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October 30, 2015

Mr. Anthony Leverock, P.E.
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Waste Programs Division
Arizona Department of Environmental Quality
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Re: Corrective Measures Study Report:
Former Universal Propulsion, Inc. Company, Inc.
Facility 25401 North Central Avenue
AZ HWMA Permit
ID No. AZD 980 814 479

Dear Mr. Leverock:

The Universal Propulsion Company, Inc. (UPCO) is submitting the attached Corrective Measure Study (CMS) Report for your review. This CMS Report has been revised to address Arizona Department of Environmental Quality (ADEQ) draft comments dated August 28, 2015.

The attached report was prepared by ARCADIS U.S., Inc. (ARCADIS) at the direction of UPCO pursuant to Part IV, Section A.5 of the Arizona Hazardous Waste Management Act (AZ HWMA) Permit for the UPCO Facility, ID No. AZD 980 814 479.

I certify, under penalty of law, that this document and all attachments were prepared under my direction or supervision according to a system designed to assure that qualified personnel properly gathered and evaluated the information submitted. Based upon my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my

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knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Please contact me at 704.423.7071 if you have any questions or need additional information.

Sincerely,

Bruce C. Amig
Manager, Remedial Programs

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Imagine the result

Universal Propulsion Company, Inc.

Corrective Measures Study Report

Former Universal Propulsion Company, Inc. Facility
25401 North Central Avenue
Phoenix, Arizona
USEPA ID No. AZD 980 814 479

October 2015

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Corrective Measures Study Report

Former Universal Propulsion Company, Inc. Facility
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Phoenix, Arizona
USEPA ID No. AZD 980 814 479

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Acronyms and Abbreviations

µg/L	micrograms per liter
1,1-DCE	1,1-dichloroethene
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
amsl	above mean sea level
ARCADIS	ARCADIS U.S., Inc.
ASLD	Arizona State Land Department
AWQS	Arizona Water Quality Standard
AZ HWMA	Arizona Hazardous Waste Management Act
bgs	below ground surface
CAD	cartridge actuated device
CAO	corrective action objective
CMS	Corrective Measures Study
CMS Report	Corrective Measures Study Report
CMS Work Plan	Corrective Measures Study Work Plan
COC	constituent of concern
COPC	constituent of potential concern
CSM	conceptual site model
cy	cubic yards
DO	dissolved oxygen
EED	electronic explosive device
EVO	emulsified vegetable oil

ft/day	foot (feet) per day
ft^2/day	square foot (feet) per day
GPL	groundwater protection level
gpm	gallons per minute
H+A	Hargis+Associates, Inc.
HBGL	health-based guidance level
K	hydraulic conductivity
LAU	lower alluvial unit
MAU	middle alluvial unit
MEK	methyl ethyl ketone
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitored natural attenuation
NCP	National Contingency Plan
O&M	operation and maintenance
OBU	Open Burn Unit
PAD	propellant actuated device
POTW	publicly owned treatment works
ppbv	parts per billion by volume
PRG	Preliminary Remediation Goal
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
RI Report	Final Remedial Investigation Report

ROI	radius of influence
Sedimentary Unit	Tertiary/Quaternary sedimentary strata
Site	former UPCO Facility in Phoenix, Arizona
SMA	Storage Magazine Area
SRL	soil remediation level
SWMU	solid waste management unit
T	transmissivity
TGAC	tailored granular activated carbon
TTU	Thermal Treatment Unit
UAU	upper alluvial unit
UPCO	Universal Propulsion Company, Inc.
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

1. Introduction

On behalf of Universal Propulsion Company, Inc. (UPCO), ARCADIS U.S., Inc. (ARCADIS) prepared this revised Corrective Measures Study Report (CMS Report) for the former UPCO Facility in Phoenix, Arizona (Site; Facility ID Number AZD 980 814 479). This CMS Report was developed in accordance with Part IV, Condition I.5 of the Arizona Hazardous Waste Management Act (AZ HWMA) Permit.

The March 2012 CMS Report summarizes the results of previous investigations and provides the results of testing carried out in accordance with the Aquifer Test and Monitor Well Installation Work Plan (ARCADIS 2012a). This CMS Report refines the understanding of current conditions at the Site and the conceptual site model (CSM). Based on the exposure assessment and current conditions at the Site, ARCADIS developed corrective action objectives (CAOs) and identified and screened applicable remedial technologies. This CMS Report presents the development, evaluation, and recommendation of corrective measures alternatives for the Site.

1.1 Purpose and Objectives

The purpose of this CMS Report is to describe the field investigations conducted in support of the CMS, provide the results of the investigations and pre-design studies, and present the process by which the corrective measures alternatives were developed and evaluated to address constituents of concern (COCs) present in soil and groundwater at the Site. These COCs were identified during the remedial investigation (RI) activities conducted at the Site and summarized in the Final Remedial Investigation Report (RI Report; ARCADIS 2011a). This CMS Report includes a screening of remedial technologies that can potentially address the COCs observed at the Site, development of possible remedial alternatives, evaluation of the assembled remedial alternatives, and a recommendation of the most appropriate corrective measures alternatives to be implemented at the Site based on the CAOs.

1.2 Report Organization

This CMS Report was prepared in accordance with the requirements outlined under Part IV, Condition I.5 of the facility's AZ HWMA Permit and the approved Corrective Measures Study Work Plan (CMS Work Plan; ARCADIS 2011b), along with the CMS requirements presented in the Resource Conservation and Recovery Act (RCRA) Corrective Action Plan - Final, May 1994 (EPA 520/R/94/004) guidance document (United States Environmental Protection Agency [USEPA] 1994).

This CMS Report is organized as follows:

Section 1 – Introduction: Discusses the objectives and organization of this CMS Report.

Section 2 – Site Background: Describes the site operations and land use and provides a relevant history of the Site.

Section 3 – Current Site Conditions: Discusses the site physical setting, summarizes the nature and extent of COCs, describes field testing and investigations performed in support of the CMS, and presents the updated CSM.

Section 4 – Corrective Action Objectives: Presents CAOs and the cleanup goals for the site COCs.

Section 5 – Identification and Screening of Remedial Technologies: Identifies potential remedial technologies, describes the screening process, and summarizes the technologies eliminated or retained for further evaluation.

Section 6 – Identification and Detailed Analysis of Remedial Alternatives: Establishes the evaluation process and criteria, and discusses and evaluates the assembled remedial alternatives with respect to the criteria.

Section 7 – Recommendation of Corrective Measures Alternatives: Presents the recommended corrective measures alternatives.

- **Section 7.1 – Soil:** Concludes that Soil Remedial Alternative SA-2 (soil excavation and off-site disposal, soil capping, deed restrictions) as described in Section 6.1.1.2. is the recommended soil remedial alternative.
- **Section 7.2 – Groundwater:** Concludes that Groundwater Remedial Alternative GW-2 (source area groundwater extraction, ex situ treatment with anaerobic bioreactor, reinjection, and alluvium in situ biological reduction) as described in Section 6.1.2.2. is the recommended groundwater remedial alternative.

Section 8 – References: Provides the literature references used to develop this CMS Report.

2. Site Background

This section summarizes the site description and history. This information is also discussed in the RI Report (ARCADIS 2011a).

2.1 Site Description and Land Use

The Site is located at 25401 North Central Avenue in Phoenix, Arizona, near the intersection of Central Avenue and Happy Valley Road (Figure 1). The Site is within the southeast quarter, Section 5, Township 4 North, Range 3 East of the Union Hills 7.5-minute U.S. Geological Survey (USGS) quadrangle. The former UPCO Facility was constructed in 1972 on approximately 160 acres of land leased from the State of Arizona. Land adjacent to the western, southern, and eastern boundaries of the Site is undeveloped land owned by the State of Arizona. Residential properties are located to the north along Yearling Road. The former operational areas of the Site are surrounded by a security fence, and primary access is limited to a gate along Happy Valley Road.

The former UPCO Facility consisted of various manufacturing, storage, and administrative buildings/structures, which were separated into eight operational areas. These areas of the Site are illustrated on Figure 2 and include:

- A-Complex
- B-Complex
- C-Complex
- D-Complex
- E-Complex (Storage Magazine Area [SMA])
- F-Complex
- Old Burn Area
- New Burn Area (Open Burn Unit [OBU]).

The former UPCO Facility primarily produced components for crew escape systems for military aircraft. Component products, such as gas generators, rocket motors, cartridge actuated devices (CADs), propellant actuated devices (PADs), and electronic explosive devices (EEDs), were also developed and manufactured at the former UPCO Facility.

The former UPCO Facility included several separate operational areas for manufacturing, assembling, testing, and storing energetic materials (Figure 2). The A-Complex Area consisted of buildings associated with the administrative and management functions. The B-Complex Area consisted of various buildings/structures used primarily for ejection seat, EED, CAD, and PAD assemblies. The C-Complex Area consisted of various buildings/structures used to manufacture castable propellants, including material weigh-out, oxidizer grinding, propellant mixing, and casting.

The D-Complex Area was located in the northeastern portion of the Site and consisted of various buildings/structures used primarily for device testing, as well as the waterbore process. Three specific areas of focus were located within the D-Complex, including the Old Burn Area, Thermal Treatment Unit (TTU), and Waterbore Area. The Old Burn Area was located in the northern portion of the D-Complex and was used to burn off-specification energetic materials and devices. Burning of waste materials occurred in the Old Burn Area during the 1970s and early 1980s, until burn operations were moved to the OBU in the New Burn Area. The TTU was located south of the D-Complex fence line and was used to burn off-specification solid propellant materials. From 1983 to 2009, a high-pressure water spray wand operation was used to remove solid propellant and binders from rocket motor tubes so that the tubes could be reused. This process was referred to as the waterbore operation. The Waterbore Area, where the waterbore operation was performed, was located at the southern end of the D-Complex within the fence line. The E-Complex, also referred to as the SMA, consisted of portable prefabricated metal (Conex-type) containers used to store energetic materials and devices used at the former UPCO Facility.

The F-Complex Area consisted of various buildings/structures used to manufacture powder-based energetic formulations, for assembly operations, and for quality assurance/quality control testing. Historically, this area was also used to manufacture castable and extruded propellant and large rocket motors; for lining rocket motor tubes, liner drying, tool pull, propellant mixing, propellant casting, and propellant curing; and for weigh-out of oxidizers, binders, and fuel powders.

The OBU was operated in the New Burn Area, located south of the C-Complex near the south-central site boundary. Open burning of waste/off-specification solid propellant materials was performed in this area from 1980 to 2004.

Utilities available at the Site at the time of operation included electrical power and communications; however, municipal services were not available in the area. Therefore, the former UPCO Facility relied on a production well (PW-1) and septic systems.

2.2 Site History

UPCO, a Delaware corporation, is the successor to the original Universal Propulsion Co., a California Corporation, incorporated in 1959. UPCO began operations at the Site in 1972. UPCO became part of Goodrich Corporation in 1998. A more detailed corporate history is included in the Draft Remedial Investigation Work Plans (Hargis+Associates, Inc. [H+A] 2004a and 2004b).

The UPCO operations were transferred to a facility in Fairfield, California during the fourth quarter of 2009. Demolition of the former UPCO Facility occurred throughout 2009 and was completed in January 2010.

3. Current Site Conditions

This section summarizes the physical setting and nature and extent of COCs at the Site, describes the field investigations performed in support of the CMS, and presents the CSM. Historical site investigations are also described in the RI Report (ARCADIS 2011a).

3.1 Physical Setting

The Site is located within the Basin and Range physiographic province of Arizona. The Site is located between and within the southern flanks of the Union Hills, a northwest-trending bedrock mountain range, and the northern margin of the West Salt River Valley within the Union Hills USGS 7.5-minute Quadrangle (Figure 1).

3.1.1 Topography and Drainage

Topographic relief near the Site ranges up to 800 feet and generally slopes in a south-southwest direction from the Union Hills toward the West Salt River Valley. The geology of the Union Hills and West Salt River Valley are described below.

3.1.2 Geology

The surface geology of the Site can be grouped into two categories: Tertiary/ Quaternary sedimentary strata (Sedimentary Unit) and Precambrian basement rock of various lithologies. The surface deposits (upper 2 feet) of the Sedimentary Unit are generally poorly consolidated and poorly sorted, with particle sizes ranging from clay to boulder. Locally, desert pavement is observed in undisturbed areas of the Site and caliche is found in the upper few feet of the soil horizon, as observed at bank cuts of entrenched washes in the area. Surface bedrock surrounds the leased property on the north, east, and south boundaries in somewhat of a crescent shape. Geologic cross-sections of the Site are presented on Figures 3 through 7.

3.1.3 Groundwater Hydrology

The regional hydrogeology encompasses two significant hydrogeologic units: the Sedimentary Unit within the West Salt River Valley Basin and the Proterozoic bedrock, which comprises the Union Hills and underlies the alluvial deposits.

The West Salt River Valley Basin comprises valley fill deposits divided based on lithologic characteristics. In descending order from the land surface, the water-bearing units include the upper alluvial unit (UAU), fine-grained middle alluvial unit (MAU), and lower alluvial unit (LAU). The primary water-bearing unit in the West Salt River Valley Sub-basin is the UAU. A direct correlation between the typical hydrogeologic units of the Salt River Valley (e.g., UAU, MAU, and LAU) and those underlying the Site has not been made.

Depths to groundwater vary within the UAU temporally and with location. On a regional scale, the groundwater flow direction near the Site appears to be from the northeast to the southwest away from the Union Hills (Rascona 2003). The bedrock unit, which underlies the basin sediments and comprises the Union Hills, may contain usable amounts of groundwater where they are significantly fractured or faulted (Anderson 1995). Near the former UPCO operations, groundwater elevations have been relatively flat and groundwater flow has historically been consistent with the regional flow on the southern half of the Site. On the northern half of the Site (north of the Waterbore Area), groundwater elevations are dropping, and groundwater flow has shifted to the north-northwest due to years of groundwater extraction at the residential wells north of the Site. A representative potentiometric map from December 2014 is presented on Figure 8.

3.2 Summary of Investigations

The RI soil characterization activities were conducted in phases between 2002 and 2008 with pre-design soil investigations conducted in 2014 and in April 2015. The soil investigation activities included the sampling and analysis of surface and subsurface soil samples at each of the following operational areas: B-Complex, C-Complex, D-Complex (Waterbore Area, TTU, and Old Burn Area), E-Complex (SMA), F-Complex, and New Burn Area (OBU).

The following hydrogeologic investigation activities were conducted between December 2003 and December 2014 at and near the Site:

- Installation of eight groundwater wells (MW-22, EW-1, EW-2, IW-1, IW-2, IW-3, RW-1, and RW-2) to confirm conceptual design parameters for groundwater extraction, treatment, and reinjection as part of the Supplemental Groundwater Pre-Design Study (ARCADIS 2014c)

- Installation of two substrate injection wells (IN-1As and IN-1Ad) and two dose response wells (DR-01s and DR-01d) to collect field data necessary to calculate site-specific parameters for design and operational optimization of an in situ, biological, perchlorate-reduction test in the alluvium aquifer near well MW-6 as part of the Supplemental Groundwater Pre-Design Study (ARCADIS 2014c)

- Installation of monitoring wells (MW-1 through MW-19) to assess the prevailing hydrogeologic conditions and the nature and extent of COCs in groundwater near the Site

- Installation of two monitoring wells (MW-20 and MW-21) in February 2012 to further define groundwater conditions within suspected source areas (C-Complex and New Burn Area, respectively) for corrective measure evaluation purposes

- Collection of core samples from four monitoring well locations (MW-5, MW-6, MW-9, and MW-13) to assess the subsurface geology

- Collection of geophysical logs from the open boreholes at most of the monitoring well locations to assess the subsurface geology

- Documentation of groundwater elevations from the monitoring wells, using a combination of manual depth to water measurements and pressure data downloaded from dedicated transducers installed in select wells to assess groundwater elevation trends

- Collection of quarterly groundwater samples from monitoring wells to assess groundwater quality trends beneath the Site

- Analysis of the surface drainage pattern near the Site

- Semiannual collection of samples from private off-site domestic wells north of the Site, along Yearling Road

- Aquifer testing in the Waterbore Area (MW-19) in February 2012 and testing north of the former operations (MW-14) in September 2008, near the residential wells

- Aquifer testing in the Waterbore Area (EW-2 and IW-1) and testing in the south portion of the New Burn Area (EW-2)

- Substrate and tracer dye injection testing in the alluvium aquifer near well MW-6

The RI soil vapor characterization activities were conducted in phases between 2005 and 2008 (ARCADIS 2012a). These activities included the sampling and analysis of subsurface soil vapor samples at each of the following operational areas: B-Complex, C-Complex, D-Complex (Waterbore Area and Old Burn Area), F-Complex, and New Burn Area (OBU). In addition to the soil vapor characterization activities, a nested soil vapor monitoring well (SVMW-1) was installed within the B-Complex area to monitor soil vapor at four intervals within vadose zone soils (ARCADIS 2012a). SVMW-1 has been sampled annually since installation. A copy of the as-built SVMW-1 construction diagram is provided in Appendix A.

3.3 Corrective Measures Study Field Testing

Based on a review of RI data for the Site and the development of potential remediation technologies for soil and groundwater discussed in Section 5, it was determined that additional site-specific data were required to support a detailed evaluation of potential remediation technologies and potential corrective measures alternatives for the Site. The following sections summarize additional field testing and data collection performed in support of the CMS.

3.3.1 Additional Water Quality Monitoring

Additional water quality data were collected to evaluate in situ and ex situ biological reduction as potentially applicable remedial technologies. The following additional parameters were analyzed as part of the first quarter 2012 monitoring event to evaluate total electron donor demand: biochemical oxygen demand, chemical oxygen demand, dissolved oxygen (DO), and total organic carbon. These analyses were conducted on groundwater samples collected from monitoring wells MW-1, MW-2, MW-4, MW-5, MW-13, and MW-19. The groundwater chemistry data collected indicate that alternative electron acceptor concentrations were in ranges easily reduced to support in situ or ex situ perchlorate reduction. DO concentrations observed ranged between 2.4 and 5.4 milligrams per liter (mg/L), and nitrate (as nitrogen) concentrations ranged from 1.2 to 6.7 mg/L. Table 1 summarizes the additional water quality monitoring data collected in support of the CMS.

3.3.2 Well Installations

To further support the CMS alternatives evaluation and the design and implementation of the groundwater remedial alternative, additional wells were drilled and installed in bedrock at the Site. In 2012, groundwater monitoring wells MW-20 and MW-21 were installed within the C-Complex and the New Burn Area, respectively. These areas are identified in the Final RI Report (ARCADIS 2011a) as source areas. The monitoring wells were used to confirm perchlorate concentrations and to assess groundwater extraction. The wells were designed for use as potential extraction wells and were similar in design to monitoring well MW-19 (Table 2), located in the Waterbore Area. Well installation and construction details for MW-20 and MW-21 are presented in the CMS Report dated March 2012 (ARCADIS 2012b), an excerpt of which is provided in Appendix B for reference.

As part of the pre-design study, six wells (IW-1, IW-2, MW-22, EW-1, RW-1, and RW-2) were installed in bedrock within the Waterbore Area, one well (IW-3) was installed within the C-Complex Area, and one well (EW-2) was installed in the New Burn Area near monitoring well MW-1 (Figure 3). All six of these wells were designed for use as potential extraction or injection wells. A summary of well installation activities for IW-1, IW-2, IW-3, MW-22, EW-1, and EW-2 is presented in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c). Well construction details are provided in Appendix C for reference.

Four wells were installed in alluvium near well MW-6 to collect field data as part of an in situ biological perchlorate-reduction pilot test. Two reagent injection wells (IN-1Ad and IN-1As) were installed southeast of well MW-6, and two dose-response wells (DR-01d and DR-01s) were installed southwest of well MW-6 (Figure 3). A summary of well installation activities for IN-1Ad, IN-1As, DR-01d, and DR-01s is presented in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c). Well construction details are provided in Appendix C for reference. The pilot test was successful at remediating perchlorate concentrations in the vicinity of MW-6 (ARCADIS 2015c).

3.3.3 Groundwater Pumping Tests

In February 2012, a pumping test was performed at well MW-19 using the dedicated purge/sampling pump installed at the well. The pumping test consisted of a step-drawdown test to determine the optimal pumping rate for the pump test, a 24-hour constant-rate pumping test, and a recovery test. Summaries of the methodologies used for each phase of testing in MW-19, and data from the constant-rate pumping test used to evaluate aquifer hydraulic conductivity, are presented in the CMS Report dated March 2012 (ARCADIS 2012b). An excerpt from the 2012 CMS Report that describes the details of the pump test is provided in Appendix B.

Results and analysis of the MW-19 pump test indicated that, after 24 hours of pumping at 8 gallons per minute (gpm), approximately 13 feet of drawdown was observed in the pumping well (MW-19) and approximately 0.6 foot of drawdown was observed in the closest observation well (MW-13), located 20 feet from MW-19 and screened from 440 to 490 feet below ground surface (bgs). Drawdown was not observed in the other observation wells during the constant-rate test. Graphs of drawdown versus time after pumping started were used to evaluate the relationship between storage coefficient, transmissivity, pumping rate, and drawdown. Two parameters (transmissivity [T] and the average hydraulic conductivity [K]) were estimated based on the aquifer responses observed during this test. Transmissivity was estimated to be approximately 110 square feet per day (ft^2/day) and K was estimated to be approximately 0.6 to 0.8 foot per day (ft/day), assuming an aquifer thickness of 50 feet (screened interval of pumping well). These values are higher than the T and K ranges estimated during RI aquifer testing at MW-14 (0.30 to 0.39 ft^2/day and 6.6×10^{-3} to 7.7×10^{-3} ft/day, respectively, based on pump and hydrogeophysical testing); however, this variability is consistent with the fractured bedrock environment and anticipated spatial variability of aquifer properties. In general, these results indicate that the UAU can sustain the modest pumping rates (i.e., several gpm) that will be associated with extraction-based groundwater remedies. However, variability in well yields is expected.

During the second quarter of 2014, pump testing was performed at wells EW-1, EW-2, and IW-1 as part of the supplemental pre-design study. Pump testing at well EW-1 consisted of an initial 10-hour step-drawdown test to determine the sustainable pumping rate for the longer-term test. EW-1 was pumped at five rates (4, 6, 8, 10, and 16 gpm). This was followed by a 6-day constant-rate test at approximately 15 gpm to provide long-term drawdown data for the pumping well and observation wells. Finally, well recovery in the pumping and observation wells was manually monitored for 24 hours after pumping ceased. The pump test and recovery period were carried out from May 5 to 13, 2014.

Pump testing at IW-1 consisted of a 24-hour constant-rate test, with the well being pumped at approximately 8 gpm. The constant-rate pumping test was performed on May 14 and 15, 2014, followed by well recovery monitoring over approximately 24 hours.

Pump testing at well EW-2 consisted of an initial 10-hour step-drawdown test to select the optimal pumping rate for the constant-rate testing. Five pumping rates were applied (4, 6, 8, 10, and 16 gpm) in EW-2 for at least 2 hours for each step. Step-drawdown testing was followed by a 2.5-day (60-hour) constant-rate test at 16 gpm to provide long-term drawdown data for the pumping well and observation wells. The constant-rate test was completed between June 3 and 5, 2014. After completion of the constant-rate test, recovery was manually monitored in the pumping well and observation wells for a 24-hour period.

The results of the pumping tests at EW-1, IW-1, and EW-2 demonstrated the ability of each well to sustain relatively high pumping rates (8 to 16 gpm) with limited drawdown, which is a key requirement for the groundwater remediation strategy. In addition, perchlorate samples collected during each pump test confirmed that the wells are located in areas of the plume where perchlorate mass can be recovered efficiently. Summaries of the pump tests at wells EW-1, IW-1, and EW-2 used to refine the remedial simulation and numerical model are presented in the Numerical Model Update and Revisions dated October 2014 (ARCADIS 2014b) and the Supplemental Groundwater Pre-Design Study Summary Report dated December 2014 (ARCADIS 2014c).

3.4 Conceptual Site Model Summary

The following sections outline the current understanding of the CSM based on data gathered during the RI activities and the more recent CMS-related field activities.

3.4.1 Constituents of Potential Concern in Soil

To identify and delineate the nature and extent of constituents of potential concern (COPCs) in soil, characterization targets were established during RI activities. Analytical results for soil samples collected during the RI were compared to these characterization targets. For perchlorate in soil, the characterization targets were the USEPA Region 9 Preliminary Remediation Goal (PRG) of 7.8 milligrams per kilogram (mg/kg) horizontally and the perchlorate method detection limit of 0.04 mg/kg vertically. The characterization targets for arsenic and lead in soil were the Arizona residential soil remediation levels (SRLs) of 10 and 400 mg/kg, respectively.

Analytical results for soil samples collected during the RI indicated detections of perchlorate and select metals (arsenic and lead) at concentrations higher than characterization targets. Table 3 presents the highest perchlorate detections reported in soil for each operational area. Soil analytical results are also presented in Appendix D.

3.4.1.1 Perchlorate

The RI activities conducted at the Site indicate that perchlorate was released to the environment during former site operations. The refurbishing of rocket motor tubes at the Waterbore Area is considered the source of the majority of the perchlorate mass observed in soil. This conclusion is based on the elevated concentrations of perchlorate detected in soil at the Waterbore Area, which are presented in the RI Report (ARCADIS 2011a). In addition to the Waterbore Area, perchlorate was also identified in soil at concentrations exceeding the cleanup standard at the C-Complex, E-Complex, and New Burn Area. Additional soil investigations were conducted in 2014 and 2015, as part of the pre-design study, to better define the extent of perchlorate in soil higher than the cleanup standard. The additional soil investigation data are summarized in the October 2014 Supplemental Soil Pre-Design Summary Report (ACRADIS 2014a) and Additional Soil Characterization at Proposed Deep Excavation Areas letter dated May 15, 2015 (ARCADIS 2015).

Noteworthy monitoring results regarding perchlorate in soil at the Waterbore Area are provided in the following table.

Waterbore Area	
Maximum depth of perchlorate concentrations above the cleanup standard:	175 feet bgs
Highest perchlorate detection in soil:	1,800 mg/kg Soil Boring D 0.25 foot bgs
Associated figure:	Figure 9

See Appendix D for analytical data.

Within the C-Complex Area, perchlorate detections in soil exceeding the cleanup standard were identified near former buildings C-1, C-2, and C-4, with depths ranging from surface to 20 feet bgs. While the highest perchlorate detection in soil at the C-Complex Area was 330 mg/kg in soil boring CC-SB08 collected from the surface, perchlorate detections from 1 to 20 feet bgs did not exceed 83 mg/kg.

Noteworthy monitoring results regarding perchlorate in soil at the C-Complex Area are provided in the following table.

C-Complex Area	
Locations of perchlorate exceedances:	Near former buildings C-1, C-2, and C-3 (surface to 20 feet bgs)
Highest perchlorate detection in soil:	330 mg/kg Soil Boring CC-SB08 Surface
Associated figure:	Figure 10

See Appendix D for analytical data.

Perchlorate detections in soil exceeding the cleanup standard in the E-Complex Area were identified in three surface samples east of former facility E-1. While the highest perchlorate detection in soil at the E-Complex Area was 124 mg/kg in soil boring UPCO-4 collected from the surface, perchlorate detections from 1 to 5 feet bgs did not exceed 6.2 mg/kg. Soil boring locations are shown on Figure 11, and analytical data are provided in Appendix D.

After completion of the limited soil removal activities performed as part of RCRA closure of the OBU within the New Burn Area, soil borings drilled below and surrounding the former OBU revealed perchlorate concentrations higher than the cleanup standard in soil samples to a depth of approximately 30 feet bgs. The highest perchlorate detection in soil at the New Burn Area was 251 mg/kg in soil boring NB-SB73 at a depth of approximately 5 feet bgs. Soil boring locations are shown on Figure 12, and analytical data are provided in Appendix D.

3.4.1.2 Metals

Analytical results for soil samples collected during the RI indicated that select metals (arsenic and lead) were detected at concentrations above characterization targets, and were limited to surface and near-surface soils near the location of the former open burning activities in the Old Burn Area. Table 4 summarizes the highest concentrations of lead and arsenic detected in soil for each operational area. Additional soil investigations performed in 2014 as part of the pre-design study confirmed that lead and arsenic concentrations exceeding the cleanup standard in soil were limited to surface and near-surface soils in the Old Burn Area. The additional soil investigation data are summarized in the October 2014 Supplemental Soil Pre-Design Summary Report (ARCADIS 2014a).

Noteworthy monitoring results regarding lead and arsenic in soil at the Old Burn Area are provided in the following table.

Old Burn Area	
Locations of lead and arsenic exceedances:	Surface to 2 feet bgs
Highest lead detection:	4,800 mg/kg Soil Boring OB-SB45 Surface
Highest arsenic detection:	18.6 mg/kg Soil Boring OB-SB56 1 foot bgs
Associated figure:	Figure 13

See Appendix D for analytical data.

3.4.2 Hydrogeologic Framework

As discussed in Section 3.1, the Site is located in a transition zone between mountain-front areas of the Union Hills and valley-fill deposits of the West Salt River Valley Basin. The two significant water-bearing units beneath the Site are alluvium, comprising sand and gravel with variable cementation, and granodioritic fractured bedrock. In general, the uppermost water-bearing unit in the southwestern portion of the Site is in alluvium, and the uppermost water-bearing unit in the remainder of the Site is in bedrock. Groundwater elevations at the Site range from approximately 1,324.68 to 1,347.94 feet above mean sea level (amsl) for bedrock wells and 1,350.22 to 1,401.73 feet amsl for alluvium wells. Groundwater levels in the saturated alluvium are approximately 20 feet higher than those in saturated bedrock, and there is an apparent structural discontinuity between these two flow regimes.

Based on hydrogeologic testing, observations during drilling activities, geophysical logging, and the effects of long-term pumping on water levels, the bulk hydraulic conductivity of the saturated bedrock is low, on the order of 0.001 to 0.01 ft/day. While localized areas may have some order of magnitude higher hydraulic conductivity based on interconnections of water-transmitting features (such as heavily fractured bedrock associated with fault zones), large-scale transmissivity and groundwater flux of the fractured bedrock beyond these localized areas is understood to be low.

3.4.3 Water Use, Recharge, Groundwater Flow, and Constituent Migration

Water use and recharge to groundwater on and near the Site changed significantly during the period leading up to, during, and after Waterbore Area operations at the Site, which occurred from approximately 1983 to 2008.

3.4.3.1 Prior to Waterbore Operations

Based on historical water use patterns in the Phoenix basin, the groundwater system at the Site was in a relatively steady dynamic equilibrium, with no anthropogenic or external stresses. Water levels likely changed only with seasonal variations in precipitation and longer-term climate cycles of drought and non-drought conditions. Recharge from precipitation on and near the Site was primarily from losing portions of washes that transmitted rainwater from the hilly slopes, trending generally from north-northeast to south-southwest across the Site. Infiltration in other areas outside of washes was negligible, based on extremely low precipitation rates, runoff from highly cemented surface alluvium, and transpiration of plants. Based on these conditions, groundwater in the saturated bedrock generally flowed from north-northeast to south-southwest, with localized, transient mounding beneath losing reaches of washes. The cross-sections in Appendix E show hypothetical conditions prior to Waterbore Area operations.

3.4.3.2 During Waterbore Area Operations – No Residential Pumping

Transient, non-equilibrium groundwater conditions likely dominated during Waterbore Area operations at the Site. The primary water use was for washing operations, and the sole water source was the supply well (PW-1) screened in deep bedrock and located in the southwestern portion of the Site (Figure 3). In the Waterbore Area, wash water was released via unlined ponds and infiltrated downward through unsaturated zone alluvium to the water table in bedrock. Mounding of the water table likely occurred in this area, creating a steepened local gradient with a slightly south-southwestward bias (direction of the natural water table gradient at the time). The transport of perchlorate and other constituents in the wash water was driven by these water use and groundwater conditions. Once in the water table, the constituents were transported primarily via advection and diffusion (see cross-sections in Appendix E).

3.4.3.3 During Waterbore Area Operations – Residential Pumping Increases

Prior to increased residential development to the east and north of the Site in the 1980s and 1990s, groundwater conditions were controlled by the pumping and infiltration activities described above. Variations in natural recharge were likely a minor influence. Residential development and the associated pumping of individual water supply wells gradually increased during Waterbore Area operations. This pumping introduced a new external stress on the groundwater system. As water was pumped from bedrock, aquifer storage water levels began to decline, first near the residential wells and gradually farther out toward the Site. The trend of groundwater levels in bedrock wells in the northern portion of the Site was downward for much of the 2000s and continues today.

The Waterbore Area ponds were excavated and then lined in 1988. Wastewater from the Waterbore Area operations conducted after 1988 was discharged to high-density polyethylene tanks with secondary containment, preventing further infiltration of water containing perchlorate and other constituents. During that time, pumping of PW-1 for these operations continued, maintaining a water table gradient in bedrock toward the southwest. Residual constituents remained in soil beneath the Waterbore Area; however, downward vertical migration would have become negligible because of the lack of infiltration and flushing in this area (see cross-sections in Appendix E).

3.4.3.4 After Waterbore Area Operations

Waterbore Area operations ceased in 2008; however, during demolition of buildings at the Site from 2009 to 2010, PW-1 was operated for dust suppression and other water supply needs. Since January 2010, on-site pumping has ceased and bedrock water levels near PW-1 have begun to recover. Residential pumping continues to the north of the Site, and water levels continue to decline in areas away from the localized recovery near PW-1 (see cross-sections in Appendix E).

3.4.4 Constituents of Potential Concern in Groundwater

As with soil, characterization targets for analytical results in groundwater samples were established during RI activities to identify and delineate the nature and extent of COPCs in groundwater. For perchlorate in groundwater, the characterization target was the Arizona Department of Health Services (ADHS) health-based guidance level (HBGL) of 14 micrograms per liter (µg/L). The Arizona Aquifer Water Quality Standard (AWQS) of 7 µg/L was used as the characterization target for 1,1-dichloroethene (1,1-

DCE). A site-specific cleanup goal of 3.5 µg/L for 1,4-dioxane was established by the Arizona Department of Environmental Quality (ADEQ) in its May 3, 2013 letter (ADEQ 2013). Analytical results for groundwater samples were compared to these characterization targets. Routine groundwater monitoring at the Site indicated that perchlorate, 1,4-dioxane, and 1,1-DCE were historically detected in groundwater monitoring wells at or higher than their respective characterization targets. Monitoring well construction information is summarized in Table 2. Groundwater sampling results through December 2014 for perchlorate, 1,4-dioxane, and 1,1-DCE are summarized in Table 5.

3.4.4.1 Perchlorate

The remedial investigation activities conducted at the Site indicate that perchlorate has been released to the environment from past operations. The refurbishing of rocket motor tubes at the Waterbore Area is considered the source that has contributed the majority of the perchlorate mass observed in the soil and groundwater. This conclusion is based on the elevated concentrations of perchlorate detected in soil at the Waterbore Area, a historical hydraulic driver (infiltration of hundreds to thousands of gallons of wastewater, potentially containing perchlorate from historical waterbore operations), and the apparent direction of historical groundwater flow (southwest). The CSM described in this section indicates that there is a core area of perchlorate in groundwater from the Waterbore Area to the C-Complex. It is likely that concentrations in the C-Complex are from the following combined sources and pathways:

- Migration of perchlorate-containing groundwater from the Waterbore Area during Waterbore Area operations

- A relatively minor component of direct infiltration from former operations in the C-Complex and the New Burn Area

Within this core area, transmissive flux is relatively low, indicated by relatively high perchlorate concentrations in the Waterbore Area (21,000 µg/L at MW-19 in October 2014; Table 5) and lower perchlorate concentrations downgradient of the C-Complex (81.2 µg/L at MW-2 in October 2014; Table 5).

Noteworthy monitoring results regarding perchlorate in groundwater are provided in the following table.

Perchlorate	
Locations historically yielding detections higher than 14 µg/L:	MW-1, MW-2, MW-5, MW-6, MW-13, MW-19, MW-20, IW-1, IW-3, EW-1, and EW-2
Highest concentration detected in 2014:	IW-1: 47,600 µg/L

See Table 5 for details.

Another area with minor concentrations of perchlorate in groundwater is in bedrock at well MW-1. The area near MW-1, centrally located along the southern site boundary, likely represents dissolved perchlorate that migrated from the core Waterbore Area/C-Complex Area, based primarily on historical groundwater levels through time and the relatively low concentration (4.5 µg/L) in well MW-21 (Figure 3). MW-21 was installed in the vicinity of the former burn pad, and the low perchlorate detection in groundwater suggests that infiltration through soil was not a primary constituent pathway in the New Burn Area. During Waterbore Area operations, MW-1 was located downgradient of the core Waterbore Area/C-Complex source area due to the mounding of wash water as explained in Section 3.4.3.2. Since on-site pumping ceased, as described in Section 3.4.3.4, water levels in MW-1 have recovered to approximately the same elevation as the core Waterbore Area/C-Complex source area. The likely transport mechanism for perchlorate in MW-1 was migration from the core Waterbore Area/C-Complex, with possible diluted infiltration from the nearby wash in this area. The wash is located on the east side of the New Burn Area, which extends north, back to the Waterbore Area/C-Complex.

The alluvium aquifer near monitoring well MW-6 is apparently hydraulically disconnected from the bedrock conditions near the Waterbore Area and C-Complex. Historically, perchlorate concentrations were relatively stable in MW-6. Prior to the recent emulsified vegetable oil (EVO) injection pilot test, perchlorate concentrations ranged from 15 to 20 µg/L in the MW-6 alluvium monitoring well, with an average of 17.5 µg/L (Table 5). These historical values are slightly higher than the HBGL of 14 µg/L for perchlorate in groundwater. The possible transport mechanism was diluted infiltration from the nearby wash in this area. However, following the EVO injection test performed September 16, 2014 to October 6, 2014, no perchlorate has been detected in wells MW-6, IN-1Ad, IN-1As, DR-01d, or DR-01s in this area (ARCADIS 2015b). Thus, this area is considered remediated pending confirmation by ongoing performance groundwater monitoring.

3.4.4.2 1,4-Dioxane

Historically, 1,4-dioxane has only been detected in groundwater monitoring wells MW-1, MW-2, MW-20, PW-1, and EW-2. Based on known site operations and distribution of 1,4-dioxane in groundwater (only detected in wells MW-1, MW-2, MW-20, PW-1, and EW-2), the likely transport mechanism for 1,4-dioxane is through diluted infiltration from the C-Complex Area. The ADEQ-established site-specific cleanup goal is 3.5 µg/L for 1,4-dioxane in groundwater. Concentrations of 1,4-dioxane in groundwater from wells MW-2, MW-20, PW-1, and EW-2 were 3.2 µg/L, 16.7 µg/L, 3.6 µg/L, and 2.3 µg/L, respectively, during the July 2014 sampling event (Table 5). Groundwater containing 1,4-dioxane above the ADEQ-established site-specific cleanup goal of 3.5 µg/L, is present in the vicinity of well MW-20. Since the installation of well MW-20 in 2012, 1,4-dioxane concentrations ranged from 12.2 µg/L to 16.7 µg/L. Well MW-2, located approximately 375 feet southeast of well MW-20, has had detectable concentrations with all detections below the cleanup goal of 3.5 µg/L. The other wells with detected 1,4-dioxane concentrations have been consistently below the ADEQ-established site-specific cleanup goal of 3.5 µg/L. Higher concentrations of 1,4-dioxane are not anticipated outside of the area of well MW-20 based on historical data trends (Table 5).

MW-20 is located within the perchlorate plume, which will be addressed with the final site remedy. 1,4-dioxane will be monitored during the remediation process. Remediation of 1,4-dioxane will be considered complete once concentrations remain below the cleanup goal of 3.5 µg/L for a minimum duration as yet to be established by ADEQ. For purposes of estimating, UPCO has assumed a minimum duration of four sampling events or two years. As part of the final remedy, groundwater will be extracted from well MW-20. 1,4-dioxane from MW-20 will be treated prior to reinjection. All reinjected groundwater will be less than or equal to the cleanup goal of 3.5 µg/L. During the final remedy, the flow path of groundwater will be controlled through directed groundwater recirculation, therefore; reinjected treated groundwater is unlikely to migrate towards private wells to the north during remedy operation.

3.4.4.3 1,1-Dichloroethene

1,1-DCE was used in several buildings at the Site as part of the assembly process, and a known solvent release occurred in the B-Complex at a former waste storage shed. Only groundwater samples collected from production well PW-1 (located within the B-Complex, with intermittent operation) contained concentrations of 1,1-DCE near or above the AWQS. The highest 1,1-DCE concentration recently detected at PW-1 was 7.1 µg/L in January 2014. Concentrations of 1,1-DCE detected in PW-1 have predominantly been lower than the AWQS of 7.0 µg/L since 2004 (Table 5), and 1,1-DCE was detected at a concentration of only 5.6 µg/L during first quarter 2015 monitoring. 1,1-DCE will continue to be monitored in well PW-1 during operation of the final site remedy. Remediation of 1,1-DCE will be considered complete once concentrations remain below the AWQS of 7.0 µg/L for a minimum duration as yet to be established by ADEQ. For purposes of estimating, UPCO has assumed a minimum duration of four sampling events or two years.

3.4.5 Constituents of Potential Concern in Soil Vapor

To identify and delineate the nature and extent of COPCs in soil vapor, characterization targets were established during the soil vapor investigations and RI activities. Characterization targets for the three volatile organic compounds (VOCs) of concern in soil gas (1,1-DCE, acetone, and methyl ethyl ketone [MEK]) were identified based on a combination of the following criteria: consistent detections of soil vapor collected in multiple areas, elevated concentrations (higher than 1,000 parts per billion by volume [ppbv]), common use at the facility, and constituents with established AWQSs. Using USEPA's online screening tool, soil gas concentrations protective of indoor air were calculated to be 26,900 ppbv for 1,1-DCE, 65,440 ppbv for acetone, and 194,200 ppbv for MEK, assuming a depth to contamination of 10 feet bgs (ARCADIS 2012a) and using default parameters for building design. These concentrations have been established as the characterization targets and remedial goals for 1,1-DCE, acetone, and MEK in soil gas. Analytical results for soil vapor samples collected were compared to these characterization targets.

VOCs present in soil vapor were identified primarily in the B-Complex, C-Complex, and F-Complex, which are also the operational areas with the highest historical solvent usage (Figure 2). 1,1-DCE and acetone are the primary COPCs at the B-Complex for soil vapor. VOCs were detected in soil gas samples collected throughout the B-Complex at various depths. The highest concentrations were detected beneath solid waste management unit (SWMU) 5, which was a former solvent storage shed (ARCADIS 2012b). COPC impacts to soil vapor extended to the water table within the area of SWMU 5 based on soil gas sampling during the B-Complex site investigation and the installation of the nested soil vapor monitoring well SVMW-1. Soil gas monitoring results from SVMW-1 through 2014 are provided in Table 6. The highest 1,1-DCE concentration measured from SVMW-1 was detected in 2009 from the 90- to 100-foot bgs interval at a concentration of 23,000 ppbv, which is below the remedial goal of 26,900 ppbv. For all sampling intervals within SVMW-1, MEK and acetone were consistently measured at concentrations lower than their respective characterization targets (Table 6). Because these concentrations are lower than the remedial goals for 1,1-DCE, MEK, and acetone in soil vapor, these constituents are not considered COPCs in soil vapor at the Site.

4. Corrective Action Objectives

The purpose of the CMS is to identify, develop, evaluate, and recommend corrective measures alternatives that will eliminate or reduce to acceptable levels the risks to human and/or ecological receptors posed by releases and/or potential releases of COCs from the Site. This section presents the CAOs that will provide the basis for forming and evaluating the remedial alternatives considered for the Site.

4.1 Exposure Assessment

The assessment of exposure includes characterization of the physical environment, identification of exposure pathways (including migration pathways, exposure points, and exposure routes), and identification of potentially exposed individuals and populations. Developing an exposure assessment defines the scope of the corrective action and the associated CAOs. The potential human receptors and exposure pathways are identified and presented in the Final RI Report (ARCADIS 2011a).

4.2 Regulatory Standards

This section describes the regulatory standards and guidance that may be applied to corrective actions at the Site. These regulatory standards and guidance are divided into three categories: chemical-specific, location-specific, and action-specific requirements. The regulatory standards include cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, constituent, remedial action, location, or other circumstance at a site. Regulatory guidance comprises non-promulgated advisories or guidance issued by federal or state governments that is not legally binding.

4.2.1 Potential Chemical-Specific Standards

Chemical-specific requirements set health- or risk-based concentration limits or ranges for specific hazardous substances in various environmental media. These standards provide media cleanup levels or a basis for calculating cleanup levels for COCs. Chemical-specific standards are also used to indicate an acceptable level of discharge, to determine treatment and disposal requirements for a particular remedial activity, and to assess the effectiveness of a remedial alternative. Table 7 presents the potential chemical-specific standards identified for corrective action at the Site.

4.2.2 Potential Location-Specific Standards

Location-specific requirements set restrictions on the types of remedial activities that can be performed based on specific site characteristics or location. Location-specific standards provide a basis for assessing restrictions during the formulation and evaluation of site-specific remedies. Remedial alternatives may be restricted or precluded based on citing laws for hazardous waste facilities and based on proximity to wetlands; floodplains; or manmade features such as landfills, disposal areas, and/or local historic buildings. Table 8 presents the potential location-specific standards identified for corrective action at the Site.

4.2.3 Potential Action-Specific Standards

Action-specific requirements set controls or restrictions on the design, implementation, and performance of waste management actions. These standards specify performance levels, actions, or technologies and specific levels for discharge of residual chemicals. They also provide a basis for assessing the feasibility and effectiveness of the remedial alternatives. Table 9 presents the potential action-specific standards identified for corrective action at the Site.

4.3 Corrective Action Objectives for Soil

The CAOs established for the CMS are intended to be specific to the affected medium, but sufficiently broad that they do not overly restrict the potential remedial technology available. The CAOs for soil are based on requirements listed in the AZ HWMA facility permit and also consider guidance provided in the RCRA Corrective Action Plan - Final, May 1994 (EPA 520/R/94/004) (USEPA 1994).

The following CAOs for soil were developed to be protective of human health:

- Reduce or eliminate direct contact by a potential receptor (including ingestion, inhalation, or dermal absorption) or threat of direct contact with COCs in surface and subsurface soils.

- Reduce or eliminate the potential for COCs in surface and subsurface soils to migrate to groundwater.

- To the maximum extent practicable, reduce or eliminate further releases that might pose a threat to human health and the environment.

- In accordance with Part IV, Condition C.10 of the AZ HWMA facility permit, achieve a cleanup level for soils that complies with the Arizona Soil Remediation Standards rule (Arizona Administrative Code Title 18, Chapter 7, Article 2).

- Meet applicable waste management requirements.

4.3.1 Media Cleanup Standards

Once COPCs in soil were identified, cleanup levels were established based on Arizona residential SRLs or groundwater protection levels (GPLs). The constituents present at concentrations exceeding these cleanup levels are considered COCs for soil. Arizona residential SRLs have been established for arsenic, lead, and perchlorate concentrations in soil that are protective of direct contact with potential human receptors in a residential scenario. The Arizona residential SRLs identified as cleanup levels in soil at the Site are 10 mg/kg for arsenic and 400 mg/kg for lead.

ADEQ has not developed a minimum GPL for perchlorate. However, due to the solubility and mobility of perchlorate and the potential for migration to groundwater, a site-specific GPL was developed for perchlorate using a batch test leaching method model approved by ADEQ. The site-specific GPL for perchlorate in soil (16 mg/kg) was calculated for the Site and is presented in the Final RI Report (ARCADIS 2011a). Because this concentration is more stringent than the Arizona residential SRL of 55 mg/kg, ADEQ established the site-specific GPL as the cleanup level for perchlorate in soil at the Site.

Table 10 summarizes the soil cleanup goals. Section 4.5 discusses identified source areas.

4.4 Corrective Action Objectives for Groundwater

As indicated previously, the CMS objectives are intended to be specific to the affected medium, but sufficiently broad so that they do not overly restrict the potential remedial technology available. The CMS objectives for groundwater are based on requirements listed in the AZ HWMA facility permit and also consider guidance provided in the RCRA Corrective Action Plan - Final, May 1994 (EPA 520/R/94/004) (USEPA 1994).

The following groundwater CAOs were developed to be protective of human health:

- Minimize, stabilize, or eliminate further migration of the constituent plume.

- Prevent migration of perchlorate in groundwater at concentrations higher than 14 µg/L to any active private domestic well in the area bounded by Central Avenue, 7th Street, Yearling Road, and Jomax Road.

- Control the source(s) of release(s) to reduce or eliminate, to the maximum extent practicable, further releases that might pose a threat to human health and the environment.

- In accordance with Part IV, Condition C.9 of the AZ HWMA facility permit, achieve a site-wide groundwater cleanup goal for perchlorate of 14 µg/L.

- Achieve the site-wide groundwater cleanup goal within 30 years.

- Meet applicable waste management requirements.

4.4.1 Media Cleanup Standards

Once COPCs in groundwater were identified, cleanup levels were established. Constituents present at concentrations that exceeded the cleanup levels were identified as COCs for groundwater. The RCRA permit for the Site, issued on June 30, 2011, specified the ADHS HBGL of 14 µg/L for perchlorate in groundwater, which is protective of ingestion in a residential exposure scenario. Therefore, the HBGL of 14 µg/L was subsequently established as the cleanup level for perchlorate in groundwater at the Site. As stated in ADEQ's May 3, 2013 letter, the site-specific remediation level for 1,4-dioxane in groundwater is established as 3.5 µg/L.

Table 10 summarizes the groundwater cleanup goals. Section 4.5 discusses identified source areas.

4.5 Scope of the Corrective Action

The scope of the corrective action for soil and groundwater is based on the CSM presented in Section 3.4 and the exposure assessment discussed in Section 4.1. The scope of the corrective action is discussed below.

4.5.1 Soil

4.5.1.1 Perchlorate

During RI activities, perchlorate was detected at concentrations exceeding the cleanup levels in surface and subsurface soil at the former Waterbore Area, C-Complex, E-Complex, and New Burn Area. The soil sample locations are presented on Figures 9 through 13, and sampling results are presented in Appendix D.

Perchlorate concentrations exceeding cleanup levels in soil at the Waterbore Area are limited to soil adjacent to and beneath the former evaporation ponds where wastewater from the water wand operation was discharged (Figure 9). Perchlorate detections exceeding cleanup levels beneath the former ponds extend vertically to approximately 175 feet bgs.

Within the C-Complex, perchlorate detections exceeding the cleanup levels in soil are limited to six locations at depths ranging from surface to approximately 20 feet bgs (Figure 10). The locations of these perchlorate concentrations include:

Location	Number of Samples	Sample Depth
North of former Building C-1	One subsurface	20 feet bgs
South of former Building C-1	Three subsurface	20 feet bgs
Between former Buildings C-1 and C-2	One surface One subsurface	Surface 2 feet bgs
West of former Building C-2	One subsurface	10 feet bgs
Southeast of former Building C-4	One surface	Surface

Perchlorate concentrations exceeding cleanup levels in the former E-Complex were only detected in three surface soil samples located near a former storage magazine where an accidental deflagration of approximately 3,000 pounds of oxidizers and solid propellant occurred in 2002 (Figure 11).

Surface soil located beneath the former burn pad in the New Burn Area that yielded perchlorate detections exceeding the cleanup levels was removed during RCRA OBU closure activities. Subsurface soil was not excavated as part of those activities. Remaining sample locations with perchlorate concentrations exceeding the remedial goals reported in the New Burn Area include 12 locations beneath and adjacent to the former OBU burn pad, at depths ranging from approximately 5 feet bgs to 20 feet bgs (Figure 12).

4.5.1.2 Metals

Lead detections exceeding the remedial goals were reported in surface and near-surface soil samples at the Old Burn Area and the New Burn Area. An elevated lead concentration was detected in one surface soil sample located near the former OBU burn pad in the New Burn Area. This area was excavated during RCRA OBU closure activities; therefore, lead is no longer a COC at the New Burn Area. The Old Burn Area is the only remaining area with lead concentrations in soil exceeding the cleanup level. Surface to near-surface soil sample locations with lead detections exceeding the cleanup level are located near the open burn area. Sample locations are shown on Figures 12 and 13, and sampling data are presented in Appendix D.

Arsenic was detected in soil at concentrations exceeding the cleanup level at locations within the Old Burn Area, F-Complex, B-Complex, and the New Burn Area. An elevated arsenic concentration was detected in the New Burn Area in one surface soil sample located beneath the former OBU burn pad. This area was excavated during RCRA OBU closure activities; therefore, arsenic is no longer a COC at the New Burn Area.

Arsenic was detected in soils in the B-Complex at one surface location in the wash that borders the west and north sides of the operational area. Arsenic was detected at concentrations exceeding the cleanup level in the F-Complex in one sample (20 feet bgs) located off the southwest corner of former Building F-1. Arsenic occurs naturally in soils near the Site. The slightly elevated arsenic detections (12 mg/kg) in one location at 20 feet bgs at the F-Complex and one location in a wash behind the B-Complex are considered naturally occurring and are not attributable to historical UPCO operations. Arsenic was detected at concentrations exceeding the cleanup level at the Old Burn Area at locations near the former burn pad. Sample locations are shown on Figures 12 and 13, and sampling data are presented in Appendix D.

4.5.1.3 Areas Requiring Corrective Action

The scope of corrective action to address perchlorate impacts in surface and subsurface soil includes the Waterbore Area (around the former ponds), C-Complex (around former buildings), E-Complex (around a former storage magazine), and New Burn Area (around the former burn pad). The scope of corrective action to address lead and arsenic impacts in near-surface soil includes locations in the D-Complex (at the Old Burn Area). Figures 9 through 13 identify areas that require corrective action for constituents in soil.

4.5.2 Groundwater

4.5.2.1 Perchlorate

As part of the RI activities conducted since 2004, perchlorate has been historically detected in groundwater at concentrations exceeding the cleanup level at monitoring wells MW-1, MW-2, MW-5, MW-6, MW-13, MW-19, MW-20, IW-1, IW-3, EW-1, and EW-2. Perchlorate concentrations exceeding the cleanup level at MW-20, MW-2, and MW-1 may be attributed to historical Waterbore operations, propellant production in the C-Complex, or a combination of these potential sources. MW-6 is an alluvium monitoring well where perchlorate concentrations previously ranged from 15 to 20 µg/L, with an average of 17.5 µg/L, prior to the recent EVO injection pilot test. No perchlorate has been detected at MW-6 since the EVO injection test was completed October 6, 2014 (ARCADIS 2015b). The alluvium in the vicinity of MW-6 has been effectively remediated, and the only additional corrective action necessary at this location is to complete ongoing performance monitoring of the existing wells in this area to confirm that remediation is complete.

Figure 14 shows the inferred extent of perchlorate concentrations in groundwater at the Site. Historical trends of perchlorate at the Site are presented on Figure 15.

4.5.2.2 1,4-Dioxane

As part of the investigation activities conducted since 2004, 1,4-dioxane has been historically detected in groundwater at concentrations exceeding the cleanup level in only one monitoring well (MW-20).

4.5.2.3 Areas Requiring Corrective Action

The scope of corrective action for groundwater is limited to groundwater with concentrations of dissolved perchlorate in bedrock that are higher than the cleanup levels. Corrective actions will be undertaken at locations beneath the former Waterbore Area, C-Complex, and New Burn Area. Potential perchlorate source areas and areas exceeding cleanup goals are shown on Figure 16. The single well with consistent but low exceedances of 1,4-dioxance (MW-20) is within the perchlorate plume area, which is to be addressed with the final site remedy.

5. Identification and Screening of Remedial Technologies

This section identifies and screens remedial technologies for the Site that could potentially meet the CAOs for soil and groundwater developed in Section 4 and summarized in Table 11. Remedial technologies that are appropriate, reasonable, and have demonstrated the potential for application at the Site are summarized in Sections 5.1.1 and 5.1.2 for soil and groundwater, respectively. Section 5.2 presents the screening criteria to be applied to these technologies.

This screening process is a constraint analysis used to eliminate those technologies that may not be implementable, are unlikely to perform satisfactorily or reliably, do not achieve the CAOs within a reasonable timeframe, or are not cost-effective. The screening process focuses on eliminating those technologies that exhibit multiple limitations in addressing the COCs and/or site-specific conditions. The retained technologies are further evaluated and assembled into remedial alternatives in Section 6. In addition, the remedial alternative analysis assumes site access is granted and the land owner will execute a declaration of environmental use restriction (DEUR).

5.1 Potential Remedial Technologies

The remedial technologies evaluated were previously identified and approved by ADEQ in the CMS Work Plan (ARCADIS 2011b).

5.1.1 Soil

The following technologies have been identified as potentially applicable for corrective action of site soil. Table 12 summarizes the soil technologies evaluated for this CMS.

5.1.1.1 No Action

The No Action technology does not implement measures to correct current conditions at the Site. This technology is included in the CMS as required by the National Contingency Plan (NCP) and USEPA guidance to provide a baseline for comparing the other technologies.

5.1.1.2 Institutional Controls

Institutional controls can reduce potential hazards by eliminating potential routes of exposure or by monitoring conditions at the Site for any changes in potential risk.

Institutional controls may reduce exposure pathways, but will not reduce the mobility, toxicity, or volume of COCs in soil.

Deed Restrictions

Deed restrictions are a form of institutional control that uses legal mechanisms to control future land use. A deed restriction can restrict access to the Site and thereby reduce the potential for direct contact with COCs in soils by receptors. Deed restrictions require cooperation with local government agencies and strict enforcement to effectively control future development and access. The effectiveness of land use deed restrictions can be increased when used in conjunction with physical barriers that limit access to areas with COCs, if needed.

Access Restrictions

The use of a physical barrier, such as a fence, is an institutional control that limits potential access to the Site and areas with COCs, thereby reducing the potential for direct contact with COCs in soil by receptors. Fencing requires inspections and maintenance to effectively control access. A barbed-wire perimeter fence is already in place at the Site, with chain-link fencing around the former operational areas.

5.1.1.3 Containment – Engineered Cover

An engineered cap can control potential hazards by eliminating routes of exposure to the COCs in soil and by potentially reducing constituent migration through isolation and elimination of surface water infiltration. The construction of an engineered cover over soils containing COCs at concentrations higher than cleanup levels will reduce the potential for direct contact of COCs in soil by receptors. The low permeability of the engineered cover will also reduce surface water infiltration and prevent potential leaching of COCs from soil to groundwater.

5.1.1.4 Removal – Soil Excavation with Off-Site Landfill Disposal

Soil excavation and off-site disposal at a landfill can be an effective means of source and residual constituent removal and is most notably applied as a removal measure for surface and shallow soil impacts. By removing the soils containing COCs from the Site for off-site disposal, the potential for direct contact by Site receptors with COCs in soils has been eliminated, and the potential for migration of COCs in soil to groundwater has been reduced or eliminated. Soil excavation typically involves the use of standard earth-moving equipment such as track hoes, dozers, and loaders.

5.1.1.5 Ex Situ Treatment – Physical Treatment with Stabilization

The ex situ stabilization technology mixes additives into the excavated soil to immobilize constituents by encapsulating or immobilizing them within the soil matrix. This reduces the leachability of the COCs and reduces the overall mobility of the constituents.

5.1.1.6 In Situ Treatment

In situ treatment technologies control potential hazards by reducing the toxicity or volume of COCs in soil.

Physical Treatment with Soil Flushing

In situ soil flushing involves injection or infiltration of water into a zone of soil containing COCs, followed by downgradient extraction of groundwater and elutriate (flushing solution containing COCs) and ex situ treatment and discharge or reinjection (Groundwater Remediation Technologies Analysis Center 1998). Soil flushing reduces the mass of COCs in soil, which reduces the potential for receptors to have direct contact with COCs at concentrations higher than cleanup levels and the potential for future migration of COCs to groundwater.

Physical Treatment with Solidification

In situ solidification involves mixing additives into the soil to immobilize constituents by encapsulating or immobilizing them in place within the soil matrix. This reduces the leachability and overall mobility of the COCs.

Biological Treatment with Anaerobic Reduction

In situ biological reduction is a controlled biological process in which naturally occurring perchlorate-reducing microorganisms convert perchlorate to carbon dioxide, water, and chloride. A biological reduction zone is created by injecting carbon substrates into the vadose zone, and perchlorate is reduced via enzymatic degradation by select species of bacteria under anaerobic conditions. For biological treatment of vadose zone soils containing perchlorate, the soils must be saturated with a degradable carbon source, typically a dilute mixture of substrate and water. Delivery of dilute substrates also dissolves solid-phase perchlorate salts, making them available for microbial respiration. The added carbon is a food source and electron donor for microorganisms, growing the microbial community and supporting perchlorate degradation.

5.1.2 Groundwater

The following technologies have been identified as potentially applicable for corrective action of dissolved COCs in groundwater at the Site. Table 13 summarizes the groundwater technologies evaluated in this CMS.

5.1.2.1 No Action

The No Action technology does not implement measures to correct current conditions at the Site. This technology is included in the CMS as required by the NCP and USEPA guidance to provide a baseline for comparing technologies to address COCs in groundwater at the Site.

5.1.2.2 Institutional Controls

Institutional controls can reduce potential hazards by eliminating potential routes of exposure or monitoring conditions at the Site for any changes in potential risk. Institutional controls may reduce exposure pathways, but will not reduce the mobility, toxicity, or volume of COCs in groundwater.

Deed Restrictions

Deed restrictions can protect against potential human exposure to dissolved COCs in groundwater by preventing groundwater use, particularly potable use of groundwater, and controlling land use. Deed restrictions are often used in conjunction with other technologies.

Access Restrictions

The use of a physical barrier, such as a fence, is an institutional control that limits potential access to the Site and areas with COCs, thereby reducing the potential use of groundwater. Fencing requires inspections and maintenance to effectively control access. A barbed-wire perimeter fence is already in place at the Site, with chain-link fencing around the former operational areas.

5.1.2.3 Containment

Containment technologies control potential hazards by eliminating potential routes of exposure or reducing the potential rate of exposure to acceptable risk levels. Containment technologies may reduce the mobility of COCs, but may not necessarily reduce the toxicity or volume of COCs in groundwater.

Hydraulic Control through Groundwater Extraction

Extraction of groundwater involves the removal of dissolved COCs in groundwater and the dissolved constituents from the subsurface to prevent further migration. Extraction is coupled with ex situ chemical or biological treatments. Groundwater extraction wells are installed and operated at a pumping rate sufficient to capture the dissolved COCs in groundwater.

Hydraulic Control with an In Situ Barrier

An in situ barrier physically blocks the flow of dissolved COCs in groundwater. An impermeable physical barrier, such as sheet pile or a soil-bentonite wall, is constructed to control groundwater flow. The implementation of an in situ barrier minimizes or eliminates further migration of the groundwater plume and reduces the potential for migration.

5.1.2.4 Ex Situ Treatment

Ex situ treatment technologies are used in conjunction with the groundwater extraction technology to reduce concentrations of COCs in extracted groundwater.

Physical Treatment with Reverse Osmosis

Reverse osmosis uses high pressure to force the extracted groundwater through a semi-permeable membrane. This membrane allows the water molecules to pass through while removing cations and anions. The constituents in the water are concentrated into a rejectate stream that requires off-site disposal.

Chemical Treatment with Ion Exchange

The ion exchange process involves the substitution of an innocuous anion (generally chloride) for the perchlorate anion. This is generally accomplished by processing the extracted groundwater through a continuous counter-current ion exchange system that contains an ion exchange resin. As the extracted groundwater passes through the resin, the perchlorate anion is exchanged for the chloride anion in the resin and removes the perchlorate from the water. Once the ion exchange resin becomes saturated with perchlorate, the resin can be either managed as a solid waste with new resin replacing it or transported to a regeneration facility and then returned to the treatment system for continued use.

Biological Treatment with an Anaerobic Bioreactor

An anaerobic bioreactor cultivates perchlorate-reducing microorganisms and uses a combined electron donor (carbon source) and select nutrients to create anaerobic conditions that reduce the perchlorate anion to treat extracted groundwater. Different types of bioreactors may be used depending on the volumes and concentrations of extracted groundwater to be treated, including fluidized bed reactors, packed bed reactors, dynamic suspended bed reactors, and membrane biofilm reactors.

5.1.2.5 In Situ Treatment

In situ treatment technologies control potential hazards by reducing the toxicity or volume of COCs in groundwater.

Biological Treatment with Anaerobic Reduction

In situ biological reduction is a controlled biological process in which naturally occurring perchlorate-reducing microorganisms convert perchlorate to carbon dioxide, water, and chloride. A biological reduction zone is created by injecting carbon substrates into the aquifer, and perchlorate is reduced via enzymatic degradation by select species of bacteria under anaerobic conditions. For biological treatment of dissolved perchlorate in groundwater, a degradable carbon source (typically a dilute mixture of substrate and water) must be delivered to the saturated zone. The added carbon is a food source and electron donor for microorganisms, growing the microbial community and supporting perchlorate degradation.

Monitored Natural Attenuation

Monitored natural attenuation (MNA) is a technology that relies on natural attenuation processes along with monitoring to achieve the site-specific CAOs. Natural attenuation processes can include biological degradation, adsorption, and dilution to reduce the mass, toxicity, mobility, volume, or concentration of COCs in groundwater.

5.1.2.6 Waste Management Technologies

Waste management technologies are used in conjunction with groundwater extraction and ex situ treatment technologies.

Reinjection

This technology involves injecting treated groundwater back into the aquifer. The groundwater could be injected at the site boundary to create a hydraulic barrier, or the treated groundwater could be reinjected in the source area to enhance the mass flux toward the groundwater extraction wells, which can increase the pace and efficiency of remediation.

Discharge to Publicly Owned Treatment Works

Treated groundwater is discharged to a publicly owned treatment works (POTW). This waste management technology will require ready access to a POTW, a permit with the POTW, and discharge monitoring.

Discharge to Land Surface

This technology discharges treated groundwater to the land surface for infiltration back to the aquifer and requires a permit and discharge monitoring.

Off-Site Disposal

Off-site disposal involves the on-site storage of treated groundwater or ex situ treatment wastes and transportation to an off-site disposal facility.

Discharge to Surface Water

Treated groundwater is discharged to an existing surface water body. Use of this waste management technology requires ready access to a surface water body, a surface water discharge permit, and discharge monitoring.

5.2 Screening Criteria

The potentially applicable remedial technologies were evaluated against four screening criteria: effectiveness, implementability, past performance, and cost. During the screening process, the level of technology development; performance record; and inherent construction, operation, and maintenance problems were considered for each technology. Technologies that were unreliable, perform poorly, or were not fully demonstrated were eliminated from further consideration. Site characteristics and information obtained from the site investigations were used to screen out technologies that cannot be effectively implemented (either technically and/or due to cost). For example, a technology can be deemed unsuitable if it is not compatible with the identified waste characteristics. In addition, the technology can be deemed unsuitable if it does not affect the contaminated medium in a way that leads to meeting the CAOs.

Technologies judged to be inferior in meeting these criteria were eliminated from further consideration. In cases where individual technologies within the same technology type achieve the same level of effectiveness at a lower cost, the higher cost technology was eliminated on the basis of cost alone. The evaluation criteria are further defined below.

5.2.1 Effectiveness

Effectiveness screening considers the ability of each technology to reduce the estimated mass of the COCs and treat the respective volumes of media to meet CAOs. Effectiveness screening also considers the potential impacts to human health and the environment during the construction or implementation of the technology, as well as potential long-term impacts (after the corrective measure is complete). It considers the ability of each technology to effectively decrease the inherent threats or risks associated with the COCs while minimizing or preventing the generation of treatment residuals that could be harmful to human health or the environment.

5.2.2 Implementability

Implementability screening encompasses both the technical and administrative feasibility of implementing the technology. The technical feasibility assesses site information regarding constituent types and concentrations and site characteristics (e.g., geology and hydrogeology) to screen out options that cannot be effectively implemented at the Site. Site characteristics that could affect the technical implementability of a technology include, but are not limited to, access, depth to impervious formations, depth to groundwater, and presence of bedrock fracturing. Factors that are considered during the assessment of administrative feasibility include, but are not limited to, the ability to obtain necessary permitting; availability of treatment, storage, or disposal facilities for remediation-derived wastes; permitting constraints; or availability of necessary equipment.

5.2.3 Past Performance

Past performance screening considers the ability of each technology to treat constituents at the Site based on proven success at other sites. Case studies of treatment technologies successfully implemented at sites with characteristics (e.g., nature and extent of impacts, geology, and hydrogeology) similar to those at the Site have been evaluated.

5.2.4 Cost

Cost screening addresses the relative magnitude of capital and operation and maintenance (O&M) costs. Capital costs consist of direct and indirect costs. Direct costs are those associated with construction, equipment, materials, transportation, disposal, analytical services, treatment, and operation. Indirect costs are those expenses related to engineering, design, legal fees, permits, and startup. O&M costs are those associated with operation, maintenance, energy, residual disposal, monitoring, and support.

Three cost ranges (high, moderate, and low) were used in the initial evaluation of capital and O&M costs for each process option. This evaluation was made based on engineering judgment and prior experience with cases of comparable scope and magnitude.

5.3 Remedial Technology Screening

The potential technologies for remediation of soil and groundwater are evaluated in Tables 12 and 13. Retention and elimination of technologies are summarized below. The retained technologies are assembled into remedial alternatives for further evaluation in Section 6.

5.3.1 Soil Remedial Technology Screening

Table 12 summarizes and compares the potential soil technologies based on relative effectiveness, implementability, past performance, and cost. Soil stabilization, soil flushing, and solidification technologies were eliminated from further consideration due to low implementability potential. Retained technologies include access restrictions by deed restrictions and fencing, soil excavation with off-site disposal, soil capping with compacted clay cover, and in situ biological reduction. The No Action technology was also retained for baseline comparison as required by the NCP and USEPA guidance. The assembled remedial alternatives are presented in Section 6.

5.3.2 Groundwater Remedial Technologies

Table 13 summarizes and compares the groundwater technologies based on relative effectiveness, implementability, past performance, and cost. The following technologies were eliminated from further consideration for remediation of perchlorate in bedrock: access restrictions by deed restriction, hydraulic control with an in situ barrier, reverse osmosis, ion exchange, MNA, discharge of treated water to a POTW, discharge of treated water to land surface or surface water, and off-site disposal of extracted groundwater. The elimination of MNA, ion exchange, discharge to land surface, and discharge to surface water waste management technologies was based on further consideration of the technology costs and implementation.

The following technologies were retained for further consideration for remediation of perchlorate in bedrock: access restrictions by fencing, hydraulic control through groundwater extraction, anaerobic bioreactor, reinjection, and in situ biological reduction. The No Action technology was also retained for baseline comparison with the other remedial alternatives as required by the NCP and USEPA guidance. Section 6 details the assembled remedial alternatives.

6. Identification and Detailed Analysis of Remedial Alternatives

This section assembles retained technologies into remedial alternatives for further evaluation. This section also describes the alternative evaluation criteria, reviews each alternative against the evaluation criteria, compares remedial alternatives, and discusses implementation of the retained technologies.

6.1 Identification of Remedial Alternatives

The assembled corrective measures alternatives are summarized in Table 14 and presented below.

6.1.1 Soil Alternatives

The following four remedial alternatives were developed to address COCs in soil at the Site:

- SA-1 – No Action
- SA-2 – Excavation, Soil Capping, and Deed Restrictions
- SA-3 – In Situ Biological Reduction and Excavation
- SA-4 – ADEQ Soil Treatment Scenario (Excavation and Soil Capping)

These alternatives were assembled from the remedial technologies deemed potentially applicable and retained for further consideration based upon the evaluation presented in Section 5. The soil treatment scenario developed by ADEQ, presented as part of its review of the permit renewal application for the Site (ADEQ 2010), is also included in the detailed and comparative analysis to aid in remedial alternative selection.

Alternatives SA-2 and SA-3 are included based on their ability to address and achieve each of the CAOs identified in Table 11. Alternative SA-4 and Alternative SA-1 are included for comparison purposes. The soil remedial alternatives that will be evaluated for the Site are described in the following sections.

6.1.1.1 SA-1 – No Action

This alternative consists of no remedial activities to reduce, control, or monitor potential human health or ecological risks associated with COCs in soils. There will be no controls preventing land uses at the Site, potentially resulting in direct contact with COCs in soils. It is the minimum proposed corrective measure for soils at the Site. This alternative is retained for detailed analysis as a baseline for comparing the remaining alternatives.

6.1.1.2 SA-2 – Soil Excavation, Soil Capping, and Deed Restrictions

Alternative SA-2 includes excavation and off-site disposal of soil as follows:

Area	Excavations	COCs	Associated Figure
Waterbore Area	One 2-foot-deep excavation beneath the engineered cap area, including former water wand area and former TTU area	Perchlorate	17
C-Complex	One 2-foot-deep excavation beneath the engineered cap area (near former Building C-1), and four excavation areas south of the engineered cap area ranging from 1 to 11 feet deep	Perchlorate	18
E-Complex	Three 1-foot excavation areas	Perchlorate	19
New Burn Area	One 5-foot-deep excavation beneath the engineered cap area, and eleven excavation areas ranging from 1 to 12 feet deep	Perchlorate	20
Old Burn Area	Five excavation areas at the Old Burn Area ranging from 1 to 3 feet deep	Lead, Arsenic	21

Excavations in these areas will not extend deeper than the maximum depth indicated in the associate figures unless necessary to meet specifications of the engineered cap design, or as necessary to meet the data quality objectives for incremental confirmatory soil sampling (ARCADIS 2015a).

To address deeper soils in the Waterbore Area and parts of the C-Complex Area and New Burn Area with perchlorate concentrations that exceed cleanup levels, engineered caps will be constructed (Figures 17, 18, and 20, respectively). Combined excavation and capping will remove constituent mass and prevent potential receptor contact with COCs in soils and potential leaching of COCs in soil to groundwater. Deed restrictions and maintenance of the existing perimeter fence will be used to maintain the engineered caps.

A pre-design soil investigation was performed in 2014 to further define the horizontal and vertical extent of each excavation area. Historical soil characterization data and pre-design soil investigation data are presented in the Supplemental Soil Pre-Design Summary Report dated October 6, 2014 (ARCADIS 2014a).

In April 2015, an additional soil investigation was performed in the C-Complex Area and New Burn Area to further define the previously proposed deep (20-foot) excavation areas. The boring locations and results for the C-Complex are shown on Figure 18. The boring locations and results for the New Burn Area are shown on Figure 20. Results of the April 2015 additional soil investigation are presented in a summary letter as an attachment to the Response to HWP EX2843 May 14, 2015 letter (ARCADIS 2015d). Soil analytical results are also provided in Appendix D for reference.

Figures 17, 18, 19, 20, and 21 show proposed excavation areas for the Waterbore Area, C-Complex Area, E-Complex Area, New Burn Area, and Old Burn Area, respectively. The table below provides a summary of estimated soil volumes for each of the proposed soil excavation areas. The calculation for the values listed in the column labeled "Excavated Volume" assumes soil expansion of 30 percent over in-place volumes.

Excavated Soil Volume Estimates

Area	Excavation ID	Depth (ft)	Area (ft^2)	In-Place Volume (ft^3)	Excavated Volume (ft^3)
C-Complex	CC-EX-01-1	1	180	180	230
C-Complex	CC-EX-01-2	1	340	340	450
C-Complex	CC-EX-03-1	3	230	700	910
C-Complex	CC-EX-11-1	11	380	4,120	5,360
C-Complex	CC-EX-02-1	2	6,240	12,480	16,200
New Burn	NB-EX-01-1	1	340	340	440

Area	Excavation ID	Depth (ft)	Area (ft^2)	In-Place Volume (ft^3)	Excavated Volume (ft^3)
New Burn	NB-EX-07-1	7	400	2,800	3,640
New Burn	NB-EX-07-2	7	1,630	11,400	14,820
New Burn	NB-EX-07-3	7	250	1,710	2,220
New Burn	NB-EX-12-1	12	500	6,010	7,810
New Burn	NB-EX-12-2	12	290	3,400	4,420
New Burn	NB-EX-12-3	12	350	4,190	5,450
New Burn	NB-EX-12-4	12	380	4,650	6,050
New Burn	NB-EX-12-5	12	310	3,660	4,760
New Burn	NB-EX-12-6	12	570	6,780	8,810
New Burn	NB-EX-12-7	12	550	6,610	8,600
New Burn	NB-EX-05-1	5	1,130	5,630	7,320
Old Burn	OB-EX-01-1	1	1,070	1,070	1,390
Old Burn	OB-EX-02-1	2	230	450	590
Old Burn	OB-EX-02-2	2	660	1,310	1,700
Old Burn	OB-EX-03-1	3	140	420	540
Old Burn	OB-EX-03-2	3	80	220	280
SM	SMA-EX-01-1	1	400	400	520
SM	SMA-EX-01-2	1	150	150	190
SM	SMA-EX-01-3	1	190	190	250
Waterbore	WB-EX-02-1	2	15,320	30,640	40,830
Total				**109,850**	**143,780**

Notes:

ft^2 = square feet

ft^3 = cubic feet

SM = Storage Magazine

All excavated soils with COCs exceeding the cleanup standard will be transported off Site for disposal at an appropriate waste facility and the excavated areas will be backfilled with clean soil, compacted, and completed with a surface cover where appropriate. An engineered cap will be used in the Waterbore Area, C-Complex Area, and New Burn Area, and within other areas if warranted.

Figures 17, 18, and 20 present the areas to be excavated and capped in the Waterbore Area, C-Complex Area, and New Burn Area, respectively. Each cap is estimated to be approximately 10 percent larger than the area requiring coverage. A basis of design report for the engineered cap is provided in Appendix F.

For purposes of estimating costs, it is assumed that excavation and off-site disposal of soils containing COCs and installation of the engineered cap can be completed in one year. After each cap construction is complete, monitoring and maintenance of the caps will be conducted. Performance of the caps will be monitored through annual inspections and groundwater monitoring for perchlorate at the monitoring wells located within and near the caps. The caps are assumed to be maintained for the entire 30-year horizon evaluated in this CMS.

6.1.1.3 SA-3 – In Situ Biological Reduction and Excavation

Similar to Alternative SA-2, Alternative SA-3 includes excavation and disposal of shallow soils with concentrations of COCs that exceed cleanup levels in the Old Burn Area (lead or arsenic), as well as shallow soils with concentrations of COCs that exceed cleanup levels in the C-Complex, E-Complex, New Burn Area, and Waterbore Area (perchlorate). To reduce concentrations of perchlorate in soils at the Waterbore Area and New Burn Area that are deeper than is feasible for excavation, a carbon substrate will be injected into the vadose zone to biologically reduce perchlorate. Maintenance of the existing perimeter fence will continue during remediation to control potential receptor access to the Site until soil CAOs are met.

The areas to be excavated as part of Alternative SA-3, along with the excavation depths, are shown on Figures 19, 21, 22, 23, and 24. During the pre-design soil investigation, the horizontal and vertical extent of each excavation was better defined. Approximately 2,840 in-place cubic yards (cy) of soil are estimated to be excavated in the E-Complex, Old Burn Area, and C-Complex. In the New Burn Area, it is assumed that excavation will be conducted to depths of 1, 7, 10, and 12 feet bgs (approximately 2,810 in-place cy). In the Waterbore Area, it is assumed that excavations will be conducted to depths of 4, 7, 10, and 12 feet bgs (approximately 3,160 in-place cy).

Excavated soils will be transported off Site for disposal at an appropriate waste facility. The excavated areas will be backfilled with clean soil and compacted, and the surface cover will be restored.

A preliminary treatment design and a treatment plan were developed in the 2012 CMS (ARCADIS 2012b). The preliminary design developed in the 2012 CMS includes a network of 12 injection wells installed in four clusters of three wells each, with a targeted 15-foot radius of influence (ROI) from each well. At each well cluster, the well screens will be staggered to provide a total injection depth interval of 160 feet, with the treatment interval starting at 10 feet bgs. Quarterly injections of a dilute carbohydrate (molasses) solution are assumed for 10 years.

A pre-design injection test was performed in 2014 to further define the injection well design and spacing along with the injection volume, frequency, and substrate concentration. While the target conceptual in situ biological reduction treatment area extends to approximately 180 feet bgs, the injection test focused on the upper third (i.e., 20 to 60 feet bgs) of the conceptual in situ biological reduction treatment area. Because of the similarity of the shallow and deep vadose zone geologies, the test results of injectate distribution, injectability, and treatment performance in the upper portion of the vadose zone are considered representative of deeper vadose zone soils. The pre-design activities were conducted in accordance with the approved remedial approach described in the 2012 CMS Report and the Supplemental Soil Pre-Design Study Work Plan (ARCADIS 2012b and 2013b).

The ROI tested for the injection test was conservatively set to 5 feet to minimize the volume of injectate required, and in turn to minimize the potential for flushing perchlorate to groundwater during the test. During the injection, a steady decrease (despite increases in injection pressure) in flow and injection capacity with increased volume was observed due to the very low permeability of the geologic media in the unsaturated zone. During the testing, only approximately 450 gallons of reagent could be injected and the 5-foot ROI was not achieved. Overall, the testing demonstrated that the substrate injection is not feasible due to low geologic permeability and low injection capacity (less than 0.004 gpm/pounds per square inch for the last 50 gallons injected). A detailed summary of the pre-design injection test is presented in the Supplemental Soil Pre-Design Study Summary Report dated October 6, 2014 (ARCADIS 2014a).

For this alternative, it is assumed that a full-scale design would require a maximum ROI of 5 feet. For purposes of evaluating such a remedial alternative, the updated design is assumed to include a network of 30 injection wells installed in 10 clusters of three wells each, with a 5-foot ROI from each well. At each well cluster, the well screens will be staggered to provide a total injection depth interval of 150 feet, with the treatment interval starting at 10 feet bgs. The areas where in situ biological reduction is proposed to be implemented are presented on Figures 23 and 24.

Performance of an in situ biological reduction system will be evaluated using samples collected from suction lysimeters installed within the in situ biological reduction area. A suction lysimeter is a soil water sampler that is permanently installed in the vadose zone, with access tubing connecting the lysimeter to the ground surface. By connecting a pump to the access tubing, a vacuum can be applied through the lysimeter to the vadose zone. This vacuum causes water to move from the soil and into the suction lysimeter, allowing the collection of water samples for performance monitoring. The locations, depths, type, and testing of the suction lysimeters will be evaluated as part of the design if this remedy is chosen. After soil confirmation sampling confirms that soil cleanup goals for perchlorate have been met, the injection well network will be abandoned. For costing purposes, it is estimated that the CAOs will be achieved in approximately 12 years (two-year implementation and 10-year remedy) with this remedial alternative. However, CAOs are not likely to be achieved within the 30-year horizon, because substrate injection is not feasible due to low geologic permeability and low injection capacity. This will likely increase costs for this alternative.

6.1.1.4 SA-4 – Arizona Department of Environmental Quality Soil Treatment Scenario

The soil treatment scenario developed by ADEQ to establish financial assurance requirements consists of excavation and off-site disposal for soils containing perchlorate at concentrations exceeding CAOs in the Waterbore Area to a depth of 20 feet bgs (11,345 in-place cy), in the C-Complex (depth and volume not specified), and in the New Burn Area to a depth of 5 feet bgs (9,260 in-place cy). Excavation will remove constituent mass and prevent potential receptor contact with soils containing COCs and potential leaching of COCs in soil to groundwater. An impermeable cap will also be constructed in the Waterbore Area at locations where soils containing perchlorate concentrations that exceed the CAOs are present at depths greater than is feasible for excavation. By placing an engineered cap in the Waterbore Area (Figure 25), the potential for water infiltration through the vadose zone will be reduced, lowering the potential for perchlorate in the soil to migrate to groundwater.

No additional remedial technologies will be implemented to reduce the potential for direct contact by receptors with COCs located in the SMA or Old Burn Areas. The execution of deed restrictions to restrict access to the Site by potential receptors or ensure the maintenance of the engineered cap in the Waterbore Area was not included in ADEQ's remedy description.

Excavation and off-site disposal of soils and installation of the engineered cap are assumed to be completed in one year. After construction of the impermeable cap is complete, monitoring and maintenance of the cap are assumed for the entire 30-year horizon evaluated in this CMS.

6.1.2 Groundwater Alternatives

Four alternatives were assembled to address groundwater CAOs at the Site:

- GW-1 – No Action
- GW-2 – Source Area Groundwater Extraction, Ex Situ Treatment with Anaerobic Bioreactor, Reinjection, and Alluvium In Situ Biological Reduction
- GW-3 – Source Area Hydraulic Control and In Situ Biological Reduction, and Alluvium In Situ Biological Reduction
- GW-4 – ADEQ Groundwater Treatment Scenario (Site-wide Groundwater Extraction, Ex Situ Treatment, and Site Boundary Reinjection)

Alternatives GW-2 and GW-3 were assembled from the remedial technologies deemed potentially applicable and retained for further consideration in Section 5. The groundwater treatment scenario developed by ADEQ is included in the detailed and comparative analysis to aid in the remedial alternative selection.

6.1.2.1 GW-1 – No Action

This alternative consists of no remedial activities to reduce, control, or monitor potential human health or ecological risks associated with COCs in groundwater. There will be no controls on land use at the Site to prevent the use of groundwater, potentially resulting in direct contact with COCs in groundwater. This alternative is retained for detailed analysis as a baseline for evaluating the remaining alternatives.

6.1.2.2 GW-2 – Bedrock Source Area Groundwater Extraction, Ex Situ Treatment with Anaerobic Bioreactor, Reinjection, and Alluvium In Situ Biological Reduction

To address perchlorate concentrations in groundwater exceeding CAOs in the bedrock aquifer source area of the Site, Alternative GW-2 includes groundwater extraction, ex situ treatment with an anaerobic bioreactor, and reinjection of treated groundwater into the bedrock aquifer around the periphery of the perchlorate plume. Groundwater extraction, ex situ treatment, and reinjection will remove constituent mass and provide hydraulic control of the constituent plume to minimize further migration of perchlorate. Additionally, groundwater extraction and reinjection within the bedrock aquifer source area will increase flushing through the source area, thereby increasing the constituent mass removal rate and decreasing the time to achieve the groundwater CAOs.

The recirculation flow field created by the injection and extraction wells will be balanced as needed in response to real-time performance data by adjusting the recirculation flow rates and other operational parameters to ensure hydraulic containment is maintained and to optimize contaminant removal rates. A network of extraction and injection wells will be employed, and extracted groundwater will be conveyed to the groundwater treatment system containing the anaerobic bioreactor. After treatment is complete, groundwater will be conveyed to the injection wells for reinjection. As summarized in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c), four extraction wells and six injection wells will be used to target the highest perchlorate concentrations in bedrock at the Waterbore Area and C-Complex, and also capture groundwater near bedrock well MW-1 along the southern site boundary (Figure 26).

To remediate groundwater containing perchlorate concentrations higher than the cleanup goal in the alluvium, carbon substrate injection wells were installed in the general vicinity of MW-6 as part of a pilot test to establish anaerobic conditions and destroy perchlorate in situ. A solution of dilute EVO was injected into the aquifer through two alluvium injection wells to provide a relatively long-lasting carbon source as groundwater flows through the treated area. The slow desorption of dissolved organic carbon from EVO will reduce the frequency of injections required to maintain conditions appropriate for perchlorate reduction versus other electron donors such as carbohydrates. The locations of the alluvial injection pilot test wells are shown on Figure 3. Because no perchlorate has been detected in alluvium monitoring wells in this area following the EVO injection pilot test in October 2014, the only corrective action that remains is groundwater monitoring.

Maintenance of the existing perimeter fence will continue during remediation to control potential receptor access to the Site until groundwater CAOs are met.

Alternative GW-2 pre-design testing was performed in accordance with the approved Supplemental Groundwater Pre-Design Study Work Plan dated May 20, 2013 (ARCADIS 2013a), and the pre-design testing is summarized in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c). Pre-design testing was performed to further define the bedrock extraction well capture width and the design and spacing of the bedrock injection wells for treated groundwater, along with treatment testing for the anaerobic bioreactor. The locations of the bedrock groundwater extraction and injection wells are shown on Figure 26. The selected wells and the proposed simulation extraction rates and injection rates are listed in the following table.

Proposed Preliminary Well Selection for Groundwater Alternative GW-2

Extraction Well	Simulation Extraction Rate (gpm)	Maximum Extraction Rate (gpm)	Injection Well	Simulation Injection Rate (gpm)	Maximum Injection Rate (gpm)
IW-1	4	8	RW-1	3	5
EW-1	6	20	RW-2	2	2
MW-20	4	5	MW-5	8	10
EW-2	20	25	MW-11	5	5
			IW-3	16	100
			RW-3*	3	10*

Note:
* Proposed Remediation Well; Maximum Injection Rate is assumed.

For cost estimating purposes, use of a membrane biofilm anaerobic bioreactor was assumed for ex situ groundwater treatment and can achieve the perchlorate cleanup goal of 14 µg/L or less in treated groundwater, as demonstrated by a supplemental bench-scale study performed in 2014. The bench-scale study is summarized in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c). The specific type of bioreactor will be selected during remedial design following implementation of a brief pilot study to establish full-scale system kinetics using pilot-scale bioreactors. Installation of the remediation wells and groundwater treatment system can be completed in approximately two years. After construction of the system is complete, operation of the system will continue until CAOs are achieved.

Due to the complexity and heterogeneity of the bedrock aquifer, time required to achieve CAOs is very difficult to estimate. Remediation timeframes from similar complex and heterogeneous sites can be notably longer than sites with simple hydrogeological conditions; cleanup timeframes for many fractured bedrock sites have been reported to be a decade or longer. Therefore, although the C-Complex and Waterbore Area bedrock aquifer source areas are actively and aggressively being pumped and flushed, it is assumed that numerous pore volume flushes will need to be completed to reduce contaminant concentrations to target levels. As a result, the time required to achieve CAOs in this area is assumed to be approximately 10 years. The estimated time required to flush and treat the zone between the injection wells and downgradient well MW-1 is estimated to be less than 10 years because current concentrations are lower than at the water bore area. Based on these approximations, this CMS assumes that 10 years of active operation will be needed to achieve CAOs.

The pre-design alluvial in situ biological reduction design includes two injection wells (IN-1As and IN-1Ad) with a 15-foot ROI from well MW-6 and two dose-response wells (DR-01s and DR-01s). Each shallow and deep well were installed to a total depth of 175 and 205 feet bgs, respectively, with each having a 20-foot screen interval (ARCADIS 2014c). Figure 3 shows the locations of the alluvial injection wells. Injection of a substrate and a non-toxic fluorescein tracer solution was performed between September 16 and October 6, 2014. The injection test is summarized in the Supplemental Groundwater Pre-Design Study Summary Report (ARCADIS 2014c), and performance monitoring is being conducted through 2015. Because no perchlorate has been detected in alluvium monitoring wells in this area following the EVO injection pilot test in October 2014, the only corrective action that remains is groundwater monitoring.

Performance of the source area recirculation network and alluvial in situ biological reduction system will be tracked using the groundwater monitoring program already established for the Site. It is assumed that post-remediation groundwater monitoring will be conducted for two years after active remediation is complete, although based on performance, a shorter timeframe may be appropriate. After groundwater sampling confirms that site-wide groundwater cleanup goals for perchlorate have been met, the treatment system, extraction well, and injection well networks will be abandoned. For costing purposes, a 14-year (two-year implementation, 10-year remedy, and two-year post-remedy monitoring) timeframe from design to closure is assumed.

6.1.2.3 GW-3 – Bedrock Source Area Hydraulic Control and In Situ Biological Reduction and Alluvium In Situ Biological Reduction

To address perchlorate concentrations in groundwater, Alternative GW-3 includes groundwater extraction, addition of a dilute carbon source, and reinjection of amendment-enhanced groundwater into the bedrock source area. The addition of a dilute carbon source to the groundwater stream will allow for the establishment of anaerobic conditions in the source area and the in situ degradation of perchlorate, thereby potentially decreasing the COC mass. However, it is uncertain if this would result in a reduction in the amount of time needed to achieve CAOs when compared to Alternative GW-2. Furthermore, there is uncertainty regarding the flowpath of injected reagent and undemonstrated treatment effectiveness for in situ biological reduction within the bedrock aquifer at the Site, which may jeopardize source control.

Additionally, groundwater extraction and reinjection within the source area will increase the hydraulic flux through the source area, which may also decrease the time needed to achieve groundwater CAOs, similar to Alternative GW-2. The recirculation flow field created by the injection and extraction wells will need to be balanced in response to real-time performance data by adjusting the recirculation flow rates and other operational parameters to accelerate and maximize perchlorate degradation. A network of extraction and injection wells will be installed; extracted groundwater will be mixed with a dilute carbon (e.g., molasses) solution, and then injected through the injection network. For cost purposes, the extraction and injection system layout is assumed to be the same as that for Alternative GW-2 and is shown on Figure 26. However, there is potential to extract total organic carbon and redistribute it outside of the source area in bedrock groundwater, which would limit the effectiveness of in situ biological reduction. In addition, there is uncertainty regarding degree to which TOC may be distributed throughout the source zone with this number and configuration of injection and extraction wells. Also, there is higher risk of injection well fouling when a source of carbon is applied, which requires increased well maintenance, well rehabilitation, and well replacement. This will result in an extended remediation timeframe and additional costs.

Alternative GW-3 also includes in situ biological reduction of perchlorate in the alluvium in the southwestern portion of the Site using EVO, as included in Alternative GW-2. Carbon substrate injection wells, installed near MW-6, were used to establish anaerobic conditions and destroy perchlorate in situ as part of the EVO injection pilot test performed in October 2014. The locations of the alluvial injection wells are shown on Figure 3. Because no perchlorate has been detected in alluvium monitoring wells in this area following the EVO injection pilot test in October 2014, the only corrective action that remains is groundwater monitoring.

For the source area, the preliminary design developed assumes that a dilute solution of 0.25 to 2 percent molasses (by weight) will be added to the extracted groundwater stream prior to reinjection in the source area. This remedy has similar hydraulic control and flushing benefits associated with GW-2, but groundwater treatment occurs in situ instead of ex situ. It is uncertain whether this process could shorten the overall remedial timeframe compared to GW-2.

Installation of source area remediation wells and a carbon feed system can be completed in approximately two years. After construction of the system is complete, operation of the system will continue until CAOs are achieved within the treatment area. It is assumed that 10 years of active system operation will be required to achieve CAOs. When incorporating in situ mixing and the subsequent additional treatment that will be realized, it is possible that the remedial timeframe will be shorter than 10 years for areas outside the bedrock source area.

The performance of the source area and alluvial in situ biological reduction systems will be tracked using the groundwater monitoring program already established for the Site. After groundwater sampling confirms that site-wide groundwater cleanup goals for perchlorate have been met, the extraction well and injection well networks will be abandoned and remediation will be complete. It is assumed that post-remediation groundwater monitoring will be conducted for two years after active remediation is complete, although, based on performance, a shorter timeframe may be appropriate. For costing purposes, a 14-year (two-year implementation, 10-year remedy, and two-year post-remedy monitoring) timeframe from design to closure is assumed.

6.1.2.4 GW-4 – Arizona Department of Environmental Quality Groundwater Treatment Scenario

The groundwater treatment scenario developed by ADEQ to establish financial assurance requirements consists of groundwater extraction, ex situ treatment with tailored granular activated carbon (TGAC), and reinjection of treated groundwater at the former operations boundary. For this CMS, ex situ treatment for Alternative GW-4 was changed from TGAC to an anaerobic bioreactor because the bioreactor will be less expensive and more effective and TGAC is no longer readily available. Groundwater extraction and ex situ treatment will remove constituent mass and provide hydraulic control of the constituent plume to minimize any potential off-site migration of perchlorate. The reinjection of treated groundwater at the former operations boundary will create a hydraulic barrier and further minimize the potential for off-site migration of perchlorate.

The groundwater extraction and reinjection design developed by ADEQ includes 10 extraction wells to provide hydraulic control over the groundwater plume. Within the Waterbore Area, two wells (IW-1 and EW-1) will be used as extraction wells. Two wells (MW-20 and IW-3) will be used as extraction wells in the C-Complex Area, and well MW-21 and one newly installed remediation well will be use as extraction wells in the New Burn Area. An additional three remediation wells will be installed near well EW-2 and used as extraction wells downgradient of the source area to provide further hydraulic control to the plume. Groundwater extracted from these three new remediation wells and well EW-2 will be conveyed to a central groundwater treatment system, and then reinjected at five injection wells. The newly installed extraction wells will be constructed to 400 feet bgs, with a screen length of 150 feet. All extraction wells will operate at an extraction rate of 2.5 gpm each. Three new injection wells and two existing wells (RW-1 and IW-2) will be used as injection wells along the north side of the source area. The new injection wells will be installed to 400 feet bgs, with a screen length of 300 feet. Approximate locations of the extraction and injection wells included as part of the ADEQ groundwater treatment scenario are shown on Figure 27.

Installation of the additional remediation wells and groundwater treatment system can be completed in approximately two years. After construction is complete, O&M of the groundwater extraction network will be conducted until the groundwater CAOs are achieved. The scenario prepared by ADEQ assumes that 30 years of O&M will be needed.

6.2 Evaluation Criteria

The purpose of the detailed analysis is to objectively evaluate the available and identified remedial alternatives against the nine established RCRA Corrective Action criteria. The performance of each remedial alternative with respect to each criterion is individually assessed to identify the relative strengths and weaknesses of that alternative. The evaluation criteria to be applied are described below.

6.2.1 Overall Protection of Human Health and the Environment

This criterion evaluates how the alternative protects human health and the environment. This assessment focuses on how an alternative achieves protection through time and indicates how each historical source of COCs will be minimized, reduced, or controlled through treatment, engineering, or institutional controls. The evaluation of the degree of overall protection associated with each alternative is based largely on the exposure pathways and scenarios set forth in the exposure assessment.

6.2.2 Attainment of Media Cleanup Objectives

This criterion addresses whether the corrective measures alternative attains the media cleanup standards. Each alternative must be evaluated for how it achieves the identified media cleanup standard along with any other remediation objectives. The media cleanup standards and CAOs for soil and groundwater are summarized in Tables 10 and 11, respectively.

6.2.3 Control the Sources of Releases

This criterion evaluates the effectiveness of the alternative in eliminating further environmental degradation by controlling or eliminating the potential for future releases that may pose a threat to human health and the environment. The limitations of each remedial technology, in conjunction with site constraints, are considered in evaluating source control to the extent practicable.

6.2.4 Compliance with Standards for the Management of Wastes

The waste management criterion addresses compliance of the remedial alternative with applicable state or federal regulations for waste management activities. These standards may include landfill closure requirements and land disposal restrictions established at the federal and state levels.

6.2.5 Long-Term Reliability and Effectiveness

The long-term reliability and effectiveness criterion addresses the degree, extent, and manner in which the remedial alternative continues to protect human health and the environment in terms of residual risk at the Site after the CAOs have been met. This criterion considers the residuals following completion of the actions, expected duration of the remedy, and degree of controls required to ensure protectiveness of the remedy.

6.2.6 Reduction of Toxicity, Mobility, or Volume of Wastes

This criterion relates to the extent to which remedial alternatives permanently reduce the toxicity, mobility, and volume of constituents present at the Site. Factors for this criterion include the degree of permanence of the corrective measure, amount of hazardous materials destroyed, and type and quantity of residual contamination remaining after treatment.

6.2.7 Short-Term Effectiveness

Short-term effectiveness addresses the effects of the remedial alternative during construction and implementation of the remedy, until the CAOs are met. This criterion considers the protection of the community and workers, including the air quality effects and hazards from excavation, transportation, and on-site treatment. This criterion also considers the expected length of time for completion of the corrective measure.

6.2.8 Implementability

This criterion addresses the technical and administrative feasibility of implementing each remedial alternative and the availability of services and materials. This criterion also considers the degree of coordination required by the regulatory agencies, successful implementation of the corrective measure at similar sites, and research to realistically predict field implementability.

6.2.9 Cost

The cost criterion addresses the capital and O&M costs, and includes a present-worth analysis of all costs. Cost as a criterion may be used to screen alternatives where each alternative equally meets or exceeds the CAOs. The capital costs consist of direct costs (construction) and indirect costs (non-construction and overhead). Direct capital costs include construction costs, equipment costs, land and development costs, relocation expenses, and disposal costs. Indirect capital costs include engineering expenses, legal fees and license or permit costs, startup costs, and contingency allowances.

O&M costs are post-construction costs necessary to confirm the continued effectiveness of a corrective measure. These costs include operating labor costs, maintenance materials and labor costs, auxiliary materials and energy, treatment residue disposal costs, purchased services, administrative cost, insurance, taxes, licensing costs, maintenance reserve and contingency funds, rehabilitation costs, and costs of periodic site reviews, if required.

The cost estimates presented in this CMS were developed using USEPA guidance, professional engineering judgment, and quotations from appropriate vendors. In accordance with USEPA guidance, the cost estimates in this CMS have been prepared to provide accuracy in the range of -30 to +50 percent (USEPA 2000). All capital and O&M cost estimates are expressed in 2015 dollars.

After development of the capital and O&M costs, a present-worth analysis of the overall corrective measure costs associated with each alternative was completed. A present-worth analysis relates costs that occur over different time periods to present costs by discounting all future costs to the present value. This allows comparison of the cost of alternatives based on a single figure that represents the capital required in 2015 dollars to construct, operate, and maintain the alternative throughout its planned life. The present-worth calculations are based on a discount rate of 7 percent (USEPA 2000). Lifecycle costs are calculated for each alternative.

6.3 Individual Analysis of Remedial Alternatives

The analysis of each of the identified remedial alternatives in relation to the criteria discussed in Section 6.2 is presented in the following sections.

6.3.1 Soil Alternatives

Four soil remedial alternatives have been retained for detailed analysis. The detailed analyses of each soil remedial alternative are summarized in Tables 15 through 18 and presented in the following sections.

6.3.1.1 SA-1 – No Action

The following sections present a detailed analysis of remedial alternative SA-1 for soil. Table 15 summarizes this analysis. This alternative is retained as a baseline for evaluating the remaining alternatives.

Overall Protection of Human Health and the Environment

Although the No Action Alternative does not incorporate activities that will present exposure risks to the community, workers, or the environment, it does not further reduce existing COC concentrations in soil or provide measures to eliminate or control potential exposure pathways associated with the soil. Natural attenuation processes may reduce perchlorate concentrations to cleanup levels, although specific monitoring of these processes will not be performed to evaluate changes in risks or determine when cleanup levels were met. Additionally, this alternative has the potential to allow COCs in soil to leach to groundwater.

Attainment of Media Cleanup Objectives

Alternative SA-1 will not achieve the soil CAOs because no action will be taken to control potential exposure pathways or address COC concentrations in soil.

Control the Sources of Releases

Historical operations at the Site were the source of COCs in soil; there are no ongoing sources present at the Site. While lead and arsenic present in soils are not mobile constituents and will likely not migrate to groundwater, the potential exists for perchlorate in soils to migrate to groundwater. Alternative SA-1 will not implement any controls to reduce the potential for COCs in soils to migrate to groundwater.

Compliance with Standards for the Management of Wastes

Alternative SA-1 will not comply with chemical-specific standards for soil because no action will be taken to control potential exposure pathways or address COC concentrations in soil. There are no location- or action-specific standards for Alternative SA-1.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence will not be achieved through the No Action Alternative because reduction of COC concentrations in soil will not be addressed and controls will not be implemented to reduce or eliminate potential exposure pathways. Additionally, this alternative has the potential to allow COCs in soil to leach to groundwater, potentially exposing downgradient receptors. It may also increase the capital and O&M expenditures if future remediation is required.

Reduction of Toxicity, Mobility, or Volume of Wastes

Natural attenuation mechanisms may result in the reduction of perchlorate mobility, toxicity, and volume in soil, primarily through dilution, although monitoring of these processes will not be performed with Alternative SA-1 to evaluate changes in risks or determine when cleanup levels are met. Natural attenuation mechanisms are unlikely to reduce the mobility, toxicity, or volume of lead and arsenic in soil.

Short-Term Effectiveness

The No Action Alternative does not incorporate any activities that will present exposure risks to the community, workers, or the environment.

Implementability

Because no technical implementation is required, the No Action Alternative is technically feasible and may not limit or interfere with the ability to perform future corrective measures. However, because potential exposure pathways will not be controlled and the potential leaching of COCs in soil to groundwater will continue, the No Action Alternative is likely not administratively feasible.

Cost

Table 15 and Appendix G present summaries of the present-value cost calculations for Alternative SA-1 and the detailed cost backup, respectively. There are no actions to be implemented; therefore, no capital or O&M costs are associated with Alternative SA-1. Total costs for this alternative are estimated to be $0 in 2015 dollars.

6.3.1.2 SA-2 – Excavation, Soil Capping, and Deed Restrictions

The following sections present a detailed analysis of remedial alternative SA-2 for soil. This alternative will use excavation and off-site disposal to remove COCs in shallow soils at the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area and will eliminate the potential for direct contact with COCs in soil by potential receptors. An engineered cap will be installed and maintained in the Waterbore Area, C-Complex Area, and New Burn Area to reduce the potential for receptors to contact COCs in soil and reduce the potential for leaching of COCs in soils to groundwater. Deed restrictions will be implemented, and the current perimeter fence will be maintained to restrict access to the Site by potential receptors and maintain the surface covers. Table 16 summarizes this analysis. The proposed engineered cap areas are presented on Figures 17, 18, and 20.

Overall Protection of Human Health and the Environment

Implementation of this alternative will potentially result in short-term exposure risks to the community, workers, or the environment that will be managed with engineering controls and worker training. COCs in soils at the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area will be permanently removed and disposed of at an off-site waste management facility, which will eliminate the potential exposure pathway in these areas. The construction and maintenance of an engineered cap at the Waterbore Area, C-Complex Area, and New Burn Area will place a physical barrier between potential receptors and COCs in soil to reduce the potential exposure pathway and the potential for leaching of COCs in soil to groundwater. Deed restrictions will be implemented, and the perimeter fence and engineered caps will be monitored to reduce the potential for future migration of COCs in soil to groundwater or direct contact with perchlorate in soils by potential receptors. Therefore, Alternative SA-2 will be protective of human health and the environment by removing COC mass, reducing potential exposure pathways, and limiting the potential for COCs in soils to migrate to groundwater.

Attainment of Media Cleanup Objectives

Alternative SA-2 will achieve the soil CAOs. Excavation and off-site disposal of soils in the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area will reduce the mass of COCs in soil. This action reduces or eliminates the potential for direct contact by a receptor with COCs in soil, reduces the potential for COCs in soils to migrate to groundwater, achieves the cleanup levels established for soils, and meets applicable waste management requirements. Construction and maintenance of an engineered cap in the Waterbore Area, C-Complex Area, and New Burn Area will reduce the potential for perchlorate in deep soils to migrate to groundwater and the potential for direct contact with COCs in soil by potential receptors. Placing deed restrictions on the Site and maintaining the perimeter fence and engineered cap will reduce or eliminate the potential for a future exposure pathway to COCs in soil or leaching of COCs in soil to groundwater.

Control the Sources of Releases

The constituent sources are from historical operations, and ongoing sources are not present. Lead and arsenic are not likely to be mobile and will be removed from the Site through excavation. Potential migration of perchlorate in soils to groundwater will be controlled by excavating soils containing COCs at concentrations exceeding the cleanup standard from the C-Complex, SMA, Waterbore Area, and New Burn Area, and by constructing and maintaining an engineered cap in the Waterbore Area, C-Complex Area, and New Burn Area where soil containing COCs at concentrations exceeding the cleanup standard is located at depths beyond the feasibility of excavation.

Compliance with Standards for the Management of Wastes

Alternative SA-2 will comply with chemical-specific standards for soils by removing the COCs present in soils at the C-Complex, New Burn Area, SMA, Waterbore Area, and

Old Burn Area and reducing the potential for leaching of perchlorate in soils to groundwater in the Waterbore Area, C-Complex Area, and New Burn Area. Alternative SA-2 will comply with location- and action-specific standards.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence will be achieved through Alternative SA-2. Permanent reduction of COC concentrations in soil will be achieved through excavation, which will eliminate the potential for direct contact with COCs in soil by a receptor in these areas. An off-site disposal facility will properly handle the excavated soil to minimize any residual risk. The engineered caps in this alternative also reduce the potential exposure pathway and the potential for COCs in soil to leach to groundwater while the caps are in place and maintained, although soil containing COCs will stay in place. The caps must be maintained beyond the standard 30-year horizon evaluated in this CMS.

Reduction of Toxicity, Mobility, or Volume of Wastes

Alternative SA-2 will permanently reduce the volume of COCs in soil by excavation. The mobility of COCs in soil will also be reduced by installing engineered caps, which will extend beyond the source area determined in the pre-design investigation by 10 percent. Potential leaching of COCs from soil to groundwater will be controlled by the caps. After this alternative has been implemented, the only residual contamination remaining in soils at the Site will be perchlorate in soils located beneath the caps. Natural attenuation mechanisms in that area may result in the reduction of perchlorate toxicity and volume in soil, although these processes will not be monitored with Alternative SA-2.

Short-Term Effectiveness

Implementation of this alternative will result in short-term exposure risks to the community, workers, and the environment that will be managed using engineering controls and worker training. Engineering measures will be used to control potential air emissions, fugitive dust, surface water runoff, erosion, and sedimentation during excavation and cap construction. Real-time perimeter monitoring tied to a contingency plan will also be implemented to protect the surrounding community during excavation. Excavated soil will require transport to an off-site disposal facility, creating potential risks to the community due to truck traffic and potential risks to the environment from vehicle emissions. These risks can be mitigated through measures such as transportation during off-peak hours, and clean diesel technologies may be used to reduce emissions from diesel-powered equipment and trucks. Waste derived from remedial activities will be handled using approved methods by trained workers. This alternative will be effective in the short term because the remedial alternative can be implemented in approximately one year following permitting and design.

Implementability

Implementation of this alternative is technically feasible, although the soil types at the Site will limit excavation depths. Equipment and subcontractors for excavation and installation of the engineered caps are readily available. Periodic monitoring of the engineered caps will control their reliability in the future. Institutional controls will be readily implementable. This alternative is administratively feasible, and the remedial technology is conventional and proven effective for the COCs at the Site.

Cost

Table 16 and Appendix G present summaries of the present-value calculations for Alternative SA-2 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $2,026,950 for the design and implementation of soil excavation and the soil cap. Total annual O&M costs are estimated to be approximately $15,300 each year for 30 years to monitor and maintain the caps and deed restrictions. Based on USEPA guidance, the total present-value lifecycle cost of Alternative SA-2 using a discount rate of 7 percent for 30 years is $2,089,000 (USEPA 2000).

6.3.1.3 SA-3 – In Situ Biological Reduction and Excavation

This alternative would use excavation and off-site disposal to remove COCs in soils from the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area and eliminate the potential for direct contact with COCs in soil by potential receptors. A vadose zone injection well network would be installed in the Waterbore Area and New Burn Area with 10 years of quarterly injections performed to establish anaerobic conditions and reduce perchlorate concentrations in soils to levels protective of groundwater. The current perimeter fence will be maintained to restrict access to the Site by potential receptors. In 2014, a pre-design study was conducted to determine the feasibility of remedial alternative SA-3. As presented in the Supplemental Soil Pre-Design Study Summary Report (ARCADIS 2014a), it was identified that remedial alternative SA-3 is not likely to be feasible because the vadose zone does not support adequate injection rates and reagent distribution for full-scale implementation. The following sections present a detailed analysis of remedial alternative SA-3 for soil. Table 17 summarizes this analysis.

Overall Protection of Human Health and the Environment

Implementation of this alternative will potentially result in short-term exposure risks to the community, workers, or the environment that will be managed with engineering controls and worker training. COC concentrations in soils at the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area will be permanently reduced through excavation and off-site disposal, eliminating the potential for direct contact with COCs in soils by potential receptors. In situ biological reduction is not likely to reduce perchlorate concentrations in soils at the Waterbore Area and New Burn Area to levels protective of groundwater because substrate injection is not feasible due to low geologic permeability and low injection capacity. This will likely result in an increase in cost for this alternative. Therefore, Alternative SA-3 is not likely to be protective of human health and the environment.

Attainment of Media Cleanup Objectives

This alternative is not likely to achieve the soil CAOs. Excavation and off-site disposal of soils in the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area will reduce the mass of COCs in soil. This action eliminates the potential for direct contact by a receptor with COCs in soil, reduces the potential for COCs in soils to migrate to groundwater, achieves the cleanup levels established for soils, and meets applicable waste management requirements for those areas. Implementing an in situ biological reduction system in the Waterbore Area and New Burn Area, however, is not likely to reduce the mass of COCs in soil because substrate injection is not feasible due to low geologic permeability and low injection capacity. Therefore, this corrective measure is not likely to eliminate the potential for perchlorate in soils to migrate to groundwater, and is not likely to achieve the established perchlorate cleanup level.

Control the Sources of Releases

Historical operations at the Site were identified as the source of COCs in soil; there are no ongoing sources present at the Site. While lead and arsenic present in soils are not mobile constituents and will likely not migrate to groundwater, the potential exists for perchlorate in soils to migrate to groundwater. Alternative SA-3 will reduce or eliminate the potential for COCs in soils to migrate to groundwater through excavation of soil containing concentrations of lead, arsenic, and perchlorate exceeding cleanup standards. However, in situ biological reduction of perchlorate is not likely to eliminate the potential for COCs in soils to migrate to groundwater because substrate injection is not feasible.

Compliance with Standards for the Management of Wastes

Alternative SA-3 is not likely to comply with chemical-specific standards for COCs in soil because substrate injection is not feasible; thus, COCs present in soils at concentrations higher than the standard would likely remain in place at the C-Complex, New Burn Area, and Waterbore Area. Alternative SA-3 is not likely to comply with location- and action-specific standards for the same reason.

Long-Term Reliability and Effectiveness

Alternative SA-3 will not be effective and reliable in the long term. Permanent reduction of COC concentrations in soil will be achieved through excavation, but not by in situ biological reduction. Soil excavation will eliminate the potential for direct contact with COCs in soil by a receptor and for COCs in soil to leach to groundwater. During the pre-design study, in situ biological reduction testing demonstrated low injection capacity and low geologic permeability. Therefore, the vadose zone does not support adequate injection rates or reagent distribution to provide long-term reliability and effectiveness.

An off-site disposal facility will properly handle the excavated soil to minimize any residual risk; no residual risk is associated with in situ biological reduction because perchlorate will be destroyed. Due to the likely ineffectiveness of in situ biological reduction as an active treatment method in the Waterbore Area and New Burn Area, it is assumed that this alternative is likely to increase the overall timeframe required to achieve CAOs.

Reduction of Toxicity, Mobility, or Volume of Wastes

Alternative SA-3 will permanently reduce the mobility, toxicity, and volume of some COC mass in soil. Excavation and off-site disposal of soils in the C-Complex, Old Burn Area, SMA, Waterbore Area, and New Burn Area will permanently reduce the volume of COCs. In situ biological reduction will result in the permanent degradation of some COC mass in the Waterbore Area and New Burn Area. However, because of the ineffectiveness of in situ biological reduction, some COC mass is likely to remain in place without the implementation of additional actions. It is expected that soil cleanup goals are not likely to be met with this alternative.

Short-Term Effectiveness

The implementation of Alternative SA-3 will result in limited exposure risks to the community, workers, and the environment that will be managed through engineering controls and worker training. Excavation and installation of injection wells could create short-term exposure risks. Engineering measures will be used to control potential air emissions, fugitive dust, surface water runoff, erosion, and sedimentation during excavation and well installation. Monitoring will be implemented as required by a dust control permit to protect the surrounding community during excavation. Excavated soil will require transport to an off-site disposal facility, creating potential risks to the community due to truck traffic and potential risks to the environment from vehicle emissions. If necessary, these risks could be mitigated through measures such as transportation during off-peak hours or the use of clean diesel technologies to reduce emissions from diesel-powered equipment and trucks. All O&M activities will be performed by trained personnel. Waste generated during remedial activities will be managed by trained workers using approved methods. This alternative will be effective in the short term because the alternative can be implemented in approximately one year and be completed within approximately 10 years if a 5-foot ROI reagent distribution is attainted.

Implementability

Implementation of this alternative is administratively feasible but not technically feasible. Excavation will require readily available equipment and services. Injection wells for in situ biological reduction will be installed using standard well drilling methods and materials. These services are readily available, as are the services and materials necessary for the injection system and injection events. Excavation is a conventional remediation technology and is proven for the applicable COCs. Biological reduction of perchlorate and in situ biological reduction of constituents located within the vadose zone are proven technologies. Even in desert conditions, the soil moisture is sufficient to support microbiological communities, and perchlorate reduction can occur when carbon sources can be delivered effectively and anaerobic conditions are established and maintained. The effectiveness of Alternative SA-3 depends upon the ability to deliver sufficient carbon substrate to the vadose zone soils to establish and maintain the anaerobic conditions that will degrade perchlorate. According to the Supplemental Soil Pre-Design Study Summary Report (ARCADIS 2014a), the vadose zone does not support adequate injection rates or reagent distribution due to cementation of the alluvium sediments. Therefore, the carbon substrate cannot be effectively delivered to the vadose zone. It may also increase the capital and O&M expenditures if future remediation is required.

Cost

Table 17 and Appendix G present summaries of the present-value calculations for Alternative SA-3 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $2,602,386 for the design and implementation of soil excavation and the in situ biological reduction system. Total annual O&M costs are estimated to be approximately $107,000 each year for 10 years. Periodic costs include confirmation soil sampling and system decommissioning when CAOs are achieved and are estimated to be $199,000. Based on USEPA guidance, the total present-value lifecycle cost of Alternative SA-3 using a discount rate of 7 percent is $3,010,000 (USEPA 2000).

6.3.1.4 SA-4 – Arizona Department of Environmental Conservation Soil Treatment Scenario

The following sections present a detailed analysis of remedial alternative SA-4 for soil. This alternative was developed by ADEQ and will use excavation and off-site disposal to remove COCs in soils from the Waterbore Area, C-Complex, and New Burn Area. Excavation in this area will reduce the potential for direct contact by potential receptors with perchlorate in soil and reduce the potential for COCs in soil to leach to groundwater. Excavation in the New Burn Area will be conducted over a 1.1-acre area to a depth of 5 feet bgs. For the Waterbore Area, an area of approximately 15,450 square feet will be excavated to a depth of 20 feet bgs.

This alternative includes construction and maintenance of an engineered cap in the Waterbore Area where soils containing perchlorate concentrations exceeding CAOs are at depths greater than is feasible for excavation. By placing an engineered cap in this area, the potential for water infiltration through the vadose zone will be reduced, lowering the potential for perchlorate in the soil to migrate to groundwater. No additional remedial technologies will be implemented to reduce the potential for direct contact by receptors with COCs located in the SMA or Old Burn Area. ADEQ did not specify that deed restrictions will be implemented to restrict access to the Site by potential receptors or to ensure maintenance of the cap in the Waterbore Area. Table 18 summarizes this analysis.

Overall Protection of Human Health and the Environment

Implementation of Alternative SA-4 will potentially result in short-term exposure risks to the community, workers, or the environment during excavation; these potential risks will be managed with engineering controls and worker training. Perchlorate concentrations in soils in the Waterbore Area, C-Complex, and New Burn Area will be permanently reduced through excavation, and the potential for perchlorate in soils at the Waterbore Area to migrate to groundwater will be reduced by the engineered cap. However, no actions will be implemented in any other areas of the Site to eliminate or control potential exposure pathways associated with the soil or to reduce the potential leaching of COCs in soil to groundwater. Natural attenuation processes may reduce perchlorate concentrations to cleanup levels outside of the Waterbore Area, C-Complex, or New Burn Area, although specific monitoring of these processes will not be performed to evaluate changes in risks or to determine when cleanup levels were met. While Alternative SA-4 will be protective of human health and the environment in the Waterbore Area, C-Complex, and New Burn Area, it will not be protective for the entire Site.

Attainment of Media Cleanup Objectives

Alternative SA-4 will not achieve the soil CAOs because no action will be taken to control potential exposure pathways or to address COC concentrations in soils at the SMA or Old Burn Area. The CAOs will be achieved in the Waterbore Area, C-Complex, and New Burn Area, where excavation and soil capping will be implemented. The actions in these areas will reduce or eliminate the potential for direct contact by a receptor with COCs in soil, reduce the potential for COCs in soil to migrate to groundwater, achieve the cleanup levels established for soils, and meet applicable waste management requirements.

Control the Sources of Releases

Historical operations at the Site were the source of COCs in soil; no ongoing sources are present at the Site. While lead and arsenic present in soils are not mobile constituents and will likely not migrate to groundwater, the potential exists for perchlorate in soils to migrate to groundwater. Alternative SA-4 will implement excavation in the Waterbore Area, with an engineered cap in the area where soils containing COCs at concentrations exceeding the cleanup standard are located at depths beyond the feasibility of excavation. Alternative SA-4 will also involve excavation in the C-Complex and New Burn Area to reduce the potential for COCs in soils to migrate to groundwater. However, no controls will be implemented in the Old Burn Area or SMA, and the potential for perchlorate in soils to migrate to groundwater will not be controlled throughout the entire Site.

Compliance with Standards for the Management of Wastes

Alternative SA-4 will not comply with chemical-specific standards for soil because no action will be taken to control potential exposure pathways or to address COC concentrations in soil for areas outside of the Waterbore Area, C-Complex, and New Burn Area. Where implemented, Alternative SA-4 will comply with location- and action-specific standards.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence will not be achieved through Alternative SA-4 because controls will not be implemented to reduce or eliminate potential exposure pathways for all applicable areas of the Site. Additionally, this alternative has the potential to allow COCs in soil to leach to groundwater in the Old Burn Area and SMA, potentially exposing downgradient receptors. It may also increase the capital and O&M expenditures if future remediation is required.

Reduction of Toxicity, Mobility, or Volume of Wastes

Alternative SA-4 will permanently reduce the mobility and volume of perchlorate in the Waterbore Area, C-Complex, and New Burn Area soils through excavation and the installation of an engineered cap. The reduction of toxicity, mobility, or volume of perchlorate in soil at other areas of the Site will only result from natural attenuation mechanisms, although monitoring of these processes will not be performed to evaluate changes in risks or determine when cleanup goals are met. Natural attenuation mechanisms are unlikely to reduce the mobility, toxicity, or volume of lead and arsenic in soil, and no corrective measure will be taken to address lead or arsenic concentrations in soil.

Short-Term Effectiveness

Implementation of this alternative will result in limited exposure risks to the community, workers, and the environment that will be managed with engineering controls and worker training. Construction of the impermeable cap in the Waterbore Area and excavation of soils in the Waterbore Area, C-Complex, and New Burn Area could create short-term exposure risks. Engineering measures will be used to control potential air emissions, fugitive dust, surface water runoff, erosion, and sedimentation during excavation and cap construction. Monitoring will be implemented, as required by a dust control permit, to protect the surrounding community during excavation.

Excavated soil will require transport to an off-site disposal facility, creating potential risks to the community due to truck traffic and to the environment from vehicle emissions. If necessary, these risks could be mitigated through measures such as transportation during off-peak hours or the use of clean diesel technologies to reduce emissions from diesel-powered equipment and trucks. Trained personnel will perform all O&M activities. Waste generated during remedial activities will be managed by trained workers using approved methods. This alternative will be effective in the short term for the area where it is implemented because the remedial alternative can be implemented within one year.

Implementability

Implementation of this alternative is technically feasible, although the soil types at the Site will limit excavation depths. Equipment and subcontractors used to excavate and install the engineered cap are readily available. Periodic maintenance of the cap will control its future reliability. Although this alternative was developed by ADEQ to establish financial assurance requirements, it is likely not administratively feasible because all potential exposure pathways will not be controlled and the potential leaching of COCs in soil to groundwater will continue.

Cost

Table 18 and Appendix G present summaries of the present-value calculations for Alternative SA-4 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $4,484,250 for the design and implementation of soil excavation and the engineered cap. Total annual O&M costs are estimated to be approximately $270,000. Based on USEPA guidance, the total present-value lifecycle cost of Alternative SA-4 for 30 years using a discount rate of 7 percent is $4,303,000 (USEPA 2000).

6.3.2 Groundwater Alternatives

Four groundwater remedial alternatives were retained for detailed analysis. The detailed analysis of each groundwater remedial alternative is summarized in Tables 19 through 22 and presented in the following sections.

6.3.2.1 GW-1 – No Action

The following sections present a detailed analysis of remedial alternative GW-1 for groundwater. Table 19 summarizes this analysis. This alternative is retained as a baseline for evaluating the remaining alternatives.

Overall Protection of Human Health and the Environment

Although the No Action Alternative does not incorporate activities that will present exposure risks to the community, workers, or the environment, it will not further reduce existing COC concentrations in groundwater or provide measures to eliminate or control potential migration of the constituent plume. Natural attenuation processes may reduce perchlorate concentrations to cleanup levels, although specific monitoring of these processes will not be performed to evaluate changes in risks or determine when CAOs are met.

Attainment of Media Cleanup Objectives

Alternative GW-1 will not achieve the groundwater CAOs because no action will be taken to control potential migration of perchlorate in groundwater or to address perchlorate concentrations in groundwater.

Control the Sources of Releases

Historical operations at the Waterbore Area were the primary source of perchlorate in groundwater; no ongoing sources are present at the Site. Alternative GW-1 will not implement controls to reduce the potential migration of groundwater containing COCs at concentrations higher than cleanup levels.

Compliance with Standards for the Management of Wastes

Alternative GW-1 will not comply with chemical-specific standards for groundwater because no action will be taken to control potential exposure pathways or to address

COC concentrations in groundwater. There are no location- or action-specific standards for Alternative GW-1.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence will not be achieved through the No Action Alternative because reduction of perchlorate concentrations in groundwater will not be addressed and controls will not be implemented to reduce or eliminate potential exposure pathways by controlling the potential migration of groundwater. It may also increase capital and O&M expenditures if future remediation is required.

Reduction of Toxicity, Mobility, or Volume of Wastes

Natural attenuation mechanisms may result in the reduction of perchlorate mobility, toxicity, and volume in groundwater. However, monitoring of these processes will not be performed with Alternative GW-1 to evaluate changes in risks or determine when CAOs are met.

Short-Term Effectiveness

The No Action Alternative does not incorporate activities that will present exposure risks to the community, workers, or the environment.

Implementability

Because no technical implementation is required, the No Action Alternative is technically feasible and may not limit or interfere with the ability to perform future corrective measures. However, because potential exposure pathways will not be controlled and the potential migration of perchlorate in groundwater will continue, the No Action Alternative is likely not administratively feasible.

Cost

Table 19 and Appendix G present summaries of the present-value cost calculations for Alternative GW-1 and the detailed cost backup, respectively. There are no actions to be implemented and therefore no capital or O&M costs associated with Alternative GW-1. Total costs for this alternative are estimated to be $0.

6.3.2.2 GW-2 – Bedrock Source Area Groundwater Extraction, Ex Situ Treatment with Anaerobic Bioreactor, Reinjection, and Alluvium In Situ Biological Reduction

The following sections present a detailed analysis of remedial alternative GW-2 for groundwater. This alternative includes groundwater extraction, ex situ treatment with an anaerobic bioreactor, and reinjection into the bedrock source area through directed groundwater recirculation and will achieve CAOs in the bedrock source area groundwater in approximately 10 years. The alluvial injection well network near MW-6 was used to perform EVO injections to establish anaerobic conditions and reduce perchlorate concentrations in groundwater near MW-6 to the cleanup goal. Because no perchlorate has been detected in alluvium monitoring wells in this area following the EVO injection pilot test in October 2014, the only corrective action that remains is groundwater monitoring to confirm achievement of CAOs. The current perimeter fence will be maintained to restrict access to the Site by potential receptors. Table 20 summarizes this analysis. The preliminary locations of the source area extraction and injection well network and the alluvial injection well network are presented on Figure 26.

Overall Protection of Human Health and the Environment

Implementation of this alternative will potentially result in short-term exposure risks to the community, workers, or the environment that will be managed with engineering controls and worker training. COC concentrations in source area groundwater will be permanently reduced through groundwater extraction, ex situ treatment, and reinjection. The reduction in groundwater concentrations and the hydraulic control provided by the extraction wells will minimize or eliminate potential migration of the constituent plume. In situ biological reduction in the alluvium around MW-6 will permanently reduce perchlorate concentrations in groundwater to lower than the cleanup goals. Alternative GW-2 will therefore be protective of human health and the environment by preventing potential migration of groundwater and removing or destroying the COC mass.

Attainment of Media Cleanup Objectives

This alternative will achieve the groundwater CAOs. Groundwater extraction and ex situ treatment in the source area will prevent the potential migration of groundwater and reduce the mass of COCs in groundwater. The reinjection of treated groundwater in the source area will increase the hydraulic flux through the source area, accelerate the rate of mass removal, and allow for optimization of the remediation system (Payne et al. 2008). COCs in groundwater at depths greater than the bottom of the screened intervals of the existing proposed extraction wells near the source area (EW-1 and IW-1), are anticipated to be reduced by an upward gradient that is likely to be induced by pumping groundwater from wells EW-1 and IW-1. This source area action minimizes or eliminates further migration of the constituent plume, prevents the migration of perchlorate in groundwater to any active private domestic well at concentrations higher than cleanup goals, controls the source of the release to reduce or eliminate potential future releases, achieves the site-wide groundwater cleanup goal, meets applicable waste management requirements, and achieves the groundwater cleanup goals within 30 years (10 years is estimated). Implementing an in situ biological reduction system in alluvium near MW-6 has reduced the mass of COCs in groundwater. This corrective measure stabilizes and eliminates the constituent plume, eliminates the potential for perchlorate in groundwater to migrate to any active private domestic well, meets the groundwater cleanup goal, and achieves the groundwater cleanup goal within the required 30-year timeframe.

Control the Sources of Releases

Historical operations at the Waterbore Area were the primary source of perchlorate in groundwater; no ongoing sources are present at the Site. The majority of dissolved perchlorate mass in groundwater at the Waterbore Area is present within the top 100 feet of the groundwater table, approximately 245 to 345 feet bgs. Perchlorate concentrations above the remedial goal of 14 µg/L have also been detected in well MW-13 at depths ranging from 440 feet to 490 feet bgs. If the perchlorate mass within the deeper groundwater interval at the Waterbore Area, as monitored in well MW-13, is not remediated during initial operation of the final site remedy, optimization of the remedy will be conducted to address the deeper groundwater interval. Alternative GW-2 will reduce or eliminate the potential migration of groundwater containing COCs above cleanup levels through groundwater extraction and in situ biological reduction.

Compliance with Standards for the Management of Wastes

Alternative GW-2 will comply with chemical-specific cleanup goals for COCs in groundwater by removal or in situ degradation of perchlorate in groundwater. Alternative GW-2 will comply with location- and action-specific cleanup goals.

Long-Term Reliability and Effectiveness

Long-term reliability and effectiveness will be achieved with Alternative GW-2. Alternative GW-2 will result in the permanent reduction of COC concentrations in groundwater through groundwater extraction and ex situ treatment and in situ biological reduction. This reduction in COC concentrations will permanently minimize or eliminate the potential for migration of the constituent plume. By using an anaerobic bioreactor for ex situ treatment, perchlorate will be destroyed and no residual risk will remain in groundwater after CAOs have been met. By reinjecting treated groundwater into the source area, the hydraulic flux through the source area will be increased. This increase in mass flux will increase the perchlorate mass removal rate, and it is assumed that this alternative will significantly decrease the overall timeframe required to achieve CAOs (Payne et al. 2008). This CMS assumes that operation of the groundwater extraction, treatment, and reinjection system will be conducted until sufficient aquifer pore volume flushing is achieved (anticipated to be 10 years), and that monitoring of the alluvial in situ biological reduction will be conducted for approximately two years. It is expected that, after 10 years of operating the bedrock source area remedial system, the perchlorate groundwater cleanup goals will have been met and remediation will be complete.

Reduction of Toxicity, Mobility, or Volume of Wastes

Alternative GW-2 will permanently reduce the mobility, toxicity, and volume of COCs in groundwater. Extraction and ex situ treatment of source area groundwater will permanently reduce the volume of COCs. Mobility of COCs in groundwater will be reduced through the hydraulic control provided by the groundwater extraction and injection network. In situ biological reduction of perchlorate will reduce the toxicity and volume of perchlorate in the alluvial groundwater. It is expected that groundwater cleanup goals will be met with this alternative, and no residual COCs will remain in groundwater.

Short-Term Effectiveness

The implementation of Alternative GW-2 will result in limited exposure risks to the community, workers, and the environment that will be managed through engineering controls and worker training. Installation of extraction and injection wells, conveyance piping, and treatment systems could create short-term exposure risks. Engineering measures will be used to control potential air emissions, fugitive dust, or surface water runoff during installation of the wells, conveyance piping, and treatment system. Trained personnel will perform all O&M activities. The recirculation cell created by the groundwater extraction and injection system can be intermittently balanced in response to real-time performance data, which leads to less energy consumption, generation of fewer greenhouse gases, fewer air emissions during the remedy lifetime, and less potential risk to the community and environment. Waste generated during remedial activities will be managed by trained workers using approved methods. This alternative will be effective in the short term because the remedial alternative can be implemented in approximately two years and completed within approximately 12 years.

Implementability

Implementation of this alternative is both technically and administratively feasible. Groundwater extraction and reinjection will require readily available equipment and services. Extraction and injection wells will be installed using standard well drilling methods and materials. These services, as well as the services and materials necessary for the in situ biological reduction injection system and injection events, are readily available. Groundwater extraction is a conventional remediation technology. The anaerobic bioreactor is commercially available, or can be constructed using conventional materials, and use of anaerobic bioreactors for ex situ treatment of groundwater is proven for the applicable COCs. Biological reduction of perchlorate in groundwater is also a proven technology.

Cost

Table 20 and Appendix G present summaries of the present-value calculations for Alternative GW-2 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $3,221,900 for the design and implementation of source area groundwater extraction, ex situ treatment, the reinjection system, and the alluvial in situ biological reduction system. Total annual O&M costs are estimated to be approximately $6,697,500. Periodic costs include system decommissioning when CAOs are achieved, and are estimated to be $313,200. Based on USEPA guidance, the total present-value lifecycle cost of Alternative GW-2 using a discount rate of 7 percent is $6,669,000 (USEPA 2000).

6.3.2.3 GW-3 – Bedrock Source Area Hydraulic Control and In Situ Biological Reduction and Alluvium In Situ Biological Reduction

The following sections present a detailed analysis of remedial alternative GW-3 for groundwater. This alternative will implement in situ biological reduction of perchlorate in the bedrock source area by extracting groundwater, adding a dilute carbon source (such as molasses), and reinjecting the groundwater in the bedrock source area. In addition to providing the hydraulic control and flushing noted for Alternative GW-2, this alternative will also destroy perchlorate mass in situ instead of ex situ. Carbon substrate injection wells, installed near alluvium groundwater monitoring well MW-6, were used to establish anaerobic conditions and destroy perchlorate in situ as part of the EVO injection pilot test performed in October 2014. Because no perchlorate has been detected in alluvium monitoring wells in this area following the EVO injection pilot test in October 2014, the only corrective action that remains is groundwater monitoring. The current perimeter fence will be maintained to restrict access to the Site by potential receptors. Table 21 summarizes this analysis. The preliminary locations of the extraction and injection wells for the in situ biological reduction systems are presented on Figure 26.

Overall Protection of Human Health and the Environment

Implementation of this alternative will include well installation, which will potentially result in short-term exposure risks to the community, workers, or the environment that will be managed with engineering controls and worker training. The use of groundwater extraction wells in the bedrock source area will provide hydraulic control over the constituent plume to prevent migration of perchlorate in bedrock source area groundwater and permanently destroy perchlorate through in situ biological reduction. However, the injection of untreated groundwater from the bedrock extraction wells directly into the proposed injection wells has the potential to cause further migration of the constituent plume outside of the areas under hydraulic control. Therefore, Alternative GW-3 is not likely to be protective of human health and the environment because of the potential to redistribute COCs in the bedrock groundwater. Groundwater within the alluvium near MW-6 has been remediated by the EVO pilot test and continued monitoring will confirm that CAOs have been met in this area.

Attainment of Media Cleanup Objectives

Alternative GW-3 may not achieve the groundwater CAOs. While in situ biological reduction in the source area will reduce the mass of COCs, and groundwater extraction will prevent the potential migration of groundwater, the reinjection of untreated groundwater into the bedrock source area injection wells has the potential to spread COC mass outside of areas under hydraulic control. This action has the potential to cause further migration of perchlorate in groundwater to active private domestic wells at concentrations higher than cleanup goals. Implementation of groundwater monitoring of the in situ biological reduction system in alluvium near MW-6 will confirm that the mass of COCs in the alluvium groundwater has been destroyed and that the CAOs have been obtained within the required 30-year timeframe.

Control the Sources of Releases

The constituent sources in groundwater are primarily from historical operations in the Waterbore Area, and ongoing sources are not present. Alternative GW-3 has the potential to redistribute groundwater containing COCs at concentrations higher than cleanup levels by injecting untreated groundwater outside areas under hydraulic control. There is also uncertainty regarding the flowpath of reagent reinjection and undemonstrated treatment effectiveness for in situ biological reduction within the bedrock aquifer at the Site, which may jeopardize source control.

Compliance with Standards for the Management of Wastes

Alternative GW-3 is not likely to comply with chemical-specific standards for groundwater because of the potential to inject untreated groundwater into bedrock at concentrations higher than the standard. Alternative GW-3 is not likely to comply with location- and action-specific standards for the same reason. Additionally, there is potential to extract total organic carbon and redistribute it outside of the source area in bedrock groundwater.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence are not likely to be achieved through Alternative GW-3. Permanent reduction of COC concentrations in groundwater will be achieved through in situ biological reduction in both the bedrock source area and alluvium, which will permanently minimize or eliminate portions of the constituent plume. However, it is uncertain whether the treatment period would be shorter than that of Alternative GW-2. Additionally, the injection of untreated groundwater from the bedrock extraction wells directly into the proposed injection wells has the potential to cause further migration of the constituent plume outside of the areas under hydraulic control. This will result in residual risk of COC migration at the Site after implementation of this alternative. It is expected that, after 10 years of operating the bedrock source area remedial system, the perchlorate groundwater cleanup goals will have been met within the bedrock source area, but additional action will likely be required to manage redistributed COC mass; thus, remediation may not be complete. Furthermore, there is higher risk of injection well fouling when a source of carbon is applied, which requires increased well maintenance, well rehabilitation, and well replacement. This will result in an extended remediation timeframe and additional costs.

Reduction of Toxicity, Mobility, or Volume of Wastes

The mobility, toxicity, and volume of COCs in groundwater will be permanently reduced with Alternative GW-3. The volume and toxicity of perchlorate in groundwater will be reduced through in situ biological reduction in the source area and alluvial groundwater. The source area groundwater extraction and injection network will reduce the mobility of COCs in groundwater. However, the injection of untreated groundwater from the bedrock extraction wells directly into the proposed injection wells has the potential to cause further migration of the constituent plume outside of the areas under hydraulic control. Therefore, it is possible that groundwater cleanup goals will not be met with this alternative and that residual contamination will remain in groundwater.

Short-Term Effectiveness

Implementation of this alternative could result in short-term exposure risks to the community, workers, and the environment during system construction and well installation activities that will be managed through engineering controls and worker training. Engineering measures will be used to control potential air emissions, fugitive dust, or surface water runoff during installation of the wells, conveyance piping, and carbon feed system. Trained personnel will perform all O&M activities. The recirculation cell created by the groundwater extraction and injection system can be optimized regularly in response to real-time performance data, which also leads to less energy consumption, generation of fewer greenhouse gases, fewer air emissions during the remedy lifetime, and less potential risk to the community and environment. Waste generated during the remedial alternatives will be managed using approved methods. This alternative will be effective in the short term because the remedial alternative can be implemented in approximately two years and completed within approximately 12 years.

Implementability

Implementation of Alternative GW-3 is both technically and administratively feasible. Readily available equipment, materials, and services will be required for groundwater extraction, dosing, and reinjection. Extraction and injection wells will be installed using standard well drilling methods, and associated materials and services are readily available. The materials and services necessary for the alluvium in situ biological reduction injection system and injection events are also readily available. Groundwater extraction and reinjection are conventional remediation technologies that are proven to provide hydraulic control of a plume and accelerate mass removal. Biological reduction of perchlorate in groundwater is also a proven technology.

Cost

Table 21 and Appendix G present summaries of the present-value calculations for Alternative GW-3 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $1,584,300 for the design and implementation of the in situ biological reduction systems. Total annual O&M costs are estimated to be approximately $5,856,800. Periodic costs include system decommissioning when CAOs are achieved and are estimated to be $313,200. Based on USEPA guidance, the total present-value lifecycle cost of Alternative GW-3 using a discount rate of 7 percent is $4,750,000 (USEPA 2000).

6.3.2.4 GW-4 – Arizona Department of Environmental Quality Groundwater Treatment Scenario

The following sections present a detailed analysis of remedial alternative GW-4 for groundwater. This alternative was developed by ADEQ to establish financial assurance requirements and will use groundwater extraction, ex situ treatment with an anaerobic bioreactor, and reinjection of treated groundwater at the former operations boundary to remove COCs from groundwater and prevent the potential migration of the constituent plume. Extraction well networks with accompanying groundwater treatment systems and injection wells will be constructed in the Waterbore Area, New Burn Area, and C-Complex, along with additional wells throughout the Site as needed to provide hydraulic control over the plume. Two extraction wells each will be installed in the Waterbore Area, New Burn Area, and C-Complex. An additional four extraction wells will be installed downgradient of the source area to achieve hydraulic control of the plume. Extracted groundwater will be conveyed to a central groundwater treatment system and then reinjected through five injection wells. Table 22 summarizes this analysis. The preliminary locations of the groundwater extraction and injection well networks are presented on Figure 27.

Overall Protection of Human Health and the Environment

Implementation of Alternative GW-4 will potentially result in short-term exposure risks to the community, workers, or the environment during well installation; these potential risks will be managed with engineering controls and worker training. Perchlorate concentrations in groundwater throughout the Site will be permanently reduced through ex situ treatment of extracted groundwater. The potential for dissolved perchlorate in groundwater to migrate off Site will be reduced through the hydraulic control provided by groundwater extraction and the hydraulic barrier provided by the injection well network at the former operations boundary. However, no actions will be taken to increase mass removal rates or accelerate the remediation timeframe. Alternative GW-4 is expected to be protective of human health and the environment.

Attainment of Media Cleanup Objectives

Alternative GW-4 may achieve the groundwater CAOs. Groundwater extraction will prevent the potential migration of groundwater, ex situ treatment of groundwater will reduce COC concentrations, and reinjection of groundwater at the former operations boundary will create a hydraulic barrier to further prevent potential off-site migration of groundwater. This alternative will minimize or eliminate further migration of the constituent plume, prevent the migration of perchlorate in groundwater to any active private domestic well at concentrations higher than cleanup goals, control the source of the release to reduce or eliminate potential future releases, achieve the site-wide groundwater cleanup goal, and meet applicable waste management requirements. For the purposes of financial assurance calculations, a 30-year remediation timeframe is assumed.

Control the Sources of Releases

Historical operations at the Waterbore Area were the primary source of perchlorate in groundwater; no ongoing sources are present at the Site. Alternative GW-4 will reduce or eliminate the potential migration of groundwater containing COCs at concentrations higher than cleanup levels through groundwater extraction with ex situ treatment and reinjection of treated groundwater to create a hydraulic barrier.

Compliance with Standards for the Management of Wastes

Alternative GW-4 will comply with chemical-specific standards for groundwater because actions will be taken to control potential migration of dissolved COCs in groundwater and address COC concentrations in groundwater. Alternative GW-4 will also comply with location- and action-specific standards.

Long-Term Reliability and Effectiveness

Long-term effectiveness and permanence will be achieved through Alternative GW-4 because permanent reductions in COCs concentrations will occur due to groundwater extraction and ex situ treatment. The reduction in perchlorate concentrations will permanently minimize or eliminate the potential migration of the constituent plume. By using an anaerobic bioreactor for ex situ treatment, perchlorate will be destroyed and no residual risk will remain in groundwater after CAOs have been met. This alternative assumes that operation of the groundwater extraction, ex situ treatment, and reinjection systems will be conducted for 30 years.

Reduction of Toxicity, Mobility, or Volume of Wastes

Alternative GW-4 will permanently reduce the mobility and volume of perchlorate in groundwater. Groundwater extraction and reinjection will create hydraulic capture zones and hydraulic barriers, reducing the mobility of COCs in groundwater. The volume of COCs will be reduced by extraction and ex situ treatment.

Short-Term Effectiveness

Implementation of this alternative will result in limited exposure risks to the community, workers, and the environment that will be managed with engineering controls and worker training. Installation of the extraction and injection wells, conveyance piping, and treatment system could create short-term exposure risks. Engineering measures will be used to control potential air emissions, fugitive dust, or surface water runoff during installation of the wells, conveyance piping, and treatment system. Trained personnel will perform all O&M activities. Waste generated during remedial activities will be managed using approved methods. This alternative will be effective in the short term because the remedial alternative can be implemented in approximately two years. It is expected that it will take 30 years to meet the groundwater cleanup goals using this remedial alternative.

Implementability

Implementation of Alternative GW-4 is both technically and administratively feasible. Groundwater extraction and reinjection will require readily available equipment and services. Extraction and injection wells will be installed using standard well drilling methods and materials. These services, as well as the services and materials necessary for ex situ treatment of extracted groundwater with a bioreactor, are readily available. Groundwater extraction, ex situ treatment, and groundwater reinjection are conventional and proven remediation technologies.

Cost

Table 22 and Appendix G present summaries of the present-value calculations for Alternative GW-4 and the detailed cost backup, respectively. Total capital costs are estimated to be approximately $5,261,400 for the design and implementation of the groundwater extraction and reinjection system. Total annual O&M costs are estimated to be approximately $10,006,900. Based on USEPA guidance, the total present-value lifecycle cost of Alternative GW-4 for 30 years using a discount rate of 7 percent is $8,770,000 (USEPA 2000).

6.4 Comparative Analysis of Remedial Alternatives

In Section 6.3, each of the corrective measures alternatives for soil and groundwater are evaluated individually. The individual analyses of the soil and groundwater corrective measures alternatives are summarized in Tables 15 through 22. This section provides a comparative analysis of the expected performance of each alternative relative to the other alternatives to identify their respective advantages and disadvantages. Tables 23 and 24 summarize the comparative analyses.

6.4.1 Comparative Analysis of Soil Alternatives

A comparative ranking of soil alternatives based on the evaluation criteria is presented below and summarized in Table 23. As described in Section 7, this comparative analysis concludes that Soil Alternative SA-2 (soil excavation and off-site disposal, soil capping, and deed restrictions) is implementable, effective in meeting the CAOs, and is reasonable with respect to present-worth cost; thus, it is the recommended corrective measures alternative for soil at the Site.

Overall Protection of Human Health and Environment

Alternatives SA-2 and SA-3 achieve each of the CAOs identified for soils and will both provide overall protection of human health and the environment. Alternative SA-2 has the highest implementability and reliability and will therefore achieve the highest level of protection of human health and the environment. Assuming that carbon sources can effectively be delivered to the vadose zone to establish and maintain the reducing conditions that will degrade perchlorate, Alternative SA-3 will achieve the soil CAOs in a short period of time through active in situ degradation of COCs. It is estimated that Alternative SA-3 will achieve the soil CAOs in 10 years compared to the 30-year estimate for Alternative SA-2. Alternative SA-4 will provide some protection to human health and the environment through excavation and capping of soils containing COCs at concentrations higher than cleanup goals in portions of the Site. Alternatives SA-1 and SA-4 will not include specific monitoring to evaluate changes in risks or determine when CAOs are met. Without institutional controls, Alternatives SA-1 and SA-4 do not reduce the potential exposure pathways throughout the entire Site and are not protective of human health.

Attainment of Media Cleanup Objectives

The media cleanup objectives will not be met by implementing Alternatives SA-1 or SA-4. Alternatives SA-2 and SA-3 will both attain media cleanup standards if the in situ biological reduction included in Alternative SA-3 can be effectively implemented in vadose zone soils. Alternative SA-3 will meet the CAOs in the shortest period of time if the alternative can be effectively implemented.

Control the Sources of Releases

As discussed in Section 6.3, the constituent sources are from historical operations, and no ongoing sources to soil are present at the Site. Lead and arsenic concentrations in soils are not likely to mobilize and migrate to groundwater, and Alternatives SA-2 and SA-3 will remove these COCs from the Site through excavation. The potential for migration of perchlorate in soils to groundwater will be reduced with Alternatives SA-2, SA-3, and SA-4. The combination of excavation and capping included in Alternative SA-2 will provide the most reliable reduction to the potential for COCs in soil to leach to groundwater; however, perchlorate mass will remain in place beneath the cap. Assuming that anaerobic conditions can be established and maintained in the vadose zone, the excavation and in situ biological reduction technologies in Alternative SA-3 will permanently remove or destroy perchlorate and eliminate the potential for perchlorate in soils to migrate to groundwater.

Compliance with Standards for the Management of Wastes

Alternatives SA-2 and SA-3 will both comply with chemical-, location-, and action-specific standards. Neither Alternative SA-1 nor Alternative SA-4 will comply with chemical-specific standards because no action will be taken site-wide to control potential exposure pathways or reduce COC concentrations. Alternative SA-4 will comply with chemical-, location-, and action-specific standards for the areas of the Site where remediation actions will be implemented.

Long-Term Reliability and Effectiveness

Alternative S-1 will provide the least long-term effectiveness because there will be no controls to limit potential exposure to COCs in soil or to limit potential leaching of COCs from soil to groundwater. Alternative SA-4 will be more effective than Alternative SA-1 because some of the soils with perchlorate at concentrations exceeding the cleanup standard will be excavated and an engineered cap will be installed in the Waterbore Area to reduce the potential leaching of COCs from soil to groundwater. However, potential exposure to soils containing lead and arsenic at concentrations exceeding the cleanup standard in the Old Burn Area and soils containing perchlorate concentrations exceeding the cleanup standard in the SMA could continue to occur under Alternative SA-4.

Alternatives SA-2 and SA-3 will be more effective than Alternative SA-4 because excavation will be implemented in the Old Burn Area to prevent potential exposure to lead or arsenic in soil. Excavation of soils containing perchlorate concentrations exceeding the cleanup standard will also be implemented in the C-Complex, SMA, and New Burn Area to prevent potential contact by receptors to COCs in soil and to prevent potential leaching of COCs from soil to groundwater. For the Waterbore Area, C-Complex, and New Burn Area, Alternative SA-2 will use a combination of excavation, soil capping, and deed restrictions to reduce potential exposure pathways and limit the potential for perchlorate in soil to migrate to groundwater. Alternative SA-3 will incorporate excavation and in situ biological reduction to achieve those objectives. As part of each alternative, soil will be disposed of at an off-site disposal facility to minimize any residual risk. Alternatives SA-2 and SA-3 are the most effective alternatives in the long term because they will actively remove COCs from the soil, will limit the potential for COCs in soil to migrate to groundwater, and will be implemented throughout all identified source areas. As part of Alternative SA-2, soil containing COCs at concentrations higher than the cleanup standard will stay in place under the cap, and the cap must be maintained beyond the standard 30-year horizon evaluated in this CMS. Assuming that anaerobic conditions can be established and maintained to destroy perchlorate concentrations in the vadose zone, Alternative SA-3 provides the greatest permanence in the shortest timeframe.

Reduction of Toxicity, Mobility, or Volume of Waste

Alternative SA-1 will potentially reduce toxicity and volume of perchlorate through natural attenuation processes. No other reductions in COC toxicity, mobility, or volume are anticipated with Alternative SA-1 because no remedial measures will be implemented, and monitoring of these processes will not be performed.

Excavation conducted as part of Alternative SA-4 will remove perchlorate from some areas of the Site, but will not remove lead, arsenic, or perchlorate at concentrations higher than cleanup levels in shallow soils throughout the entire Site. Alternatives SA-2 and SA-3 will use excavation to remove lead, arsenic, and perchlorate present in shallow soils at concentrations higher than cleanup goals throughout all areas of Site.

Construction and maintenance of the Waterbore Area soil cap included in Alternatives SA-2 and SA-4 will restrict migration of perchlorate from soil to groundwater. Implementation of in situ biological reduction as part of Alternative SA-3 will destroy perchlorate present in the vadose zone of the Waterbore Area, and no contamination will remain. Alternative SA-3 will result in the most aggressive reduction in the mobility, toxicity, or volume of the remaining perchlorate mass. If Alternative SA-2 is implemented, the only residual contamination in soils at the Site will be perchlorate in soils located beneath the cap. Residual contamination in soils after implementation of Alternative SA-4 will include perchlorate located beneath the cap and in the SMA and lead and arsenic in the Old Burn Area. Natural attenuation mechanisms may reduce the perchlorate volume and toxicity in soil, although monitoring of these processes will not be performed as part of Alternatives SA-1 and SA-4.

Short-Term Effectiveness

Alternative SA-1 is the most effective at attaining short-term results with minimal risks because there will no activities to implement and therefore no exposure risks. Alternative SA-4 will require limited activities (limited excavation, and soil cap installation and maintenance) that will result in short-term exposure risks to workers, the community, or the environment, although these activities will be managed through engineering controls and worker training. Under Alternative SA-2, potential risks to the community, workers, or the environment will increase compared to Alternative SA-4 due to the larger excavation area. These potential risks will be managed through engineering controls and worker training.

Alternatives SA-2 and SA-4 will require maintenance of the soil cap for up to 30 years. The soil excavation, installation of injection wells, and injection events included as Alternative SA-3 may result in the greatest short-term exposure risks to workers, but these potential risks will be managed through engineering controls and worker training. Alternative SA-3 may also result in the highest short-term exposure risks to the community and environment because this alternative has the largest volume of soil to be transported off Site by truck for disposal. Traffic from off-site transportation creates a potential risk to the community and also leads to vehicle emissions that are a potential risk to the environment.

During implementation of each alternative, engineering measures will be used to control potential air emissions, fugitive dust, surface water runoff, erosion, and sedimentation. Monitoring will be implemented, as required by a dust control permit, to protect the surrounding community during excavation. Potential risks to the community and environment from off-site transportation of excavated soils may, if necessary, be managed through the use of off-peak transportation or clean diesel technologies. If anaerobic conditions can be effectively established and maintained, Alternative SA-3 will also achieve soil CAOs in a significantly shorter time period (10 years of active remediation) compared to the other corrective measure alternatives.

Implementability

Alternative SA-1 is simple to implement and involves no O&M. Alternatives SA-2 and SA-4 require excavation, installation of a soil cap, and long-term maintenance of the cap. Both of these alternatives will use conventional equipment that is readily available. The in situ biological reduction planned as a component of Alternative SA-3 will use conventional equipment as will the excavation component. However, the effectiveness of Alternative SA-3 will depend upon the ability to deliver sufficient carbon substrate to the vadose zone soils to establish and maintain the anaerobic conditions that will degrade perchlorate. According to the Supplemental Soil Pre-Design Study Summary Report (ARCADIS 2014a), the vadose zone does not support adequate injection rates or reagent distribution due to cementation of the alluvium sediments. Therefore, the carbon substrate cannot be effectively delivered to the vadose zone. It may also increase capital and O&M expenditures if future remediation is required.

Alternatives SA-1 and SA-4 are unlikely to be administratively feasible because there will be no controls on potential exposure pathways or potential leaching of COCs in soil to groundwater for part or all areas of the Site. Alternative SA-2 likely has the highest administrative feasibility because it is the most reliable technology for the site conditions.

Cost

Alternative SA-1, estimated to cost $0, is the most economical option. Alternative SA-2, estimated to cost $2,089,000, is the most economical of the other three alternatives. Alternative SA-4 is the most costly alternative, with a present-worth cost estimate of $4,303,000, and will not meet all of the soil CAOs. With a present-worth cost estimate of $3,010,000, Alternative SA-3 is the second most costly alternative, and is not implementable.

6.4.2 Comparative Analysis of Groundwater Alternatives

A comparative ranking of groundwater alternatives based on the evaluation criteria is presented below and summarized in Table 24. As described in Section 7, this comparative analysis concludes that Groundwater Alternative GW-2 (source area groundwater extraction, ex situ treatment with anaerobic bioreactor, reinjection, and alluvium in situ biological reduction) is implementable, effective in meeting the CAOs, and is reasonable with respect to present-worth cost; thus, it is the recommended corrective measures alternative for groundwater at the Site.

Overall Protection of Human Health and Environment

As indicated in Table 24, Alternatives GW-2 and GW-4 will achieve each of the CAOs identified for groundwater. Alternatives GW-2, and to a lesser extent GW-3, are protective of human health and the environment by preventing migration of COCs in groundwater and by permanently destroying perchlorate through either in situ biological reduction or an aboveground anaerobic bioreactor. However, Alternative GW-3 has substantial uncertainty and may cause spreading of the perchlorate downgradient of injection wells. Therefore, Alternative GW-3 is not likely to be protective of human health and the environment.

Alternative GW-4 will also offer a high level of protection to human health and the environment by preventing migration of COCs in groundwater and removing perchlorate from groundwater through treatment. It is assumed that Alternative GW-4 will require 30 years to achieve the groundwater CAOs compared to the 14 years estimated for Alternatives GW-2 and GW-3. Monitoring will verify that the CAOs are met for each of these alternatives.

Alternative GW-1 will not further reduce existing COC concentrations in groundwater or provide measures to eliminate or control potential migration of the constituent plume.

Natural attenuation processes may nominally reduce perchlorate concentrations, but monitoring of these processes will not be performed with Alternative GW-1 to evaluate changes in risks or to determine when CAOs are met.

Attainment of Media Cleanup Objectives

Alternative GW-1 will not attain media cleanup objectives because no remediation will take place. Alternatives GW-2 and GW-4 will each attain media cleanup objectives in the long term. Due to the active flushing of perchlorate mass from the source area, Alternatives GW-2 will attain CAOs in approximately one-half the timeframe as Alternative GW-4. Alternative GW-3 may not attain media cleanup objectives because this alternative could possibly cause spreading of the perchlorate downgradient of injection wells.

Control the Sources of Releases

As discussed in Section 6.3, the constituent sources are from historical operations in the Waterbore Area. Ongoing sources are not present. The potential for migration of perchlorate in groundwater will be reduced or eliminated with Alternatives GW-2 and GW-4. Potential migration of the constituent plume will not be controlled with Alternative GW-1. Alternative GW-3 has the potential to redistribute groundwater containing COCs at concentrations higher than cleanup levels by injecting untreated groundwater outside areas under hydraulic control. There is also uncertainty regarding the flowpath of reagent reinjection and undemonstrated treatment effectiveness for in situ biological reduction within the bedrock aquifer at the Site, which may jeopardize source control.

Compliance with Standards for the Management of Wastes

Alternatives GW-2 and GW-4 will comply with chemical-, location-, and action-specific standards because action will be taken site-wide to control potential migration of groundwater or to reduce COC concentrations. Alternative GW-1 will not comply with chemical-specific standards because no action will be taken to control potential exposure pathways or reduce COC concentrations. Alternative GW-3 is not likely to comply with chemical-, location-, and action-specific standards because of the potential to reinject perchlorate above the cleanup goal downgradient of injection wells.

Long-Term Reliability and Effectiveness

Alternative GW-1 will provide the least long-term effectiveness because there will be no controls to limit potential exposure to COCs in groundwater or to limit potential migration of COCs in groundwater. Alternative GW-4 will be more effective than Alternative GW-1 because the perchlorate mass in groundwater will be reduced through extraction and ex situ treatment, while groundwater extraction and injection will prevent the potential migration of groundwater until groundwater cleanup goals are met. It is assumed that 30 years of operation will be needed to achieve the groundwater cleanup goals for Alternative GW-4.

Alternative GW-2 will also use groundwater extraction and reinjection, combined with ex situ biological reduction, to prevent the potential migration of groundwater until the cleanup goal is achieved. However, Alternative GW-2 will use reinjection of extracted groundwater in the source area to increase the hydraulic flux through the source area to significantly reduce the time needed to achieve CAOs. Alternative GW-2 will provide higher long-term effectiveness than Alternative GW-4 and will provide the greatest permanent reductions in COC concentrations in the shortest timeframe.

Long-term effectiveness and permanence is not likely to be achieved by Alternative GW-3. Permanent reduction of COC concentrations in groundwater will be achieved through in situ biological reduction in both the bedrock source are and alluvium, which will permanently minimize or eliminate portions of the constituent plume. However, it is uncertain whether the treatment period is shorter and if lifecycle costs are less than Groundwater Alternative GW-2. Alternative GW-3 poses a higher risk of injection well fouling, increased maintenance, and increased costs for well rehabilitation and replacement. The reinjection of untreated groundwater from the bedrock extraction wells directly into the proposed injection wells has the potential to cause further migration of the constituent plume outside the areas under hydraulic control. Reinjection of the untreated groundwater may result in residual risks of COC migration remaining at the Site after implementing this alternative. It is assumed that, after 10 years of operating the bedrock source remedial system, the perchlorate groundwater cleanup goals will have been met within the bedrock source area, but additional action will likely be required to manage redistributed COC mass. This will result in extending the remediation timeframe for Alternative GW-3.

Reduction of Toxicity, Mobility, or Volume of Waste

Each alternative will potentially reduce the toxicity and volume of COCs through natural attenuation processes. The groundwater extraction and reinjection systems included in Alternatives GW-2, GW-3, and GW-4 will be effective in reducing the mobility of COCs in groundwater in the bedrock aquifer. Alternative GW-4 will permanently reduce the volume of COCs throughout the Site by extraction and ex situ treatment. Alternatives GW-2 and GW-3 will also permanently reduce the volume of COCs in the source area through either ex situ treatment of extracted groundwater or by establishing and maintaining the anaerobic conditions sufficient for perchlorate reduction. Both GW-2 and GW-4 remediation alternatives will achieve CAOs through perchlorate degradation, with no residual contamination after CAOs are attained. However, the injection of untreated groundwater from the bedrock extraction wells directly into the proposed injection wells under the GW-3 Alternative has the potential to cause further migration of the constituent plume outside of the areas of hydraulic control.

Short-Term Effectiveness

Alternative GW-1 is the most effective at attaining short-term results with minimal risks, because there will be no activities to implement and therefore no exposure risks. Alternatives GW-2 and GW-3 will require limited activities (installation of four extraction wells and eight injection wells, and O&M) that will result in short-term exposure risks to workers, the community, or the environment. These activities will be managed through engineering controls and worker training.

During implementation of each alternative, engineering measures will be used to control potential air emissions, fugitive dust, or surface water runoff. Comparatively, Alternative GW-4 will create the highest potential risks to the community, workers, or environment due to the greater number of wells to be installed (10 extraction and five injection wells), energy required to operate the anaerobic bioreactor for 30 years, and a longer remediation timeframe requiring more O&M.

Implementability

Alternative GW-1 is simple to implement and involves no O&M. The groundwater extraction and injection wells and the carbon feed system for Alternative GW-2 will use conventional equipment that is readily attainable, with maintenance required for 10 years of operation. Alternative GW-3 will be more difficult to implement due to the higher maintenance requirements in comparison with the carbon feed system (GW-3).

Maintenance of this system will also be required for approximately 10 years. Alternative GW-4 will be the most difficult to implement because this alternative requires the greatest number of wells; the anaerobic bioreactor has higher maintenance requirements; and the groundwater extraction and injection wells, piping, and treatment system will require maintenance for 30 years.

Alternative GW-1 is unlikely to be administratively feasible because there will be no controls on potential exposure pathways or potential migration of COCs in groundwater. Alternatives GW-2 and GW-4 require groundwater extraction, reinjection, and ex situ biological reduction of perchlorate and therefore have equal administrative feasibility.

While biological reduction of perchlorate in groundwater is a proven technology, injection of untreated groundwater is likely to meet with high resistance from regulatory agencies; thus, Alternative GW-3 is not administratively feasible.

Cost

Alternative GW-1, with an estimated cost of $0, is the most economical option. Alternative GW-3, estimated to cost $4,750,000, is the most economical of the other three alternatives and will achieve the CAOs in approximately 14 years or sooner. Alternative GW-4 is the most costly alternative, with a present-worth cost estimate of $8,770,000, and will require 30 years to achieve the groundwater cleanup standards. Alternative GW-2 is more costly than Alternative GW-3, with an estimated cost of $6,669,000, and will also achieve CAOs in approximately 14 years or sooner.

7. Recommendation of Corrective Measures Alternatives

This section provides recommendations, with justification, for the corrective measures alternatives for the Site. Section 6.3 evaluates each corrective measures alternative. Section 6.4 presents a comparative analysis of the performance of each alternative relative to the other alternatives. A numerical ranking of each of the corrective measures alternatives was developed for each of the evaluation criteria. Rankings between 0 (lowest) and 5 (highest) were assigned based on a subjective appraisal of the degree to which each alternative meets the criteria. Tables 23 and 24 present the rankings and overall scores for each alternative.

The following corrective measures alternatives are recommended for the Site:

- Soil Alternative SA-2 – Soil Excavation and Off-Site Disposal, Soil Capping, and Deed Restrictions

- Groundwater Alternative GW-2 – Source Area Groundwater Extraction, Ex Situ Treatment with Anaerobic Bioreactor, Reinjection, and Alluvium In Situ Biological Reduction

These alternatives are implementable, effective in meeting the CAOs, and are reasonable with respect to present-worth cost. These alternatives are discussed below.

7.1 Soil

The primary CAOs for soils are to minimize the potential for direct contact by a receptor; minimize the potential leaching of COCs from soil to groundwater; and meet soil cleanup goals for arsenic, lead, and perchlorate. A comparison analysis was conducted of several potential remedial alternatives consistent with RCRA guidelines. Of these alternatives, Alternative SA-2 is the recommended corrective measure for soil, and involves soil removal and localized soil capping.

Table 23 presents the reviewed corrective measures alternatives for soil and their ranking by each evaluation criteria. Soil capping with deed restrictions will be implemented for Alternative SA-2 after excavation and off-site disposal of the soil capping footprint. COC concentrations will remain in soil under the cap once Alternative SA-2 is implemented, and this residual risk will be managed with deed restrictions. Alternative SA-2 is ranked highest for overall protection of human health and the environment due to the high reliability and effectiveness of the soil cap in combination with deed restrictions. Alternative SA-2 also has the most reasonable present-worth cost of the three active remedial alternatives and is highly implementable. UPCO is in the process of purchasing the property from the Arizona State Land Department (ASLD) and will implement a DEUR on the property deed for portions of the Site after completion of the purchase. Therefore, Alternative SA-2 is the recommended corrective measures alternative for soil.

The remaining alternatives were eliminated for the following reasons. Alternative SA-1 (No Action) will not further reduce the mobility, toxicity, or volume of COCs in soil and is eliminated due to having the lowest overall ranking.

The effectiveness and overall protection of Alternative SA-3 with an in situ biological treatment component depends on the ability to effectively deliver a carbon substrate to the vadose zone and establish and maintain the anaerobic conditions required for perchlorate reduction. According to the Supplemental Soil Pre-Design Study Summary Report (ARCADIS 2014a), the vadose zone does not support adequate injection rates or reagent distribution due to cementation of the alluvium sediments. Therefore, the carbon substrate cannot be effectively delivered to the vadose zone. Consequently, Alternative SA-3 is not implementable, and the scores for overall protection, control of the source of releases, long-term reliability, and effectiveness are lower; thus, it is eliminated.

Alternative SA-4 will reduce exposure pathways and the potential for COCs in soil to migrate to groundwater for some portions of the Site through excavation and soil capping, but will not be implemented for areas of the Site that have COCs at concentrations higher than cleanup levels. Therefore, Alternative SA-4 will not achieve soil CAOs and is eliminated due to a low overall score.

7.2 Groundwater

For groundwater, CAOs include minimizing groundwater plume migration, preventing off-site plume migration, and reducing perchlorate concentrations to 14 µg/L or lower. A comparison analysis was conducted of several potential remedial alternatives consistent with RCRA guidelines. Of these alternatives, Alternative GW-2 is the recommended corrective measure for groundwater, and involves groundwater extraction, ex situ treatment, and reinjection for the bedrock aquifer, as well as alluvial in situ biological reduction near MW-6.

Table 24 presents the reviewed corrective measures alternatives for groundwater and their ranking by each evaluation criteria. Based on flow field analysis, the recirculation flow field created from Alternative GW-2 by extracting and reinjecting into the bedrock source area will increase the hydraulic flux through the source area and decrease the remedial timeframe. Because no perchlorate has been detected in alluvium monitoring wells in the area near MW-6 following the EVO injection pilot test in 2014, the only corrective action remaining to confirm achievement of CAOs in the alluvium is groundwater monitoring. Alternative GW-2 will provide the highest level of overall protection of human health and the environment and is assumed to have the highest probability of stakeholder acceptance. Therefore, the recommended corrective measures alternative for groundwater is Alternative GW-2.

The remaining alternatives were eliminated for the following reasons. The lowest ranking alternative is Alternative GW-1 (No Action), which will not meet groundwater CAOs and is eliminated.

Because Alternative GW-3 will inject untreated groundwater from the bedrock extraction wells directly into the proposed injection wells as part of its remedy, it has the potential to cause further migration of the constituent plume outside of the areas under hydraulic control. Therefore, Alternative GW-3 is not likely to be protective of human health and the environment because of the potential to redistribute COCs in the bedrock groundwater. There is uncertainty regarding the flowpath of reagent reinjection and undemonstrated treatment effectiveness for in situ biological reduction within the bedrock aquifer at the Site, which may jeopardize source control. There is potential to extract total organic carbon and redistribute it outside of the source area in bedrock groundwater, which would limit the effectiveness of in situ biological reduction. Furthermore, there is higher risk of injection well fouling when a source of carbon is applied, which requires increased well maintenance, well rehabilitation, and well replacement. This will result in an extended remediation timeframe and additional costs compared to Alternative GW-2. Therefore, Alternative GW-3 has a relatively low ranking and is eliminated.

Alternative GW-4 will prevent potential plume migration through hydraulic control established by groundwater extraction throughout the plume and reinjection at the site boundary. Alternative GW-4 will also achieve groundwater cleanup goals through ex situ treatment of groundwater. However, the remedial timeframe for Alternative GW-4 is assumed to be 30 years. Alternative GW-4 is less protective overall of human health and the environment, will require the most energy and O&M during the remediation system lifespan (which increases potential risks to the community, workers, and the environment), and has the least reasonable present-worth cost. Alternative GW-4 will also be the most difficult alternative to implement because it requires the greatest number of wells and the system will require maintenance for 30 years. Therefore, Alternative GW-4 has a relatively low ranking and is eliminated.

8. References

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