Proposed Plan for Site 1 (Fire Training Area #2)
Buckley Air Force Base, Colorado
Department of the Air Force

INTRODUCTION AND OVERVIEW OF THE PROPOSED PLAN

This Proposed Plan identifies the Preferred Alternative for cleaning up contaminated groundwater at Site 1, Buckley Air Force Base (AFB), Aurora, Colorado, and provides the rationale for this preference. In addition, this Proposed Plan includes summaries of other cleanup alternatives evaluated for use at this site. This document is issued by the United States Air Force (USAF), the lead agency for site activities, in consultation with the Colorado Department of Public Health and Environment (CDPHE) and the United States Environmental Protection Agency (EPA) – Region 8 as the regulatory agencies. The USAF, in consultation with regulatory agencies, will select a final remedy for the site after reviewing and considering all information submitted during the 30-day public comment period. The USAF, in consultation with the regulatory agencies, may modify the Preferred Alternative or select another remedy presented in this Proposed Plan based on new information or public comments. Therefore, the public is encouraged to review and comment on the remedial alternatives presented in this Proposed Plan.

The USAF prepared this Proposed Plan in consultation with the regulatory agencies as part of its public participation responsibilities under Section 117(a) of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA, 42 USC § 9617(a)) and Section 300.430(f)(2) and (3) of the National Oil and Hazardous Substances Pollution Contingency Plan, commonly referred to as the National Contingency Plan (NCP).

The regulatory agencies reviewed an earlier version of this document (URS Group, Inc. 2008), and their comments are incorporated in this version. Agency comments concerning the remedial alternatives can be found in the Final Site 1 Feasibility Study Addendum (AECOM Technical Services, Inc. [AECOM] 2018).

MARK YOUR CALENDARS

PUBLIC COMMENT PERIOD:
27 December 2018 – 31 January 2019
The USAF will accept written comments on the Proposed Plan during the public comment period. Comment letters must be postmarked by 31 January 2019 and should be submitted to:

Scott Wilson
Restoration Program Manager, AFCEC/CZO
660 S. Aspen St, MS 86
Buckley AFB, CO 80011
Email: Scott.Wilson.7@us.af.mil
Fax: (720) 847-6159

To request an extension, send a request in writing to Scott Wilson by 31 January 2019.

For more information, see the Information Repository at the following location:
Aurora Public Library, Central
14949 E. Alameda Parkway
Aurora, CO 80012
(303) 739-6600
Hours: Monday-Thursday – 8 a.m. to 10 p.m.
Friday - 8 a.m. to 8 p.m.
Saturday - 8.a.m. to 6 p.m.
Sunday - 10 a.m. to 6 p.m.
Or the Buckley Air Force Base Environmental Website at:
https://www.buckley.af.mil/About-Us/Environmental/

Regulatory Background: The USAF, under its Environmental Restoration Program (ERP), is the lead agency responsible for developing and implementing the remedial action. The CDPHE and EPA – Region 8 are the regulatory agencies responsible for participating in the remedy selection process. ERP input is also provided by the City of Aurora, Colorado, the Tri-County Health Department, and Arapahoe County. As indicated earlier, the USAF prepared this Proposed Plan in consultation with the regulatory agencies as part of its public participation responsibilities under CERCLA. This document describes the Preferred Remedial Alternative developed during the

Remedial Investigation/Feasibility Study (RI/FS) for Site 1.

Proposed Plan Organization: Following this introduction, the Proposed Plan contains sections including Site Background, Site Characteristics, Scope and Role of the Proposed Response Action, Summary of Site Risks, Summary of *in situ* Chemical Oxidation (ISCO) Treatability Study (TS), Remedial Action Objectives (RAO), Summary of Remedial Alternatives, Evaluation of Alternatives, Preferred Alternative, and Community Participation. Document references, a glossary and acronym list, and a comment form are also provided for the reader's convenience.

The Proposed Plan summarizes information that can be found in greater detail in the documents listed below and other documents contained in the Administrative Record file for Buckley AFB, which may be reviewed at the Aurora Public Library, or via the U.S. Air Force Civil Engineer Center Administrative Record website by going to http://afcec.publicadmin-record.us.af.mil/Search.aspx; by selecting "Buckley AFB, CO"; clicking search; then selecting "FT001 Fire Training Area No. 2", and clicking search.

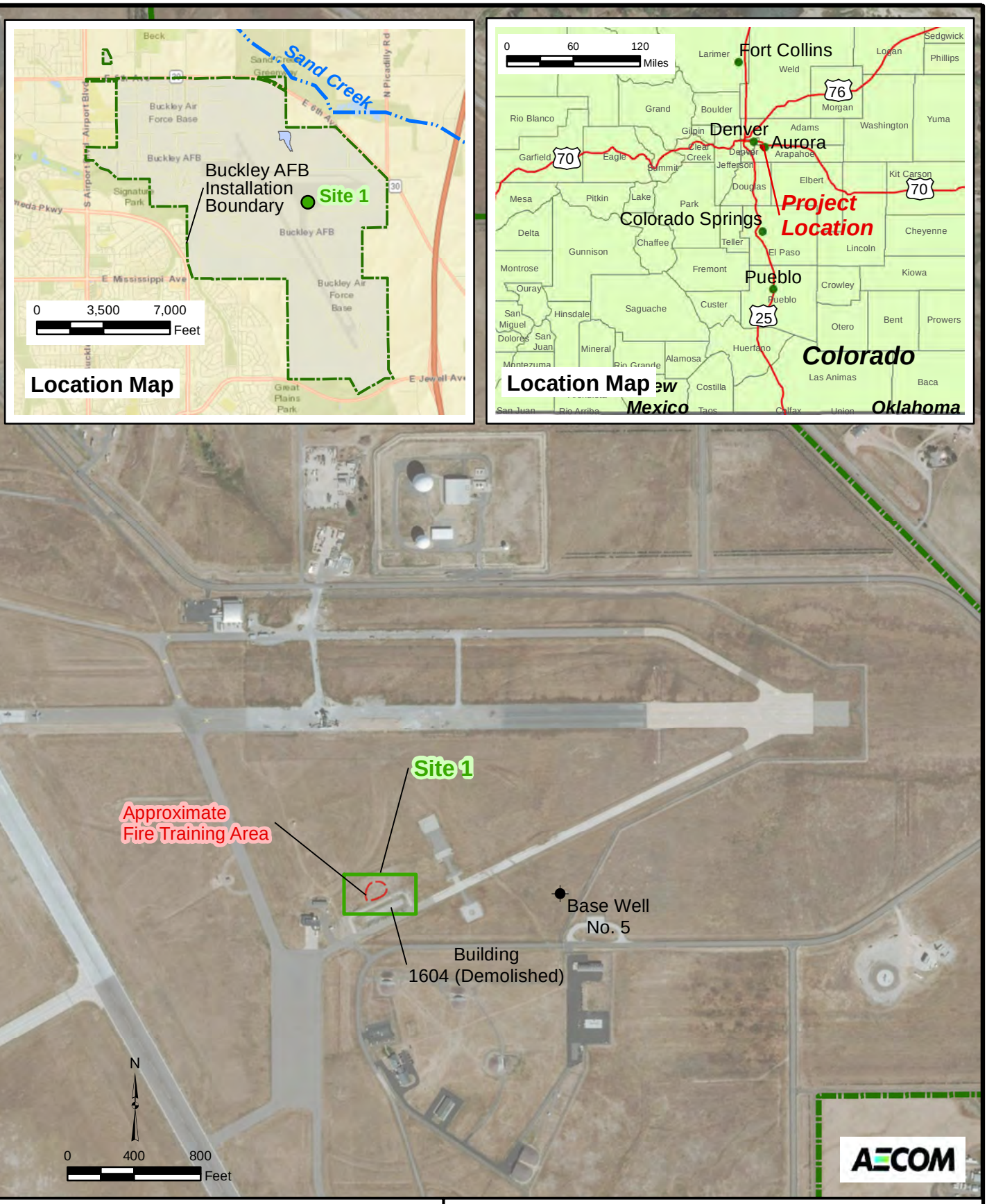
- Remedial Phase I Records Search, Buckley Air National Guard Base, September 1982 (Simons, Li & Associates, Inc.)
- Installation Restoration Program Phase II Confirmation/Quantification Stage I (Site Investigation), March 1986 (Dames and Moore 1986)
- Remedial Investigation Report, Volume I, August 1995 (SAIC 1995)
- Draft Remedial Investigation Report, October 1999 (ERM 1999)
- Final Supplemental Remedial Investigation Report at Site 1 (URS Group, Inc. 2006a)
- Final Site 1 Feasibility Study (URS Group, Inc. 2006b)
- Final Site 1 Data Gap Investigation Report (AECOM 2013)
- Final Site 1 Deep Weathered Denver Aquifer Investigation Report (AECOM 2014)
- Site 1 Treatability Study Work Plan Revision 0 (AECOM 2016a)
- Site 1 Treatability Study Implementation Report (AECOM 2016b)
- Final Site 1 Feasibility Study Addendum (AECOM 2018)

SITE BACKGROUND

Facility Description: Buckley AFB is located in Arapahoe County, north-central Colorado, approximately 5 miles east of Denver, Colorado. The base occupies approximately 3,328 acres (Figure 1). The U.S. Army Air Corps operated the base from 1942 until the base was deactivated in 1946. In 1946, ownership was transferred to the State of Colorado and the base was occupied by the Colorado Air National Guard. In 1947, the U.S. Navy assumed control of a portion of the base for use as a training area. In 1959, the U.S. Navy deactivated its station and transferred the property back to the Colorado Air National Guard. On 1 October 2000, Buckley became an active air force base.

The base has stored and used various types of fuels and other chemicals during its history in support of its primary missions of combat training, transient aircraft support, and search and rescue response.

Site 1 is located on the east side of Buckley AFB near former Building 1604 (Figure 1) and covers approximately 8,000 square feet (ft). The site is a former fire training area (FTA), which includes an old burn pit, approximately 50 ft in diameter. The area is unlined, undiked, and within 2,000 ft of Base Well No. 5, a former potable water supply well. Building 1604, constructed as a hangar, was immediately adjacent to the site and extensive concrete and asphalt pavements are in place to the south of the area. The area to the north of Site 1 is an open field, which leads to the runways. Site 1 is currently inactive and remains an open field. Building 1604 was removed and there are no current or future plans for USAF land use at the site.



Legend

- Base Well No 5
- Site 1 Boundary
- Fire Training Area
- Installation Boundary

Figure 1

LOCATION MAP

SITE 1
BUCKLEY AIR FORCE BASE, COLORADO

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Suspected Causes of Contamination and Contaminated Media: Historic use of Site 1 included igniting aviation gasoline (AVGAS), jet fuel (JP-4), and possibly waste solvents for fire training purposes. Approximately six exercises per month were held between 1950 and 1972.

Summary of Previous Environmental Investigations: Several previous investigations were conducted at Site 1 between 1982 and 2014 as indicated in the document list above.

Summary of Remedial Actions to Date: In June 2016, a field-scale TS was performed to assess whether the treatment technology, ISCO, can effectively be used to meet Site 1 Remedial Action Objectives (RAOs), which include compliance with the USEPA Maximum Contaminant Levels (MCLs, USEPA 2009). The ISCO TS was implemented in the treatment area (Figure 2) where a majority of the trichloroethylene (TCE) mass was found to be present. The treatment area covered approximately 11,300 square ft including the hot spot bounded with TCE concentrations above 50 micrograms per liter (µg/L), and a downgradient area with TCE above 30 µg/L. Potassium permanganate (30 percent by weight) was selected as the oxidant. Approximately 10,000 pounds (lbs.) of potassium permanganate was distributed by environmental fracturing and injection to the groundwater where the highest TCE concentrations were present. Five injection wells were installed to deliver the potassium permanganate. At each injection point, potassium permanganate was emplaced at about 5-ft vertical intervals throughout the saturated thickness of 25 ft. Post injection performance monitoring data showed promising results. TCE concentrations were reduced to non-detect levels in the hot spot and downgradient area in less than a year. This TS falls under the USEPA's definition of "remedy-selection testing" (USEPA 1992) and demonstrated successful application of ISCO as a remedy at Site 1.

Summary of Public Involvement Activities Regarding Site 1: In 2001, the USAF prepared and implemented a Community Involvement Plan in accordance with CERCLA and 40 Code of Federal Regulations (CFR) § 300.430(c)(2). The plan describes community involvement activities that Buckley AFB will undertake during remedial activities. Buckley AFB also hosts periodic meetings of the Community Advisory Group, where current status and issues regarding the Buckley ERP are shared with community stakeholders. Members of the public may comment on the USAF's intent to implement the preferred Site 1 alternative in writing as discussed earlier in this document.

SITE CHARACTERISTICS

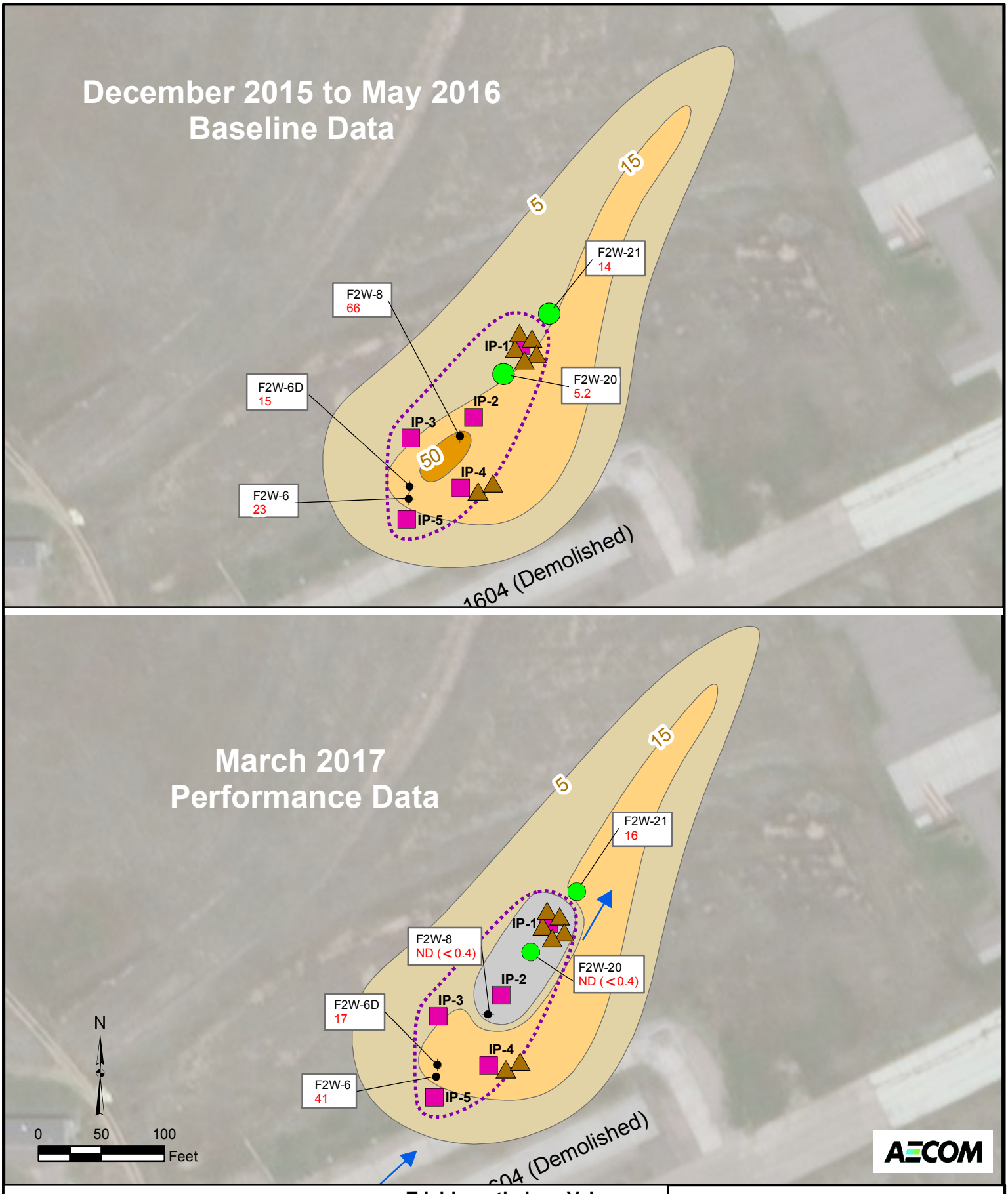
Physical Site Characteristics: Site 1 and Buckley AFB are located above the Denver Formation. The formation is approximately 850 ft thick near the site. It is covered with a thin mantle (typically 10 to 15 ft) of alluvial and/or windblown deposits of loess and fine sand.

Soils encountered at Site 1 are characteristic of the Denver Formation and overlying surficial deposits described above. Alluvial and possibly aeolian soils were encountered from ground surface to approximately 12 ft below ground surface (bgs). Below the alluvium is predominately the weathered claystone of the Denver Formation with minor weathered interbedded sandstone lenses.

Groundwater at Site 1 resides primarily within the weathered claystone of the Denver Formation and is considered to be unconfined. Groundwater within the claystone is present at approximately 25 to 30 ft bgs.

Site 1 is within 2,000 ft of Buckley AFB Well No. 5, a former potable water supply well. This well was registered to the Colorado Air National Guard under Permit # 16118 with a depth of 2,100 ft bgs and a typical water level of 315 ft bgs.

Surface water at Site 1 drains through overland sheet flow to the north and northeast, following the surface topography in the area. Surface water collects in storm water drainage channels and is directed around the runway, located approximately 1,000 ft north of the site.



Legend

- Confirmation Boring
- Injection Point
- New Performance Monitoring Well
- Existing Monitoring Well
- Groundwater Flow Direction (Interpreted)
- Red Text = TCE Value (µg/L)
- Treatment Area

Trichloroethylene Values (Micrograms Per Liter)

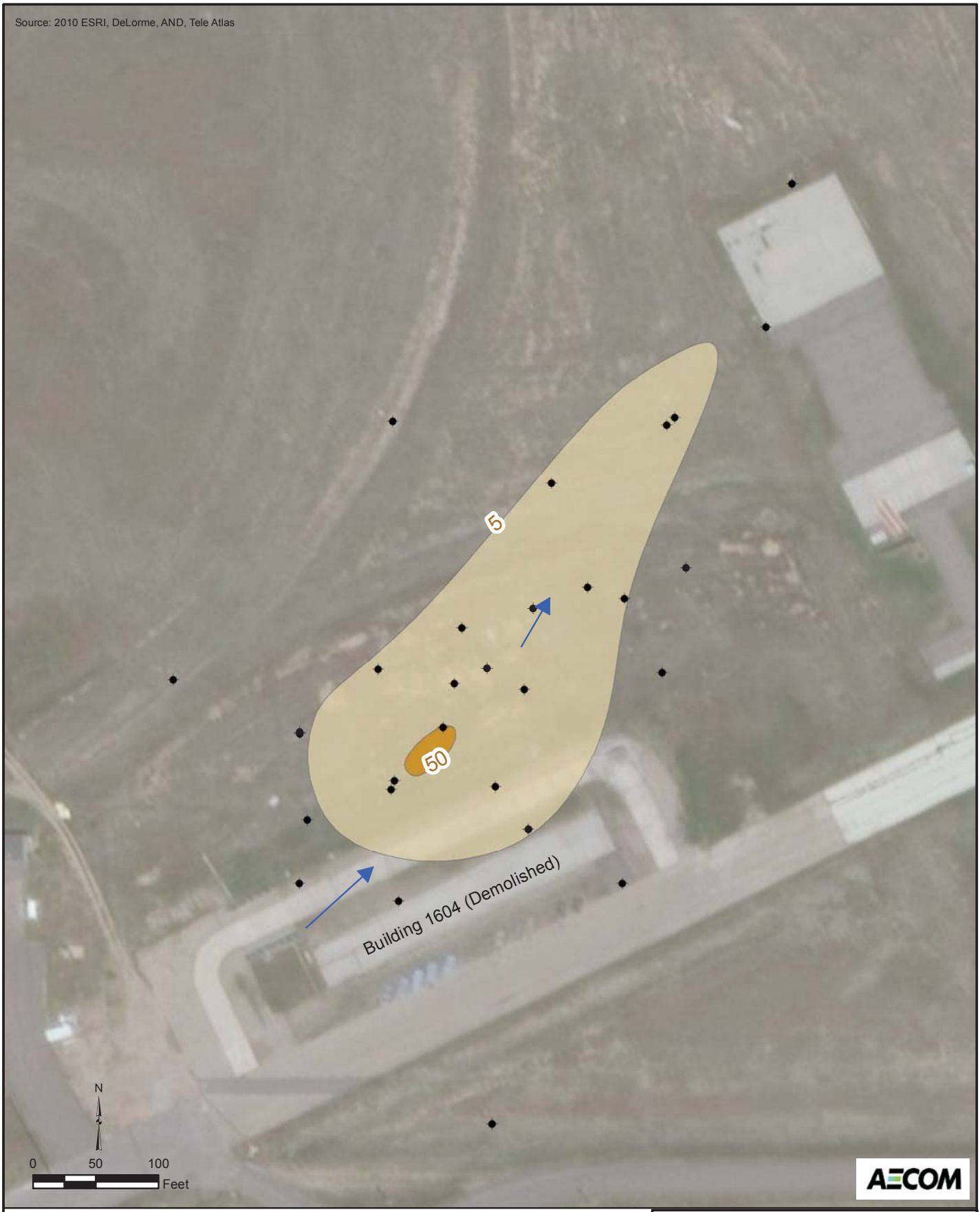
- >50
- 15-50
- 5-15
- <5

Figure 2

TCE PLUME - BASELINE and POST TREATABILITY STUDY

SITE 1
BUCKLEY AIR FORCE BASE, COLORADO

C:\Buckley\Site 1\Fig 2 Site 1 TCE BaseLn Post Trtmnt Data Rev2.mxd 11/20/2018 (SHOTNIKA)



Legend

- Existing Monitoring Well
- Groundwater Flow Direction (Interpreted)

Trichloroethylene Values - 2016 (Baseline) (Micrograms Per Liter)

- >50
- 5-50

Figure 3

GROUNDWATER PLUME AND WELL LOCATIONS

SITE 1

BUCKLEY AIR FORCE BASE, COLORADO

C:\Buckley\Site 1\Fig 3 Site 1 GW Plumes and Wells Rev1.mxd 6/14/2018 (SHOTNIKA)

Nature and Extent of Contamination:
Investigation results concluded that no contaminants were present in soils exceeding the regulatory soil screening levels. Therefore, soil was not considered a media of concern.

TCE is the only contaminant of concern (COC) present in the groundwater at Site 1. TCE is a volatile organic compound (VOC) that has consistently been detected above the EPA MCL of 5 µg/L (EPA 2009) at multiple locations. Concentrations have been declining over time, and the highest TCE concentrations have been detected in samples from monitoring wells located within the FTA source area boundary where 2016 concentrations prior to the TS injections ranged from 23 µg/L to 66 µg/L. At that time, the estimated areal extent of the TCE groundwater plume greater than 5 µg/ was approximately 61,000 square ft (Figure 2) and the 50 µg/L hot spot boundary isopleth covered approximately 1,000 square ft. Vertically, TCE is present primarily in the upper portion of the aquifer between 25 and 50 ft bgs. The monitoring well locations are shown on Figure 3. The 2013 Deep Weathered Denver Aquifer investigation indicated that no significant downward vertical migration of TCE has occurred from the upper portion to the deeper weathered Denver aquifer (60-70 ft bgs) where concentrations ranged from 3.4 µg/L to 5.9 µg/L.

Cis-1,2-dichloroethylene (cis-1,2-DCE), a daughter product of TCE, has also been historically detected at Site 1, but below the MCL of 70 µg/L. The highest concentrations were from wells located within and downgradient of the FTA source area boundary where 2016 baseline concentrations ranged from 0.97 µg/L to 13 µg/L. Vinyl chloride (VC), another TCE daughter product, has not been detected at Site 1. Recent samples were also analyzed for 1,4-dioxane and the highest detected concentration was 0.034 µg/L (J-flagged as the detection was between the method detection limit and the limit of quantitation), less than the Colorado Basic Standard for Groundwater (CBSG) of 0.35 µg/L for 1,4-dioxane (CDPHE 2016).

During historical investigations (prior to 2010), tetrachloroethylene (PCE) and four other compounds (bromodichloromethane, bromoform, chloroform, and dibromomethane) were detected. Only PCE was detected at a concentration greater than it's MCL of 5 µg/L (maximum concentration of 7.27 µg/L in December 2002). PCE has not been detected at levels greater than the MCL since that time and therefore is not a COC.

The presence of nitrate in groundwater is not a result of previous operations at Site 1, and elevated concentrations have been determined to be associated with former sewage leach fields located west and upgradient of Site 1. Although nitrate is present in groundwater, it is not a Site 1 COC and nitrate remediation is not considered under this Proposed Plan.

SCOPE AND ROLE OF THE PROPOSED RESPONSE ACTION

The Supplemental RI and the initial FS were completed for Site 1 in 2006. While the Record of Decision (ROD) was in the signature process in 2010, additional groundwater monitoring was performed as part of the long-term monitoring (LTM) program (the selected remedy at that time). Results from that event indicated that the groundwater contamination extent was not fully defined. The ROD was, therefore, not signed, and two additional investigations (AECOM 2013 and 2014) were performed to delineate the extent of the groundwater contamination. Discussions between the USAF, regulatory agencies, and other stakeholders identified the desire for a TS which was performed in 2016. This was followed by the FS Addendum (AECOM 2018) which included the results of investigations that have been performed since the initial FS (URS Group, Inc. 2006). The 2016 TS results and discussion/comparative analyses of remedial alternatives are also presented in the FS Addendum.

This Proposed Plan addresses a proposed remedial action to address remaining TCE in groundwater at Site 1.

SUMMARY OF SITE RISKS

A quantitative human health risk assessment was not performed for Site 1 during the Supplemental RI as no complete and significant pathways of exposure were identified in the site conceptual model for current or future human receptors. Risk was qualitatively evaluated for soil and groundwater at the site. Surface soil at Site 1 was determined to not pose an unacceptable risk to current or future site workers. It was also determined that site workers had no direct exposure to groundwater at Site 1. There is no planned future use of the site groundwater. Therefore, current and future direct exposure to groundwater at Site 1 is incomplete. If land and/or groundwater use at the site changes in the future, it will then be appropriate to reevaluate the risk. Vapor intrusion from groundwater was also evaluated. The overall results indicate that groundwater VOC concentrations in the vicinity of Site 1 do not represent unacceptable indoor air risks to the hypothetical resident.

SUMMARY OF ISCO TREATABILITY STUDY

As discussed earlier, a TS was conducted to compare the effectiveness and implementability of ISCO in a field setting. The TS also evaluated the effectiveness of environmental fracturing and pressure injection as a means to distribute the potassium permanganate (oxidant) in the subsurface. The environmental fracturing and pressure injection method resulted in the distribution of about 2,000 lbs. of potassium permanganate at each of five injection locations, for a total injection quantity of 10,000 lbs. The effective radius of influence (ROI) of the potassium permanganate was evaluated by various measurements and observations including visual observations of potassium permanganate crystals (dark purple) in the confirmation borings. Potassium permanganate was generally observed in fractures within about 10 ft of each injection location, however it was locally observed to extend up to 20 ft away from the injection locations. The success of injecting potassium permanganate to treat TCE at Site 1 was further evaluated through the performance monitoring program. Performance monitoring included collecting groundwater samples for field parameter measurements and laboratory analysis of TCE and geochemical constituents. Performance monitoring was conducted using five monitoring wells in July 2016, October 2016, and March 2017. The highest pre-TS TCE concentration of 66 µg/L, representing the hot spot, was reduced to a non-detect level in July 2016 and showed no rebound since then. Similar treatment effectiveness was observed for the downgradient well (from the hot spot) with a baseline TCE concentration of 5.2 µg/L.

During the performance monitoring period, no reduction of TCE concentrations was observed at three remaining monitoring wells which suggest that potassium permanganate had not reached these wells during the monitoring time period. Potassium permanganate is known to persist in the subsurface for several years, and unused potassium permanganate is still available in site groundwater to continue to drive the ISCO process. This situation is evidenced by purple- to pink-colored water in the treatment zone wells during the most recent sampling event, TCE concentrations will likely decrease in these wells as the potassium permanganate crystals dissolve and subsequently disperse within the formation. The overall performance monitoring results, supported by geochemistry data, show that ISCO was effective in treating TCE in groundwater at Site 1.

REMEDIAL ACTION OBJECTIVES

Based on the Applicable or Relevant and Appropriate Requirements (ARARs) and point of compliance (POC) requirements for Site 1, RAOs were developed for groundwater. RAOs identify the media specific goals for protecting human health and the environment. The following RAOs have been identified for groundwater at Site 1:

- Protect human health by preventing exposure to groundwater containing TCE exceeding the MCL until concentrations have been reduced to levels that allow unlimited use and unrestricted exposure (UU/UE);

- Protect human health and the environment by achieving regulatory requirements (i.e., achieving the MCL for TCE in groundwater) at and beyond the POC.

SUMMARY OF REMEDIAL ALTERNATIVES

The USAF has considered six remedial alternatives to address groundwater contamination at Site 1. These options include different approaches to contain, remove, or treat contamination in order to protect human health and the environment. Alternatives were evaluated following the FS process outlined in the NCP. The alternatives evaluated include:

Alternative GW1 – No Action

Alternative GW2 – Land Use Controls (LUCs)

Alternative GW3 – Long-Term Monitoring (LTM) and Land Use Controls

Alternative GW4 – *In situ* Chemical Oxidation (ISCO) with Long-Term Monitoring and Land Use Controls

Alternative GW5 – *In situ* Chemical Reduction (ISCR) and Biostimulation with Long-Term Monitoring and Land Use Controls

Alternative GW6 – *In situ* Enhanced Reductive Dechlorination (ERD) with Long-Term Monitoring and Land Use Controls

Based on information currently available, it is the USAF's opinion that Alternative GW4 "*In situ* Chemical Oxidation with Long-Term Monitoring and Land Use Controls" is the Preferred Alternative for addressing TCE contamination in groundwater at Site 1.

During the public comment period, the USAF welcomes public comments on the Proposed Plan, the Preferred Alternative, and on the other alternatives that were evaluated. Each of these alternatives is summarized in the following sections.

Common Elements of GW2 Through GW6

With the exception of Alternative GW1, the alternatives presented above include common elements of Performance Monitoring and LTM, except for the "No Action" and "LUCs only" alternatives. These two elements are discussed here instead of repeating the detail in each of the active remedy alternatives below as they are identical.

Performance Monitoring

To monitor the performance of the remedial action, seven monitoring wells (including two new performance monitoring wells) would be sampled for VOCs and geochemical parameters. One round of baseline monitoring would be performed before injecting the chemical reagent or substrate. Performance monitoring would include monthly sampling for the first 3 months and then quarterly sampling for the first year.

LTM

LTM would be performed as a stand-alone activity or after completion of performance monitoring to evaluate the processes of advection, dispersion, diffusion, and adsorption and their role in attenuation of contaminant concentrations to meet the cleanup objectives within expected timelines.

Twelve monitoring wells would be sampled for selected VOCs (TCE, cis-1,2-DCE, trans-1,2-dichloroethylene [trans-1,2-DCE], and VC) and geochemical parameters semi-annually for Years 1 and 2, annually for Years 3 through 5, and biannually for Years 6 through 10. After the first 10 years, eight monitoring wells are expected to be sampled every 3 years until Site Closure is achieved.

Description of the Remedial Alternatives Considered for this Action: The remedial alternatives considered for Site 1 are presented below. The key features and costs, for each alternative are summarized in the table below.

Alternative GW1 – No Action. The NCP requires that a "no action" alternative be evaluated to establish a basis for comparison with other alternatives. The no action alternative assumes no further action will be taken at Site 1 to address groundwater contamination. Although there are no capital costs involved with this alternative, future costs and liabilities are unknown.

Alternative GW2 – Land Use Controls (LUCs). The absence of an active remedy would leave TCE concentrations in groundwater above its MCL; therefore LUCs would be implemented. LUCs are institutional or engineering controls that limit the use of resources or restrict receptors' exposure to contaminants to protect human health and the environment. The LUCs for Alternatives GW2, GW3, GW4, GW5, and GW6 will be maintained until concentrations of hazardous substances in the groundwater are at levels allowable for UU/UE.

The ROD will document any finalized LUCs needed to protect human health. The preliminary LUCs planned for Site 1 are:

1. The base well permitting system will prevent any use of groundwater for drinking water. The Buckley AFB digging permit system requires all entities to file a form with the Customer Service Section of Base Civil Engineering that must be approved before the subsurface (below 4 inches bgs) is disturbed. This system will prevent drilling of any groundwater production wells and, therefore, any use of groundwater within the Site 1 boundary.
2. The base dig permit system will prevent activities that could disturb any components of the groundwater monitoring network or any other engineered components of the remedy. Any construction action that might damage or interfere with the proper operation or maintenance of any engineered component of the remedy, including monitoring or remediation wells, will not be permitted. The Buckley AFB digging permit system requires all entities to file a form with the Customer Service Section of Base Civil Engineering that the 460th Civil Engineering Squadron (CES) must approve before ground below 4 inches is disturbed. This form will activate formal utility and infrastructure clearance procedures.
3. All proposed construction over any part of the TCE plume shall be reviewed by the 460th CES for potential hazards or risks posed by contaminated groundwater. The Buckley AFB construction review process, triggered by submittal of a Base Civil Engineer Work Request form and the Buckley AFB digging permit system, will prevent construction before review. The 460th CES will require additional investigation (e.g., updated groundwater data) or analysis of hazard and risk for the plume to determine if there is an unacceptable risk to human health or the environment. If unacceptable risk is identified, the 460th CES will require new construction to include engineering controls to protect human health and the environment.
4. The base environmental impact analysis process will assess the potential environmental impact of any action proposed at the site, to include compliance with LUCs for the site. The environmental impact analysis process is implemented by the 460th CES, Installation Management Flight, Environmental Element (460 CES/CEIE).
5. All ROD use limitations and exposure restrictions shall be entered in the Base Installation Development Plan and the Geographical Information System by the Base Community Planner within 30 days after ROD signature.
6. The USAF is responsible for implementing, maintaining, monitoring, reporting and enforcing all on-base LUCs.
7. The USAF shall inform, monitor, enforce, and bind, where appropriate, authorized lessees, tenants, contractors, and other authorized occupants of the site regarding the LUCs affecting the site.
8. The USAF will notify CDPHE as soon as practicable, but no longer than ten (10) days after discovery, of any

activity that is inconsistent with the LUC objectives or use restrictions, or any other action that may interfere with the effectiveness of the LUCs. The USAF will include in such notice(s) a list of corrective actions taken or planned, and associated dates, to address such deficiency or failure.

9. The USAF must provide notice to CDPHE at least six (6) months prior to any transfer or sale of property containing LUCs, including federal-to-federal transfers of property accountability, so that CDPHE can be involved in discussions to ensure that appropriate provisions are included in the transfer or conveyance documents to maintain effective LUCs. If it is not possible to notify CDPHE at least six months prior to any transfer or sale, then the facility will notify the state as soon as possible but no later than 60 days prior to the transfer or sale of any property subject to LUCs.
10. The USAF shall not modify or terminate LUCs, modify land uses that might impact the effectiveness of the LUCs, take any anticipated action that might disrupt the effectiveness of the LUCs, or take any action that might alter or negate the need for LUCs without 45 days prior to the change seeking and obtaining approval from CDPHE of any required ROD modification.
11. The USAF will monitor and inspect all site areas subject to LUCs at least annually.
12. The USAF will report annually to CDPHE on the frequency, scope, and nature of LUC monitoring activities, the results of such monitoring, any changes to the LUCs, and any corrective measures resulting from monitoring during the time period. With the exception of the LUC addressing engineering controls (item 3 above), these LUCs apply in plume areas where groundwater concentrations exceed the MCL, as highlighted on Figure 4.

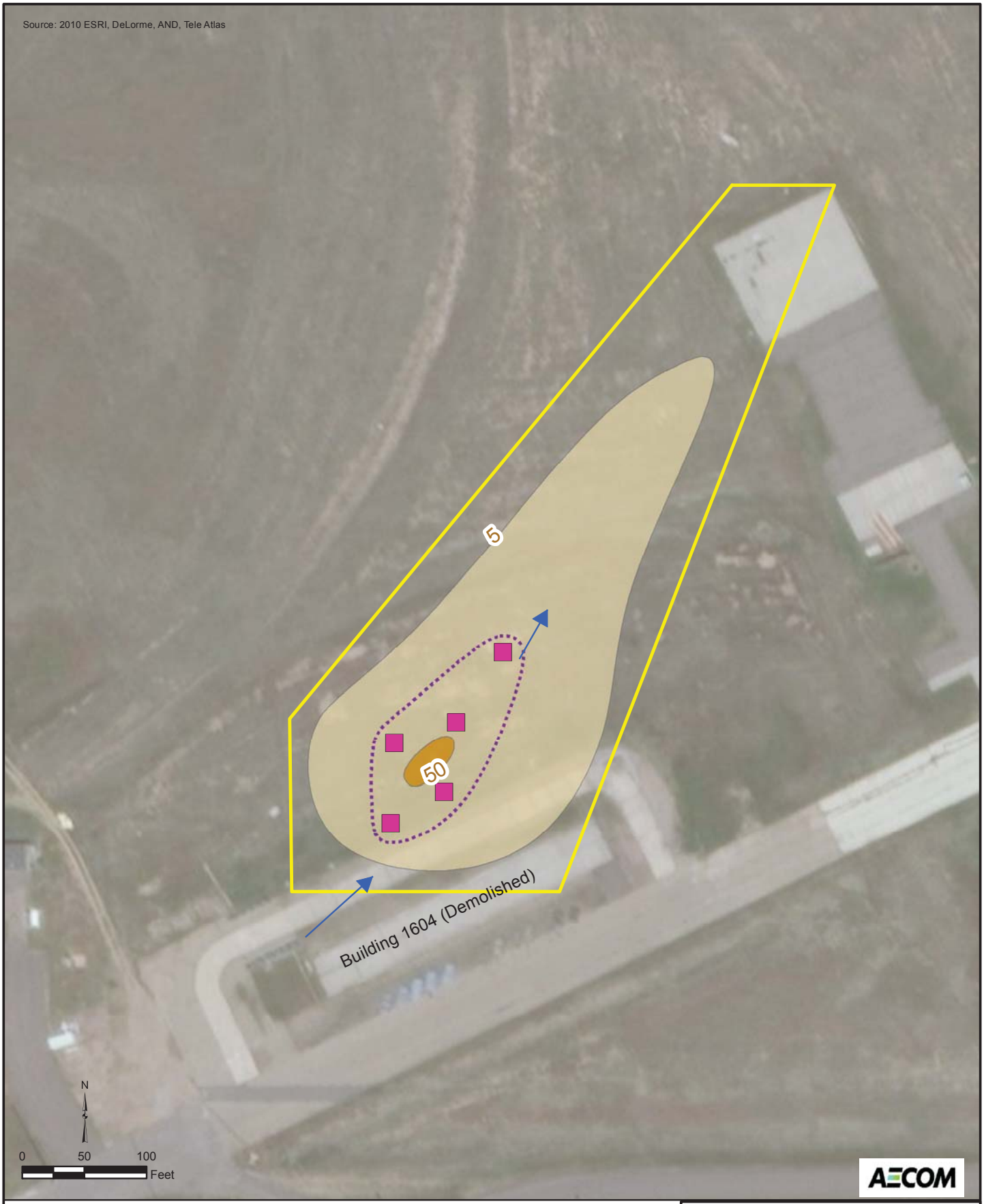
Alternative GW3 – Long-Term Monitoring (LTM) and LUCs. LTM is discussed under the "Common Elements" section and LUCs are presented as Alternative GW2 above.

Alternative GW4 – ISCO with LTM and LUCs. ISCO involves the delivery of potassium permanganate (an oxidant chemical) to affected groundwater to oxidize and chemically break down the COCs into innocuous compounds such as carbon dioxide (CO_2), water, and chloride. The rate and extent of destruction of the COCs is based on the properties of the COCs, their susceptibility to oxidation, and subsurface conditions. The treatment area is approximately 11,300 square ft with a thickness of 25 ft.

This alternative involves delivering potassium permanganate slurry (30 percent by weight in water) into the aquifer through the use of environmental fracturing/pressure injection. Environmental fracturing involves injecting fluid into the subsurface geologic formation at a rate and pressure high enough to increase the permeability of the geologic formation.

At each injection point, approximately 2,000 lbs. of potassium permanganate in a water-based slurry would be pressure injected directly into the aquifer through environmental fracturing. The injection borings would be drilled with a solid-stem auger to a depth of about 55 ft bgs**.** Environmental fracturing and injection would be accomplished using injection tooling consisting of a nozzle and straddle packer assembly that would be lowered to the bottom of the open boring and held in place during environmental fracturing and injection using a Geoprobe track-mounted rig. Based on an effective ROI of 20 ft, five injection points would be installed to treat TCE within the treatment area. At each injection point, potassium permanganate slurry would be emplaced at about 5-ft vertical intervals throughout the saturated thickness of a given injection point. The equipment necessary to achieve this task is readily available.

The field TS performed in June 2016 (discussed previously) implemented the ISCO step of the Alternative GW4 remedy described in this section.



Legend

- Injection Point
- Treatment Area
- Proposed Land Use Control Boundary
- Groundwater Flow Direction (Interpreted)

Trichloroethylene Values - 2016 (Baseline)
(Micrograms Per Liter)

- >50
- 5-50

AECOM

Figure 4
PREFERRED ALTERNATIVE
GW4
SITE 1
BUCKLEY AIR FORCE BASE, COLORADO

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Post injection monitoring data showed that the ISCO TS effectively remediated the hot spot and downgradient area. Excess oxidant, over the volume required to treat the estimated TCE mass, was emplaced in the fractures. Unused potassium permanganate is still present in the aquifer, as evidenced by purple- to pink-colored water in the treatment zone wells during the most recent sampling event, and will continue to migrate laterally in the downgradient direction with the groundwater flow within the TCE plume. ISCO is expected to remain effective for several years because potassium permanganate is a stable oxidant and its longevity has been increased by being injected in a slurry phase instead of dissolved phase in a solution. As a result, potassium permanganate slurry injected during the TS will provide a sustained release of oxidant on a long-term basis to address residual TCE contamination present at Site 1. Based on the successful implementation of ISCO which remediated a majority of TCE mass to harmless end products at Site 1, the ISCO TS has been incorporated as an active remedial component for this alternative.

Although the ISCO hydraulic fracturing and injection steps are complete, LTM and LUCs will be implemented, as discussed above, for full implementation of this alternative. LTM results will be evaluated to determine if additional remediation steps, such as additional oxidant injections, will be required in the future.

Alternative GW5 – *In situ* Chemical Reduction (ISCR) and Biostimulation with LTM and LUCs. The steps to implement ISCR are similar to those of ISCO, except this alternative utilizes a chemical reductant for the breakdown of TCE.

EHC™ (controlled release carbon with zero-valent iron) was selected as the chemical reductant that would be used to treat the TCE groundwater plume. Corrosion of iron creates a strongly reducing anaerobic environment (oxidation reduction potential of negative 400 millivolts [-400 mV]) where TCE can be abiotically degraded to ethene and ethane through beta-elimination processes; bypassing the production of VC. Iron corrosion can also generate hydrogen which may facilitate biotic dehalogenation of TCE by naturally occurring dechlorinating bacteria; this would result in the production of intermediate products such as cis-1,2-DCE and VC before degrading to ethene and ethane. Approximately 29,000 lbs. of 25 percent emulsion of EHC™ liquid would be injected at the site.

Environmental fracturing/pressure injection for the emplacement of reductant in the aquifer, treatment area and thickness, and follow-on performance monitoring, LTM, and LUCs would be the same as described previously. It should be noted that current site conditions at Site 1 are not amenable to ISCR because permanganate injected into the groundwater during the ISCO TS would interfere with the establishment of geochemical conditions suitable for ISCR. This effect is generally transitory but would result in an increased lag time to initiate ISCR.

Alternative GW6 – *In situ* Enhanced Reductive Dechlorination (ERD) with LTM and LUCs. The steps to implement *In situ* ERD are similar to those of ISCO and ISCR, except this alternative utilizes a substrate for the biological degradation (reductive dechlorination) of TCE to cis-1,2-DCE, VC, ethene and ethane. Approximately 1,600 gallons of a 10% high fructose corn syrup (HFCS) solution or 17,000 lbs. HFCS would be pressure injected to enhance reductive dechlorination of TCE/degradation products. This alternative assumes that two follow-up injections would be performed.

Environmental fracturing/pressure injection for the emplacement of substrate in the aquifer, treatment area and thickness, and follow-on performance monitoring, LTM, and LUCs would be the same as described previously. It should be noted that current site conditions at Site 1 are not amenable to ERD because permanganate injected into the groundwater during the ISCO TS would interfere with the establishment of geochemical conditions suitable for ERD. This effect is generally transitory but would result in an increased lag time to initiate ERD.

Discussion and Summary of Distinguishing Features of Each Alternative: Distinguishing features between the remedial alternatives are discussed in the following paragraphs.

- RAOs would not be met by implementing Alternatives GW1, GW2 or GW3 in a reasonable timeframe. RAOs could be met by implementing Alternatives GW4, GW5 or GW6.
- The estimated time for TCE to achieve the MCL is within the predicted remediation time range of 18 to 42 years for Alternatives GW4, GW5, or GW6; most of the TCE plume is expected to achieve the MCL in the earlier period of this remediation time range
- Approximately 11,300 square ft with a thickness of 25 ft of the TCE plume would be directly treated through chemical or biological reactions in groundwater under Alternatives GW4, GW5 or GW6. Alternative GW4 would treat the hot spot in the shortest time frame.
- Alternative GW1 has no special implementation requirements. Alternatives GW2 or GW3 would require LTM and LUCs as long as TCE remains above the MCL in the groundwater. This duration is expected to be 60 years as predicted by the groundwater model. Alternatives GW4, GW5 or GW6 would require LTM and LUCs during the remediation period ranging between 18 to 42 years.
- Implementing any of the alternatives is not expected to have an effect on future land use at Site 1 as no development is outlined in the Base Master Plan.
- No construction activities would be required to implement Alternatives GW1 or GW2. Minimal construction activities would be required for well installation under Alternative GW3. A moderate level of construction activities associated with environmental fracturing and pressure injection would be required for Alternatives GW4, GW5 or GW6.

The ISCO TS conducted in 2016 is the same as the ISCO element of Alternative GW4. Therefore Alternative GW4 (and associated capital costs) has been partially implemented at Site 1.

The following table summarizes the key features of each of these alternatives.

EVALUATION OF ALTERNATIVES

In order to evaluate the remedial alternatives, each alternative was compared to the nine criteria established at 40CFR300.430 (e) (9) (iii). These criteria fall into one of three categories (40CFR300.430(f)(1)(i)): threshold criteria, primary balancing criteria, and modifying criteria. These categories are summarized below:

- **Threshold criteria** are requirements that each alternative must meet in order to be eligible for selection.
- **Primary balancing criteria** are used to weigh major trade-offs among alternatives.
- **Modifying criteria** can be considered early in the alternative development process but is formally considered after public comment is received on the Proposed Plan.

The evaluation of each alternative with respect to the nine criteria is summarized in the following sections.

Threshold Criteria

1. Overall Protection of Human Health and Environment

Alternative GW1 is not protective of human health and the environment and is not consistent with the objectives of the FS for this site.

Alternatives GW2 or GW3 provide moderate protection of human health through institutional controls.

Alternatives GW4, GW5 or GW6 provide greater protection of human health and environment through active treatment such as ISCO, ISCR or ERD.

2. Compliance with ARARs

Alternatives GW1, GW2 or GW3 would not comply with chemical-specific ARARs in a reasonable time frame. Alternatives GW4,

GW5 or GW6 would comply with ARARs within a preferred shorter time frame.

Primary Balancing Criteria

3. Long-Term Effectiveness and Permanence

There would be no significant change in TCE concentrations due to intrinsic degradation or physical processes under Alternatives GW1, GW2 or GW3. Implementing Alternatives GW1, GW2 or GW3 would not provide long-term effectiveness and permanence.

Alternative GW4 would provide a high level of long-term effectiveness and permanence by treating approximately 90% of TCE concentrations in the treatment area (including hot spot) to meet the MCL in less than a year. This is based on the ISCO TS conducted at Site 1.

Alternatives GW5 or GW6 (ISCR or ERD) would provide a moderate level of long-term effectiveness and permanence as the treatment area (including hot spot) groundwater remediation time is expected to be longer than ISCO. However, these technologies are not geochemically compatible with the existing oxidizing conditions created by the ISCO TS.

4. Reduction of Toxicity, Mobility, or Volume of Contaminants Through Treatment

Alternatives GW1, GW2 or GW3 would not reduce the toxicity, mobility, or volume of contaminants.

Significant reduction of toxicity, mobility, or volume is expected to occur through implementation of Alternatives GW4, GW5 or GW6. No significant metal mobilization was observed during the ISCO TS. Should stalled reactions or undesirable accumulation of cis-1,2-DCE or VC occur during the implementation of ERD (Alternative GW6), corrective actions would be taken to address such issues. No such undesirable effects would be expected to occur during ISCO (GW4) or ISCR (GW5) reactions. ISCR is dominantly an abiotic process and generation of degradation products due to the added carbon source is expected to be minimal. The oxidation reactions under ISCO do not generate any intermediate products that could accumulate over time.

5. Short-Term Effectiveness

Alternative GW1 has no remedial activities that could pose short-term risks to human health or the environment. However, short-term risks due to potential groundwater exposure to receptors exist as long as TCE concentrations remain above the MCL.

Under Alternative GW2, no intrusive activities are involved and LUCs would prevent any potential exposures of groundwater to receptors. There are no short–term risks from the implementation of Alternative GW2**.**

For Alternative GW3, intrusive activities associated with well drilling and groundwater sampling pose moderate short-term risks to workers. Similarly, construction activities such as environmental fracturing and handling of chemicals pose moderate short-term risks to workers under Alternatives GW4, GW5 or GW6. Appropriate safety measures for the workers would be taken during LTM and construction activities during the implementation of Alternatives GW3 through GW6.

6. Implementability

Implementability addresses the technical and administrative feasibility of a remedy from design through construction and operation. Factors such as availability of services and materials, administrative feasibility, and coordination with other governmental entities are also considered.

Alternative GW1 (No Action) has no technical implementability or administrative feasibility considerations because no action is undertaken.

Alternatives GW2 or GW3 are easier to implement than Alternatives GW4, GW5 or GW6 because they consist of administrative controls and/or routine groundwater sampling and analysis technologies.

Alternatives GW4, GW5 or GW6 are technically and administratively implementable. Alternative GW4 offers higher implementability than Alternatives GW 5 or GW6 as the GW4 treatment technology involves a significantly shorter reaction time

and remains unaffected by groundwater geochemistry changes that can lead to technical problems or schedule delays. Alternatives GW5 or GW6 are moderately implementable, but the technology durations are longer than Alternative GW4 and are subject to schedule delays due to any shift in unfavorable geochemical conditions.

7. Costs

The capital (remediation construction) and operations and maintenance (O&M) cost estimates for the alternatives are tabulated below. The relative accuracy of the costs are within +50% to -30% as generated by Remedial Action Cost Engineering and Requirements (RACER) software and consistent with the EPA guidance for developing FS cost estimates (EPA 2000)

Alternative	Capital Cost	O&M Cost	Total Cost*
GW1	No cost	No cost	No cost
GW2	$27,900	$67,500	$95,400
GW3	$107,300	$269,300	$376,600
GW4	$413,700	$363,600	$777,300
GW5	$447,300	$335,200	$782,500
GW6	$403,200	$531,700	$934,900

*Present Worth Costs

Alternative GW4 is the most cost-effective among the three alternatives (Alternatives GW4, GW5 and GW6) that employ active treatment as a component. The capital costs for Alternative GW4 are the ISCO injection costs (injection well construction, chemical injection, and performance monitoring). The 2016 TS completed that portion of Alternative GW4, so the Air Force has incurred these capital costs. The O&M costs associated with implementing the LTM program and LUCs remain. More detailed cost information can be found in the Final Feasibility Study Addendum (AECOM 2018).

8. State Acceptance

The State supports Alternative GW4 as the final remedy as detailed below.

9. Community Acceptance

Community acceptance of the Preferred Alternative will be evaluated after the public comment period ends and will be described in the ROD for the site.

PREFERRED ALTERNATIVE

The USAF selected Alternative GW4 consisting of ISCO, LTM and LUCs as the preferred remedial alternative for Site 1. This alternative includes ISCO steps that are the same as the TS performed in June 2016, and thus the initial ISCO and performance monitoring elements of the remedy are complete. The LTM program and LUCs remain to be implemented. LTM results will be evaluated to determine if additional remediation measures, such as additional ISCO injections, will be necessary in the future.

ISCO: Potassium permanganate will chemically breakdown TCE into innocuous compounds such as CO_2, water and chloride. Following potassium permanganate slurry injection into the contaminated groundwater, performance monitoring for ISCO will be conducted for one year.

LTM: Following completion of performance monitoring, LTM will be performed until TCE concentrations meet the MCL. LTM will also confirm that TCE concentrations meet the MCL at and beyond the POC.

LUCs: LUCs will be in place to prevent human health exposure to contaminated groundwater until TCE concentrations meet the MCL.

The groundwater model for Site 1 shows that the TCE plume would meet the MCL between 18 and 42 years. It should be noted that the majority of the TCE plume would meet the MCL in the earlier period of this remediation time range.

Alternative GW4 was selected over other alternatives because it is expected to achieve the higher amount of risk reduction through treatment in the shortest time, and provides LUCs to prevent future exposure while TCE concentrations would be reduced to levels that allow UU/UE. Based on the information available at this time, USAF and the CDPHE believe Alternative GW4, as the preferred alternative, meets the threshold criteria and provides the best balance of tradeoffs among the other alternatives with respect to the balancing and modifying criteria. The USAF expects the Preferred Alternative to satisfy the following statutory requirements of CERCLA

§121(b): (1) be protective of human health and the environment; (2) comply with ARARs; (3) be cost-effective; (4) utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable (would use utilize a technology that showed success during the TS); and (5) satisfy the preference for treatment as a principal element. CDPHE and EPA support the Preferred Alternative. The Preferred Alternative can change in response to public comment or new information.

COMMUNITY PARTICIPATION

The USAF, EPA and CDPHE provide information regarding the cleanup of Buckley AFB to the public through periodic public meetings of the Community Advisory Group, special public meetings, the Information Repository, and announcements published in the *Buckley Guardian* and the *Aurora Sentinel of Aurora, Colorado.*

Final Proposed Plans, Site Status Reports, and final documents that form the basis for the selection of the site response can be accessed via the U.S. Air Force Civil Engineer Center (AFCEC) Administrative Record website by going to http://afcec.publicadmin-record.us.af.mil/ Search.aspx; selecting "Buckley AFB, CO" and clicking on "Search"; then selecting "FT001 Fire Training Area No. 2" and clicking on "Search." The Proposed Plan will be one of the first few documents in the list at the bottom of the page. The Site Status Reports are found by typing "Status" in the "Subject or Title" field and clicking on "Search."

All final documents that form the basis for the selection of the site response, as well as information related to the community advisory group, can also be accessed through the Information Repository CDs or hard copies that are at the Central Aurora Public Library. The USAF encourages the public to gain a more comprehensive understanding of the site and CERCLA activities that are currently in progress through these avenues.

Instructions for providing public comment on this Proposed Plan are provided on the first page. A comment form is provided below for the reader's convenience.

Summary of Remedial Alternatives for Groundwater, Site 1, Fire Training Area #2 (FT001)			
Alternative	**Components**	**Description**	**Estimated Cost/Timeframe**
GW1-No Action *No action, no monitoring, and no restrictions*	None	No action	No cost or time
GW2-Land Use Controls (LUCs) *Prevents exposure to groundwater and protects monitoring network.*	LUCs	LUCs to prohibit use of groundwater and disturbing the groundwater monitoring network, and limit construction over the plume.	Capital: $27,900 O&M Cost: $67,500 Present Worth Cost (30 Years): $95,400 Construction time: 1 month. Time to Achieve RAOs: TCE-60 years.
GW3-Long-Term Monitoring (LTM) and LUCS *Monitors COC concentrations to determine whether a COC above its MCL is migrating beyond a point of compliance.*	Groundwater monitoring	Periodic groundwater monitoring and reporting.	Capital: $107,300 O&M Cost: $269,300 Present Worth Cost (30 Years): $376,600 Construction time: 1 month. Time to Achieve RAOs: TCE-60 years.
	LUCs	LUCs to prohibit use of groundwater and disturbing the groundwater monitoring network, and limit construction over the plume.	
GW4-In situ Chemical Oxidation (ISCO) with LTM and LUCs *Uses oxidizing chemicals to break down the COCs into innocuous compounds.*	Injection of oxidant	Injection of potassium permanganate through environmental fracturing/pressure injection (assuming a 20-foot ROI) in the hot spot area.	Capital: $413,700* O&M Cost: $363,600 Present Worth Cost (30 Years): $777,300 Construction time: 2 months. Time to Achieve RAOs: TCE-18-42 years.
	Groundwater monitoring	Periodic groundwater monitoring and reporting.	
	LUCs	LUCs to prohibit use of groundwater and disturbing the groundwater monitoring network, and limit construction over the plume.	
GW5-In situ Chemical Reduction (ISCR) and Biostimulation with LTM and LUCs *Creates reducing subsurface environment to aid in anaerobic biotic and abiotic degradation of COCs into nontoxic chemicals.*	Injection of carbon with ZVI	Injection of carbon and ZVI through environmental fracturing/pressure injection (assuming a 20-foot ROI) in the hot spot area.	Capital: $447,300 O&M Cost: $335,200 Present Worth Cost (30 Years): $782,500 Construction time: 2 months. Time to Achieve RAOs: TCE-18-42 years.
	Groundwater monitoring	Periodic groundwater monitoring and reporting.	
	LUCs	LUCs to prohibit use of groundwater and disturbing the groundwater monitoring network, and limit construction over the plume.	
GW6-In situ Enhanced Reductive Dechlorination (ERD) with LTM and LUCs *Modifies subsurface environment to stimulate bacteria degradation of the COCs to nontoxic chemicals.*	Injection of carbon	Injection of high-fructose corn syrup through environmental fracturing/pressure injection (assuming a 20-foot ROI) in the hot spot area. Two follow-up injections would be required.	Capital: $403,200 O&M Cost: $531,700 Present Worth Cost (30 Years): $934,900 Construction time: 2 months. Time to Achieve RAOs: TCE-18-42 years.
	Groundwater monitoring	Periodic groundwater monitoring and reporting.	
	LUCs	LUCs to prohibit use of groundwater and disturbing the groundwater monitoring network, and limit construction over the plume.	

* Capital costs already expended through June 2016 TS and performance monitoring.

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Glossary and Acronym List

Abiotic	A process that contributes to the degradation (breakdown) of contaminants. It occurs due to the influence of physical and chemical processes, rather than to the action of microorganisms.
AFB	Air Force Base
AFCEC	Air Force Civil Engineer Center
ARAR	Applicable or Relevant and Appropriate Requirement – ARARs are laws, requirements, regulations, criteria, or limitations under federal or state environmental laws that are pertinent to the site-specific remedial actions. Site-specific characteristics such as chemicals present, location, and physical features, and alternatives being considered as remedies determine which of these must be heeded as an ARAR.
AVGAS	Aviation Gasoline
BAFB	Buckley Air Force Base
bgs	Below ground surface
CBSGs	Colorado Basic Standards for Ground Water – The CBSGs are standards established by the state of Colorado to protect groundwater.
CDPHE	Colorado Department of Public Health and Environment
460 CEC/CEIE	460th Civil Engineer Squadron, Installation Management Flight, Environmental Element
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (42 USC §§ 9601-9675 (CERCLA) - the Federal act that establishes federal authority for emergency response and cleanup of hazardous substances that have been spilled, improperly disposed, or released into the environment.
CFR	Code of Federal Regulations
cis-1,2-DCE	cis-1,2-Dichloroethylene
COC	Contaminant (or chemical) of concern - COCs are the chemical substances found at the site that the EPA has determined pose an unacceptable risk to human health or the environment. These are the substances that are addressed by cleanup actions at the site.
DCE	Dichloroethene
EPA	U.S. Environmental Protection Agency
ERD	Enhanced Reductive Dechlorination - Addition of nutrients, food, or microorganisms (e.g., bacteria) to soil and groundwater to increase the number and activity of microorganisms that can naturally degrade (breakdown) chemicals under conditions where low or no oxygen is present.
ERP	Environmental Restoration Program
FS	Feasibility Study
ft	Feet
FTA	Fire Training Area
HFCS	High fructose corn syrup
in situ	In place – (i.e. remediation performed within the contaminated media)
ISCO	*In situ* chemical oxidation - involves the injection of reactive chemical oxidants into groundwater for rapid and complete contaminant destruction

ISCR	*In situ* chemical reduction - combines both biological processes and metallic particle driven abiotic pathways to chemically reduce chlorinated contaminants into harmless end products
JP-4	Jet Propellant, mixture of kerosene and gasoline, used by USAF until 1995
lbs.	pounds
LTM	Long-term monitoring - Ongoing collection of information about the environment (e.g., groundwater data) that helps gauge the effectiveness of a clean-up action.
LUC	Land use control - A LUC is an institutional or engineering control that restricts the use of, or limits access to, resources or real property to prevent or reduce risks to human health or the environment. LUCs are part of the remedial action.
MCL	maximum contaminant level
µg/L	micrograms per liter
NCP	National Contingency Plan - National Oil and Hazardous Substances Pollution Contingency Plan outline of procedures, organization, and responsibility for responding to spills and releases of hazardous substances and oil into the environment.
O&M	Operations and maintenance
PCE	Tetrachloroethylene
POC	Point of compliance - A vertical surface that is located at some specified distance downgradient of the activity being monitored for compliance. If a groundwater contaminant plume is being monitored, a POC is typically a monitoring well.
Present Worth Cost	Estimated cost in current (base) dollars that includes future spending. Determination of present worth costs evaluates expenditures that occur over different time periods. By discounting all costs to a common base year, the costs for different remedial action alternatives can be compared on the basis of a single cost for each alternative.
RACER	Remedial Action Cost Engineering and Requirements – software used to estimate remediation costs
RAO	Remedial Action Objective – Site and media specific cleanup goal that selected remedial alternatives are designed to meet.
RI	Remedial Investigation
ROD	Record of Decision
ROI	Radius of Influence
Site 1	Fire Training Area #2 (FT001)
TCE	Trichloroethylene
trans-1,2-DCE	trans-1,2-Dichloroethylene
TS	Treatability Study
USAF	U.S. Air Force
UU/UE	Unlimited use and unrestricted exposure
VC	Vinyl Chloride
VOC	Volatile organic compound

USE THIS SPACE TO WRITE YOUR COMMENTS

Your input on the Proposed Plan for Site 1, former Fire Training Area #2, at Buckley Air Force Base is important to the USAF. Comments provided by the public are valuable in helping the USAF select a final cleanup remedy for the site.

You may use the space below to write your comments, then fold and mail. Comments must be postmarked by 31 January 2019. If you have questions about the comment period, please contact Scott Wilson at (720) 847-7159. Those with access to email may submit their comments to the USAF at the following address: scott.wilson.7@us.af.mil.

Name:_____

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State:_____ Zip:_____

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