemble the retained technologies and process options into remedial alternatives that are potentially viable for remediation of TCE-impacted soil and groundwater in the SA and the MPA.
- Conduct a detailed analysis of the assembled alternatives for each area.

A discussion of GRAs is presented in Section 3.1. The initial process option and technology screening is explained in Section 3.2. Technologies considered appropriate for the SA are explained in the remaining sections. Technologies retained through the screening will then be assembled into potential remedial alternatives. These are then screened and evaluated in Sections 4, 5, and 6 for each area.

3.1 General Response Actions

GRAs are initial broad measures or activities considered to address the RAOs for impacted groundwater. GRAs include several remedial categories, such as containment, removal, disposal, and treatment of contamination within a site. Site-specific GRAs are initially developed to satisfy the RAOs for impacted soil and groundwater and then are evaluated as part of the identification and screening of remedial technologies and process options. The GRAs considered for remediation of impacted soil and groundwater at the SA include:

- No Action — leaves contaminant media in their existing condition with no control or cleanup planned. In accordance with the National Contingency Plan (NCP), this GRA must be considered to provide a baseline against which other options can be compared.
- Institutional Controls — administrative and legal restrictions intended to control or prevent present and future use of contaminated media. Institutional controls are not intended to substitute for engineering aspects of a selected remedy.
- Monitoring — involves physical measures applied to the site to determine if there is contaminant migration. Monitoring is not intended to substitute for any engineering aspect of a selected remedy and does not physically address contaminants.
3.2 Focused Selection and Screening of Technologies

Appropriate process options and technologies to be considered for soil and/or groundwater remediation have been identified and are listed, along with the screening criteria, in Table 3-1 for the SA and Table 3-2 for the MPA. The list of technologies included in Tables 3-1 and 3-2 was derived from several sources including the Remediation Technologies Screening Matrix table (FRTR 2012) and the online technology screening tool maintained by the Federal Remediation Technologies Roundtable (FRTR 2012). Only technologies whose target COCs included halogenated volatile organic compounds were considered.

3.2.1 Initial Screening Based on Technical Implementability

The remedial technologies and process options presented in Tables 3-1 and 3-2 were initially screened based on technical implementability. This preliminary screening examines the suitability of a technology to address TCE-impacted soil and/or groundwater.

During this initial screening, a technology or process option was eliminated from further consideration based on the following:

- Technical implementability - A technology or process option was screened from further considerations when site conditions or site characterization data indicated that the technology or process option was incompatible with the type of contaminant involved, the type of impacted aquifer material, depth to the impacted portion of the plume, or could not be implemented effectively due to physical limitations or constraints at the SA.

- Scalability - Some of the process options may be technically implementable on a small-scale basis for a specific location; however, the technical implementability screening and elimination were performed by evaluating use of the process option(s) to address the large-scale soil and groundwater impacts in the SA.

Remedial technologies and process options that were not deemed to be technically implementable were eliminated from further consideration. Each of the technologies retained after initial screening is summarized below.
3.3 Summary of Source Area Remedi<e2<80<92>al Technologies Retained after Initial Screening

As described in Section 1, TCE impacts are present within the SA at levels that exceed the RSK Tier 3 soil criterion and the groundwater MCLs. TCE impacts are present in vadose-zone soils and within the multiple saturated soil strata overlying the Wellington Formation shale. To address both vadose- and saturated-zone impacts, a combination of remedial technologies is being considered to prevent further migration of TCE from the SA to the MPA in order to achieve Site-wide RAOs. The combination of SA remedies for soil and groundwater is therefore considered to address TCE impacts between the point of original TCE release southward to Chisholm Creek. Successful TCE treatment within this area will ultimately enable the selected MPA remedy to achieve the groundwater RAOs. Options retained for SA treatment are described below.

3.3.1 In-Situ Soil Solidification/Stabilization

ISSS relies on achieving an overall reduction in soil permeability in order to prevent exposure to sorbed COCs (and NAPL if present) by effectively binding them into a solidified monolith with reduced permeability. ISSS of impacted site soils is typically accomplished through the addition of one or more cementitious and/or pozzolanic materials, such as Type I/II Portland cement, blast furnace slag cement, bentonite, or other locally available reagents. This process results in a gain in soil strength and a corresponding reduction in hydraulic conductivity within the solidified monolith, thus preventing the leaching of COCs bound within the monolith to the surrounding groundwater. The level of reduction is dependent on the amount of stabilized COC mass and the relative change in hydraulic conductivity between the stabilized soils and groundwater. During ISSS blending, it is common for the targeted soils to bulk (increase in volume). This effect is more pronounced in clay-based soils and often requires the removal of a proportional amount of overlying soils via excavation to accommodate the change in soil volume and return the stabilized area to the initial grade. Capping and/or grading will be used following treatment to minimize infiltration of surface water on the monolith.

ISSS application conventionally entails the use of heavy equipment or large-diameter augers to mix appropriate quantities of the stabilizing reagents into the target zones to create a homogenous mixture for monolith solidification. The minimization of excavation activities (beyond what is required to account for bulking effects) reduces the potential for release of fugitive dusts and runoff from the disturbed soil compared to traditional soil excavation techniques. However, special consideration should still be given to protect the health and safety of on-site remedial workers. Special provisions that are typically incorporated into the ISSS program include on-site air monitoring and dust, vapor, and odor control provisions.

To ensure remedial effectiveness following field deployment, this alternative requires upfront bench-scale testing to determine the appropriate stabilizing reagent(s) and optimum percent mix as well as post-treatment groundwater monitoring. Testing is used to evaluate the ability of selected admixtures to achieve target strength gain and reduce the overall hydraulic conductivity relative to the native soil strength. Typically, unconfined compressive strength of at least 30 to 50 psi, and a hydraulic conductivity of at most $1 \times 10^{-6}$ cm/sec (or two orders of magnitude lower than the in situ hydraulic conductivity) are targeted. Reagent selection is based on site-specific strength development and hydraulic conductivity goals in comparison with native soil geotechnical properties. The bench-scale testing program will also...
determine the level of bulking expected to occur during mixing operations and estimate the volume of overlying soil for removal.

As presented in the Pre-Design Source Area Soil and Groundwater Investigation Summary (contained in Appendix D), and as summarized in Section 1.5.11, a bench-scale ISSS test was completed on the SA soil to determine the level of bulking expected to occur during mixing and to estimate the volume of overlying soil for removal. The bench-scale study indicated that, while the SA soil is amenable to the ISSS technology, the baseline VOC concentrations in the test samples indicated average TCE and cis-1,2-DCE concentrations approximately two orders of magnitude lower than the cleanup goals, and suggested that the VOC concentrations in the bulk samples were not sufficiently elevated to warrant treatment by ISSS. The lack of unsaturated soil in the SA with concentrations above cleanup goals was subsequently confirmed by discrete soil sample, as presented in the Source Area Unsaturated Soil Investigation (Arcadis 2019a, included in Appendix E).

### 3.3.2 Excavation and Off-Site Disposal

Excavation and off-site disposal rely on physical removal of COC-impacted soil to reduce the amount of COC mass present. Removal of impacted soils would effectively reduce the source of dissolved-phase COC concentrations within or downgradient of a source area. The level of reduction will depend on the relative amount of COC mass removed and the location of the excavated soils with respect to the groundwater (i.e., vadose- or saturated-zone soils). The primary application of this method entails the use of heavy equipment to excavate impacted soils and load the material into trucks for off-site disposal at an approved disposal facility (e.g., landfill) that is permitted to accept special wastes (e.g., contaminated soil).

Excavation requires the use of material handling controls. One example of such controls is the construction of a secure staging area(s) to prevent exposure of unauthorized personnel, bermed to prevent stormwater runon and runoff, graded to prevent ponding, and lined to prevent groundwater contamination. The off-site transportation of wastes resulting from excavation must meet federal and state shipping and manifesting regulations. Excavations must be backfilled (with clean soil), compacted, graded, and resurfaced to match the surroundings in order to prevent settling, erosion, and the collection of rainwater. Dewatering is required for excavations that extend below the groundwater table.

Excavation can result in the release of fugitive dusts and runoff from disturbed soil. Therefore, during excavation, consideration must be given to the health and safety of on-site remedial workers and prevention of uncontrolled off-site migration of contaminated media (dust and stormwater). Implemented controls can include on-site air monitoring and dust, vapor, and odor control provisions. Examples of dust controls are water sprays or application of chemical dust suppressants. Surface water controls (such as berms) may also be required to prevent stormwater runon and control stormwater runoff.

### 3.3.3 Soil Mixing Using Zero Valent Iron

Zero valent iron (ZVI) is a reactive reagent that can facilitate direct abiotic CVOC reduction. ZVI can be applied via subsurface injection emplacement, as part of permeable reactive barriers, or blended directly into impacted soils to achieve treatment. Implementation of ZVI would need to consider site-specific characteristics such as the soil and groundwater geochemistry, the advective groundwater velocity, and total contaminant mass. Due to its potential longevity in the subsurface (e.g., at least 3 to 5 years), ZVI serves as a passive and long-term treatment reagent requiring reduced long-term operations.
maintenance, and monitoring (OM&M). The goal of implementing soil treatment using ZVI in the SA would be to homogenize native soils with ZVI in order to maximize contact, reduce the overall permeability of the soil sequence to allow sufficient residence time for COC reaction with the ZVI material, and reduce the leaching of any untreated COCs from the mixing zone.

The reduction of permeability is typically accomplished by mixing in clay soil instead of Portland cement because clay still allows for a reduced dissolved phase flux to occur (Portland does not). The longevity of the ZVI is dependent on the contaminant concentration, groundwater flow velocity, and the geochemical makeup of the groundwater. The longevity of the reactive properties of ZVI is primarily dependent on the contaminant concentration, groundwater flow velocity, and the geochemical makeup of the groundwater (such as dissolved oxygen, TOC, and carbonates).

ZVI degrades CVOCs via abiotic reductive dehalogenation processes that occur as the iron is oxidized. ZVI is not dissolved into groundwater during the reactive process and is therefore not applicable for contaminant mass that has already migrated from the mixing area. As dissolved phase CVOCs contact the reactive ZVI material, multiple reactions occur that indirectly or directly lead to the reduction of the chlorinated solvents. The direct abiotic transformation mechanism removes a chlorine atom from the compound using electrons supplied by the oxidation of the iron. Indirect ZVI treatment can be achieved via the release of dissolved hydrogen from the ZVI particle surface. Available dissolved hydrogen can be used by native microbial species to then facilitate one or more steps of the reductive dechlorination process. During this process, the chloride in the compound is replaced by hydrogen, resulting in the complete transformation of CVOCs to byproducts (ethene, ethane, and chloride ions). Because degradation rates using the process are several orders of magnitude greater than under natural conditions, any intermediate degradation byproducts formed during treatment (e.g., vinyl chloride) are also reduced to byproducts in a properly designed treatment zone. These biological processes can be further enhanced by selecting a ZVI material fabricated with an organic carbon component. The overall rate of reaction between the COCs and the ZVI material can be controlled by the specific ZVI particle size. As an example, the increased surface area of nano-scale relative to micro-scale ZVI allows for greater contact following application, but the size differences are also correlated with increased reactivity and reductions in overall longevity. The ZVI material selection must therefore be balanced with the mixing approach and nature of the source mass to optimize treatment performance (which can be evaluated via bench testing).

Similar to ISSS applications, ZVI mixing typically entails the use of heavy equipment or large-diameter augers to mix appropriate quantities of the ZVI product into the target zones and create a homogenous mixture. To optimize effectiveness, this alternative requires a bench-scale testing component to determine overall suitability, appropriate stabilizing reagent(s), and optimum percent mix.

3.3.4 Groundwater Removal

Groundwater extraction remedies involve the removal of impacted groundwater from the subsurface to control groundwater migration and remove contaminant mass. The performance of pump-and-treat systems depends directly on the nature of the COC source, its discharge to the groundwater plume, the hydrogeologic conditions that control the rate of mass recovery, and contaminant chemistry (primarily solubility). Cleanup time is strongly influenced by the rate of pore volume exchanges and the age of the plume. Pump-and-treat systems are typically successful in moderate- to high-permeability applications where consistent lithological sequences exist. As the permeability of the site decreases and the complexity of the lithological sequence increases, the effectiveness of a pump-and-treat system...
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29th and Grove Site, Wichita, Kansas

decreases. This is primarily attributed to reductions in overall pore volume exchange, the potential for diffuse mass storage within lower conductivity soil sequences, and the lack of control over the zones from which plume capture is achieved.

Successful application of this technology typically involves an initial pilot test to determine extraction rates, concentrations of COCs in extracted groundwater, the pumping capture radius, and overall feasibility. The final design will typically include a network of extraction wells installed within the core of the plume to maximize COC recovery but can also be applied for distal plume containment. Groundwater extracted from the network is processed through a treatment system and then discharged to the sanitary sewer or to surface water conveyance. Groundwater impacted with VOCs is typically treated through a combination of air stripping or GAC treatment technologies. The most common configuration consists of using air stripping as the primary means of treatment and GAC vessels as a secondary polishing treatment step.

Air stripping involves removing volatile organic compounds from groundwater by greatly increasing the surface area of the contaminated water exposed to air (aeration). Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. With GAC treatment, groundwater contaminants are removed by adsorption to GAC. Two GAC vessels are generally placed in series (lead and lag) with regular sampling after the lead unit to determine when that unit has reached its chemical loading capacity (i.e., when chemical breakthrough occurs). Any contamination that breaks through the first unit in between sampling events is adsorbed in the second unit. When breakthrough of the first vessel is detected, the carbon in the first vessel is changed out, and the vessel configuration is changed so that the previous “lag” unit is now used as the lead unit. Many VOCs, semi-volatile organic compounds (SVOCs), and non-volatile organic compounds are readily adsorbed by GAC. The carbon usage depends on the contaminant characteristics and concentrations as well as other constituents in the water that may compete for active sorption sites (USEPA 2005).

3.3.5 Enhanced Reductive Dechlorination

Chlorinated solvent treatment can be achieved in situ via abiotic and biological mechanisms. Biological treatment occurs in the presence of sufficient electron donor via ERD, and is generally applied by fostering the development of in situ reactive zones (IRZs), wherein periodic carbon dosing is used to promote the necessary geochemical conditions and sustain complete dechlorination through end products. Many of the processes are the same as those seen in natural attenuation; IRZ simply targets and accelerates these naturally occurring processes. In most instances, these treatment programs involve the injection of reagents that support depletion of existing terminal electron acceptors (e.g., dissolved oxygen, nitrate, ferric iron, sulfate) and stimulate indigenous bacteria that can sequentially transform the parent species (e.g., TCE) through intermediate daughter products (cis 1,2 DCE and vinyl chloride) to end products (ethene and ethane).

While DHC is the primary organism that can facilitate all steps of the dehalogenation process, a number of other microbial genera also support one or more initial dechlorination steps. While biological treatment often accounts for much of the treatment benefit, in most cases, both biological and abiotic processes provide treatment within any IRZ (Suthersan and Payne 2005).

For chlorinated COCs such as those found in the SA, soluble (e.g., lactate molasses, dissolved whey) or semi-soluble (e.g., EVO) carbon substrates can be added to promote development of an IRZ. Fermentation of these substrates generates an excess electron donor (dissolved hydrogen), which is used to consume available background electron acceptors and promote dechlorination. Some chlorinated
compounds and many petroleum hydrocarbons can be degraded in an IRZ through anaerobic oxidation systems such as nitrate reduction, iron reduction, or sulfate reduction. In these systems, degradation occurs when microbes extract electrons from the hydrocarbon COCs (stimulating their degradation), transferring them to nitrate, ferric iron, or sulfate. In most instances, injection of organic carbon substrates is sufficient to promote development of anaerobic groundwater conditions and stimulate existing DHC organisms to achieve complete dehalogenation through end products. Bioaugmentation can also be performed to supplement the native microbial community where insufficient DHC populations exist or to expedite overall ERD treatment.

The hydraulic driving force controlling the size and extent of the IRZ is typically the natural groundwater flow. Where pump-and-treat systems are already present, an enhanced hydraulic flow regime can be used to extend the distance over which enhanced dechlorination occurs. While natural groundwater flow plays a prominent role in reagent distribution, the rate of carbon transport and washout from the IRZ must be balanced by dosing events to sustain carbon availability. As a result, increasing groundwater velocities require increased injection frequency to sustain enhanced treatment conditions. As a result, ERD applications may not be practical under elevated flow conditions based on the injection infrastructure, reagent volumes, and injection time to successfully establish and maintain the IRZ. The average groundwater velocity across the SA is significantly lower than the groundwater velocities in the saturated sand unit present downgradient in mid-plume groundwater. This slower velocity is appropriate for ERD and will allow for sufficient residence time within the IRZ to achieve complete dechlorination. Reagent injected into the SA would likely follow the same pathways as those of the dissolved phase COCs.

Several characteristics of ERD will have a significant impact on its evaluation as a remedial option for the SA. The use of an electron donor promotes the development of highly reducing methanogenic groundwater conditions. Under these conditions, methane can be produced up to or above its aqueous solubility. The lack of overlying enclosed structures in the vicinity of the SA reduces the associated risk of methane production to levels that are significantly lower than those associated with implementation of ERD in the MPA.

Successful application of this method typically involves conducting a pilot test to establish injection rates, ROIs, and to confirm that an IRZ can be established in the subsurface. These tests (already completed in both the SA and MPA) are used to support development of the necessary well network, positioning relative to either source or plume mass, and the likely timing of full-scale remedial applications. Implementation of ERD typically consists of multiple injection lines positioned across the horizontal plume width. The ROIs of the injection wells overlap to ensure complete coverage. As the IRZ matures, biomass and cellular material accumulating within and external to injection wells can result in diminished subsurface injectability (e.g., decreased flow rates, increased injection pressure to sustain delivery) that can result in increased operation and maintenance activities over the period of operation. This effect is elevated in low-permeability formations. These detrimental effects can be managed by incorporating special design considerations, such as a redevelopment or a well replacement program, to address diminishing well injection performance.

As discussed in Section 1.7, ERD has been successfully implemented at the SA since November 2018. The continued operation and monitoring of the existing ERD treatment would comprise the ERD component of any SA remedy. Additionally, as presented in Section 1.5.12, ERD, using direct-push borings, would provide targeted treatment to residual unsaturated soil containing impacts exceeding cleanup goals in the Rail Yard Area of the SA.
3.3.6 Environmental Use Controls

EUCs are generally used to reduce the risk of chemical exposure to receptors by providing legal notice and/or restricting access or use of property containing impacted media. Such controls may be applied to both soil and groundwater. EUCs are commonly developed to address issues at sites owned by a particular individual or business. When this is impractical, such as when impacted groundwater extends beneath a residential area, EUCs may be developed by state or municipal governments.

3.4. Summary of Mid-Plume Area Remedial Technologies Retained after Initial Screening

As described in Section 1, TCE-impacted groundwater is present within the MPA at levels that exceed the groundwater MCLs. Groundwater treatment is necessary to mitigate this impact and achieve site RAOs. The MPA remedial technologies retained after initial screening would be technically implementable to address TCE impacts in the groundwater. Options retained for further MPA evaluation are described below.

3.4.1 Air Sparging/Soil Vapor Extraction

Air sparging (AS) is an in situ treatment technology that uses injected air to remove volatile or biodegradable contaminants from the saturated zone. The primary application of AS entails the injection of air directly into the saturated subsurface to remove volatile contaminants from the dissolved phase to the vapor phase through air stripping. The stripped compounds migrate vertically into the unsaturated sediments, where they are then biodegraded and/or removed via soil vapor extraction (SVE) in the vadose zone (Battelle 2001). The major components of a typical AS system include an AS/injection well, a compressor or blower to supply air, monitoring points and wells, and an optional SVE system.

In situ AS can be effective in treating groundwater at or downgradient of a source area. Biosparging is an in situ technology in which air is injected through a contaminated aquifer. Injected air traverses horizontally or vertically in channels through the soil column, creating an underground stripper.

The basic removal processes for AS are the same as those associated with SVE. Volatilization and transport is one remediation process and aerobic biodegradation another. Where the technology is applied to relatively thin vadose zones, an SVE system is also installed to recover the volatilized vapors transported from the saturated zone to the vadose zone.

In some circumstances, where there is a thicker vadose zone and the COCs are aerobically biodegradable, the system can be designed such that the vadose zone acts as a fixed-film bioreactor. The biosparging points supply oxygen, and the constituents volatilized from the treatment zone are biodegraded in the vadose zone, eliminating the need for an SVE system. Where compounds are not amenable to aerobic biodegradation (such as the chlorinated compounds present at the Site), removal of stripped compounds via SVE is critical where vapor intrusion into occupied structures is a risk.

Where there is a high degree of heterogeneity in the geologic strata, some care must be taken to ensure that excessive lateral migration of vapor-laden air does not occur along the bottom surface on relatively impenetrable layers overlying permeable units undergoing AS treatment. The technology can be applied using vertical or horizontal wells.
As described in Section 2, VOC impacts to groundwater are present within the MPA at concentrations that exceed risk-based levels or MCLs. Groundwater treatment is necessary to mitigate this impact and achieve site RAOs. Options retained for treatment of VOCs are described below.

### 3.4.2 Enhanced Reductive Dechlorination

The ERD treatment technology was previously discussed in Section 3.3.5. Components of ERD specific to its potential application at the MPA are discussed below.

For chlorinated COCs such as those found in the MPA, soluble (e.g., lactate molasses, dissolved whey) or semi-soluble (e.g., EVO) carbon substrates can be added to stimulate anaerobic bacteria that will ultimately cause the reductive dehalogenation of the chlorinated compounds. Dehalogenating microorganisms can also be directly injected to augment the native microbial community. Fermentation of organic carbon substrates generates excess electron donor (dissolved hydrogen), which is used to consume available background electron acceptors (e.g., nitrate, ferric iron, or sulfate) and promote dechlorination. Some chlorinated compounds and many petroleum hydrocarbons can be degraded in an IRZ through anaerobic oxidation systems such as nitrate reduction, iron reduction, or sulfate reduction. In these systems, degradation occurs when microbes extract electrons from the hydrocarbon COCs (stimulating their degradation) and transfer them to nitrate, ferric iron, or sulfate. These systems require redox conditions in the 0 to -200 millivolt (mV) range.

The hydraulic driving force controlling the size and extent of the IRZ is typically the natural groundwater flow. Where pump-and-treat systems are already present, an enhanced hydraulic flow regime can be used to extend the distance over which enhanced dechlorination occurs. While natural groundwater flow plays a prominent role in reagent distribution, the rate of carbon transport and washout from the IRZ must be balanced by dosing events to sustain carbon availability. As a result, increasing groundwater velocities require increased injection frequency to sustain enhanced treatment conditions. As a result, ERD applications may not be practical under elevated flow conditions based on the injection infrastructure, reagent volumes, and injection time to successfully establish and maintain the IRZ.

While EVO injection has been previously evaluated for potential application within the MPA, the elevated groundwater velocities result in a short residence time within the area where EVO was distributed. As EVO adheres to and is strained by the soil matrix following delivery, distribution via advective groundwater transport is limited relative to completely soluble carbon substrates. As a result, the COC residence time within the EVO-based IRZ is considerably shorter and can result in incomplete dechlorination.

Several characteristics of ERD will have a significant impact on its evaluation as a remedial option for the 29th and Grove Site. Under sustained carbon delivery programs, the use of an electron donor promotes the development of highly reducing methanogenic groundwater conditions. Under these conditions, methane can be produced up to or above its aqueous solubility. While the low-permeability soils present above the aquifer would generally retard vertical migration of methane into occupied structures, methane could potentially accumulate within the unsaturated zone and represent a potential concern where migration pathways were present.

As described above, the high ambient groundwater velocity within the MPA will require a carbon dosing frequency tailored to sustain organic carbon and promote treatment. Multiple injection lines would be positioned across the horizontal plume width in series along the length of the plume to divide the plume into manageable segments for treatment. In large plume applications, elongated injection time frames that
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Rely on large injection volumes can pose considerable logistical challenges associated with both field injection time and diminished injection well performance. As the IRZ develops, biomass and cellular material accumulating within and external to injection wells can result in diminished subsurface injectability (e.g., decreased flow rates, increased injection pressure to sustain delivery), which can result in an increased need for operation and maintenance activities over the period of operation. While these detrimental effects can be managed via well development and periodic well restoration, these challenges must be considered in large-scale treatment systems.

3.4.3 Pump-and-Treat

The pump-and-treat technology involves pumping groundwater from wells to a treatment system. Common forms of treatment for VOCs after the groundwater is removed from the subsurface include air stripping or GAC treatment. Air stripping involves removing VOCs from groundwater by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

With GAC treatment, groundwater contaminants are removed by adsorption to GAC. Two units are generally placed in series with regular sampling after the first unit to determine when that unit has reached its chemical loading capacity (i.e., when chemical breakthrough occurs). Any contamination that breaks through the first unit in between sampling events is adsorbed in the second unit. When breakthrough of the first vessel is detected, the carbon in the first vessel is changed out, and the vessel configuration is changed so that the previous “backup” unit is now used as the lead unit. Many VOCs, SVOCs, and non-volatile organic compounds are readily adsorbed by GAC. The carbon usage depends on the contaminant characteristics and concentrations as well as other constituents in the water that may compete for active sorption sites (USEPA 2005).

After treatment, the water can be pumped back into the subsurface, discharged to surface waters, or pumped to collection systems. Discharge permits may be required depending on the application used.

A problem associated with air stripping is inorganic or biological fouling of equipment. This increases cleaning, maintenance, and associated costs of the system. Also, compounds with low volatilization potential at ambient temperature may require pre-heating of the groundwater (USEPA 2000). The performance of pump-and-treat systems depends directly on site conditions and contaminant chemistry.

Cleanup time is influenced by system design and is strongly influenced by the rate of pore volume exchanges. A system pumping at low volumes relative to the cross-site flow may have a very long cleanup time, while one pumping higher volumes may have a shorter predicted cleanup time (USEPA 2005).

As the complexity of the site increases, the effectiveness of a pump-and-treat system decreases. Pore volume exchange rates in low-permeability sediments can be very low and can significantly increase cleanup times in low-permeability sediments or where low-permeability intervals are present in significant thicknesses. If the compounds to be treated have a relatively low solubility, such as CVOCs, the treatment time is increased, and efficiency declines due to the additional time needed for the compounds to dissolve in the groundwater. Remediation by pump-and-treat can be slow.

Additionally, in conventional pump-and-treat systems, the distribution of pore volume exchange is uncontrolled, which can result in substantial inefficiencies and relatively long remediation times.
3.4.4 Directed Groundwater Recirculation

Directed groundwater recirculation (DGR) is an aggressive remediation technique for dissolved plumes that controls the distribution of groundwater pore volume exchange to maximize remedy efficiency. DGR is differentiated from conventional pump-and-treat remedies in that a combination of extraction wells is coupled with carefully located reinjection wells to increase the rate at which water is carried through the aquifer pore spaces. In addition, the reinjection well placement can provide significantly greater control over localized groundwater flow directions than pumping alone. Several technologies, including DGR, can be effective in the coarse sands at the base of the MPA. DGR is unique for its potential to address the stranded TCE in the finer sands of the upper sand aquifer.

DGR speeds up the flushing process by recirculating clean water across each targeted aquifer segment at a rate faster than can be accomplished with ambient flow or with pumping alone, thereby increasing the number of clean water pore flushes and controlling where the flushing is occurring. The key result is a reduction in remedial time frames and associated costs.

DGR can use the placement of reinjection wells relative to pumping wells to control the zone of influence over which flushing is achieved. In the case of the 29th and Grove Site, this approach would establish hydraulic separation via clean water fronts between the multiple area-wide plumes. This also allows separation of plumes where they are beginning to commingle (i.e., KDHE PCE plumes) or located in parallel (NIC plume), and serve as a hydraulic barrier, where traditional groundwater extraction alone would induce plume migration and mixing of unrelated impacts.

DGR is an adaptable approach that allows modification of both pumping and injection rates to promote distribution and enhance treatment as additional information is collected during the installation and the initial operation of the system. DGR would also require a minimal number of wells and, with water conveyance pipe installation possible using directional drilling techniques, this approach would minimize disruption to the community. Treatment centers can be located in rights-of-way that are outside of the residential areas.

A key component of DGR is the ability to reinject the treated groundwater. As with air stripping, the long-term effectiveness of reinjection wells is dependent on the inorganic groundwater quality and the tendency for chemical precipitation and biological fouling. In addition, aquifer structure would have a major impact on the rate at which groundwater can be reinjected. The preliminary results of the long-term pilot test, conducted at the Murdock HCS as described in Section 1.7.5, suggest that DGR will be a cost-effective and implementable remediation option to treat groundwater.

3.4.5 Environmental Use Controls

EUCs are generally used to reduce the risk of chemical exposure to receptors by providing legal notice and/or restricting access or use of property containing impacted media. Such controls may be applied to both soil and groundwater. EUCs are commonly developed to address issues at sites owned by a particular individual or business. When this is impractical, such as when impacted groundwater extends beneath a residential area, EUCs may be developed by state or municipal governments.
3.5 Summary of Technology Screening

Prospective remedial technologies for the remedial actions at the SA and the MPA were identified using USEPA's Remediation Technologies Screening Matrix table. Technologies were screened using the following criteria: effectiveness, implementability, and relative cost. Explanations of each technology retained after the initial screening are provided in this chapter. These technologies would be employed to develop and evaluate remedial alternatives for each area as discussed in the following sections.
4 DEVELOPMENT AND SCREENING OF ALTERNATIVES

This section includes a detailed evaluation of the alternatives to be considered. Section 4.1 presents the rationale behind the detailed analysis, defines the nine criteria used to evaluate each detailed alternative, and presents the assembly of technologies retained as alternatives for further consideration. The remaining sections provide detailed descriptions of the five alternatives and present the initial screening based on effectiveness, implementability, and cost. Those alternatives retained after the initial screening will then be evaluated in detail in Section 5.

4.1 Definition of Evaluation Criteria

For a remedial action to meet the statutory requirements addressed in the NCP (USEPA 1988a), it must include the following requirements:

- Be protective of human health and the environment.
- Attain ARARs or provide grounds for invoking a waiver.
- Be cost-effective.
- Use permanent solutions and alternative treatment technologies, or resource recovery technologies, to the maximum extent practicable.
- Satisfy the RAOs or satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element.

In addition, other statutory requirements emphasized by CERCLA include an evaluation of the long-term effectiveness and the following related considerations:

- The persistence, toxicity, and mobility of the hazardous substances and their constituents.
- Short- and long-term potential for adverse health effects from human exposure.
- Long-term maintenance costs.
- The potential threat to human health and the environment associated with excavation, transportation and re-disposal, or containment.

These requirements have been condensed into nine evaluation criteria, which serve as the basis for evaluating the alternatives in the detailed analysis. These nine criteria include:

- Overall protection of human health and the environment.
- Compliance with ARARs.
- Long-term effectiveness and permanence.
- Reduction of toxicity, mobility, or volume.
- Short-term effectiveness.
- Implementability.
- Cost.
- State acceptance.
- Community acceptance.
These nine criteria are described in the following subsections.

4.1.1 Overall Protection of Human Health and the Environment

The assessment against this criterion describes how the detailed alternative as a whole provides adequate protection of human health and the environment and meets the RAOs. This evaluation focuses on how the RAOs are met through treatment, engineering, or EUCs.

4.1.2 Compliance with ARARs

Remedial actions must meet any federal or state standards, requirements, criteria, or limitations determined to be ARARs. Each of the five alternatives was evaluated based on the three general ARAR categories: chemical-specific ARARs, location-specific ARARs, and action-specific ARARs, as discussed in more detail below.

4.1.3 Long-Term Effectiveness and Permanence

The evaluation of detailed alternatives under this criterion addresses the results of a remedial action in terms of the risk remaining at the Site after remedial action has been implemented. This assessment includes an analysis of the magnitude of residual risk and the adequacy and reliability of engineering or EUCs. The magnitude of residual risk analysis considers the following:

- Residual risk, expressed in cancer risk levels, volumes, or concentrations, remaining from untreated waste or treatment residuals at the conclusion of remedial activities
- The volume, toxicity, and mobility of residuals remaining after remedial activities.

The adequacy and reliability of engineering or EUCs is evaluated in terms of the long-term reliability of controls used to manage treatment residuals or untreated waste remaining at the Site and considers the following:

- The likelihood that the technology would meet required process efficiencies or performance specifications
- The type and degree of long-term management and monitoring
- Operation and maintenance (O&M) functions required to maintain process efficiencies or performance specifications
- Difficulties of long-term maintenance including the potential need for replacement of technical components and the degree of confidence that controls can adequately handle potential problems.

4.1.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion is based on a preference for treatment technologies that irreversibly reduce toxicity, mobility, or volume of the compounds of interest. The primary concern is whether the detailed alternative would satisfy this preference for treatment as a principal element (treatment is defined in the USEPA guidance as the destruction or toxic COCs, reduction of the total mass of toxic COCs, irreversible reduction in contaminant mobility, or reduction of total volume of contaminated media).

The focus of this criterion is whether the proposed detailed alternative reduces the principal threats through treatment. Some considerations under this criterion include:
The treatment process and remedy, whether the treatment process addresses the principal threats, and whether there are any special process requirements or limitations.

- The mass and volume of material destroyed or treated.
- The extent to which the total mass, mobility, and volume of toxic COCs is reduced, and whether or not the reduction is irreversible.
- The type, quantity, and characteristics of treatment residuals and the risks posed by the residuals.
- The statutory preference for treatment as a principal element.

### 4.1.5 Short-Term Effectiveness

This criterion addresses the effects of the detailed alternative during the construction and implementation phases until RAOs are met, and considers the following:

- The risks, which could not be readily controlled during remedial actions, to site remediation workers and the methods used to mitigate the risks.
- The risks to the community during the remedial action and how the risks would be mitigated.
- Environmental impacts that can be expected during construction and implementation, the mitigation measures used to address those impacts and their reliability, and the impacts that cannot be avoided or controlled.
- The lengths of time until remedial objectives are met.

### 4.1.6 Implementability

This criterion addresses the technical and administrative feasibility of implementing a detailed alternative and the availability of various services and materials required during its implementation. Assessment of this criterion relies heavily on previous evaluations of technologies described in Section 3. Specific considerations include the following:

- The ability to construct and operate the detailed alternative, the difficulties and uncertainties that may be encountered during construction, and the likelihood of technical problems that may lead to schedule delays.
- The ease of undertaking additional remedial action and what those additional actions may be.
- The coordination required among agencies over the long term and the ability to obtain permits for the remedial activities.
- The availability of capacity at treatment, storage, and/or disposal services, and the measures required to ensure that capacity is available.
- The availability of necessary equipment and specialists, and whether a lack of equipment and specialists prevents implementation.
- The degree to which technologies are available and sufficiently demonstrated for the specific full-scale application.
4.1.7 Cost

The cost analysis includes estimates of capital costs (both direct and indirect) and annual O&M costs associated with each component of a detailed alternative. The target level of accuracy is +50 percent to -30 percent (USEPA 2000).

The cost may play a significant role in comparing detailed alternatives that are similar in long-term effectiveness, or in which the treatment methods provide a similar performance. The detailed alternatives with costs that are high when compared to the overall effectiveness of the detailed alternative will not be selected as the final remedy. Similarly, non-treatment alternatives that have low initial capital costs may be more costly overall than a treatment alternative when long-term O&M costs are considered. Improved performance or greater long-term risk reduction may justify higher costs. The preferred detailed alternative is generally the one that satisfies the criteria at the most reasonable cost.

Types of costs assessed for each alternative include the following:

- Capital costs
- Annual O&M costs
- Periodic costs
- Present value of capital and annual O&M costs

Cost estimates are developed according to A Guide to Developing and Documenting Cost Estimates during the Feasibility Study (USEPA 2000). Flexibility is incorporated into each alternative for the location of remedial facilities, the selection of cleanup levels, and the period during which remedial action will be completed. Assumptions of the project scope and duration are defined for each alternative to provide cost estimates for the various remedial alternatives. Important assumptions specific to each alternative are summarized in the description of the alternative. Additional assumptions are included in the detailed cost estimates for the SA and Mid-Plume Area provided in Appendices H and I.

The levels of detail employed in making these estimates are conceptual but are considered appropriate for choosing among alternatives. The information provided in the cost estimate is based on the best available information regarding the anticipated scope of the remedial alternatives. The costs are evaluated with respect to the following categories:

- Capital costs are those expenditures required to construct a remedial action. They exclude costs required to operate or maintain the action throughout its lifetime. Capital costs consist primarily of expenditures initially incurred to build or install the remedial action (e.g., construction of a water treatment system and related site work). Capital costs include all labor, equipment, and material costs associated with activities (including contractor markups and overhead and profit) such as mobilization/demobilization, monitoring of site work, installation of extraction, containment, or treatment systems; and disposal. Capital costs also include expenditures for professional/technical services necessary to support construction of the remedial alternative.

- Annual O&M costs are those post-construction costs necessary to ensure or verify the continued effectiveness of a remedial action. These costs are estimated mostly annually. Annual O&M costs include all labor, equipment, and material costs associated with activities such as monitoring (including contractor markups and overhead and profit); operating and maintaining extraction, containment, or treatment systems; and disposal. Annual O&M costs also include expenditures for professional/technical services necessary to support O&M activities.
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- Periodic costs are those that occur only once every few years (e.g., 5-year reviews or equipment replacement) or expenditures that occur only once during the entire O&M period or remedial timeframe (e.g., site closeout or remedy failure/replacement). These costs may be either capital or O&M costs but, because of their periodic nature, it is more practical to consider them separately from other capital or O&M costs in the estimating process.

- The present value of each alternative provides the basis for the cost comparison. The present value cost represents the amount of money that, if invested in the initial year of the remedial action at a given rate, would provide the funds required to make future payments to cover all costs associated with the remedial action over its planned life. Future O&M and periodic costs are included and reduced by a present value discount rate. As outlined in A Guide to Developing and Documenting Cost Estimates during the Feasibility Study (USEPA 2000), a 7 percent real discount rate should be applied over the period of evaluation for each alternative.

4.1.8 State Acceptance

This criterion evaluates the technical and administrative issues and concerns that the state or support agency may have regarding each of the detailed alternatives. State agency acceptance is a modifying criterion under the NCP. State acceptance will not be known until the KDHE issues a draft Corrective Action Decision (CAD) document. The draft CAD will provide the state’s rationale for alternative selection and acceptance. Thus, state agency acceptance is not considered in the detailed evaluation of alternatives presented in this FFS.

4.1.9 Community Acceptance

Community acceptance is also a modifying criterion under the NCP. Assessment of community acceptance will include responses to questions that any interested person of the community may have regarding any component of the remedial alternatives that will be presented in the KDHE’s draft CAD for the SA. This assessment will be completed after the KDHE receives public comments on the proposed plan during the public commenting period. Thus, community acceptance is not considered in the detailed evaluation of alternative presented in this FFS.

4.1.10 Criteria Priorities

The nine evaluation criteria described above are separated into three groups to establish priority among these criteria during detailed evaluation of the remedial alternatives. These groups are:

- Threshold Criteria – must be satisfied by the remedial alternative being considered as the preferred remedy.
  - Overall protection of human health and the environment
  - Compliance with ARARs
- Balancing Criteria – technical criteria evaluated among those alternatives satisfying the threshold criteria.
  - Reduction of toxicity, mobility, or volume through treatment
  - Short-term effectiveness
  - Long-term effectiveness and performance
4.2 Assembly of Detailed Alternatives

The technologies retained from Section 3 were selectively combined into remedial alternatives that most effectively address impacts to groundwater in the SA. The criteria for assembling and combining technologies into remedial alternatives include the following:

- Enhanced effectiveness of technologies operating as part of a treatment train
- Similarity in complexity
- Ability to address all impacted media

4.2.1 Source Area Alternatives

The assembled alternatives developed for the SA, presented in Table 4-1, include:

- Source Area Alternative 1 – No Further Action
- Source Area Alternative 2 – Hot spot excavation, targeted Rail Yard Area soil ERD and downgradient groundwater ERD
- Source Area Alternative 3 – ISSS of vadose-zone soils and groundwater removal (pump-and-treat)
- Source Area Alternative 4 – Soil excavation to bedrock and ERD
- Source Area Alternative 5 – ISSS, soil mixing using ZVI and ERD

All of the assembled SA alternatives (except for Source Area Alternative 1) will also contain an EUC component to allow soils with concentrations of TCE higher than the established RSK Tier 3 value to remain in place (below the railroad tracks). The option to access material below the railroad tracks was considered; however, it was determined that, due to the shallow nature of those impacts (e.g., less than 8 ft bgs), the benefit would be minimal in relationship to the increased complexity and cost of the operation. If activities were implemented to remediate soils under the railway, the operations would require that the overlying railroad tracks be closed, removed, and replaced.

The pre-design direct-push investigation completed in 2016 collected data to refine the conceptual site model and provide preliminary design data. The direct-push investigation was used to supplement existing site data and confirm the locations and concentrations of dissolved phase impacts between the point of release and the East Fork of Chisolm Creek. EC/HPT logging conducted during the 2016 investigation and before ERD injections confirmed that the more permeable portions of the saturated unconsolidated sediments are relatively thin (less than 10 feet) and lie atop the bedrock surface. The saturated unconsolidated sediments are very thin below the northern portion of the SA but thicken downgradient with a transition from less permeable residuum to more permeable (sandy) alluvium.
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The above listed alternatives are discussed in detail in the following subsections.

4.2.1.1 Source Area Alternative 1 - No Further Action

The No Further Action alternative is required by the NCP to provide a baseline set of conditions against which other remedial actions may be compared. This alternative allows a site to remain in its current state with no additional remedial actions being implemented in the source area. There would be no change in impacted soil or groundwater concentrations aside from that which occurs naturally because no treatment, containment, or removal of contaminated soil or groundwater is included in this alternative. Existing water well ordinances, however, would still be enforced, and existing institutional controls would be maintained.

Although no remedial action or monitoring is required for this alternative per USEPA guidance (USEPA 1989), UP currently has a Consent Order with the KDHE, which includes monitoring requirements. Therefore, the No Further Action alternative for this focused FS includes limited groundwater monitoring and 5-year site reviews.

For evaluation purposes, it is assumed that sampling and analysis would be conducted quarterly for the first 2 years, semiannually for 8 years, then annually for an additional 30 years to monitor the extent of impacted groundwater. Sample analyses would include the Site COCs discussed in Section 1 as well as typical MNA parameters. Data from each monitoring event would be compiled, and appropriate text, tables, figures, and time trends would be generated and included in reports to the KDHE.

Maintenance of monitoring wells (e.g., replacement of well vaults) was assumed to occur every 10 years. Five-year site reviews would also be a component of this alternative because groundwater contamination is not treated, contained, or removed in this alternative. Abandonment of monitoring wells is assumed to occur at the end of the 30-year performance period.

4.2.1.2 Source Area Alternative 2 – Hot Spot Excavation, Targeted Soil ERD, and Groundwater ERD

Implementation of this alternative would consist of three components:

- 'Hot spot' excavation and off-site disposal of soil beneath the Waste Storage Pad to address soil impacted above cleanup goals that has remained following the previous SA excavations
- Targeted soil ERD, using direct-push methods, to provide additional treatment at borings near the suspected release area in the Rail Yard where the 10 to 10.5 ft bgs sample results exceeded the SA Soil Remediation Goals during the 2019 SA Unsaturated Soil Investigation
- Downgradient ERD treatment by continuing the operation of the existing ERD system that has been providing treatment to the SA since November 2018.

The impacted subsurface soil beneath the Waste Storage Area will be remediated by excavation and off-site disposal. The fencing and concrete slab will be removed, and the soil beneath the slab footprint will be excavated to a depth of 3 ft. The excavated soil will be profiled and disposed at an appropriate facility. Clean fill will be imported to bring the excavation to grade, and a new concrete slab and fencing will be constructed.

The target ERD soil treatment would include a single ERD direct-push injection event at and surrounding the borings where concentrations of COCs exceeded the Soil Remediation Goals. ERD substrate would
be injected into the soil at the 10 to 10.5 ft interval at each of the three locations (SB202, SB210, and SB213) and at 10 ft step-outs in each cardinal direction at each boring.

The ERD program proposed in this alternative includes the continuation of the existing ERD treatment system at the SA, which employs transects of injection wells to deliver carbon substrate to the aquifer. Mixed solution would be injected into the injection wells by gravity feed using an injection manifold and lateral lines. The current ERD system includes three transects spanning the width of the dissolved phase with a total of 33 injection wells screened from approximately 18 to 30 feet bgs. Two of the injection well transects are located near the point of release (at and immediately downgradient of the suspected release area), and one is located downgradient. The duration of the proposed injection program is 5 years.

As described in the Source Area ERD Startup Report (Arcadis 2019b), the schedule for the point of release injection wells consisted of quarterly molasses injections through 2019. As discussed in the Fourth Quarter 2019 Progress Report (Arcadis 2020a), future injection events will be conducted annually with EVO as the carbon donor. EVO has a lower solubility, slowing the release of organic carbon, maintaining reducing conditions for a longer period, and expanding the length of time between injections. As necessary, the organic carbon injection program may be modified over the course of operation to include bioaugmentation and supplement the native microbial community.

Periodic groundwater monitoring at wells downgradient of the Rail Yard and both upgradient and downgradient of the injection well transects would be performed as part of this alternative to demonstrate effectiveness and guide remedial duration. Groundwater samples would be analyzed for Site COCs and MNA parameters. The sampling would include monitoring of field parameters (pH, conductivity, oxidation-reduction potential [ORP], temperature, and dissolved oxygen). Groundwater monitoring would continue until RAOs are achieved.

Routine maintenance (well redevelopment and well replacement) would be conducted on the injection well network as necessary during the program. Five-year site reviews would also be a component of this alternative because impacted groundwater would remain at the SA. Abandonment of injection wells was assumed to occur following the final completion of the injection.

The conceptual design for Source Area Alternative 2 is illustrated on Figure 4-1.

### 4.2.1.3 Source Area Alternative 3 – In Situ Soil Solidification/Stabilization and Groundwater Removal (Pump-and-Treat)

The implementation of this alternative would consist of ISSS to address vadose-zone (5 to 18 feet bgs) soils and groundwater removal (e.g., pump-and-treat) to remove/control dissolved phase impacts at the point of release and in downgradient areas.

ISSS, in the context that it would be implemented in the SA, would consist of the addition of one or more cementitious and/or pozzolanic materials (such as Type I/II Portland cement, blast furnace slag cement, bentonite or other locally available reagents) to solidify the vadose-zone (5 to 18 ft bgs) soils that are accessible (e.g., not below the railroad tracks) and impacted at levels above the RSK Tier 3 Value for TCE (0.14 mg/kg). The appropriate reagent and mix ratio would be identified during the bench-scale study.

The proposed extraction well network would use transects with multiple extraction wells to remove contaminant mass from the aquifer. The conceptual approach would consist of three transects spanning...
the width of the dissolved phase with a total of 16 extraction wells. The extraction wells would be screened from approximately 20 to 30 ft bgs. Due to the relatively low-permeability soils present in the saturated zone of the SA, the system would employ in-well pumps to extract groundwater and pump it to a centralized treatment system. Extracted groundwater would be treated using a combination of tray aeration and in-series GAC vessels (lead and lag). Treated groundwater would be discharged to the nearest KDHE-approved surface watershed. Acquisition of an NPDES permit would be required.

Periodic groundwater monitoring at wells downgradient of the ISSS and both upgradient and downgradient of the extraction well network would be performed as part of this alternative to demonstrate the effectiveness and guide remediation duration. Groundwater samples would be analyzed for Site COCs and MNA parameters. The sampling would include monitoring of field parameters (pH, conductivity, ORP, temperature, and dissolved oxygen). Groundwater monitoring would continue until RAOs are achieved.

Routine maintenance (well redevelopment and well replacement) would be conducted on the extraction well network as necessary during the program. Abandonment of extraction wells was assumed to occur following the final completion of the injection.

The conceptual design for Source Area Alternative 3 is illustrated on Figure 4-2.

4.2.1.4 Source Area Alternative 4 – Deep Soil Excavation and ERD

The implementation of this alternative would consist of excavating soil to bedrock (approximately 30 feet bgs) to reduce the amount of residual contaminant mass at the point of release and ERD to address adjacent and downgradient saturated zone impacts (soil and groundwater). The preliminary conceptual design for Source Area Alternative 4 is illustrated on Figure 4-3.

The objective of soil excavation at the point of release would be to excavate the portion of impacted soils with exponentially higher COC concentrations. The proposed excavation footprint that would accomplish this occupies an area of 1,600 ft² located between the railroad tracks and the roadway. Excavation would be accomplished using track-mounted excavators, and the excavations would be braced with sheet piles to ensure stability of the adjacent railroad tracks and the roadway. This option would require compliance with Resource Conservation and Recovery Act (RCRA) Large Quantity Generator requirements because impacted soils at the Site are considered a listed hazardous waste.

The proposed ERD program consists of using a portion of the excavation as an infiltration reservoir and installing transects with multiple injection wells to deliver carbon substrate to the aquifer. The purpose of the infiltration reservoir is to provide an additional treatment measure to address residual contaminant mass in the soil and groundwater adjacent to the excavation. The conceptual approach for the infiltration reservoir consists of backfilling the lower 15 feet of the excavation with a permeable medium (sand or gravel) and installing vertical risers to the surface so that carbon substrate may be delivered and allowed to dissipate into the surrounding soils.

The downgradient ERD program proposed in this alternative includes the continuation of the existing ERD treatment system at the SA, which employs transects of injection wells to deliver carbon substrate to the aquifer. Mixed solution would be injected into the injection wells by gravity feed using an injection manifold and lateral lines. The current ERD system includes three transects spanning the width of the dissolved phase with a total of 33 injection wells screened from approximately 18 to 30 feet bgs. Two of the injection well transects are located near the point of release (at and immediately downgradient of the
suspected release area), and one is located downgradient. The duration of the proposed injection program is 5 years.

As described in the Source Area ERD Startup Report (Arcadis 2019c), the schedule for the point of release injection wells consisted of quarterly molasses injections through 2019, with subsequent semi-annual event through year 5. Future injection events may use EVO as the carbon donor. EVO has a lower solubility, slowing the release of organic carbon, maintaining reducing conditions for a longer period, and expanding the length of time between injections. As necessary, the organic carbon injection program may be modified over the course of operation to include bioaugmentation and supplement the native microbial community.

Periodic groundwater monitoring at wells both upgradient and downgradient of the injection well transects would be performed as part of this alternative to demonstrate the effectiveness and guide remedial duration. Groundwater samples would be analyzed for Site COCs and MNA parameters. The sampling would include monitoring of field parameters (pH, conductivity, ORP, temperature, and dissolved oxygen). Groundwater monitoring would continue until RAOs are achieved.

Routine maintenance (well redevelopment and well replacement) would be conducted on the injection well network as necessary during the program. Five-year site reviews would also be a component of this alternative because impacted groundwater would remain at the SA. Abandonment of injection wells was assumed to occur following the final completion of the injection.

### 4.2.1.5 Source Area Alternative 5 — In Situ Soil Solidification/Stabilization, Soil Mixing Using ZVI, and ERD

Implementation of this alternative would consist of ISSS to address vadose-zone (5 to 18 feet bgs) impacts at the point of release, soil treatment using ZVI to address intermittently saturated zone (18 to 20 feet bgs) and saturated zone (20 to 30 feet bgs) impacts at the point of release, and ERD to address adjacent (upgradient and downgradient) saturated zone impacts at the point of release and in downgradient areas.

Soil stabilization associated with Source Area Alternative 5 would be carried out in the same manner as Source Area Alternative 3. ERD implementation would be carried out in the same manner as Source Area 4. See Sections 4.2.1.3 and 4.2.1.4 for brief discussions of those proposed methodologies.

The purpose of the ZVI treatment would be to provide an additional treatment measure to address residual contaminant mass in the intermittently saturated and saturated zones of the SA. The use of ZVI to treat this interval would require that the overlying soils be excavated and removed so that the saturated-zone soils could be effectively targeted and homogenized with the appropriate admixture. As previously mentioned, ISSS and ZVI treatments would require a bench-scale study to determine the final design of the solidification reagent and the ZVI mix ratio. The limited amount of available space in the targeted area would likely require that the overlying material be temporarily transported away from the excavation site. This option would require compliance with RCRA Large Quantity Generator requirements because impacted soils at the Site are considered a listed hazardous waste.

Implementation of soil mixing using ZVI in the saturated zone (through which contaminant mass flux is occurring) would require a modeling component to determine the potential for hydraulic repercussions (such as redirection of groundwater flow and/or the destabilization of surface features).
Periodic groundwater monitoring at wells downgradient of the ISSS and both upgradient and downgradient of the extraction well network would be performed as part of this alternative to demonstrate the effectiveness and guide remediation duration. Groundwater samples would be analyzed for Site COCs and MNA parameters. The sampling would include monitoring of field parameters (pH, conductivity, ORP, temperature, and dissolved oxygen). Groundwater monitoring would continue until RAOs are achieved.

Routine maintenance (well redevelopment and well replacement) would be conducted on the injection well network as necessary during the program. Five-year site reviews would also be a component of this alternative because impacted groundwater would remain at the SA. Abandonment of injection wells was assumed to occur following the final completion of the injection.

The conceptual design for Source Area Alternative 5 is illustrated on Figure 4-4.

### 4.2.2 Mid-Plume Area Alternatives

The technologies retained from Section 3 were selectively combined into remedial alternatives that most effectively address impacts to groundwater in the MPA. The criteria for assembling and combining technologies into remedial alternatives include the following:

- Enhanced effectiveness of technologies operating as part of a treatment train
- Similarity in complexity
- Ability to address all impacted media

The assembled alternatives developed for the MPA, presented in Table 4-2, include:

- Mid-Plume Area Alternative 1 - No Further Action
- Mid-Plume Area Alternative 2 - Air sparging and SVE
- Mid-Plume Area Alternative 3 - ERD
- Mid-Plume Area Alternative 4 - Downgradient hydraulic containment
- Mid-Plume Area Alternative 5 - DGR

These MPA alternatives are discussed in detail below.

#### 4.2.2.1 Mid-Plume Area Alternative 1 - No Further Action

The No Further Action alternative is required by the NCP to provide a baseline set of conditions against which other remedial actions may be compared. This alternative allows a site to remain in its current state with no remedial actions being implemented outside of separate potential source control efforts; these source controls are not considered for this FFS. There would be no change in impacted groundwater concentrations aside from that which occurs naturally because no treatment, containment, or removal of contaminated groundwater is included in this alternative. Existing water well ordinances, however, would still be enforced, and existing institutional controls would be maintained.

Although no remedial action or monitoring is required for this alternative per USEPA guidance (USEPA 1989), UP currently has a Consent Order with the KDHE for the MPA, which includes monitoring requirements. Therefore, the No Further Action alternative for this FFS includes limited groundwater monitoring in the MPA and 5-year site reviews.
FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas

For evaluation purposes, it is assumed that sampling and analysis would be conducted quarterly for the first 2 years, semiannually for 8 years, then annually for an additional 30 years to monitor the extent of impacted groundwater. Sample analyses would include the site COCs discussed in Section 1 as well as typical MNA parameters. Data from each monitoring event would be compiled, and appropriate text, tables, figures, and time trends would be generated and included in reports to the KDHE.

Maintenance of monitoring wells (e.g., replacement of well vaults) was assumed to occur every 10 years. Five-year site reviews would also be a component of this alternative because groundwater contamination is not treated, contained, or removed in this alternative. Abandonment of monitoring wells is assumed to occur at the end of the 30-year performance period.

4.2.2.2 Mid-Plume Area Alternative 2 – Air Sparging and Soil Vapor Extraction

AS is an in situ remedial technology that reduces concentrations of volatile constituents adsorbed to soils and dissolved in groundwater. This technology involves the injection of contaminant-free air into the subsurface saturated zone, enabling a phase transfer of hydrocarbons from a dissolved state to a vapor phase. The air is then vented through the unsaturated zone. When AS is combined with SVE, the SVE system creates a negative pressure in the unsaturated zone through a series of extraction wells to control the vapor plume migration.

The conceptual design for the AS/SVE system to be evaluated for the MPA is shown on Figure 4-5. AS wells should be placed so that the overlap in their ROIs completely covers the area of contamination (USEPA 2004). AS wells and SVE wells would be collocated in common transects and piping trenches where possible to increase constructability and minimize disruption to the public. Sparge blowers and vacuum pumps would be located in common treatment buildings to the extent possible to minimize the remedy overall footprint and minimize disruption.

4.2.2.3 Mid-Plume Area Alternative 3 – Enhanced Reductive Dechlorination

Mid-Plume Area Alternative 3 would enhance reductive dechlorination processes within the subsurface to degrade the chlorinated solvent groundwater plume. ERD would be performed using rows of injection wells to deliver carbon substrate to the aquifer. The injection wells would be installed in transects perpendicular to the plume axis.

The spacing and groundwater velocity between the transects would determine the length of time required to reach remediation goals. Thus, an effective design would balance the capital cost of installing the injection transects, the operating costs of the ongoing injections, and the increasing uncertainty of the injection well performance as the period of operation increases. Thus, the conceptual approach includes 11 in situ bioremediation transects spanning the width of the plume to be installed at evenly spaced distances along the dissolved-phase plume, as conceptually shown on Figure 4-5. This transect spacing would simulate a continuous treatment zone, minimizing the time required to achieve treatment. The first transect would be located directly downgradient of the SA. A soluble carbon substrate would be injected approximately quarterly to facilitate effective treatment of contaminant concentrations. Feed lines to permanent injection wells would be grouped into vaults, and a mixing trailer would be used to deliver injection solution to each vault. Before final design, an investigation would be recommended to refine the transect width and spacing.

As with the other alternatives, the existing HCS would continue to operate to limit plume migration. Groundwater monitoring would continue until RAOs are achieved.
FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas

Injection solutions would be prepared by mixing the carbon amendment with water inside a tank delivery truck; the solution would be homogenized using a pump. The mixed solution would be injected into the injection wells by either gravity feed or pressurized injections as determined during the pilot testing; an injection manifold would be used to inject into multiple wells at one time. Water required for injections would be transported to each injection area location using tanker trucks; water would be obtained from Wichita at a city-approved location.

Periodic groundwater monitoring at wells both upgradient and downgradient of the ERD systems would be performed as part of this alternative to demonstrate the effectiveness of the ERD treatment and guide remedial duration. Analysis would include the site COCs as well as geochemical and other parameters to monitor the effectiveness of ERD injections. As necessary, bioaugmentation would be completed during the operational period based on performance monitoring results to supplement the native microbial community and achieve dehalogenation end products.

Maintenance of monitoring wells (e.g., replacement of well vaults) was assumed to occur every 10 years. Maintenance of injection wells is anticipated to be required before each injection event for approximately 10 percent of the wells. Five-year site reviews would also be a component of this alternative because impacted groundwater would remain at the MPA. Abandonment of injection wells was assumed to occur following the final completion of the injection.

The current understanding of the site hydraulics indicates high groundwater velocities in the channel deposits of the northern portion of the MPA. Establishing and maintaining reducing conditions within these hydraulic conditions may potentially require increased delivery frequency to sustain organic carbon and rapid groundwater flushing from the injection area may diminish the feasibility of this technology.

4.2.2.4 Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment

Mid-Plume Area Alternative 4 consists of continuing to operate the existing HCS located along the southern extent of the MPA at Murdock Street. In this alternative, the impacted groundwater at the downgradient edge of the plume would be addressed through pump-and-treat technology. The single row of six recovery wells spaced at the plume's leading edge would collect impacted groundwater, which would then be conveyed to a treatment building, treated by air stripping with GAC polishing, and the effluent split to discharge either to the nearby Chisholm Creek under an NPDES permit or to the injection wells installed in 2013 as part of the long-term pilot test. The combined pumping rate of the existing HCS is currently 100 to 110 gpm. The current layout of the HCS is presented on Figure 4-5.

A significant concern with long-term operation of the existing downgradient hydraulic containment is that the pumping is occurring where the NIC plume and the 29th and Grove plume are closest together. Pumping of the existing HCS has the potential to expand the NIC plume towards the 29th and Grove plume, impacting previously clean areas and causing a commingling of the two plumes. The injection wells were located to the west of the 29th and Grove plume to create a hydraulic divide and reduce the potential for plume commingling in the vicinity of the HCS.

4.2.2.5 Mid-Plume Area Alternative 5 - Directed Groundwater Recirculation

Mid-Plume Area Alternative 5 - DGR uses both pumping and injection wells to increase the pore water flushing through an impacted aquifer. Groundwater extraction and treatment is the primary means of plume remediation, but the reinjection of the treated groundwater accelerates the flushing process by recirculating clean water across each targeted aquifer segment at a rate faster than can be accomplished.
with ambient flow or by pumping wells only, thereby increasing the number of clean water pore flushes and controlling where the flushing is occurring. In addition, the reinjection wells can be located to assist in separating the dry cleaner plume adjacent and commingled along the eastern boundary of the 29th and Grove plume as well as providing a hydraulic barrier to prevent migration of the NIC plume east of Chisholm Creek. This reduced time to achieve a pore flush results in reductions in remedial time frames and associated costs.

Figure 4-7 presents a conceptual design for a proposed DGR system. Six flushing transects have been located at approximately 2,000-foot intervals throughout the MPA. Reinjection wells have been spaced at the edge boundaries of the plume to increase the hydraulic gradient toward the pumping wells and provide plume capture. The effectiveness of similar proposed extraction and reinjection well locations was evaluated as part of the groundwater flow and solute transport model as discussed in Appendix A. The conceptual locations provided on Figure 4-7 are anticipated to perform in a similar manner as the modeled version. However, specific locations and system components will be determined during the design phase for the DGR system based on current site conditions.

DGR is an adaptable approach that allows for modifying both pumping and injection rates and distribution as additional information is collected during installation and the initial operation of the system. During construction, water conveyance piping can be installed using directional drilling techniques, thereby minimizing disruption to the community. Treatment centers can be located in rights-of-way outside of the residential areas, also avoiding disruption to the community. Treated effluent not reinjected as part of the DGR process would be discharged to local streams or storm sewers via NPDES permits.

Extracted groundwater would be collected at the centralized treatment centers and treated before reinjection. For the purposes of evaluation in the focused FS, water treatment would be achieved by air stripping. However, GAC or other treatment technologies may be implemented in place of or in addition to air stripping to provide additional polishing treatment, if needed. As the extent of impacted groundwater in the MPA shrinks and influent concentrations drop due to mass removal by the DGR system, it may be more cost-effective to use a different treatment method (for example, GAC compared to the original air stripper treatment). Additionally, pumping rates can be adjusted, or entire transects taken offline, as the plume concentrations and extents are reduced.

This alternative also assumes that the existing HCS at Murdock Street will remain in place and operational. However, the operation of the HCS may be reduced or terminated as the plume footprint is reduced.

Periodic groundwater monitoring at the wells both upgradient and downgradient of the DGR systems would be performed as part of this alternative to demonstrate the effectiveness of the extraction, treatment, and reinjection system. Analysis would include the site COCs as well as geochemical and other parameters to monitor the effectiveness of the DGR process.

Maintenance of monitoring wells (e.g., replacement of well vaults) was assumed to occur every 10 years. Periodic maintenance of injection wells is anticipated to be required during operation of the system. Five-year site reviews would also be a component of this alternative because impacted groundwater would remain at the MPA. Abandonment of injection wells was assumed to occur following the final completion of the injection.
4.2.3 Common Elements of Assembled Alternatives

The description and evaluation of the detailed alternatives in the following subsections includes considerations common to several or all detailed alternatives. Several elements are common to all of the detailed alternatives including the following:

- Action-, chemical-, and location-specific ARARs (such as 5-year site reviews)
- Implementation considerations
- Groundwater monitoring program
- Stream monitoring, as required by KDHE
- EUCs.

4.2.3.1 Implementation Considerations

Several implementation considerations are common to all remedial action alternatives presented in this FFS. Drilling into the subsurface is associated with all of the proposed remedial alternatives. Therefore, there is a potential for exposure of site workers to impacted material. However, based on previous investigation and interim remedial actions at the Site, Level D personal protective equipment (PPE) would be used.

In the SA, the drilling locations would be situated within the UP Rail Yard property, the right-of-way of North Hydraulic Street, and the National Guard facility property. Only temporary traffic and noise disruption would occur during installation. Before conducting work in the Rail Yard or downgradient source areas, UP staff would be notified for clearance and designation of an acceptable equipment laydown location. Additionally, a utility clearance would be performed at each drilling location before initiation of work in order to prevent encountering subsurface utilities during implementation of the remedial action.

Soil cuttings from drilling of any remediation and/or observation wells would also be generated during each remedial alternative. Soil cuttings would be containerized, labeled appropriately, and disposed off site in accordance with applicable regulations.

Periodic receptor surveys, including the vapor intrusion pathway, will be a component of the selected remedy and will be required as part of the five-year review of the implemented remediation alternative.

4.2.3.2 Groundwater Monitoring Program

A groundwater monitoring program is considered to be part of all remedial alternatives. The groundwater monitoring program would be tailored to the selected remedy and would consist of selected wells in the existing monitoring well network. For the purposes of this FFS, it is assumed that the groundwater monitoring program will extend 2 years beyond the time estimated to attain RAOs by the remedial systems in order to demonstrate the continued effectiveness of the remedy.

4.2.3.3 Stream Monitoring

As required by the KDHE, stream monitoring in the East Fork of Chisholm Creek would be performed as part of all remedial alternatives. The current stream monitoring program includes annual stream sampling...
during low-flow conditions. For the purposes of the focused FS, it is assumed that the stream monitoring program will be performed in conjunction with the groundwater monitoring program to the extent practical.

4.2.3.4 Environmental Use Controls

EUCs are presently in effect as part of the existing MPA interim measures. Existing EUCs in the City of Wichita require that an application be submitted and a permit obtained for the installation of any type of well. City of Wichita Code Section 7.30.105 prohibits new water wells from being constructed in an area of known contamination. Furthermore, this City Code prohibits the use of existing water wells for private use in these areas. Impacted groundwater associated with the 29th and Grove Site is an area of contamination recognized by the City of Wichita.

Additional EUCs required by the KDHE or the City of Wichita due to impacted media associated with the 29th and Grove Site will be implemented as necessary. It is anticipated that a deed restriction will be applied to the SA to control or prevent future excavation and groundwater use in that area.

Periodic receptor surveys will be a component of the selected remedy and will be required as part of the five-year review of the implemented remediation alternative.

Because impacted soil will potentially remain on UP property at the SA, a soil Waste Management Plan will be required as a component of the selected SA remedy.

4.2.4 Qualitative Screening of Remedial Alternatives

Following the initial screening and subsequent qualitative screening of general response actions, technologies, and process options, the retained technologies and process options were assembled into remedial alternatives. Per NCP guidance, each alternative is then to be further screened based on effectiveness, implementability, and relative cost. The purpose of this qualitative screening of remedial alternatives is to reduce the number of alternatives that undergo a more thorough and extensive analysis in subsequent sections of the FS; therefore, remedial alternatives are evaluated more generally in this section than in the detailed analyses.

Effectiveness - For the qualitative screening of remedial alternatives, effectiveness relates to the ability of the remedial alternative to satisfy the criteria of overall protection of human health and the environment; compliance with ARARs; short- and long-term effectiveness and performance; and reduction of toxicity, mobility, or volume through treatment.

For the effectiveness evaluation criteria, the alternatives are qualitatively rated using a 0 to 5 scale defined as:

- O - not effective
- 1 - low effectiveness
- 2 - low to moderate effectiveness
- 3 - moderate effectiveness
- 4 - moderate to high effectiveness
- 5 - high effectiveness

Implementability - Relates to the technical and administrative feasibility of constructing, operating, and maintaining the remedial alternative. Technical feasibility relates to the practical aspects of construction, operation, and maintenance. Administrative feasibility relates to the ability to obtain permits, procure treatment, storage, and disposal services, and procure the needed land, equipment, and expertise.
Implementability of each alternative is qualitatively rated using the following scale:

- 0 - not implementable
- 1 - low implementability
- 2 - low to moderately implementable
- 3 - moderately implementable
- 4 - moderately to easily implementable
- 5 - easily implementable

Relative Cost - cost estimates prepared for screening remedial alternatives are typically comparative estimates with relative costs. Procedures used to develop cost estimates for qualitative alternative screening are similar to those used for preparing the detailed analyses; however, for the qualitative alternative screening, alternatives and cost components are refined to a lesser degree. Both capital and O&M costs are considered in these estimates.

Because uncertainties with the details of remedial alternatives may remain in this step of the FS process, the costs developed for the qualitative screening of these proposed alternatives are not held to the accuracy required for the detailed analysis of alternatives. Typical cost accuracy ranges for alternative screening are -50/+100 percent of actual costs (USEPA 2000).

The cost of each alternative is rated on a comparative basis using a relative cost scale:

- $ - low cost
- $$ - low to moderate cost
- $$$ - moderate cost
- $$$$ - moderate to high cost
- $$$$$ - high cost

4.2.4.1 Qualitative Screening - Source Area

The qualitative screening evaluations for the five assembled alternatives are presented in Tables 4-3 through 4-7. Table 4-8 presents a summary of the qualitative screening of the alternatives assembled for the SA.

Generally, alternatives that have a low rating for effectiveness and/or implementability coupled with a high cost would be eliminated from further consideration. As shown on Table 4-8, Source Area Alternative 3 - ISSS and Groundwater Removal (Pump-and-Treat), was eliminated from further consideration, primarily because of questionable effectiveness and the likelihood of an extended time frame required to meet RAOS. Source Area Alternative 5 - ISSS, Soil Mixing Using ZVI and ERD, was eliminated from further consideration, primarily because of potential hydrogeologic side effects (such as the surfacing of groundwater or destabilizing of surface structures) associated with implementing soil mixing in a complex hydrogeologic environment.

4.2.4.2 Qualitative Screening - Mid-Plume Area

The qualitative screening evaluations for the five assembled alternatives are presented in Tables 4-9 through 4-13. Table 4-14 presents a summary of the qualitative screening of the alternatives assembled for the MPA.

Generally, alternatives that have a low rating for effectiveness and/or implementability coupled with a high cost would be eliminated from further consideration. Mid-Plume Area Alternative 2 - AS/SVE, was
eliminated from further consideration, as shown in Table 4-14, primarily because of high implementation
costs associated with the effort to address the large MPA footprint and the potential for vapor intrusion
into residential spaces caused by the sparging process and not picked up by the SVE system.

4.2.5 Assembled Alternatives Retained Following Screening

The following alternatives have been retained after initial screening and will be carried forward for detailed
evaluation in the next section:

- For the SA:
  - Source Area Alternative 1 – No Further Action
  - Source Area Alternative 2 – Hot spot excavation, targeted soil ERD treatment, and downgradient
    groundwater ERD treatment
  - Source Area Alternative 4 – Soil Excavation and ERD,

- For the MPA:
  - Mid-Plume Area Alternative 1 – No Further Action
  - Mid-Plume Area Alternative 3 – ERD
  - Mid-Plume Area Alternative 4 – Downgradient hydraulic containment
  - Mid-Plume Area Alternative 5 – DGR
5 DETAILED ANALYSIS OF RETAINED ALTERNATIVES

The detailed analysis is a multi-step process to evaluate and compare alternatives and to identify the key trade-offs among them. During the detailed analysis, each alternative is assessed against the evaluation criteria described in the subsections that follow. The results of the detailed analysis provide relevant information needed to allow selection of the most appropriate remedy.

Each retained alternative previously presented in Section 4.2.5 is further evaluated in this section. These subsections briefly describe the retained alternative and evaluate each one against seven of the nine criteria. Two criteria (state acceptance and community acceptance) will not be evaluated in this report.

In order to rank the alternatives in the detailed analysis, each criterion is qualitatively rated using a 0 to 5 scale, defined as:

- 0: None
- 1: Low
- 2: Low to moderate
- 3: Moderate
- 4: Moderate to high
- 5: High

Similarly, the costs are evaluated using a 0 to $$$$$ scale, defined as:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Source Area</th>
<th>Mid-Plume Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>$  - Low</td>
<td>less than $500,000</td>
<td>Less than $2 million</td>
</tr>
<tr>
<td>$$  - Low to moderate</td>
<td>$500,000 to $1 million</td>
<td>$2 million to $5 million</td>
</tr>
<tr>
<td>$$$  - Moderate</td>
<td>$1 million to $2 million</td>
<td>$5 million to $10 million</td>
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<tr>
<td>$$$$  - Moderate to high</td>
<td>$2 million to $3 million</td>
<td>$10 million to $15 million</td>
</tr>
<tr>
<td>$$$$$  - High</td>
<td>greater than $3 million</td>
<td>greater than $15 million</td>
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5.1 Individual Analysis – Source Area Alternatives

5.1.1 Individual Analysis for Source Area Alternative 1 – No Further Action

As previously discussed, the No Further Action alternative is required by the NCP to provide a baseline set of conditions against which other remedial actions may be compared.

Although no remedial action or monitoring is required for this alternative per USEPA guidance (USEPA 1989), UP currently has a Consent Order with the KDHE, which includes monitoring requirements. Therefore, the No Further Action alternative for this focused FS includes groundwater monitoring and 5-year site reviews.
5.1.1.1 Overall Protection

The existing water well ordinances and institutional controls provide some protection for public health and the environment; however, because no treatment, containment, or removal of contaminated soil or groundwater is included in this alternative, this criterion is not met. The overall rating for Source Area Alternative 1 – No Further Action is none (0).

5.1.1.2 Compliance with ARARs

The list of ARARs used in this evaluation was presented in Section 2. The overall rating for Source Area Alternative 1 – No Further Action against this criterion is none, primarily because contaminant concentrations in SA groundwater exceed federal drinking water standards (0).

5.1.1.3 Reduction of Toxicity, Mobility, or Volume

This alternative does not provide for an SA treatment component outside of natural attenuation, which may result in incomplete degradation of COCs. In addition, this alternative does not provide for containment or removal of impacted SA groundwater and therefore does not satisfy the preference for treatment as a principal element of the remedial action. This criterion is not met by this alternative. The overall rating for Source Area Alternative 1 – No Further Action is none (0).

5.1.1.4 Short-Term Effectiveness

The existing water well ordinances and institutional controls provide some protection for public health and the environment; however, other short-term risks to the community are unchanged by this alternative because no treatment, containment, or removal of SA contaminant mass is performed, and the time frame for monitoring is essentially open-ended. This criterion is therefore not met by Source Area Alternative 1 – No Further Action, and the overall rating is none (0).

5.1.1.5 Long-Term Effectiveness and Permanence

The existing water well ordinances and institutional controls provide some protection for public health and the environment. These would continue to be maintained as long as necessary; however, no containment or removal of SA contaminant mass is included in this alternative. Any reduction in COC concentration relies on natural attenuation processes, and the time required to complete this remedy is expected to exceed the 30 years used as a standard basis for alternative life. This criterion is therefore not met by this alternative, and the overall rating for Source Area Alternative 1 – No Further Action is none (0).

5.1.1.6 Implementability

Groundwater monitoring and maintenance of existing water well ordinances and institutional controls are easily implementable. The overall rating for Source Area Alternative 1 – No Further Action against this criterion is therefore high (0).
5.1.1.7 Cost

Evaluation of cost for this SA alternative, along with a summary breakdown of cost components, is provided in Appendix G. The overall rating for Source Area Alternative 1 – No Further Action against this criterion is low ($).

5.1.2 Individual Analysis for Source Area Alternative 2 – Hot Spot Excavation, Targeted Soil ERD, and Groundwater ERD

Source Area Alternative 2 consists of the hot spot excavation of the impacted soil beneath the Waste Storage Area, ERD treatment of impacted soil in the Rail Yard area, and downgradient ERD processes to degrade the chlorinated solvents in the saturated zone. The hot spot excavation and soil ERD treatment would be completed at the readily accessible areas (e.g., not below the railroad) down to a depth of approximately 15 ft bgs. The downgradient ERD treatment would be performed using the existing ERD system, which consists of rows of injection wells to deliver carbon substrate to the aquifer in upgradient and downgradient locations from the point of release area in the Rail Yard. The injection wells would be installed in transects perpendicular to the plume axis. The conceptual design for Source Area Alternative 2 is illustrated on Figure 4-1. Periodic groundwater monitoring at wells located both upgradient and downgradient of the ERD injection network would be performed as part of this alternative to demonstrate the effectiveness of the ERD treatment.

5.1.2.1 Overall Protection

This alternative is protective of human health and the environment. Hot spot excavation and soil ERD treatment would permanently reduce exposure to sorbed COCs in the vadose zone, and ERD would degrade saturated-zone COCs at the point of release and in downgradient areas. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD is high (6).

5.1.2.2 Compliance with ARARs

The list of ARARs used in this evaluation was presented in Section 2. Access permits for the installation of injection wells in the right-of-way of North Hydraulic Street must be obtained from the City of Wichita, and injection permits for the injection of carbon substrate must be obtained from the KDHE. Excavation, completion of the soil ERD, and construction of the ERD infrastructure (wells and piping) would comply with location-specific ARARs. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD is high (6).

5.1.2.3 Reduction of Toxicity, Mobility, or Volume

This alternative does provide an ERD treatment component that addresses the statutory preference for treatment as a principal element of remedial action in the SA. The ERD treatment component would significantly reduce the overall toxicity and volume of dissolved phase contaminant mass. The ERD treatment also generates short-term increases in methane, low redox groundwater, and elevated metals, all of which return to background conditions as organic carbon is fully degraded. Hot spot excavation would remove the soil contaminant mass beneath the Waste Storage Area. Dissolved phase TCE and other COC concentrations are expected to be lower than cleanup goals following the treatment period. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD against this criterion is high (6).
5.1.2.4 Short-Term Effectiveness

Hot spot excavation would immediately reduce the level of exposure to COCs in the soil, and ERD would have an almost immediate effect on reducing saturated-zone COC concentrations. Appropriate safety protocols would be followed during excavation and installation of the ERD system components. Construction-derived waste soil and/or groundwater generated during implementation would be appropriately contained, labeled, and disposed. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD against this criterion is moderate to high ($$).

5.1.2.5 Long-Term Effectiveness and Permanence

Hot spot excavation would permanently remove impacted soil and prevent long-term exposure to COCs from SA soils, and ERD would treat saturated-zone COCs to concentrations lower than the cleanup goals. The ERD system is anticipated to operate for 5 years, at the end of which, COC concentrations in groundwater are expected to be lower than the cleanup goal. Follow-on groundwater monitoring may be performed to verify that rebound VOC concentrations (if any) do not exceed cleanup goals and that groundwater recovers from the induced low redox condition and associated impacts such as methane and mobilized metal concentrations return to background conditions. The time period for follow-on groundwater monitoring is expected to extend to 7 years. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD against this criterion is high ($$).

5.1.2.6 Implementability

Of the presented alternatives, hot spot excavation, targeted ERD, and downgradient ERD comprise the most implementable remedy with the least intrusive footprint. The hot spot excavation would involve a much smaller quantity of soil removed from beneath the Waste Storage Area compared to other excavation alternatives; therefore, it would not require the larger footprint or the increased susceptibility associated with long-haul transportation associated with the full soil excavation alternative. However, access through the area (south side of the railroad tracks) by site personnel is not likely to be possible during a portion of the hot spot excavation and targeted soil ERD field activities.

The ERD injection network can be easily installed using standard drilling equipment and installation techniques after ISSS is complete. Technical personnel are available for O&M and groundwater monitoring. Access to the public right-of-way of North Hydraulic Street to install the ERD infrastructure is not anticipated to be difficult. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD against this criterion is therefore moderate to high ($$).

5.1.2.7 Cost

The summary breakdown of cost components for this SA alternative is provided in Appendix G. The overall rating for Source Area Alternative 2 – Hot spot excavation, targeted soil ERD, and downgradient ERD against this criterion is moderate ($$).

5.1.3 Individual Analysis for Source Area Alternative 4 – Soil Excavation and ERD

Source Area Alternative 4 consists of soil excavation to reduce the amount of sorbed COC mass at the point of release and ERD processes within the subsurface to degrade saturated-zone chlorinated solvent
impacts. Soil excavation would address soils down to bedrock, with the highest COC concentrations between the railroad and roadway. ERD would be performed using a portion of the excavation as an infiltration reservoir and downgradient rows of injection wells to deliver carbon substrate. The conceptual design for Source Area Alternative 4 is illustrated on Figure 4-3. Periodic groundwater monitoring at wells located both upgradient and downgradient of the ERD injection network would be performed as part of this alternative to demonstrate the effectiveness of the ERD treatment.

5.1.3.1 Overall Protection

The combination of soil excavation and ERD treatment would significantly reduce the amount of sorbed and dissolved phase COC mass present at the point of release and downgradient; therefore, this alternative is protective of human health and the environment. Dissolved phase COC concentrations would be treated to below cleanup goals at the point of release and in downgradient areas. However, because excavation would include aboveground handling and off-site disposal at the Clean Harbors Subtitle C Landfill in Oklahoma, it would also increase the potential for worker contact, release of fugitive emissions, and accidental release during transportation. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD is moderate to high (0).

5.1.3.2 Compliance with ARARs

The list of ARARs used in this evaluation was presented in Section 2. Access permits for the installation of injection wells in the right-of-way of North Hydraulic Street must be obtained from the City of Wichita, and injection permits for the injection of carbon substrate must be obtained from the KDHE. Excavation and construction of the ERD infrastructure (wells and piping) would comply with location-specific ARARs. Excavation and disposal of impacted soil would also require compliance with complex RCRA Large Quantity Generator requirements. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD is moderate to high (0).

5.1.3.3 Reduction of Toxicity, Mobility, or Volume

This alternative relies on physical removal by soil excavation and treatment through ERD to reduce the volume of contaminant mass present in the SA. The ERD treatment component addresses the statutory preference for treatment as a principal element. Dissolved phase TCE and other COC constituent concentrations are expected to be lower than cleanup goals following the ERD treatment period. The ERD treatment also generates short-term increases in methane, low redox groundwater, and elevated metals, all of which return to background conditions as organic carbon is fully degraded. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD against this criterion is high (0).

5.1.3.4 Short-Term Effectiveness

Excavation of impacted soils would immediately reduce the amount of sorbed COCs, and ERD would have an almost immediate effect on reducing dissolved phase CCC concentrations. Appropriate safety protocols would be followed during excavation activities and installation of the ERD system components. Waste soil and/or groundwater generated during implementation would be appropriately contained, labeled, and disposed. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD against this criterion is high (0).
5.1.3.5 Long-Term Effectiveness and Permanence

Soil excavation would significantly reduce the amount of contaminant mass present in SA soils, and ERD would treat adjacent and downgradient saturated zone to lower than cleanup levels. The ERD system is anticipated to operate for 5 years, at the end of which VOC concentrations in the SA groundwater are expected to be lower than the cleanup goal. Follow-on groundwater monitoring may be performed to verify that rebound VOC concentrations (if any) do not exceed cleanup goals and that groundwater recovers from the induced low redox condition and associated impacts, such as methane and mobilized metal concentrations, return to background conditions. The time period for follow-on groundwater monitoring is expected to extend to 7 years. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD against this criterion is high (5).

5.1.3.6 Implementability

Soil excavation activities are considered to be moderately difficult to implement due to the lack of available space present in the SA between the railroad tracks and North Hydraulic Street. The activities would most likely require the use of a remote (away from the excavation site) staging area for excavated soil, staged equipment, and backfill materials. Access through the area (south side of the railroad tracks) by site personnel is not likely to be possible during a portion of the excavation. Excavation would require the use of cross-braced sheet piling because the excavation would extend to bedrock. A partial closure of North Hydraulic Street may be required to obtain sufficient clearance for the excavation.

The ERD injection network can be easily installed using standard drilling equipment and installation techniques after soil excavation activities are complete. Technical personnel are available for O&M and groundwater monitoring. Access to the public right-of-way of North Hydraulic Street to install the ERD infrastructure is not anticipated to be difficult. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD against this criterion is therefore moderate (3).

5.1.3.7 Cost

The summary breakdown of cost components for this SA alternative is provided in Appendix G. The overall rating for Source Area Alternative 4 - Soil Excavation and ERD against this criterion is moderate to high ($$$).
5.2.1.1 Overall Protection

The existing water well ordinances and institutional controls provide some protection for public health and the environment; however, because no treatment, containment, or removal of contaminated MPA groundwater is included in this alternative, this criterion is not met. The overall rating for Mid-Plume Area Alternative 1 – No Further Action is none (0).

5.2.1.2 Compliance with ARARs

The list of ARARs used in this evaluation was presented in Section 2. The overall rating for Mid-Plume Area Alternative 1 - No Further Action against this criterion is none, primarily because concentrations in MPA groundwater exceed federal drinking water standards (0).

5.2.1.3 Reduction of Toxicity, Mobility, or Volume

This alternative does not provide for an MPA treatment component outside of natural attenuation, which may result in incomplete degradation of COCs. In addition, this alternative does not provide for containment or removal of impacted MPA groundwater and therefore does not satisfy the preference for treatment as a principal element of the remedial action. This criterion is not met by this alternative. The overall rating for Mid-Plume Area Alternative 1 - No Further Action is none (0).

5.2.1.4 Short-Term Effectiveness

The existing water well ordinances and institutional controls provide some protection for public health and the environment; however, other short-term risks to the community are unchanged by this alternative because no treatment, containment, or removal of impacted MPA groundwater is performed, and the time frame for monitoring is essentially open-ended. This criterion is therefore not met by Mid-Plume Area Alternative 1 - No Further Action, and the overall rating is none (0).

5.2.1.5 Long-Term Effectiveness and Permanence

The existing water well ordinances and institutional controls provide some protection for public health and the environment. These would continue to be maintained as long as necessary, however, no containment or removal of impacted MPA groundwater is included in this alternative. Any reduction in COC concentration relies on natural attenuation processes, and the time required to complete this remedy is expected to exceed the 30 years used as a standard basis for alternative life. This criterion is therefore not met by this alternative and the overall rating for Mid-Plume Area Alternative 1 - No Further Action is none (0).

5.2.1.6 Implementability

Groundwater monitoring and maintenance of existing water well ordinances and institutional controls are easily implementable. The overall rating for Mid-Plume Area Alternative 1 - No Further Action against this criterion is therefore high (5).
5.2.1.7 Cost
Evaluation of cost for this MPA alternative, along with a summary breakdown of cost components, is provided in Appendix H. The overall rating for Mid-Plume Area Alternative 1 – No Further Action against this criterion is low ($).

5.2.2 Individual Analysis for Mid-Plume Area Alternative 3 – Enhanced Reductive Dechlorination
Mid-Plume Area Alternative 3 consists of implementing ERD processes within the subsurface to degrade the chlorinated solvent groundwater plume. ERD would be performed using rows of injection wells to deliver carbon substrate to the aquifer. The injection wells would be installed in transects perpendicular to the plume axis. Periodic groundwater monitoring at wells located both upgradient and downgradient of the ERD systems would be performed as part of this alternative to demonstrate the effectiveness of the ERD treatment.

5.2.2.1 Overall Protection
Over time, ERD treatment would reduce COC levels in impacted groundwater to levels lower than the cleanup goals, therefore, this alternative is protective of human health and the environment. However, generation of methane within residential and commercial areas introduces a significant health and safety risk as a byproduct of the remediation process requiring additional engineering controls. The overall rating for Mid-Plume Area Alternative 3 – ERD is moderate (●).

5.2.2.2 Compliance with ARARs
The list of ARARs used in this evaluation was presented in Section 2. Permitting for the injection of carbon substrate must be obtained from the state. Construction of the ERD infrastructure (wells and piping) would comply with location-specific ARARs. The overall rating for Mid-Plume Area Alternative 3 – ERD is moderate to high (●).

5.2.2.3 Reduction of Toxicity, Mobility, or Volume
This alternative does provide a treatment component and will address the statutory preference for treatment as a principal element of remedial action in the MPA. TCE and other COC concentrations are expected to be lower than cleanup goals following treatment, and no residual material is anticipated to remain from the treatment process. The overall rating for Mid-Plume Area Alternative 3 – ERD against this criterion is moderate to high (●).

5.2.2.4 Short-Term Effectiveness
The existing water well ordinances and institutional controls provide some protection for public health and the environment. Appropriate safety protocols would be followed during installation of the ERD system components. Construction-derived waste soil and/or groundwater generated during system installation would be appropriately contained, labeled, and disposed. The carbon substrate would be handled using proper safety protocols. ERD is expected to have an almost immediate effect on reducing groundwater contaminant concentrations following system startup. The overall rating for Mid-Plume Area Alternative 3 – ERD against this criterion is moderate to high (●).
5.2.2.5 Long-Term Effectiveness and Permanence

The ERD remedy would accelerate the degradation process as opposed to an MNA-only option. The ERD system is anticipated to operate for a maximum of 7 years, at the end of which, COC concentrations in the MPA groundwater are expected to be lower than cleanup goal. Follow-on groundwater monitoring may be performed to verify that rebound VOC concentrations (if any) do not exceed cleanup goals. The period for follow-on groundwater monitoring is expected to extend beyond the 30 years used as a standard basis for alternative life.

ERD would reduce groundwater contamination to cleanup goals over time, thus the alternative generally meets this criterion. However, given the concerns with effective establishment of reducing conditions within the high groundwater velocity areas in the northern end of the MPA, ERD may not be effective over the entire MPA. ERD can potentially create treatment residuals, such as methane, low-redox groundwater, and elevated dissolved metals. The overall rating for Mid-Plume Area Alternative 3 - ERD against this criterion is therefore moderate (4).

5.2.2.6 Implementability

Groundwater monitoring and maintenance of existing water well ordinances and institutional controls are easily implementable. Installation of an ERD system involves standard drilling equipment and installation techniques. Technical personnel are available for O&M and groundwater monitoring. Access to the public right-of-way to install the ERD infrastructure would be the key to implementing this alternative. Periodic application of the carbon substrate may potentially disrupt traffic and commercial and residential areas. The overall rating for Mid-Plume Area Alternative 3 - ERD against this criterion is therefore moderate (4).

5.2.2.7 Cost

The summary breakdown of cost components for this MPA alternative is provided in Appendix H. The overall rating for Mid-Plume Area Alternative 3 - ERD against this criterion is high ($$$$$).

5.2.3 Individual Analysis for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment

Mid-Plume Area Alternative 4 consists of the continued operation of the existing HCS located along the southern extent of the MPA at Murdock Street. In this alternative, the impacted groundwater at the downgradient edge of the plume would be addressed through pump-and-treat technology.

5.2.3.1 Overall Protection

Because extraction and treatment are provided only at the downgradient edge of the plume, this alternative is not generally protective of human health and the environment for the remainder of the MPA except that mass is being removed slowly as the impacted groundwater flows downgradient. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment for this criterion is low (0).
5.2.3.2 Compliance with ARARs

The list of ARARs used in this evaluation was presented in Section 2. Permitting for the discharge of treated effluent from the state is required. Construction of the downgradient hydraulic containment infrastructure (wells and piping) has been completed and complies with location-specific ARARs. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment is high (0).

5.2.3.3 Reduction of Toxicity, Mobility, or Volume

This alternative does provide a treatment component and would address the statutory preference for treatment as a principal element of remedial action in the MPA. Achievement of cleanup goals throughout the MPA would take many years, as the impacted groundwater would have to flow downgradient to be intercepted by the extraction wells. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment against this criterion is moderate (C).

5.2.3.4 Short-Term Effectiveness

The existing water well ordinances and institutional controls provide some protection for public health and the environment. The downgradient HCS is having an immediate effect on removing mass of COCs in the immediate vicinity of the extraction wells. There is no short-term impact of the system on impacted groundwater in the remainder of the MPA. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment against this criterion is low to moderate (8).

5.2.3.5 Long-Term Effectiveness and Permanence

The HCS at Murdock would need to operate for a very long time to achieve any impact on the groundwater plume at the MPA because the only upgradient driving mechanism is natural groundwater flow toward the extraction wells. The capture zone of the six extraction wells does increase flow to the system at the southern edge of the plume. The period for system operation of the HCS is expected to extend beyond the 30 years used as a standard basis for alternative life.

In addition to the long treatment period, operation of the HCS has the potential to induce flow from the NIC plume located immediately west. Once the NIC plume has commingled with the 29th and Grove plume, it would be difficult to determine that an end point is reached (if the NIC plume requires a longer period to be fully remediated).

Because there are no treatment residuals expected, and downgradient hydraulic control may eventually reduce impacted groundwater concentrations to acceptable cleanup levels over time, the alternative generally meets this criterion. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment against this criterion is therefore low to moderate (8).

5.2.3.6 Implementability

Groundwater monitoring and maintenance of existing water well ordinances and institutional controls are easily implementable. The HCS at Murdock has been installed using standard drilling equipment and directional piping installation techniques. Technical personnel are available for O&M and groundwater monitoring. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment against this criterion is therefore high (0).
5.2.3.7 Cost
The summary breakdown of cost components for this MPA alternative is provided in Appendix H. The overall rating for Mid-Plume Area Alternative 4 – Downgradient Hydraulic Containment against this criterion is high ($$$$$).

5.2.4 Individual Analysis for Mid-Plume Area Alternative 5 – Directed Groundwater Recirculation

Mid-Plume Area Alternative 5 - DGR uses both pumping and injection wells to increase the pore water flushing through an impacted aquifer as well as to provide groundwater barriers preventing the mixing of the adjacent plumes to the east and west. DGR speeds up the flushing process by recirculating clean water across each targeted aquifer segment at a rate faster than can be accomplished with ambient flow or by pumping wells only, thereby increasing the number of clean water pore flushes and controlling where the flushing is occurring.

5.2.4.1 Overall Protection
Extraction and treatment of impacted groundwater would occur throughout the MPA; therefore, this alternative would be protective of human health and the environment. The use of injection wells to increase the rate of pore water exchanges in the aquifer results in reduced time to achieve cleanup goals compared to other alternatives. The overall rating for Mid-Plume Area Alternative 5 - DGR for this criterion is high (6).

5.2.4.2 Compliance with ARARs
The list of ARARs used in this evaluation was presented in Section 2. Permitting for the extraction wells and rejection wells must be obtained from the state. Discharge permits for treated effluent not reinjected would be required. Construction of the DGR infrastructure (wells and piping) would comply with location-specific ARARs. The overall rating for Mid-Plume Area Alternative 5 - DGR is moderate to high (6).

5.2.4.3 Reduction of Toxicity, Mobility, or Volume
This alternative does provide a treatment component and will address the statutory preference for treatment as a principal element of remedial action in the MPA. TCE and other COC concentrations are expected to be lower than cleanup goals following the treatment period, and no residual material is anticipated to remain from the treatment process. The use of injection wells to increase the rate of pore water exchanges in the aquifer result in reduced time to achieve cleanup goals compared to other alternatives. The overall rating for Mid-Plume Area Alternative 5 - DGR against this criterion is moderate to high (6).

5.2.4.4 Short-Term Effectiveness
The existing water well ordinances and institutional controls provide some protection for public health and the environment. Appropriate safety protocols would be followed during installation of the DGR system components. Construction-derived waste soil and/or groundwater generated during system installation would be appropriately contained, labeled, and disposed. Operation of the DGR is expected to have an almost immediate effect on reducing groundwater contaminant concentrations following system startup.
Each transect can be placed into operation as soon as it is completed, providing additional short-term effectiveness. The overall rating for Mid Plume Area Alternative 5 - DGR against this criterion is moderate to high (0).

5.2.4.5 Long-Term Effectiveness and Permanence

The DGR remedy would accelerate aquifer remediation by increasing the rate of pore water exchanges through the aquifer while separating the plume from the dry cleaner plume to the east and preventing mixing with the NIC plume to the west. The DGR system is anticipated to operate for a maximum of 10 years, at the end of which, COC concentrations in the MPA groundwater are expected to be lower than cleanup goals. Follow-on groundwater monitoring may be performed to confirm that the MPA is not being re-impacted by off-site sources or by other sources located within the plume boundaries not attributable to UP. The use of injection wells to increase the rate of pore water exchanges in the aquifer would result in reduced time to achieve cleanup goals compared to other alternatives.

Because there are no treatment residuals expected, and DGR would reduce groundwater contamination to cleanup goals over time, the alternative meets this criterion. The overall rating for Mid-Plume Area Alternative 5 - DGR against this criterion is therefore high (0).

5.2.4.6 Implementability

Groundwater monitoring and maintenance of existing water well ordinances and institutional controls is easily implementable. Installation of a DGR system involves standard drilling equipment and installation techniques. Technical personnel are available for O&M and groundwater monitoring. Access to the public right-of-way to install the DGR infrastructure would be the key to implementing this alternative. Following installation, disruptions to the public would be infrequent and minor. Effective long-term operation of the reinjection wells would depend on overall groundwater quality. Additional testing would be required before implementation, but preliminary data indicate the potential for successful reinjection. The overall rating for Mid-Plume Area Alternative 5 - DGR against this criterion is therefore moderate (0).

5.2.4.7 Cost

The summary breakdown of cost components for this MPA alternative is provided in Appendix H. The overall rating for Mid-Plume Area Alternative 5 - DGR against this criterion is moderate to high ($$$).
6 COMPARATIVE ANALYSIS

In Section 5, the three SA alternatives and the four MPA alternatives retained for detailed analysis were described and individually assessed against seven of the nine evaluation criteria. The state acceptance and community acceptance criteria will not be addressed in this document but will be addressed following review by KDHE and the subsequent public comment period.

In this section, a comparative analysis of the retained alternatives will discuss each alternative's ability to meet the seven evaluation criteria. The purpose of this comparative analysis is to identify the relative advantages and disadvantages of each detailed alternative. For this reason, the analysis focuses primarily on the differences among the detailed alternatives. This approach allows for evaluation of the unique advantages/disadvantages of each detailed alternative rather than emphasizing elements that do not affect the final selection of a preferred detailed alternative.

6.1 Comparative Analysis - Source Area

Table 6-1 provides a summary of the comparative evaluation of each retained SA alternative based on the seven criteria. Two of the criteria (overall protection of human health and the environment and compliance with ARARs) serve as threshold determinations because they must be met before a detailed alternative can be further considered. The threshold criteria are presented in Sections 6.1.1 and 6.1.2. Sections 6.1.3 through 6.1.7 present the remaining five criteria. Section 6.1.8 summarizes the comparative analysis of the seven detailed criteria.

6.1.1 Overall Protection of Human Health and the Environment

Overall protection of human health and the environment is accomplished by two of the three proposed alternatives that include remedial action through a combination of technologies to address impacted soil and groundwater in the SA.

The remediation methods for addressing impacted groundwater include the following:

- Source Area Alternative 1 – No Further Action – no active remediation
- Source Area Alternative 2 – SA soil remediation using hot spot excavation, targeted ERD treatment, and groundwater remediation using ERD
- Source Area Alternative 4 – SA soil remediation using soil excavation and groundwater remediation using ERD.

These alternatives, except for Source Area Alternative 1, provide overall protection to human health and the environment. Source Area Alternatives 2 and 4 achieve protection in the short term by addressing sorbed COC mass at the point of release. Source Area Alternatives 2 and 4 include excavation and off-site disposal; therefore, they carry increased potential for worker contact, release of fugitive emissions, and accidental release during transportation; however, the extent of excavation is much greater in Alternative 4.

The preferred alternative with respect to this criterion is Source Area Alternative 2.
6.1.2 Compliance with ARARs

All detailed SA alternatives would comply with all action-, location-, and chemical-specific ARARs and are therefore considered generally equal when measured against this criterion (see Table 6-1 for comparison). Source Area Alternatives 2 and 4 would require permission from the City of Wichita to install injection wells in the city street right-of-way and would require injection well permits for the carbon source injection. Source Area Alternative 4 would also require compliance with complex RCRA Large Quantity Generator requirements.

The preferred alternative with respect to this criterion is Source Area Alternative 2.

6.1.3 Reduction of Toxicity, Mobility, or Volume

Source Area Alternative 2 reduces physical risks by permanently removing soil impacted at levels exceeding cleanup goals from beneath the Waste Storage Pad and by biologically degrading COC-impacted soil through ERD. Source Area Alternative 4 reduces physical risks by removing a significant portion of the COC-impacted soils and biologically degrading saturated-zone COCs. The anticipated remediation time (5 years) is consistent between both remediation alternatives.

Implementation of ERD (included in Source Area Alternatives 2 and 4) has extensive O&M associated with its implementation, while Source Area Alternative 1 - No Further Action has no O&M component (beyond monitoring well maintenance).

Source Area Alternatives 2 and 4 are equivalent with respect to this criterion.

6.1.4 Short-Term Effectiveness

Source Area Alternative 1 - No Further Action is not effective in the short term because mass reduction beyond that of natural attenuation is not included. Short-term effectiveness in the SA is greatest with those alternatives that provide wide coverage of treatment. Source Area Alternatives 2 and 4 provide short-term effectiveness because these alternatives address sorbed COC mass at the point of release. Source Area Alternative 4 would be expected to reduce COCs at a faster rate because it employs physical removal sorbed COC mass.

The preferred alternative with respect to short-term effectiveness is Source Area Alternative 4.

6.1.5 Long-Term Effectiveness and Permanence

Source Area Alternative 1 - No Further Action does not provide a long-term effective or permanent remedy for the SA. Source Area Alternatives 2 and 4 would provide a long-term reduction of COCs in groundwater to cleanup levels. Source Area Alternative 2 prevents long-term discharge by removing soil impacted at levels above cleanup goals beneath the Waste Storage Pad and reduces saturated-zone contaminant concentrations using an aggressive ERD approach. Source Area Alternative 4 reduces the volume of COC mass by physical removal of a significant portion of the impacted soils and a less aggressive ERD approach to address dissolved phase impacts.

Implementation of ERD (included in Source Area Source Area Alternatives 2 and 4) has extensive O&M associated with its implementation, while Source Area Alternative 1 - No Further Action has no O&M component (beyond monitoring well maintenance).

Source Area Alternatives 2 and 4 are equivalent with respect to this criterion.
6.1.6 Implementability

Actions similar to those proposed in each detailed alternative have been implemented at other sites. However, the level of complexity of installation varies among the alternatives.

All alternatives are readily implementable in the SA. Source Area Alternative 2, which uses hot spot excavation and targeted ERD, is the least intrusive (compared to Source Area Alternative 4) and therefore is the most implementable. Source Area Alternative 4, which uses soil excavation, would require shoring (such as installation of cross-braced sheet piles) and a remote staging area to accumulate excavated soil and backfill materials. The overall construction phase for Source Area Alternative 2 would be of short duration because of its targeted removal efforts. Both alternatives would likely block access to the area for a portion of the site activities.

Source Area Alternatives 2 and 4 would require permission from the City of Wichita to install injection wells in the city right-of-way, well installation permits, and underground injection permits (for the injection of carbon substrates). Source Area Alternative 4 would also require compliance with complex RCRA Large Quantity Generator requirements. The RCRA requirements are extensive and would require certification of various components (such as containment systems) as well as regular inspections and reporting to the state.

The preferred alternative with respect to implementability is Source Area Alternative 2.

6.1.7 Cost

The estimated total life-cycle costs for implementation of the three SA alternatives evaluated are summarized in Table 6-1 and listed below in order of increasing cost. The costs listed below do not include a contingency component.

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Life-Cycle Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source Area Alternative 1 - No Further Action</td>
<td>$0</td>
</tr>
<tr>
<td>Source Area Alternative 2 - hot spot excavation, soil ERD, and downgradient ERD</td>
<td>$1,544,000</td>
</tr>
<tr>
<td>Source Area Alternative 4 - Soil excavation and ERD</td>
<td>$2,825,000</td>
</tr>
</tbody>
</table>

The preferred alternative with respect to cost is Source Area Alternative 2.

6.1.8 Summary of Comparative Analysis - Source Area

In the previous sections, a comparative analysis of the retained alternatives addressed each alternative's ability to meet the seven evaluation criteria. The analysis demonstrated that two of the three alternatives would satisfactorily meet the following criteria:

- All RAOs
- Overall protection of human health and the environment
- Compliance with ARARs
- Short-term effectiveness
FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment.

Source Area Alternative 1 - No Further Action, would not meet the aforementioned evaluation criteria. The criteria that were not met equally by each of the detailed alternatives were overall protection of human health and the environment, compliance with ARARs, short-term effectiveness, implementability, and cost. These criteria were used to determine the best overall alternative.

Considering all criteria, UP believes that the best alternative, based on data available at the time of this report, is Source Area Alternative 2, consisting of hot spot excavation, targeted soil ERD treatment, and groundwater ERD treatment. However, UP has recognized that the primary driver in achieving site-wide RAOs is successful treatment of dissolved phase impacts migrating from the SA to the MPA. To expedite treatment of dissolved phase impacts and ensure implementation of a comprehensive SA remedy, UP (following discussions with and concurrence from KDHE) has implemented a phased approach that allowed for initiation of the selected groundwater treatment component (ERD) in downgradient areas, with final selection of the point of release remedy to be deferred until the effectiveness of the downgradient ERD program can be evaluated over a 1- to 2-year period. The point of release remedies that would be considered after the evaluation period will be hot spot excavation and targeted soil ERD (as specified in Source Area Alternative 2) and soil excavation with an ERD infiltration reservoir (as specified in Source Area Alternative 4).

As described in Section 4.2.1 and fully discussed in the Source Area ERD Startup Report contained in Appendix F (Arcadis 2019b), the current and operational proposed downgradient ERD program consists of one injection well transect at the release area, a second injection well transect located on the south side of North Hydraulic Street, and a third transect located further downgradient to the north of the East Fork of Chisolm Creek. The Source Area ERD system has been operational since November 2018.

Following approval of this FFS from the KDHE, UP will submit a work plan to implement the additional release area remediation components of the selected SA alternative.

6.2 Comparative Analysis - Mid-Plume Area

Table 6-2 provides a summary of the comparative evaluation of each retained MPA alternative based on the seven criteria. Two of the criteria (overall protection of human health and the environment and compliance with ARARs) serve as threshold determinations because they must be met before a detailed alternative can be further considered. The threshold criteria are presented in Sections 6.2.1 and 6.2.2. Sections 6.2.3 through 6.2.7 present the remaining five criteria. Section 6.2.8 summarizes the comparative analysis of the seven detailed criteria.

6.2.1 Overall Protection of Human Health and the Environment

Overall protection of human health and the environment is accomplished by three of the four proposed alternatives that include remedial action through a combination of technologies to address impacted groundwater in the MPA.

The remediation methods for addressing impacted groundwater include the following:

- Mid-Plume Area Alternative 1 – No Further Action – no active remediation
- Mid-Plume Area Alternative 3 – Mid-Plume Area Groundwater Remediation using ERD
FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas

- Mid-Plume Area Alternative 4 – Mid-Plume Area Groundwater Remediation using Downgradient Hydraulic Containment
- Mid-Plume Area Alternative 5 – Mid-Plume Area Groundwater Remediation using DGR.

Each of these alternatives, except for Mid-Plume Area Alternative 1, provides overall protection to human health and the environment. Mid-Plume Area Alternatives 3 and 5 achieve protection in the short term by addressing impacted groundwater throughout the MPA. Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment does generally provide protection to the extent that impacted groundwater would eventually flow to the Murdock HCS, but at a lower level than other active remediation alternatives.

6.2.2 Compliance with ARARs

All detailed MPA alternatives would comply with all action-, location-, and chemical-specific ARARs and are therefore considered equal when measured against this criterion (see Table 6-2 for comparison). Mid-Plume Area Alternatives 3, 4, and 5 would require permission from the City of Wichita to install the underground system piping in the city street right-of-way. Mid-Plume Area Alternatives 4 and 5 would require compliance with NPDES discharge requirements. Mid-Plume Area Alternatives 3 and 5 would require injection well permits for the carbon source injection (Mid-Plume Area Alternative 3) and the treated effluent reinjection (Mid-Plume Area Alternative 5).

6.2.3 Reduction of Toxicity, Mobility, or Volume

For the active remediation alternatives (Mid-Plume Area Alternatives 3, 4, and 5), physical risks are reduced by physically or biologically removing the chemical impact. All of these alternatives reduce the chemical concentrations over time, and none of the active remediation alternatives leave residual risk following remediation, although the remediation times among the alternatives differ significantly. Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment would require a very long time to achieve cleanup goals.

Other long-term considerations include O&M. Mid-Plume Area Alternatives 3 - ERD and 5 - DGR have extensive O&M associated with their implementation. Mid-Plume Area Alternative 1 - No Further Action has no O&M component (beyond monitoring well maintenance), while Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment has a limited amount of O&M, although over a much longer time span. The preferred alternative to meet the objective of reduction of toxicity, mobility, or volume is Mid-Plume Area Alternative 5 - Directed Groundwater Recirculation because the plume will be reduced in volume more quickly than with Downgradient Hydraulic Control (MPA Alternative 4) and will not create a potential interior air hazard as may be created by ERD (MPA Alternative 3).

6.2.4 Short-Term Effectiveness

Mid-Plume Area Alternative 1 – No Further Action is not effective in the short term because the time frame for the remediation of impacted groundwater is open-ended. Short-term effectiveness in the MPA is greatest with those alternatives that provide wide coverage of treatment. Mid-Plume Area Alternatives 3 - ERD and 5 - DGR provide the greatest short-term effectiveness because these alternatives address impacted groundwater throughout the MPA. Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment involves pumping and treating of groundwater at the leading edge of downgradient impact only and offers the lowest short-term effectiveness of all of the alternatives.
Because Mid-Plume Area Alternatives 3 and 5 have overall shorter treatment times than Mid-Plume Area Alternative 4, they are preferred alternatives based on this criterion.

### 6.2.5 Long-Term Effectiveness and Permanence

Mid-Plume Area Alternative 1 - No Further Action does not provide a long-term effective or permanent remedy for groundwater at the Mid-Plume Area. Mid-Plume Area Alternatives 3 - ERD and 5 - DGR would provide a long-term reduction of COCs in groundwater to cleanup levels, although Mid-Plume Area Alternative 3 may not be effective in the northern portion of the MPA. Mid-Plume Area Alternative 5 would be expected to provide reduction of COCs at a faster rate and is therefore rated slightly higher than Mid-Plume Area Alternatives 3 - ERD and 4 - Downgradient Hydraulic Containment with respect to providing an effective long-term and permanent remedy for MPA groundwater.

Mid-Plume Area Alternative 4 had the potential to cause the leading edge of the NIC plume and the site plume to commingle. Mid-Plume Area Alternative 5 can be effective in separating the site plume from the dry cleaner plume to the east as well as providing an effective groundwater divide between the site plume and NIC plume.

Other long-term considerations include O&M. Mid-Plume Area Alternatives 3 and 5 have extensive O&M associated with their implementation. Mid-Plume Area Alternative 1 has no O&M component, while Mid-Plume Area Alternative 4 has a limited amount of O&M over a very long operational life. Mid-Plume Alternative 5 - Directed Groundwater Circulation is the preferred alternative for these criteria.

### 6.2.6 Implementability

Actions similar to those proposed in each detailed alternative have been implemented at other sites. However, the level of complexity of installation and O&M varies with the alternatives.

All alternatives are readily implementable. Mid-Plume Area Alternatives 3 - ERD and 5 - DGR would require a construction phase to complete system installation. The components of Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment have been installed, and the system is operational. The overall construction phase for Mid-Plume Area Alternative 5 is longest due to installation of several well transects, associated piping, and construction of treatment buildings and treatment equipment.

Permits would be required for all of the detailed alternatives. Underground injection permits would be needed for Mid-Plume Area Alternatives 3 and 5. A discharge permit and construction permits would be required for Mid-Plume Area Alternatives 4 and 5 for discharge of treated groundwater. Injection permits would be required for Mid-Plume Area Alternatives 3 and 5. All active remediation alternatives would also require drilling and well installation permits. Mid-Plume Area Alternative 4 - Hydraulic Control System is the most implementable alternative because it is currently installed.

### 6.2.7 Cost

The estimated total life-cycle costs for implementation of the four MPA alternatives evaluated are summarized in Table 6-2 and listed below in order of increasing cost.
6.2.8 Summary of Comparative Analysis – Mid-Plume Area

In the previous sections, a comparative analysis of the retained alternatives for the MPA addressed each alternative's ability to meet the seven evaluation criteria. The analysis demonstrated that three of the four MPA alternatives would satisfactorily meet the following criteria:

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

Mid-Plume Area Alternative 1 - No Further Action, would not meet the aforementioned evaluation criteria. The criteria that were not met equally by each of the detailed alternatives were short-term effectiveness, implementability, and cost. These criteria are used to determine the best overall alternative.

Considering all criteria, UP believes that the best alternative, based on data available at the time of this report, is Mid-Plume Area Alternative 5, consisting of construction and operation of a DGR system installed along transects at intervals across the groundwater plume and hydraulic containment at the leading edge of the plume.

The other alternatives are eliminated as follows:

- Mid-Plume Area Alternative 3 - ERD would require construction of significant infrastructure to effectively remediate a plume the size of the MPA. During each injection event, implementation of ERD would require an extended presence within residential and commercial areas, which would include tanks of reagent, vehicles, and maintenance personnel. The generation and potential accumulation of significant concentrations of methane vapors underneath large residential and commercial areas would require diligent monitoring and potentially vapor mitigation to minimize risks.

Based on the groundwater velocity through the MPA and the required injection frequency to sustain treatment, deployment of the ERD remedy would require considerable volumes of carbon substrate to promote and sustain treatment. ERD may also not be effective in the northern portion of the MPA. Additionally, the long-term ability to maintain operational ERD injection wells is difficult to project.
making forecasts of project costs difficult. While ERD applicability is being further evaluated to address SA COCs, this technology is less feasible for deployment through the MPA.

- **Mid-Plume Area Alternative 4 - Downgradient Hydraulic Containment,** prevents additional downgradient migration of the impacted groundwater, but would require longer remediation time to reach cleanup goals than DGR. In addition, the commingling of the Site and NIC plumes would complicate meeting site closure requirements. However, this system is currently installed and operational, and would be incorporated as a component of the final DGR remedy.

**Mid-Plume Area Alternative 5 - DGR,** offers the following benefits:

- The system is inherently flexible. Changes in pumping and injection rates and distribution can optimize system operation based on observed affects within the plume.
- Once in place, the system can be operated with minimal presence within the residential or commercial areas.
- Hydraulic containment through groundwater pumping is a demonstrated technology, and control should be established within a short period after pumping begins.
- DGR is the only alternative that can: 1) effectively separate the MPA from the 19th and Grove dry cleaner plume to the east, 2) maintain separation between the MPA and the NIC plume, and 3) promote treatment of COCs within the entire plume in an accelerated manner.
- Overall, the remedial components of Mid-Plume Area Alternative 5 are anticipated to work together to reach RAOs in an estimated period of 10 years.

UP proposes these remedial alternatives to address groundwater impacts at the MPA. However, one or more other sources of groundwater impact have been identified that occur at least partly within the extent of the 29th and Grove plume, most notably PCE-impacted groundwater evaluated by KDHE at the 19th and Grove Drycleaner Site. UP understands that mechanisms exist for cost-sharing with KDHE or responsible parties to the extent that UP has proposed remedial actions that can be used to address impacted groundwater originating from these other sources. As remedial alternatives are evaluated, UP desires to further explore and to ultimately implement cost-sharing options using the Kansas Dry Cleaning Facility Release Trust Fund.
7 SUMMARY AND RECOMMENDATIONS

The purpose of this FS was to evaluate potential remedial alternatives available to address impacted soil and groundwater at the SA and impacted groundwater at the MPA.

RAOs and Remediation Goals were presented in Section 2. Candidate remediation technologies for groundwater and soil were screened in Section 3. Remediation alternatives for the SA and the MPA were assembled and screened in Section 4. The alternative retained following screening were then further evaluated in detail in Section 5, and a comparative analysis of the retained alternatives was conducted in Section 6.

7.1 Recommended Remedial Alternatives

Based on the results of the detailed and comparative evaluation, the following remedial alternatives are recommended for implementation at the 29th and Grove Site in Wichita, Kansas:

- For the Source Area – Source Area Alternative 2 consisting of:
  - Rail Yard Area - hot spot excavation and targeted soil direct-push ERD treatment

UP has recognized that the primary driver in achieving site-wide RAOs is successful treatment of dissolved phase impacts migrating from the SA to the MPA. Consequently, UP has implemented an interim remediation for the SA groundwater.

The additional SA remedial activities, including the hot spot excavation and targeted soil ERD, can be implemented following KDHE approval of this FS.

- For the Mid-Plume Area - Mid-Plume Area Alternative 5, consisting of construction and operation of a DGR system installed along transects at intervals across the groundwater plume and hydraulic containment at the leading edge of the plume.
REFERENCES


FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas


FEASIBILITY STUDY - SOURCE AREA AND MID-PLUME AREA
29th and Grove Site, Wichita, Kansas


USEPA, 1989. CERCLA Compliance with Other Laws Manuals – Part II (Clean Air Act and Other Environmental Statutes) EPA 540/G-89/009, OSWER 9234.1-02. August.


TABLES
### Table 1-1. Physical and Chemical Properties of Trichloroethene

<table>
<thead>
<tr>
<th>Property</th>
<th>Value or Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular Weight</td>
<td>131.3889 g/mol</td>
</tr>
<tr>
<td>Appearance and Odor</td>
<td>Clear, colorless, watery liquid with a chloroform-like odor</td>
</tr>
<tr>
<td>Boiling Point</td>
<td>87.2°C</td>
</tr>
<tr>
<td>pH</td>
<td>6.7 - 7.5</td>
</tr>
<tr>
<td>Henry's Law Constant</td>
<td>0.0099 atm*m³/mol at 20°C</td>
</tr>
<tr>
<td>Ionization Potential</td>
<td>9.47 eV</td>
</tr>
<tr>
<td>Log K₁OC</td>
<td>1.81</td>
</tr>
<tr>
<td>Log Kₗow</td>
<td>2.53</td>
</tr>
<tr>
<td>Melting Point</td>
<td>-73°C</td>
</tr>
<tr>
<td>Solubility in Organics</td>
<td>Acetone, ethanol, chloroform, and ether</td>
</tr>
<tr>
<td>Solubility in Water</td>
<td>0.107g/100 g water</td>
</tr>
<tr>
<td>Solubility of Water in TCE</td>
<td>0.0225 g/100 g TCE</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>1.4642 at 20⁰C</td>
</tr>
<tr>
<td>Transformation Products</td>
<td>cis-1,2-dichloroethene, trans-1,2-dichloroethene, vinyl chloride</td>
</tr>
<tr>
<td>Vapor Density</td>
<td>5.37 g/L at 25°C</td>
</tr>
<tr>
<td>Vapor Pressure</td>
<td>7.6 kPa at 20°C</td>
</tr>
<tr>
<td>Flash Point</td>
<td>32.2°C</td>
</tr>
<tr>
<td>Lower Explosive Limit</td>
<td>8 percent at 25.5°C</td>
</tr>
<tr>
<td>Upper Explosive Limit</td>
<td>10.5 percent at 25.5°C</td>
</tr>
<tr>
<td>IDLH</td>
<td>1.000 ppm</td>
</tr>
<tr>
<td>PEL in Air</td>
<td>100 ppm, 200 ppm ceiling</td>
</tr>
<tr>
<td>Viscosity</td>
<td>0.58 cP at 20°C</td>
</tr>
<tr>
<td>Heat of Combustion</td>
<td>7.325 MJ/kg</td>
</tr>
<tr>
<td>Heat of Formation, Liquid</td>
<td>4.18 MJ/(kg*mol)</td>
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<tr>
<td>Heat of Formation, Vapor</td>
<td>-29.3 MJ/(kg*mol)</td>
</tr>
<tr>
<td>Latent Heat of Vaporization</td>
<td>57.4 cal/g</td>
</tr>
<tr>
<td>Critical Temperature</td>
<td>271°C</td>
</tr>
<tr>
<td>Critical Pressure</td>
<td>5.035 kPa</td>
</tr>
</tbody>
</table>

**Notes:**
- Values separated by a slash indicate that the first value is for a loose sample and the second is for a compacted sample.
- TCE = trichloroethene
- PEL = Permissible Exposure Limit
- °C = degrees Celsius
- eV = electronvolts
- kPa = kiloPascals
- MJ/(kg*mol) = Mega joules/(kilogram*mol)
- CP = centipoise
- IDLH = immediately dangerous to life or health
- g/mol = grams per mol
- atm*m³/mol = atmosphere*cubic meter/mol
- g = grams
- ppm = parts per million
- cal/g = calorie/gram

1 (adapted from Forrester 2006)
### Table 1-2 Groundwater Parameters and Aquifer Material Summary

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth (feet bgs)</td>
<td>5 - 7</td>
<td>15 - 17</td>
<td>19 - 24</td>
<td>47 - 52</td>
<td>10 - 12</td>
<td>25 - 30</td>
</tr>
<tr>
<td>Hydraulic Conductivity (cm/s)</td>
<td>$1.4 \times 10^{-7}$</td>
<td>$2.5 \times 10^{-7}$</td>
<td>$9.17 \times 10^{-7}$</td>
<td>$2.27 \times 10^{-7}$</td>
<td>$1.18 \times 10^{-3}$</td>
<td>$1.06 \times 10^{-3}$</td>
</tr>
<tr>
<td>Bulk Density (lbs/ft$^3$)</td>
<td>111.7</td>
<td>101.5</td>
<td>93/104.7</td>
<td>90.5/102</td>
<td>94.4/109.4</td>
<td>90/100</td>
</tr>
<tr>
<td>Total Porosity</td>
<td>0.392</td>
<td>0.414</td>
<td>0.223</td>
<td>0.239</td>
<td>0.197</td>
<td>0.251</td>
</tr>
<tr>
<td>Total Organic Carbon (%)</td>
<td>2.8</td>
<td>2.2</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>20</td>
<td>26.2</td>
<td>29.8/</td>
<td>31.6/</td>
<td>28.3/</td>
<td>32/</td>
</tr>
<tr>
<td>Grain Size Distribution (Percent Retained on Individual Sieve)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#4 (3/16&quot;)</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>#8 (0.0931&quot;)</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>11</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>#16 (0.0469&quot;)</td>
<td>15</td>
<td>25</td>
<td>25</td>
<td>3</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>#30 (0.0232&quot;)</td>
<td>1</td>
<td>4</td>
<td>23</td>
<td>26</td>
<td>4</td>
<td>17</td>
</tr>
<tr>
<td>#50 (0.0117&quot;)</td>
<td>3</td>
<td>8</td>
<td>31</td>
<td>20</td>
<td>8</td>
<td>28</td>
</tr>
<tr>
<td>#100 (0.0059&quot;)</td>
<td>4</td>
<td>11</td>
<td>9</td>
<td>8</td>
<td>30</td>
<td>10</td>
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<tr>
<td>#200 (0.0029&quot;)</td>
<td>4</td>
<td>12.5</td>
<td>1</td>
<td>0.9</td>
<td>22.7</td>
<td>3.7</td>
</tr>
</tbody>
</table>

Notes:
- Two values separated by a slash indicate that the first value is for a loose sample and the second is for a compacted sample.
- bgs = below ground surface
- lbs/ft$^3$ = pounds per cubic foot
- cm/s = centimeters per second

(1) (adapted from Forrester 2006)
### Table 2-1. ARAR Waivers

<table>
<thead>
<tr>
<th>Waiver</th>
<th>Description</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interim Measures</td>
<td>The selected remedial action will be only part of a total remedial action that will attain such level or standard of control when completed.</td>
<td>CERCLA §121(d)(4)(A)</td>
</tr>
<tr>
<td>Greater Risk to Health and the Environment</td>
<td>Compliance with such requirement at the facility will result in greater risk to human health and the environment than alternative options.</td>
<td>CERCLA §121(d)(4)(B)</td>
</tr>
<tr>
<td>Technical Impracticability</td>
<td>Compliance with such requirement is technically impracticable from an engineering perspective.</td>
<td>CERCLA §121(d)(4)(C)</td>
</tr>
<tr>
<td>Equivalent Standard of Performance</td>
<td>The selected remedial action will attain a standard of performance that is equivalent to that required under the otherwise applicable standard, requirement, criteria, or limitation through use of another method or approach.</td>
<td>CERCLA §121(d)(4)(D)</td>
</tr>
<tr>
<td>Inconsistent Application of State Requirements</td>
<td>With respect to a state standard, requirement, criteria, or limitation, the state has not consistently applied (or demonstrated the intention to consistently apply) the standard, requirement, criteria, or limitation in similar circumstances at other remedial actions.</td>
<td>CERCLA §121(d)(4)(E)</td>
</tr>
<tr>
<td>Fund Balancing</td>
<td>The Fund-balancing waiver may apply when the costs needed to meet an ARAR for an action would be so high as to threaten the availability of Fund monies for remedies at other sites. The waiver applies only to Fund-financed remedial actions under CERCLA Section 104. Even when the waiver is invoked, the alternative remedy selected must still be protective of human health and the environment and meet all other standards.</td>
<td>CERCLA §121(d)(4)(F)</td>
</tr>
</tbody>
</table>

**Notes:**

ARAR = Applicable or Relevant and Appropriate Requirement  
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
Table 2-2. Summary of Federal ARARs and TBCs

<table>
<thead>
<tr>
<th>Statue and Regulatory Citation</th>
<th>ARAR Determination</th>
<th>Description</th>
<th>Comment</th>
<th>Type of ARAR or TBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Archaeological and Historic Preservation Act of 1974 = 16 U.S.C. §489 et seq</td>
<td>Potentially Applicable</td>
<td>Provides for the preservation of historical or archaeological data which might be destroyed or lost as the result of 1) flooding, building of access roads, relocation of railroads and highways, and other alternations of terrain caused by the construction of a dam by government or persons, or 2) alteration of terrain caused by Federal construction projects or federally licensed activity or program.</td>
<td>Will be applicable if construction projects or alteration of terrain at a site have the potential to destroy or modify historic or archaeological materials.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>National Historic Preservation Act of 1966 = 16 U.S.C. §470 et seq</td>
<td>Relevant and Appropriate</td>
<td>Establishes a National Register of Historic Places. Provides for preservation of historic or prehistoric resources.</td>
<td>Will be applicable if a site is listed on historic registry and if activities permitting are initiated at a site.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 = 42 U.S.C. §9601 et seq as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986</td>
<td>Applicable</td>
<td>Enacted to provide Federal authority to respond directly to releases or threatened releases of hazardous substances that may endanger public health and the environment. Established a trust fund (i.e., Superfund) to provide for cleanup when no responsible party is identified. Provides for liability of persons responsible for releases of hazardous substances. Established prohibitions and requirements concerning closed and abandoned hazardous waste sites.</td>
<td>Will be applicable if the site is on the EPA National Priorities List (NPL). May be applicable for any site where a release of hazardous substances has occurred.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>CERCLA – National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 CFR 300)</td>
<td>Relevant and Appropriate</td>
<td>Federal government’s blueprint for responding to spills or releases of oil and hazardous substances.</td>
<td>May be applicable for any site where a release of hazardous substances has occurred.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>CERCLA – 40 CFR 300.440</td>
<td>Applicable</td>
<td>Establishes procedures for planning and implementing offsite response actions.</td>
<td>Formally referred to as the “offsite rule” wherein required to determination compliance status of the disposal facility.</td>
<td>Chemical Location Action</td>
</tr>
</tbody>
</table>
Table 2-2. Summary of Federal ARARs and TBCs

<table>
<thead>
<tr>
<th>Statue and Regulatory Citation</th>
<th>ARAR Determination</th>
<th>Description</th>
<th>Comment</th>
<th>Type of ARAR or TBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Planning and Community Right-to-Know Act (EPCRA) of 12986 – 42 U.S.C. §11001 et seq.</td>
<td>Applicable</td>
<td>Designated to help local communities protect public health, safety, and the environment from chemical hazards. Enables states and communities to prepare to respond to unplanned releases of hazardous substances. Requires facilities at which hazardous substances are present to report the presence of these materials to emergency responders. Requires companies to report the release of hazardous substances.</td>
<td>Will be applicable if hazardous chemicals are stored or used at a facility.</td>
<td>X X X</td>
</tr>
<tr>
<td>Endangered Species Act 16 U.S.C. §1531-1543</td>
<td>Applicable</td>
<td>Requires that federal agencies insure that any action by the agency is not likely to jeopardize endangered species or adversely modify their habitats.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Endangered Species Act of 1973–7 U.S.C. §136; 16 U.S.C. §§460 et. seq.</td>
<td>Relevant and Appropriate</td>
<td>Provides a program for consideration of threatened and endangered plants and animals and their habitats in which they are found.</td>
<td>Will be applicable if threatened or endangered species or their habitats are present at or near a site.</td>
<td>X</td>
</tr>
<tr>
<td>Explosives – 18 U.S.C. §847</td>
<td>Relevant and Appropriate</td>
<td>Regulates commerce in explosives. Requires licensing and permitting, record keeping, and reporting for purchase and use of explosives. Provides standards for storage of explosive materials.</td>
<td>Will be applicable if explosives are purchased, stored, or used at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Federal Hazardous Materials Transportation Law – 49 U.S.C. §5101 et seq.</td>
<td>Relevant and Appropriate</td>
<td>Regulates the transportation of hazardous wastes and hazardous substances by aircraft, railcars, vessels, and motor vehicles. Requires employers to train, test, and maintain training records for all hazmat employees.</td>
<td>Will be applicable if hazardous materials are transported to or from a site.</td>
<td>X</td>
</tr>
<tr>
<td>Clean Air Act (CAA) – 42 U.S.C. §7401 et seq. as amended in 1977 and 1990</td>
<td>Applicable</td>
<td>Regulates air emissions from area, stationary, and mobile sources. Authorizes EPA to establish National Ambient Air Quality Standards.</td>
<td>May be applicable if remedial actions result in emissions of contaminants to the air at volumes above air permitting requirements.</td>
<td>X X</td>
</tr>
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### Table 2-2. Summary of Federal ARARs and TBCs

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<tr>
<td>CAA – Standards of Performance for new Stationary Sources (40 CFR 60)</td>
<td>Applicable</td>
<td>Identifies standards of performance for new stationary sources of air emissions. Provides emission guidelines and compliance times.</td>
<td>Will be applicable for new stationary sources of air emissions.</td>
<td>Chemical X</td>
</tr>
<tr>
<td>CAA – National Emission Standards for Hazardous Air pollutants (40 CFR 61)</td>
<td>Applicable</td>
<td>Identifies standards of performance for new stationary sources of air emissions. Provides emission guidelines and compliance times.</td>
<td>Will be applicable if the identified hazardous air pollutants are emitted from a site in substantial quantities.</td>
<td>Chemical X</td>
</tr>
<tr>
<td>CAA – National Emission Standards for Hazardous Air pollutants for Source Categories including Site Remediation (40 CFR 83)</td>
<td>Applicable</td>
<td>Identifies emission standards for hazardous air pollutants that originate from specific categories of sources including site remediation.</td>
<td>Will be applicable if the identified hazardous air pollutants are emitted from a specific source category that has been identified.</td>
<td>Chemical X</td>
</tr>
<tr>
<td>Flood Control Act of 1944 – 16 U.S.C. §450</td>
<td>Relevant and Appropriate</td>
<td>Provides the public with knowledge of flood hazards and promotes prudent use and management of flood plains.</td>
<td>Will be applicable if a site is located on a designated flood plain.</td>
<td>Chemical</td>
</tr>
<tr>
<td>Executive Order on Floodplain Management EO 11988</td>
<td>Applicable</td>
<td>Requires evaluation of potential effects of action on floodplain.</td>
<td>Only applicable for remedies in floodplain.</td>
<td>Chemical</td>
</tr>
<tr>
<td>Clean Water Act (CWA) of 1977 – 40 CFR part 421</td>
<td>Applicable</td>
<td>Limits discharge to POTWs</td>
<td>Applicable if treated water is disposed of a POTW</td>
<td>Chemical XX</td>
</tr>
<tr>
<td>CWA – 33 U.S.C. §1251 et. Seq. as amended in 1987</td>
<td>Applicable</td>
<td>Implements a system to impose effluent limitations on, or otherwise prevent, discharges of pollutants into any waters of the United States from any point source</td>
<td>Will be applicable if discharges to streams, rivers, or lakes occur from a site.</td>
<td>Chemical X</td>
</tr>
<tr>
<td>CWA – National Pollutant Discharge elimination system (NPDES) (40 CFR 122)</td>
<td>Applicable</td>
<td>Regulates discharges of pollutants from any point source into waters of the United States</td>
<td>Will be applicable if water from the site will be discharged into land or into streams, rivers, or lakes.</td>
<td>Chemical</td>
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Table 2-2. Summary of Federal ARARs and TBCs

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<tr>
<td>CWA – Storm Water Discharge Requirements NPDES (40 CFR 122.26)</td>
<td>Potentially Applicable</td>
<td>Provided requirements to obtain a permit to discharge to the stormwater sewer system under the NPDES program</td>
<td>Will be applicable if the site has stormwater that comes in contact with construction or industrial activity or if the selected remedy involves discharge of treated water to surface waters.</td>
<td>Chemical</td>
</tr>
<tr>
<td>CWA – Federal Water Quality Standards (40 CFR 131)</td>
<td>Potentially Applicable</td>
<td>Establishes methods and requirements for states in the development of ambient water quality criteria for the protection of aquatic organisms and/or the protection of human health.</td>
<td>May be indirectly applicable to surface water remediation and is directly applicable to surface water discharges.</td>
<td></td>
</tr>
<tr>
<td>CWA – General Pre-treatment Regulations for Existing and New Sources of Pollution for Publicly Owned treatment Works (40 CFR 403)</td>
<td>Potentially Applicable</td>
<td>Provides effluent limitations and guidelines for existing sources, standards of performance for new sources, and pre-treatment standards for new and existing sources.</td>
<td>Will be applicable if wastewater from a site is discharged to POTW.</td>
<td></td>
</tr>
<tr>
<td>CWA – Wetlands Protection (40 CFR 22, 40 CFR 230 to 233, and 33 CFR 320 to 330)</td>
<td>Relevant and Appropriate</td>
<td>Allows for permitting of discharge of dredged or fill material to the waters of the United States if no practicable alternative exists that are less damaging to the aquatic environment. Applicants must demonstrate that the impact to wetlands is minimized.</td>
<td>Will be applicable if designated wetlands are impacted by a remedy.</td>
<td></td>
</tr>
<tr>
<td>CWA – Federal Surface Water Quality Requirements – 33 U.S.C. §1251, et seq. as amended in 1987.</td>
<td>Applicable</td>
<td>Implements a system to impose effluent limitations on, or otherwise prevent, discharges of pollutants into any waters of the United States from any point source. As provided under section 303 of the Clean Water Act, 33 U.S.C. §1313.</td>
<td>Will be applicable if treated groundwater is discharged to the Chisholm Creek or the Little Arkansas River.</td>
<td></td>
</tr>
<tr>
<td>Executive Order on the Protection of Wetlands EG 1199040 CFR § 6.302(a)</td>
<td>Applicable</td>
<td>Requires avoidance of destruction or loss of wetlands and construction in wetlands.</td>
<td></td>
<td></td>
</tr>
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<tr>
<td>Safe Drinking Water Act (SDWA) of 1974 – 42 U.S.C §300f et seq. as amended in 1986</td>
<td>Relevant and Appropriate</td>
<td>Established to protect the quality of drinking water in the United States. Focuses on all waters actually of potentially designed for drinking use, whether from above ground or underground sources. The Act authorized the EPA to establish safe standards of purity and required all owners or operators of public water supply systems to comply with primary (health related) standards.</td>
<td>May be applicable, relevant or appropriate at sites where waters that are used or may potentially be used as drinking water supplies are impacted or threatened.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>SDWA – National Primary Drinking Water Regulations and Implementation (40 CFR 141 and 142)</td>
<td>Applicable</td>
<td>Establishes maximum contaminant levels (MCLs) which are health risk-based standards for public water systems</td>
<td>Will be applicable at the distribution point (i.e., at the tap). Will be relevant and appropriate for groundwater cleanup at sites where potential drinking water sources (aquifers) are impacted.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>SDWA – National Secondary Drinking Water Standards (40 CFR 143)</td>
<td>Applicable</td>
<td>Establishes welfare-based secondary standards for public water systems</td>
<td>Will be applicable at the distribution point (i.e., at the tap)</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>SDWA – Underground Injection Control Program (40 CFR 144 to 148)</td>
<td>Applicable</td>
<td>Assures that Underground Injection will not endanger drinking water sources. Provides regulations governing the use of underground injection wells including; identification of the classifications of injection wells; and the permitting, construction, operation, monitoring, testing, and reporting requirements. Also provides requirements for plugging of injection wells.</td>
<td>Will be applicable if underground injection of liquids or air is conducted as part of a site remedy.</td>
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<tr>
<td>Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1972 – 7 U.S.C. §136 et seq.</td>
<td>Relevant and Appropriate</td>
<td>Provides Federal control of pesticide distribution, sale, and use. Allows the EPA to study the consequences of pesticide use. Requires users of pesticides to take exams for certification as applicators of pesticides. Pesticide users must register purchases of these materials.</td>
<td>May be applicable if pesticides were distributed, sold, or used at a site.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Fish and Wildlife Conservation Act – 16 U.S.C. §2901 to 2911</td>
<td>Relevant and Appropriate</td>
<td>Action to conserve fish and wildlife, particularly those species that are indigenous to the state.</td>
<td>Will be applicable if significant populations are present at a site or they are affected by site activities.</td>
<td>X</td>
</tr>
<tr>
<td>Fish and Wildlife Coordination Act – 16 U.S.C. §661-667e</td>
<td>Relevant and Appropriate</td>
<td>The Act allows the Departments of Agriculture and Commerce to assist Federal and State agencies to study the effects of domestic sewage, trade wastes, and other polluting substances on wildlife.</td>
<td>Will be applicable if significant populations are present at a site or they are affected by site activities.</td>
<td>X</td>
</tr>
<tr>
<td>Occupational Safety and Health Act (OSHA) of 1970 – 29 U.S.C. §651 et seq.</td>
<td>Applicable</td>
<td>Enacted to ensure worker and workplace safety. Employers are required to provide workers a place of employment that is free from recognized hazards to safety and health.</td>
<td>Applies to workers and workplaces.</td>
<td>X</td>
</tr>
<tr>
<td>OSHA – Occupational Safety and Health Standards (29 CFR 1910)</td>
<td>Applicable</td>
<td>Provides standards for workers and the workplace including: working surfaces; means of egress; ventilation; noise; hazardous materials; personal protective equipment; sanitation; medical services and first aid; fire protection, detection, and suppression; materials handling and storage; machinery and machinery guards; power tools; and welding and electrical equipment. Also requires training for workers.</td>
<td>Will be applicable to workers and workplace including hazardous waste sites.</td>
<td>X</td>
</tr>
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<tbody>
<tr>
<td>OSHA - Safety and Health Regulations for Construction (29 CFR 1926)</td>
<td>Potentially Applicable</td>
<td>Provides standards for construction activities including: work practices; safety equipment; scaffolding and ladders; fall protection; heavy equipment; excavations; concrete and masonry construction; steel erection; tunnels and shafts; demolition; use of explosives; power transmission and distribution; and overhead protection.</td>
<td>Will be applicable to workers and workplaces where construction activities take place.</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Resource Conservation and Recovery Act (RCRA) of 1976 - 42 U.S.C. §6901 et seq. as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA) and 1986, the Federal Facilities Compliance Act of 1992, and the Land Disposal Program Flexibility Act of 1996.</td>
<td>Applicable</td>
<td>Enacted to provide control of hazardous waste by imposing management requirements on generators and transporters of hazardous waste and upon owners and operators of treatment, storage, and disposal (TSD) facilities. Also set forth a framework for management of nonhazardous waste. Focuses only on active or future facilities. HSWA requires phasing out land disposal of hazardous waste.</td>
<td>Applies to active hazardous and solid wastes facilities including facilities that treat, store, and dispose of these materials as well as generators and transporters of hazardous wastes.</td>
<td>x x x</td>
</tr>
<tr>
<td>RCRA - Solid Waste Disposal Facility Criteria (40 CFR 257 - 259)</td>
<td>Relevant and Appropriate</td>
<td>Regulations apply to owners and operators of facilities that treat, store, or dispose of solid wastes.</td>
<td>Will be applicable if site activities are analogous to solid waste facility activities.</td>
<td>x x</td>
</tr>
<tr>
<td>RCRA - Standards for Identification and Listing of Hazardous Waste (40 CFR 261)</td>
<td>Relevant and Appropriate</td>
<td>Provides criteria for identification of hazardous and solid wastes.</td>
<td>Will be applicable for identifying hazardous wastes.</td>
<td>x x</td>
</tr>
<tr>
<td>RCRA - Standards Applicable to Generators of Hazardous Waste (40 CFR 262)</td>
<td>Relevant and Appropriate</td>
<td>Regulates the manifesting, pre-transport requirements, and record keeping and reporting for hazardous waste generators.</td>
<td>Will be applicable if hazardous waste is generated at a site.</td>
<td>x x</td>
</tr>
<tr>
<td>RCRA - Standards Applicable to Transporters of Hazardous Waste (40 CFR 263)</td>
<td>Relevant and Appropriate</td>
<td>Establishes standards that apply to persons transporting hazardous waste within the United States if the transportation requires a manifest under RCRA.</td>
<td>Will be applicable if hazardous waste is disposed offsite.</td>
<td>x x</td>
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<tr>
<td>RCRA - Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (40 CFR 264)</td>
<td>Relevant and Appropriate</td>
<td>Regulations apply to owners and operators of facilities that treat, store, or dispose of hazardous waste through the use of surface impoundments, waste piles, incinerators, land treatment units, and landfills</td>
<td>Will be applicable if site activities are analogous to hazardous waste facility activities</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCRA - Manifesting, Record Keeping, and Reporting Requirements (40 CFR 264.70 to 264.77)</td>
<td>Relevant and Appropriate</td>
<td>These standards apply to owners and operators of all facilities which treat, store, or dispose of hazardous wastes</td>
<td>Will be applicable if site activities are analogous to hazardous waste facility activities</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCRA - Releases from Solid Waste Management Units (40 CFR 264 90 to 264.101)</td>
<td>Relevant and Appropriate</td>
<td>Regulations apply to owners or operators of hazardous waste treatment, storage, or disposal facilities</td>
<td>Will be applicable if solid waste is stored at a site</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCRA - Closure and Post-Closure Requirements (40 CFR 264.110 to 264.120)</td>
<td>Relevant and Appropriate</td>
<td>Facility owner or operator must close a hazardous waste facility in a way that minimizes the need for further maintenance and maximizes the protection of human health and the environment</td>
<td>Will be applicable upon the closure and post-closure of a hazardous waste facility</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCRA - Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities (40 CFR 255)</td>
<td>Applicable</td>
<td>Regulations apply to owners and operators of facilities that treat, store, or dispose of hazardous waste</td>
<td>Will be applicable if site activities are analogous to hazardous waste facility activities</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RCRA - Land Disposal Restrictions (40 CFR 263)</td>
<td>Applicable</td>
<td>Identifies hazardous wastes that are restricted from land disposal and defines those limited circumstances under which an otherwise prohibited waste may continue to be land disposed</td>
<td>Will be applicable depending on the type of waste generated at the site</td>
<td>X</td>
<td>X</td>
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<tr>
<td>RCRA - Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (40 CFR 280)</td>
<td>Relevant and Appropriate</td>
<td>Establishes regulations relating to underground storage tanks (UST) including: performance standards; spill control; corrosion protection; record keeping and reporting; release detection; environmental investigations of releases; corrective actions; and closure of UST systems.</td>
<td>Will be applicable if underground storage tanks are or were present at a site and if a petroleum release is present. Also provides for environmental assessment at closure of UST systems.</td>
<td>X</td>
</tr>
<tr>
<td>Resource Conservation and Recovery Act and Regulations</td>
<td>Applicable</td>
<td>Requirements for construction in floodplain and distance from faults are given.</td>
<td>May be applicable for any portion of the site that is a designated floodplain.</td>
<td>X</td>
</tr>
<tr>
<td>Toxic substances Control Act (TSCA) of 1976 15 U.S.C. § 2601 et seq.</td>
<td>Relevant and Appropriate</td>
<td>Enacted to give the EPA the ability to track industrial chemicals currently produced or imported into the United States. The EPA screens these chemicals and may require reporting or testing of those that pose an environmental or human-health hazard. The EPA may ban the manufacture and import of those chemicals that pose an unreasonable risk.</td>
<td>Will be applicable if site activities involve handling of toxic substances such as polychlorinated biphenyls (PCBs) or remediation of these substances.</td>
<td>X</td>
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<tr>
<td>Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, EPA540-G-89-004, October 1988</td>
<td>TBC</td>
<td>Provides the methodology that the Superfund program uses to characterize the nature and extent of risk posed by uncontrolled hazardous wastes sites and for evaluating potential remedial alternatives.</td>
<td></td>
<td>Chemical</td>
</tr>
<tr>
<td>Guidance for Quality Assurance Project Plans, EPA240-R-02-009, December 2002</td>
<td>TBC</td>
<td>Describes the Quality Assurance Project Plan as four basic element groups covering project management, data generation and acquisition, assessment and oversight, and data validation and usability.</td>
<td></td>
<td>Location</td>
</tr>
<tr>
<td>Guidance for the Data Quality Objectives Process, EPA600-R-96-055, August 2000</td>
<td>TBC</td>
<td>Provides a systematic planning process to develop acceptance or performance criteria for collection, evaluation, or use of environmental data.</td>
<td></td>
<td>Action</td>
</tr>
<tr>
<td>Development and Evaluation of Consensus Based Sediment Quality Guidelines for Freshwater Ecosystems, 2000, MacDonald, D.D., C.G., Ingersoll, and T.A. Berger, Archives of Environmental Contamination and Toxicology 39:20-31</td>
<td>Not TBC</td>
<td>Identifies Threshold Effect Concentration (TEC) to be used to assess impacts to sediment.</td>
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<tr>
<td>Management of Remediation Waste under RCRA, EPA530-F-98-026, October 1998.</td>
<td>TBC</td>
<td>Describes management of contaminated environmental media, etc.</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Best Management Practices (BMPs) for Soils Treatment Technologies, EPA530-R-97-007, May 1997</td>
<td>TBC</td>
<td>Describes various BMPs to be implemented during remedy implementation</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, EPA OSWER Directive 9200.4-17P, April 21, 1999</td>
<td>TBC</td>
<td>Describes EPA's policy regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites administered by the EPA's Office of Solid Waste and Emergency Response.</td>
<td></td>
<td>X</td>
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<tr>
<td>National Risk Management Research Laboratory (NRMRL), Ada, Oklahoma, Publication EPA/600/R-04/027, 92p</td>
<td>TBC</td>
<td>Describes EPA's policy regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites administered by the EPA's Office of Solid Waste and Emergency Response.</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air. OSWER Publication 9200-Z-154. June 2015</td>
<td>TBC</td>
<td>Presents EPA's current technical recommendations for assessing whether a subsurface vapor intrusion pathway is complete and provides technical recommendations about monitoring and implementing building mitigation systems.</td>
<td>X</td>
<td></td>
</tr>
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</table>
### Table 2-2. Summary of Federal ARARs and TBCs

**Notes:**
- TBC = To Be Considered
- POTW = Publicly Owned Treatment Works
- ARAR = Applicable or Relevant and Appropriate Requirement
- CFR = Code of Federal Regulations
- EPA = U.S. Environmental Protection Agency
- EO = Executive Order
- TRC =
- OSWER = Office of Solid Waste and Emergency Response
- MNA = monitored natural attenuation
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<tr>
<td>Kansas Historic Preservation Act – K.A.R. 118-3-1 to 118-3-6.</td>
<td>Potentially Applicable</td>
<td>Provides for the protection and preservation of sites and buildings listed on state or federal historic registries.</td>
<td>Will be applicable if a site or building is listed on the state or federal historic registry and if activities requiring permitting are initiated at a site.</td>
<td>X X</td>
</tr>
<tr>
<td>Ambient Air Quality Standards and Air Pollution Control – K.A.R. 28-19-1 to 28-19-801.</td>
<td>Potentially Applicable</td>
<td>Regulates air emissions from processing operations, indirect heating equipment, and incinerators. Establishes requirements for Attainment and Non-Attainment Areas. Establishes requirements for stack heights. Resticts open burning.</td>
<td>Will be applicable if a remedy results in the release of contaminants to the air. Establishes emissions criteria.</td>
<td>X X</td>
</tr>
<tr>
<td>Kansas Drinking Water Rules – K.A.R Title 28 Article 15.</td>
<td>Potentially Applicable</td>
<td>Establishes health-based standards for public water systems.</td>
<td>No levels have been set for VOCs.</td>
<td>X</td>
</tr>
<tr>
<td>Water Pollution Control – K.A.R. 28-16-1 to 28-16-154.</td>
<td>Potentially Applicable</td>
<td>Provides regulation of sewage discharge. Establishes pre-treatment standards for industry. Designates uses of rivers and streams. Establishes River basin Quality Criteria and Surface Water Quality Criteria. Provides for the establishment of Critical Water Quality Management Areas.</td>
<td>Will be applicable if water is to be discharged to state waterways.</td>
<td>X X</td>
</tr>
<tr>
<td>Kansas Drycleaner Environmental Response Act – K.A.R. 28-68-1 to 28-68-9.</td>
<td>Applicable</td>
<td>Enacted to provide funds to assist with assessment and corrective action of former and existing drycleaner facilities. Requires registration of drycleaning facilities and compliance with waste management measures.</td>
<td>May be applicable if a drycleaner operated onsite.</td>
<td>X</td>
</tr>
</tbody>
</table>
### Table 2-3. Summary of State ARARs and TBCs

<table>
<thead>
<tr>
<th>Statue and Regulatory Citation</th>
<th>ARAR Determination</th>
<th>Description</th>
<th>Comment</th>
<th>Type of ARAR or TBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Game, Threatened, or Endangered Species – K.A.R. 115-15-1 to 115-15-4.</td>
<td>Potentially Applicable</td>
<td>Identifies Threatened and Endangered Species.</td>
<td>Will be applicable if any of the identified species are present at a site.</td>
<td>Chemical</td>
</tr>
<tr>
<td>Environmental Use Controls – K.S.A. 65-1,221 to 65-1,235.</td>
<td>Applicable</td>
<td>An environmental use control &quot;means an institutional control or administrative control, a restriction, prohibition, or control of one or more uses of, or activities on, a specific property, as requested by the property owner at the time of issuance, to ensure future protection of public health and the environment when environmental contamination which exceeds department standards for unrestricted use remains on the property following the appropriate assessment and/or remedial activities as directed by the department pursuant to the secretary's authority.&quot;</td>
<td>These restrictions are strictly voluntary as the landowner applies for the restriction to their property to mitigate the risk posed to human health and the environment from contamination at their property (in lieu of active remediation).</td>
<td></td>
</tr>
<tr>
<td>Kansas Antidegradation Policy – State of Kansas – August 6, 2001.</td>
<td>Applicable</td>
<td>&quot;EPA's water quality standards regulations require states to adopt and implement an antidegradation policy containing the minimum requirements for such a policy. The antidegradation policy is a component of the Surface Water Quality Standards in the State's overall water quality program. [see K.A.R. 28-16-28(a)]. The intent of the antidegradation policy is to limit discharges and other activities that will negatively impact water quality, impair designated uses, or threaten to impair designated uses of surface waters. The antidegradation policy provides a baseline level of protection relative to established water quality criteria to all classified surface waters, and a higher level of protection to those waterbodies recognized as unique ecologically, highly valued for its resources, or having high water quality.&quot;</td>
<td>Will be applicable where groundwater discharges to surface water bodies with designated uses.</td>
<td></td>
</tr>
</tbody>
</table>

Feasibility Study
29th and Grove Site
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### Table 2-3. Summary of State ARARs and TBCs

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Explosive Materials – KAR. 22-4-1 to 22-4-4.</td>
<td>Potentially Relevant and Appropriate</td>
<td>Requires all contractors to obtain explosive storage site permits before moving, storing, or using any explosives or blasting agents at any job site within the state.</td>
<td>Will be applicable if explosives or blasting agents are used or stored at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Asbestos Control – KAR. 28-50-1 to 28-50-14</td>
<td>Potentially Relevant and Appropriate</td>
<td>Established the requirements for licensing of businesses and examination and certification of asbestos workers. Established requirement for notification of asbestos projects. Establishes work practices for asbestos projects. Establishes rules for disposal of asbestos containing materials.</td>
<td>Will be applicable if asbestos is handled or removed from a site or encapsulated.</td>
<td>X</td>
</tr>
<tr>
<td>Hazardous Waste Management Standards and Regulations – KAR. 28-31-1 to 28-31-16.</td>
<td>Applicable</td>
<td>Identifies the characteristics and listing of hazardous waste. Prohibits underground burial of hazardous waste except as granted by the EPA or KDHE. Establishes restrictions on land disposal. Establishes standards for generators of transporters of hazardous waste. Establishes standards for hazardous waste storage, treatment, and disposal facilities.</td>
<td>Will be applicable if hazardous wastes are present, generated, disposed, and/or transported at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Mined Land Reclamation – KAR. 47-16-1 to 47-16-11.</td>
<td>Not Relevant and Appropriate</td>
<td>Allows for the reclamation of mined land and associated waters.</td>
<td>Will be applicable if mined land or associated waters are to be reclaimed.</td>
<td>X</td>
</tr>
<tr>
<td>Kansas Board of Technical Professions – KAR. 66-6-1 through 66-14-12</td>
<td>Applicable</td>
<td>Establishes the requirements for licensing of engineers, land surveyors, geologists, and architects.</td>
<td>Will be applicable if the services of a geologist, engineer, or land surveyor are required for site investigations or remediation.</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 2-3.  Summary of State ARARs and TBCs

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<tbody>
<tr>
<td>Water Well Contractor’s License: Water Well Construction and Abandonment – K.A.R. 28-30-1 to 28-30-10</td>
<td>Applicable</td>
<td>Establishes the requirements for licensing of drillers. Regulates drilling activities including the construction of wells.</td>
<td>Will be applicable if drilling and/or well construction or abandonment is conducted at a site.</td>
<td>X</td>
</tr>
<tr>
<td>PCB Facility Construction Permit Standards and Regulations – K.A.R. 28-55-1 to 28-55-5</td>
<td>Potentially Relevant and Appropriate</td>
<td>Establishes the requirement for permitting of facilities constructed for the treatment, storage, or disposal of materials containing PCBs. Establishes standards for PCB facilities.</td>
<td>Will be applicable if treatment, storage or disposal of materials containing PCBs occurs.</td>
<td>X</td>
</tr>
<tr>
<td>Agricultural Chemicals, Commercial Fertilizers, Anhydrous Ammonia, and Chemigation – K.A.R. 4-1-1 to 4-1-17, K.A.R. 4-4-1 to 4-4-984, K.A.R. 4-10-1 to 4-10-17, and K.A.R. 4-20-1 to 4-20-15.</td>
<td>Relevant and Appropriate</td>
<td>Requires labeling and registration of agricultural chemicals. Provides regulations for storage and secondary containment, transportation and recordkeeping for commercial fertilizers and anhydrous ammonia. Requires permitting and certification of operators of chemigation equipment.</td>
<td>Will be applicable if treatment storage or disposal of materials containing PCBs occurs.</td>
<td>X</td>
</tr>
<tr>
<td>Pesticides – K.A.R. 4-13-1 to 4-13-65.</td>
<td>Relevant and Appropriate</td>
<td>Requires licensing of pesticide businesses and certification of persons that apply pesticides.</td>
<td>Will be applicable if pesticides are present at a site or application of pesticides occurs.</td>
<td>X</td>
</tr>
<tr>
<td>Hydrocarbon Storage Wells and Well Systems – K.A.R. 28-45-1 to 28-45-11</td>
<td>Not Relevant and Appropriate</td>
<td>Establishes a system for permitting of hydrocarbon storage wells. Establishes requirements for construction, operation and monitoring, and plugging of hydrocarbon storage wells.</td>
<td>Will be applicable if hydrocarbon storage wells are present at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Petroleum Products Storage Tanks – K.A.R. 28-44-1 to 28-44-29.</td>
<td>Potentially Relevant and Appropriate</td>
<td>Provides requirements for permitting of the installation and operation of underground storage tanks (USTs). Provides requirements for design and construction of storage tanks. Provides a system for licensing contractors who install and test USTs. Requires implementation of methods for detecting releases and reporting releases from USTs.</td>
<td>Will be applicable if petroleum storage tanks are or were present at a site.</td>
<td>X</td>
</tr>
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Table 2-3. Summary of State ARARs and TBCs

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<tr>
<td>Radiation – K.A.R. 28-35-1 to 28-35-363</td>
<td>Potentially Relevant and Appropriate</td>
<td>Regulations require registration of radiation producing devices and licensing of sources of radiation. Provides standards for protection against radiation. Provides requirements for industrial radiographic operations and wireline and subsurface tracer studies.</td>
<td>Will be applicable if radiation producing devices or sources of radiation are present at or are used at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Emergency Planning and Right-to-Know – K.A.R. 28-65-1 to 28-65-4</td>
<td>Applicable</td>
<td>Designated to help local communities protect public health, safety, and the environment from chemical hazards. Enables communities to prepare to respond to unplanned releases of hazardous substances. Requires facilities at which hazardous substances are present to report the presence of these materials to emergency responders. Requires companies to report the release of hazardous substances.</td>
<td>Will be applicable if hazardous chemicals are stored or used at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Spill Reporting – K.A.R. 28-48-1 to 28-48-2</td>
<td>Potentially Applicable</td>
<td>Requires reporting of unpermitted discharges or accidental spills. Requires that containment and immediate environmental response measures be implanted. Also provides for technical assistance for mercury-related spills.</td>
<td>Will be applicable if unpermitted discharges or accidental spills occur at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Solid Waste Management – K.A.R. 28-29-1 to 28-29-121 and K.A.R. 28-29-2101 to 28-29-2113</td>
<td>Relevant and Appropriate</td>
<td>Provides standards for management of solid wastes. Establishes administrative procedures. Establishes the requirements for development and submittal of Solid Waste Management Plans.</td>
<td>Will be applicable if solid waste is generated, stored, or disposed at a site.</td>
<td>X</td>
</tr>
<tr>
<td>Kansas Underground Injection Control Regulations – K.A.R. Title 28, Article 47</td>
<td>Potentially Applicable</td>
<td>Controls pressure, flow rate, volume, and quality of injected water.</td>
<td>May be applicable if remedial action chosen has reinjection component.</td>
<td>X</td>
</tr>
</tbody>
</table>
Table 2-3. Summary of State ARARs and TBCs

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</thead>
<tbody>
<tr>
<td>Underground Injection Control Regulations – K.A.R. 28-46-1 to 28-46-44.</td>
<td>Potentially Applicable</td>
<td>Provides regulations governing the use of underground injection wells including: identification of the classifications of injection wells, and the permitting, construction, operation, monitoring, testing, and reporting requirements. Also provides requirements for plugging of injection wells.</td>
<td>Will be applicable if the remedy involves the injection of fluids or air into the subsurface.</td>
<td>Chemical X Location X Action</td>
</tr>
<tr>
<td>Underground Storage, Disposal Wells, and surface Ponds – K.A.R. 28-13-1 to 28-13-9.</td>
<td>Potentially Relevant and Appropriate</td>
<td>Regulates the construction and use of underground storage reservoirs, disposal wells, and surface ponds for the confinement, storage, and disposal of industrial fluids including but not limited to brine. Also pertains to removal of material from surface ponds upon abandonment. Does not include regulations pertaining to oil field activities.</td>
<td>Will be applicable if underground reservoirs, disposal wells, or surface ponds are used for storage or disposal of industrial fluids at a site. Will be applicable if use of a surface pond is discontinued.</td>
<td>Chemical X Location X</td>
</tr>
<tr>
<td>Kansas Underground Storage tank Rules – K.A.R. Title 28 Article 44.</td>
<td>Relevant and Appropriate</td>
<td>Corrective action policy establishes petroleum site remediation levels.</td>
<td>Sets soil levels for TPH, BEN and 12DCA and groundwater levels for BTEX, Pb, and 12DCA.</td>
<td>Chemical X Location X</td>
</tr>
<tr>
<td>Voluntary Cleanup Property Redevelopment Program – K.A.R. 28-71-1 to 28-71-12.</td>
<td>Potentially Relevant and Appropriate</td>
<td>Provides a mechanism for property owners, facility operators, prospective purchasers, and local governments to voluntarily address contaminated properties with technical and regulatory guidance from the KDHE. Identifies remedial standards for cleanup of environmental media. Establishes that groundwater cleanup of environmental media shall be based on the most beneficial use of the groundwater (i.e., current and future use.).</td>
<td>May be applicable if a site meets the criteria for acceptance into the Voluntary Cleanup Program. Remedial standards established under KAR 28-72-22 are relevant and appropriate for all other sites being managed under KDHE oversight.</td>
<td>Chemical X Location X</td>
</tr>
</tbody>
</table>
### Table 2-3. Summary of State ARARs and TBCs

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</tr>
</thead>
<tbody>
<tr>
<td>Kansas Water Appropriations Act – KSA 82a-701 et seq.</td>
<td>Potentially Applicable</td>
<td>Establishes procedures for the appropriation/distribution of groundwater.</td>
<td>According to the KDHE Division of Water Resources, a permit must be obtained for diversion of water whether the use is for remediation or other typical uses. The only time a permit is not required is for domestic wells for a private residence.</td>
<td>X</td>
</tr>
<tr>
<td>Kansas Water Appropriations Act – K.A.R. 5-1-1 through 5-10-6 and K.A.R. 5-50-1 to 5-50-8</td>
<td>Potentially Applicable</td>
<td>Establishes the requirements for obtaining, maintaining, and transferring water appropriations.</td>
<td>Will be applicable if water appropriations are required for groundwater remediation.</td>
<td>X</td>
</tr>
<tr>
<td>Water Well Construction and Abandonment Rules and Regulations – KARR Title 28, Article 30</td>
<td>Applicable</td>
<td>Establishes license requirements for Water Well Contractors, and well installation and abandonment rules and regulations.</td>
<td>Wells installed and abandoned on the Site must meet the requirements of this legislation.</td>
<td>X</td>
</tr>
<tr>
<td>Construction, Operation, Monitoring, and Abandonment of Salt Solution Mining Wells – K.A.R. 28-43-1 to 28-43-11.</td>
<td>Not Relevant and Appropriate</td>
<td>Regulates the construction, operation, monitoring, testing and abandonment of salt solution mining wells.</td>
<td>Will be applicable if salt solution mining wells are present.</td>
<td>X</td>
</tr>
<tr>
<td>Consideration for Hydraulic Containment BER-RS-028</td>
<td>TBC</td>
<td>Presents conditions for consideration of hydraulic containment as remedial strategy.</td>
<td>RSK levels in Appendix A to be used as guidance and potential remedial action levels.</td>
<td>X</td>
</tr>
<tr>
<td>KDHE Bureau of Environmental Remediation (BER), Risk Based Standards for Kansas, RSK Manual, 5th Version. October 2010, revised September 2015.</td>
<td>TBC</td>
<td>Compiles risk-based cleanup screening goals for contaminants in soil, groundwater, and indoor air.</td>
<td>RSK levels in Appendix A to be used as guidance and potential remedial action levels.</td>
<td>X</td>
</tr>
</tbody>
</table>
### Table 2-3. Summary of State ARARs and TBCs

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</tr>
</thead>
<tbody>
<tr>
<td>Kansas Vapor Intrusion Guidance, Published by KDHE, June 2007</td>
<td>TBC</td>
<td>Provides guidance on vapor intrusion including soil vapor and indoor air sampling. References standard operating procedures for indoor air, soil vapor, and subslab soil vapor sampling.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Evaluating Future Land Use, KDHE BER Policy #BER-RS-005</td>
<td>TBC</td>
<td>Future land use influences the types and frequencies of exposures that may occur to any residual contamination remaining on the site and therefore must be considered in making corrective action decisions.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Recommended Remedial Levels for Nitrate in Soil, KDHE BER Policy #BER-RS-012</td>
<td>TBC</td>
<td>Addresses nitrate and ammonia contamination in the soil from point sources of contamination.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Investigation and Remediation of Salt (Chloride)-Impacted Soil and Groundwater, KDHE BER Policy #BER RS-013A</td>
<td>Not TBC</td>
<td>Provides information on methods for investigating, evaluating, and remediating soil and groundwater contaminated with brine or salt.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Consideration for Remedial Standards, KDHE BER Policy #BER RS-33</td>
<td>TBC</td>
<td>Identifies remedial standards and situations where they should be used.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Total Petroleum Hydrocarbons (TPH) and Light Non-Aqueous Phase Liquids (LNAPL) Characterization, Remediation, and Management, KDHE BER Policy #BER RS-041</td>
<td>TBC</td>
<td>Establishes TPH human health and environmental risk-based action levels consistent with the procedures adopted within the Risk-Based Standards for Kansas (RSK) manual.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
<tr>
<td>Monitored Natural Attenuation, KDHE BER policy #BER-RS-042</td>
<td>TBC</td>
<td>Provides further clarification of additional KDHE BER requirements to the guidance on monitored natural attenuation provided by EPA Directive 9200.4-17P.</td>
<td>X</td>
<td>Chemical Location Action</td>
</tr>
</tbody>
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<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>Considerations for Groundwater Use and Applying RSK Standards to Contaminated Groundwater KDHE BER Policy #BER-RS-045.</td>
<td>Establishes a mechanism for consistency across BER program in protecting public health and the environment, in addition to protection of groundwater resources to the State.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design Guidance for Excapsulation Cells KDHE BER Policy #BER-RS-054. May 2013</td>
<td>Serves as a guide to the suitability, selection, design, and construction of encapsulation cells containing contaminated soil, sediment, and/or waste material as part of a state-lead removal or remedial action under KDHE.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment Policy, KDHE BER Policy #BER ARS-045</td>
<td>Provides a consistent definition and assessment approach for contaminated sediment sites in Kansas.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

- TBC = To be considered
- VOCs = Volatile organic compounds
- PCBs = Polychlorinated biphenyls
- TPH = Total petroleum hydrocarbons
- BEN = Benzene
- 12DCA = 1,2-Dichloroethane
- BTEX = Benzene + toluene + ethylbenzene + xylenes
- Pb = Lead
- K.A.R. = Kansas Administrative Regulations
- ARAR = Applicable or Relevant and Appropriate Requirement
- K.S.A. = Kansas Statutes Annotated
- EPA = U.S. Environmental Protection Agency
- KDHE = Kansas Department of Health and Environment
### Table 3-1. Source Area - Screening of Remedial Technologies and Process Options for Technical Implementability

<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Action</td>
<td>None</td>
<td>No Action</td>
<td>No action would be taken. The source area and groundwater contamination will remain in their existing conditions</td>
<td>Retained (Required by NCP as stand-alone alternative)</td>
<td>Yes</td>
</tr>
<tr>
<td>Institutional Controls</td>
<td>Deed Restrictions</td>
<td></td>
<td>Would prevent future site construction activities and subsequent exposure to contaminated groundwater in source areas</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Government and Proprietary Controls</td>
<td>Groundwater Use Restrictions</td>
<td>Groundwater use restrictions would restrict use of groundwater in the zone of contamination</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td>Monitoring</td>
<td>Groundwater Monitoring</td>
<td></td>
<td>Periodic environmental monitoring to determine extent of contaminant plume</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Five-Year Site Review</td>
<td></td>
<td>Five-Year Reviews generally are required by CERCLA or program policy when hazardous substances remain on site above levels which permit unrestricted use and unlimited exposure</td>
<td>Retained per CERCLA</td>
<td>Yes</td>
</tr>
<tr>
<td>Soil Solidification</td>
<td>Portland Cement</td>
<td>Mix Portland cement into the source area soils to prevent discharge of TCE into groundwater</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Soil Removal</td>
<td>Excavation</td>
<td>Landfarming</td>
<td>Excavate impacted source area soils, landfarm on adjacent property to degrade/ remove contaminant mass, and backfill the excavation with remediated soils</td>
<td>Not technically implementable because the excavated soil would be considered a listed hazardous waste. Also there is not a suitable space in the area that would accommodate a landfarming operation</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Off-site Disposal</td>
<td>Excavate source area soils to remove TCE mass from the Site</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Soil Treatment</td>
<td>Soil Mixing</td>
<td>Zero Valant Iron (ZVI)</td>
<td>Mix ZVI into the source area soils to destroy sorbed TCE mass</td>
<td>Not applicable to vadose zone impacts; however, it is technically implementable and potentially applicable for saturated soils</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Shading indicates remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.

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### Table 3-1. Source Area - Screening of Remedial Technologies and Process Options for Technical Implementability

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<tr>
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<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Response</td>
<td>Sodium Persulfate</td>
<td>Mix sodium persulfate into the source area soils to destroy TCE mass.</td>
<td>Technically implementable and potentially applicable but not retained as other options are preferable based on historical experience.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Thermal</td>
<td>Vapor and Groundwater Extraction</td>
<td>Install a combination of heating elements and multi-phase extraction wells to remove TCE mass from saturated and unsaturated soils.</td>
<td>Sufficient surface area is not available in the source area to allow for the aboveground components (extraction/treatment system, electrode wiring)</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater</td>
<td>Vertical Barriers</td>
<td>Excavate trench upgradient of the source area to prevent groundwater from contacting plume filled with a low permeable bentonite mixture to contain plume migration.</td>
<td>Not technically implementable due to the hydrogeologic conditions present in the source area.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Groundwater</td>
<td>Sheet Piling</td>
<td>Lengths of steel of HDPE sheets are connected together and driven into the ground to form an impermeable barrier to groundwater flow.</td>
<td>Not technically implementable due to the hydrogeologic conditions present in the source area.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Collection</td>
<td>Vertical Extraction Well(s)</td>
<td>Removal of groundwater through extraction wells, causing gradient that controls migration of contaminant plume. Series of wells installed to collect groundwater for surface treatment.</td>
<td>Technically implementable and potentially applicable.</td>
<td>Yes</td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Horizontal Extraction Well(s)</td>
<td>Series of laterally installed wells to extract contaminated groundwater for surface treatment.</td>
<td>Technically implementable for site application; however, vertical extraction wells would be the preferable lower cost alternative.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Interceptor Trench</td>
<td>Collection of groundwater through installation of perforated pipe placed in trenches</td>
<td>Commercial land use dowgradient of the source area does not provide area required for installation of the interceptor trench.</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Shading indicates remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
Table 3-1. Source Area - Screening of Remedial Technologies and Process Options for Technical Implementability

<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td></td>
<td>Reuse for Potable Water Supply</td>
<td>Treated groundwater discharged to potable water supply treatment plant</td>
<td>Technically implementable and potentially applicable but not retained as other options are preferable</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow Well Injection</td>
<td>Reinjection of treated groundwater as part of a potential a DGR alternative</td>
<td>Technically implementable and potentially applicable but not retained as other options are preferable</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Infiltration Galleries/Basins</td>
<td>Gradual infiltration of treated groundwater into soils matrix using galleries or basins</td>
<td>Commercial land use in the source area does not provide area required for installation of either basins or galleries.</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge to Surface Water Body or Storm Sewer</td>
<td>Discharge of extracted groundwater either directly to a surface water body or to a storm sewer which leads to a surface water body</td>
<td>Technically implementable and potentially applicable. Requires NPDES permit for discharge.</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Shading indicates remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological</td>
<td>Natural Attenuation</td>
<td>A variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in the groundwater.</td>
<td>Technically implementable and potentially applicable.</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>Enhanced Reductive Dechlorination</td>
<td>Degradation of contaminants by naturally occurring microorganisms would be stimulated through the addition of substrate to degrade contaminants.</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical/Biological</td>
<td>Reactive Barrier Wall</td>
<td>An in-ground trench would be backfilled with reactive media to provide passive treatment of contaminated groundwater passing through the trench.</td>
<td>Commercial land use dowgradient of the source area does not provide area required for installation of the interceptor trench.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>Ex Situ UV/Oxidation</td>
<td>Organic contaminants would be destroyed through chemical oxidation/reduction reactions. Used when destruction of contaminants is preferred or when contaminants cannot be removed with granular activated carbon or air stripping.</td>
<td>Not technically implementable due to the hydrogeologic conditions present in the source area.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>In situ Chemical Oxidation</td>
<td>Strong chemical oxidants (e.g., H2O2, KMnO4, or O3) would be injected into the contaminated aquifer to destroy organic contaminants.</td>
<td>Technically implementable and potentially applicable; however, ERD would be a lower cost alternative for site contaminants.</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

Shading indicates remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Action</td>
<td>None</td>
<td>No Action</td>
<td>No action would be taken. The source area and groundwater contamination will remain in their existing conditions</td>
<td>Retained (Required by NCP as stand-alone alternative)</td>
<td>Yes</td>
</tr>
<tr>
<td>Institutional Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use Restrictions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Government and</td>
<td>Groundwater</td>
<td></td>
<td>Would prevent future site construction activities and subsequent exposure to contaminated groundwater in source areas.</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td>Proprietary Controls</td>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td>Site Inspection</td>
<td></td>
<td>Periodic environmental monitoring to determine extent of contaminant plume</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td>Sampling and</td>
<td>Groundwater</td>
<td></td>
<td>Five-Year Reviews generally are required by CERCLA or program policy when hazardous substances remain on site above levels which permit unrestricted use and unlimited exposure.</td>
<td>Retained per CERCLA</td>
<td>Yes</td>
</tr>
<tr>
<td>Analysis</td>
<td>Monitoring</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater Containment</td>
<td>Vertical Barriers</td>
<td></td>
<td>Excavated trench at the leading edge of the groundwater plume filled with a low permeable bentonite mixture to contain plume migration</td>
<td>Not technically implementable due to size of the plume.</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>Slurry Wall</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sheet Piling</td>
<td></td>
<td>Lengths of steel of HOPE sheets are connected together and driven into the ground to form an impermeable barrier to groundwater flow</td>
<td>Not technically implementable due to size of the plume.</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Collection</td>
<td></td>
<td>Removal of groundwater through extraction wells, causing gradient that controls migration of contaminant plume. Series of wells installed to collect groundwater for surface treatment</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Shading indicates that remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
Table 3-2. Mid-Plume Area – Screening of Remedial Technologies and Process Options for Technical Implementability

<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Horizontal Extraction Well(s)</td>
<td>Series of laterally installed wells to extract contaminated groundwater for surface treatment</td>
<td>May not be technically implementable due to size of the plume</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Interceptor Trench</td>
<td>Collection of groundwater through installation of perforated pipe placed in trenches</td>
<td>Commercial land use throughout the operable units does not provide area required for installation of the interceptor trench</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reuse as Non-Potable Water Supply</td>
<td>Use of treated groundwater as non-potable water source (irrigation or industry)</td>
<td>Commercial land use throughout OU does not require irrigation.</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Collection (continued)</td>
<td>Discharge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reuse for Potable Water Supply</td>
<td>Treated groundwater discharged to potable water supply treatment plant</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shallow Well Injection</td>
<td>Reinjection of treated groundwater as part of a potential DGR alternative</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Infiltration Galleries/Basins</td>
<td>Gradual infiltration of treated groundwater into soils matrix using galleries or basins</td>
<td>Commercial and residential land use throughout the operable units does not provide area required for installation of either basins or galleries</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge to Surface Water Body or Storm Sewer</td>
<td>Discharge of extracted groundwater either directly to a surface water body or to a storm sewer which leads to a surface water body</td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

Shading indicates that remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
Table 3-2. Mid-Plume Area – Screening of Remedial Technologies and Process Options for Technical Implementability

<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Removal (continued)</td>
<td>Discharge owned treatment works (POTW)</td>
<td>Discharge or extracted groundwater to POTW</td>
<td>Technically implementable and potentially applicable. Discharge permits and discharge fees will be required. Discharge fees may be exorbitant. Receiving POTW may not have the capacity to receive anticipated volume of extracted groundwater.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Groundwater Removal (continued)</td>
<td>Ex Situ Biological Degradation</td>
<td>Degradation of contaminants by naturally occurring microorganisms through the addition of nutrients, oxygen, and/or substrates in an engineered reactor.</td>
<td>Not technically implementable for site application. Anaerobic conditions required for biological degradation.</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>Natural Attenuation</td>
<td>A variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in the groundwater.</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>Enhanced Reductive Dechlorination</td>
<td>Degradation of contaminants by naturally occurring microorganisms would be stimulated through the addition of substrate to degrade contaminants.</td>
<td>Technically implementable and potentially applicable as a long-term solution</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Shading indicates that remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundwater Treatment (continued)</td>
<td>Chemical/Biological Treatment</td>
<td>Reactive Barrier Wall</td>
<td>An in-ground trench would be backfilled with reactive media to provide passive treatment of contaminated groundwater passing through the trench. Depth of application is limited.</td>
<td>Not technically implementable for site application because of the dept to which contamination is present at the site and width of the leading edge of the contaminant plume</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater Treatment (continued)</td>
<td>Chemical Treatment</td>
<td>Ex Situ UV/Oxidation</td>
<td>Organic contaminants would be destroyed through chemical oxidation/reduction reactions. Used when destruction of contaminants is preferred or when contaminants cannot be removed with granular activated carbon or air stripping.</td>
<td>Technically implementable for site application; however, granular activated carbon or air stripping would be lower cost alternatives for site contaminants.</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater Treatment (continued)</td>
<td></td>
<td>In Situ Chemical Oxidation</td>
<td>Strong chemical oxidants (e.g., H2O2, KMnO4, or O3) would be injected into the contaminated aquifer to destroy organic contaminants.</td>
<td>Technically implantable and potentially applicable; however, granular activated carbon or air stripping would be lower cost alternatives for site contaminants.</td>
<td>No</td>
</tr>
<tr>
<td>Groundwater Treatment (continued)</td>
<td>Physical Treatment</td>
<td>Granular Activated Carbon (GAC) Adsorption</td>
<td>Organic contaminants would be removed from groundwater through adsorption onto activated carbon.</td>
<td>Technically implementable and potentially applicable.</td>
<td>Yes</td>
</tr>
<tr>
<td>Groundwater Treatment (continued)</td>
<td></td>
<td>Reverse Osmosis</td>
<td>Membrane separation of water from constituents by pressure-gradient forces.</td>
<td>Technically implementable for site application; however, this technology was eliminated from consideration based on high costs involved with the technology and the disposal requirements for the supernatant.</td>
<td>No</td>
</tr>
</tbody>
</table>

Shading indicates that remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Description of Response Action</th>
<th>Screening Comments</th>
<th>Retained</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Groundwater Treatment (continued)</td>
<td>Air Stripping</td>
<td>Contaminants would be removed from groundwater to the air through phase transfer mechanisms.</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>Groundwater Treatment (continued)</td>
<td>Physical Air Sparging/Soil Vapor Extraction (AS/SVE)</td>
<td>Air would be injected through subsurface vertical and/or horizontal wells. Volatile organic contaminants partition into the air stream as it passes through the contaminated groundwater. Technology would be completed by using soil vapor extraction, as previously described in this table.</td>
<td>Technically implementable and potentially applicable</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Notes:
- NCP = National Contingency Plan
- CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act
- HDPE = high-density polyethylene
- OU = Operable Unit
- UV = ultraviolet

Shading indicates that remedial technologies/process options have been eliminated from further consideration based on lack of technical implementability.
Table 4-1. Source Area - Retained Remedial Technologies and Assembled Remedial Alternatives

<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Source Area Alternative 1</th>
<th>Source Area Alternative 2</th>
<th>Source Area Alternative 3</th>
<th>Source Area Alternative 4</th>
<th>Source Area Alternative 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>No Action</td>
<td>Hot Spot Excavation and ERD</td>
<td>ISSS and Groundwater Removal</td>
<td>Deep Soil Excavation and ERD</td>
<td>ISSS, Soil Mixing using ZVI and ERD</td>
</tr>
<tr>
<td>No Action</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institutional Controls</td>
<td>Use Restrictions</td>
<td>Environmental Use Controls (EUC)</td>
<td>(•)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monitoring</td>
<td>Sampling and Analysis</td>
<td>Groundwater Monitoring</td>
<td>(•)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inspection</td>
<td>Five-year Site Review</td>
<td>(•)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Solidification</td>
<td>In-Situ Soil Mixing</td>
<td>Portland Cement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(•)</td>
</tr>
<tr>
<td>Soil Removal</td>
<td>Excavation</td>
<td>Off-Site Disposal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil Treatment</td>
<td>Soil Mixing</td>
<td>Zero Valent Iron (ZVI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Collection</td>
<td>Vertical Extraction Wells</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Discharge</td>
<td>Discharge to stream or storm sewer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>Biological</td>
<td>Natural Attenuation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Enhanced Reductive Dechlorination</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:
(•) indicates that EUCs, groundwater monitoring, and the 5-year review will be part of the No Action Alternative
<table>
<thead>
<tr>
<th>General Response Action</th>
<th>Remedial Technology</th>
<th>Process Option</th>
<th>Mid-Plume Area Alternative 1</th>
<th>Mid-Plume Area Alternative 2</th>
<th>Mid-Plume Area Alternative 3</th>
<th>Mid-Plume Area Alternative 4</th>
<th>Mid-Plume Area Alternative 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Action</td>
<td></td>
<td></td>
<td>No Action</td>
<td>Air Sparging / Soil Vapor Extraction</td>
<td>Enhanced Reductive Dechlorination</td>
<td>Downgradient Hydraulic Containment</td>
<td>Directed Groundwater Recirculation</td>
</tr>
<tr>
<td>Institutional Controls</td>
<td>Use Restrictions</td>
<td>Environmental Use Controls (EUC)</td>
<td></td>
<td>(●)</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Monitoring</td>
<td>Groundwater Monitoring</td>
<td></td>
<td>(●)</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Inspection</td>
<td>Five-year Site Review</td>
<td></td>
<td>(●)</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Groundwater Removal</td>
<td>Collection</td>
<td>Vertical Extraction Wells</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Discharge</td>
<td>Vertical Injection Wells</td>
<td></td>
<td></td>
<td></td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge to stream or storm sewer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td>Groundwater Treatment</td>
<td>In Situ Biological Treatment</td>
<td>Enhanced Reductive Dechlorination</td>
<td></td>
<td></td>
<td>●</td>
<td></td>
<td>●</td>
</tr>
<tr>
<td></td>
<td>Physical Treatment</td>
<td>Granular Activated Carbon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air Sparging / SVE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>●</td>
</tr>
</tbody>
</table>

Notes:

(●) indicates that EUCs, groundwater monitoring, and the 5-year review will be part of the No Action Alternative.

SVE = Soil Vapor Extraction
Table 4-3 Qualitative Screening: Source Area - Alternative 1 – No Further Action

<table>
<thead>
<tr>
<th>Effectiveness Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall protection of human health and the environment</td>
<td>• The no action alternative does not address or quantify the risks presented by the chemicals of concern in the groundwater</td>
</tr>
<tr>
<td></td>
<td>• Rating: 0</td>
</tr>
<tr>
<td>Compliance with ARARs</td>
<td>• Rating: 0</td>
</tr>
<tr>
<td>Reduction of toxicity, mobility, or volume through treatment</td>
<td>• Does not provide a source area treatment component outside of natural attenuation</td>
</tr>
<tr>
<td></td>
<td>• Rating: 0</td>
</tr>
<tr>
<td>Short-term effectiveness (during the remedial construction and implementation period)</td>
<td>• The short term risks to the community are unchanged by this activity</td>
</tr>
<tr>
<td></td>
<td>• Rating: 0</td>
</tr>
<tr>
<td>Long-term effectiveness and permanence (Following remedial construction)</td>
<td>• Existing water well ordinances and institutional controls provide some protection to public health and the environment</td>
</tr>
<tr>
<td></td>
<td>• Rating: 1</td>
</tr>
<tr>
<td>Overall Effectiveness Rating Based on Lowest Score</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 4-3 Qualitative Screening: Source Area - Alternative 1 – No Further Action

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | • No remedial actions are implemented.  
• Rating: 5 |
| Ability to operate, maintain, replace and monitor technical components | • No remedial actions are implemented.  
• Rating: 5 |
| Ability to obtain permits from other agencies | • No permits required for implementation of alternative.  
• Rating: 5 |
| Availability and capacity of treatment, storage, and disposal facility | • No waste generated during implementation of alternative.  
• Rating: 5 |
| Availability of property, specific material, equipment, and technical specialists required for a remedial action | • None required for implementation of alternative.  
• Rating: 5 |

**Overall Implementability Rating Based on Lowest Score**  
5

**Evaluation Factors for Cost**

<table>
<thead>
<tr>
<th>Generalized cost (score)</th>
</tr>
</thead>
</table>
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs | • Capital Cost: $  
• Operation & Maintenance: $  
• Monitoring Costs: $  
• Closure Cost: $ |

**Cost Rating**

$
Table 4-4. Qualitative Screening: Source Area - Alternative 2 – Hot Spot Excavation, Targeted Soil ERO and Groundwater ERO

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Overall protection of human health and the environment | • Hot Spot Excavation and Targeted ERO would permanently reduce exposure to residual COCs in Rail Yard Area soils, and ERO would treat COCs to below RAOs, given sufficient well coverage.  
• Rating: 5 |
| Compliance with ARARs | • Alternative would be compliant with ARARs. Permits would be needed for injection wells.  
• Wastes generated during implementation will be handled in compliance with action specific ARARs.  
• Rating: 5 |
| Reduction of toxicity, mobility, or volume through treatment | • Hot Spot Excavation and Targeted ERO would prevent human contact and reduce mobility (off-site migration) of COCs. ERD would reduce volume of COCs in groundwater.  
• Rating: 5 |
| Short-term effectiveness (during the remedial construction and implementation period) | • Hot Spot Excavation and Targeted ERO would immediately reduce the level of exposure to sorbed COCs and ERO would have an almost immediate effect on reducing dissolved phase COC concentrations.  
• Rating: 4 |
| Long-term effectiveness and permanence (Following remedial construction) | • The combination of Hot Spot Excavation and ERO would effectively reduce COC concentrations to achieve RAOs.  
• Rating: 5 |
| Overall Effectiveness Rating Based on Lowest Score | 4 |
### Implementability Criteria

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | • Soil beneath the Waste Storage Area is readily accessible for Hot Spot excavation. Targeted ERD in the Rail Yard Area will require coordination with yard personnel. Access to the ERD injection well network is available without modifying surface land use.  
  • Rating: 4                                                                                                                                                                                                                                                                          |
| Ability to operate, maintain, replace and monitor technical components                    | • Hot Spot Excavation and Targeted ERD will not require ongoing maintenance. Operation and monitoring of the ERD injection component is available without modifying surface land use.  
  • Rating: 5                                                                                                                                                                                                                                                                          |
| Ability to obtain permits from other agencies                                             | • It will be necessary to acquire permission from the City of Wichita to excavate below North Hydraulic Street, to install wells in the right-of-way, and obtain injection permits from the KDHE. Securing these permits is not anticipated to be a problem.  
  • Rating: 5                                                                                                                                                                                                                                                                          |
| Availability and capacity of treatment, storage, and disposal facility                    | • Limited amounts of waste would be generated during Hot Spot excavation, well installation, well development and sampling.  
  • Generated material will require transportation to the Clean Harbors Landfill in Lone Mountain, Oklahoma (~165 miles one way)  
  • Rating: 4                                                                                                                                                                                                                                                                              |
| Availability of property, specific material, equipment, and technical specialists required for a remedial action | • With the exception of the downgradient ERD injection wells, all remedial actions occur on UPRR property.  
  • Injection materials (molasses, EVO, etc.) are readily available.  
  • ARCADIS maintains staff that is experienced in the implementation of excavation events and ERD.  
  • Rating: 5                                                                                                                                                                                                                                                                              |
Table 4-4. Qualitative Screening: Source Area - Alternative 2 – Hot Spot Excavation, Targeted Soil ERD and Groundwater ERD

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
</table>
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs. | - Capital Cost: $$
- Operation & Maintenance: $$
- Monitoring Costs: $
- Closure Cost: $ |

Cost Rating

$$$

Overall Implementability Rating Based on Lowest Score

4
Table 4-5. Qualitative Screening: Source Area - Alternative 3 - In-Situ Soil Solidification/Stabilization (ISSS) and Groundwater Removal (Pump and Treat)

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall protection of human health and the environment</td>
<td>• ISSS would permanently reduce exposure to residual COCs in source area soils, and over time, groundwater removal would reduce COC levels to achieve RAOs. Achievement of RAOs throughout plume would take a long time.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Compliance with ARARs</td>
<td>• Alternative would be compliant with ARARs. NPDES permit is required for stream discharge.</td>
</tr>
<tr>
<td></td>
<td>• Wastes generated during implementation will be handled in compliance with action specific ARARs.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 2</td>
</tr>
<tr>
<td>Reduction of toxicity, mobility, or volume through treatment</td>
<td>• ISSS would prevent human contact and reduce mobility (off-site migration) of COCs. Groundwater removal would reduce volume of COCs in groundwater.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Short-term effectiveness (during the remedial construction and implementation period)</td>
<td>• ISSS would immediately reduce the level of exposure to sorbed COCs. Low permeability soils present in the source area would limit the groundwater removal rate and extend the time required to reduce dissolved phase COC concentrations.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Long-term effectiveness and permanence (Following remedial construction)</td>
<td>• The combination of ISSS and groundwater removal would effectively reduce COC concentrations to achieve RAOs overtime.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td>3</td>
</tr>
</tbody>
</table>
### Table 4-5. Qualitative Screening: Source Area - Alternative 3 – In-Situ Soil Solidification/Stabilization (ISSS) and Groundwater Removal (Pump and Treat)

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | • Sufficient ISSS may be accomplished by addressing readily accessible (e.g. not below railroad tracks or roadway) soils, but excavation below North Hydraulic will be required, resulting in lane and possibly street closing. ISSS will require the use of wood cribbing or a slide rail system adjacent to tracks and roadway.  
  • Installation of the groundwater removal component will require boring under the roadway and installation of conveyance lines and a centralized treatment system. Space is limited at the site so the groundwater removal component could be difficult to construct.  
  • Rating: 3                                                                                                                                                                                                                     |
| Ability to operate, maintain, replace and monitor technical components                      | • ISSS will not require ongoing maintenance. Operation of the groundwater removal component will require a treatment system with a moderate footprint.  
  • Rating: 4                                                                                                                                                                                                                     |
| Ability to obtain permits from other agencies                                              | • It will be necessary to acquire permission from the City of Wichita to excavate below North Hydraulic Street, install wells in the right-of-way, and obtain an NPDES permit from the KDHE to discharge treated groundwater. Securing the NPDES permit may be moderately difficult depending on the proximity of an acceptable discharge location.  
  • Rating: 5                                                                                                                                                                                                                     |
| Availability and capacity of treatment, storage, and disposal facility                     | • Limited amounts of waste would be generated during ISSS (through anticipated bulking effects only), well installation, well development and sampling.  
  • Generated material will require transportation to the Clean Harbors Landfill in Lone Mountain, Oklahoma (~165 miles one way).  
  • Rating: 4                                                                                                                                                                                                                     |
Table 4-5. Qualitative Screening: Source Area - Alternative 3 - In-Situ Soil Solidification/Stabilization (ISSS) and Groundwater Removal (Pump and Treat)

| Availability of property, specific material, equipment, and technical specialists required for a remedial action | • With the exception of a portion of the ISSS below North Hydraulic Street and downgradient extraction wells all remedial actions occur on UPRR property.  
• ISSS materials (Portland cement and other pozzolanic materials) and injection materials (molasses, EVO, etc.) are readily available.  
• ARCADIS maintains staff that is experienced in the implementation of ISSS and groundwater removal.  
• Rating: 6 |

| Overall Implementability Rating Based on Lowest Score | 3 |

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
</table>
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs | • Capital Cost: $$$  
• Operation & Maintenance: $$$  
• Monitoring Costs: $  
• Closure Cost: $ |

| Cost Rating | $$$$ |
Table 4-6. Qualitative Screening: Source Area - Alternative 4 – Deep Soil Excavation and Enhanced Reductive Dechlorination (ERD)

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Overall protection of human health and the environment | - Deep soil excavation would reduce sorbed COC mass and ERD would treat COCs to below RAOs, given sufficient well coverage.  
- Increased potential for worker exposure, fugitive emissions and accidental release during transportation component.  
- Rating: 4 |
| Compliance with ARARs | - Alternative would be compliant with ARARs. Permits would be needed for injection wells.  
- Wastes generated during implementation will be handled in compliance with action specific ARARs. This alternative will require a remote staging area and generate in excess of 2,000 tons of a listed hazardous waste.  
- Rating: 4 |
| Reduction of toxicity, mobility, or volume through treatment | - Deep soil excavation would significantly reduce the amount of sorbed COC mass present at the site and ERD would reduce volume of COCs in groundwater.  
- Rating: 5 |
| Short-term effectiveness (during the remedial construction and implementation period) | - Deep soil excavation would immediately reduce the level of exposure to sorbed COCs and ERD would have an almost immediate effect on reducing dissolved phase COC concentrations.  
- Rating: 5 |
| Long-term effectiveness and permanence (Following remedial construction) | - The combination of deep soil excavation and ERD would effectively reduce COC concentrations to achieve RAOs. Low permeability soils in the source area would necessitate regular maintenance and replacement of injection wells.  
- Rating: 5 |
| Overall Effectiveness Rating Based on Lowest Score | 4 |
### Table 4-6. Qualitative Screening: Source Area - Alternative 4 – Deep Soil Excavation and Enhanced Reductive Dechlorination (ERD)

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | - The limited amount of space present at the excavation site would make deep soil excavation, staging of materials, and backfilling difficult. Excavation will require the use of wood cribbing or a slide rail system adjacent to tracks and roadway.  
  - Installation of the ERD injection well network and access to it is available without modifying surface land use.  
  - Rating: 3                                                                                                     |
| Ability to operate, maintain, replace and monitor technical components                     | - Deep soil excavation will not require ongoing maintenance. Operation and monitoring of the ERD injection component is available without modifying surface land use.  
  - Rating: 5                                                                                                     |
| Ability to obtain permits from other agencies                                               | - It will be necessary to acquire permission from the City of Wichita to install wells in the right-of-way and obtain injection permits from the KDHE.  
  - A RCRA large quantity generator permit will also be required for disposal of excavated soil.  
  - Securing these permits is not anticipated to be a problem.  
  - Rating: 3                                                                                                     |
| Availability and capacity of treatment, storage, and disposal facility                     | - A significant amount of a listed waste would be generated during soil excavation.  
  - Generated material will require transportation to the Clean Harbors Landfill in Lone Mountain, Oklahoma (~165 miles one way).  
  - Rating: 4                                                                                                     |
Table 4-6. Qualitative Screening: Source Area - Alternative 4 – Deep Soil Excavation and Enhanced Reductive Dechlorination (ERD)

| Availability of property, specific material, equipment, and technical specialists required for a remedial action | With the exception of downgradient ERD injection wells, all remedial actions occur on UPRR property. |
| ARCADIS maintains staff that is experienced in the implementation of soil excavation and ERD. | Rating: 3 |

Overall Implementability Rating Based on Lowest Score

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost associated with implementation of the alternative including capital, monitoring, operation, and maintenance, and closure costs</td>
<td>Capital Cost: $$$</td>
</tr>
<tr>
<td>Operation &amp; Maintenance: $$</td>
<td>Monitoring Costs: $</td>
</tr>
<tr>
<td>Closure Cost: $</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$$$$$</td>
</tr>
</tbody>
</table>

ARCAOIS maintains staff that is experienced in the remedial action implementation of soil excavation and ERD.
<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall protection of human health and the environment</td>
<td>• ISSS would reduce exposure to sorbed COC mass. Soil mixing and ERD would treat COCs to below RAOs, given sufficient well coverage.</td>
</tr>
<tr>
<td></td>
<td>• Increased potential for worker exposure, fugitive emissions and accidental release during transportation component.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Compliance with ARARs</td>
<td>• Alternative would be compliant with ARARs. Permits would be needed for injection wells and effluent discharge.</td>
</tr>
<tr>
<td></td>
<td>• Wastes generated during implementation will be handled in compliance with action specific ARARs.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Reduction of toxicity, mobility, or volume through treatment</td>
<td>• ISSS would prevent human contact and reduce mobility (off-site migration) of COCs. Soil mixing and ERD would reduce volume of COCs in groundwater.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Short-term effectiveness (during the remedial construction and implementation period)</td>
<td>• ISSS would immediately reduce the level of exposure to sorbed COCs, ERD would have an almost immediate effect on reducing dissolved phase COC concentrations, and soil mixing would have a delayed effect on reducing dissolved phase COC concentrations.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Long-term effectiveness and permanence (Following remedial construction)</td>
<td>• The combination of ISSS, soil mixing and ERD would effectively reduce COC concentrations to achieve RAOs. Low permeability soils in the source area would necessitate regular maintenance and replacement of injection wells.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Overall Effectiveness Rating Based on Lowest Score</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 4</td>
</tr>
</tbody>
</table>
Table 4-7. Qualitative Screening: Source Area - Alternative 5 – In-Situ Soil Solidification/Stabilization (ISSS), Soil Mixing Using ZVI and Enhanced Reductive Dechlorination (ERD)

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | • The limited amount of space present at the site would make soil mixing difficult. To ensure complete mixing, the overlying materials would have to be excavated and staged before soil mixing could be conducted.  
• Implementation would also require a modeling analysis be conducted to understand the potential effects of redirecting groundwater flow on contaminant mass transport.  
• Rating: 2                                                                                                                                                                                                                           |
| Ability to operate, maintain, replace and monitor technical components                     | • ISSS and soil mixing will not require ongoing maintenance. Operation and monitoring of the ERD injection component is available without modifying surface land use.  
• Rating: 5                                                                                                                                                                                                                           |
| Ability to obtain permits from other agencies                                             | • It will be necessary to acquire permission from the City of Wichita to excavate below North Hydraulic Street, install wells in the right-of-way, and obtain injection permits from the KDHE. Securing these permits is not anticipated to be a problem.  
• Rating: 5                                                                                                                                                                                                                           |
| Availability and capacity of treatment, storage, and disposal facility                    | • Limited amounts of waste would be generated during ISSS/soil mixing (through anticipated bulking effects only), well installation, well development and sampling.  
• Generated material will require transportation to the Clean Harbors Landfill in Lone Mountain, Oklahoma (~165 miles one way)  
• Rating: 4                                                                                                                                                                                                                           |
Table 4-7. Qualitative Screening: Source Area - Alternative 5 - In-Situ Soil Solidification/Stabilization (ISSS), Soil Mixing Using ZVI and Enhanced Reductive Dechlorination (ERD)

| Availability of property, specific material, equipment, and technical specialists required for a remedial action | With the exception of a portion of the ISSS below North Hydraulic Street and downgradient ERD injection wells all remedial actions occur on UPRR property. |
| - ISSS materials (Portland cement and other pozzolanic materials), injection materials (molasses, EVO, etc.) are locally available. ZVI would most likely require shipment from a non-local source. |
| - ARCADIS maintains staff that is experienced in the implementation of ISSS and ERD. |
| Rating: 5 |

Overall Implementability Rating Based on Lowest Score

| Evaluation Factors for Cost | Generalized cost (score) |
| - Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs | - Capital Cost: $$$ |
| - Operation & Maintenance: $$ |
| - Monitoring Costs: $ |
| - Closure Cost: $ |

Cost Rating: $$$$
Table 4-8. Source Area - Summary of Qualitative Screening of Alternatives

<table>
<thead>
<tr>
<th>Source Area Alternative</th>
<th>Description</th>
<th>Effectiveness</th>
<th>Implementability</th>
<th>Approximate Overall Relative Cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Action</td>
<td>0</td>
<td>5</td>
<td>$</td>
<td>Retained as a baseline option. Costs would include on-going groundwater monitoring required by Consent Order.</td>
</tr>
<tr>
<td>2</td>
<td>Hot Spot Excavation and Targeted ERD in Rail Yard with groundwater ERD</td>
<td>4</td>
<td>4</td>
<td>$$$</td>
<td>Implementable and will achieve cleanup goals within a reasonable time period.</td>
</tr>
<tr>
<td>3</td>
<td>ISSS and groundwater removal (pump and treat)</td>
<td>3</td>
<td>3</td>
<td>$$$$</td>
<td>Removed from consideration due to the extended time required to achieve dissolved phase remedial action objectives.</td>
</tr>
<tr>
<td>4</td>
<td>Deep soil excavation and ERD</td>
<td>4</td>
<td>3</td>
<td>$$$$</td>
<td>Implementable and will achieve cleanup goals within a reasonable time period. Implementation of soil excavation will require the setup of a remote staging area and long distance transportation of approximately 2,250 tons of a listed waste.</td>
</tr>
<tr>
<td>5</td>
<td>ISSS, soil mixing using ZVI and ERD</td>
<td>4</td>
<td>2</td>
<td>$$$$</td>
<td>Removed from consideration due to the complex hydrogeologic environment through which contaminant mass flux is occurring. Historical models indicated the presence of a high k zone, if this zone is obstructed then the groundwater flow path would likely be redirected. Also the cost is similar to soil excavation therefore it would not make sense to treat impacted soil if you could remove it for approximately the same cost.</td>
</tr>
</tbody>
</table>

Note:

1 – Composite screening score using a 0 (none) to 6 (high) relative ranking.

2 – Shaded alternatives are removed from consideration and not carried forward to the detailed analysis.
Table 4-9. Qualitative Screening: Mid-Plume Area - Alternative 1 – No Action

<table>
<thead>
<tr>
<th>Effectiveness Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall protection of human health and the environment</td>
<td>• The No Action Alternative does not address or quantify the risks presented by the chemicals of concern in the groundwater</td>
</tr>
<tr>
<td>Compliance with ARARs</td>
<td>• Rating: 0</td>
</tr>
<tr>
<td>Short-term effectiveness (during the remedial construction and implementation period)</td>
<td>• The short-term risks to the community are unchanged by this activity. There are no adverse affects to construction workers or the environment</td>
</tr>
<tr>
<td>Long-term effectiveness and permanence (Following remedial construction)</td>
<td>• Future risks to human health and the environment would not be monitored and evaluated.</td>
</tr>
<tr>
<td>Reduction of toxicity, mobility, or volume through treatment</td>
<td>• No evaluation of the reduction of toxicity, mobility, or volume of contaminants.</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td></td>
</tr>
</tbody>
</table>
Table 4-9. Qualitative Screening: Mid-Plume Area - Alternative 1 – No Action

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action</td>
<td>• No Mid-Plume Area remedial actions are implemented.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Ability to operate, maintain, replace and monitor technical components</td>
<td>• No Mid-Plume Area remedial actions are implemented.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Ability to obtain permits from other agencies</td>
<td>• No permits required for implementation of alternative.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Availability and capacity of treatment, storage, and disposal facility</td>
<td>• No waste generated during implementation of alternative.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Availability of property, specific material, equipment, and technical specialists required for a remedial action</td>
<td>• None required for implementation of alternative.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 5</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td>5</td>
</tr>
</tbody>
</table>

**Evaluation Factors for Cost**                                                                                                                                                                                                 |
| Generalized cost (score)                                                                                                                                                                                                      |
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs                                                                                           | • Capital Cost: $                                                                                           |
|                                                                                                                                                                                                                          | • Operation & Maintenance: $                                                                              |
|                                                                                                                                                                                                                          | • Monitoring Costs: $$                                                                                     |
|                                                                                                                                                                                                                          | • Closure Cost: $                                                                                           |
| Cost Rating                                                                                                                                                                                                                 | $                                                                                                             |

**Note:**
ARAR = Applicable or Relevant and Appropriate Requirement.
## Table 4-10. Qualitative Screening: Mid-Plume Area - Alternative 2 – Air Sparging/Soil Vapor Extraction

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall protection of human health and the environment</td>
<td>• Air sparging could treat COCs to below RAOs, given sufficient well coverage. SVE coverage would be necessary to prevent potential residential vapor intrusion issues</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Compliance with ARARs</td>
<td>• Alternative would be compliant with ARARs. Permits would be needed for injection wells.</td>
</tr>
<tr>
<td></td>
<td>• Wastes generated during the installation of AS and SVE wells and well development would have to be handled in compliance with action specific ARARs.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Short-term effectiveness (during the remedial construction and implementation period)</td>
<td>• Construction of AS/SVE infrastructure would have a short-term impact on neighborhoods where transects are located. AS would have an almost immediate effect on reducing the COCs concentrations following system startup.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Long-term effectiveness and permanence (Following remedial construction)</td>
<td>• Over time, AS would decrease concentrations of COCs to achieve RAOs. Limited radius of influence would necessitate that many AS wells be installed to provide effectively treatment of Mid-Plume Area groundwater.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Reduction of toxicity, mobility, or volume through treatment</td>
<td>• AS treatment would reduce volume of COCs in groundwater. Potential vapor intrusion issues are possible unless SVE is very effective in eliminating VI pathway.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td></td>
</tr>
</tbody>
</table>
### Table 4-10. Qualitative Screening: Mid-Plume Area - Alternative 2 – Air Sparging/Soil Vapor Extraction

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action</td>
<td>- Although the installation of AS and SVE wells is straightforward. The spacing and number of wells required to provide treatment and effectively capture the sparged off-gas may impact constructability and be very expensive. Rating: <strong>2</strong></td>
</tr>
<tr>
<td>Ability to operate, maintain, replace and monitor technical components</td>
<td>- Obtaining access to public property for the installation of AS/SVE wells could be a factor in the implementation of this alternative. Rating: <strong>3</strong></td>
</tr>
<tr>
<td>Ability to obtain permits from other agencies</td>
<td>- It will be necessary to obtain access to City right-of-way(s) to install the wells. Securing these permits is not anticipated to be a problem. Rating: <strong>3</strong></td>
</tr>
<tr>
<td>Availability and capacity of treatment, storage, and disposal facility</td>
<td>- Limited amounts of investigative derived waste would be generated during well installation, development and sampling. Rating: <strong>0</strong></td>
</tr>
<tr>
<td>Availability of property, specific material, equipment, and technical specialists required for a remedial action</td>
<td>- Access to public property for the installation and sampling of AS/SVE wells could be a factor. Well installation, system operation and maintenance are straightforward. Rating: <strong>3</strong></td>
</tr>
</tbody>
</table>

**Overall Implementability Rating Based on Lowest Score**: **2**
### Table 4-10. Qualitative Screening: Mid-Plume Area - Alternative 2 – Air Sparging/Soil Vapor Extraction

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs</td>
<td>• Capital Cost: $$$$$$$</td>
</tr>
<tr>
<td></td>
<td>• Operation &amp; Maintenance: $$</td>
</tr>
<tr>
<td></td>
<td>• Monitoring Costs: $$$</td>
</tr>
<tr>
<td></td>
<td>• Closure Cost: $$$$$$$</td>
</tr>
</tbody>
</table>

**Cost Rating**

$$$$$$

**Notes:**

COC = contaminant of concern  
RAO = Remedial Action Objective  
ARAR = Applicable or Relevant and Appropriate Requirement  
AS = air sparging  
SVE = soil vapor extraction  
VI = vapor intrusion
### Table 4-11. Qualitative Screening: Mid-Plume Area - Alternative 3 – Enhanced Reductive Dechlorination

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Overall protection of human health and the environment | • Over time, ERD would reduce COC levels to achieve RAOs.  
   • Rating: 3 |
| Compliance with ARARs | • Alternative would be compliant with ARARs. Permits would be needed for injection wells.  
   • Rating: 4 |
| Short-term effectiveness (during the remedial construction and implementation period) | • Construction of substrate delivery infrastructure would have a short-term impact on neighborhoods where transects are located. ERD would have an almost immediate effect on reducing the COCs concentrations following system startup.  
   • Rating: 4 |
| Long-term effectiveness and permanence (Following remedial construction) | • ERD may not be effective over the entire Mid-Plume Area due to reducing conditions with the high groundwater velocity area in the northern end.  
   • Rating: 3 |
| Reduction of toxicity, mobility, or volume through treatment | • ERD treatment will reduce TCE and other COC constituents to below cleanup goals. No residual material is anticipated to remain from the treatment process.  
   • Rating: 4 |
| Overall Implementability Rating Based on Lowest Score | 3 |
## Table 4-11. Qualitative Screening: Mid-Plume Area - Alternative 3 – Enhanced Reductive Dechlorination

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action | - The installation of injection wells and substrate injection is straightforward. Construction within residential areas may cause some disruption.  
- Rating: 3 |
| Ability to operate, maintain, replace and monitor technical components | - Obtaining access to private property for the installation of additional monitoring wells could be a factor in the implementation of this alternative.  
- Rating: 3 |
| Ability to obtain permits from other agencies | - It may be necessary to obtain access to City right(s)-of-way to install new monitoring. Securing these permits is not anticipated to be a problem. Injection permits will be required.  
- Rating: 3 |
| Availability and capacity of treatment, storage, and disposal facility | - Limited amounts of investigative derived waste would be generated during well installation, development and sampling. Substrate delivery would be temporary and portable.  
- Rating: 4 |
| Availability of property, specific material, equipment, and technical specialists required for a remedial action | - Access to public property for the installation and sampling of monitoring wells could be a factor.  
- Well installation, sampling and waste disposal are straightforward.  
- Rating: 4 |

### Overall Implementability Rating Based on Lowest Score

3
### Table 4-11. Qualitative Screening: Mid-Plume Area - Alternative 3 – Enhanced Reductive Dechlorination

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs</td>
<td></td>
</tr>
<tr>
<td>• Capital Cost: $$$$$</td>
<td></td>
</tr>
<tr>
<td>• Operation &amp; Maintenance: $$$$$</td>
<td></td>
</tr>
<tr>
<td>• Monitoring Costs: $$$</td>
<td></td>
</tr>
<tr>
<td>• Closure Cost: $$</td>
<td></td>
</tr>
</tbody>
</table>

**Cost Rating**

| $$$ |

**Notes:**

- ERD = enhanced reductive dechlorination
- RAO = Remedial Action Objective
- ARAR = Applicable or Relevant and Appropriate Requirement
- TCE = trichloroethylene
- COC = contaminant of concern
Table 4-12. Qualitative Screening: Mid-Plume Area - Alternative 4 – Downgradient Hydraulic Containment

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Overall protection of human health and the environment | • Removal of COCs would occur only as groundwater flowed toward treatment at downgradient edge of plume. Extraction wells would prevent further migration of plume. Achievement of RAOs throughout plume would take a long time.  
Rating: 3 |
| Compliance with ARARs | • Alternative would be compliant with ARARs. NPDES permit is required for stream discharge.  
Rating: 4 |
| Short-term effectiveness (during the remedial construction and implementation period) | • Capture and treatment of groundwater near the downstream edge of the plume would occur immediately after startup. Treatment of remainder of impacted groundwater would take a long time. Community disruption would be minimal.  
Rating: 3 |
| Long-term effectiveness and permanence (Following remedial construction) | • Over time, the impacted groundwater would move to the downgradient extraction wells. GAC treatment is effective in treating COCs to RAOs. Frequent carbon changeout can negatively impact O&M costs.  
Rating: 3 |
| Reduction of toxicity, mobility, or volume through treatment | • GAC treatment does reduce the volume of COCs on groundwater. GAC is disposed in a landfill.  
Rating: 3 |
| Overall Implementability Rating Based on Lowest Score | 3 |
Table 4-12. Qualitative Screening: Mid-Plume Area - Alternative 4 - Downgradient Hydraulic Containment

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action</td>
<td>• Extraction well and treatment system has been installed as an interim measure. Future expansion or maintenance would have minimal disruption on the community. Rating: 5</td>
</tr>
<tr>
<td>Ability to operate, maintain, replace and monitor technical components.</td>
<td>• Installing system required City ROW permit. Components for wells and treatment building are readily obtainable. Rating: 4</td>
</tr>
<tr>
<td>Ability to obtain permits from other agencies.</td>
<td>• It was necessary to obtain access to City ROW(s) to install extraction wells and place treatment building. NPDES permit is required for stream discharge. Rating: 4</td>
</tr>
<tr>
<td>Availability and capacity of treatment, storage, and disposal facility.</td>
<td>• Spent carbon is transported by commercial TSD for disposal. Rating: 5</td>
</tr>
<tr>
<td>Availability of property, specific material, equipment, and technical specialists required for a remedial action</td>
<td>• GAC is a common treatment technology for the COGs. Well installation, treatment, waste disposal are straightforward. Rating: 5</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 4-12. Qualitative Screening: Mid-Plume Area - Alternative 4 - Downgradient Hydraulic Containment

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
</table>
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs | • Capital Cost: Low – $$
• Operation & Maintenance: - $$$$$
• Monitoring Costs: - $$
• Closure Cost: - $$$$ |

Cost Rating

$$ $$

Notes:
COC = contaminant of concern
ARAR = Applicable or Relevant and Appropriate Requirement
O&M = Operation and Maintenance
NPDES = National Pollutant Discharge Elimination System
RAO = Remedial Action Objective
GAC = granular active carbon
ROW = right-of-way
TSD = Treatment, Storage, and Disposal
Table 4-13. Qualitative Screening: Mid-Plume Area - Alternative 5 - Directed Groundwater Recirculation

<table>
<thead>
<tr>
<th>Effectiveness Criteria Alternative</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
</table>
| Overall protection of human health and the environment | • COCs concentration would be treated throughout the plume area with multiple treatment transects and injection wells increasing pore flush rates  
• Rating: 5 |
| Compliance with ARARs | • Alternative would be compliant with ARARs. Permits would be needed for injection wells and effluent discharge.  
• Wastes generated during the installation of wells, well development and groundwater monitoring would have to be handled in compliance with action specific ARARs.  
• Rating: 4 |
| Short-term effectiveness (during the remedial construction and implementation period) | • Construction of well network and treatment buildings would have short-term impact on residential areas. Reduction in COC concentrations would begin immediately upon system startup.  
• Rating: 4 |
| Long-term effectiveness and permanence (Following remedial construction) | • COCs would be efficiently reduced to RAOs given that the injection wells would increase pore flushing rates.  
• Rating: 4 |
| Reduction of toxicity, mobility, or volume through treatment | • COCs in groundwater are reduced. GAC or air stripping treatment does not destroy chemicals.  
• Rating: 4 |

Overall Implementability Rating Based on Lowest Score | 4
### Table 4-13. Qualitative Screening: Mid-Plume Area - Alternative 5 – Directed Groundwater Recirculation

<table>
<thead>
<tr>
<th>Implementability Criteria</th>
<th>Evaluation Summary (score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to construct, reliably operate, and meet technology-specific regulations for process options until completion of the remedial action</td>
<td>• The installation of extraction and injection wells and treatment building is straightforward but not trivial. Permits would be required for right-of-way, injection, and stand-by discharge.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 3</td>
</tr>
<tr>
<td>Ability to operate, maintain, replace and monitor technical components</td>
<td>• Obtaining access to public property for the installation of wells and treatment buildings will be a factor in the implementation of this alternative.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Ability to obtain permits from other agencies</td>
<td>• It will be necessary to obtain access to City right-of-way to install wells and treatment buildings. Injection and discharge permits will be required.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Availability and capacity of treatment, storage, and disposal facility</td>
<td>• Limited amounts of investigative derived waste would be generated during well installation, development and sampling. If GAC treatment is used, spent carbon must be dispose of.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Availability of property, specific material, equipment, and technical specialists required for a remedial action</td>
<td>• Access to public property for the installation of wells and treatment buildings could be a factor.</td>
</tr>
<tr>
<td></td>
<td>• Well installation, treatment construction, and system operation are straightforward.</td>
</tr>
<tr>
<td></td>
<td>• Rating: 4</td>
</tr>
<tr>
<td>Overall Implementability Rating Based on Lowest Score</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 4-13. Qualitative Screening: Mid-Plume Area - Alternative 5 – Directed Groundwater Recirculation

<table>
<thead>
<tr>
<th>Evaluation Factors for Cost</th>
<th>Generalized cost (score)</th>
</tr>
</thead>
</table>
| Cost associated with implementation of the alternative including capital, monitoring, operation and maintenance, and closure costs | • Capital Cost: $$$$  
• Operation & Maintenance: $$$  
• Monitoring Costs: $$  
• Closure Cost: $$$ |

Cost Rating: $$$$  

Notes:  
ARAR = Applicable or Relevant and Appropriate Requirement  
COC = contaminant of concern  
GAC = granular  
RAO = Remedial Action Objective
<table>
<thead>
<tr>
<th>Mid-Plume Area Alternative</th>
<th>Description</th>
<th>Effectiveness¹</th>
<th>Implementability¹</th>
<th>Approximate Overall Relative Cost</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Action</td>
<td>0</td>
<td>5</td>
<td>$</td>
<td>Retained a baseline option. Costs would include on-going groundwater monitoring required by Consent Order.</td>
</tr>
<tr>
<td>2</td>
<td>Air Sparging/</td>
<td>3</td>
<td>2</td>
<td>$$$$$$</td>
<td>Removed from consideration due to high costs to implement for a large plume and potential for vapor intrusion issues at residential locations.</td>
</tr>
<tr>
<td></td>
<td>Soil Vapor Extraction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Enhanced Reductive</td>
<td>4</td>
<td>2</td>
<td>$$$$</td>
<td>Can be implemented, but will require significant infrastructure and periodic disruption during carbon source injection events.</td>
</tr>
<tr>
<td></td>
<td>Dechlorination</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Downgradient Hydraulic Containment</td>
<td>3</td>
<td>4</td>
<td>$$$$</td>
<td>This option is currently implemented as an interim measure. Effectiveness is limited by long time to achieve cleanup goals.</td>
</tr>
<tr>
<td></td>
<td>§</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Directed Groundwater Recirculation</td>
<td>4</td>
<td>3</td>
<td>$$$$</td>
<td>Implementable and will achieve cleanup goals within a reasonable time period.</td>
</tr>
</tbody>
</table>

Notes:
1 – Composite screening score using a (none) to (high) relative ranking.
2 – Shaded alternatives are removed from consideration and not carried forward to the detailed analysis.
3 – This alternative is currently in place as an interim measure in the form of the Murdock HCS. High costs are due to O&M costs associated with GAC change out.
4 – Costs include operation and maintenance because this alternative is currently implemented as the Murdock HCS.
HCS = Hydraulic Containment System
O&M = Operation and Maintenance
GAC = granular activated carbon
### Table 6-1. Comparative Analysis of Alternatives for the Source Area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Components:</strong></td>
<td>Limited groundwater monitoring</td>
<td>Hot Spot soil excavation beneath Waste Storage Area, Targeted ERD of Rail Yard soil and ERD transacts in upgradient and downgradient areas.</td>
<td>Deep soil excavation of readily accessible soils to bedrock and ERD transacts in upgradient and downgradient areas.</td>
</tr>
<tr>
<td></td>
<td>Five-year Site Reviews</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall Protection of Human Health and the Environment</strong></td>
<td>Hot Spot Excavation and Targeted ERD would permanently reduce exposure to sorbed COC mass and ERD would degrade COC mass in the saturated zone. Cleanup goals can be achieved over time.</td>
<td>Deep soil excavation would significantly reduce the amount of sorbed COC mass and ERD would degrade COC mass in the saturated zone. Cleanup goals can be achieved over time.</td>
<td>Hot Spot Excavation and Targeted ERD would permanently reduce exposure to sorbed COC mass and ERD would degrade COC mass in the saturated zone. Cleanup goals can be achieved over time.</td>
</tr>
<tr>
<td></td>
<td>Would comply with ARARs. Several permits (well construction, injection, access) would be required.</td>
<td>Would comply with ARARs. Several permits (well construction, injection, access) would be required.</td>
<td>Would comply with ARARs. Several permits (well construction, injection, access) would be required.</td>
</tr>
<tr>
<td><strong>Reduction of Toxicity, Mobility, or Volume through Treatment</strong></td>
<td>No treatment or reduction in mobility, mobility, or volume of contaminants.</td>
<td>Excavation and Rail Yard soil ERD provides a reduction in mobility and ERD reduces volume of dissolved phase COC mass.</td>
<td>Deep soil excavation and ERD provide a reduction in the volume of source area COC mass.</td>
</tr>
<tr>
<td></td>
<td>The short-term risks are not addressed and the time frame is open-ended</td>
<td>Hot Spot excavation would immediately reduce the mobility of sorbed COC mass and ERD would have an almost immediate effect on reducing dissolved phase COC concentrations.</td>
<td>Deep soil excavation would immediately reduce the volume of sorbed COC mass in the vadose zone and the saturated zone. ERD would have an almost immediate effect on reducing dissolved phase COC concentrations.</td>
</tr>
<tr>
<td><strong>Balancing Criteria</strong></td>
<td>Existing water well ordinances and institutional controls provide some protection to public health and the environment.</td>
<td>The combination of Hot Spot excavation and ERD would effectively reduce COC concentrations to achieve RAOs.</td>
<td>The limited amount of space present at the site would require soil excavation, staging of materials, and backfilling difficult. Installation of wells and injection lines is implementable.</td>
</tr>
<tr>
<td><strong>Long-Term Effectiveness and Permanence</strong></td>
<td>Monitoring is highly implementable.</td>
<td>Excavation and ERD area readily implementable. Permits will be required but they are not anticipated to be a problem.</td>
<td>Monitoring is highly implementable.</td>
</tr>
<tr>
<td><strong>Implementability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td>Period of Operation/ Active Treatment</td>
<td>Capital Cost</td>
<td>Total Periodic O&amp;M Cost</td>
</tr>
<tr>
<td></td>
<td>&gt;30 years</td>
<td>$0</td>
<td>$660,000</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>$860,000</td>
<td>$427,000</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>$1,927,000</td>
<td>$427,000</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>$2,825,000</td>
<td>$471,000</td>
</tr>
<tr>
<td></td>
<td>5 years</td>
<td>$1,544,000</td>
<td>$2,825,000</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
<td>1. Assumes 5 years of ERD injections and source area groundwater monitoring.</td>
<td>2. The no-action alternative would require some confirmatory monitoring, but monitoring costs are not included in this evaluation.</td>
<td></td>
</tr>
</tbody>
</table>

**Legend for Qualitative Rating System:**

<table>
<thead>
<tr>
<th>Ratings Categories for Threshold and Balancing Criteria</th>
<th>Ratings Categories for Cost Criteria (Present Value Cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Low (less than $500,000)</td>
</tr>
<tr>
<td>Low to moderate</td>
<td>Low to moderate (between $500,000 and $1 million)</td>
</tr>
<tr>
<td>Moderate</td>
<td>Moderate (between $1 million and $2 million)</td>
</tr>
<tr>
<td>Moderate to high</td>
<td>Moderate to high (between $2 million and $3 million)</td>
</tr>
<tr>
<td>High</td>
<td>High (greater than $3 million)</td>
</tr>
</tbody>
</table>
### Table 6-2. Comparative Analysis of Alternatives for Mid-Plume Area Groundwater

<table>
<thead>
<tr>
<th>Remedial Alternative:</th>
<th>Mid-Plume Area Alternative 1: No Action</th>
<th>Mid-Plume Area Alternative 2: Enhanced Reductive Dechlorination</th>
<th>Mid-Plume Area Alternative 3: Downgradient Hydraulic Containment</th>
<th>Mid-Plume Area Alternative 4: Directed Groundwater Restoration</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Major Components:</strong></td>
<td>Limited groundwater monitoring Five-year Site Reviews</td>
<td>ERD transects throughout Mid-Plume Area, with quarterly carbon substrates injections</td>
<td>Operation of the existing hydraulic containment system at Murdock Street. Six extraction wells, GAC treatment and NPDES discharge to Chisholm Creek.</td>
<td>Extraction well transects throughout Mid-Plume Area, with injection well placed to increase rate of pure water flushing in aquifer.</td>
</tr>
<tr>
<td><strong>Threshold Criteria</strong></td>
<td>Overall Protection of Human Health and the Environment:</td>
<td>Cleanup objectives would not be met</td>
<td>ERD would degrade COC masses throughout Mid-Plume Area. Cleanup goals can be achieved over time</td>
<td>Over time, upgradient impacted groundwater will migrate to treatment system at southern plume edge</td>
</tr>
<tr>
<td>Compliances with ARARs:</td>
<td>Would not comply with ARARs</td>
<td>Several permits (well construction, injection, access) would be required</td>
<td>Would comply with ARARs</td>
<td>Several permits (well construction, injection, access) would be required</td>
</tr>
<tr>
<td><strong>Balancing Criteria</strong></td>
<td>Reduction of Toxicity, Mobility, or Volume Through Treatment:</td>
<td>No treatment or reduction in toxicity, mobility, or volume of contaminants</td>
<td>Provides active treatment to all areas of the plume</td>
<td>Provides active treatment to downgradient portion of the plume. Over time, the impacted plume would migrate to system</td>
</tr>
<tr>
<td>Short-Term Effectiveness:</td>
<td>The short-term risks are not addressed and the time frame is unspecified.</td>
<td>Disruption of community from installation of water line and treatment plant. Effective immediately upon startup.</td>
<td>System is in place and operating. Effective for impacted groundwater at downgradient edge.</td>
<td>Disruption of community from installation of water line and treatment plant. Effective immediately upon startup.</td>
</tr>
<tr>
<td>Long-Term Effectiveness and Permanence:</td>
<td>Future risks to human health and the environment would not be eliminated.</td>
<td>Impacted groundwater would be remediated throughout Mid-Plume Area.</td>
<td>It will take many years for impacted groundwater to migrate to existing system.</td>
<td>Impacted groundwater would be remediated throughout Mid-Plume Area.</td>
</tr>
<tr>
<td>Implementability:</td>
<td>Monitoring is highly implementable.</td>
<td>Installation of wells and injection lines is implementable. Permits and access will be required.</td>
<td>System is currently installed and operational.</td>
<td>Installation of wells, water lines, and treatment systems is implementable. Permits and access will be required.</td>
</tr>
<tr>
<td><strong>Project Duration:</strong></td>
<td>Period of Operations: Active Treatment:</td>
<td>30</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>Capital Cost:</strong></td>
<td>$0</td>
<td>$4,176,000</td>
<td>$465,000</td>
<td>$4,675,000</td>
</tr>
<tr>
<td><strong>Total Periodic O&amp;M Cost:</strong></td>
<td>$0</td>
<td>$2,000,000</td>
<td>$0</td>
<td>$2,172,000</td>
</tr>
<tr>
<td><strong>Life Cycle Cost:</strong></td>
<td>$0</td>
<td>$535</td>
<td>$535</td>
<td>$535</td>
</tr>
<tr>
<td><strong>Notes:</strong></td>
<td>1. Estimated cost to install existing Murdock Hydraulic Containment System (from Forrester 2007).</td>
<td>2. Assumes continuation of existing GAC treatment.</td>
<td>3. The No Action Alternative would require some confirmatory monitoring but monitoring costs are not included in this evaluation.</td>
<td></td>
</tr>
</tbody>
</table>

Legend for Qualitative Rating System:

- **ARAR** = Applicable to Relevant and Appropriate Requirements
- **ERD** = Enhanced Reductive Dechlorination
- **COC** = Contaminant to Conserve

**Rating Categories for Qualitative Rating System**

- **Low**
- **Moderate**
- **High**

**Rating Categories for Cost Criteria (Present Value Cost)***

- **Low** (less than $2 million)
- **Moderate** (between $2 million and $5 million)
- **High** (greater than $15 million)

**Rating Categories for Threshold and Balancing Criteria**

- **Low**
- **Moderate**
- **High**

**Rating Categories for Cost Criteria (Present Value Cost):**

- **Low**
- **Moderate**
- **High**

*DGAR = direct groundwater remediation

**GAC** = granular activated carbon

**NPDES** = National Pollution Discharge Elimination System
PROJECTION: NAD 1983 StatePlane Kansas South FIPS 1502 Feet
AERIAL SOURCE: ESRI Online Imagery (NAIP, June 2014).
Notes:
1. Road and railroad data obtained from Sedgwick County Kansas GIS.
2. Not all well locations have been surveyed and their locations are approximate.
3. NM = Not Measured

Legend
- Monitoring and Observation Well
- NPDES Discharge Point
- Extraction Well
- Injection Well
- Piezometer
- Pumping Well
- Railroads

Sitewide Groundwater Elevations - November 2019

UNION PACIFIC RAILROAD 29 AND GROVE SITE
WICHITA, KANSAS
Groundwater Analytical Results for TCE, DCE, and VC - November 2019

Legend
- Monitoring and Observation Well
- NPDES Discharge Point
- Extraction Well
- Injection Well
- Piezometer
- Pumping Well

Railroads
Roads
Chisholm Creek
Ponds

Notes:
1. All concentrations are in micrograms per liter (µg/L)
2. Road and railroad data obtained from Sedgwick County Kansas GIS.
3. Not all well locations have been surveyed and their locations are approximate.
4. TCE = Trichloroethene
5. DCE = 1,2-Dichloroethene
6. VC = Vinyl Chloride
7. J+ = Concentration estimated; biased high
8. J = Concentration estimated
9. R = Rejected data
10. • = Resampled due to laboratory dilution error
11. •+ = Resampled due to laboratory dilution error
Hydrogeologic Conceptual Model

29TH AND GROVE SITE
WICHITA, KANSAS

Shale

Silt/Clay

> 1,000 ug/L

> 100 ug/L

Sands

Hydraulic barrier

Chisholm Creek

Transect 1

Transect 2

ERD Pilot Study Location

Transect 3

TCE source zone

Figure 1-4

G:\project\Union Pacific Railroad\Wichita, KS - 29th & Grove\Reports\Mid-Plume Feasibility Study\Figures\Figure 1-4 - Conceptual Site Model.xlsx
Legend
• Proposed Extraction Well
■ Extent of proposed in situ soil stabilization

INSET MAP AREA

SCALE IN FEET

0 20 40

UNION PACIFIC RAILROAD
29TH AND GROVE SITE
WICHITA, KANSAS

CONCEPTUAL DESIGN
SOURCE AREA ALTERNATIVE 3
IN SITU SOIL SOLIDIFICATION/STABILIZATION
AND GROUNDWATER PUMP-AND-TREAT

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Legend

▲ ERD Injection Well

ERD Injection Areas

Extent of proposed in situ soil stabilization and deeper ZVI treatment

INSET MAP AREA

UNION PACIFIC RAILROAD
29TH AND GROVE SITE
WICHITA, KANSAS

CONCEPTUAL DESIGN
SOURCE AREA ALTERNATIVE 5
IN SITU SOIL SOLIDIFICATION/STABILIZATION,
SOIL MIXING USING ZVI, AND ERD

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Service Layer Credits: Esri, HERE, Maxar, Garmin, Intermax, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Legend
- TCE Concentration Contour - 5 µg/L
- TCE Concentration Contour - 100 µg/L
- TCE Concentration Contour - 1,000 µg/L
- TCE Concentration Contour - 10,000 µg/L
- PCE Concentration Contour - 5 µg/L
- PCE Concentration Contour - 10 µg/L
- Existing Murdock Extraction Well
- Proposed Murdock Extraction Well
- Proposed DGR Extraction Well
- Existing Murdock Injection
- Proposed DGR Injection
- Railroads
- Chisholm Creek
- Historic Creek Channel - 1894 Topo

Note: TCE and PCE plume configurations developed in 2018.
Union Pacific Railroad

GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT

29th and Grove Site
Wichita, Kansas
Consent Order 01-E-0191

March 31, 2016
GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT

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1 INTRODUCTION

Union Pacific Railroad (UP) retained Arcadis U.S., Inc. (Arcadis) to develop a three-dimensional numerical groundwater flow and solute transport model for the 29th and Grove rail yard facility (Site) in Wichita, Kansas. The purpose of the model is to refine the understanding of subsurface flow conditions, capture zones associated with remedial systems, and the fate and transport of trichloroethene (TCE).

This modeling report has been prepared pursuant to the requirements identified in the Consent Order (Case Number 01-E-191) for the 29th and Grove Site between UP and the Kansas Department of Health and Environment (KDHE), dated September 20, 2002.

1.1 Site Location and History

The Site is located in the northeastern portion of Wichita, Sedgwick County, Kansas (Figure 1). The rail yard facility associated with the Site was originally owned by Missouri Pacific Railroad (MoPac). UP acquired the facility in 1982 as a result of a merger. Circumstances surrounding TCE impacts in soil and groundwater at the Site are currently unknown. TCE is the contaminant of concern (COC) at the Site, and the source area is located in the northern portion of the UP rail yard, east of Interstate 135. The area of delineated TCE groundwater impacts associated with the Site is known hereafter as the Project Area.

Other sources of chemical impacts (e.g., benzene, toluene, ethylbenzene, and xylenes (BTEX), from gasoline stations and perchloroethylene (PCE) from dry cleaners) have been detected within the groundwater at the Mid-Plume Area (MPA), evident by the horizontal and vertical extent of impact within the water-bearing zone. In particular, local sources are indicated by chemical concentrations that occur in the upper part of the water-bearing zone, while impacts in the lower part of the water-bearing zone indicate a more distant source.

1.2 Study Objectives and Scope

The objectives of this modeling study were to develop a groundwater flow and solute transport model for use as follows:

- Evaluate subsurface flow conditions
- Evaluate capture zones associated with a proposed Directed Groundwater Recirculation (DGR) remedial system
- Evaluate the fate and transport of TCE

This modeling report describes the results of the following five major components of the modeling study:

- Refinement of the conceptual site model (CSM)
- Development and calibration of the groundwater flow model
• Design of a DGR remedial system
• Development and prediction of a solute transport model
• Summary and conclusions
2 CONCEPTUAL MODEL - GROUNDWATER FLOW

A CSM is a description of the significant components of a groundwater flow system developed from regional, local, and site-specific data. These include, but are not limited to the following: (1) areal extent, configuration, and type of aquifers and aquitards; (2) hydraulic properties of aquifers and aquitards; (3) natural groundwater recharge and discharge zones; (4) anthropogenic influence on groundwater (sources and sinks); and (5) areal and vertical distribution of groundwater elevations. These aquifer system components serve as the framework for the construction of a numerical groundwater flow model (described in Section 3). Sections 2.1 and 2.2 provide a brief description of Site geology and hydrogeology, respectively.

2.1 Site Geology

The near surface geology at the Site typically consists of low-permeability clay. These deposits range in thickness from 0 to 20 ft and are on average 8 to 10 ft thick. Underlying the surficial deposits are alluvial sequences of coarse grained sands with silts. The alluvial deposits range in thickness from 10 to 45 feet and are 28 to 30 ft thick on average. The alluvial deposits are generally thinnest in the vicinity of the source area, increasing in thickness towards the southern and western limits of the Project Area. Beneath the alluvial deposits is the Wellington Formation, composed of Ordovician shale bedrock. The shale lies at approximately 30 to 50 ft below ground surface (bgs) increasing in elevation to the east of Grove Street. The surface contours of the shale surface indicate a buried paleochannel at the base of the alluvial deposits. The eastern margin of the paleochannel is located largely east of Grove Street, denoted by a north-to-south trending ridge (The Forrester Group 2007).

2.2 Site Hydrogeology

The Site lies near the eastern edge of the Arkansas River alluvial valley. The alluvial aquifer is not fully saturated, behaving as an unconfined aquifer across most of the Site and Project Area. The alluvial aquifer thins to the east of the Site as the underlying Wellington Formation increases in elevation, ultimately causing the alluvial aquifer to pinch out. Similarly, the aquifer thickens westward toward the center Arkansas River alluvial valley west. At the western limits of the alluvial valley, the Wellington Formation again increases in elevation, causing the alluvial aquifer to pinch out. The primary surface water features in the vicinity of the Site are the Little Arkansas River, Chisholm Creek and associated minor tributaries, and nearby ponds. Additional details on the Site CSM are provided in the Revised Feasibility Study (The Forrester Group 2007).

2.2.1 Groundwater Flow Conditions

2.2.1.1 Sources and Sinks

The primary source of groundwater for the aquifers is recharge from precipitation. The total annual precipitation for the site area is approximately 33 inches per year (in/yr) (NOAA 2010). Approximately 6.5 percent of this total annual precipitation is expected to infiltrate the land surface, leading to a recharge rate of 2.15 in/yr. This value is consistent with the range of reported recharge rates (2-4 in/yr) in literature.
for the Wichita, Kansas area (Hansen, 1991 and Sophocleous, 2003). Another groundwater source is the
borrow pond as recharge over the footprint of this feature is enhanced as this feature directly intercepts
and stores a larger percentage of precipitation. An additional source of groundwater is exfiltration from
the Little Arkansas River, located north and west of the Project Area. Sinks for groundwater in the
aquifers include Murdock Line Extraction Wells (in the vicinity of the southern end of the current TCE
plume delineation) and Chisholm Creek (located west of the Project Area). The extraction well pumping
rates for the regional and Project Area injection and extraction wells for 2013 are presented in Table 1.
3 GROUNDWATER FLOW MODEL CONSTRUCTION

The primary phases in the development of a numerical groundwater flow model include the construction of a finite-difference grid for the model area, specification of model structure, assignment of boundary conditions, specification of hydraulic parameter values and zones, and selection of appropriate water-level measurements for model calibration. These elements form the Site and Project Area conceptual model, which serves as the basis for the construction and subsequent calibration of the numerical model to observed groundwater flow conditions in the Site and Project Area.

3.1 Code Selection and Description

For the construction and calibration of the numerical groundwater flow model in the Site and Project Area, Arcadis selected the simulation program MODFLOW, a publicly available groundwater flow simulation program developed by the U.S. Geological Survey (USGS; McDonald and Harbaugh 1988). MODFLOW is thoroughly documented; widely used by consultants, government agencies, and researchers; and is consistently accepted in regulatory and litigation proceedings. In addition, Arcadis has developed utilities for use with MODFLOW to ease in the construction and calibration of groundwater models.

MODFLOW can simulate transient or steady-state saturated groundwater flow in one, two, or three dimensions and offers a variety of boundary conditions including specified head, areal recharge, injection or extraction wells, evapotranspiration, horizontal flow barriers (HFBs), drains, and rivers or streams. Aquifers simulated by MODFLOW can be confined or unconfined, or convertible between confined and unconfined conditions. For the Site and Project Area, which consists of a heterogeneous geologic system with variable unit thicknesses and boundary conditions, MODFLOW's three-dimensional capability and boundary condition versatility are essential for the proper simulation of groundwater flow conditions.

MODFLOW simulates transient, three-dimensional groundwater flow through porous media described by the following partial differential equation for a constant density fluid:

\[
\frac{\partial}{\partial t} \left( K_{xx} \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial y} \left( K_{yy} \frac{\partial h}{\partial y} \right) + \frac{\partial}{\partial z} \left( K_{zz} \frac{\partial h}{\partial z} \right) - W = S_s \frac{\partial h}{\partial t}
\]  

(3-1)

where:

- \( K_{xx}, K_{yy}, \) and \( K_{zz} \) are values of hydraulic conductivity along the x, y, and z coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity [L/T]
- \( h \) is the potentiometric head [L]
- \( W \) is a volumetric flux and represents sources and/or sinks of water [1/T]
- \( S_s \) is the specific storage of the porous material [1/L]
- \( t \) is time [T]
In Equation 3-1, the hydraulic parameters (i.e., $K_{xx}$, $K_{yy}$, $K_{zz}$ and $S_s$) may vary in space but not in time, while the source/sink ($W$) terms may vary in both space and time.

MODFLOW uses a numerical approximation technique known as the method of finite differences to solve Equation 3-1 on a computer. Using a block-centered finite-difference approach, MODFLOW replaces the continuous system represented in Equation 3-1 by a set of discrete points in space and time. This process of discretization ultimately leads to a system of simultaneous linear algebraic equations. The solution of the finite-difference equations predicts water levels at each of the discrete points representing the real aquifer system. Given a sufficient number of discrete points, the simulated water levels are close approximations of those provided by exact solutions to Equation 3-1.

3.2 Model Discretization

The finite-difference technique employed in MODFLOW to simulate water-level (hydraulic head) distributions in multi-aquifer systems requires areal and vertical discretization, or subdivision of the continuous aquifer system into a set of discrete blocks that form a three-dimensional model grid. In the block-centered finite-difference formulation used in these codes, the center of each grid block corresponds to a computational point or node. When MODFLOW solves the set of linear algebraic finite-difference equations for the complete set of blocks, the solution yields values of hydraulic head at each node (or three-dimensional block) in the three-dimensional grid.

Water levels computed for each block represent an average water level over the volume of the block. Thus, adequate discretization (i.e., a sufficiently fine grid) is required to resolve features of interest. MODFLOW allows the use of variable grid spacing to manage the total number of blocks in the model, thereby reducing the computational burden. A typical model will have a finer grid in areas of interest where greater accuracy is required and a coarser grid in areas requiring less detail.

The three-dimensional model grid developed for this Site occupies approximately 21 square miles. The model grid was aligned so the majority of grid cells are in the direction of groundwater flow (north to south). The finite-difference grid is composed of 278 columns, 843 rows, and two layers for a total of 468,708 active nodes. The model grid uses 20-foot areal grid spacing in the area of concern and grades to 400 ft spacing toward the model boundaries (Figure 2).

Individual model layers were used to represent the aquifer of sand and gravel beneath the Site, where groundwater movement occurs. The two layers were designated as follows:

- Model layer 1 consists of the Shallow Alluvial Aquifer.
- Model layer 2 consists of the Deep Alluvial Aquifer.

The alluvial aquifer was divided into two distinct layers because of variations in both hydraulic properties and water quality with depth. Evaluation of hydraulic conductivity values calculated from hydraulic testing at the Site indicates a general increase of hydraulic conductivity with depth in the alluvial aquifer. Hydraulic conductivity values from aquifer tests range from 200 feet per day (ft/d) to 1,200 ft/d (Arcadis 2015). The alluvial deposits are 28 to 30 ft thick on average, with the transition between the finer shallow sands and deeper gravels at approximately the middle of the aquifer. Therefore, the middle of the saturated aquifer is assigned as the bottom of layer 1 and the top of layer 2.
Monitoring wells in the alluvial aquifer indicate variations in the TCE plume footprint between the upper and lower portions of the alluvial aquifer. Simulating the alluvial aquifer as a two-layer model allows for potential vertical transport of TCE within the alluvial aquifer and evaluation of potential solute transport under surface water features. The surficial deposits consist of low-permeability clay. These deposits range in thickness from 0 to 20 ft and are on average 6 to 10 ft thick. The clay-dominated surficial deposit that overlies the alluvial aquifer is not discretely simulated, as it is mostly unsaturated, but the contact between the two units was used as the top of model layer 1 to allow for confined conditions in areas of elevated groundwater levels. The Wellington Formation that underlies the alluvial aquifer has relatively low permeability (ranging from $1.5 \times 10^{-6}$ ft/day to $2.42 \times 10^{-4}$ ft/day [Kelly et al. 2013]). The Wellington Formation is 6 to 9 orders of magnitude lower in permeability than the overlying alluvial aquifer. This extreme contrast in permeabilities resulted in the simulation of the Wellington Formation as a no-flow boundary condition.

### 3.3 Boundary Conditions

Boundary conditions are imposed to define the spatial boundaries of the model on the top, bottom, and all sides of the model grid. In addition to these boundary conditions, sources and sinks of groundwater, such as wells, drains, and rivers, are included within the model boundaries. This model includes five types of boundary conditions: no flow, recharge, rivers, general head boundaries, and pumping wells. The boundary conditions of model layers 1 and 2 are shown on Figure 3.

The Little Arkansas River is a major surface water feature located approximately 1.9 miles west of the Site. The Little Arkansas River will be represented in MODFLOW using river cells with assigned heads estimated from regional stage and topographic data. The river cells were defined in model layer 1 to account for partial penetration of the aquifer by the river. Although the river does not fully penetrate the alluvial aquifer (i.e., the bottom of the river is not in contact with the Wellington Formation), it is still a significant surface water feature that impacts groundwater flow. Moreover, given its size, behavior as a flow divide, and distance from the Project Area, it was selected as an appropriate western boundary for the groundwater flow model. The eastern boundary is represented by no-flow cells because the alluvial aquifer pinches out at the eastern extent of the paleochannel. The southern boundary of the model domain was formed by general head boundaries in both model layers. The general head boundary elevation was defined by interpolated regional groundwater levels that were a sufficient distance downgradient of the Site to minimize potential influence on the Project Area.

Within the model interior, Chisholm Creek and its associated drainage features were originally represented using drain cells with assigned heads estimated from regional data; the drain cell only serves as a groundwater sink and does not contribute water to the model. In order to account for potential leakage from Chisholm Creek during periods of low groundwater levels, the final calibrated groundwater model simulates Chisholm Creek as river cells that can serve as both a source and sink of water in the model. Portions of Chisholm Creek are channelized based on aerial photography and were accordingly assigned low conductance values. Also within the model domain, regional and Project Area extraction and injection wells were simulated as sinks and sources.
3.4 Bottoms and Hydraulic Parameters

In constructing the model for the Site and Project Area, representative values for model parameters were selected based on site- and Project Area-specific data. These model parameters included model bottoms, the horizontal and vertical hydraulic conductivity, and the recharge of the aquifer. The model was initially constructed with a simplified hydraulic conductivity zonation based on site and Project Area aquifer test data. During the calibration of the model, hydraulic conductivity zones were added and parameter values were adjusted within reason to minimize the difference between observed and simulated groundwater elevations.

The model bottoms for layers 1 and 2 are shown on Figure 4. Model layer bottoms were generated based on and interpolation of available site and regional boring logs. The model bottoms were not adjusted based on calibration. In general, bottom elevations decrease from north to south.

Model layer 1 represents the Shallow Alluvial Aquifer and consists of four hydraulic conductivity (K) zones (Figure 5). Zone 1 (K = 135 ft/d) extends throughout most of the model domain. Zone 2 (K = 25 ft/d) represents a less permeable portion of the Shallow Alluvial Aquifer that occurs in the immediate vicinity of the site source area. Zone 3 (K = 20 ft/d) represents an even lower conductivity zone that occurs along northeast edge of the Wellington Shale boundary. Zone 4 (K = 180 ft/d) represents a higher-conductivity paleochannel beneath Chisholm Creek.

Model layer 2 represents the Deep Alluvial Aquifer and consists of five hydraulic conductivity zones (Figure 5). Zone 5 (K = 270 ft/d) extends throughout most of the model domain. Zone 6 (K = 140 ft/d) and Zone 7 (K = 150 ft/d) represent less permeable portions of the Deep Alluvial Aquifer that occur in the vicinity of the Site source area and the fork of Chisholm Creek. Zone 8 (K = 75 ft/d) is an even lower conductivity zone that occurs along the northeast edge of the Wellington Shale boundary. Zone 9 (K = 562.5 ft/d) represents a high-conductivity paleochannel beneath Chisholm Creek.

A typical alluvial aquifer horizontal to vertical hydraulic conductivity ratio of 10:1 was utilized for all model layer 1 and 2 hydraulic conductivity zones. This ratio is supported by the limited vertical gradient between the shallow and deep alluvial aquifers on the regional scale of the model.

Areal precipitation recharge reaching the water table was modeled as two zones in model layer 1 (Figure 6). Recharge Zone 1 covers most of the model domain and has an estimated rate of 2.15 in/yr. This value is consistent with the range of reported recharge rates (2-4 in/yr) in literature for the Wichita, Kansas area (Hansen, 1991 and Sophocleous, 2003). Recharge Zone 2 covers Grove Pond and has an estimated rate of 20.0 in/yr to reflect water contribution from this surface water feature, as this borrow pond has been identified as a source of water in the model domain. Recharge over the footprint of this borrow pond is enhanced as this feature directly intercepts and stores a larger percentage of precipitation.

3.5 Calibration Targets

Calibration targets are a set of field measurements, typically groundwater elevations, used to test the ability of a model to reproduce observed conditions within a groundwater flow system. Table 2 presents the monitoring wells and water-level elevations from the time periods selected for the calibration and validation periods of the groundwater flow model. The May 2013 and December 2014 calibration and validation periods were selected as representative average conditions for simulation comparisons.
list of calibration targets is a set of water-level elevations measured during May 2013 that comprise a total of 39 monitoring wells, screened in the Shallow Alluvial Aquifer and the Deep Alluvial Aquifer. Six monitoring wells (MW-UP-01S, MW-UP01D, MW-UP-03, MW-UP-04Rd, OW-01S, and OW-01D) located in the immediate vicinity of the Source Area were not included in the statistical analysis due to being screened in an area with an increased degree of heterogeneity and complex geology where the Wellington Uplands transitions into the Arkansas River Alluvium that could not be adequately represented given the regional scale of the model. This May 2013 data set was selected as calibration targets because it is comprehensive and was collected from across the entirety of the Site and Project Area. A second set of water levels from December 2014 was chosen to further validate the calibrated groundwater flow model during the winter season. The December 2014 observed water levels consists of 34 monitoring wells screened in the Shallow Alluvial Aquifer and the Deep Alluvial Aquifer.
4 GROUNDWATER FLOW MODEL CALIBRATION

Calibration of a groundwater flow model refers to the process of adjusting model parameters to obtain a reasonable match between observed and simulated water levels. In general, model calibration is an iterative procedure that involves adjustment of hydraulic properties or boundary conditions to achieve the best match between observed and simulated water levels. During model calibration, site- and Project Area-specific data and prior aquifer tests were used to constrain estimates of hydraulic conductivity.

4.1 Calibration Procedure

For best results, the calibration of a model should rely on discrete measurements (water levels) to produce answers free of contouring interpretations. In the calibration of a groundwater flow model, use of point data eliminates the potential for interpretive bias that may result from attempting to match a contoured potentiometric surface (Konikow 1978; Anderson and Woessner 1992). The groundwater flow model for the Site and Project Area was calibrated using 39 water-level calibration targets measured during May 2013 and validated using 34 water-level calibration targets from December 2014 (Table 2).

As a further goal for the calibration of a model, the principle of parameter parsimony is applied to achieve an adequate calibration of the model through the use of the fewest model parameters. It should be noted that the use of more model parameters during model calibration creates a situation in which many combinations of model parameter values produce similar calibration results. In this case, the model calibration parameters are called non-unique. Following the principal of parameter parsimony reduces the degree of non-uniqueness and results in more reliable calibrated parameter values. The information gathered for the conceptual model guides any decision to add model parameters (e.g., zones of hydraulic conductivity) to the model during the calibration process. Therefore, the simpler model is preferred.

The primary criterion for evaluating the calibration of a groundwater flow model is the difference between simulated and observed water levels at a set of calibration targets. A residual or model error ($e_i$) is defined as the difference between the simulated ($h_i$) and observed ($h_i'$) hydraulic head measured at a target location:

$$e_i = h_i - h_i'$$

The calibration procedure seeks to minimize an objective function defined by the residual sum of squares (RSS):

$$RSS = \sum_{i=1}^{n} (h_i - h_i')^2$$

where $h_i$ is the simulated value of hydraulic head and $h_i'$ is the measured value at a specific target location. A residual with a positive sign indicates over prediction by the model (i.e., the simulated head is higher than the measured value). Conversely, a negative residual indicates under prediction.
The residual standard deviation (RSTD) is useful for comparing model calibrations with different numbers of calibration targets and estimated parameters. Another calibration measure is the mean of all residuals ($\bar{e}$):

$$
\bar{e} = \frac{1}{n} \sum_{i=1}^{n} e_i
$$

(4-4)

A mean residual significantly different from zero indicates model bias. The Gauss-Newton parameter estimation procedure produces a near-zero mean residual at the minimum RSS.

The groundwater flow model calibration required numerous individual computer simulations. The values and shapes of the various parameter zones in the model were gradually varied until a reasonable solution was achieved in agreement with the conceptual model. This primary calibration was achieved using MODFLOW and parameter estimation techniques designed for use with MODFLOW. The groundwater flow model calibration conducted was a steady-state calibration.

### 4.2 Calibration Results

The water-level calibration targets measured during May 2013 were used to evaluate the model calibration by analyzing the following: 1) simulated hydraulic head distributions across the Site and Project Area, 2) residual statistics, and 3) sensitivity of estimated hydraulic parameters.

#### 4.2.1 Simulated Hydraulic Head Distributions

As a part of evaluating the numerical model steady-state calibration, simulated potentiometric surface maps were prepared for the entire modeled region to ensure that simulated groundwater flow patterns were reasonable. Simulated potentiometric surface maps were prepared to depict groundwater flow conditions from May 2013 for each model layer in the model domain (Figure 7). The majority of observed vertical hydraulic gradients between the shallow and deep portions of the main alluvial aquifer in the vicinity of the plume are neutral.

#### 4.2.2 Analysis of Residuals

The primary goals of the groundwater flow model steady-state calibration were to minimize the calculated residual sum of squares (Equation 4-2) and to match the observed groundwater flow direction in the Site and Project Area. The calculated residual sum of squares is 39.4 square feet ($ft^2$). The primary groundwater flow direction is north-to-south in the Site and Project Area, which is matched in the simulation (Figure 8). Table 2 lists the simulated water elevations and model residuals for the calibration targets from May 2013. The Site and Project Area map of simulated hydraulic heads (Figure 8) shows the spatial distribution of the residuals for May 2013 in model layers 1 and 2. The plotted calculated residuals
indicate that the majority of the residuals fall within the 10 percent observed range of data (Figure 9). Overall, the model shows a good match to the measured water levels.

Residual statistics for the calibrated steady-state groundwater flow model also indicate good agreement between simulated and measured groundwater elevations (Figure 9 and Table 2). The residual standard deviation was calculated to be 0.77 ft. The residual standard deviation is less than 5 percent of the range of observed water-level elevations for the targets. Table 3 presents the water balance, which indicates that the model had a good degree of closure, with the volumetric budget equal to $-1.21 \times 10^{-3}$. The water balance also indicates that the river boundary conditions account for approximately 20% of the total inflow to the model and 30% of the total outflow of the model, which indicates these surface water features are a significant portion of this regional flow model. Figure 7 indicates the different portions of the surface water feature that are gaining, losing, or are predominantly neutral under the steady-state calibration conditions. The bulk of Chisholm Creek in the area of concern is a gaining feature with the exception of the channelized portions of Chisholm Creek are predominantly neutral due to the limited hydraulic connection.

4.3 Model Validation

No modifications were made to the calibrated groundwater flow model boundary conditions or hydraulic parameters for the December 2014 model validation analysis. Table 2 lists the simulated water elevations and model residuals for the steady-state calibration targets from December 2014. The calculated residual sum of squares is 40.3 ft$^2$. Residual statistics for the December 2014 target set also indicate good agreement between simulated and measured groundwater elevations (Table 2). The residual standard deviation was calculated to be 0.75 ft. The residual standard deviation is less than 5 percent of the range of observed water-level elevations for the targets. These statistics, along with the May 2013 statistics, indicate that an acceptable degree of calibration has been achieved in this modeling effort. As there were no changes to boundary conditions of hydraulic parameters, the water balance presented for the model calibration (Table 3) is the same for this model validation period.

4.4 Murdock Line Extraction Wells Capture Extent

An analysis was performed to determine the simulated extent of hydraulic capture in both model layers based on recent operation of the Murdock Line extraction wells. Flow field information from the calibrated steady-state MODFLOW Model was used for this purpose. Capture zones were delineated using the MODular flow ALlocation (MODALL) program (Potter et al. 2006, 2008), which uses the MODFLOW-calculated cell-by-cell flow terms to delineate the zone of capture. Capture zones delineated by MODALL provide a conservative estimate of capture limits similar to a pathline analysis using MODPATH. The capture zones for model layers 1 and 2 are depicted on Figure 10. The model indicates that the Murdock Line extraction wells effectively capture contaminants moving north-to-south from the Site and a portion of the contamination south of the Murdock Line.
5 SENSITIVITY ANALYSIS

A limited sensitivity analysis was conducted with respect to hydraulic conductivity, recharge, and river conductance. Sensitivity analyses were only conducted with respect to the groundwater flow model. Hydraulic conductivity, recharge, and river conductance were varied by multiplying each parameter by 0.5, 0.75, 1.25, 1.5, 1.75, and 2.0. The multipliers simulated in the sensitivity analysis were selected based on the observed range of hydraulic parameters for the Site and regional areas from available aquifer tests and literature reviews. The sum of squared residuals of each model run was compared to test the relative sensitivity of the model calibration to each parameter. The results of the sensitivity analysis are shown in Table 4.

5.1 Hydraulic Conductivity

Available aquifer test data for the alluvial aquifer indicate hydraulic conductivity vary between 200 and 1,200 ft/d. Accordingly, the calibrated hydraulic conductivity values were multiplied by factors of 0.5 to 2.0 to assess the impact on model calibration. As the hydraulic conductivity multiplier is increased from 1.0 to 2.0 (i.e., the hydraulic conductivity in the model increases), the residual sum of squares increases indicating poorer calibration. Similarly, the model calibration worsens as hydraulic conductivity of the model decreases to 50 percent of the calibrated value (a multiplier of 0.5). This sensitivity analysis indicates that the model achieves its best calibration with the base values simulated.

5.2 Recharge

The range of typical recharge rates for the Wichita, Kansas area is approximately 2 to 4 in/yr (Hansen, 1991 and Sophocleous, 2003). The initial model calibration indicated that a lower recharge value of 2.15 in/yr (6.5 percent of average annual precipitation) for the majority of the model domain was appropriate based on the area being fairly developed. Increasing the simulated recharge indicated a relatively high degree of sensitivity. Increasing the multiplier from 1.0 to 2.0 resulted in an increase the sum squared residual from 39.4 ft² to 259.1 ft². As the recharge multiplier decreases, the model indicated a low degree of sensitivity, and the sum squared residual decreases (from a value of 39.4 ft² at a multiplier of 1.0 to 21.4 at a multiplier of 0.5). Although the residual sum of squares slightly improves with a lower recharge value, the calibrated recharge value is more realistic and falls within the range of reported literature recharge rates for the area, and was maintained as the selected recharge value.

5.3 River Conductance

As the river conductance is dependent on the permeability of the riverbed sediment, the same multipliers applied to the hydraulic conductivity were assessed in the sensitivity analysis. Decreasing river conductance indicates a relatively high degree of sensitivity as the residual sum of squares increases significantly, indicating a poorer model calibration. This indicates the importance of the hydraulic connection of the surface water features to the model. Increasing the river conductance parameter resulted in lower sensitivity, and the residual sum of squares improved. Doubling the river conductance parameter changes the sum squared residual from 39.4 ft² to 17.8 ft². Despite the
improvement in model calibration, the initial calibrated riverbed conductance terms were used to represent more conservative site conditions to allow for a greater potential of groundwater flow under Chisholm Creek.
6 DIRECTED GROUNDWATER RECIRCULATION SYSTEM DESIGN

Although the capture analysis described in Section 4.3 indicates that the Murdock Line extraction wells captures the majority of the plume, the period of performance and capture can be further enhanced by a DGR system. The simulated DGR system has three primary goals:

- Clean up the TCE plume to concentrations lower than 5 micrograms per liter (µg/L) within a 10-year period of performance.
- Isolate the site source area from the rest of the plume.
- Minimize pumping rates for efficiency.

The proposed well layout for the DGR system is presented on Figure 11. The proposed well layout was optimized for plume control and mass removal. The implementation was divided into two steady-state time periods: years 0 to 5 and years 5 to 10. Seasonal variations were not incorporated into the predictive modeling of the DGR system as the modeling represents long term average conditions. The only flow model parameters or boundary conditions that were varied in these two sequential steady-state stress periods were the pumping wells. The following discussion assumes that the Murdock extraction line and associated injection wells will continue to operate during the 10-year period. From years 0 through 5, the DGR system will be operated using 14 extraction wells and 17 injection wells recirculating water at 475 gallons per minute (gpm). Line 1 is located northwest of 26th and Grove Streets to isolate the source area from the rest of the plume. The Line 2 DGR Wells are located along 24th Street, between Platt Avenue and Grove Street. The Line 3 DGR Wells are located along 21st Street, between Jardine and Grove Streets. The Line 4 DGR Wells are located along 17th Street, between Ash and Spruce Streets. The Line 5 DGR Wells are located along 12th Street, between Minneapolis and Madison Streets. Finally, the Murdock Line Extraction Wells are located along Murdock Street between Interstate 135 and Ash Street.

Consistent with all remedial systems, a major optimization will be needed during remedy operation to enhance site restoration. In application, the time for optimization will be based upon system data. For this assessment it was estimated to occur approximately 5 years into the remedy. After year 5, the remedy will continue to operate at 475 gpm but there will be a total of 21 extraction wells and a total of 21 injection wells. The locations for the DGR lines remain the same between the two layouts. Additional extraction wells were added between the treatment lines, and additional injection wells were added between Line 5 and the Murdock Line. Table 5 summarizes the proposed layout pumping rates for each line.

6.1 DGR System Capture Extent

An analysis was performed to evaluate the DGR system capture extent in both model layers. MODALL (Potter et al. 2006; 2008) was again used to simulate the fraction of hydraulic capture for both layouts. The simulated steady-state groundwater capture for the first 5 years in model layers 1 and 2 is shown on
Figure 12. Essentially all (99.4 percent) of the on-site and project area TCE is within the capture zone of the DGR and Murdock Line extraction wells in both model layers. The simulated groundwater capture for the second 5 year period in model layers 1 and 2 is presented on Figure 13. Approximately 96.9 percent of the on-site and Project Area TCE is captured by the DGR and Murdock Line Extraction Wells in both model layers. The simulated 5 year TCE plume was used to approximate the percent of TCE captured by the DGR system.

6.2 Solute Transport Modeling

Solute transport modeling was performed to evaluate the migration and fate of TCE and the period of performance of the proposed design. The solute transport model used the steady-state flow output from the simulated DGR system layouts to evaluate the proposed remedial system. The steady-state flow model was selected because although short term fluctuations in conditions may occur seasonally or annually, they not anticipated to impact the long term overall performance of the remedial design. All of the steady-state groundwater model flow parameters are consistent with the calibrated steady state model. No formal solute transport model calibration was conducted in this modeling analysis, but solute parameter values assigned to generate the simulation results were a result of available site data, literature searches, and professional judgement.

6.2.1 Code Selection

The modular three-dimensional transport model referred to as MT3D was originally developed by Zheng (1990) at S.S. Papadopulos & Associates, Inc., and subsequently documented for the Robert S. Kerr Environmental Research Laboratory of the U.S. Environmental Protection Agency. The MT3D code uses the flow terms and velocities computed by MODFLOW in its transport calculations. MT3D also uses the same finite-difference grid structure and boundary conditions as the groundwater flow model, minimizing the effort necessary to construct a solute transport model. MT3D underwent a major revision in 1999 (Zheng and Wang 1999) being renamed MT3DMS. The MS denotes the multi-species structure for accommodating add-on reaction packages. MT3DMS has a comprehensive set of options and capabilities for simulating advection, dispersion/diffusion, and chemical reactions of contaminants in groundwater flow systems under general hydrogeologic conditions. MT3DMS (version 5.3) was selected over previous versions of MT3D and RT3D because it more readily accounts for multi-species transport, transformation, and incorporates the dual-domain formulation.

6.2.2 Transport Parameters

The primary solute transport model parameters considered in this analysis were porosity, mass transfer coefficient, dispersion, sorption, and initial concentration distributions in the mobile and immobile fractions of the aquifer. As there is minimal evidence for degradation of TCE and the production of daughter products such as cis-1,2 dichloroethene or vinyl chloride, no degradation of TCE was simulated. Also, with the intent of the model is to simulate solute transport and remediation due to DGR, and hydraulically isolating the source area from the rest of the plume, the potential impact of non-aqueous phase liquids on plume concentrations outside the source area were not evaluated.
6.2.2.1 Porosity

Solute transport was simulated using the dual-domain approximation. In a dual-domain model, two fraction terms are entered, one for the mobile aquifer fraction and one for the immobile aquifer fraction. The mobile fraction represents the portion of the aquifer where groundwater moves (advection dominated); while the immobile fraction represents groundwater is static (diffusion dominated). Mass is transferred between compartments slowly because the process is controlled by diffusion (Gillham et al. 1984; Moiz et al. 2006; Flach et al. 2004; Harvey and Gorelick 2000; Feehley et al. 2000; Julian et al. 2001; Zheng and Bennett 2002). The total porosity of the model was estimated to be 35 percent and is the sum of the two domains (mobile fraction and immobile fraction). Each model layer has the same mobile fraction of 12 percent and immobile fraction of 23 percent. These fractions are based on lithologic descriptions, literature, and professional judgment.

6.2.2.2 Mass Transfer Coefficient

The mass transfer coefficient (MTC) value for the solute transport model was systematically adjusted between $1.0 \times 10^{-5}$ (1/day) and 1.0 (1/day), and small-scale and short-term plume movements were evaluated until the solute transport model produced reasonable plume movement. These values were also justified by evaluating the average flow velocities through the individual grid cells over the footprint of the plume. The final calibrated mass transfer coefficients of $9.19 \times 10^{-4}$/day and $2.10 \times 10^{-3}$/day were used in model layers 1 and 2, respectively. These values are consistent with commonly applied literature values (Gillham et al. 1984; Moiz et al. 2006; Flach et al. 2004; Harvey and Gorelick 2000; Feehley et al. 2000; Julian et al. 2001; Zheng and Bennett 2002). The solute transport model was run with initialized current plumes (second quarter 2014) to determine if the selected MTC produced reasonable results with the constituent distribution currently observed.

6.2.2.3 Dispersion

Numerical dispersion was considered in the transport analysis in the Site and Project Area; a limitation of the finite-difference scheme applied by MT3D is that some numerical dispersion is inherent in the simulation results. Numerical dispersion is a function of the size of the mesh, the time step size, the hydrogeologic properties assigned in the model, and the simulated water levels. Numerical dispersion is an artifact of the solution process, but there is no mathematical difference between the effects of physical or numerical dispersion. The numerical dispersivity can be computed on a block-by-block basis in models solved using finite difference methods (Zheng and Bennett 1996). Application of the equations reported by Zheng and Bennett (1996) indicates that the numerical dispersivity is approximately one half the modeled grid size (approximately 10 feet for this analysis in the Site and Project Area); therefore, dispersion coefficients were not explicitly defined.

6.2.2.4 Sorption

The retardation factor ($R_t$) is used by the solute transport model to represent the amount of adsorption of a constituent between the dissolved and solute phase and adsorbed to the aquifer. The retardation factor is calculated using the bulk density ($p_b$), the total porosity ($n$) of the aquifer material, and a distribution coefficient ($K_d$) according to the following equation:
The distribution coefficient is the product of the organic carbon content in the aquifer ($f_{oc}$) and the constituent distribution coefficient normalized to particulate organic carbon ($K_{oc}$):

$$K_d = K_{oc} \times f_{oc}$$  \hspace{1cm} (6-2)$$

A $f_{oc}$ value of 0.05 percent was assumed throughout the model domain for TCE. The literature reports a range of $K_{oc}$ values for TCE. A representative value of 60.7 milliliters per gram (ml/g) (USEPA 2014) was chosen for this transport simulation. In the areas where the TCE source was simulated, a higher sorbed mass was assumed; therefore, the $K_d$ was increased in these areas to represent the persistent elevated source area TCE concentrations observed over time. As the goal of the solute transport modeling is to hydraulically isolate the source area and focus on the remediation of the plume footprint downgradient of the source area, no discrete source zone remediation was simulated.

### 6.2.2.5 Initial TCE Distribution

The initial TCE plume concentration was based on both second quarter 2014 monitoring results and on July-August 2003 Soil Borings (The Forrester Group 2006). In both model layers, the plume delineation was varied to reflect the differing TCE concentration with depth. The distribution of TCE for model layers 1 and 2 is shown on Figure 14. Equal contaminant concentrations were initialized in both the mobile and immobile domains.

### 6.2.3 Transport Results

The solute transport results for years zero through 10 are shown on Figures 14 through 24. During the first 2 years, areas exhibiting TCE concentrations lower than 5 µg/L begin to emanate from the injection wells, as shown on Figures 14 through 16. By year 3 (Figure 17), the source area is completely separated from the rest of the plume in model layer 2. The plume separates once again in model layer 2 in year 4 between Lines 2 and 3 (Figure 18). In year 5, the well layout switches from the 0-5 year layout to the 5-10 year layout. Throughout the first 5 years of simulation, there is no substantial east-west spread of the plume (Figures 14 through 19). By year 6, the source area is completely separated from the rest of the plume in model layer 1. At year 8, the vast majority of the plume exhibits TCE concentrations lower than 5 µg/L in layer 2, and there are only a few interior portions of the plume with concentrations higher than 50 µg/L in layers 1 and 2 (Figure 22). By the end of the period of performance of 10 years (Figure 24), the majority of the plumes in layers 1 and 2 exhibit TCE concentrations lower than 50 µg/L. In total, 97 percent of the mass is removed from the plumes in model layers 1 and 2 (not including the source area) during the 10-year period of performance. The mass balance summary at annual intervals for the predictive solute transport model run are presented in Table 6.
7 UNCERTAINTIES

As with all mathematical models of natural systems, the groundwater flow and solute transport model is limited by factors such as scale, accuracy of the estimated hydraulic properties and/or boundary conditions, and the underlying simplifications and assumptions incorporated into the model. These factors result in limitations to the model's appropriate uses and to the interpretations that may be made of the simulation results. The proposed DGR design was based on the CSM, calibrated groundwater flow model, the predictive solute transport modeling, and professional judgment. Flexibility in design needs to be considered in the operation of any remedy to address potential changes in target treatment areas and changes in conditions. Individual groundwater flow parameters, boundary conditions, and solute transport parameters may influence the simulated predictive results of the solute transport modeling presented in this report. Greater hydraulic conductivity values may result in faster groundwater flow velocities and enhance the remedial timeframe while lower hydraulic conductivity values would have the converse effect. Increases in recharge may enhance pore flushing thereby reducing the remedial timeframe, but increases in recharge may also reduce the capture extent of the simulated extraction wells. Increases in riverbed conductance would result in a greater potential of recharge or discharge to the surface water features which may impact the extent of hydraulic capture zones of extraction wells near the river. Increases in sorption parameters may result in longer remedial timeframes as additional pore flushes would be needed to reach remedial targets. Increases in total porosity would result in a lower retardation factor which would enhance remedial timeframes. Decreases in mobile porosity would cause an increase in groundwater flow velocity resulting in faster remedial timeframes. As the mass transfer coefficient approaches the value of 1, the more the simulated porosity will behave as total porosity, and as the mass transfer coefficient is reduced (approaches 0), the more the porosity will behave as mobile porosity as mass exchange would be restricted between the mobile and immobile fractions. While all of these parameters may influence the predictive solute transport model results, the predictive solute transport model results represents the best estimate of plume behavior based on the individually justified flow model parameters, boundary conditions, and solute transport model parameters.

Several strategies were used to address the uncertainties inherent in the predictive model. The hydraulic conductivity distribution was based on actual aquifer test results, and the calibration was adjusted within reason to match these results (as described in Section 3.4). The plume extent and magnitude was based on both second quarter 2014 monitoring results and on July-August 2003 Soil Borings (The Forrester Group 2006). This enabled the outside of the plume to be delineated more accurately than with monitoring well data alone.

However, some uncertainty still remains, especially with respect to the mobile and immobile fractions. The difference in concentrations between the mobile and immobile fractions cannot be directly quantified. For the solute transport modeling, mobile and immobile initialized concentrations were assumed to be equivalent. This was based on TCE concentration data collected in second quarter 2014 and also considered historical TCE concentration data and trends.

The purpose of the modeling was to simulate the movement and transport of groundwater impacted from the TCE release at the UP rail yard. The presence of the down gradient and non-rail yard sources of PCE from dry cleaner and benzene, toluene, ethylbenzene, and xylenes (BTEX) from gas station releases will affect the concentrations observed in the field. Because TCE is a breakdown product of PCE, some TCE in the plume is likely contributed by PCE sources.
The primary transport mechanisms in the model are advection and mixing, both of which are based on the parameters defined in the groundwater flow model. The rate of advection is also a function of the defined retardation factor. In this model a typical value was selected for the TCE retardation factor (based on an assumed f_{oc} of 0.05%) which provides a reasonable estimate of remedial timeframes. However, it is recognized that aquifer heterogeneity and plume distribution varies in the physical system and the remedy system operation will need to be continually optimized during remediation to address the changing plume. Given the results of the sensitivity analysis of the groundwater flow model, it is expected that a 25% range in solute transport results (remedial timeframe) is reasonable as the solute transport model results are proportional to groundwater flow rates (advection and/or mixing).

While the model simulations suggest that the TCE plume from the rail yard source can be substantially cleaned up in approximately 10 years, the existing downgradient sources may continue to create elevated detections in shallow groundwater that are locally observed. Unless these identified downgradient sources of impacts to groundwater are independently remediated, they will continue to impact the groundwater.

Upon completion of the remedial action at the MPA, the disposition of the DGR system will be determined.
8 CONCLUSION

Historical and recent hydrogeologic data were collected at the Site and Project Area, and additional published information was used to construct and calibrate a three-dimensional groundwater flow and solute transport model. The simulation of groundwater flow and contaminant transport was performed to evaluate the migration of TCE on site and in the Project Area and to support the design of a DGR system.

The groundwater flow model was developed to simulate flow and be integrated into a solute transport model to simulate TCE transport within the Shallow and Deep Alluvial Aquifer (model layers 1 and 2, respectively). The solute transport model simulated a dual-domain system with sorption. In areas where the TCE source was simulated, a higher retardation factor was used to reflect the persistent high concentrations observed in the source area.

Modeling simulations were conducted to evaluate the effectiveness of the proposed DGR system design. The solute transport model evaluated the system for a period of 10 years. Simulation results suggest that the proposed DGR system can remove 97.2 percent of the mass in the shallow and deep plume (not including the source area). In order to effectively remediate the plume downgradient of the source area, hydraulic isolation and remediation of the source area are recommended. The proposed DGR system simulated in this modeling exercise demonstrates effective isolation of the source area from the downgradient plume.

The modeling conducted in this report uses conservative assumptions that may over predict the shallow and deep plume migration and extent. Monitoring should be conducted to ensure the model's predictive capability, and the model should be updated if necessary to allow for future evaluations and potential optimizations.
9 REFERENCES


Molz, F. J., C. Zheng, S. M. Gorelick, and C. F. Harvey. 2006. Comment on “Investigating the Macrodispersion Experiment (MADE) site in Columbus, Mississippi, using a three-dimensional inverse flow and transport model” by Heidi Christiansen Barlebo, Mary C. Hill, and Dan Rosbjerg. Water Resources Research. 42 no. 6 W06603


TABLES
### Table 1: 2013 Pumping Well Rate

Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

<table>
<thead>
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*All Wells Are Screened in Layers 1 and 2*
Table 2. Calibration Targets and Calculated Residuals
Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

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Residual Statistics

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<th>December 2014</th>
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<tr>
<td>Total Used</td>
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<tr>
<td>Minimum (ft)</td>
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<tr>
<td>Maximum (ft)</td>
<td>2.195</td>
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<tr>
<td>Mean (ft)</td>
<td>0.65</td>
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<tr>
<td>Standard Deviation (ft)</td>
<td>0.777</td>
</tr>
<tr>
<td>Sum Squares Residual (ft²)</td>
<td>40.435</td>
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<tr>
<td>Range in Observed Water Levels (ft)</td>
<td>16.1</td>
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<tr>
<td>Scaled Standard Deviation (%)</td>
<td>4.80%</td>
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Table 3. Water Balance
Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

<table>
<thead>
<tr>
<th>CUMULATIVE VOLUMES, cu. ft</th>
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<th>TOTAL IN</th>
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</thead>
<tbody>
<tr>
<td>STORAGE</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>CONSTANT HEAD</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>WELLS</td>
<td>7,507</td>
<td></td>
</tr>
<tr>
<td>RIVER LEAKAGE</td>
<td>74,196</td>
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</tr>
<tr>
<td>HEAD DEP BOUNDS</td>
<td>57,061</td>
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<tr>
<td>RECHARGE</td>
<td>208,930</td>
<td>347,694</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>RATES FOR THIS STEP, cu. ft/day</th>
<th>IN</th>
<th>TOTAL IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE</td>
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<td></td>
</tr>
<tr>
<td>CONSTANT HEAD</td>
<td>0</td>
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<tr>
<td>WELLS</td>
<td>7,507</td>
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<tr>
<td>RIVER LEAKAGE</td>
<td>74,196</td>
<td></td>
</tr>
<tr>
<td>RECHARGE</td>
<td>208,930</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL IN                          | 347,694       |

<table>
<thead>
<tr>
<th>CUMULATIVE VOLUMES, cu. ft</th>
<th>OUT</th>
<th>TOTAL IN</th>
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<tbody>
<tr>
<td>STORAGE</td>
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</tr>
<tr>
<td>CONSTANT HEAD</td>
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<tr>
<td>WELLS</td>
<td>142,450</td>
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</tr>
<tr>
<td>RIVER LEAKAGE</td>
<td>115,410</td>
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<tr>
<td>HEAD DEP BOUNDS</td>
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<tr>
<td>RECHARGE</td>
<td>0</td>
<td>347,698</td>
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<table>
<thead>
<tr>
<th>RATES FOR THIS STEP, cu. ft/day</th>
<th>OUT</th>
<th>TOTAL IN</th>
</tr>
</thead>
<tbody>
<tr>
<td>STORAGE</td>
<td>0</td>
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</tr>
<tr>
<td>CONSTANT HEAD</td>
<td>0</td>
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<tr>
<td>WELLS</td>
<td>142,450</td>
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<td>RIVER LEAKAGE</td>
<td>115,410</td>
<td></td>
</tr>
<tr>
<td>RECHARGE</td>
<td>89,838</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL OUT                        | 347,698       |

| IN-OUT                           | -4.20E+00     |
|                                  | Volumetric Budget | -1.21E-03 |
Sensitivity Analyses

Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

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<th>Multiplier</th>
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<tr>
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<td>Recharge</td>
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Values in the table are the Sum Squared Residual (ft²)
Table 5. Proposed Well Layout Pumping Rates
Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

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<th>Year 5-10</th>
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<td>Number Injection Wells</td>
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<td>55</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>4</td>
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<tr>
<td>4</td>
<td>100</td>
<td>4</td>
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<td>5</td>
<td>120</td>
<td>4</td>
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<tr>
<td>Sub Total</td>
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<tr>
<td>Murdock Line</td>
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<tr>
<td>Total</td>
<td>514</td>
<td>21</td>
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Line numbers refer to Figure 11.
Table 6. Mass Balance
Groundwater Flow and Solute Transport Model Report
Union Pacific Railroad, 29th and Grove Site, Wichita, Kansas

<table>
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<tr>
<th>Time (days)</th>
<th>Time (years)</th>
<th>Total In (percent of total initial mass)</th>
<th>Total Out (percent of total initial mass)</th>
<th>Sources (percent of total initial mass)</th>
<th>Sinks (percent of total initial mass)</th>
<th>Total Mass in Aquifer (percent of total initial mass)</th>
<th>Total Mobile Sorbed Mass (percent of total initial mass)</th>
<th>Total Mobile Liquid Phase Mass (percent of total initial mass)</th>
<th>Total Immobile Sorbed Phase Mass (percent of total initial mass)</th>
<th>Total Immobile Liquid Phase Mass (percent of total initial mass)</th>
<th>Percent Discrepancy</th>
<th>Total Source Mass North of A line (percent of total initial mass)</th>
<th>Total Mass in Aquifer Excluding Source (percent of total initial mass)</th>
<th>Percent of total mass remaining excluding source</th>
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<td>0.5</td>
<td>0.001</td>
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<td>0.00%</td>
<td>-0.03%</td>
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<td>44.53%</td>
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<td>47.14%</td>
<td>41.96%</td>
<td>10.07%</td>
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<td>43.96%</td>
<td>1.53%</td>
<td>3.2%</td>
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FIGURES
Legend:
- No Flow Boundary Cell
- River Boundary Cell
- Well Boundary Cell
- General Head Boundary Cell
- Source Area

*Note: River Boundary Condition is in Layer 1 only.

Boundary Conditions

UNION PACIFIC RAILROAD
UNION PACIFIC RAILROAD
TRANSPORT MODEL REPORT

ARCADIS

GROUNDWATER FLOW AND SOLUTE
WICHITA, KANSAS

BOUNDARY CONDITIONS

FIGURE 3
LEGEND

- **No Flow**
- **Boundary Cell**
- **Source Area**

- **Zone 1**: $K_h/K_v = 135/13.5$ ft/day
- **Zone 2**: $K_h/K_v = 25/2.5$ ft/day
- **Zone 3**: $K_h/K_v = 20/2.0$ ft/day
- **Zone 4**: $K_h/K_v = 180/18.0$ ft/day
- **Zone 5**: $K_h/K_v = 270/27.0$ ft/day
- **Zone 6**: $K_h/K_v = 140/14.0$ ft/day
- **Zone 7**: $K_h/K_v = 150/15.0$ ft/day
- **Zone 8**: $K_h/K_v = 75/7.5$ ft/day
- **Zone 9**: $K_h/K_v = 562.5/56.25$ ft/day
LEGEND

- No Flow Boundary Cell
- Source Area
- Zone 1: Recharge = 2.15 in/yr
- Zone 2: Recharge = 20.0 in/yr

(Zone 2 is Grove Pond)
LEGEND

- No Flow Boundary Cell
- Simulated Groundwater Level (ft)
- Residuals (ft)

*Residual = Simulated - Observed

0 1,500 3,000 Scale in Feet

UNION PACIFIC RAILROAD
2IP AND GROVE SITE
WICHITA, KANSAS
GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT

SIMULATED GROUNDWATER LEVELS AND RESIDUALS MODEL LAYERS 1 AND 2

@ARCADIS
Residual Statistics

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</tr>
<tr>
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<tr>
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OBSERVED VS. SIMULATED WATER LEVELS
LEGEND

- 5 μg/L TCE Contour from 2nd Quarter 2014
- Simulated Groundwater Level (ft)
- No Flow Boundary Cell
- Murdock Line Injection Well
- Murdock Line Extraction Well

Contours represent groundwater capture efficiency. A value of 1.0 represents 100% capture.
LEGEND
- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

5 mg/L TCE Contour from 2nd Quarter 2014

All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.

Contours represent groundwater capture efficiency. A value of 1.0 represents 100% capture.

UNION PACIFIC RAILROAD
27th AND GROVE SITE
WICHITA, KANSAS
GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT

SIMULATED GROUNDWATER CAPTURE MODEL LAYERS 1 AND 2 YEAR 0-5

ARCADIS
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well
- 5 Year 6 µg/L Simulated TOC Contour

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2. Contours represent groundwater capture efficiency. A value of 1.0 represent 100% capture.
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

TCE Concentration (µg/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

TCE Concentration (µg/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Extraction Well
- Proposed Injection Well

TCE Concentration (\(\mu\)g/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.

UNION PACIFIC RAILROAD
220 AND GROVES SITE
WICHITA, KANSAS
GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT
SIMULATED TCE RESULTS YEAR 2

ARCADIS
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

TCE Concentration (µg/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.
LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Injection Well
- Proposed Extraction Well

TCE Concentration (µg/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.

UNITED PACIFIC RAILROAD 23RD AND GROVE SITE WICHITA, KANSAS GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT SIMULATED TCE RESULTS YEAR 5"
**LEGEND**

- **No Flow Boundary Cell**
- **Existing Injection Well**
- **Murdock Line Extraction Well**
- **Proposed Injection Well**
- **Proposed Extraction Well**

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.*

**TCE Concentration (µg/L)**

**SCALE IN FEET**

**UNION PACIFIC RAILROAD**
29TH AND GROVE SITE
WICHITA, KANSAS
GROUNDWATER FLOW AND SOLUTE TRANSPORT MODEL REPORT
SIMULATED TCE RESULTS YEAR 6

**FIGURE 20**
*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.

LEGEND

- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Extraction Well
- Proposed Injection Well
Simulated TCE Results Year 10

Legend:
- No Flow Boundary Cell
- Existing Injection Well
- Murdock Line Extraction Well
- Proposed Extraction Well
- Proposed Injection Well

TCE Concentration (µg/L)

*All pumping rates are in gallons per minute (gpm) and are total rates between Layers 1 and 2.
APPENDIX B

Mid-Plume Area Injection and Long-Term Pilot Test Summary
Union Pacific Railroad

Mid-Plume Hydraulic and Injection Testing Report

29th and Grove Site, Wichita, Kansas
Consent Order 01-E-0191
KDHE Code C2-087-70135

April 2015
Revised May 26, 2016
Mid-Plume Hydraulic and Injection Testing Report

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Acronyms and Abbreviations

btoc  below tcp of casing
DCE  dichloroethene
DGR  directed groundwater circulation
ft   feet
gpm  gallons per minute
HCS  Hydraulic Containment System
IW   injection well
KDHE Kansas Department of Health and Environment
µg/L micrograms per liter
mg/L milligrams per liter
NPDES National Pollutant Discharge Elimination System
NTU nephelometric turbidity units
PCE tetrachloroethene
TCE trichloroethene
UP Union Pacific
VOC volatile organic compound
1. Introduction

This report provides a summary of the hydraulic and injection testing activities conducted in the mid-plume area of the Union Pacific Railroad (UP) 29th and Grove Site in Wichita, Kansas (Site), presented on Figure 1. The reported activities have been conducted to support pilot-scale reinjection testing of treated groundwater from the existing Hydraulic Containment System (HCS) currently in operation at the Site. The HCS was installed to control downgradient migration of dissolved chlorinated volatile organic compounds (VOCs), primarily trichloroethylene (TCE), in the groundwater plume.

The hydraulic data collected will be used to support the successful design and implementation of a full-scale directed groundwater recirculation (DGR) system, which is being evaluated as a potential new remedial strategy for the mid-plume portion of the Site. The hydraulic testing and reinjection pilot testing had two principal objectives:

- Evaluate the hydraulic capability of the alluvial sediments to accept reinjection of treated groundwater.
- Determine the long-term impacts of groundwater reinjection on the aquifer and evaluate potential operational and/or maintenance issues that will need to be addressed in the DGR design.

1.1 Scope of Work

The hydraulic and injection testing was conducted in two phases. An initial phase of discrete short-term hydraulic and injection tests was conducted at four locations throughout the mid-plume area (IW-3, IW-6, IW-7, and IW-8), each positioned to investigate different regions of the potential injection aquifer. A second phase of long-term injection testing was conducted at four reinjection wells located north and west of the HCS (IW-1, IW-2, IW-3, and IW-4). Locations of these wells are presented on Figure 2. The scope of work included the following activities:

- Geoprobe electrical conductivity and rate of penetration profiling, collection of soil samples and grain size data to support injection well design (July 31 to August 1, 2013)
- Installation and development of injection wells and adjacent observation wells at selected locations (September 5 to 8, 2013)
Completion of hydraulic step testing to evaluate specific pumping capacity of each injection well and associated drawdown characteristics (November 12 to 14, 2013)

Collection of baseline groundwater samples from the injection wells (November 12 to 15, 2013)

Completion of short-duration injection step tests to evaluate the short-term well-specific injection capacity of each injection well (November 15 to 20, 2013)

Evaluation of the hydraulic testing results to determine design injection rates for long-term testing

Installation of injection piping between the HCS and the injection wells and modification of the HCS to allow partial discharge of treated effluent to the newly installed injection wells, the schematics for which are illustrated on Figures 3 and 4 (February and March 2014)

Conducting long-term injection testing on wells IW-1 through IW-4, including monitoring changes in injection specific capacity (April 10, 2014 to March 27, 2015)

All activities were conducted in accordance with the Mid-Plume Re-injection Pilot Test Work Plan (Mid-Plume Work Plan), which was revised and submitted to the Kansas Department of Health and Environment (KDHE) on February 1, 2013 and approved by KDHE in a letter dated February 6, 2013.
2. Borehole Advancement and Well Installation Activities

To collect the required information for screen size and filter pack selection for the injection wells, four boreholes (BH-4, BH-6, BH-7, and BH-8) were advanced from July 31 to August 1, 2013 by direct-push methodology for geotechnical assessment. Associated activities included lithological core logging, electrical conductivity profiling, and the collection of soil samples for grain size analysis. The borehole locations are presented on Figure 2, and the advancement depths are provided in Table 1. The geotechnical laboratory results for grain size analysis and well design parameters (screen and filter pack) are presented in Attachment 1, and borehole logs and electrical conductivity and rate of penetration profiling logs are provided in Attachment 2.

Borehole drilling was followed by the drilling and installation of seven 6-inch-diameter injection wells (IW-1, IW-2, IW-3, IW-4, IW-6, IW-7, and IW-8) from September 5 to 8, 2013, by Rotasonic drilling methodology. The well locations are presented on Figure 2, and the installation details are presented in Table 1. The lithological logs and well construction diagrams are provided in Attachment 2. Each of the wells was developed by air lifting and surge and pump methodologies. The volume of water extracted and ending turbidity (nephelometric turbidity units [NTU]) are presented in Table 1 and well development logs provided in Attachment 3. Groundwater generated by the development of the injection wells was transported by a truck-mounted tank to the HCS for treatment and discharge via the system National Pollutant Discharge Elimination System (NPDES) outfall.

To enable the collection of additional observation data during hydraulic testing activities on the injection wells, four observation wells (OW-3, OW-6, OW-7, and OW-8) were installed adjacent to the injection wells, from October 24 to 25, 2013, by direct-push methodology. The observation wells were each installed at a distance of approximately 5 feet (ft) from the respective injection well (IW) location. The observation well locations are presented on Figure 2, advancement depths are provided in Table 1, and well construction diagrams provided in Attachment 2. Lithology was not logged during installation due to the close proximity to the adjacent injection well. Each of the observation wells was developed by surging and pumping using a Waterra inertial pump configuration, with the volume of water extracted and ending turbidity (NTU) presented in Table 1. Groundwater generated by the development of the observation wells was transported by a truck-mounted tank to the HCS for treatment and discharge via the system NPDES outfall.
3. Hydraulic and Short-Term Injection Testing Activities

Hydraulic pumping and injection testing were conducted on injection wells (IW-3, IW-6, IW-7, and IW-8) from November 11 to 20, 2013. The results were used to evaluate the aquifer's capacity to receive injected water and to determine injection rates for the long-term testing. The testing activities and results are presented below.

3.1 Injection Well IW-3

Injection well IW-3 is located in the south of the investigation area, adjacent to the HCS, as presented on Figure 2. IW-3 exhibited a static water level of 16.10 ft below top of casing (btoc) with a water column of 10.90 ft. A step test was conducted on IW-3 on November 12, 2013, pumping for three 20-minute increments at rates of 2.5 gallons per minute (gpm), 7 gpm and 10 gpm, with a maximum drawdown of approximately 5.7 ft. The specific capacity data are summarized in Table 2 and a graphical trend is presented in Attachment 4. The specific capacity trend was linear for the first two steps, but at 10 gpm and deviated from a straight line with increased drawdown. The specific capacity was approximately 2.0 gallons per foot of drawdown at a rate of 7 gpm. After completion of pumping activities, the well recovered to static water level conditions in approximately 20 minutes. The adjacent observation well (OW-3, approximately 5 ft away) exhibited a maximum drawdown of 0.4 ft over the test period.

Injection testing was conducted on November 15, 2013, with potable water being injected at rates of 2.9 gpm, 8.7 gpm, and 12.5 gpm. IW-3 had a freeboard of approximately 16.1 ft bgs, and during testing exhibited maximum mounding of 8.66 ft, resulting in a reduction of freeboard to approximately 7.4 ft bgs. The specific injection capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific injection capacity was approximately 2.0 gallons per foot of mounding at a rate of 8.7 gpm. The specific injection capacity trend was linear for the first two steps, but at 12.5 gpm deviated from linear with increased mounding. After completion of injection activities, the well recovered to static water level conditions in approximately 20 minutes. The adjacent observation well (OW-3) displayed 0.45 ft of mounding over the test period, with a decreasing trend of mounding for the final step note and final recovery to 0.1 ft below static conditions. The final trend and recovery to a water level below static is likely due to changing atmospheric conditions during the test period.
### 3.2 Injection Well IW-6

Injection well IW-6 is located in the central western portion of the investigation area, as presented on Figure 2. IW-6 exhibited a static water level of 13.73 ft bgl, with a water column of 16.27 ft. A step test was conducted on IW-6 on November 13, 2013, pumping at three 20- to 25-minute increments at rates of 25 gpm, 50 gpm, and 94 gpm, with a maximum drawdown of approximately 3.5 ft. The specific capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific capacity trend was linear for all three steps. The specific capacity was approximately 27 gallons per foot of drawdown at a rate of 94 gpm. After completion of the pumping activities, the well recovered to static water level conditions in approximately 10 minutes. The adjacent observation well (OW-6, approximately 5 ft away) exhibited a maximum drawdown of 1.2 ft over the test period.

Injection testing was conducted on November 19, 2013, with potable water being injected at rates of 20 gpm, 40 gpm, and 80 gpm. IW-6 had freeboard of approximately 13.7 ft bgs, and during testing exhibited maximum mounding of 3.01 ft, resulting in a reduction of freeboard to approximately 10.7 ft bgs. The specific injection capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific injection capacity was approximately 33 gallons per foot of mounding at a rate of 50 gpm. The specific injection capacity trend was linear for the first two steps, but at 80 gpm, deviated slightly from linear with increased mounding. After completion of injection activities, the well recovered to static water level conditions in approximately 15 minutes. The adjacent observation well (OW-6) displayed approximately 0.55 ft mounding over the test period.

### 3.3 Injection Well IW-7

Injection well IW-7 is located in the central eastern portion of the investigation area, as presented on Figure 2. IW-7 exhibited a static water level of 20.69 ft bgl with a water column of approximately 14.3 ft. A step test was conducted on IW-7 on November 13, 2013, pumping at three 20- to 25-minute increments at rates of 25 gpm, 50 gpm, and 94 gpm, with a maximum drawdown of 7.2 ft. The specific capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific capacity trend was linear for the first two steps, but at 94 gpm, deviated from linear with increased drawdown. The specific capacity was approximately 18 gallons per foot of drawdown at a rate of 50 gpm. After completion of pumping activities, the well recovered to static conditions in approximately 30 minutes. The adjacent
observation well (OW-7, radius approximately 5 ft) exhibited a maximum drawdown of 1.2 ft over the test period.

Injection testing was conducted on November 20, 2013, with potable water being injected at rates of 20 gpm, 40 gpm, and 80 gpm. IW-7 had freeboard of approximately 20.7 ft bgs, and during testing had maximum mounding of 5.70 ft, resulting in a reduction of freeboard to 15.0 ft bgs. The specific injection capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific injection capacity was approximately 14.5 gallons per foot of mounding at a rate of 80 gpm. The specific injection capacity trend was linear for all three steps. After completion of injection activities, the well recovered to static water level conditions in approximately 1 hour. The adjacent observation well (OW-7) displayed approximately 1.2 ft mounding over the test period.

3.4 Injection Well IW-8

Injection well IW-8 is located in the northern portion of the investigation area, approximately 3,000 ft downgradient of the source zone, as presented on Figure 2. IW-8 exhibited a static water level of 19.40 ft bgs with a water column of approximately 16.6 ft. A step test was conducted on IW-8 on November 12, 2013, pumping at three 20- to 23-minute increments at rates of 25 gpm, 50 gpm, and 87 gpm, with a maximum drawdown of approximately 7.0 ft. The specific capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific capacity trend was linear for the first two steps, but at 87 gpm, deviated from linear with increased drawdown. The specific capacity was approximately 16 gallons per foot of drawdown at a rate of 50 gpm. After completion of pumping activities, the well recovered to static conditions in approximately 120 minutes. The adjacent observation well (OW-8, radius approximately 5 ft) exhibited a maximum drawdown of 1.2 ft over the test period.

Injection testing was conducted on November 20, 2013, with potable water being injected at rates of 20 gpm, 40 gpm, and 80 gpm. IW-8 had freeboard of approximately 19.4 ft bgs, and during testing, exhibited maximum mounding of 5.47 ft, resulting in a reduction of freeboard to 13.9 ft bgs. The specific injection capacity data are summarized in Table 2, and a graphical trend is presented in Attachment 4. The specific injection capacity was approximately 14.5 gallons per foot of mounding at a rate of 80 gpm. The specific injection capacity trend was linear for all three steps. After completion of injection activities, the well recovered to static water level conditions in approximately 60 minutes. The adjacent observation well (OW-7) displayed approximately 1.2 ft mounding over the test period.
3.5 Waste Disposal

A total volume of 12,000 gallons of waste water was extracted as part of the hydraulic testing activities, which was transported by a truck-mounted tank to the HCS for treatment and discharge via the system NPDES outfall.
4. **Long-Term Injection Testing**

Long-term injection testing provides an understanding of each individual injection well's capacity to inject and the aquifer's capacity to receive injected water. Injection capacity is assessed by comparison of injection flow and mounding in response to injection in the injection wells (well capacity) and surrounding non-injecting groundwater monitoring wells (aquifer capacity).

**Well Capacity:** Reduction in capacity of injection wells over time can be due to well fouling by physical blocking (sediment), biological growth (biofouling), chemical precipitation and/or air entrainment due to injected and trapped air in the well pack and adjacent formation. Well capacity reductions are identified by increased injection well mounding combined with minimal or no change in mounding conditions to adjacent non-injecting monitoring wells.

**Aquifer Capacity:** Aquifer capacity is indicated by change in both the injecting and non-injecting groundwater monitoring wells. Where, mounding increases with time at a sustained injection rate can indicate the presence aquifer boundary conditions in proximity to the injection area, such as creeks, rivers, changes in the aquifer thickness, and/or lithological conditions. In the HCS area, potential boundary and/or aquifer changes exist in the form of:

- **Chisolm Creek,** which flows from north-northwest to south-southwest, parallel and 200 ft to the west of the injection wells (**Figure 2**)

- **Variable aquifer thickness and grain size,** increasing from the north to south (from IW-4 to IW-1), as indicated by the borehole lithological logs presented on the cross section included in **Attachment 2**.

To test the aquifer receiving capacity in the vicinity of the HCS, long-term injection testing was conducted on injection wells IW-1, IW-2, IW-3, and IW-4 (**Figure 2**). These wells are orientated north-to-south and are intended to create a hydraulic barrier to the western edge of the treatment area.

Injection of treated effluent was commenced on April 10, 2014 to March 27, 2015. As part of the testing activities, the flow rates (system and individual wells) and water level readings in the injection wells were monitored. This enabled assessment of the treatment system performance, injection system performance, and provides an evaluation of aquifer response and capacity. Water levels in the wells were recorded as...
depth block, both during injection to assess the well performance and after a period of recovery (while not injecting) to establish static water level conditions.

4.1 Treatment System Design and Performance

The injection system was designed so that treated water could be injected into wells IW-1 through IW-4 or discharged from the NPDES permitted outfall. Piping was installed to connect the HCS to the injection wells, with the schematics presented on Figures 3 and 4. The water flow rate through the treatment system is graphically presented on Figure 5, including the system influent, outfall effluent, and combined injection well flow rate. The combined injection well flow rate is also presented on Figure 6, and the cumulative injection volume is presented on Figure 7. The goal was to establish and maintain a fairly consistent injection rate to enable long-term assessment of the aquifer response. Over the course of the entire period of the long-term injection, the average daily flow rate delivered to the injection wells was 21.6 gpm, with a total volume of approximately 11,000,000 gallons of water injected up to March 26, 2015.

At system startup, the inflow was set to approximately 130 gpm. Outflow was split between the injection wells and the outfall, with daily flow averaging 25.1 gpm and 104.9 gpm, respectively, with a peak daily injection flow of 30.7 gpm. These flows were maintained until June 2014, after which the system flow to injection declined and became inconsistent, with daily injection flow averaging 16.6 gpm for the period of June 1, 2014 through to the August 26, 2014. This was caused by biofouling blocking the bag filters, thereby restricting and reducing flow to the injection wells.

Bag filtering was part of the system flow path for injection but not for discharge to the outfall. The bag filters were typically changed bi-weekly, resulting in an instantaneous injection flow rate increase coupled with corresponding decline in flow rate to the outfall. Then, over the interim period, a steady decline in injection flow rate occurred until the next bag filter change. However, from June 2014 through August 2014, a steady decline in the maximum achievable flow to the injection wells was observed due to overall biofouling increase in the system, including the air stripper, which if not cleaned would quickly lead to re-blocking of the bag filters.

On August 26, 2014, in response to the issue of system biofouling, systematic monthly system cleaning was initiated, including air stripper treatment and bag filter replacement. The cycle resulted in the immediate increase to maximum monthly injection rates, up to approximately 60 gpm (Figure 6), followed by a slow decline in...
injection flow until the next cleaning event was conducted a month later. Additionally, on occasion, the system was shut down for other maintenance tasks, during which time the bag filters were also changed, resulting in a more frequent flow cycle during some periods. During the period of August 27, 2014 to March 26, 2015, daily injection flow averaged 22.9 gpm.

4.2 Injection Well Performance

The locations of injection wells IW-1, IW-2, IW-3, and IW-4 are presented on Figure 2, with IW-4 the northernmost and IW-1 the southernmost well. The total injection flow rate is presented on Figure 6, injection into each of wells is presented on Figure 8, and individual injection rates for each well are presented on Figures 9 through 12.

During the injection testing activities, the combined daily injection flow averaged 21.6 gpm, with maximum average daily and weekly injection rates of 60.6 gpm and 49.6 gpm, respectively. The injection flow was split among the four injection wells, with the majority of flow (70 to 100 percent) directed towards wells IW-1 and IW-2 due to their higher injection capacities. In the first month of testing, the valves directing flow were adjusted such that IW-1 and IW-2 were fully open, but IW-3 and IW-4 were adjusted to be only partially open. This configuration limited the risk of potential system shutdown due to a high water level in one of the wells.

The injection well water levels are presented combined on Figure 13, and individually for each well on Figures 14 through 17. The graphs illustrate the response to injection, with water levels rising during injection and then returning to static conditions upon cessation of injection. The water level in injection well IW-3 was elevated to within 6 ft of the top of casing at the start of the injection program (Figure 16); hence, flow was reduced to this well. All wells displayed a slight decrease in static groundwater level over the course of the program due to a regional decline in groundwater levels.

The injection well capacities, in order of greatest injection capacity to least, were as follows: IW-1 > IW-2 > IW-4 > IW-3. The primary difference in respective injection well capacity was due to lithological differences of the aquifer into which the respective injection wells are screened. Each well was screened across the entire extent of the aquifer at the respective location. However, the boring logs indicate (Attachment 2) that the aquifer thickness and grain size vary in the HCS area.

Injection well IW-1 displayed the greatest injection capacity, and correspondingly, the lithological log indicates an aquifer thickness in this area of more than 10 ft, primarily...
comprising course grained materials. The aquifer thicknesses at IW-2 through to IW-4 are thinner than that of IW-1. The lithological log for IW-3 also indicated a higher proportion of fine grained materials. The long-term injection testing results from each of the injection wells are described individually below.

4.2.1 Injection Well IW-1

The injection rate for IW-1 is presented on Figure 9, and water level response on Figure 14. A total volume of approximately 5,100,000 gallons of water was injected into IW-1 over the course of the injection testing (April 8, 2014 to March 26, 2015). Injection was performed at an average flow rate of 10.2 gpm, with maximum injection rates of 32.4 gpm and 26.4 gpm over a day and week, respectively, during the testing period.

During the injection activities, the water level varied from approximately 16.7 ft btdc to 12.7 ft btdc, with up to 4.0 ft of head increase in response to active injection. The long-term specific injection capacity data are summarized in Table 2, and a graphical trend is included in Attachment 4. The average specific injection capacity was 8.6 gallons per foot of head, which followed a linear trend at the injection rates tested. Long term specific capacity trends at similar pumping rates are presented in Table 3. A reduction in specific capacity of approximately 12% for well IW-1 was observed between October 2014 and March 2015.

4.2.2 Injection Well IW-2

The injection rate for IW-2 is presented on Figure 10, and water level response on Figure 15. A total volume of approximately 4,100,000 gallons of water was injected into IW-2 over the course of the injection testing (April 8, 2014 to March 26, 2015). Injection was performed at an average flow rate of 8.2 gpm, with maximum injection rates of 19.4 gpm and 15.3 gpm over a day and week, respectively, during the testing period.

During the injection activities, the water level varied from approximately 16.8 ft btdc to 11.7 ft btdc, with up to 4.5 ft of head increase in response to active injection. The long-term specific injection capacity data are summarized in Table 2, and a graphical trend is included in Attachment 4. The average specific injection capacity was 4.9 gallons per foot of head, which followed a linear trend at the injection rates tested. Long term specific capacity trends at similar pumping rates are presented in Table 3. A reduction in specific capacity of approximately 29% for well IW-2 was observed between October 2014 and March 2015.
in specific capacity of approximately 16\% for well IW-2 was observed between September 2014 and March 2015.

### 4.2.3 Injection Well IW-3

The injection rate for IW-3 is presented on Figure 11, and water level response on Figure 16. A total volume of approximately 290,000 gallons of water was injected into injection well IW-3 over the course of the injection testing (April 8, 2014 to March 26, 2015). Injection was performed at an average flow rate of 0.6 gpm, with maximum injection rates of 7.9 gpm and 5.3 gpm over a day and week, respectively, during the testing period.

During the injection activities, the water level varied from approximately 15.7 ft btoc to 6.3 ft btoc, with up to 9.2 ft of head increase in response to active injection. The long-term specific injection capacity data are summarized in Table 2, and a graphical trend is included in Attachment 4. The average specific injection capacity was 0.6 gallon per foot of head, which followed a relatively linear trend at the injection rates tested. Long-term specific capacity trends at similar pumping rates are presented in Table 3. A reduction in specific capacity of approximately 23\% for well IW-3 was observed between September 2014 and March 2015.

### 4.2.4 Injection Well IW-4

The injection rate for IW-4 is presented on Figure 12, and water level response on Figure 17. A total volume of approximately 1,510,000 gallons of water was injected into IW-4 over the course of the injection testing (April 8, 2014 to March 26, 2015). Injection was performed at an average flow rate of 3.0 gpm, with maximum injection rates of 16.8 gpm and 13.9 gpm over a day and week, respectively, during the testing period.

During the injection activities, the water level varied from approximately 16.3 ft btoc to 8.6 ft btoc, with up to 7.7 ft of head increase in response to active injection. The long-term specific injection capacity data are summarized in Table 2, and a graphical trend is included in Attachment 4. The average specific injection capacity was 2.6 gallons per foot of head, which followed a linear trend at the injection rates tested. Long-term specific capacity trends at similar pumping rates are presented in Table 3. A reduction in specific capacity of approximately 15\% for well IW-4 was observed between September 2014 and March 2015.
4.3 Aquifer Response and Receiving Capacity

The long-term aquifer receiving capacity has been assessed by the sustained injection of treated water into the HCS area aquifer from April 10, 2014 to March 26, 2015, coupled with static water level monitoring (measured when injection was stopped). A total volume of approximately 11,000,000 gallons of water was injected (Figure 9) at an average rate of approximately 21.6 gpm (Figure 6). The majority of volume, typically 70 to 100 percent, was injected into wells IW-1 and IW-2.

During this period, static water levels in the injection wells area decreased by approximately 0.2 ft. Concurrent groundwater monitoring results from other non-injection groundwater monitoring wells in the area are compared in Table 4. The water levels indicate that approximately 0.14 ft of mounding has occurred in the HCS area in response to the long-term water injection. This created a hydraulic barrier to the western edge of the HCS treatment area.

The degree of mounding indicates that the receiving aquifer in the HCS area has not been significantly stressed by the injection activities and has the ability to receive a sustained injection flow rate greater than that injected as part of the long-term injection activities. Injection wells IW-1 and IW-2 appear to have significant additional injection capacity and are currently only limited by the HCS treatment system capacity due to biofouling.

Additionally, the short-term hydraulic testing of wells further to the north of the HCS area (IW-6, IW-7, and IW-8) indicated that there is significant additional aquifer capacity further north in the mid-plume area. These wells indicated high short-term injection capacities (up to 90 gpm), and the lithological logs indicated greater aquifer thickness and grain size (see borehole logs in Attachment 2) when compared to the HCS area wells. This indicates that the aquifer receiving capacity would potentially be higher in these regions, although long-term injection would be required to confirm this assumption.

4.4 Hydraulic Data Analysis and Aquifer Estimations

Aquifer hydraulic estimates were obtained using both the specific capacity data and by curve matching methods using AQTESOLV for Windows Pro 4.5. The determinations

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made using AQTESOLV should be considered the more accurate, as they incorporate analysis of the whole data set. Estimates derived from the specific capacity data should only be used for comparative purposes.

The primary curve matching solutions used to assess the observed step test data were the Hantush-Jacob Leaky Step Test and the Theis Confined Step Test methods. Data analysis for each solution was performed by curve matching of the data derived from the monitoring well rather than the pumping well, which provide better estimates of the aquifer response. The step test analyses for each well using the solutions are presented in Attachment 6, which also includes reports documenting the raw test data. The results of the hydraulic analysis are presented in Table 5, which are summarized as follows:

* The hydraulic conductivity of the alluvial sediments tested ranged from 280 ft per day (ft/day) up to 1,200 ft/day, with the highest hydraulic conductivities related to injection wells IW-6, IW-7, and IW-8. The lowest hydraulic conductivity was related to injection well IW-3, located adjacent to the HCS treatment system. Injection well IW-1 was determined to have a specific capacity approximately eight times greater than that of IW-3 during development activities, similar to IW-8.

* For the injection wells tested, the aquifer transmissivity was estimated to range from 2,850 square ft per day (ft²/day) to 17,300 ft²/day, with a distribution similar to that of hydraulic conductivity regarding the most and least productive wells.

* Hydraulic estimates using specific capacity provided estimates slightly higher but similar to those derived by curve matching methods.

* Estimated storativity ranges from $1.04 \times 10^{-2}$ to $3.83 \times 10^{-3}$, which when combined with an inspection of the lithological logs, indicates that the producing sediments can be considered a leaky-confined or semi-confined aquifer.

* Well efficiency estimates using the pumping well data indicated that well efficiencies for injection wells IW-6, IW-7, and IW-8 range from 89 to 99 percent, whereas the well efficiency for IW-3 was only approximately 40 percent.

4.5 Groundwater Sampling and Laboratory Analysis

At the conclusion of the hydraulic testing activities, baseline groundwater samples were collected from the hydraulically tested injection wells. Additionally, groundwater
samples were collected from injection wells IW-1, IW-2, and IW-4, which were purged using a low-flow procedure. The groundwater samples were submitted to Test America for chemical analysis. Results are summarized in Table 6, the laboratory analytical reports are provided in Attachment 7, and the field sampling sheets are presented in Attachment 3. The chemical results indicate that:

- Injection wells IW-1, IW-2, IW-3, and IW-4 were found to be of similar geochemistry for each of the following chemical constituents: calcium, dissolved magnesium, dissolved sodium, fluoride, sulfate, alkalinity, and pH (7.83 to 8.22). Injection wells IW-6 and IW-8, located further to the north, yielded lower concentrations of calcium, sodium, chloride, sulfate, and alkalinity relative to the wells in the south.

- Injection well IW-7 analytical results indicated a differing geochemistry from all of the other wells tested in that it indicated higher concentrations of calcium, total iron, dissolved magnesium, dissolved sodium, chloride, sulfate, nitrate, alkalinity, and hardness and a lower pH. The differing chemistry, combined with the injection well's location in the eastern portion of the area, indicates that a portion of the groundwater is likely being provided by the Wellington Formation, known to contain gypsum deposits and groundwater with elevated mineral content relative to the alluvial materials.

- Total Iron was indicated at <1.0 milligrams per liter (mg/L) in groundwater extracted for all wells except IW-7, which contained a concentration of 3.60 mg/L total iron.

- TCE was detected in groundwater samples collected from all injection wells except IW-7. In the wells with detections, the concentration ranged from 0.431 microgram per liter (µg/L) up to 33.0 µg/L. The lowest concentration was detected in injection well IW-8.

- Cis-1, 2-dichloroethene (1,2-DCE) was detected in injection wells at concentrations ranging from 1.24 µg/L to 8.82 µg/L in injection wells IW-1 through IW-4, located near the HCS, in the south area of interest, but was absent in the injection wells closer to the source zone. The presence of 1, 2-dichloroethene indicates that degradation of TCE is likely occurring, as it represents a daughter product in the degradation cycle.

- Tetrachloroethene (PCE) was detected in all injection wells tested at concentrations ranging from 0.179 µg/l to 182 µg/L. The lowest concentrations
were detected in injection wells IW-6 and IW-8, in the central and northern parts of the area of interest. Injection well IW-7 contained 182 µg/L PCE, approximately two orders of magnitude greater than any other injection well tested. This is believed to be derived from a separate source of this chemical constituent, located to the east of the area of interest.

* Chloroform (trichloromethane) was detected only in water collected from injection wells IW-6 and IW-7, at concentrations of 0.476 µg/L and 0.347 µg/L, respectively.

Groundwater generated by the sampling activities was temporarily stored in a plastic poly tank on site, which was later pumped into the HCS for treatment and discharge via the system NPDES outfall.
5. Summary

Hydraulic testing and reinjection pilot testing was conducted on the mid-plume portion of the Site to evaluate the hydraulic capability of the aquifer to accept the reinjection of treated groundwater, to determine the long-term hydraulic impacts of groundwater reinjection, and to evaluate potential operational and/or maintenance issues that will need to be addressed for the DRG design. The following is a summary of the findings of the testing activities:

- The alluvial sediments that overlie the shale bedrock (Wellington Formation) are composed of permeable fine to coarse sands, with some gravel, in turn overlain by less permeable silts and clays. Each injection well was screened from the bedrock interface across the permeable sediments. The static water levels in the injection wells were typically at the permeable/less permeable interface or just into the less permeable materials, indicating semi-confined conditions.

- Hydraulic and short-term injection testing indicated that the specific capacities were as follows for the injection wells:
  - IW-3 specific capacity for both pumping and injection was approximately 2.0 gallons per foot of drawdown or mounding, at rates of 7.1 gpm and 8.7 gpm respectively.
  - IW-6 specific capacity for pumping was approximately 31 gallons per foot of drawdown at a rate of 50 gpm and for injection was approximately 33 gallons per foot of mounding at a rate of 40 gpm.
  - IW-7 specific capacity for pumping was 18 gallons per foot of drawdown at a rate of 50 gpm, and for injection was 16 gallons per foot of mounding at a rate of 40 gpm.
  - IW-8 specific capacity for pumping was 16 gallons per foot of drawdown at a rate of 50 gpm, and for injection was 17 gallons per foot of mounding at a rate of 40 gpm.

- The hydraulic conductivity of the alluvial sediments tested ranged from 280 ft/day up to 1,200 ft/day, with the largest hydraulic conductivities related to injection wells IW-6, IW-7, and IW-8 and the lowest at IW-3.
The estimated storativity of the alluvial sediments ranges from $3.83 \times 10^{-3}$ to $1.04 \times 10^{-2}$, which when combined with an inspection of the lithological logs, indicates that the sediments can be considered semi-confined, with the overlying less permeable sediments considered leaky.

Well efficiencies for injection wells IW-6, IW-7, and IW-8 range from 89 to 99 percent, whereas the well efficiency for IW-3 was only 40 percent. This also correlates with lithology, with the IW-3 installed in the less permeable sediments.

Long-term injection testing indicated that the HCS area injection well capacities were as follows: IW-1 > IW-2 > IW-4 > IW-3, with greater capacity due to larger aquifer thickness and increased grain size. Long term injection specific capacities were as follows:

- IW-1 specific capacity for long-term injection was approximately 8.6 gallons per foot of mounding, which reduced by approximately 12% over the period of October 2014 to March 2015. During the testing activities mounding in this well was approximately 4 feet at a rate of 30 gpm, with the static water level approximately 16.5 feet below the ground surface. This provides an additional 12.5 feet of freeboard.

- IW-2 specific capacity for long-term injection was approximately 4.9 gallons per foot of mounding, which reduced by approximately 16% over the period of September 2014 to March 2015. During the testing activities mounding in this well was approximately 4 feet at a rate of 25 gpm, with the static water level approximately 16.5 feet below the ground surface. This provides an additional 12.5 feet of freeboard.

- IW-3 specific capacity for long-term injection was approximately 0.6 gallons per foot of mounding, which reduced by approximately 23% over the period of September 2014 to March 2015. Only very limited injection volumes increased the water level to that of the high level switch for this well.

- IW-4 specific capacity for long-term injection was approximately 2.6 gallons per foot of mounding, which reduced by approximately 15% over the period of September 2014 to March 2015. During the testing activities mounding in this well was approximately 4 feet at a rate of 6 gpm, with the static water level approximately 16.5 feet below the ground surface. This provides an additional 12.5 feet of freeboard.
During long-term injection testing over approximately a 12-month period, a total of approximately 11,000,000 gallons of water was injected into the HCS area, at an average rate of approximately 21.6 gpm. This resulted in approximately 0.14 ft of mounding, creating a slight hydraulic barrier, but also indicates that the aquifer has not been stressed by the testing activities and has a higher receiving capacity both in the HCS area and likely further north in the central investigation area.

Injection wells IW-1, IW-2, IW-3, and IW-4 were found to be of similar geochemistry. Injection wells IW-6 and IW-8, located further to the north, exhibited lower mineral concentrations of calcium, sodium, chloride, sulfate, and alkalinity.

Injection well IW-7 yielded a higher mineral content than the other wells tested, including sulfate and alkalinity, indicating that a portion of the groundwater is likely being provided by the Wellington Formation at this location.

TCE was detected in groundwater samples collected from all injection wells except IW-7. In the wells with detections, the concentration ranged from 0.431 µg/L up to 33.0 µg/L, with the lowest concentration in injection well IW-8 adjacent to the source zone.

Cis-1, 2-Dichloroethene, a daughter by-product of TCE, was detected in injection wells IW-1 through IW-4, located near the HCS treatment system, indicating that degradation of TCE is likely occurring.

PCE was detected in injection well IW-7 at a concentration of 182 µg/L, approximately two orders of magnitude higher than any other injection well tested. This is believed to be derived from a separate source of this chemical constituent, located to the east of the area of interest.
6. Conclusions

The following are the conclusions relating the injection potential for the mid-plume area, system and well constraints and potential for hydraulic containment to the west of the area:

- The mid-plume aquifer has indicated it can receive the sustained long term injection of treated groundwater.

- The mid-plume aquifer has been found to be spatially variable in injection potential due to geological variations including aquifer thickness and grain size variation, with thicker and courser sand units being more permeable. The HCS region indicated specific capacities ranging from 0.6 to 8.6 gallons per foot of mounding.

- Short term injection testing indicates that mid-plume wells further to the north of the HCS area potentially have higher specific capacities and therefore higher injection potential. This indicates that the injection potential is good in all regions of the aquifer investigated.

- Over a one year period of injection in the HCS area, at a rate of 21.6 gpm, groundwater levels displayed a slight mounding response of 0.14 feet. This created a slight hydraulic barrier to the west of the HCS area.

- Long term injection testing indicated the potential problem of system bio-fouling and the requirement for monthly system cleaning and bag filter changes, which was initiated as part of the testing activities.

- Long term injection well capacities, as measured by change in specific capacity over time, typically reduced by approximately 12-16% over a period of 6-months. Monitoring of the specific capacity trends and injection well water levels could be used to indicate potential well cleaning/rehabilitation requirements. However, over the testing period this was not a constraint to the injection system in the HCS area as the wells typically had several feet of available freeboard remaining.
Tables
<table>
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<tr>
<th>Well</th>
<th>Installation Date</th>
<th>Longitude</th>
<th>Latitude</th>
<th>Elevation (ft AMSL)</th>
<th>Drilling Method</th>
<th>Depth (ft bgs)</th>
<th>Diameter (inches)</th>
<th>Diameter (inches)</th>
<th>Interval (ft bgs)</th>
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Notes:
IW - Wells installed with bottom of screen at the alluvium/shale interface.
AMSL - above mean sea level
ft bgs - feet below ground surface
PVC - Polyvinyl chloride
NTU - nephelometric turbidity units
gal - gallons
<table>
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<tr>
<th>Well</th>
<th>Rate (gpm)</th>
<th>Average Specific Capacity (gal/ft drawdown)</th>
<th>Rate (gpm)</th>
<th>Injection Specific Capacity (gal/ft mounding)</th>
<th>Ratio of Injection/Pumping Capacity (Mid Rate)*</th>
<th>Selected Injection Well Injection Rate (gpm)</th>
<th>Injection Specific Capacity at Selected Rate (gal/ft mounding)</th>
<th>Average Specific Capacity Based on Whole Data Set (gal/ft mounding)</th>
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Notes:
*At each of the mid rates for both pumping and injection the specific capacity trends were linear therefore comparison at slightly different rates appears appropriate. Frequent the higher rate diverged from the trend so has not been used.
gpm - gallons per minute
gal - gallons
gal/ft - gallons per foot
### Table 3: Injection Wells Long Term Specific Capacity Trends

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<th>Well</th>
<th>Approx. Rate (gpm)</th>
<th>Date</th>
<th>Sep-14</th>
<th>Oct-14</th>
<th>Nov-14</th>
<th>Dec-14</th>
<th>Jan-15</th>
<th>Feb-15</th>
<th>Mar-15</th>
<th>Specific Capacity Change (%)</th>
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<td>Water Level (ft BTUC)</td>
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<tr>
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<td>Water Level (ft BTUC)</td>
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<td>15.5</td>
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<tr>
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<td>Static (ft BTUC)</td>
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<td>15.5</td>
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<td>15.5</td>
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<tr>
<td></td>
<td>Specific Capacity (gal/ft)</td>
<td>1.5</td>
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<td>1.5</td>
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<td>IW-4</td>
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<td>Date</td>
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<td>4</td>
<td></td>
<td>Date</td>
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<tr>
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<td>Specific Capacity (gal/ft)</td>
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</table>

**Average Specific Capacity Change (%)**
- IW-1: -12.1
- IW-2: -15.8
- IW-3: -22.7
- IW-4: -14.8

**Notes:**
- At each of the mid rates for both pumping and injection the specific capacity trends were linear therefore comparison at slightly different rates appears appropriate. Frequently the higher rate diverged from the trend so has not been used.
- gpm = gallons per minute
- gal/ft = gallons per foot
Table 4: Groundwater Level Change Between Injection and Monitoring Wells

<table>
<thead>
<tr>
<th>MW Wells Near Extraction Wells</th>
<th>Groundwater Level Change between 2nd and 4th Quarter (ft)</th>
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<tbody>
<tr>
<td>MW-UP-24</td>
<td>-0.39</td>
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<tr>
<td>MW-UP-25</td>
<td>-0.30</td>
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<td>MW-UP-26</td>
<td>-0.37</td>
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<td>Average</td>
<td>-0.35</td>
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</table>

<table>
<thead>
<tr>
<th>MW Wells Not Close to Extraction Wells</th>
<th>Groundwater Level Change between 2nd and 4th Quarter (ft)</th>
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<tbody>
<tr>
<td>MW-UP-21D</td>
<td>-0.14</td>
</tr>
<tr>
<td>MW-UP-22D</td>
<td>-0.44</td>
</tr>
<tr>
<td>MW-UP-22S</td>
<td>-0.44</td>
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<td>Average</td>
<td>-0.34</td>
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<table>
<thead>
<tr>
<th>Injection Wells</th>
<th>Groundwater Level Change between 2nd and 4th Quarter (ft)</th>
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<tbody>
<tr>
<td>IW-01</td>
<td>-0.50</td>
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<tr>
<td>IW-02</td>
<td>-0.10</td>
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<tr>
<td>IW-03</td>
<td>-0.10</td>
</tr>
<tr>
<td>IW-04</td>
<td>-0.10</td>
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<td>Average</td>
<td>-0.20</td>
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Water Level Change in Injection Relative to Extraction Affected Monitoring Wells (ft) = 0.15

Water Level Change in Injection Relative to Non-Extraction Affected Monitoring Wells (ft) = 0.14

Notes:
Injection well static conditions noted after a period of recovery
MW - Monitoring Well
<table>
<thead>
<tr>
<th>Well</th>
<th>Method</th>
<th>Well Used</th>
<th>$H$ (ft)</th>
<th>Thickness (ft)</th>
<th>$T$ (ft²/day)</th>
<th>$S$ (ft³/day)</th>
<th>$K$ (ft²/day)</th>
<th>Efficiency</th>
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<tr>
<td>IW-3</td>
<td>Leaky</td>
<td>OW-3</td>
<td>942</td>
<td>10</td>
<td>92</td>
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<td>OW-3</td>
<td>4,769</td>
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<td>OW-3</td>
<td>3,068</td>
<td>10</td>
<td>301</td>
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<td>OW-3</td>
<td>4,845</td>
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<td>2,855</td>
<td>10</td>
<td>280</td>
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<td>IW-5</td>
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<td>OW-6</td>
<td>17,370</td>
<td>14</td>
<td>1,217</td>
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<td>OW-6</td>
<td>17,200</td>
<td>14</td>
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Notes:
Matches made to single well with pumping well used as observation well typically indicated T and K data an order of magnitude less than when the observation well was used.
*T estimates from Theis residual drawdown method may not be accurate because data do not satisfy the assumption of a confined aquifer (due to significant leakage/recharge).
T - transmissivity
K - hydraulic conductivity
S - storativity

ft/day - feet per day
ft²/day - feet squared per day

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<tr>
<th>Sample Location:</th>
<th>IW-01</th>
<th>IW-02</th>
<th>IW-03</th>
<th>IW-04</th>
<th>IW-06</th>
<th>IW-07</th>
<th>IW-08</th>
<th>IW-09</th>
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<td>Sample ID:</td>
<td>WG-2660-IW04 (151113)</td>
<td>WG-2660-IW02 (151113)</td>
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<td>Metals - mg/L</td>
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<tr>
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<td>179</td>
<td>167</td>
<td>146</td>
<td>133</td>
<td>210</td>
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<tr>
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<td>0.111</td>
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<td>&lt; 1.00</td>
<td>&lt; 1.00</td>
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<td>1,1-Dichloroethane</td>
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<tr>
<td>2-Butanone (Methyl ethyl ketone) (MEK)</td>
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<td>&lt; 50.0</td>
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Notes:
- F.D.: Field duplicate of groundwater sample.
- mg/L: milligrams per liter.
- N.: Groundwater sample.
- s.u.: Standard unit.
- mg/L: Micrograms per liter.
- VOA: Volatile organic compound.