LONGHORN ARMY AMMUNITION PLANT KARNACK, TEXAS

ADMINISTRATIVE RECORD

Volume 5

2019

Bate Stamp Numbers

00920217 – 00920847

Prepared for

Department of the Army
Longhorn Army Ammunition Plant

1976 – 2019

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS
ADMINISTRATIVE RECORD – CHRONOLOGICAL INDEX

VOLUME 5

2019

A. Title: Transmittal Letter – Draft Explanation of Significant Differences, Record of Decision Dated September 2010, Contingency Remedy at LHAAP-50, Former Sump Water Tank, Longhorn Army Ammunition Plant, Karnack, Texas, February 2019
Author(s): Department of the Army
Recipient: Environmental Protection Agency
Date: April 18, 2019
Date Stamp: 00920217 – 00920217

B. Title: Transmittal Letter – Draft Explanation of Significant Differences, Record of Decision Dated September 2010, Contingency Remedy at LHAAP-50, Former Sump Water Tank, Longhorn Army Ammunition Plant, Karnack, Texas, February 2019
Author(s): Department of the Army
Recipient: Texas Commission on Environmental Quality
Date: April 18, 2019
Bate Stamp: 00920218 – 00920218

C. Title: Transmittal Letter – Draft Record of Decision, LHAAP-29, Former TNT Production Area, Group 2, Longhorn Army Ammunition Plant, Karnack, Texas
Author(s): Department of the Army
Recipient: Environmental Protection Agency
Date: April 24, 2019
Date Stamp: 00920219 – 00920219

D. Title: Transmittal Letter – Draft Record of Decision, LHAAP-29, Former TNT Production Area, Group 2, Longhorn Army Ammunition Plant, Karnack, Texas
Author(s): Department of the Army
Recipient: Texas Commission on Environmental Quality
Date: April 24, 2019
Bate Stamp: 00920220 – 00920220

E. Title: Minutes – Final Minutes, Quarterly Restoration Advisory Board (RAB) Meeting, October 18, 2018, Longhorn Army Ammunition Plant, Karnack, Texas
Author(s): Department of the Army
Recipient: All Parties
Date: April 25, 2019
Bate Stamp: 00920221 – 00920265

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2019

F. Title: Minutes – Transcript of April 25, 2019, Public Meeting for LHAAP-18/24 Proposed Plan, Longhorn Army Ammunition Plant, Karnack, Texas
Author(s): Department of the Army
Recipient: Public
Date: April 25, 2019
Bate Stamp: 00920266 – 00920276

G. Title: Report – Final Remedial Design and Remedial Action Work Plan, LHAAP-04 Former Pilot Wastewater Treatment Plant, Longhorn Army Ammunition Plant, Karnack, Texas, April 2019
Author(s): Department of the Army
Recipient: Environmental Protection Agency
Date: May 3, 2019
Bate Stamp: 00920277 – 00920407

H. Title: Report – Final Five Year Review Report, Longhorn Army Ammunition Plant, Karnack, Texas
Author(s): Department of the Army
Recipient: Environmental Protection Agency
Date: May 15, 2019
Bate Stamp: 00920408 – 00920847

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
LONGHORN ARMY AMMUNITION PLANT
POST OFFICE BOX 220
RATCLIFF, AR 72951

April 18, 2019

DAIM-ODB-LO

Mr. Rich Mayer
U.S. Environmental Protection Agency
Federal Facilities Section R6
1445 Ross Avenue
Dallas, TX 75202-2733

Re: Draft Explanation of Significant Differences, Record of Decision Dated September 2010, Contingency Remedy at LHAAP-50, Former Sump Water Tank, Longhorn Army Ammunition Plant, Karnack, Texas, February 2019

Dear Mr. Mayer,

Two hard copies and two compact discs (CDs) of the above-referenced document is being transmitted to you for your review. Review comments are requested by May 20, 2019.

The document was prepared by Bhate Environmental Associates, Inc., (Bhate) team, on behalf of the Army as part of Bhate's Performance Based Remediation contract for the facility. I ask that Kim Nemmers, Bhate's Project Manager, be copied on any communications related to the project.

The point of contact for this action is the undersigned. I may be contacted at 479-635-0110, or by email at rose.m.zeiler.civ@mail.mil.

Sincerely,

Rose M. Zeiler

Rose M. Zeiler, Ph.D.
Longhorn AAP Site Manager

Copies furnished:
A. Palmie, TCEQ, Austin, TX (letter)
P. Bruckwicki, Caddo Lake NWR, TX (1 hard copy and 1 CD)
A. Williams, USACE, Tulsa District, OK (1 CD)
R. Smith, USACE, Tulsa District, OK (electronic only)
A. Maly, USAEC, San Antonio, TX (1 CD)
K. Nemmers, Bhate, Lakewood, CO (1 CD)
P. Srivastav, APTIM, Houston, TX (letter)

DEPARTMENT OF DEFENSE
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POST OFFICE BOX 220
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April 18, 2019

DAIM-ODB-LO

Ms. April Palmie
Texas Commission on Environmental Quality
Superfund Section, MC-136
12100 Park 35 Circle, Bldg D
Austin, TX 78753

Re: Draft Explanation of Significant Differences, Record of Decision Dated September 2010, Contingency Remedy at LHAAP-50, Former Sump Water Tank, Longhorn Army Ammunition Plant, Karnack, Texas, February 2019

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Longhorn AAP Site Manager

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UNITED STATES OF AMERICA

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RATCLIFF, AR 72951

April 24, 2019

DAIM-ODB-LO

Mr. Rich Mayer
US Environmental Protection Agency
Federal Facilities Section R6
1445 Ross Avenue
Dallas, TX 75202-2733

Re: Draft Record of Decision for LHAAP-29, Former TNT Production Area, Group 2, April 2019, Longhorn Army Ammunition Plant, Karnack, Texas

Dear Mr. Mayer,

The above-referenced document is being transmitted to you for review. In accordance with the FFA, please provide your comments by May 24, 2019.

The document was revised by HDR Environmental, Operations and Construction, Inc. (HDR) on behalf of the Army as part of HDR's contract for the facility. I ask that Phil Werner, HDR's Project Manager, be copied on any communications related to the project.

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P. Werner, HDR, Englewood, CO
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Longhorn Army Ammunition Plant
Restoration Advisory Board
3rd Quarter 2018 Meeting

Subject: Final Minutes, Quarterly Restoration Advisory Board (RAB) Meeting
Longhorn Army Ammunition Plant (LHAAP)
Location of Meeting: Karnack Community Center, Karnack, Texas
Date of Meeting: October 18, 2018, 6:00-7:15 PM Central Daylight Time (CDT)

Meeting Participants:

Army BRAC:	Rose M. Zeiler
USACE:	Aaron Williams
USAEC:	Nicholas Smith
USGS:	Kent Betcher
Bhate:	Kim Nemmers
APTIM:	William (Bill) Foss
USEPA Region 6:	Rich Mayer
TCEQ:	April Palmie
RAB:	Present: Judy VanDeventer, Tom Walker, Nigel R. Shivers, and Richard Le Tourneau Absent**:** Paul Fortune; Carol Fortune; Charles Dixon; Terry Britt; and John Pollard, Jr.
Public:	Laura-Ashley Overdyke (Executive Director of the Caddo Lake Institute)

An agenda for the RAB meeting, a color copy of the Bhate Environmental Associates, Inc. (Bhate) slide presentation, and handouts (see list at end of meeting minutes) were provided for meeting attendees.

Welcome and Introduction

Ms. Rose Zeiler, RAB Installation Co-Chair, called the RAB meeting to order at 6:05 pm CDT. Ms. Judy VanDeventer noted that Mr. Terry Britt was in Canada. Ms. Zeiler noted that Paul and Carol Fortune had notified her that they would not be able to attend the meeting.

Ms. Zeiler pointed out the three sites not included in the Bhate contract, which are LHAAP-18/24, LHAAP-29, and LHAAP-47. Ms. Zeiler noted that these sites are in a different color on the LHAAP map.

Ms. Zeiler noted that no new persons were present but asked for suggestions to get more RAB members. Mr. Nigel Shivers stated that it is difficult to get more volunteers. Ms. Laura-Ashley Overdyke suggested having an information table at the next community event and offered to man the table. Ms. Zeiler stated that the Army would send information to support that if the date for the next event could be provided. Ms. Overdyke stated that she would want an application for the RAB membership and some information about how to get involved in the RAB. Mr. Bill Foss stated that the master naturalists get credit for volunteering and suggested reaching out to the local chapter.

Open Items

Ms. Zeiler noted that the RAB Meeting minutes had been sent out in August 2018. Ms. VanDeventer made a motion to approve the July 2018 RAB Meeting minutes. Mr. Tom Walker seconded the motion.

Defense Environmental Restoration

Overview of Waste Management

Ms. Zeiler explained that the first presentation on waste management at LHAAP was developed in response to interest expressed during the previous RAB meeting. Ms. Kim Nemmers stated that the slides are meant to help with the discussion and hopefully more clearly present how waste is managed at LHAAP. Ms. Nemmers explained that the waste typically generated at LHAAP is investigation derived waste, which is typically the soil generated from cuttings from borings or from installation of wells. Ms. Nemmers stated that groundwater extracted from monitoring activities is the second main waste generated at LHAAP. Ms. Nemmers also stated that other waste generated from LHAAP includes excavated soils and a dried cake from the metals precipitation system at the Groundwater Treatment Plant (GWTP). Mr. Walker asked if the naturally occurring metals are considered during waste management. Ms. Nemmers confirmed that metals are analyzed for in the filter cake and that the Interim Record of Decision (IROD) for LHAAP-18/24 requires treatment for metals even though the current levels of metals in groundwater at the site is consistent with background concentrations. Ms. Zeiler stated that soils are not always analyzed for nutrient metals because these metals are not used in hazardous waste determination. Mr. Rich Mayer stated that the concern is for metals that are hazardous.

Ms. Nemmers then explained the terms often used in waste management. Ms. Nemmers stated that a disposal facility means a permitted facility or part of a permitted facility where waste will be placed based upon the facility’s permit. Ms. Nemmers stated that a manifest is the document used to take waste from cradle to grave because it is signed by the generator, signed by the transporter, and signed by the disposal facility and then copies are provided to each of these participants. If the waste is non-hazardous, then another document like a bill of lading can be used instead. However, Ms. Nemmers noted that the non-hazardous waste process provides the same documentation with the only exception being that a copy of the bill of lading or manifest doesn’t need to be sent to the U.S. Environmental Protection Agency (USEPA). Ms. Zeiler clarified that Ms. Nemmers was discussing waste that goes offsite only. Ms. Nemmers explained that the generator for LHAAP is the Army. Ms. Nemmers stated that most of the waste generated is special waste, which means that the waste requires special handling, but is not considered hazardous.

Ms. Nemmers explained what a solid waste was and that nothing can be considered special waste or hazardous waste until it is determined to be a solid waste. Ms. Nemmers stated that the reason for that is some material can be reused or recycled in place of being a waste. Ms.

Nemmers stated that the USEPA defines solid waste as a garbage, refuse, sludge, or other discarded material. Hazardous waste breaks down per the Federal regulations as either listed waste, meaning we know the process that generated the waste; or characteristic waste, which is most typical for environmental waste. Ms. Nemmers explained that the waste gets tested and is classified as characteristically hazardous waste if the waste has a high flash point or is reactive, toxic, or ignitable. Ms. Nemmers explained that environmental waste is most often hazardous based upon toxicity of the soils. Mr. Mayer asked if hazardous waste was generated at LHAAP. Ms. Zeiler explained that the drying bed sludge was considered hazardous due to the process generating the metals but then the mixture rule was applied to allow for the waste stream to be non-hazardous, special waste.

Ms. Nemmers explained that toxicity is most often the reason for environmental waste to be considered hazardous waste because it is based upon a specific compound, such as lead, exceeding an established criteria. Ms. Nemmers explained the process for determining if a waste is hazardous using the flow chart in the slides and how there are several ways of excluding a waste from being classified as hazardous. Ms. Zeiler clarified that even though a waste may not be considered hazardous based upon being a listed hazardous waste, the waste could be classified as hazardous due to high lead or TCE. Ms. Nemmers explained that the waste is tested by an offsite laboratory to determine if the waste is hazardous. Ms. Nemmers clarified that the waste can be classified by generator knowledge but that is often a very specific situation whereby the source of the waste is known though testing is usually completed regardless.

The documentation is provided by the Contractor (Bhate) for Army review and/or sent to the disposal facility to prepare a waste profile. Then the Army will sign the waste profile documenting that the information about the waste is correct. Mr. Mayer asked if the receiving facility will test the waste. Ms. Nemmers stated that the receiving facility typically pushes the testing back onto the contractor based upon so many yards or tons of material received. Ms. Zeiler explained that annual recertification of waste is also required. Mr. Foss stated that typically a sample is required every 1,000 yards or a similar volume, but that sampling at the landfill is usually focused on free liquids present in the waste in case the facility needs to solidify the waste.

Ms. Nemmers then discussed the slide showing the USEPA waste classifications and the Texas Commission on Environmental Quality (TCEQ) waste classifications. Ms. Nemmers stated that the waste is non-hazardous when it is considered Class 1, 2, or 3 under the TCEQ regulations. Ms. April Palmie explained that non-hazardous waste still has contamination present but at a much lower concentration than hazardous waste. Ms. Palmie stated that the waste is industrial waste and must be disposed of based upon the Class that the waste falls under. Mr. Walker asked if the “F” listing is based upon flammability. Ms. Zeiler stated that the drying bed filter cake waste used to be classified as “F” listed based on its source prior to use of the mixture rule. Mr. Mayer stated that "F" does not necessarily mean flammability. Mr. Walker stated that he wondered if the letter code matched up with the characteristic to the right of the code on the slide. Ms. Palmie clarified that there was no relationship in that way but that the wastes that are listed have similarities. Ms. Nemmers stated that each listed waste is a very specific industry process that generated the waste.

Ms. Nemmers explained that waste generated during investigation of a site is typically placed into a drum that is then labeled "Pending Analysis" to know what the drum contains but that the waste is not classified. Ms. Nemmers explained that if the waste was determined to be hazardous then a date would be placed on the waste because Federal regulations require you to dispose of the waste within a certain period of time. Ms. Nemmers explained that waste water is either treated by the GWTP or transported and disposed offsite. Ms. Nemmers stated that drilling waste is tested and then either spread on the ground where it was generated or disposed offsite depending on the results of the analysis. Ms. Nemmers stated that excavated soil is sent off typically as Class 2 or Class 3 non-hazardous waste. Ms. Zeiler stated that perchlorate waste is classified as hazardous waste based on the ignitability characteristic and is not listed waste. Mr. Mayer stated that this classification rarely occurs to which Ms. Zeiler concurred. Mr. Shivers asked if the timeframe discussed was 90 days. Ms. Zeiler stated that the time is 90 days. Mr. Shivers asked where the waste is stored. Ms. Zeiler stated that waste is typically stored in a closed drum with a label on it. Ms. Nemmers stated that LHAAP does not produce very much hazardous waste and is considered a Conditionally Exempt Small Quantity Generator, otherwise additional requirements might apply to LHAAP.

LHAAP-03

Mr. Foss provided an update on LHAAP-03, which was discussed more completely at the previous RAB Meeting. Mr. Foss stated that LHAAP-03 is a very small soils site contaminated with lead and arsenic. The Record of Decision (ROD) was finalized, and the public notice was published a few days ago. Mr. Foss explained that the technical memorandum for soil sampling was issued and reviewed by the regulators. Those comments are being addressed. Mr. Foss explained that the hope was to move forward with the soil sampling within the next month or two. The soil data will then be used to prepare the remedial design. Mr. Foss explained the purpose of the sampling, which is to confirm the size of the excavation presented in the ROD.

LHAAP-16

Mr. Foss explained that bioremediation is planned for LHAAP-16, but first a series of wells need to be installed for both monitoring of the groundwater plume and injections for the bioremediation. Mr. Foss pointed out on the map where the low-lying area is at the site, which has made well installation difficult due to the recent rain events. Mr. Foss explained that the handout of slides presents what was hoped to be completed by now, but the presentation correctly lists the wells installed to date. Mr. Foss said that 17 wells were installed in April 2018 but the remainder were not installed due to the site being so wet. Mr. Foss stated that the team remobilized in October 2018, but 5.5-inches of rain fell over the weekend prior to the mobilization. Mr. Foss stated that four wells were installed leaving six wells to be installed. Mr. Foss stated that the baseline sampling of the wells installed has been completed. Mr. Foss stated that once the other wells are installed, those wells will be sampled as part of the baseline sampling event also. Mr. Shivers asked what was being injected. Mr. Foss stated that vegetable oil and sodium lactate will be injected to allow for microbial growth. Ms. Zeiler stated that the lines shown are lines of injections. Mr. Foss clarified that some wells will be used for injections and others will be used to circulate the injectate. Mr. Shivers asked where the bugs are incubated. Mr. Foss explained that some of the bug are naturally occurring, but the bacteria is also used to inoculate. Ms. Zeiler explained that the aquifer is first treated to prepare the groundwater for the bacteria and then the bacteria are added to the aquifer. Mr. Foss explained that the bacteria needs a low dissolved oxygen level, which is tested prior to inoculating. Mr. Foss presented a photo of the track-rig being used at Site 16. Mr. Shivers asked the depth of the wells. Mr. Foss stated that the depth is 20 to 35 feet deep with one monitoring well about 50 to 55 feet deep. Ms. Zeiler stated that the work is being coordinated with Fish and Wildlife.

LHAAP-58

Ms. Nemmers provided an update on LHAAP-58, which has an eastern and western lobe. The eastern lobe had the remedy implemented several years ago, and the remedy is being monitored. Ms. Nemmers stated that the western plume received injections in March and April 2018. Ms. Nemmers explained that the focus is on the groundwater as the soil does not pose a threat to human health. The ROD for LHAAP-58 stated that natural attenuation would be implemented for the western lobe of the plume, which was evaluated for a couple of years. The evaluation determined that natural attenuation was not successfully remediating the plume and that active treatment was necessary to help reduce the plume. Ms. Nemmers explained that microbial analysis prior to the injections indicated that the bacteria necessary was naturally occurring. Ms. Nemmers presented the remedial action completed in March/April 2018 including the additional two monitoring wells installed. Ms. Nemmers explained that one of the monitoring wells installed was used to define the extent of the plume, which it did based upon laboratory analysis. Ms. Nemmers then presented the plume shapes prior to and following the 2018 groundwater treatment. Ms. Nemmers noted that bioremediation is still being observed within the eastern plume after 5 years, which is a good surprise. Ms. Nemmers also pointed out the significant decrease in the western lobe of the plume within a short period of time. Ms. Nemmers stated that the groundwater would continue to be monitored.

Overview of Sites

Ms. Nemmers explained that the work continues at LHAAP-16 as presented by Mr. Foss but the soil samples were able to be collected from LHAAP-17 in August 2017 to prepare the remedial design. Remedial action operations (RA-O) sampling continues for many sites. Ms. Nemmers explained that some sites are sampled every 6 months and other sites are sampled every 3 months. Ms. Nemmers stated that the sites will have a lot of RA-O sampling as remedies are put in place or were in place and continue to be evaluated.

Ms. Nemmers explained the repairs to the fluidized bed reactor (FBR) at the GWTP, which treats the perchlorate. Ms. Nemmers stated that the nozzles and laterals were replaced. These parts are used to fluidize the granular activated carbon. The FBR was repaired in July 2018, and Ms. Nemmers stated that big improvements have been observed following the repairs.

Ms. Nemmers stated that surface water samples have been collected for both the third and fourth quarters due to the rainfall observed.

Ms. Nemmers stated that with sampling comes reporting of the data so many RA-O Reports are in process. Ms. Nemmers stated that technical memorandums are being prepared based upon data collected or planned to be collected. Ms. Nemmers stated that the Land Use Controls (LUCs) for the munitions response sites were the primary update for the LUC Management Plan Update. Ms. Nemmers stated that the remedial design for LHAAP-17 was in process.

Ms. Nemmers stated the goal going forward is to get the wells installed and the injections completed at LHAAP-16. Ms. Nemmers said the look ahead included a lot of groundwater sampling for performance remedy evaluations. Ms. Nemmers explained that the reports in the 3 month lookahead appears similar to the current documents because of the time to complete those documents.

Groundwater Treatment Plant

Ms. Nemmers explained the dip in the extraction and treatment in July and August 2018 was due primarily to the repairs to the FBR coupled with lower precipitation during that time. Ms. Nemmers also stated that the pumps for the extraction wells require maintenance which was behind due to the FBR repairs. However, Ms. Nemmers pointed out that the treatment system jumped back up with increased treatment volumes in September 2018.

Surface Water Sampling

Ms. Nemmers explained the surface water sampled from August 2018 was non-detect for perchlorate.

LHAAP-18/24 and LHAAP-29

Mr. Aaron Williams explained that a separate contractor, HDR, is responsible for developing the final remedy for LHAAP-18/24, LHAAP-29, and LHAAP-47. Mr. Williams explained that the Sites 29 and 18/24 are in the Proposed Plan (PP) stage and that LHAAP-47 already has a PP. For LHAAP-18/24, Mr. Williams explained that the PP is ahead of schedule and the public meeting for the PP will be in conjunction with the next RAB in January 2019. For Site 29, the PP is draft final and will have the public meeting in November or early December 2018.

Mr. Williams stated that Site 18/24 is a 34.5-acre area that was used for the treatment, storage, and disposal of solid and liquid explosive, pyrotechnic, and solvent waste by open burning/open detonation, incineration, and evaporation. Mr. Williams explained that interceptor collection trenches (ICTs) operate along with the GWTP as the interim remedy to control the plume until the permanent remedy is put into place. Mr. Williams stated that the sampling at Site 18/24 identified dense non-aqueous phase liquid (DNAPL) and dissolution of that DNAPL is considered a continuing source. Mr. Williams explained that there are two groundwater zones with one being the shallow zone and the other is the Wilcox Formation. Ms. Zeiler stated that contamination is present in both the shallow zone and the Wilcox Formation. Ms. VanDeventer asked if the Wilcox Formation had contamination. Ms. Zeiler confirmed that both zones do have contamination. Mr. Shivers asked if this is a problem. Ms. Zeiler stated that the problem is more that it moved. Ms. Zeiler explained that the layering of the soils makes it difficult to understand why and how the contamination moved. Mr. Mayer stated that LHAAP-18/24 is the worst site at LHAAP. Ms. Palmie stated that the burning ground was located in an area distant from the rest of the plant. Ms. Nemmers pointed out that this is the reason for the GWTP and interim remedy so this contamination is not a surprise. Ms. Zeiler explained that the selected remedy presented in the PP was a collaborative effort with regulators to aggressively treat the most contaminated areas at LHAAP-18/24 and identify areas where additional information will be collected to support the remedial design.

Mr. Williams summarized that volatile organic compounds (VOCs), perchlorate, and metals are present in both the shallow and Wilcox zones. Mr. Williams indicated that the draft PP will be submitted to the Regulators in October 2018. A total of six remedies were evaluated which are more fully detailed in the Feasibility Study (FS). The selected remedy is Alternative 5 which includes enhanced groundwater extraction and treatment, LUCs, enhanced in-situ bioremediation inside and outside the containment area in the shallow and Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal DNAPL removal. Mr. Williams then presented an overview of the other remedies considered which all included containment of the plume. Mr. Williams explained that the difference in Alternative 4 for LHAAP-18/24 was that surfactant was evaluated in place of thermal removal for the DNAPL. For Alternative 6, Zero-Valent Iron was considered in place of thermal DNAPL removal. Mr. Williams then explained that Alternative 5 was selected based upon best value considering cost and time for remedy implementation. Mr. Williams then showed a slide that visually depicts the implementation of Alternative 5 as presented in the FS that shows gridding for in-situ bioremediation and the areas of thermal treatment. Ms. Zeiler added that this depiction is just conceptual and that some changes from the FS are already planned based upon discussion with the regulators and costing.

Mr. Williams then presented the trinitrotoluene (TNT) production area, LHAAP-29, which produced 400 millions pounds of TNT between 1942 and 1945. Mr. Williams stated that the site was used for “soak-out” or solvent bath for rocket motors, which is the primary source for the out-of-specification methylene chloride (MC) present in the intermediate aquifer. Mr. Williams stated that the MC in the intermediate aquifer is the primary area that requires treatment at the site. In addition, Mr. Williams explained the contaminants of concern (COCs) in soil are explosives and perchlorate and in shallow groundwater are VOCs, explosives, perchlorate, and metals. Mr. Williams explained that metals and other VOCs are also COCs in the intermediate aquifer. The transite TNT waste water line and vitrified clay cooling water lines have COCs that are explosives. Mr. Williams stated that all remedies evaluated for Site 29 included flushing and capping of those lines. Ms. Overdyke asked if testing beyond the shallow groundwater zone had been completed, to which Mr. Williams said "yes." Mr. Williams stated that the PP was sent to the Regulators on the day of the October 2018 RAB Meeting and that once the PP is finalized it will be distributed for Public Comment and review.

Mr. Williams presented the preferred remedy consisting of excavation and off-site disposal and LUCs for soil; flush and plug lines; in-situ thermal desorption (ISTD) using either electrical resistance heating (ERH) or thermal conduction heating (TCH); monitored natural attenuation (MNA) and LUCs for intermediate zone groundwater; and MNA and LUCs for shallow zone groundwater. Mr. Williams then presented the other remedies considered including excavation and off-site disposal and LUCs, flushing and plugging of lines, in situ chemical oxidation (ISCO) of the intermediate zone for the MC, MNA and LUCs for the intermediate zone groundwater, and MNA and LUCs for the shallow groundwater that makes up Alternative 2. Alternative 3 is similar but considered groundwater extraction for the intermediate zone as opposed to ISCO. Mr. Williams explained that the MC was detected in the millions of milligrams per liter. Ms. Palmie pointed out the area is isolated and in a very small footprint.

Mr. Williams explained that if anyone wants more details there are documents in the Administrative Record with the information. For LHAAP-18/24, there is a Final Revised FS and for LHAAP-29 there is a Final FS and a Draft Final FS Addendum. Mr. Williams stated that the MC concentration and information is contained in the Draft Final FS Addendum for LHAAP-29. Ms. Zeiler state that ISCO was first selected in the Final FS for LHAAP-29 but that has been revised due to the cost associated with follow-on ISCO treatments that would be needed.

LHAAP-47

Mr. Williams then presented LHAAP-47, which already has a PP and is ready for the ROD. However, due to the time since the PP, additional investigation was completed to confirm previous data and re-evaluate monitoring wells that had been dry. Mr. Williams said that a post-screening investigation (PSI) is being completed. Mr. Williams stated that the direct push technology (DPT) results were presented during the previous RAB Meeting. Since then, additional wells were installed and a total of 25 wells were sampled in July 2018. Mr. Williams explained that results from the July 2018 groundwater sampling are presented during this October 2018 RAB Meeting. An additional 11 wells were sampled in September 2018 and those results will be presented at the next RAB Meeting. All of the wells are installed and sampled so the next step is preparing the PSI Report. Mr. Williams also stated that surface water samples will be collected in the winter. Ms. Zeiler stated that a draft ROD had been prepared, but then the dispute resolution occurred and time passed. So, the Army made the decision to re-evaluate the site due to the amount of time that has passed to ensure that everything gets addressed. Ms. Zeiler confirmed with Mr. Williams that there were not any big surprises. Ms. Zeiler stated than many of the shallow wells remain dry which is believed to be because the process related activities are no longer generating water and that it was a perched system. Ms. Zeiler stated that there are nine new monitoring wells and a lot of DPT points were advanced. Mr. Williams stated that DPT results presented at the last RAB Meeting showed non-detect but a source area was known to be present. So, a new shallow well was installed to ensure that the area was not larger than envisioned. The new monitoring well to the west had 120,000 micrograms per liter (µg/L) of trichloroethylene (TCE), which was a little bit of a surprise because the previous detection had been 25,000 µg/L of TCE. Mr. Williams also pointed out the area to the east where additional investigation was completed and did not result in any changes to the plan for the remedy. Mr. Williams explained that since TCE was detected in the eastern part of the site for the intermediate groundwater zone, new intermediate monitoring wells were installed which were sampled in September 2018. Mr. Williams stated the data from these new monitoring wells will be presented at the next RAB Meeting and will determine if there is a need to re-design the remedy for LHAAP-47. Ms. Zeiler explained that the ROD would not need to be revised because the remedy itself will remain in-situ bioremediation. Ms. Overdyke asked if the plume is further east than known. Mr. Williams confirmed the statement.

Other RAB Items Discussed

Ms. Zeiler discussed the Five-Year Review (FYR). Ms. VanDeventer stated that she and Paul (Fortune) had responded to the FYR interview form. Ms. Zeiler stated that the FYR is in Army and AEC review currently and will then be sent as draft to the Regulators in December 2018. Ms. Zeiler also asked for any topics of interest that could be presented at the next RAB Meetings.

Ms. Zeiler named the four parcels (Signal Test, Pistol Range, South Test/South Bomb and the Demolition Debris Landfill Areas) that are included in Environmental Condition of Property (ECP) VII document that is used for Fed-to-Fed transfers. The sites are on the schedule to be transferred to the U.S. Fish and Wildlife Service (USFWS) for incorporation into the refuge. Ms. Zeiler stated that the ECP has been through Army and legal review and is with USFWS and the regulators currently. Once the ECP is final, then the letter of offer is sent from the Army to the USFWS and that letter includes the Environmental Protection Provisions (EPPs) within the ECP as well as a land use survey and other information. The USEPA Reviews the ECP because of the LUCs as a requirement of the RODs. Ms. Zeiler stated that USFWS is also working on transfer of some water rights also that will result in a total of 85% transfer of water rights.

Next RAB Meeting Schedule and Closing Remarks

Ms. Zeiler then discussed the next meeting with the RAB members. It was decided that the next RAB Meeting will be held on **January 17, 2019,** with the **meeting starting at 5:00 pm CST** at the Karnack Community Center. The **PP meeting for LHAAP-18/24 is planned for 6:00 pm to 7:30 pm CST** on the same night following the January 2019 RAB Meeting. Ms. Zeiler explained that there will be a court reporter for the PP portion of the meeting. For LHAAP-29, the PP Meeting was selected as December 6 or November 29, 2018 (which is the 5th Thursday), at 6 pm to 7:30 pm CST.

Adjourn

Mr. Richard LeTourneau motioned to adjourn. Ms. VanDeventer seconded the motion. The Meeting adjourned at 7:21 pm CDT.

October 2018 Meeting Attachments and Handouts:

- Meeting Agenda
- Color Copy of Bhate Presentation Slides
- Groundwater Treatment Plant (GWTP) – Processed Groundwater Volumes Handout
- Surface Water Sampling Handout

LONGHORN ARMY AMMUNITION PLANT
RESTORATION ADVISORY BOARD
Karnack, Texas
(479) 635-0110

AGENDA

DATE: Thursday, July 19, 2018
TIME: 6:00 – 7:00 PM
PLACE: Karnack Community Center, Karnack, Texas

06:00 Welcome and Introduction

06:05 Open Items {RMZ}

- Purpose of the RAB Meeting
- RAB Administrative Issues
- Minutes (April 2018 RAB Meeting)
- Ongoing Outreach/Website

06:15 Defense Environmental Restoration Program (DERP) Update {Bhate}

- LHAAP Geology and Hydrology Discussion
- LHAAP-03 ROD and LHAAP-35A(58) ESD Status Update
- Documents and Field Work Completed in 2nd Quarter 2018
- Three Month Lookahead
- Groundwater Treatment Plant (GWTP) Update

06:45 Other Defense Environmental Restoration Program (DERP) Update {RMZ}

06:50 Next RAB Meeting Schedule and Closing Remarks {RMZ}

Longhorn Army Ammunition Plant Quarterly Restoration Advisory Board Meeting

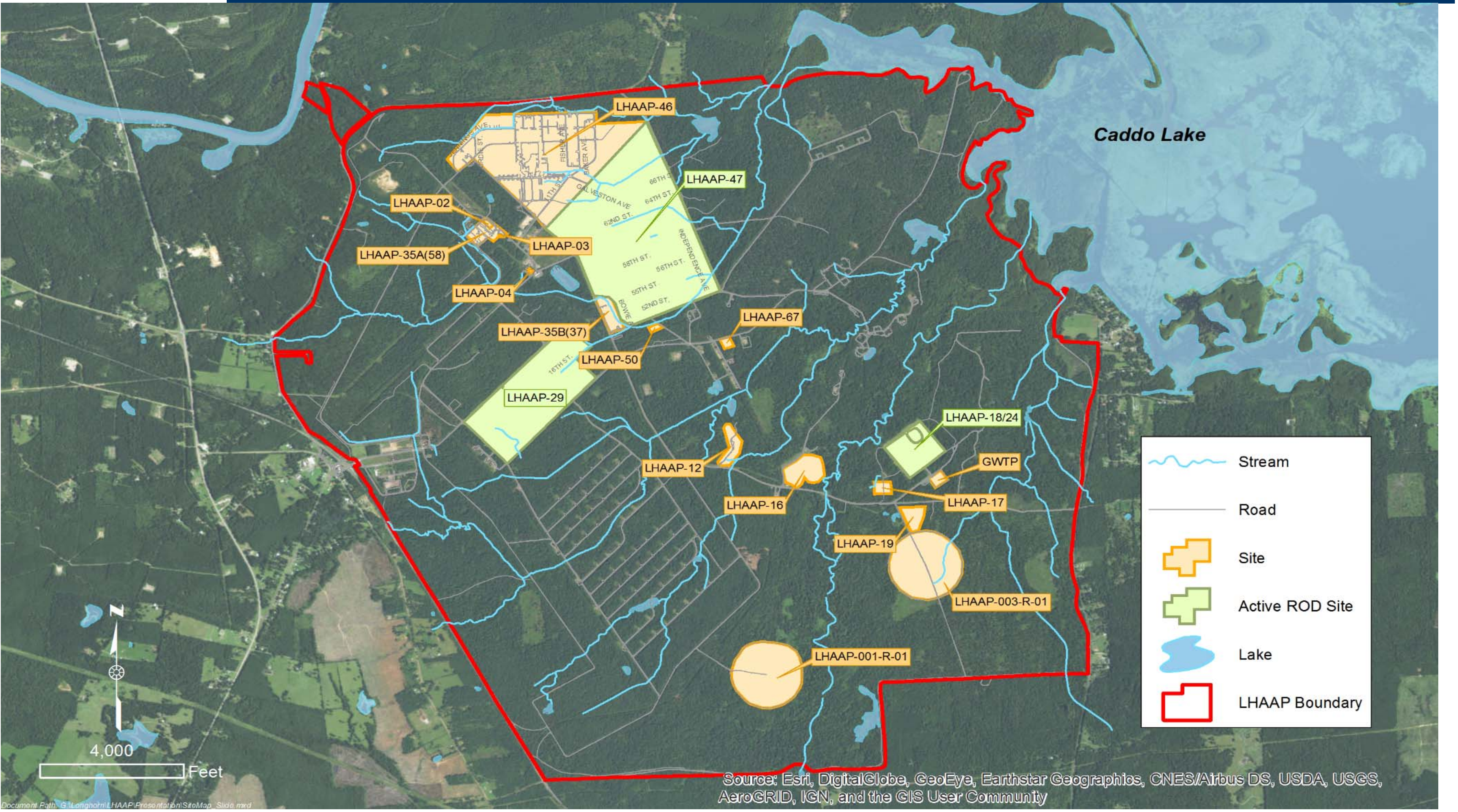
Karnack Community Center
April 25, 2019
5:00 PM CDT

APTIM

bhate

Restoration Advisory Board Meeting

Site Map



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Document Path: G:\Longhorn\LHAAP\Presentation\SiteMap_Slide.mxd

Restoration Advisory Board Meeting

Abbreviations and Acronyms

µg/L	Micrograms per liter
DERP	Defense Environmental Restoration Program
ECP	Environmental Condition of Property
EISB	Enhanced In-situ Bioremediation
FBR	Fluidized Bed Reactor
ft bgs	Feet below ground surface
GWTP	Groundwater Treatment Plant
ISB	In-Situ Bioremediation
LHAAP	Longhorn Army Ammunition Plant
LUC	Land Use Control
MNA	Monitored natural attenuation

PCL	Protective Concentration Level
PDI	Pre-Design Investigation
PSI	Pre-Screening Investigation
RAB	Restoration Advisory Board
RA(O)	Remedial Action Operation
RAWP	Remedial Action Work Plan
RD	Remedial Design
ROD	Record of Decision
TCEQ	Texas Commission on Environmental Quality
TRRP	Texas Risk Reduction Program
USEPA	U.S. Environmental Protection Agency
VOCs	Volatile organic compounds

Restoration Advisory Board Meeting

Agenda

05:00 Welcome and Introduction

05:05 Open Items {RMZ}

- Purpose of the Restoration Advisory Board (RAB) Meeting
- RAB Administrative Issues
    - RAB Applicants
    - Minutes (October 2018 RAB Meeting)
- Ongoing Outreach/Website

05:15 Defense Environmental Restoration Program (DERP) Update {Bhate}

- LHAAP-03 Field Work Status Update
- LHAAP-04 Field Work Status Update
- LHAAP-17 Remedial Design Update
- Documents and Field Work Completed Since Last RAB
- Three Month Look Ahead
- Groundwater Treatment Plant (GWTP) Update

05:45 Other DERP Update {AW}

- LHAAP-18/24 Proposed Plan
- LHAAP-29 Record of Decision (ROD) and Responsiveness Summary
- LHAAP-47 Pre-Screening Investigation (PSI) Update
- Five Year Review Update

05:55 Next RAB Meeting Schedule and Closing Remarks {RMZ}

Purpose of the RAB Meeting

- **Held every 3 months**
- **The mission of the Longhorn Army Ammunition Plant (LHAAP) RAB is to promote community awareness and obtain constructive community review and comments on environmental restoration activities at the former LHAAP**

The Army Wants You to be Informed

- **The Army is committed to protecting human health and the environment; key to that commitment is engaging the community and increasing public participation in environmental restoration at LHAAP**

- **You are encouraged to:**
  - **Attend RAB Meetings and/or become a member of the RAB**
  - **Visit the Longhorn environmental website at www.longhornaap.com**
    - **Website is regularly updated to indicate the upcoming field events at each site including groundwater sampling, monitoring well installations, soil sampling, or remediation activities**
  - **Make suggestions for improving communication – the Army welcomes and appreciates community feedback**

Restoration Advisory Board Meeting

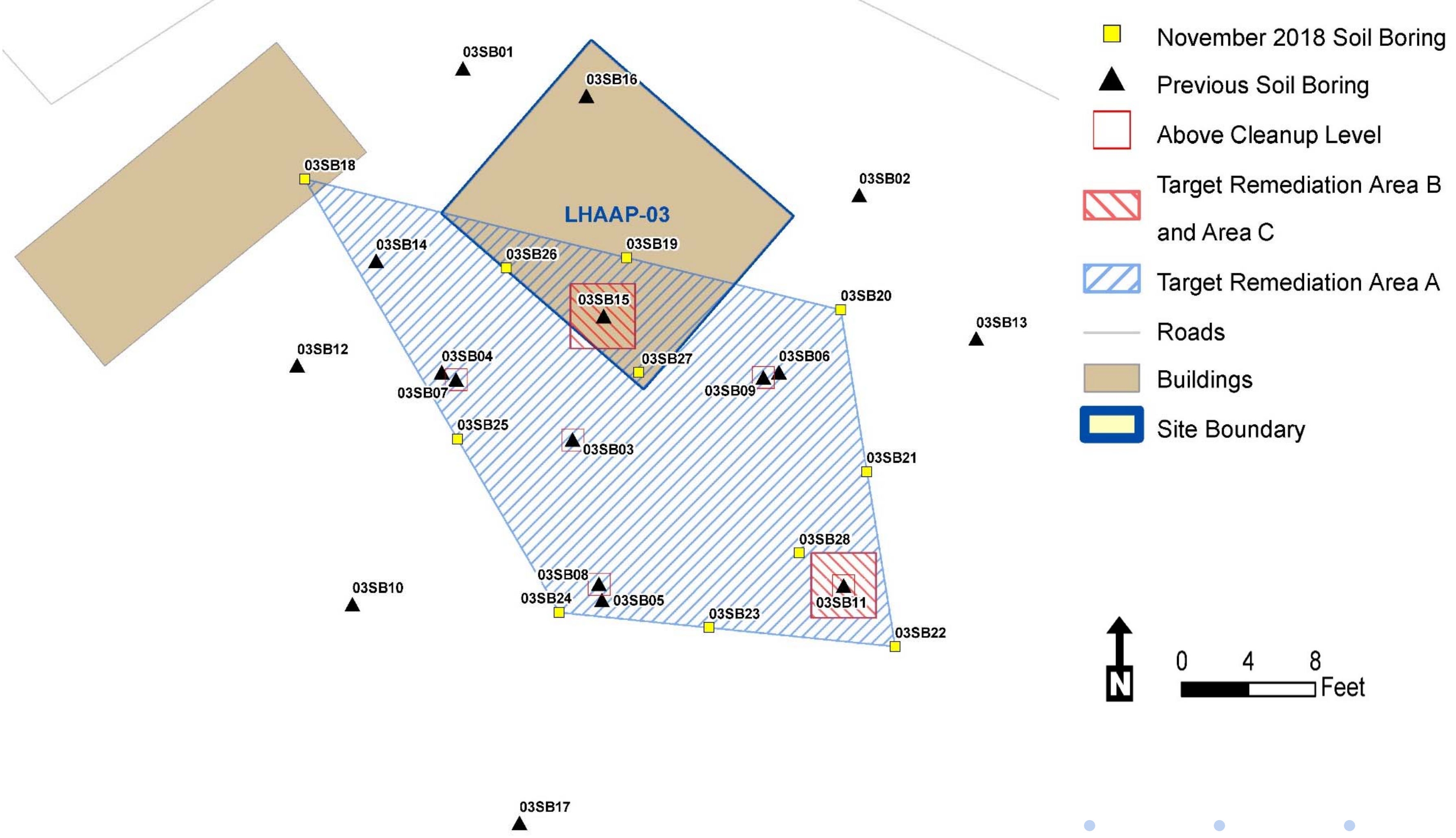
RAB Administrative Issues

- RAB Membership
- Discussion of October 2018 RAB Meeting minutes/motion to accept

LHAAP-03 Pre-Excavation Soil Sampling

- Site Background
  - LHAAP-03 is the site of a former Waste Collection Pad for the Building 722-P Paint Shop
  - Building 722-P and the surrounding structures have been demolished
  - Soil is contaminated with arsenic and lead at concentrations that could be a risk to groundwater and the ROD selected excavation and offsite disposal as the remedy
  - Groundwater is being addressed as part of site LHAAP-35A(58)
- Recent Activities
  - Pre-excavation soil samples were collected in late November 2018 from locations surrounding the excavation area defined in the ROD
  - Samples were used to better define the area where excavation is required
  - Soil sample data will be included in the Remedial Design (RD) and Remedial Action Work Plan (RAWP)
  - RD/RAWP is currently in preparation for submittal to the U.S. Environmental Protection Agency (USEPA) and Texas Commission on Environmental Quality (TCEQ)

LHAAP-03 Pre-Excavation Soil Sampling



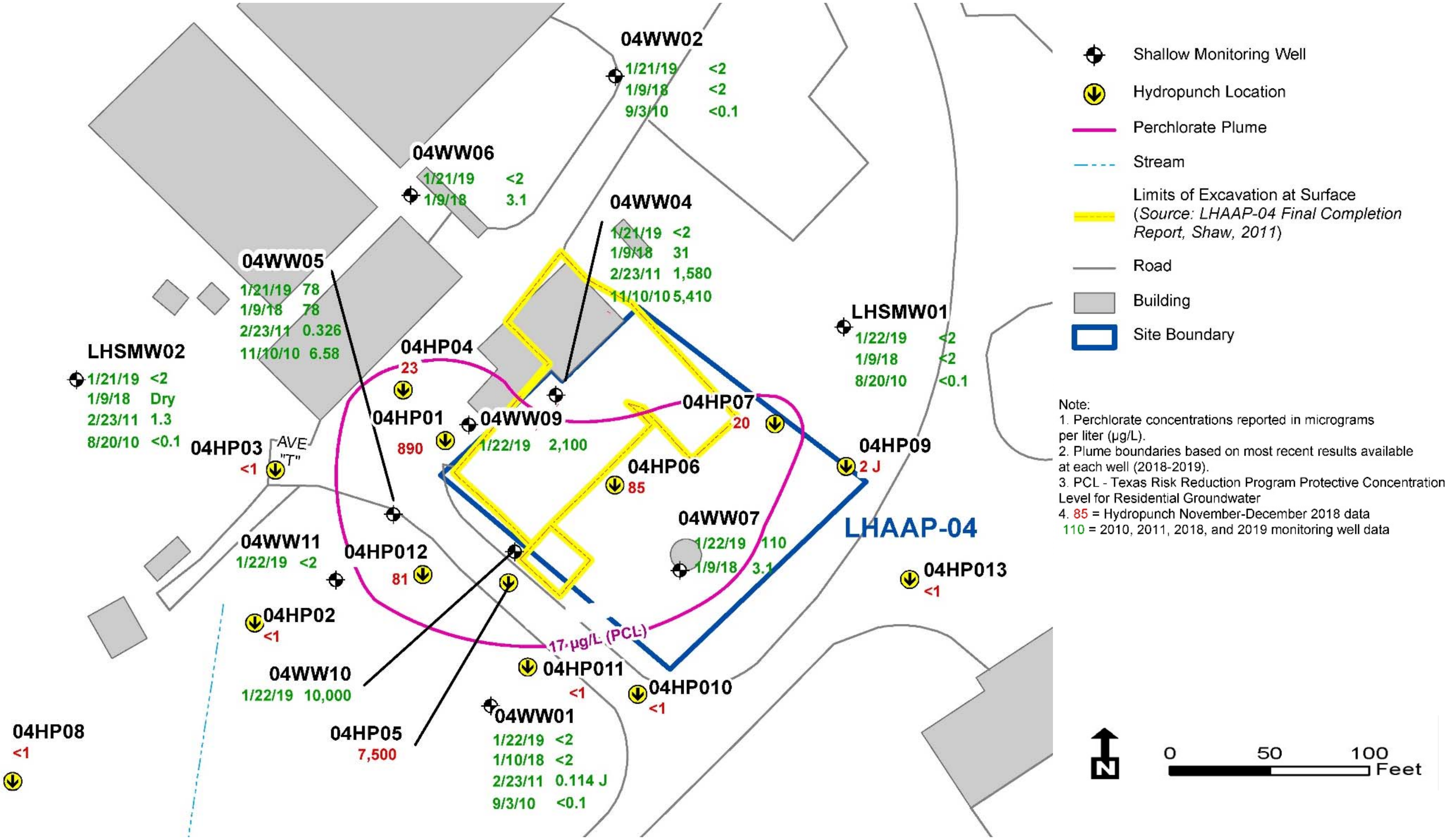
Restoration Advisory Board Meeting

LHAAP-04 Remedial Design

- Site Background
  - LHAAP-04 is the site of the former Pilot Wastewater Treatment Plant, located near the former Fire Station
  - Demolition of the structures and disposal of associated wastes was conducted in 1997
  - Soil contaminated with mercury and perchlorate was excavated in 2009
  - The ROD published in October 2016 selected In-Situ Bioremediation (ISB), Long-Term Monitoring, and Land Use Controls (LUCs) as the remedy for groundwater
- Recent Activities
  - Groundwater sampling in January 2018 revealed that the groundwater plume may have migrated since the previous sampling in 2010-2011
  - Additional direct-push groundwater sampling was performed in November-December 2019 and additional monitoring wells were installed in January 2019
  - January 2019 sampling of the new and existing wells confirmed that the plume had migrated slightly to the southwest, but is still adequately delineated

Restoration Advisory Board Meeting

LHAAP-04 2010-2019 Perchlorate Data



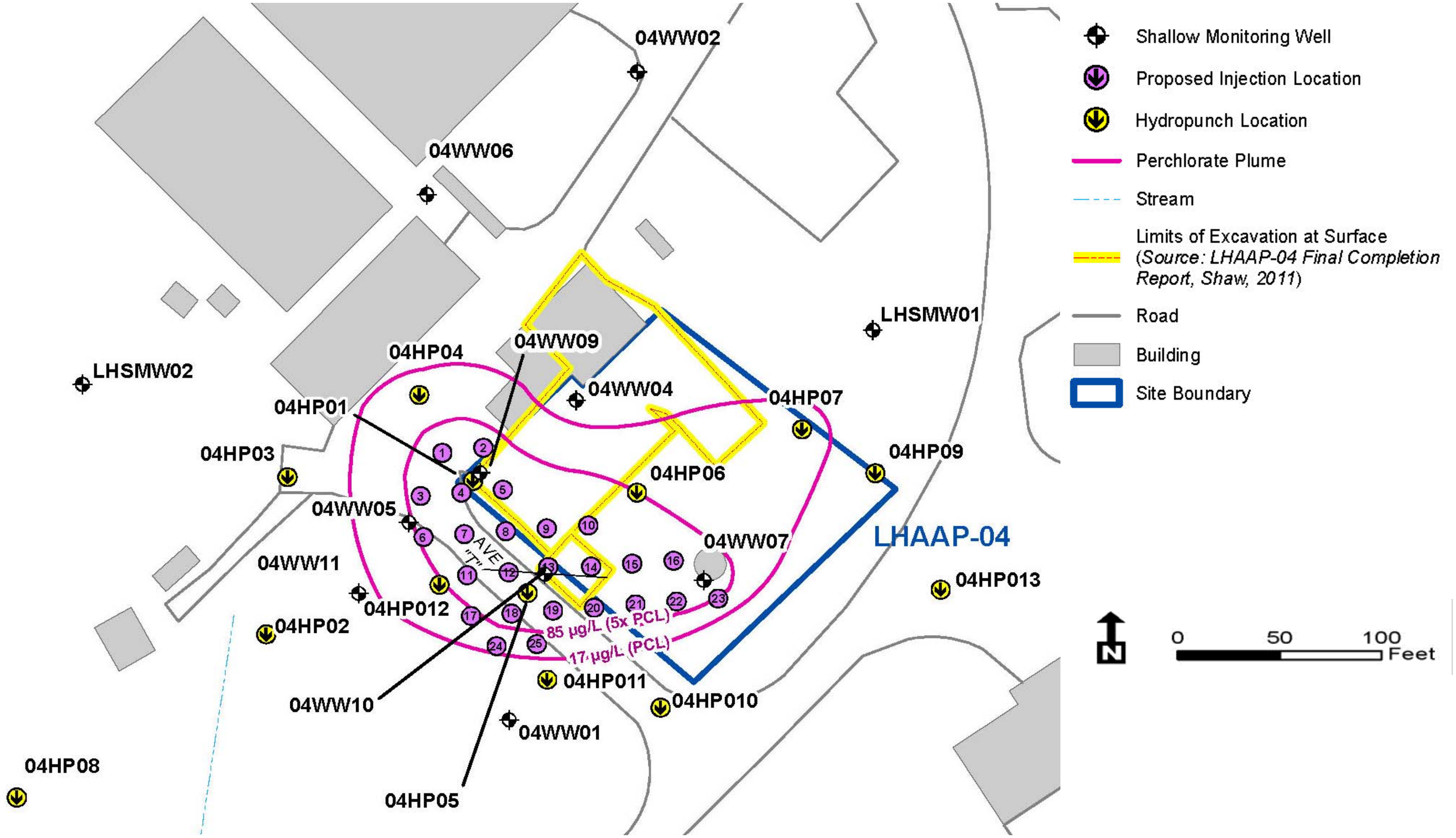
Note:
1. Perchlorate concentrations reported in micrograms per liter (µg/L).
2. Plume boundaries based on most recent results available at each well (2018-2019).
3. PCL - Texas Risk Reduction Program Protective Concentration Level for Residential Groundwater
4. 85 = Hydropunch November-December 2018 data
110 = 2010, 2011, 2018, and 2019 monitoring well data

LHAAP-04 Remedial Design

- Remedial Design
  - ISB will be implemented for the hot-spot defined as 5 times the Texas Risk Reduction Program (TRRP) Protective Concentration Level (PCL) for Residential Groundwater (17 micrograms per liter [µg/L])
  - 25 direct push injection locations will be used to inject emulsified vegetable oil (EVO)
  - Each location will receive approximately 15 gallons of EVO, 6 gallons of nutrients, and 1,463 gallons of water to treat a radius of approximately 10 feet around the location
  - Injection grid is spaced approximately 20-25 feet apart and shifted slightly to the south and west to account for future migration of the plume
- Long-Term Monitoring and LUCs
  - Baseline sampling of all site wells prior to injections, quarterly sampling for the first 2 years, semi-annual sampling for years 3 through 5, and annual sampling thereafter
  - LUCs include prohibition on use of groundwater (except for environmental monitoring), restriction to non-residential land use, and maintenance of remediation and monitoring systems
  - LUCs will remain in place until the concentration of perchlorate allows for unrestricted use and unlimited exposure

Restoration Advisory Board Meeting

LHAAP-04 Injection Plan



Restoration Advisory Board Meeting

LHAAP-17 Remedial Design

- Site Background
  - LHAAP-17 is the site of the former Burning Ground No. 2/Flashing Ground used from 1959 to 1980 for burning of bulk TNT, photo flash powder, and reject material from Universal Match Corporation
  - Waste material was reportedly removed from the burning trenches in 1984
  - Contaminants include explosives and metals in soil, and perchlorate and chlorinated solvents in groundwater
  - The ROD published in August 2016 selected Groundwater Extraction, Monitored Natural Attenuation (MNA), Soil Excavation, Long-Term Monitoring, and LUCs as the remedy
- Recent Activities
  - Pre-Design Investigation (PDI) (aquifer pumping test and soil and groundwater sampling) conducted in January 2018
  - Groundwater sampling to assess current plume conditions
  - Soil sampling refined the extent of the soil contamination requiring excavation
  - Aquifer pumping test provided design basis for the groundwater extraction system design

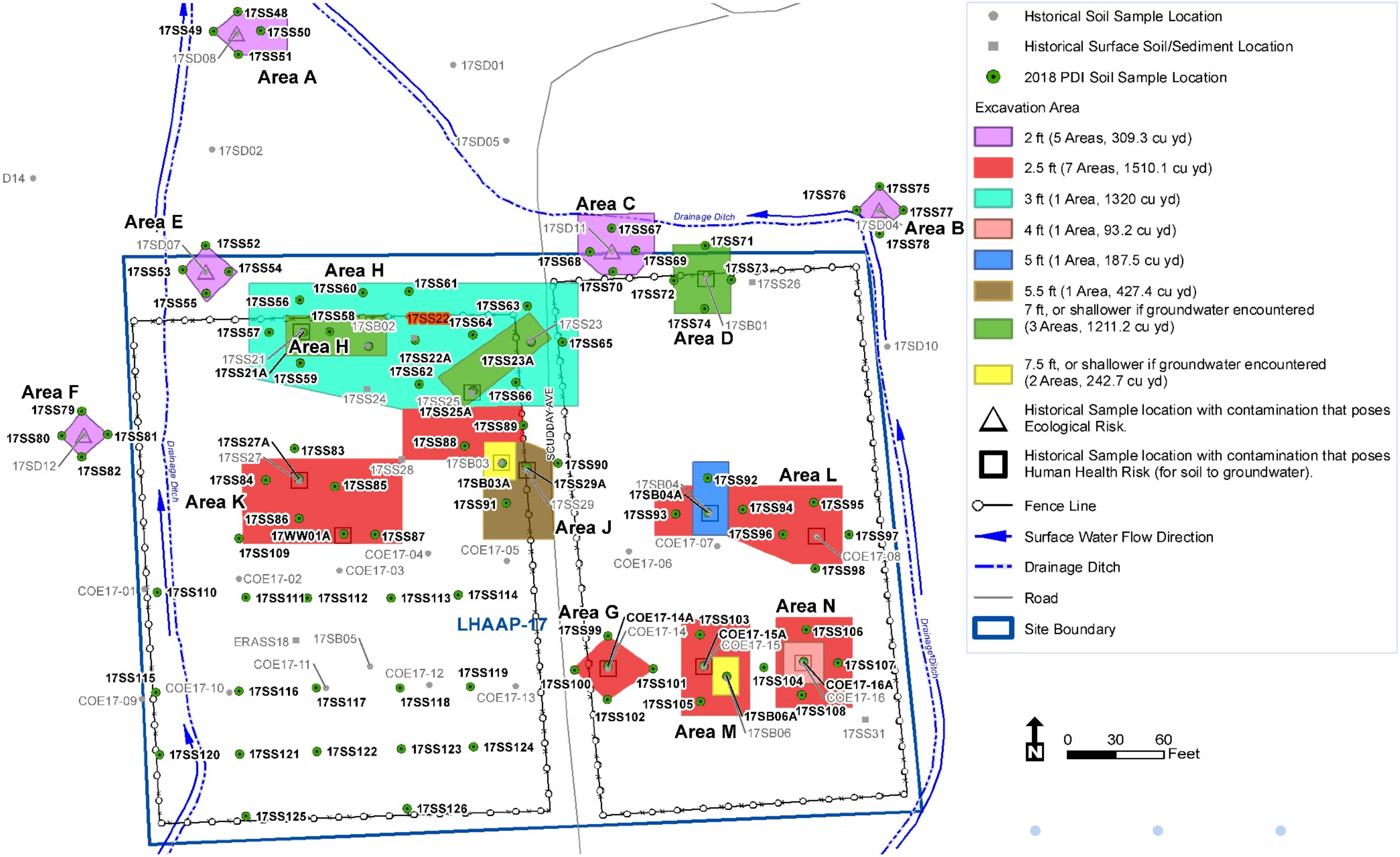
Restoration Advisory Board Meeting

LHAAP-17 Remedial Design

- Remedial Design
  - Approximately 5,300 in-place cubic yards of soil will be excavated based on the previous soil sampling data and transported to an offsite licensed disposal facility
  - Excavation will be backfilled with clean soil once sampling confirms contaminated soil has been removed
  - Groundwater extraction will be conducted for 18 months in up to three wells to reduce perchlorate concentrations to less than 20,000 μg/L
  - MNA will be the remedy for chlorinated solvents and perchlorate in groundwater unless perchlorate remains above 20,000 μg/L
- Long-Term Monitoring and LUCs
  - Extraction: Baseline sampling prior to extraction, monthly sampling for first 6 months of extraction, quarterly sampling for last 12 months of extraction
  - MNA: quarterly sampling for the first 2 years, semi-annual sampling for years 3 through 5, and annual sampling thereafter
  - LUCs include prohibiting use of groundwater (except for environmental monitoring), restricting land use to non-residential, and maintaining remediation/monitoring systems
  - LUCs will remain in place until the concentration of perchlorate allows for unrestricted use and unlimited exposure

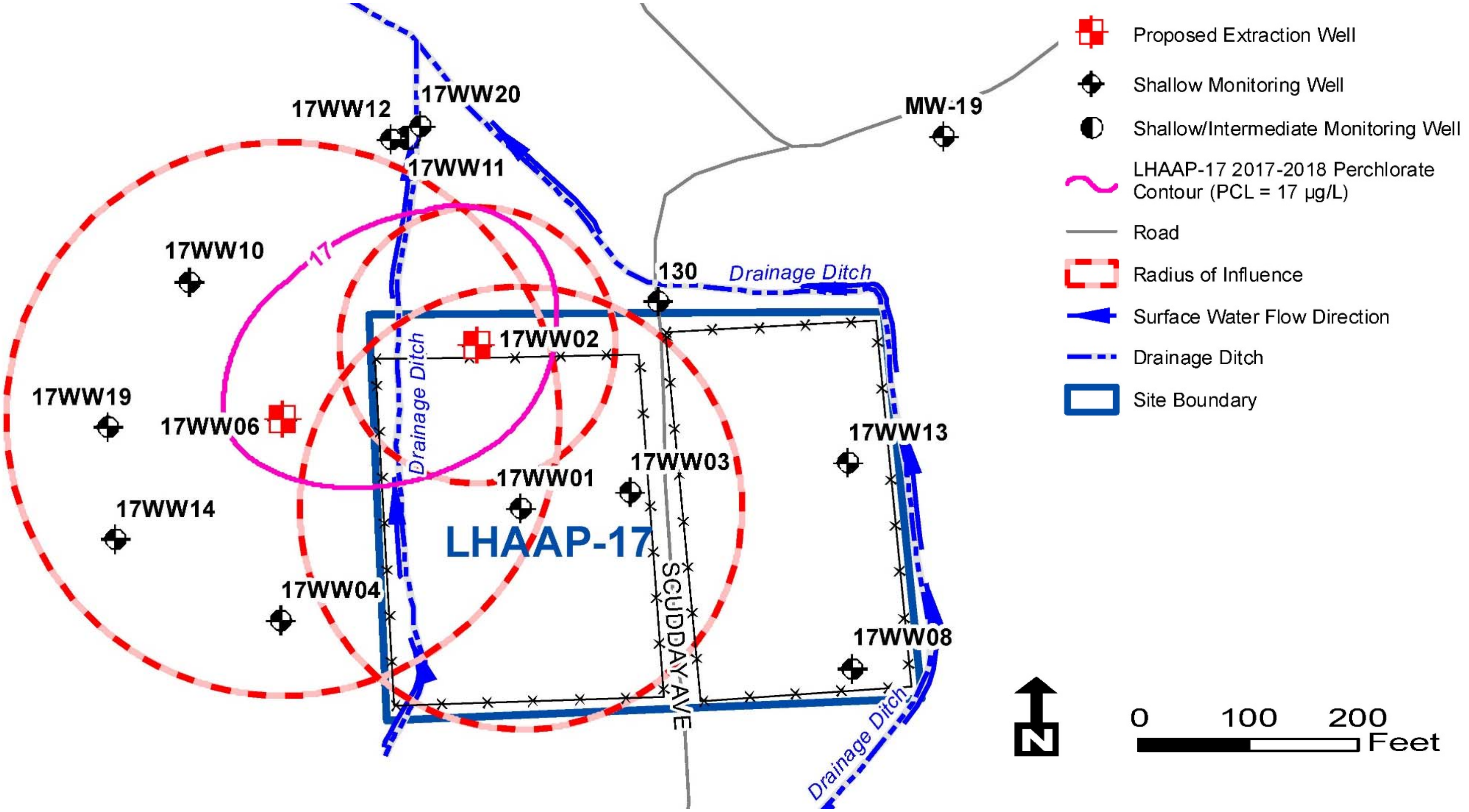
Restoration Advisory Board Meeting

LHAAP-17 Soil Excavation Areas



Restoration Advisory Board Meeting

LHAAP-17 Groundwater Extraction



Restoration Advisory Board Meeting

Completed Field Work Since Last RAB Meeting

Site	Activity
LHAAP-03	Supplemental Soil Sampling – November 2018
LHAAP-04	Supplemental Groundwater Sampling – November 2018 to January 2019
LHAAP-12	Remedial Action Operation (RA(O)) Sampling – December 2018
LHAAP-16	Annual Compliance Sampling – February 2019
LHAAP-37	RA(O) Sampling – November 2018, February 2019
LHAAP-46	RA(O) Sampling – February 2019
LHAAP-50	RA(O) Sampling – November 2018
LHAAP-58	RA(O) Sampling –December 2018, March 2019
LHAAP-67	RA(O) Sampling – October/November 2018
LHAAP-001-R	Groundwater Sampling – November 2018
LHAAP-001-R and LHAAP-003-R	Annual LUC Report-Year 1
GWTP	Replaced and disposed of ion exchange vessels (used to polish groundwater for perchlorate)
LHAAP-18/24	RA(O) Sampling – December 2018

Restoration Advisory Board Meeting

Documents in Process

Site	Document
LHAAP-03	Remedial Design and Remedial Action Work Plan
LHAAP-12	Annual RA(O) Report
GWTP	Quarterly Evaluation 4th Quarter (October - December 2018) Quarterly Evaluation 1st Quarter (January – March 2019)

3 Month Look Ahead - Field Work

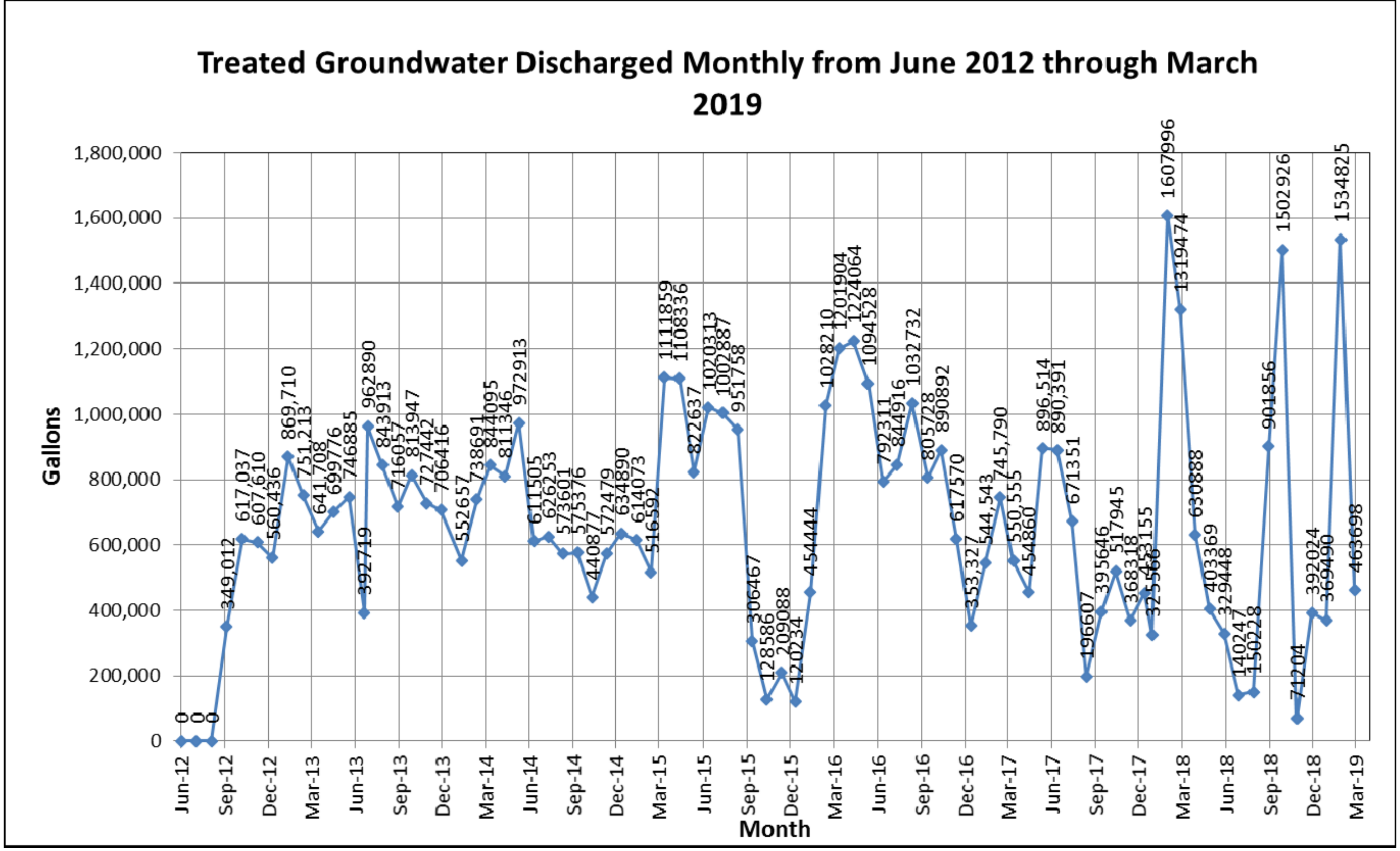
Site	Activity
LHAAP-03	Complete soil excavation
LHAAP-04	Complete ISB injections
LHAAP-16	Complete well installations and ISB injections
LHAAP-17	Complete soil excavation and extraction system installation
LHAAP-37	RA(O) Sampling – May 2019
LHAAP-50	RA(O) Sampling – May 2019
LHAAP-58	RA(O) Sampling – June 2019
LHAAP-67	RA(O) Sampling – May 2019
LHAAP-18/24	RA(O) Sampling – June 2019

3 Month Look Ahead - Documents

Site	Document
LHAAP-03	Remedial Design and Remedial Action Work Plan
LHAAP-12	2018 RA(O) Report
GWTP, LHAAP-16, and LHAAP-18/24	Quarterly Evaluation Report: Fourth Quarter (October – December) 2018 Quarterly Evaluation Report: First Quarter (January – March 2019)

Restoration Advisory Board Meeting

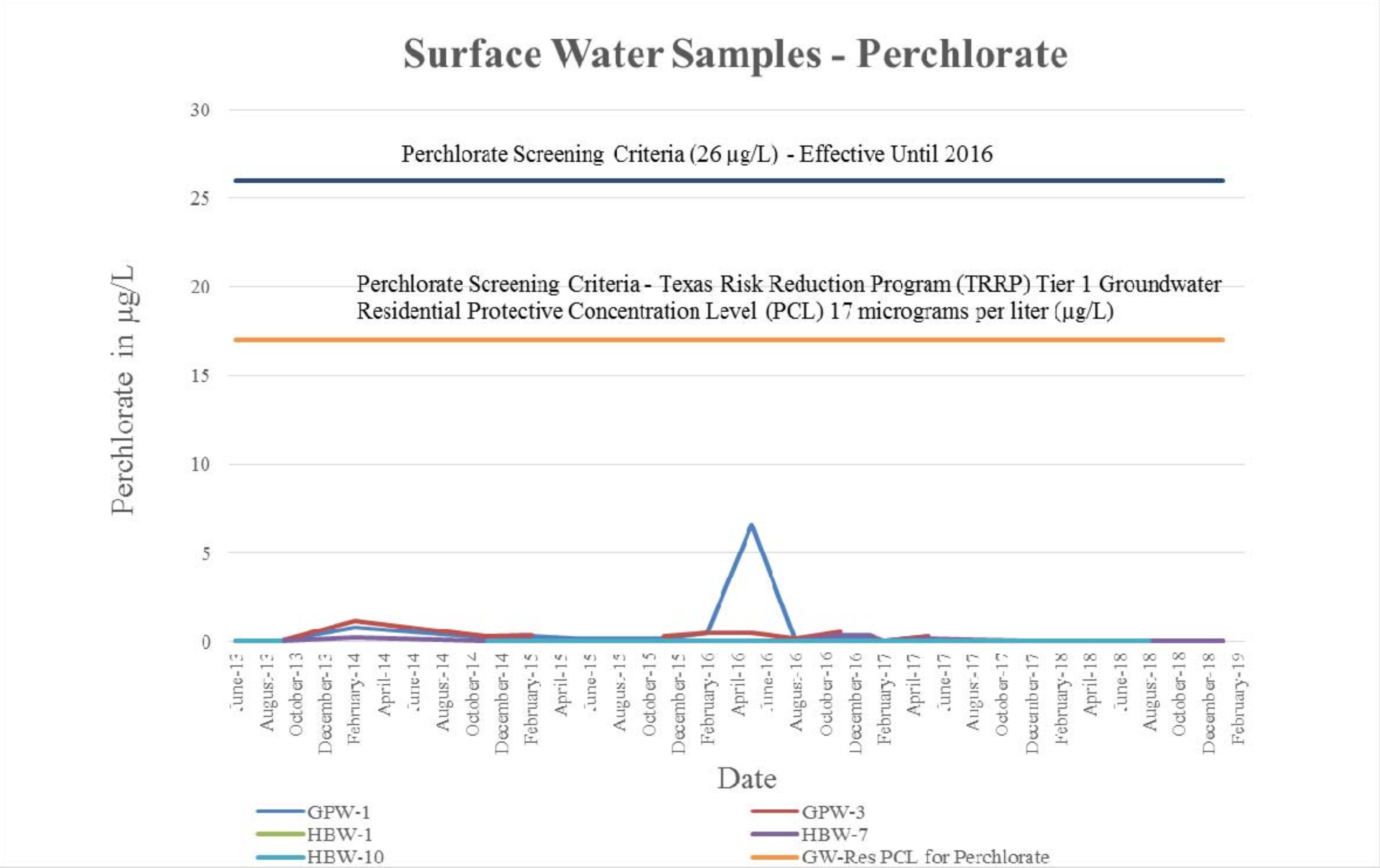
GWTP Update



Treated Groundwater Discharged Monthly from June 2012 through March 2019

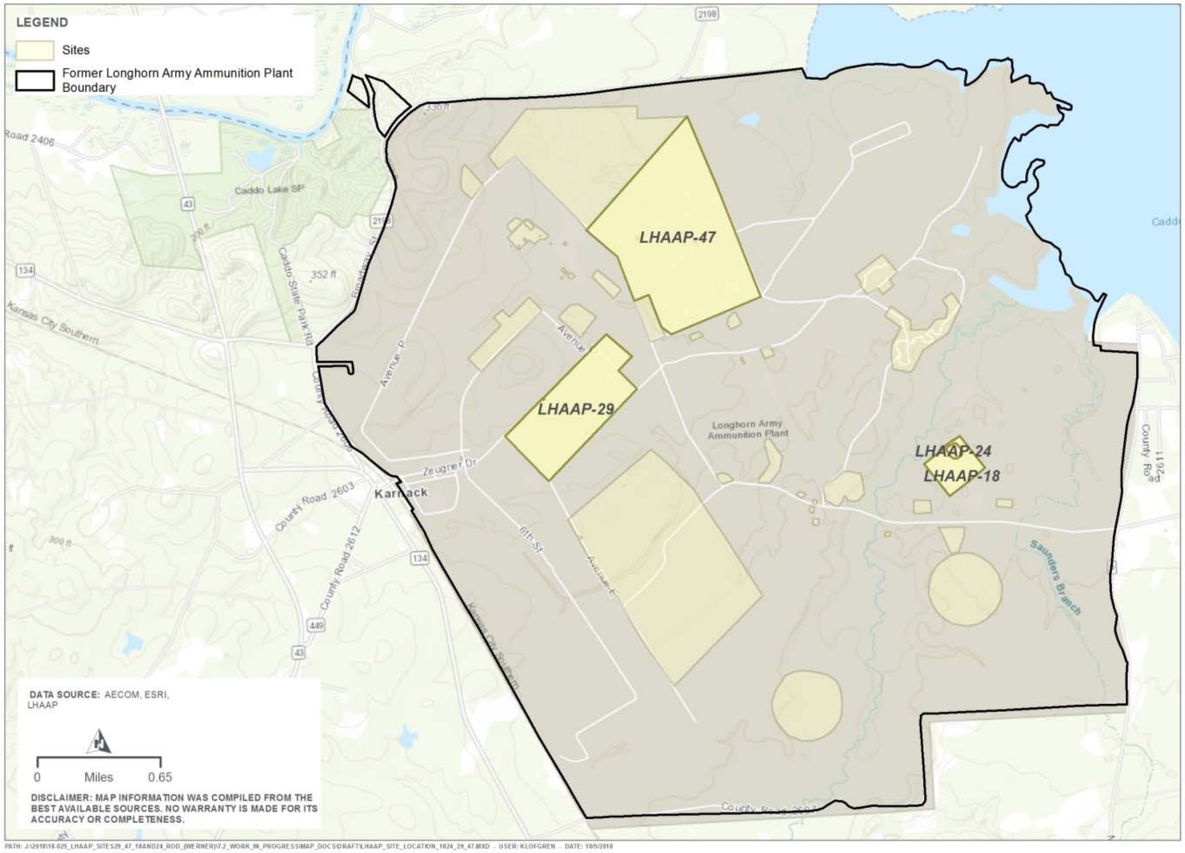
Restoration Advisory Board Meeting

Surface Water Sample Results



Restoration Advisory Board Meeting

LHAAP-18/24, 29, 47 Status Update



Restoration Advisory Board Meeting

LHAAP-18/24, 29 & 47 Document Status

- **LHAAP-18/24**
  - **Proposed Plan finalized February 2019**
  - **Public meeting April 25, 2019, 6:00pm – 7:30pm**
  - **Public comment period April 2 to May 2, 2019**
  - **Draft Record of Decision submittal planned for September 2019**
- **LHAAP-29**
  - **Proposed Plan finalized November 2018 and public meeting was held December 6, 2018.**
  - **Draft Record of Decision submittal planned for May 2019**
- **LHAAP-47**
  - **Post Screening Investigation Report finalized April 2019**
  - **Revised Draft Final Record of Decision submittal planned for August 2019**

Feasibility Study for LHAAP-18/24

- LHAAP-18/24
  - Final Revised Feasibility Study located in the Administrative Record, Volume 1, 2017, Bate Stamp 00692951 - 00731961

Administrative Record located on the Longhorn environmental website at www.longhornaap.com

LHAAP-47 Field Work Update

- **Work Completed**
  - Collected 4 surface water samples March 2019

Next RAB Meeting Schedule & Closing Remarks

- Schedule July 2019 RAB Meeting
- Other Issues/Remarks
- Thank you for coming

Groundwater Treatment Plant - Processed Groundwater Volumes

The amount of groundwater treated is determined by measuring the number of gallons of processed water discharged.

Processed Water Discharged Data

(in gallons)

Oct-07	Nov-07	Dec-07	Jan-08	Feb-08	Mar-08	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08
1,041,491	848,356	804,822	792,148	665,883	818,872	791,306	568,812	776,904	748,377	690,052	617,199

Oct-08	Nov-08	Dec-08	Jan-09	Feb-09	Mar-09	Apr-09	May-09	Jun-09	Jul-09	Aug-09	Sep-09
655,059	619,274	726,118	552,299	598,144	433,800	488,807	526,958	387,644	0	414,853	735,716

Oct-09	Nov-09	Dec-09	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10
808,322	636,306	727,492	391,898	695,343	802,656	894,731	962,121	1,257,977	1,314,924	1,041,495	1,136,547

Oct-10	Nov-10	Dec-10	Jan-11	Feb-11	Mar-11	Apr-11	May-11	Jun-11	Jul-11	Aug-11	Sep-11
956,567	705,805	849,712	811,679	668,281	1,090,348	817,325	900,338	916,552	784,369	652,524	733,456

Oct-11	Nov-11	Dec-11	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12
748,102	658,250	684,903	865,453	725,000*	730,000*	980,000*	630,000*	0	0	0	349,012

Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13
617,037	607,610	560,436	869,710	751,213	641,708	699,776	746,885	392,719	962,890	843,913	716,057

Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14
813,974	727,442	706,416	552,657	738,691	844,095	811,346	972,913	611,505	626,253	573,601	575,376

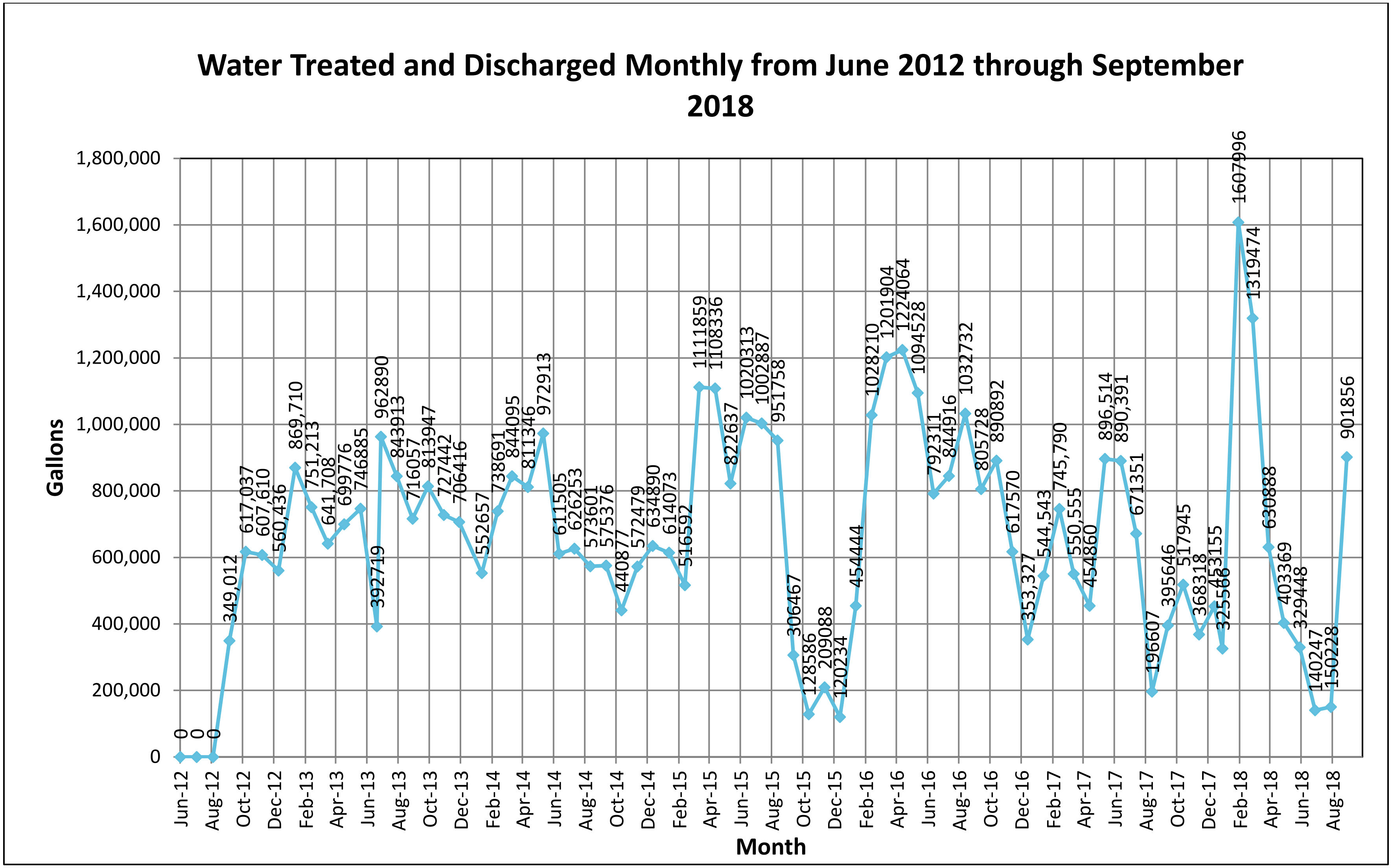
Oct-14	Nov-14	Dec-14	Jan-15	Feb-15	Mar-15	Apr-15	May-15	Jun-15	Jul-15	Aug-15	Sep-15
440,877	572,479	634,890	614,073	516,592	1,111,859	1,108,336	822,637	1,020,313	1,002,887	951,758	306,467

Oct-15	Nov-15	Dec-15	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16
128,586	209,088	120,234	454,444	1,028,210	1,201,904	1,224,064	1,094,528	792,311	844,916	1,032,732	805,728

Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17
890,892	617,570	353,327	544,543	745,790	550,555	454,860	896,514	890,391	528,538	195,198	961,324

Oct-17	Nov-17	Dec-17	Jan-18	Feb-18	Mar-18	Apr-18	May-18	Jun-18	Jul - 18	Aug-18	Sep-18
517,945	368,318	453,155	325,566	1,607,996	1,319,474	630,888	403,369	329,448	140,247	150,228	901,856

*Indicates Estimate



Water Treated and Discharged Monthly from June 2012 through September 2018

Water Discharge Location and Volume (Gallons)

Month	Total Combined to Harrison Bayou	LHAAP-18/24 Sprinklers	GWTP To INF Pond	INF Pond to Harrison Bayou	Contract Hauled Off-Site
Dec-16	0	236,688	0	0	0
Jan-17	0	0	0	0	0
Feb-17	0	0	0	0	14,355
Mar-17	127,242	0	0	0	14,400
Apr-17	113,038	0	236,821	0	0
May-17	205,665	0	534,155	0	0
Jun-17	467,830	0	294,550	490,574	0
Jul-17	0	0	528,538	0	0
Aug-17	0	0	195,197	0	0
Sep-17	0	0	309,980	651,434	0
Oct-17	0	0	517,945	0	0
Nov-17	0	0	368,318	0	0
Dec-17	0	0	453,155	560,350	0
Jan-18	325,566	0	253,177	325,566	0
Feb-18	1,607,996	0	62,017	1,430,634	0
Mar-18	1,319,474	0	0	870,816	0
Apr-18	630,888	0	0	630,888	0
May-18	403,369	0	0	403,369	0
Jun-18	193,669	0	135,779	0	0
Jul -18	0	0	140,247	0	0
Aug -18	49,409	0	100,819	0	0
Sep-18	585,397	0	316,459	524,484	0

Harrison Bayou and Goose Prairie Creek – Perchlorate Data

Surface water samples are collected quarterly from each location in Harrison Bayou and Goose Prairie Creek, unless the sampling location is dry.

Surface Water Sample Data (in micrograms per liter)

Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st
Creek Sample ID	**Jul 1999**	**Sep 1999**	**Feb 2000**	**Apr 2000**	**Aug 2000**	**Dec 2000**	**Feb 2001**	**Apr 2001**	**July 2001**	**Oct 2001**	**Jan 2002**
GPW-1	<1.0U	-	4	<4.0 U	<4.0 U	<4.0 U	-	2.65	<4.0 U	<4.0 U	<4.0 U
GPW-3	<1.0U	<4.0 U	17	8	<4.0 U	<4.0 U	-	2.28	<4.0 U	<4.0 U	<4.0 U
HBW-1	-	<80.0 U	310	23	-	-	<4.0 U	-	<4.0 U	<4.0 U	<4.0 U
HBW-7	-	<8.0 U	370	110	-	-	<4.0 U	-	<4.0 U	<4.0 U	<4.0 U
HBW-10	-	<8.0 U	905	650	<4.0 U	-	<4.0 U	-	<4.0 U	-	-

Quarter	2nd	3rd	4th	1st	2nd	3rd	3rd	4th	2nd	3rd	4th
Creek Sample ID	**June 2002**	**Sept 2002**	**Dec 2002**	**Feb 2003**	**June 2003**	**Aug 2003**	**July 2004**	**Dec 2006**	**May 2007**	**Aug 2007**	**Dec 2007**
GPW-1	<4.0 U	<4.0 U	18.3	18.6	59.9	-	2.25	-	<1.0 U	<1.0 U	10.7
GPW-3	<4.0 U	<4.0 U	5.49	12.6	14.7	-	2.2	-	<1.0 U	<1.0 U	7.48
HBW-1	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	99.3	<0.2U	<1.0 U	<1.0 U	122	<1.0 U
HBW-7	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	<4.0 U	<0.2U	<1.0 U	<1.0 U	1.02	<1.0 U
HBW-10	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	-	<0.2U	<1.0 U	<1.0 U	<1.0 U	<1.0 U

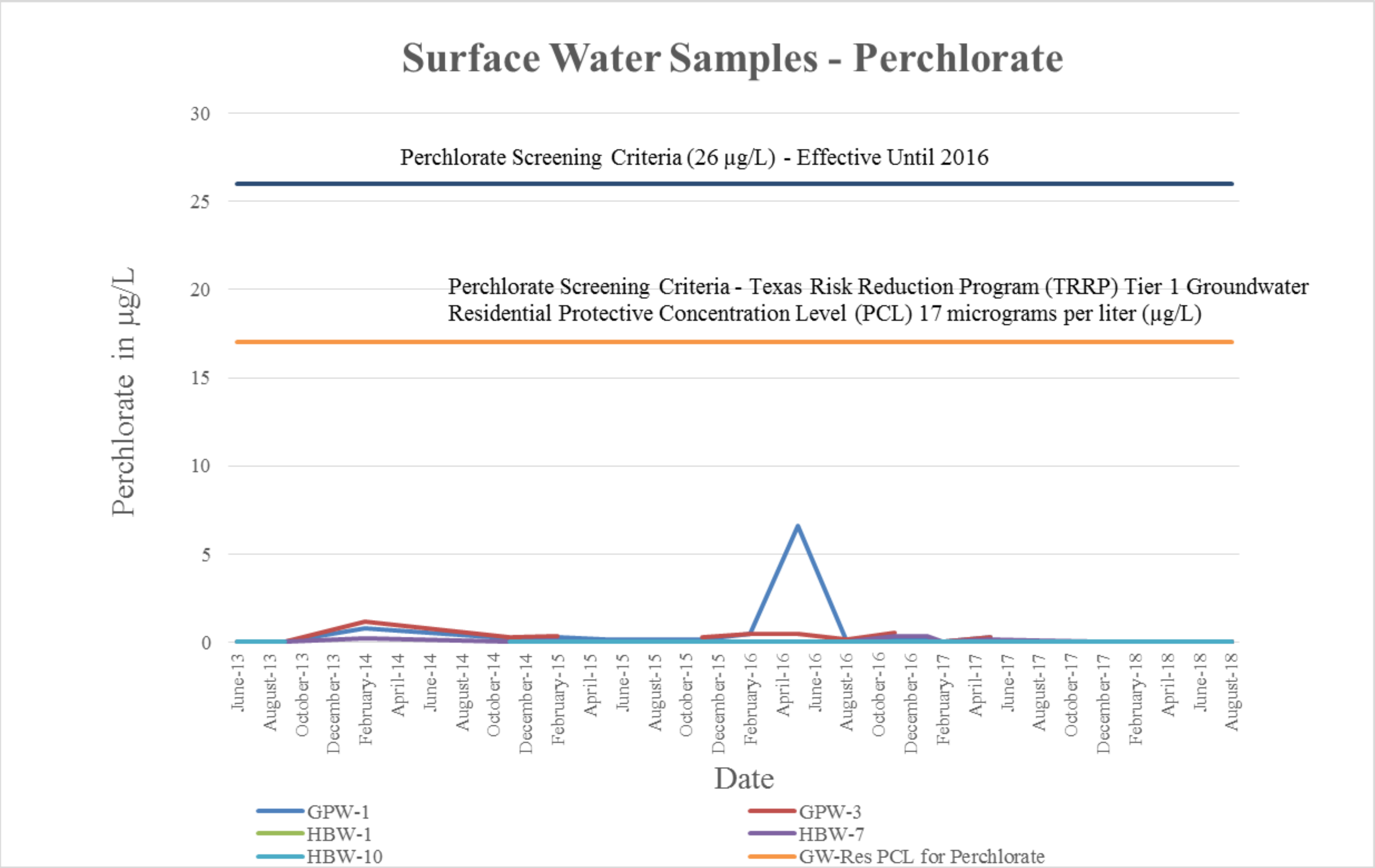
Quarter	1st	2nd	3rd	4th	2nd	3rd	3rd	3rd	4th	1st	2nd
Creek Sample ID	**Mar 2008**	**Jun 2008**	**Sep 2008**	**Dec 2008**	**May 2009**	**Jul 2009**	**Aug 2009**	**Sep 2009**	**Dec 2009**	**Mar 2010**	**Jun 2010**
GPW-1	27	<0.5U	<0.5U	<0.22U	16	<4U	NS	<1.2U	3.7	1.3J	<0.6U
GPW-3	21.9	9.42	1.1	<0.22U	8.9	<4U	NS	<0.6U	2.8	1.8J	<0.6U
HBW-1	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	NS	<1.5U	<0.275U	1.5U	<0.6U
HBW-7	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	24	<1.2U	<0.275U	1.5U	<0.6U
HBW-10	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	NS	<1.5U	<0.275U	1.2U	<0.6U

Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st
Creek Sample ID	**Sep 2010**	**Dec 2010**	**Mar 2011**	**Jun 2011**	**Sep 2011**	**Dec 2011**	**Mar 2012**	**Jun 2012**	**Not Applicable**	**Jan & Feb 2013**	**Mar 2013**
GPW-1	dry	<0.1U	8.7	dry	dry	1.76	0.163J	dry	NS	1.65	0.735
GPW-3	dry	0.199J	0.673	dry	dry	1.31	0.261	dry	NS	1.74	0.754
HBW-1	dry	<0.1U	<0.2U	dry	dry	<0.1U	0.1U	dry	NS	<0.2U	<0.2U
HBW-7	dry	<0.1U	<0.2U	dry	dry	0.171J	0.1U	dry	NS	<0.2U	<0.2U
HBW-10	dry	<0.1U	<0.2U	dry	dry	<0.1U	0.1U	dry	NS	<0.2U	<0.2U

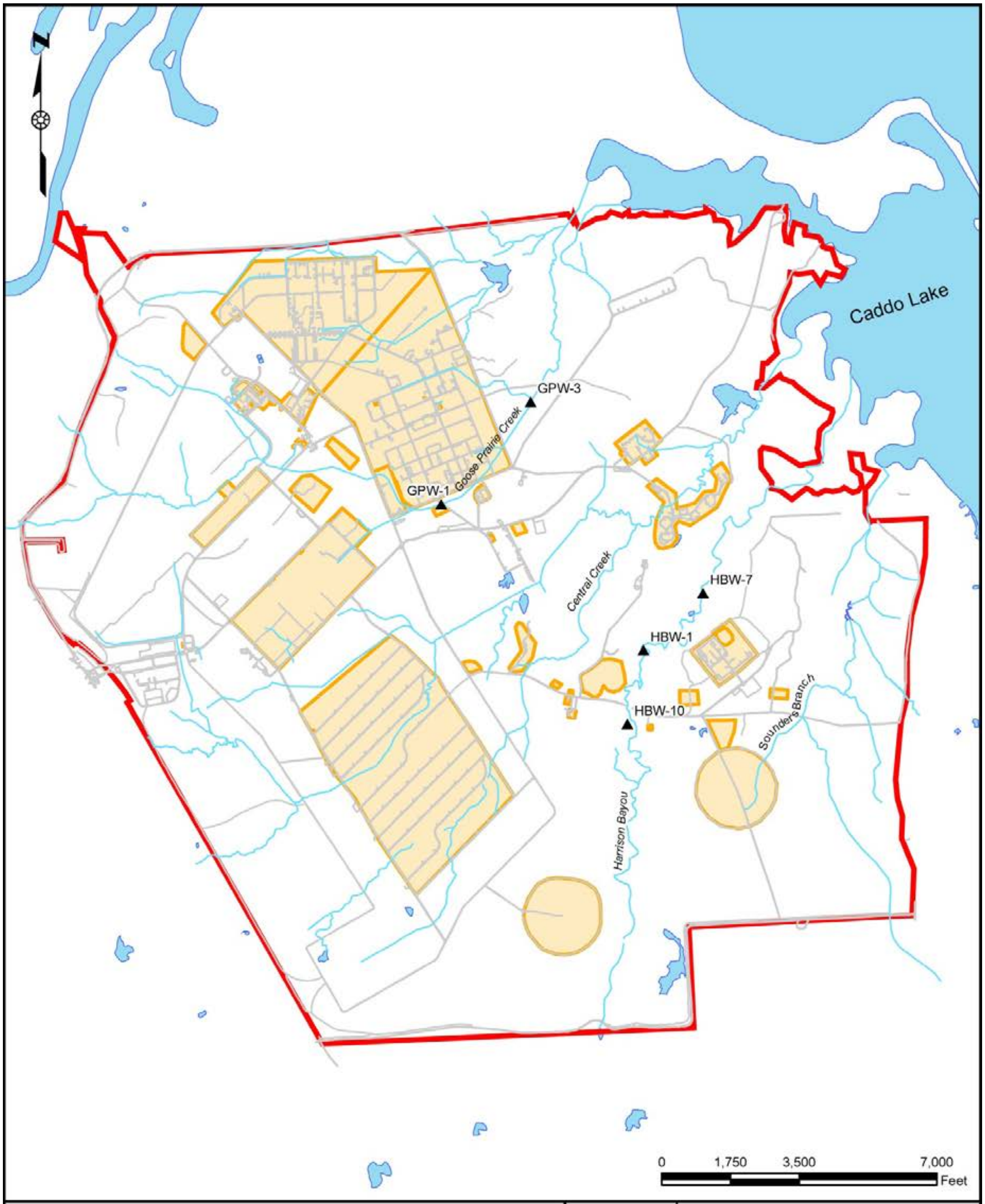
Quarter	2nd	3rd	4th	1st	2nd	3nd	4th	1st	2nd	3rd	4th
Creek Sample ID	**Jun 2013**	**Sept 2013**	**Dec 2013**	**Feb 2014**	**May 2014**	**Aug 2014**	**Nov 2014**	**Feb 2015**	**May 2015**	**Aug 2015**	**Nov 2015**
GPW-1	dry	<0.2 U	dry	0.766	dry	dry	0.244 J	0.311 J	0.156J	dry	0.142 J
GPW-3	dry	<0.2 U	dry	1.15	dry	dry	0.276 J	0.344 J	dry	dry	0.311 J
HBW-1	<0.2U	<0.2 U	dry	<0.2 U	dry	dry	<0.2 U	<0.2 U	dry	dry	<0.2 U
HBW-7	<0.2U	<0.2 U	dry	0.201 J	dry	dry	<0.2 U	0.124 J	dry	dry	<0.2 U
HBW-10	<0.2U	<0.2 U	dry	<0.2 U	dry	dry	<0.2 U	<0.2 U	dry	dry	<0.2 U

Quarter	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd
Creek Sample ID	**Feb 2016**	**May 2016**	**Aug 2016**	**Nov 2016**	**Feb 2017**	**May 2017**	**Aug 2017**	**Dec 2017**	**Mar 2018**	**June 2018**	**August 2018**
GPW-1	0.447	6.59	<0.2 U	0.301 J	<1 U	0.263	dry	<4.0 U	<4.0 U	dry	<2.0 U
GPW-3	0.474	0.457	0.141	0.563	<1 U	0.274	dry	<4.0 U	<4.0 U	dry	<2.0 U
HBW-1	<0.2 U	<0.2 U	<0.2 U	<0.2 U	<1 U	<0.2 U	<0.2 U	1.1 J	<4.0 U	dry	<2.0 U
HBW-7	<0.2 U	<0.2 U	<0.2 U	0.318 J	<1 U	0.155	<0.2 U	<4.0 U	<4.0 U	dry	<2.0 U
HBW-10	<0.2 U	<0.2 U	<0.2 U	<0.2 U	<1 U	<0.2 U	0.111J	<4.0 U	<4.0 U	dry	<2.0 U

NS – not sampled U – non-detect J – Estimated Dry – no surface water


Surface Water Samples - Perchlorate
Perchlorate Screening Criteria (26 µg/L) - Effective Until 2016
Perchlorate Screening Criteria - Texas Risk Reduction Program (TRRP) Tier 1 Groundwater Residential Protective Concentration Level (PCL) 17 micrograms per liter (µg/L)
Perchlorate in µg/L
30
25
20
15
10
5
0
June-13
August-13
October-13
December-13
February-14
April-14
June-14
August-14
October-14
December-14
February-15
April-15
June-15
August-15
October-15
December-15
February-16
April-16
June-16
August-16
October-16
December-16
February-17
April-17
June-17
August-17
October-17
December-17
February-18
April-18
June-18
August-18
Date
GPW-1
GPW-3
HBW-1
HBW-7
HBW-10
GW-Res PCL for Perchlorate

Longhorn Army Ammuntion Plant Creek Sampling Locations



Legend

▲ Surface Water Sampling Location

— Stream

— Road

🟧 Site

🟦 Lake

U.S. ARMY CORPS OF ENGINEERS
TULSA DISTRICT
TULSA, OKLAHOMA

SURFACE WATER SAMPLING LOCATION

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

PUBLIC MEETING
THURSDAY, APRIL 25, 2019
6:03 P.M. - 7:24 P.M.
KARNACK COMMUNITY CENTER
KARNACK, TEXAS

(The following transcript contains questions posed during presentation, by individuals present at public meeting.)

MR. GEORGE RICE: My name is George Rice. Looking at the figure against the wall that shows the plumes in the Shallow Zone --

MR. GREGORY KELLY: Uh-huh.

MR. GEORGE RICE: -- it also shows an area for monitored natural attenuation.

MR. GREGORY KELLY: Yes, sir.

MR. GEORGE RICE: But that doesn't cover the -- all the plumes are not covered by that MNA area. Could you explain why?

MR. GREGORY KELLY: We'll actually get to that a little bit further down in the slides here; but, yeah, that's -- the reason that that isn't part of the MNA is because those concentrations in the wells there have been shown to either be steady or decreasing over time. There's kind of this trend going on. That's all upgradient of where the contamination is. So, historically, those concentrations haven't been increasing because everything's flowing out towards the bayou, so those would -- and this wouldn't come in the remedial design phase.

But what would occur for MNA is you

select certain wells that you want to monitor for monitored natural attenuation parameters. Those -- some of those wells that are not in that boundary might actually be part of the sampling program for that, but they're -- we're really looking for the area that is in gray; we're looking for those contaminants to be dropping -- concentrations dropping over time.

The upgradient ones, we're -- we're not seeing any increases in concentrations, so that's why that MNA boundary looks like that.

MR. GEORGE RICE: Thank you.

MR. GREGORY KELLY: Does that answer your question?

A lot of this comes down to the -- a lot of this gets decided in the remedial design phase, so this is kind of the 10,000-foot look at what your remediation alternative is, and then you really get into the nitty-gritty of it, the alternative design phase.

MR. GEORGE RICE: Thank you.

(Presentation continued, during which the following question was posed:)

MS. JUDY VANDEVENTER: Judy Vandeventer.

Why weren't we given a copy of these slides tonight?

DR. ROSE ZEILER: Why weren't you?

MS. JUDY VANDEVENTER: Uh-huh.

DR. ROSE ZEILER: Because tonight's the presentation. I'm sure you can have -- are we going to post those to the website?

MR. GREGORY KELLY: We can --

DR. ROSE ZEILER: Because it takes us time to prepare all this.

MS. JUDY VANDEVENTER: Well, couldn't we have had a copy of the slides, though, that he...?

DR. ROSE ZEILER: Well, I suppose you could have. We can do that or we can load them up to the website. Would that work?

MS. JUDY VANDEVENTER: Uh-huh.

DR. ROSE ZEILER: Okay.

MS. JUDY VANDEVENTER: But then I have --

DR. ROSE ZEILER: We can send her a copy.

MS. JUDY VANDEVENTER: I want to be sent a copy than to have to print it out.

DR. ROSE ZEILER: Right, I understand that. Okay, we'll do that.

Anyone else?

Did you want a set, too, George, Mr. Rice? Does anyone else want set of the slides? Okay.

Okay. Did you get Judy Vandeventer's

name? Larry.

And her -- we have her address, mailing address, so we can just send it to her.

Okay, we'll get that done, Judy.

MS. JUDY VANDEVENTER: Thank you.

DR. ROSE ZEILER: All right.

George?

MR. GEORGE RICE: Yes, George Rice.

I have a question and then a brief comment. My question has to do with where you intend to use EISD. You said that was inside and outside the containment area.

MR. GREGORY KELLY: Yes, sir.

MR. GEORGE RICE: On your maps here and the ones you've shown, to me they all seem to be inside the containment area.

MR. GREGORY KELLY: Yeah. They are, actually, outside the linear. So this row here, here, here, here, and here, those were the injection areas. And, again, this is the very first phase of that, so for the remedial design phase, may get shifted. This is kind of the preliminary locations of the injection points in the remedial design phase. That will get refined, so those borders or those linear injection lines could -- could be changed to better address the contamination.

MR. GEORGE RICE: Thank you.

MR. GREGORY KELLY: Uh-huh.

MR. GEORGE RICE: And I thought -- and so a quick comment. I have -- I've read the proposed plan, and I've also read that other document, the one associated with the site, and I've come to some preliminary conclusions about it.

Now, when I evaluate these kind of plans, I try to answer three -- there are three questions I try to answer. First is, have all the contaminants been identified; the second is, has the extent of contamination been determined--that's both horizontally and vertically--and, finally, if the proposed plan is implemented, is it likely to clean up contaminants in a reasonable amount of time. And my initial answers to all three of those questions is yes. I think that you've identified all the contaminants; you've identified the extent; and as far as the cleanup plan working, I am concerned mostly with DNAPL, because we all -- for those of you who have been involved, you know that DNAPLs are probably the most difficult thing to clean up that we deal with.

And this technology that you plan to use is new to me; but I've done a little research on it, and

I went looking for examples where the technology didn't work, but I was unable to find an example where it didn't work. It might be out there; but in all the cases I've looked at, have worked, so I think it's quite promising.

Now, I do have one criticism, though, and that has to do with metals. You know, you've mentioned the fact that metals are present in groundwater, including arsenic and chromium; but nowhere in any of the documents I've looked at does the Army explicitly say "This is how we're going to clean up the metal" or do they say, alternatively, like "We don't need to clean up the metals in this one," you know. I think that we need more explanation of what you intend to do, if anything, about the metal.

Other than that, yeah, I think it's -- it's a good plan. It's a reasonable plan.

DR. ROSE ZEILER: Thank you.

MR. GREGORY KELLY: Thank you.

Any more comments? Questions? Discussion?

(No response in the affirmative.)

MR. GREGORY KELLY: Okay. Well, I guess that's a wrap.

DR. ROSE ZEILER: All right. Thank you

very much.

(Meeting adjourned, 7:24 p.m.)

THE STATE OF TEXAS:

REPORTER'S CERTIFICATE

I, AMANDA J. LEIGH, a Certified Shorthand Reporter in and for the State of Texas, do hereby certify that the foregoing 8 pages contain a true and correct transcription of all portions of the public meeting requested to be taken down stenographically at the time of the public meeting and transcribed thereafter to the best of my skill and ability.

Certified to by me this 25th day of May, 2019.

NDTCA · Signed Electronic Transcript

/S/ Amanda J. Leigh

AMANDA J. LEIGH, Texas CSR 3791
Expiration: January 31, 2021
LEIGH & ASSOCIATES
COURT REPORTING AND VIDEO
911 West Loop 281, Suite 211
Longview, Texas 75604

From: April Palmie <april.palmie@tceq.texas.gov>
Sent: Wednesday, April 10, 2019 11:01 AM
To: Foss, William A.; Mayer, Richard
Cc: Zeiler, Rose M CIV USARMY HQDA ACSIM (US); Williams, Aaron K SWF @SWT (Aaron.K.Williams@usace.army.mil); Maly, Andrew R CIV USARMY IMCOM AEC (US); Kim Nemmers (knemmers@bhate.com); Srivastav, Praveen
Subject: TCEQ acceptance: 04_2019 Draft Final LHAAP-04 RD/RAWP

EXTERNAL SENDER

Good morning. TCEQ has reviewed the Draft Final LHAAP-04 RD/RAWP and accepts the document and RTCs.

April Palmie
Project Manager
Superfund Section
Remediation Division
Texas Commission on Environmental Quality
Phone: (512) 239-4152
Email: April.Palmie@tceq.texas.gov

From: Foss, William A. <William.Foss@aptim.com>
Sent: Wednesday, April 3, 2019 7:04 PM
To: Mayer, Richard <mayer.richard@epa.gov>; April Palmie <april.palmie@tceq.texas.gov>
Cc: Zeiler, Rose M CIV USARMY HQDA ACSIM (US) <rose.m.zeiler.civ@mail.mil>; Williams, Aaron K SWF @SWT (Aaron.K.Williams@usace.army.mil) <Aaron.K.Williams@usace.army.mil>; Maly, Andrew R CIV USARMY IMCOM AEC (US) <andrew.r.maly.civ@mail.mil>; Kim Nemmers (knemmers@bhate.com) <knemmers@bhate.com>; Srivastav, Praveen <Praveen.Srivastav@aptim.com>
Subject: 04_2019 Draft Final LHAAP-04 RD/RAWP

Rich and April,

The *Draft Final Remedial Design and Remedial Action Work Plan for LHAAP-04*, incorporating responses to EPA and TCEQ comments has been uploaded to the portal under Documents/Recent. Hard copies and CDs were sent today via UPS and should be delivered to you tomorrow. The document can be accessed directly on the portal via the link below. Please let us know if you have any comments or questions. Thanks!

04_19 DRAFT FINAL LHAAP-04 Remedial Design and Remedial Action Work Plan

WILLIAM A. FOSS, PG
Scientist IV

APTIM | Environmental & Sustainability

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2500 CityWest Blvd., Suite 1700
Houston, TX 77042

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DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
LONGHORN ARMY AMMUNITION PLANT
POST OFFICE BOX 220
RATCLIFF, AR 72951

April 3, 2019

DAIM-ODB-LO

Mr. Rich Mayer
U.S. Environmental Protection Agency
Federal Facilities Section R6
1445 Ross Avenue
Dallas, TX 75202-2733

Re: Draft Final Remedial Design and Remedial Action Work Plan, LHAAP-04 Former Pilot Wastewater Treatment Plant, Longhorn Army Ammunition Plant, Karnack, Texas, April 2019

Dear Mr. Mayer,

One hard copy and one compact disc (CD) of the above-referenced document are being transmitted to you for your records. The document includes revisions based upon the Environmental Protection Agency's (EPA) comments on the Draft version received on March 5, 2019, and Texas Commission on Environmental Quality's (TCEQ) comments received on March 12, 2019. In accordance with Federal Facility Agreement, this Draft Final will be considered Final after 30 days without further comment. Response to comments on the Draft version of the document are included with this Draft Final.

The document was prepared by Bhate Environmental Associates, Inc., (Bhate) team, on behalf of the Army as part of Bhate's Performance Based Remediation contract for the facility. I ask that Kim Nemmers, Bhate's Project Manager, be copied on any communications related to the project.

The point of contact for this action is the undersigned. I may be contacted at 479-635-0110, or by email at rose.m.zeiler.civ@mail.mil.

Sincerely,

Rose M. Zeiler

Rose M. Zeiler, Ph.D.
Longhorn AAP Site Manager

Copies furnished:
A. Palmie, TCEQ, Austin, TX (letter)
P. Bruckwicki, Caddo Lake NWR, TX (1 hard copy and 1 CD)
A. Williams, USACE, Tulsa District, OK (1 CD)
R. Smith, USACE, Tulsa District, OK (electronic only)
A. Maly, USAEC, San Antonio, TX (1 CD)
K. Nemmers, Bhate, Lakewood, CO (1 CD)
P. Srivastav, APTIM, Houston, TX (letter)

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
LONGHORN ARMY AMMUNITION PLANT
POST OFFICE BOX 220
RATCLIFF, AR 72951

April 3, 2019

DAIM-ODB-LO

Ms. April Palmie
Texas Commission on Environmental Quality
Superfund Section, MC-136
12100 Park 35 Circle, Bldg D
Austin, TX 78753

Re: Draft Final Remedial Design and Remedial Action Work Plan, LHAAP-04 Former Pilot Wastewater Treatment Plant, Longhorn Army Ammunition Plant, Karnack, Texas, April 2019

Dear Ms. Palmie,

One hard copy and one compact disc (CD) of the above-referenced document are being transmitted to you for your records. The document includes revisions based upon the Environmental Protection Agency's (EPA) comments on the Draft version received on March 5, 2019, and Texas Commission on Environmental Quality's (TCEQ) comments received on March 12, 2019. In accordance with Federal Facility Agreement, this Draft Final will be considered Final after 30 days without further comment. Response to comments on the Draft version of the document are included with this Draft Final.

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The point of contact for this action is the undersigned. I may be contacted at 479-635-0110, or by email at rose.m.zeiler.civ@mail.mil.

Sincerely,

Rose M. Zeiler

Rose M. Zeiler, Ph.D.
Longhorn AAP Site Manager

Copies furnished:
R. Mayer, USEPA Region 6, Dallas, TX (letter)
P. Bruckwicki, Caddo Lake NWR, TX (1 hard copy and 1 CD)
A. Williams, USACE, Tulsa District, OK (1 CD)
R. Smith, USACE, Tulsa District, OK (electronic only)
A. Maly, USAEC, San Antonio, TX (1 CD)
K. Nemmers, Bhate, Lakewood, CO (1 CD)
P. Srivastav, APTIM, Houston, TX (letter)

Response to Comments on Draft Remedial Design / Remedial Action Work Plan LHAAP-04 Former Pilot Wastewater Treatment Plant, Longhorn Army Ammunition Plant, Karnack, Texas

Document Date: 20 February 2019
Comment Date: 5 March 2019

Reviewer: Mr. Richard Mayer, USEPA
Respondent: Dr. Rose Zeiler

1. Respondent Concurs (C), Does Not Concur (D), Takes Exception (E), or Delete (X)
2. Commenter Agrees (A) with response, or Does Not Agree (D) with response

Comment No.	Section, Page ref.	USEPA Comment	C, D, E, or X[1]	Response	A or D[2]
1.	Section 2.5, Page 2-5, Last Paragraph	While the Fire Station was not used as a public supply well, EPA believes that the well was originally used for drinking water (for fire station employees) for a short period but was discontinued due to bad taste. The well continued to be used for showering and washing, etc. The water from the well was also chlorinated for some time, as chlorine cylinders were eventually removed from the well house.	C	The first two sentences of the last paragraph of Section 2.5 will be revised as follows: While the Fire Station well was installed to supply industrial process water for the groundwater treatment system, it may have been used briefly for drinking water and non-potable contact use by fire station employees. The well is not currently used or planned to be used as a public supply well or drinking water source.	
2.	Figure 2-2	The potable wells labelling on this figure should be changed to non-potable to be consistent with the narrative discussion.	C	Figure 2-2 has been revised to label the three water supply wells on LHAAP as “Non-Potable Water Supply Wells”	
3.	Figure 4-1	The LUC boundary should be larger than indicated on the figure if you consider the perchlorate contamination found in 04WW05 and 04HP012.	C	The Army and USFWS will coordinate revision of the LUC boundary to reflect the plume expansion beyond the Army property line onto the refuge. The revised LUC boundary will be published in the Response Action Completion Report. The process described in Section 4.1 will be followed to implement and record the revised LUC boundary.	

Comment No.	Section, Page ref.	USEPA Comment	C, D, E, or X[1]	Response	A or D[2]
4.	Appendix A, Sample Collection Logs	Monitoring wells 04WW07 and LHSMW01 have a 0 reading [for turbidity] from the beginning to the end of the purge. Are those readings correct?	C	The turbidity readings shown on the form match the values recorded in the field. The logs for 04WW01 and 04WW10, collected on the same day immediately before and immediately after the two wells in question, both show measurable turbidity values, indicating that the meter was functioning properly.	
5.	Table 7-1	The schedule indicates that it will take one day to conduct the baseline sampling and gauging of the wells. There are 14 wells in the baseline sampling according to table 6-1. One day for sampling and gauging the wells seem rather optimistic.	C	Table 7-1 has been revised to show a 3-day duration for the baseline sampling.	

Response to Comments on
Draft Remedial Design / Remedial Action Work Plan
LHAAP-04 Former Pilot Wastewater Treatment Plant,
Longhorn Army Ammunition Plant, Karnack, Texas

Document Date: 20 February 2019
Comment Date: 12 March 2019

Reviewer: Ms. April Palmie, TCEQ
Respondent: Dr. Rose Zeiler

1. Respondent Concurs (C), Does Not Concur (D), Takes Exception (E), or Delete (X)
2. Commenter Agrees (A) with response, or Does Not Agree (D) with response

Comment No.	Section, Page ref.	TCEQ Comment	C, D, E, or X[1]	Response	A or D[2]
1.	Section 5.2.1	Suggest revisions to match LHAAP-16 RAWP page 4-1 where Permitting and Notification are separate sections. Also, TCEQ needs 30-days for UIC coordination (as indicated in the schedule).	C	The text in section 5.2 has been revised to split Permitting and Notification as requested. The 30-day UIC coordination with TCEQ is noted.	
2.	Table 2-1	Completion dates for the most recent wells are incorrect.	C	The dates for the wells have been revised on the table and on the boring logs to reflect the actual completion date for each well.	
3.	Figure 4-1	LUC boundary doesn't include the entire plume.	C	The Army and USFWS will coordinate revision of the LUC boundary to reflect the plume expansion beyond the Army property line onto the refuge. The revised LUC boundary will be published in the Response Action Completion Report. The process described in	

Comment No.	Section, Page ref.	TCEQ Comment	C, D, E, or X[1]	Response	A or D[2]
				Section 4.1 will be followed to implement and record the revised LUC boundary.	

Draft Final
Remedial Design and Remedial Action Work Plan, LHAAP-04 Former Pilot Wastewater Treatment Plant

Longhorn Army Ammunition Plant
Karnack, Texas

Prepared for U.S. Army Corps of Engineers, Tulsa District
Contracting Division
2488 East 81st Street
Tulsa, Oklahoma 74137-4290

Prepared by

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INFRASTRUCTURE

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Prepared by

APTIM

Aptim Federal Services, LLC
2500 CityWest, Suite 1700
Houston, Texas 77042

Contract No. W9128F-13-D-0012
Task Order No. W9128BV17F0150

Project No. 501032

Rev 0

April 2019

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List of Tables

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Acronyms and Abbreviations

µg/L	micrograms per liter
APTIM	Aptim Federal Services, LLC
Bhate	Bhate Environmental Associates, Inc.
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
COC	constituent of concern
DAP	diammonium phosphate
DNAPL	dense non-aqueous phase liquid
DO	dissolved oxygen
DPT	direct-push technology
ECP	Environmental Condition of Property
EDS-ER™	Electron Donor Solution – Extended Release
EPA	see USEPA
EVO	emulsified vegetable oil
ft bgs	feet below ground surface
GPS	global positioning system
GWTP	groundwater treatment plant
ISB	in situ bioremediation
IWWP	Installation-Wide Work Plan
Jacobs	Jacobs Engineering Group, Inc.
LHAAP	Longhorn Army Ammunition Plant
LOE	lines of evidence
LTM	long-term monitoring
LUC	land use controls
MATOC	Multiple Award Task Order Contract
MCL	maximum contaminant level
MEGA	Multiple Environmental Government Acquisition
MMRP	Military Munitions Response Program
MOA	Memorandum of Agreement
mV	millivolts
NCP	National Contingency Plan
O&M	operation and maintenance
O_2	oxygen
ORP	oxidation-reduction potential

Acronyms and Abbreviations (continued)

PCL	Protective Concentration Level
psi	pounds per square inch
RA	remedial action
RACR	Response Action Completion Report
RA-O	Remedial Action-Operation
RAOs	remedial action objectives
RAWP	Remedial Action Work Plan
RCRA	Resource Conservation and Recovery Act
RD	remedial design
ROD	Record of Decision
ROI	radius of influence
Shaw	Shaw Environmental, Inc.
TAC	Texas Administrative Code
TCEQ	Texas Commission on Environmental Quality
TOC	total organic carbon
TRRP	Texas Risk Reduction Program
U.S. Army	U.S. Department of the Army
USACE	U.S. Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service

1.0 INTRODUCTION

The U.S. Army Corps of Engineers (USACE), Tulsa District, contracted Bhate Environmental, Inc. (Bhate), under the Omaha Multiple Environmental Government Acquisition (MEGA) National Small Business Multiple Award Task Order Contract (MATOC) Environmental Remediation Services with Military Munitions Response Program (MMRP), Task Order No. W9128BV17F0150 to conduct environmental restoration of LHAAP-04 at Longhorn Army Ammunition Plant (LHAAP). The Bhate Team is comprised of Bhate and Aptim Federal Services, LLC (APTIM). LHAAP is an inactive, government owned formerly contractor operated and maintained Department of Defense facility located central east Texas (Figure 1-1). This Remedial Design (RD) and Remedial Action Work Plan (RAWP) describes the basis for the design of the planned remedial action (RA) and the activities and methods planned to implement the RA to address risks associated with contaminated groundwater at LHAAP-04. This RD/RAWP has been developed to implement the selected remedy for LHAAP-04 described in the *Final Record of Decision* (ROD) for LHAAP-04 (AECOM 2016).

1.1 Organization of Work Plan

This document is composed of the following sections:

- **Section 1.0:** "Introduction" summarizes the site background, proposed remedy, and remedial action objectives (RAOs).
- **Section 2.0:** "Site Characteristics" summarizes the geology and hydrogeology of the site, as well as the nature and extent of contamination.
- **Section 3.0:** "In-Situ Bioremediation Remedial Design" describes the basis for design of the in-situ bioremediation (ISB) injections, the calculations used to determine bioremediation and bioaugmentation amendments to be used, and the proposed injection volumes. The section also described monitoring and the lines of evidence (LOE) used to evaluate the performance of the remedy.
- **Section 4.0:** "Land Use Control Remedial Design/Plan" describes the land use controls (LUCs) to be implemented to achieve the remedial objectives.
- **Section 5.0:** "In Situ Bioremediation Work Plan" describes the injection activities and methodologies to be implemented for the in-situ bioremediation component of the remedy.
- **Section 6.0:** "Post-Remedial Monitoring and Reporting" describes the remedial performance monitoring and reporting that will be performed after ISB injections.

- **Section 7.0:** “Schedule” describes the proposed implementation schedule for the RA activities.
- **Section 8.0:** “Operation and Maintenance Procedures” describe the operation and maintenance activities and other routine activities that form part of the final remedy.
- **Section 9.0:** “References” provides a list of references cited in the document.

This work plan also includes the following appendices supporting the main text.

- **Appendix A** includes the boring logs for the newly installed shallow and intermediate zone monitoring wells.
- **Appendix B** includes the calculation sheets and proposed injection volume worksheets for the ISB component of the remedy.
- **Appendix C** includes the Product Specification and Safety Data Sheets for the emulsified vegetable oil (EVO) product used in the RD calculations.
- **Appendix D** includes a blank injection log that will be used in the field to track injection volumes, flow rates and pressures.
- **Appendix E** includes the sample Annual LUC Compliance Checklist and Compliance Certification.

1.2 Site Description

LHAAP is approximately 14 miles northeast of Marshall, Texas, and approximately 40 miles west of Shreveport, Louisiana. The installation occupies approximately 1,400 of its former 8,416 acres between State Highway 43 at Karnack, Texas, and the western shore of Caddo Lake. The facility can be accessed via State Highways 43 and 134.

LHAAP-04, known as Site 04 or the former pilot wastewater treatment plant, is approximately 0.5 acres and is located in the central portion of LHAAP at the northwest corner of 6th and 60th Streets near the former fire station (**Figure 1-2**). LHAAP-04 is surrounded by light duty roads. Wastewater treatment operations began at LHAAP-04 in 1984. The demolition of the former pilot wastewater treatment facility structures, tanks, and piping, and the disposal of the associated wastes were completed in the summer of 1997 as part of the Resource Conservation and Recovery Act (RCRA) closure of the plant. Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) program, excavation of soil impacted with mercury and perchlorate at the LHAAP-04 site was completed in 2009 along the southern edge of the slab, which formerly housed storage tanks for the former pilot wastewater treatment facility.

The U.S. Department of the Army (U.S. Army) issued the Final ROD for LHAAP-04 (AECOM 2016) in October 2016, and was signed by the Army on December 15, 2016, and the U.S. Environmental Protection Agency (USEPA) on March 30, 2017. The Texas Commission on Environmental Quality (TCEQ) issued a letter concurring with the ROD on February 7, 2017. The ROD identified perchlorate as the only constituent of concern (COC) in groundwater for LHAAP-04. The remedy selected in the ROD included in-situ bioremediation (ISB) for perchlorate concentrations in groundwater, long-term monitoring (LTM) of groundwater, and LUCs to maintain the remedy and prohibit groundwater use until COC concentrations are reduced to levels supportive of unlimited use and unrestricted exposure. The selected remedy is summarized further in **Section 1.3**.

1.3 Selected Remedy

The selected remedy was summarized in Section 1.4 of the Final ROD (AECOM 2016) as follows:

- ISB of perchlorate contaminated groundwater in an area in the vicinity of monitoring well 04WW04. Multiple injections of substrate may be needed based on effectiveness of the ISB. Bioaugmentation using appropriate microbial culture to facilitate ISB may be performed, if necessary. Prior to ISB, two shallow zone and one intermediate zone monitoring wells are planned to refine the perchlorate plume configuration.
- LTM to confirm the protection of human health and the environment by documenting the return of groundwater to the cleanup level (maximum contaminant level [MCL] or Texas Risk Reduction Program [TRRP] Tier 1 Residential Groundwater Protective Concentration Level [PCL]) through reduction of the contaminant mass, and by preventing the perchlorate-contaminated groundwater plume from migrating into surface water.
- The LUC objectives include maintaining the integrity of any current or future remedial or monitoring systems and preventing the use of groundwater contaminated above cleanup levels as a potable water source. The groundwater treatment and LTM remedial components include a groundwater monitoring system that will be used to characterize the condition of the groundwater during the period the groundwater remedy is in place until the groundwater remediation goals are achieved, and to demonstrate achievement of the groundwater remediation goals when the groundwater remedy is complete. As a part of this groundwater remedy, the Army will maintain the remedial and monitoring systems associated with the groundwater remedies until these components of the remedy are no longer needed to achieve cleanup levels, and cleanup levels have been achieved. During the period of operation of the groundwater remedy, if any of the elements of the remedial and groundwater

monitoring systems are damaged, destroyed, or become ineffective, they will be repaired or replaced with suitable components to assure that the remedial and groundwater monitoring systems are able to provide data of the quality necessary to determine the progress of and eventual completion of this component of the remedy. The actions to be taken to implement these LUC objectives and requirements will be provided through modifying the "Comprehensive Land Use Control Management Plan, Former Longhorn Army Ammunition Plant, Karnack, Texas" and detailed in the LUC RD.

- The LUC for prohibition of groundwater use (except for monitoring and testing) shall be implemented and shall remain in place at the Site until the levels of COCs in surface and subsurface soil and groundwater are reduced below levels that would support unlimited use and unrestricted exposure. A LUC RD will be finalized as the land use component of the RD. Within 21 days of the issuance of the ROD, the Army will propose deadlines for completion of the RD Work Plan, RD, and RAWP. The documents will be prepared and submitted to the EPA and the TCEQ pursuant to the Federal Facility Agreement. The LUC RD will contain implementation and maintenance actions, including periodic inspections. The LTM groundwater plan will also be presented in the RD. The recordation notification for the Site which will be filed with Harrison County, will include a description of the LUCs.
- CERCLA five-year reviews until the levels of COCs in groundwater allow for unlimited use and unrestricted exposure.

1.4 Remedial Action Objectives

The RAOs developed for LHAAP-04 and outlined in the Final ROD (AECOM 2016) are:

- Protect human health by preventing ingestion of groundwater contaminated with perchlorate
- Return groundwater to its potential beneficial use, wherever practicable, within a reasonable time period given the particular site circumstances
- Prevent groundwater contaminated with perchlorate from migrating into nearby surface water

The above RAOs recognize the USEPA's policy to return all groundwater to beneficial uses, based on the non-binding programmatic expectation in the National Contingency Plan (NCP) and is consistent with the NCP regulations requiring the lead agency, the U.S. Army in this case, to establish RAOs specifying contaminants and media of concern, potential exposure pathways, and remediation goals.

Per the ROD's RAOs, and consistent with the NCP, groundwater will be returned to its beneficial uses as drinking water. The groundwater cleanup level for perchlorate at the Site is the TRRP Tier 1 PCL for residential groundwater, 17 micrograms per liter (µg/L), and is protective of human health and the environment.

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2.0 SITE CHARACTERISTICS

2.1 Geology and Hydrogeology

LHAAP-04 is situated on the outcrop of the Wilcox Group which generally consists of a few feet of residually derived soils overlying interbedded silts and clays. Based on the site lithology, the shallow zone water bearing sand at monitoring well 04WW04 appears to be only one- to two-feet-thick, and surrounding monitoring wells mostly show clay or silt layers at the same depth.

The depth to groundwater across LHAAP varies with typical depths being 8 to 20 feet below ground surface (ft bgs) in the shallow zone. The regional groundwater flow direction beneath the facility is generally east- northeast towards Caddo Lake but varies by site location (Jacobs 2002).

As required by the Final ROD (AECOM 2016), two additional shallow groundwater monitoring wells (04WW06 and 04WW07) and one intermediate zone monitoring well (04WW08) were installed to refine the perchlorate plume configuration. The boring logs for these wells are included as **Appendix A**.

Shallow groundwater at LHAAP-04 has been assessed via twelve monitoring wells installed near LHAAP-04 to depths of approximately 20 to 25 ft bgs. An intermediate zone well (04WW08) was installed with a screened interval from 31 to 41 ft bgs and confirmed that the intermediate zone was present. Well construction information is shown on **Table 2-1**. Based on the 2018 and 2019 potentiometric surface maps (**Figure 2-1a** and **Figure 2-1b**), the groundwater flow direction in the shallow saturated zone below LHAAP-04 is to the southwest across the area of the site where perchlorate concentrations exceed the PCL. The groundwater elevations measured in January 2019 were 1 to 3 feet higher than those measured in January 2018, which is reflective of the increased recharge to the shallow aquifer from the unusually high rainfall received during 2018.

Rising head slug tests were performed on one well near LHAAP-04 to calculate hydraulic conductivity values using the Bouwer-Rice method. The hydraulic conductivity value for the shallow saturated zone was 3.5×10^{-5} centimeters per second at well LHSMW01 (Shaw 2012).

Goose Prairie Creek runs approximately 700 feet to the south of LHAAP-04 site as shown on **Figure 2-2**. Based on the network of monitoring wells located at the site, perchlorate-impacted groundwater in the shallow zone does not appear to have migrated more than 100 feet from the source area, indicating no threat to Goose Prairie Creek. Groundwater modeling also concluded there should be no impact to surface water from shallow zone groundwater

(Shaw 2007). The modeling was conservative, utilizing the highest previously detected perchlorate concentration in groundwater at the source (78,200 µg/L) that was approximately 1000 times the highest groundwater concentration measured at LHAAP-04 in 2018 (78 µg/L). Finally, perchlorate concentrations in surface water samples collected in 2010 and 2011 were less than the TRRP Tier 1 Groundwater Residential PCL (AECOM 2016).

2.2 Nature and Extent of Contamination

The former pilot wastewater treatment plant was the most likely source of contaminants being released into the environment. Since the plant has been removed and the mercury and perchlorate contaminated soil associated with leaks and/or spills from the plant was excavated in a non-time critical removal action in 2009 (Shaw 2011), there is no longer a potential soil source for releases to groundwater. The groundwater to surface water migration pathway is not complete under current conditions. Protection of surface water will be confirmed with groundwater monitoring and evaluation of plume behavior with implementation of the groundwater remedy (AECOM 2016). The only groundwater COC for LHAAP-04 identified in the Final ROD (AECOM 2016) is perchlorate.

2.2.1 2017 Monitoring Well Installation and Sampling

As required in the ROD, two additional shallow groundwater monitoring wells (04WW06 and 04WW07) and one intermediate zone monitoring well (04WW08) were installed in December 2017 (**Figure 2-3**). Ten monitoring wells at LHAAP-04 were sampled in January 2018 to determine the current plume conditions from which to plan the RD. The concentration at 04WW04 was significantly lower than the previous concentrations detected in 2011, upon which the ROD was based. The perchlorate concentration at 04WW05 also increased to above the PCL, indicating that the plume may have shifted slightly to the south and west, but the lack of monitoring locations west of 04WW05 meant the plume was not fully delineated. The January 2018 concentrations observed in the remaining wells were less than the PCL. The intermediate zone well (04WW08) contained a perchlorate concentration of 1.5 µg/L, well below the PCL and not indicative of significant vertical plume migration.

2.2.2 Supplemental Groundwater Investigation

Due to the undelineated western edge of the shallow perchlorate plume, a supplemental groundwater sampling investigation was performed in accordance with a Technical Memorandum (Bhate 2018a) that was revised and approved by EPA and TCEQ. The purpose of the investigation was to collect groundwater samples to delineate the western and southern plume boundaries. The work proposed in the Technical Memorandum included groundwater sampling at 12 direct-push technology (DPT) points in a phased manner, installation of three monitoring wells, and a round of groundwater sampling from the existing shallow wells and the three new wells. Eight initial DPT borings (04HP01 through 04HP08) were drilled in

November 2018 using a tractor mounted direct-push sampling rig. Groundwater samples were collected in accordance with the procedures outlined in the Technical Memorandum (Bhate 2018a).

The analytical results from the first eight DPT sample locations were used to select the four additional locations to be sampled. The four additional DPT borings were drilled and groundwater sampled in December 2018. One of the borings was inadvertently drilled at the wrong location, so a fifth location was drilled in the proper location. The analytical results from all 13 locations are shown on **Figure 2-3** and were used to select the locations for three new monitoring wells to be installed. The coordinates for the DPT locations shown on **Figure 2-3** were measured in the field using a Trimble handheld GPS unit and are accurate to within approximately two feet. The perchlorate concentrations detected at 04HP01 and 04HP05 confirmed that high levels of perchlorate were still present in the vicinity of the soil excavation area but had shifted slightly west from 04WW04. Non-detect results at 04HP02, 04HP03, 04HP09, 04HP10, 04HP11, and 04HP13 successfully delineated the western and southern extent of the plume.

Three 4-inch-diameter wells were installed in January 2019. One shallow monitoring well (04WW11) was installed to the west of 04HP05 to provide a downgradient clean well to bound the plume for future monitoring, while two monitoring wells (04WW09 and 04WW10) were placed adjacent to the DPT locations with the highest perchlorate concentrations detected. The well locations are shown on **Figure 2-3**.

Upon completion of the monitoring well installations, they were developed and sampled along with the nine existing shallow monitoring wells in January 2019. **Figure 2-3** shows the 2010, 2011, 2018, and 2019 perchlorate concentrations detected and shows a plume boundary based on the January 2019 analytical results. Based on the 2019 results, there is a hot spot centered along the western boundary of the soil excavation area. The concentrations are similar in magnitude to those previously detected at 04WW04 and indicate that the plume has moved slightly west from 04WW04 between 2010-2011 and 2019.

2.3 Current and Future Land Use

LHAAP is located near the unincorporated community of Karnack, Texas. Karnack is a rural community with a population of approximately 775 people. The incorporated community of Uncertain, Texas, approximate population 205, is located to the northeast of LHAAP on the edge of Caddo Lake and is a resort area and an access point to Caddo Lake. The industries in the surrounding area consist of agriculture, timber, oil and natural gas production, and recreation.

LHAAP has been an industrial facility since 1942. Production activities and associated waste management activities continued until the facility was determined to be in excess of the U.S. Army's needs in 1997. The plant area has been relatively dormant since that time. LHAAP is surrounded by a fence (except on the border with Caddo Lake) with an access gate that is locked after daylight hours, which restricts public access. The fence now represents the National Wildlife Refuge boundary. The public can access most of the facility during the day with additional fencing and signage restricting access from environmental sites.

The reasonably anticipated future use of LHAAP-04 is as part of a national wildlife refuge. This anticipated future use is based on a Memorandum of Agreement (MOA) (U.S. Army 2004) between the U.S. Fish and Wildlife Service (USFWS) and the U.S. Army. That MOA documents the transfer process of the LHAAP acreage to USFWS to become the Caddo Lake National Wildlife Refuge and will be used to facilitate a future transfer of LHAAP-04. Presently the Caddo Lake National Wildlife Refuge occupies approximately 7,000 acres of the 8,416-acre former installation. In accordance with the National Wildlife Refuge System Administration Act of 1966 and its amendments (16 USC 668dd), the land will remain as a national wildlife refuge unless there is a change brought about by an act of Congress, or the land is part of an exchange authorized by the Secretary of the Interior. (AECOM 2016).

2.4 Current and Future Surface Water Use

There are no surface water bodies present within LHAAP-04. Surface water runoff from LHAAP-04 drains toward the southern branch of Goose Prairie Creek, located approximately 700 feet south of LHAAP-04, and which flows into Caddo Lake, a large recreational lake covering 51 square miles with a mean depth of 6 feet. The watershed of the lake encompasses approximately 2,700 square miles. Caddo Lake is used extensively for fishing and boating and provides drinking water supply to multiple cities/towns. The anticipated future uses of surface water are the same as the current uses.

2.5 Current and Future Groundwater Use

Groundwater in the drinking water aquifer (250 to 430 ft bgs) under and near LHAAP is currently used as a drinking water source. The drinking water aquifer should not be confused with LHAAP "deep zone" groundwater, which extends only to a depth of approximately 151 ft bgs. The aquifer containing contaminated groundwater and the aquifer utilized for drinking water are distinct from each other with no connectivity. TCEQ identifies six active public water supply wells completed in the drinking water aquifer near LHAAP (see **Figure 2-2**). Karnack Water Supply Corporation operates two source wells servicing the town of Karnack. These wells were completed in 1905 to depths of 287 and 285 ft bgs and are located hydraulically upgradient approximately one-quarter mile northwest and one-half mile southwest of the town center, respectively. Caddo Lake Water Supply Corporation operates three source wells located north and northwest of LHAAP that have been in use since 1905. These wells are hydraulically upgradient of LHAAP (Jacobs 2002) with completion depths of 244, 185, and 310 ft bgs. Caddo Lake State Park operates one source well located approximately 1.6 miles northwest upgradient of LHAAP. This well was installed in 1905 with a total depth of 292 feet. Due to the large distance between these wells and LHAAP, water removal from these wells is not expected to affect groundwater flow at the site. In addition, there are several livestock and domestic wells located in the vicinity of LHAAP with depths averaging approximately 250 ft bgs. Because the extent of perchlorate contaminated groundwater is limited, it is not relevant to any of the drinking water wells.

Three water supply wells are located within the boundary of LHAAP itself (**Figure 2-2**). One well is located at the Fire Station with a total depth of 128 feet and a screened interval from 58 to 128 ft bgs; the second well is located upgradient of LHAAP-04 approximately 0.35 miles southwest of the Fire Station. The third well is located north of the USFWS administration building for Caddo Lake National Wildlife Refuge, near the main entrance to LHAAP. Two additional wells previously supplied water to the installation, but these have been plugged and abandoned. None of these three wells are currently used for drinking water at LHAAP, although they may supply water for non-potable uses.

While the Fire Station well was installed to supply industrial process water for the groundwater treatment system, it may have been used briefly for drinking water and non-potable contact use by fire station employees. The well is not currently used or planned to be used as a public supply well or drinking water source. The taps in or around the firehouse are not used for drinking water and are marked non-potable. Although the anticipated future use of the facility as a national wildlife refuge does not include the use of the groundwater at LHAAP-04 as a drinking water source, the State of Texas designates all groundwater as potential drinking water, unless otherwise classified, and consistent with 30 Texas Administrative Code (TAC) 335.563(h)(1). To be conservative, a hypothetical industrial use scenario was evaluated for risk. The future industrial scenario for LHAAP assumes limited use of groundwater as a drinking water source.

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3.0 IN-SITU BIOREMEDIATION REMEDIAL DESIGN

In general, implementation of ISB will include injection of an electron donor/substrate in the subsurface. The indigenous microorganisms will grow and multiply using injected substrate as a carbon and energy source, thereby degrading perchlorate. The schematic showing the degradation pathway for perchlorate is provided below.

Perchlorate Degradation Pathway

$$\begin{array}{ccccccc} ClO_4^- & \longrightarrow & ClO_3^- & \longrightarrow & ClO_2^- & \longrightarrow & Cl^- + O_2 \\ \text{Perchlorate} & & \text{Chlorate} & & \text{Chlorite} & & \text{Chloride + Oxygen} \end{array}$$

ISB will be implemented at LHAAP-04 to remediate groundwater impacted with perchlorate. The ISB remedy rationale described in Section 2.12.1 of the Final ROD (AECOM 2016) was to treat the hot spot of perchlorate in the vicinity of 04WW04. The 2019 data discussed in **Section 2.2.2** indicates that the hot spot has moved slightly west from 04WW04 to the vicinity of 04WW09 and 04WW10. Accordingly, the remedy described in this section is designed to treat the hot spot with concentrations exceeding five times the 17 µg/L cleanup level (85 µg/L). The ISB system has been designed and implemented to remediate perchlorate in the groundwater down to the PCL using EVO and nutrients as the injected amendments. The EVO and nutrients will be mixed with water and injected using temporary DPT injection points within the plume area currently exceeding the PCL. The specific basis for the various design parameters selected is described in the following sections. Field implementation procedures for the ISB remedy are described in **Section 5.0**. ISB calculation sheets used to develop the RD parameters described below are provided in **Appendix B**.

3.1 Substrate Injection Strategies

The ISB substrate will be injected at approximately 25 temporary DPT locations spaced approximately 20 to 25 feet apart as shown on **Figure 3-1**. A DPT injection system will be used to inject substrate over an eight-foot treatment interval coinciding with the saturated water bearing interval at each proposed injection point. The treatment interval depth will vary depending on the lithologic information from the wells and borings nearest to each injection location. The injection interval will target the saturated sandy and silty zones above the dark gray hard clay typically encountered at approximately 18 to 22 ft bgs. The injection locations within the excavation footprint may be performed slightly deeper to minimize the potential for surfacing of injection fluids through the backfilled area.

Several direct push injection points may be manifolded for simultaneous injection to maximize delivery efficiency. The substrate will be injected at relatively low pressures (generally less than 40 pounds per square inch [psi]) to avoid development of preferential flow pathways within the formation and/or surfacing of injection fluids. The injection pressure at each injection location will be dictated by the formation back pressure on the pumping system but will be controlled by use of pressure relief valves.

3.2 Radius of Influence and Injection Point Spacing

The low hydraulic conductivity and generally silty character of the shallow groundwater zone suggest that the radius of influence (ROI) for each DPT injection location will be low. Based on our experience at other locations on LHAAP and knowledge of the hydrogeologic conditions described in **Section 2.1**, the ROI used to calculate the number of points needed was 10 feet, and the DPT injection point spacing will be 20 to 25 feet.

3.3 Substrate Selection

EVO was selected as the substrate for ISB because of the relative ease of injection and the long lifespan of the substrate. It has previously been estimated that reducing concentrations to below the PCL using ISB at LHAAP-04 would require approximately six years (AECOM 2016). However, given the reduction in maximum concentrations at LHAAP-04 since those estimates were made, it is likely that the site will be fully remediated within the 3 to 5-year lifespan of the initial injections, and subsequent reinjections are likely to be unnecessary. The specific formulation of EVO used to develop the injection volumes for this project is Electron Donor Solution – Extended Release (EDS-ER™) available from Tersus Environmental (**Appendix C**). EDS-ER™ is a water-mixable oil formulated with 100% EVO content (no water in the emulsion). EDS-ER™ is a food-grade carbon and is made from renewable crop-based oils. The use of EDS-ER™ or equivalent is expected to be cost-effective since it would eliminate the need for continuous or more frequent injection of substrate into the subsurface.

EDS-ER™ is provided by the vendor as water-mixable oil that contains no water as shipped; therefore, it will be mixed with water in the field. Use of EDS-ER™ or an equivalent volume of a similar product will reduce the cost and environmental footprint associated with transportation of higher volumes of more dilute substrate to the site. The product mixes easily with water and does not require high energy mixers. It formulates a completely miscible product when mixed with water (it does not create emulsions or particles in water), thus preventing clogging effects when injected in groundwater. A mixing tank located adjacent to the location of the planned injection area will be used to mix the product with water. The product will be added to the tank in the volume desired, followed by pumping clean potable water into the tank to produce the mixture with the design concentration for injection. No mixers will be required due to the nature of the EDS-ER™ oil. The manufacturer's product information sheet is provided in **Appendix C**.

The indigenous microbial types needed to degrade perchlorate are likely to be present in the existing groundwater; therefore, no bioaugmentation is anticipated to be necessary. However, nutrients in the form of diammonium phosphate (DAP) will provide essential levels of nitrogen and phosphate required for microbial activity. The nutrients will be added to each mixed batch following addition of the mix water, prior to injection.

3.4 Substrate Loading and Injection

The mass of EVO required for the shallow treatment zone shown on **Figure 3-1** was estimated based on comparison of 1) the stoichiometric demand exerted by the native (e.g., dissolved oxygen [DO], nitrate, and sulfate) and anthropogenic electron acceptors, and 2) the quantity of EVO necessary to treat the entire treatment zone when accounting for adsorption to the aquifer material. These calculations were performed using the EOS® Remediation Source Area and dense non-aqueous phase liquid (DNAPL) Design Worksheet version 2.1f dated June 18, 2008. **Appendix B** provides the input and output calculations spreadsheets. The higher of the two values is used for the planned injection quantities.

The aquifer treatment demand based on EOS's 60% carbon product is 5,107 pounds (**Appendix B**). That is equivalent to 3,064 pounds of 100% carbon EDS-ER™. The concentrated solution of EDS-ER will be diluted by mixing 15 gallons of EDS-ER™ and 6 gallons or nutrients with approximately 1,463 gallons of water to achieve the desired treatment volume for each injection point as shown on the treatment area calculation sheet in **Appendix B**. Approximately 36,945 gallons of dilute EDS-ER™ mixture will be injected into 25 injection points shown on **Figure 3-1**.

3.5 Performance Monitoring

Per the Final ROD (AECOM 2016), performance monitoring will be performed on a quarterly basis for a period of two years and will include analysis of perchlorate and geochemical parameters (sulfate, nitrate, nitrites, alkalinity). Field parameters will include DO, redox potential and ferrous ion. Performance monitoring activities are discussed in greater detail in **Section 7.2.3**. Annual reports will be prepared to document the effectiveness of the treatment. The first year annual report will include a review of the four quarters of data and provide an evaluation of the effectiveness of the selected remedy.

3.6 Long-Term Monitoring

Per the Final ROD (AECOM 2016), LTM will begin in Year 3 after treatment and will be conducted semiannually for 3 years (through Year 5), and annually thereafter. Additional details regarding LTM are provided in **Section 7.2.4**.

3.7 Remedy Evaluation and Follow-up Injections

Remedial performance will be evaluated using two primary LOEs to determine if the remedy is operating properly:

- Plume stability (i.e., plume concentrations are declining in the performance wells, and the plume is not expanding in area as demonstrated by downgradient monitoring wells)
- Reducing conditions conducive for the degradation of perchlorate are present within the treatment area

Follow-up injections may be needed if the remedy is determined to not be performing, although reinjections are not expected to be needed within the 3 to 5-year lifespan of the EVO mixture selected. Nonetheless, the decision for reapplication of organic carbon will be made based on groundwater monitoring results. Three criteria for determining the potential need to reinject are:

- Contaminant concentrations in groundwater are not trending downward at a rate indicative of achieving the cleanup level in approximately six years
- Depletion of the organic carbon to below 20 mg/L
- Oxidation-reduction potential (ORP) increases above -50 millivolts (mV)

If one or more of the criteria described above are met for two consecutive sampling events in the same sampling location, the need for additional injections in that area will be evaluated.

4.0 LAND USE CONTROLS REMEDIAL DESIGN/PLAN

This section describes the LUC RD for LHAAP-04. In accordance with the Final ROD (AECOM 2016), the LUC RD will be finalized as the land use component of the RD.

Per the Final ROD (AECOM 2016), LUCs' performance objectives are to:

- Prohibit the use of groundwater (except for environmental testing and monitoring) as a potable water source
- Restrict land use to nonresidential
- Maintain the integrity of any current or future remedial or monitoring systems

The implementation, maintenance, and inspection requirements associated with each of the performance objectives that comprise this LUC RD are described below. The proposed actions to be taken to implement the LUC objectives during the RA phase are described in **Section 6.0**. The implementation activities, as well as ongoing maintenance, monitoring and reporting requirements will be presented in the Remedial Action Completion Report (RACR), as the final LUC RD. Upon regulatory review and concurrence with the final LUC RD, it will be included as part of the Comprehensive LUC Management Plan.

For portions of the Site subject to LUCs that are not owned by the Army, the Army will monitor and report on the implementation, maintenance, and enforcement of LUCs, and coordinate with federal, state, and local governments and owners and occupants of properties subject to LUCs. The Army remains responsibility for ensuring that the remedy remains protective of human health and the environment.

4.1 LUC Implementation

The actions required to implement the LUCs for LHAAP-04 are described below. The first of these, the initial notice of LUCs, was completed on June 26, 2017. The June 26, 2017, Notice letters that were sent to relevant government officials (U.S. Army 2017) included a preliminary LUC boundary shown on **Figure 4-1**. The following actions will be undertaken to implement the LUCs for LHAAP-04:

- Finalize the boundary for the LUCs as a part of the RA.
  - Revise the boundary, if necessary, based on perchlorate results from the baseline groundwater sampling. The final boundary of the groundwater LUCs (prevent the use of groundwater contaminated above cleanup levels as a potable water source and prohibit access to the contaminated groundwater except for environmental monitoring and testing only); the remedial or monitoring system

LUCs (maintain the integrity of any current or future remedial or monitoring systems); and, the nonresidential land use LUC (restrict land use to nonresidential) will be reviewed during RA activities after an evaluation of the baseline data has been completed and revised if necessary.

  - Survey the LUC Boundaries. The boundaries will be finalized after concurrence by USEPA and TCEQ, and the LUC boundaries will be surveyed by a State-licensed surveyor. A legal description of the surveyed areas will be appended to the survey plat.

- Record the LUCs in Harrison County. The LUC plat, legal description and LUC restriction language will be recorded in the Harrison County Courthouse in accordance with TAC Title 30, §335.566.
- Notify the Texas Department of Licensing and Regulation of the groundwater LUCs. The Texas Department of Licensing and Regulation will be notified of the groundwater restrictions, which include the prohibition of water well installation for any purpose other than environmental monitoring and testing without prior approval from the Army, the USEPA, and the TCEQ. The survey plat, legal boundary and description of the groundwater restriction LUCs, in conjunction with a locator map, will be provided in hard and electronic copy.
- Provide notice of the LUCs with the revised LUC boundary.
  - Prepare the notice of the groundwater and soil (surface and subsurface) contamination and any land use restrictions referenced in the ROD. The notice will consist of a brief description of the contaminants in groundwater and soil, a written description of the LUCs and a figure depicting the revised LUC boundary.
  - Transmit the notice to federal, state, and local governments involved at this site and the owners and occupants of the properties subject to those use restrictions and LUCs within 90 days of RACR acceptance by the regulators. The notices will be sent to federal, state and local officials including: both U.S. Senators, U.S. Congressman (Texas District 1), State Senator (District 1), State Representative (District 9), Harrison County Judge, Harrison County Commissioner Precinct 1, City of Uncertain Mayor, Leigh Water Supply Corporation Board Members, Caddo Lake Water Supply Corporation Board of Directors, and the Caddo Lake National Wildlife Refuge Manager.

4.2 Maintenance and Monitoring Requirements

The LUCs will be maintained in place as follows:

- The LUCs restricting the use of groundwater to environmental monitoring and testing only and the LUC restricting land use to nonresidential will remain in place until the levels of COCs (i.e., including all hazardous substances, pollutants, and contaminants found at the Site at cleanup levels as listed in Table 2-3 of the ROD) in surface and subsurface soil and groundwater allow for unlimited use and unrestricted exposure.
- The LUC to maintain the integrity of any current or future remedial or monitoring systems will remain in place until groundwater cleanup levels of COCs (i.e., including all hazardous substances, pollutants and contaminants found at the Site at cleanup levels as listed in Table 2-3 of the ROD) are met.

Remedial or Monitoring System LUCs include physical components that require repair and maintenance. These are described in **Section 8.0**. The RAO and Extraction System Inspection and Maintenance Checklists is provided in **Appendix E**.

The administrative maintenance required to ensure the LUCs remain in place and effective until the cleanup levels of the COCs are at levels that allow unrestricted use and unlimited exposure are:

- Annual field inspections of the site to confirm that no violations of the LUCs have occurred. Documentation of the inspection will be included in the Inspection and Maintenance Checklist (see **Appendix E**).
- Annual certifications that no LUC-restricted activities have been authorized and that site conditions and use are consistent with the LUCs. The Certification Form is presented in **Appendix E**.
- Periodic transmittal of a LUC Notice to federal, state, and local authorities and to owners and occupants of LHAAP-04. The notice will include the groundwater and soil (surface and subsurface) contamination and any land use restrictions referenced in the ROD, a written description of the LUCs and a figure depicting the LUC boundaries. The transmittal will coincide with each Five-Year Review and will be documented in the report.
- The final LUC RD appendix of the RACR will be added to the Comprehensive LUC Management Plan and the plan will be provided to the owner or occupant of LHAAP-04.

The U.S. Army will address LUC problems within its control that are likely to impact remedy integrity and shall address problems as soon as practicable.

4.3 LUC Inspection and Monitoring

Beginning with finalization of this RD/RAWP and approval of the Inspection form and the Annual Certification Form, the U.S. Army will undertake inspections and certify continued compliance with the LUC objectives. The U.S. Army, or the transferee after transfer, will retain the LUC Inspection and Certification documents in the project files for incorporation into the five-year review reports, and these documents will be made available to USEPA and TCEQ upon request. In addition, should any violations be found during the certification, the U.S. Army will provide to USEPA and TCEQ, along with the document, a separate written explanation indicating the specific violations found and what efforts or measures have or will be taken to correct those violations. The need to continue inspections and certifications will be revisited at five-year reviews.

4.3.1 Notice of Planned Property Conveyances

Upon transfer of Army-owned property, the Army will provide written notice to the transferee of the LHAAP-04 groundwater contamination and any land use restrictions. Within 15 days of transfer, the U.S. Army will provide written notice to USEPA and TCEQ of the division of implementation, maintenance, and enforcement responsibilities unless the information has already been provided in the LUC RD. The notice will describe the mechanism by which the LUC will continue to be implemented, maintained, inspected, reported, and enforced. Upon transfer, such responsibilities may shift to the transferee via appropriate provisions placed in the Environmental Condition of Property (ECP) or other environmental document for transfer. Although the U.S. Army may transfer responsibility for various implementation actions, the U.S. Army will also retain ultimate responsibility for the remedy integrity. This means that the U.S. Army is responsible for addressing substantive violations of the LUC performance objectives that would undermine the U.S. Army's CERCLA remedy. The U.S. Army also will be responsible for incorporating RD information and outlining the transferee's LUC obligations into property transfer documentation. In the event property is transferred out of Federal control, the LUCs relating to property and groundwater restrictions shall be recorded in the deed and shall be enforceable by the United States and the state of Texas.

4.3.2 Opportunity to Review Text of Intended Land Use Controls

The U.S. Army will provide a copy of the groundwater and land use restriction notification to TCEQ for review and approval prior to its recordation in Harrison County. USEPA will also receive a copy for review. The U.S. Army will produce an ECP or other environmental document for transfer of LHAAP-04, but before executing transfer, the U.S. Army will provide USEPA and TCEQ with a copy of the ECP or other environmental document for transfer so that they may have reasonable opportunity, before transfer, to review all LUC-related provisions.

4.3.3 Notification Should Action(s) which Interfere with Land Use Control Effectiveness be Discovered Subsequent to Conveyance

Should the U.S. Army discover after conveyance of the site any activity on the property inconsistent with the LUC performance objectives, the U.S. Army shall notify USEPA and TCEQ within 72 hours of such discovery. Consistent with **Section 4.3.5** below, the U.S. Army will then work with USEPA, TCEQ and the transferee to correct the problem(s) discovered. This reporting requirement does not preclude the U.S. Army from taking immediate action pursuant to its CERCLA authorities to prevent any perceived risk(s) to human health or the environment.

4.3.4 Land Use Control Enforcement

Should the LUC remedy reflected in this RD fail, the U.S. Army will coordinate with USEPA and TCEQ to ensure that appropriate actions are taken to reestablish its protectiveness. These actions are taken to reestablish its protectiveness. These actions may range from informal resolutions with the USFWS or its lessee, to the institution of judicial action against non-federal third parties. Alternatively, should the circumstances warrant such, the U.S. Army could choose to exercise its response authorities under CERCLA. Should the U.S. Army become aware that any future owner or user of the property has violated any LUC requirement over which a local agency may have independent jurisdiction, the U.S. Army may notify those agencies of such violation(s) and work cooperatively with them to re-achieve owner/user compliance with the LUC.

4.3.5 Modification or Termination of Land Use Controls

The LUCs shall remain in effect until such time as the U.S. Army and USEPA agree that the concentrations of perchlorate in groundwater have met cleanup levels and allow unrestricted use. When this occurs, the LUC will be terminated as needed. The decision to terminate the LUC will be documented consistent with the NCP process for post-ROD changes, potentially including an Explanation of Significant Difference or a Remedial Action Completion Report. If the property has been transferred and a determination by the U.S. Army and USEPA has been made to terminate the LUC, the U.S. Army shall provide to the owner of the property an appropriate release for recordation pertaining to the site and will also timely advise other local stakeholders of the action.

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5.0 IN-SITU BIOREMEDIATION WORK PLAN

ISB will be conducted at LHAAP-04 to remediate groundwater impacted with perchlorate. The Proposed Injection Plan for LHAAP-04 is shown on **Figure 5-1**.

The plume geometry and proposed injections have been developed using the basis and details of the RD in **Section 3.0**. The specific formulation of EVO used to develop the RD is EDS-ER^{TM}. If EDS-ER™ is not available at the time the injections are ready to proceed, an equivalent EVO product will be used, and the volumes of EVO will be adjusted if the EVO content is less than the 100% in EDS-ER™. Details of the pre-mobilization, mobilization, injection, and demobilization field activities are provided in the following sections.

5.1 ISB Injection Plan

To treat the perchlorate impacted groundwater in the shallow groundwater aquifer, a biogrid will be installed by injecting EDS-ER^{TM} or an equivalent EVO product and nutrients, into 25 DPT points as shown in **Figure 5-1**. **Table 5-1** specifies the volume of amendment mixture to be injected at each injection point.

In order to minimize the potential for dispersion of the perchlorate plume due to injections, the outermost ring of injection locations will be injected first, beginning at the downgradient edge (injection locations 4, 8, 14, 20-25, 19, and 13), and injections will proceed counter clockwise and inward, finishing in the center of the perchlorate plume.

5.2 Pre-Mobilization Activities

5.2.1 Permitting

No permitting is required prior to the commencement of field work.

5.2.2 Notification

TCEQ and USEPA will be notified two weeks in advance of commencement of fieldwork activities.

5.2.3 Utility Clearance

Utility location and clearance for intrusive activities will be conducted prior to drilling as follows:

The site health and safety officer will:

- Prepare a map indicating the area(s) where intrusive activity is planned to occur.
- Perform the necessary reviews.

- Contact the Texas Excavation Safety System, Inc. utility notification service by calling 811 or 800 892 0123 or using their online submittal system. This notification is to be made a minimum of three working days prior to the initiation of intrusive activity (excluding Saturdays, Sundays, and holidays), but not greater than 14 days.
- Verify that all underground installations have been located, physically marked, and then noted on the map. If needed, a third-party location service will be used.
- Mark all overhead utilities with kilovolts rating on the map. It is not anticipated that the existing overhead lines will impact the proposed injection location layout.
- Notify the appropriate agencies, contracting officer’s representative, and property owners (when applicable).
- Confirm that utility clearance is complete and documented.

A safety meeting shall be held, and a job safety analysis shall be completed by all personnel who are involved in the intrusive activities prior to initiating work.

5.3 Site Activities

Once the premobilization activities are completed, the field crew, DPT crew, and injection equipment will mobilize to the site to perform the following activities.

5.3.1 Baseline Sampling

Baseline samples will be collected from all of the LHAAP-04 monitoring wells prior to the implementation of injections to characterize the perchlorate concentrations and geochemical conditions in the shallow zone. As discussed in the Final ROD (AECOM 2016) the fire station well will also be sampled during the baseline to determine if additional sampling of the well will be needed during the post-injection monitoring discussed in **Section 7.0**. The baseline sampling results will be compared to sample results collected post-ISB injections. The monitoring network is discussed in **Section 7.0** and will be finalized in the RACR after the baseline sampling has been completed.

5.3.2 Injection Activities

1. Mobilize materials, equipment, mixing tanks, and labor for injections
2. Set up traffic signage and controls as needed
3. Layout injection locations and clear DPT injection points (**Section 5.5.1.1**)
4. Core concrete/asphalt at injection points, if needed, and adjust any points if obstructions are found and push rods to the desired injection interval (**Section 5.4**)

5. Setup amendment, equipment, and materials onsite
6. Begin preparing amendment solution for injection a day before planned injections. Preparation of amendment solution will be a continual activity (**Section 5.5.1.2**)
7. Inject amendments following the sequencing described above using DPT (**Section 5.1** and **5.5.2**)
8. Record injection intervals and volumes during injections (**Appendix D**)
9. Once injection is complete at a DPT injection point, abandon point (**Section 5.4**)
10. Record DPT injection point locations with global positioning system (GPS)

5.3.3 Post Injection Activities

After injections, the site will be restored as needed and the injection personnel and equipment will be demobilized. Groundwater sampling and reporting will be conducted as described in **Section 7.0**.

5.4 DPT Drilling

Drilling will utilize DPT rigs for in situ injections through a probe with a 4-foot injection screen interval. The injections will be performed over an 8-foot injection interval using a top down approach, unless the lithology and field conditions cause persistent jamming or clogging of the injection tooling; in which case a bottom up approach will be used. The injection depth intervals will be adjusted to best treat the saturated zone identified in the nearest monitoring wells or soil boring where lithology was recorded (**Table 5-1**). A total of 25 points will be installed using a DPT rig in accordance with the procedures presented in the Installation-Wide Work Plan (IWWP) (Bhate 2018b). Each DPT point will be abandoned by filling with grout after injections are completed.

5.5 ISB Injection

Placement of DPT points is shown on **Figure 5-1**. **Table 5-1** provides the number of injection points, target depths, volumes of each amendment to be prepared, and target volumes to be injected. The calculations to determine the required volumes are based on the calculation sheets provided in **Appendix B**.

5.5.1 Preparation

5.5.1.1 Location Preparation

Prior to the ISB injection, the site will be cleared of aboveground hazards. A GPS device will be used to locate each injection point. After the third-party utility locator service has marked the underground utilities (if any), the locations will be reviewed to confirm that there are no injection points that will impact any utility. Additionally, the locations will be reviewed to determine if concrete coring is needed at a location. If the concrete is too thick to core at a location, the location will be adjusted as needed. If there are points that are affected by utility locations, the plan will be altered to relocate those points to avoid the utility, while still meeting the injection objectives. The final DPT injection point locations will be recorded with the GPS. Prior to drilling with the DPT at each point, the location will be excavated with a hand auger or post-hole digger to 5 feet to check for underground obstructions/utilities unless the location has been cleared by other means and an exemption authorized.

5.5.1.2 Amendment Preparation

There are various EVO formulations commercially available in the market. EDS-ER^{TM} or an equivalent product will be used for injections. The ISB amendments will be mixed in 2,000 to 4,000-gallon mixing tanks. The tanks will be located at LHAAP-04 adjacent to the injection area. The amendment solution will be mixed prior to the day of injection. The potable water required for mixing will be obtained from the groundwater treatment plant (GWTP) or from an off-base fire hydrant and transported to the mixing tank in a water truck.

Steps required for preparation of ISB amendments are as follows:

- Approximately 24 hours prior to injection, the anaerobic solution will be prepared by adding the required volume of EVO, dilution water, and nutrients into the mixing tank. The same EVO amendment mixture is used for all injection locations. Microbes in the water will grow on a small amount of the carbon, and during respiration, they will use the available oxygen in the mixing tank, creating an anaerobic medium.
- When the solution has become anaerobic, based upon a DO meter reading of less than 1.0 milligrams per liter, the amendments will be injected. The amendment solution will be injected into the subsurface using an injection system, as shown on **Figure 5-2**.
- The injection volume for each point at an injection area along with the associated mass and volume of amendment are provided in **Table 5-1** and are based on 100% EVO oil by weight.

5.5.2 In Situ Injections

5.5.2.1 Injection System

An injection system will be used to allow for multiple DPT injections at a single time under low pressure (i.e., less than 40 psi). The injection system will include volume and pressure gauges, so amendment volume can be recorded for each injection location. The total volumes per well, injection pressures and gallon per minute will be tracked on paper and electronically using the Injection Log in **Appendix D**. The injection system will be connected to each DPT probe using hoses as shown in the schematic on **Figure 5-2**.

5.5.2.2 Monitoring During Injections

During the ISB injections, possible amendment surfacing (also called daylighting) may occur at the ground surface and will be monitored visually. Injection pressures will also be monitored since sudden reductions may be an indication of amendment loss into subsurface, possibly from fracturing induced by the injection or from a high-permeability zone. If daylighting on the surface is observed, injection rates will be reduced. If the reduction in pressure does not eliminate the daylighting, injections will be shut down and the remaining injection volume will be divided among the nearest injection locations to ensure the full design volume is injected in the area. If daylighting into a surface water feature is observed, the injection at that location will cease and necessary measure to capture the fluid released and to maintain the DO levels in the surface water will be implemented, if necessary. The remaining volume will be distributed to the other nearby injection locations. Total organic carbon (TOC) will be monitored in the performance wells during the injections using field methods and approximately 1 week after the completion of injections at an offsite laboratory as an indicator of distribution of the EVO (carbon). TOC will be used as an indicator of amendment distribution in the performance monitoring wells within the injection area (04WW04 and 04WW05).

5.5.3 Remediation Derived Waste Management

Remediation derived waste include the following:

- Groundwater generated from purging of wells prior to sampling
- Decontamination fluids
- Disposable protective clothing and supplies

Wastewater generated from equipment decontamination, well development, groundwater sampling, or other investigative and remedial activities will be stored in 55-gallon drums and transported to the GWTP at LHAAP-18/24 as specified in Section 3.8.2 of the IWWP (Bhate 2018b).

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6.0 POST-REMEDIAL MONITORING AND REPORTING

6.1 Monitoring Network

The monitoring network for the baseline sampling will include all of the LHAAP-04 monitoring wells and the fire station well. A subset of these wells will be selected in the RACR based on the results of the baseline sampling to be used to evaluate the performance of the LHAAP-04 remedy. Performance wells within the treatment area and at impacted locations near the treatment area will be analyzed for perchlorate and TOC, as well as geochemical parameters (sulfate, nitrate, nitrites, and alkalinity) and field parameters (DO, ORP, and ferrous iron). Perimeter wells surrounding the plume area will be used to evaluate plume stability and will be analyzed for perchlorate, DO, and ORP. The preliminary monitoring network wells are shown on **Figure 6-1** but may change based on the results of the baseline sampling.

6.2 Groundwater Sampling

Groundwater sampling events performed for LHAAP-04 will consist of:

- A baseline monitoring event conducted no more than 30 days prior to the initiation of ISB injections
- Performance monitoring that will be conducted quarterly for two years and used to evaluate the performance of the RA
- LTM monitoring that will be conducted semiannually in years 3 through 5 and annually thereafter until the groundwater perchlorate concentrations are below the PCL or the Army and regulators agree that less frequent sampling schedule is more appropriate

Areas around the wells will be cleared of vegetation and biohazards prior to each sampling event to protect the field staff. Low-flow groundwater sampling will be performed in accordance with Section 3.5 of the IWWP. Validated data packages will be provided at the monthly managers meeting as they become available.

6.2.1 Baseline Sampling

All of the LHAAP-04 monitoring wells along with the fire station well will be analyzed for the parameters shown on **Table 6-1** prior to initiating injections to allow establishment of baseline conditions against which the remedial performance can be evaluated.

6.2.2 Evaluation of Injection Effectiveness

Groundwater samples will be collected for TOC analysis from the performance monitoring wells approximately one week after completion of the injections to evaluate effectiveness of the ISB injections.

6.2.3 Performance Monitoring Year 1 and Year 2

Wells included in **Tables 6-1** (as modified in the RACR**)** will be used to monitor the performance of ISB injections and the long-term stability of the plume. The process of biodegradation results in depletion of DO and ORP. Performance monitoring will be conducted to evaluate change in geochemical conditions and perchlorate concentrations and LTM monitoring will be conducted to verify that the plume extent is stable or shrinking. For the first two years post-injection the wells will be analyzed quarterly, with results provided in the monthly manager's meetings and summarized more fully in the Annual Remedial Action-Operation (RA-O) reports described in **Section 6.4**. The number of LTM wells may be reduced based on the RA-O monitoring results and recommendations made in RA-O Reports.

6.2.4 Long-Term Monitoring Years 3 through 5

After two years of quarterly performance monitoring, the monitoring will shift to semiannual LTM monitoring, and the analyte list for the performance wells will be reduced to perchlorate, TOC, and field parameters (DO and ORP). The number of LTM wells may be reduced based on the RA-O monitoring results and recommendations made in RA-O Reports. Monitoring will be discontinued with regulator concurrence after perchlorate concentrations in all wells drop below the PCL. The need for any additional LTM will be discussed in the next Five-Year Review.

6.2.5 Long-Term Monitoring Beyond Year 5

LTM will continue annually after Year 5, if needed, using a monitoring network and analyte list established in the Year 5 RA-O Report based on the ongoing monitoring data.

6.3 Response Action Completion Report

A RACR will be submitted upon implementation of the ISB injection and LUC work plans to document activities performed to complete the RA. Performance monitoring and LTM monitoring results will be included in RA-O Reports.

6.4 Annual RA-O Reports

An Annual RA-O Report will be prepared at the end of each year post-injection to present groundwater monitoring results. The Year 1 and Year 2 Annual RA-O Reports will include an evaluation of the effectiveness of treatment for LHAAP-04. Wells within the plume areas will be evaluated for effectiveness of treatment and wells surrounding the plume will be used to evaluate plume stability. The report will provide recommendations if possible for reducing the number of monitoring wells to be included in the monitoring program and/or frequency of monitoring events. The Annual RA-O Report will also include the annual LUC inspection, and monitoring system operation and maintenance (O&M) discussion.

6.4.1 Remedy Evaluation

Remedial performance will be evaluated using two primary LOEs to determine if the remedy is operating properly:

- Plume stability (i.e., plume concentrations are declining in the performance wells, and the plume is not expanding in area as demonstrated by downgradient monitoring wells)
- Reducing conditions conducive for the degradation of perchlorate are present within the treatment area

Follow-up injections (**Section 6.5**) may be needed if the remedy is determined to not be performing, although reinjections are not expected to be needed within the 3 to 5-year lifespan of the EVO mixture selected. Nonetheless, the decision for reapplication of organic carbon will be made based on groundwater monitoring results.

6.5 Follow-up Injection Criteria

Three criteria for determining the potential need to reinject are:

- Contaminant concentrations in groundwater are not trending downward at a rate indicative of achieving the cleanup level in approximately 6 years
- Depletion of the organic carbon to below 20 mg/L
- ORP increases above -50 mV

If one or more of the criteria described above are met for two consecutive sampling events in the same sampling location, the need for additional injections in that area will be evaluated.

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7.0 SCHEDULE

Table 7-1 shows the estimated duration for each major site activity and timeline. Weather and unknown site conditions could affect this schedule.

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8.0 OPERATION AND MAINTENANCE PROCEDURES

Some components of the final remedy at LHAAP-04 require O&M and those O&M activities are described in this section, along with other routine maintenance activities. The remedy components that require O&M are maintenance of the groundwater monitoring system (this would include all wells that serve some purpose) and maintenance of the LUCs. These activities will be conducted annually unless recommended otherwise during a five-year review. An RA-O Inspection and Maintenance Checklist is presented in **Appendix E**.

8.1 Maintenance of the Current or Future Groundwater Monitoring System

The groundwater monitoring system is comprised of a network of monitoring wells used to implement ISB, monitor progress of the remedial activities, and determine the magnitude and extent of COCs. This system of wells will be inspected and maintained as part of the annual inspection and maintenance program. The monitoring wells will be inspected for the integrity of the pad, bollards, surface casing, and well markings, the presence and accumulation of silt in the well screen, the presence and integrity of a locking mechanism, positive drainage around the well pad, the presence of encroaching vegetation, such as tree roots and weeds, and the presence of biological hazards, such as ant mounds and bee nests. Maintenance activities will be performed as needed and could include replacement of the pads and well markings, resurfacing/painting the well casing and bollards, and redevelopment of the wells. Photo documentation of well conditions will be collected during inspection and maintenance activities. The annual inspection and maintenance activities will be documented in the Annual RA-O reports.

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9.0 REFERENCES

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Tables

Table 2-1
Monitoring Well Completion Summary

Well ID	Zone	Completion Date	Northing [a]	Easting [a]	Ground Surface Elevation (ft amsl) [b,c]	Top of Casing Elevation (ft amsl) [b]	Well Depth (ft bgs) [c]	Top of Screen (ft bgs) [c]	Bottom of Screen (ft bgs) [c]	Well Construction
04WW01	Shallow	29-Nov-00	6958971.173	3305911.786	208.78	212.51	24	13	23	4" SS
04WW02	Shallow	29-Nov-00	6959284.718	3305973.89	212.80	216.70	23	13	23	4" SS
04WW03	Shallow	29-Nov-00	6959561.995	3306189.503	212.38	215.93	25	13	23	4" SS
04WW04	Shallow	18-Aug-10	6959126.04	3305944.13	211.30	214.10	27	8	18	2" PVC
04WW05	Shallow	18-Aug-10	6959066.75	3305863.17	211.00	213.70	26.5	16	26	2" PVC
04WW06	Shallow	12-Dec-17	6859225.38	3305871.99	212.52	215.63	25	15	25	4" PVC
04WW07	Shallow	12-Dec-17	6859038.63	3306006.11	211.66	214.64	20	10	20	4" PVC
04WW08	Intermediate	14-Dec-17	6959148.15	3305963.41	212.07	214.82	41	31	41	10" PVC Surface Casing to 23', 4" PVC well
04WW09	Shallow	15-Jan-19	6959090.67	3305897.71	211.47	214.61	20	10	20	4" PVC
04WW10	Shallow	15-Jan-19	6959041.73	3305928.94	210.40	213.67	19	9	19	4" PVC
04WW11	Shallow	16-Jan-19	6959032.36	3305839.02	209.31	212.01	15.5	5.5	15.5	4" PVC
LHSMW02	Shallow	20-Aug-94	6959133.73	3305705.23	213.75	215.43	16	5.5	15.5	4" PVC riser, 316 SS screen
LHSMW01	Shallow	19-Aug-94	6959159.79	3306087.69	211.19	214.43	16	4.5	14.5	4" PVC riser, 316 SS screen

Notes:

[a] Northing and Easting Coordinates are Texas State Plane Coordinate System, North Central Zone (4202), 1983 North American Datum (NAD 83).

[b] Survey elevations are North American Vertical Datum of 1988 (NAVD 88).

[c] The ground surface elevation is measured at the soil surface adjacent to the well pad.

ID - identification

ft amsl - feet above mean sea level

ft bgs - feet below ground surface

PVC - polyvinyl chloride

SS - stainless steel

Table 5-1
Injection Locations and Amendment Volumes

DPT Location	Amendment Volume per Location			Nearest Monitoring Well	DPT Injection Depths (ft bgs)
	Gallons of EVO (EDS-ER or Equivalent)	Gallons of Nutrients (DAP)	Gallons of Water		
04DPT03, -06, and -07	15	6	1,463	04WW05	12 - 20
04DPT01, -02, -04, and -05	15	6	1,463	04WW09	6 - 14
04DPT08, -09, -10, -11, -12, -13, -14, -17, -18, -19, -20, -24, and -25	15	6	1,463	04WW10	7 - 15
04DPT15, -16, -21, -22, and -23	15	6	1,463	04WW07	7 - 15

Notes:

ft bgs - feet below ground surface

DAP - Diammonium phosphate

DPT - direct-push technology

evo - emulsified vegetable oil

Table 6-1
Proposed Monitoring Network Locations and Analyses

Monitoring Location	Primary Rationale for Well Selection	Proposed Analyses																					
		Baseline								1 Week Post Injection [a]	Performance – Years 1 and 2 (Quarterly)								LTM – Years 3 thru 5 (Semiannual)				
		Perchlorate (314.0)	DO (field reading)	ORP (field reading)	pH (field reading)	Ferrous Iron (field reading)	Alkalinity (2320B)	Anions [b] (E300.0)	TOC (SW9060)	TOC (SW9060)	Perchlorate (314.0)	DO (field reading)	ORP (field reading)	pH (field reading)	Ferrous Iron (field reading)	Alkalinity (2320B)	Anions [b] (E300.0)	TOC (SW9060)	Perchlorate (314.0)	DO (field reading)	ORP (field reading)	pH (field reading)	TOC (SW9060)
04WW05	Performance data within the treatment zone	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
04WW07	Performance data within the treatment zone	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
04WW09	Performance data within the treatment zone	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
04WW10	Performance data within the treatment zone	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
04WW01	Downgradient well for measuring plume stability	✓	✓	✓	✓						✓	✓	✓	✓					✓	✓	✓	✓	
04WW04	Upgradient well for measuring plume stability	✓	✓	✓	✓						✓	✓	✓	✓					✓	✓	✓	✓	
04WW06	Upgradient well for measuring plume stability	✓	✓	✓	✓						✓	✓	✓	✓					✓	✓	✓	✓	
04WW11	Downgradient well for measuring plume stability	✓	✓	✓	✓						✓	✓	✓	✓					✓	✓	✓	✓	
LHSMW01	Crossgradient well for measuring plume stability	✓	✓	✓	✓						✓	✓	✓	✓					✓	✓	✓	✓	
LHSMW02	Crossgradient well	✓	✓	✓	✓						The need for continued sampling of these wells will be determined based on the results of the baseline sampling.												
04WW02	Upgradient well	✓	✓	✓	✓																		
04WW03	Upgradient well	✓	✓	✓	✓																		
04WW08	Intermediate Zone well	✓	✓	✓	✓																		
Fire Station Well	Downgradient well	✓	✓	✓	✓																		

Notes:

[a] To be conducted approximately 7 days after the completion of substrate injection. A second sample will be collected between 30 and 45 days if the results from the first event were inconclusive.

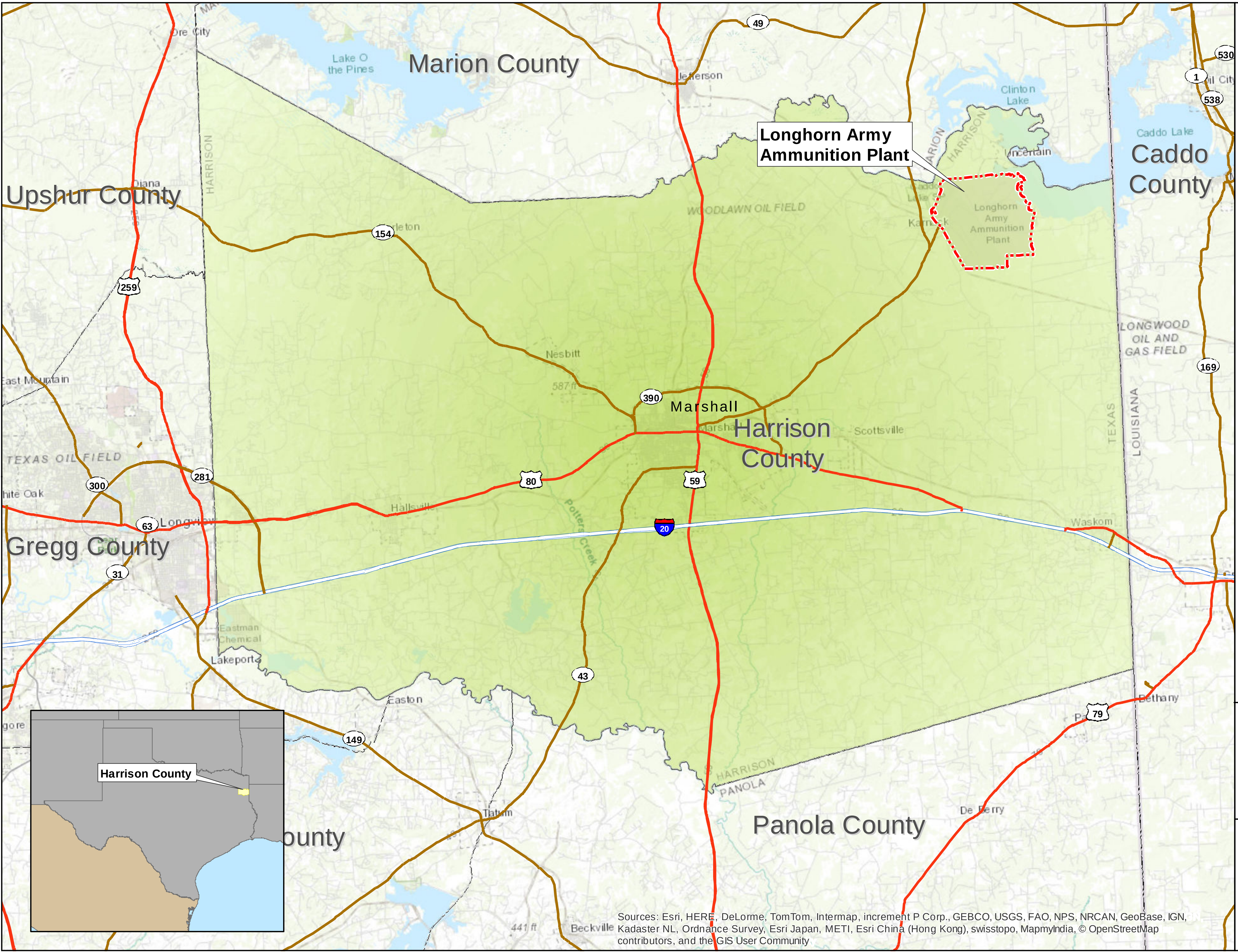
[b] Anions include nitrate, nitrites, and sulfate.

✓ Indicates that sample will be collected and analyzed for the listed analyte.

Table 7-1
Schedule for Major Site Activities

Activities	Duration
Provide Injection Information to State	30
Baseline Sampling and Gauging	3
Utility Clearance	1
Mobilization / Site Set-up for Injections	1
Clear Injection Locations	2
Conduct Injection	9
Demobilization	1
Total Number of Days	47

Figures



Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Date: 2/7/2018

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\RD_RAWP\Fig1-1_LHAAP_LocationMap.mxd

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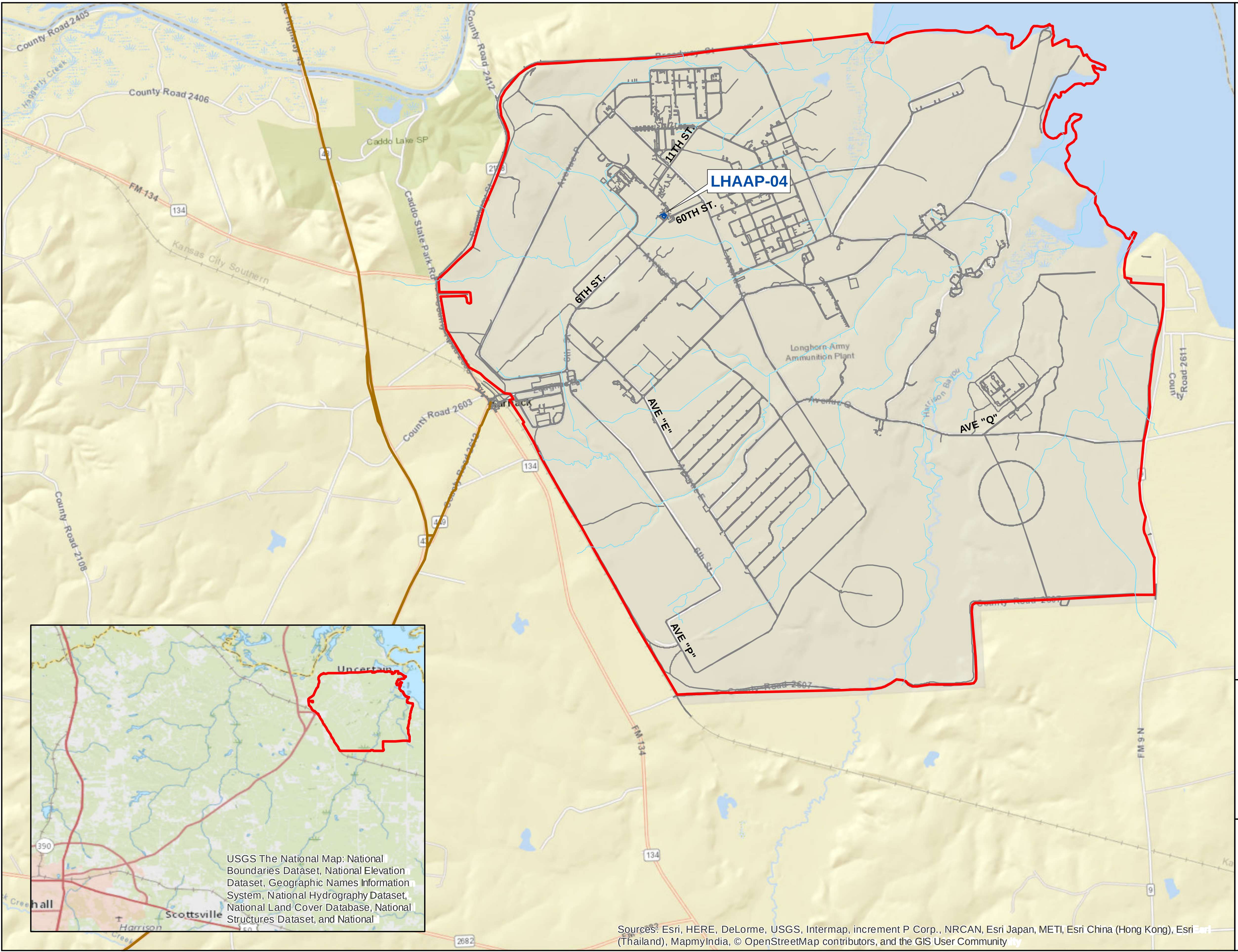
Figure 1-1

LHAAP Location Map
LHAAP-04
Remedial Design/Remedial Action Work Plan
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS



USGS The National Map: National Boundaries Dataset, National Elevation Dataset, Geographic Names Information System, National Hydrography Dataset, National Land Cover Database, National Structures Dataset, and National

Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

〰	Stream
—	Road
🟥	LHAAP Boundary
🟨	LHAAP-04 Site Boundary

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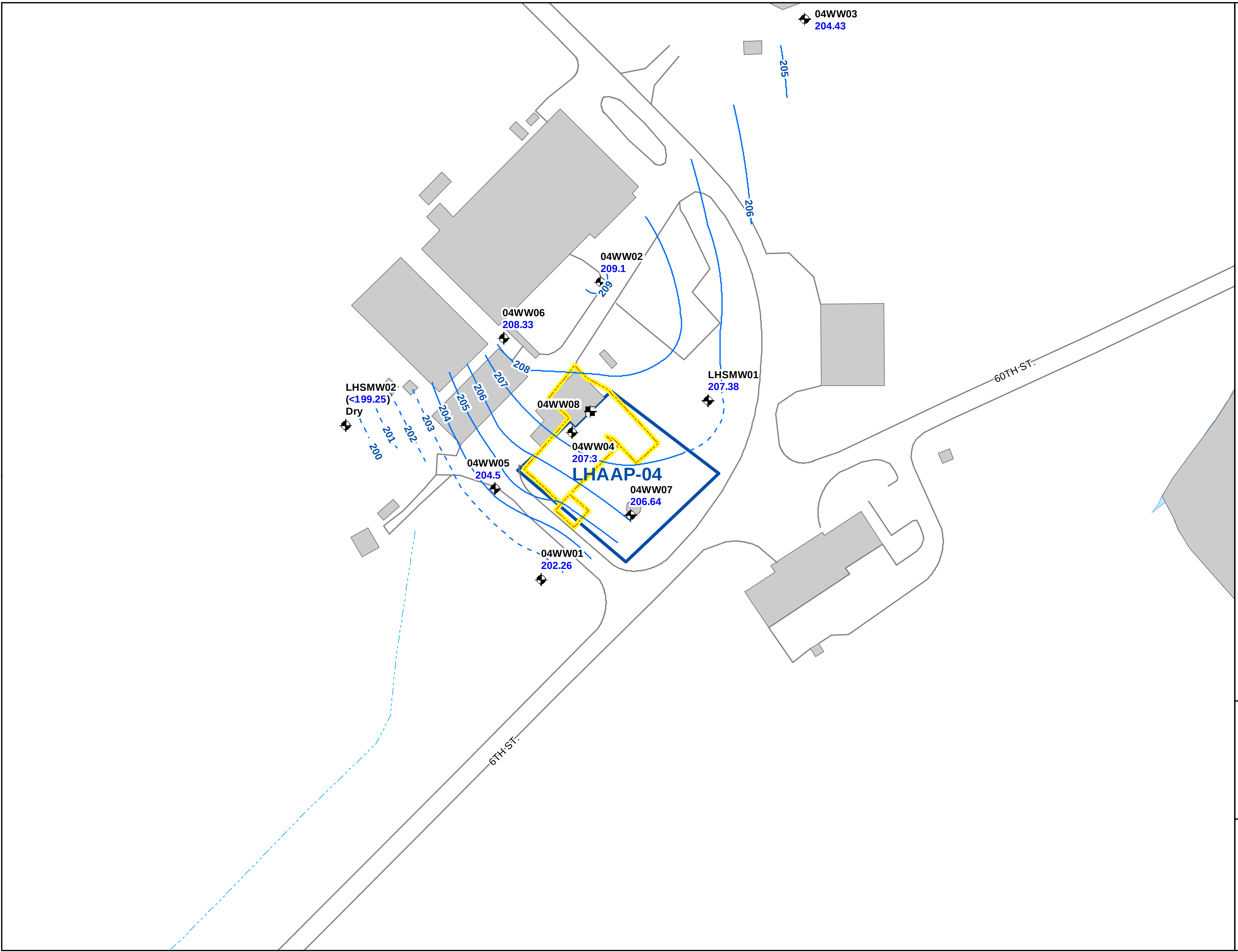
Figure 1-2

LHAAP Site Location Map
LHAAP-04
Remedial Design/Remedial Action Work Plan
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/7/2018

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\RD_RAWP\Fig1-2_LHAAP_SiteLocationMap.mxd



⯐ Shallow Monitoring Well

⯐ Intermediate Monitoring Well

〜 *Groundwater Contour (Dashed where inferred based on bottom of screen elevation in LHSMW02)*

- - - Stream

- - - Limits of Excavation at Surface (*Source: LHAAP-04 Final Completion Report, Shaw, 2011*)

— Road

▨ Building

▭ Site Boundary

▨ Lakes

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Figure 2-1a

Potentiometric Map (January 2018)
LHAAP-04

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 10/18/2018

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\TechMemo\LHAAP04_Jan2018_PotentiometricSurface.mxd

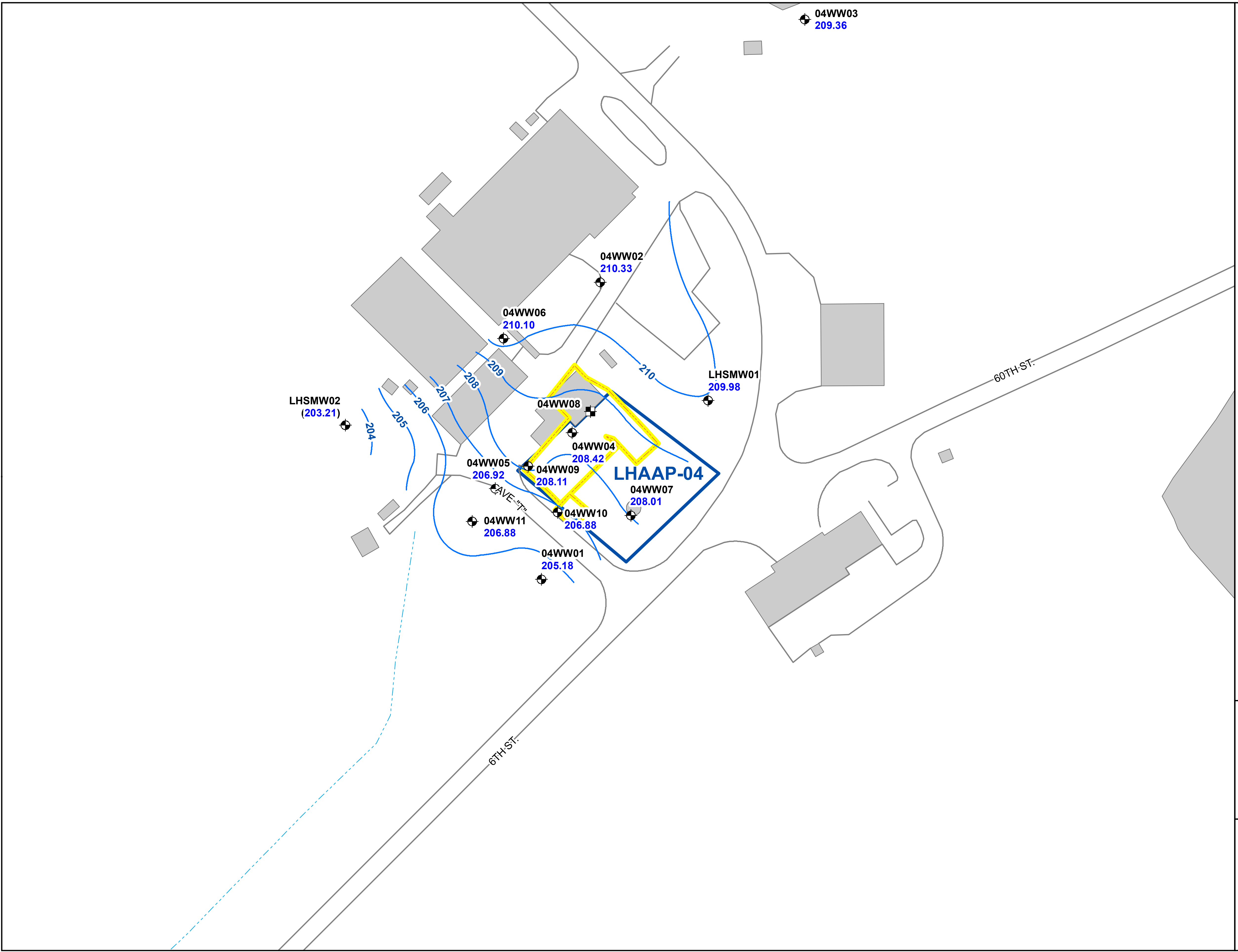

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Figure 2-1b

Potentiometric Map (January 2019)
LHAAP-04

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/7/2019

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\TechMemo\LHAAP04_Jan2019_PotentiometricSurface.mxd

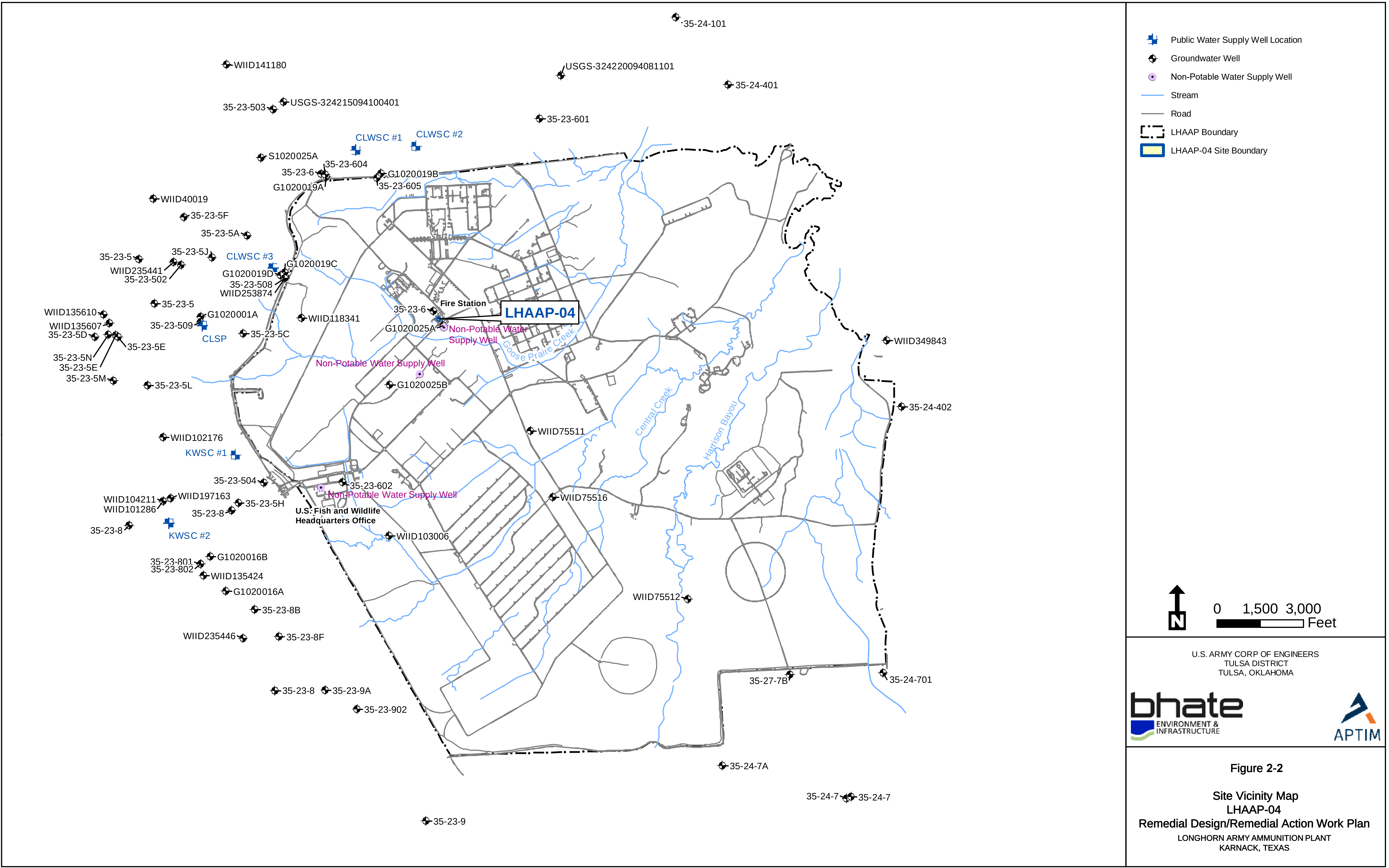

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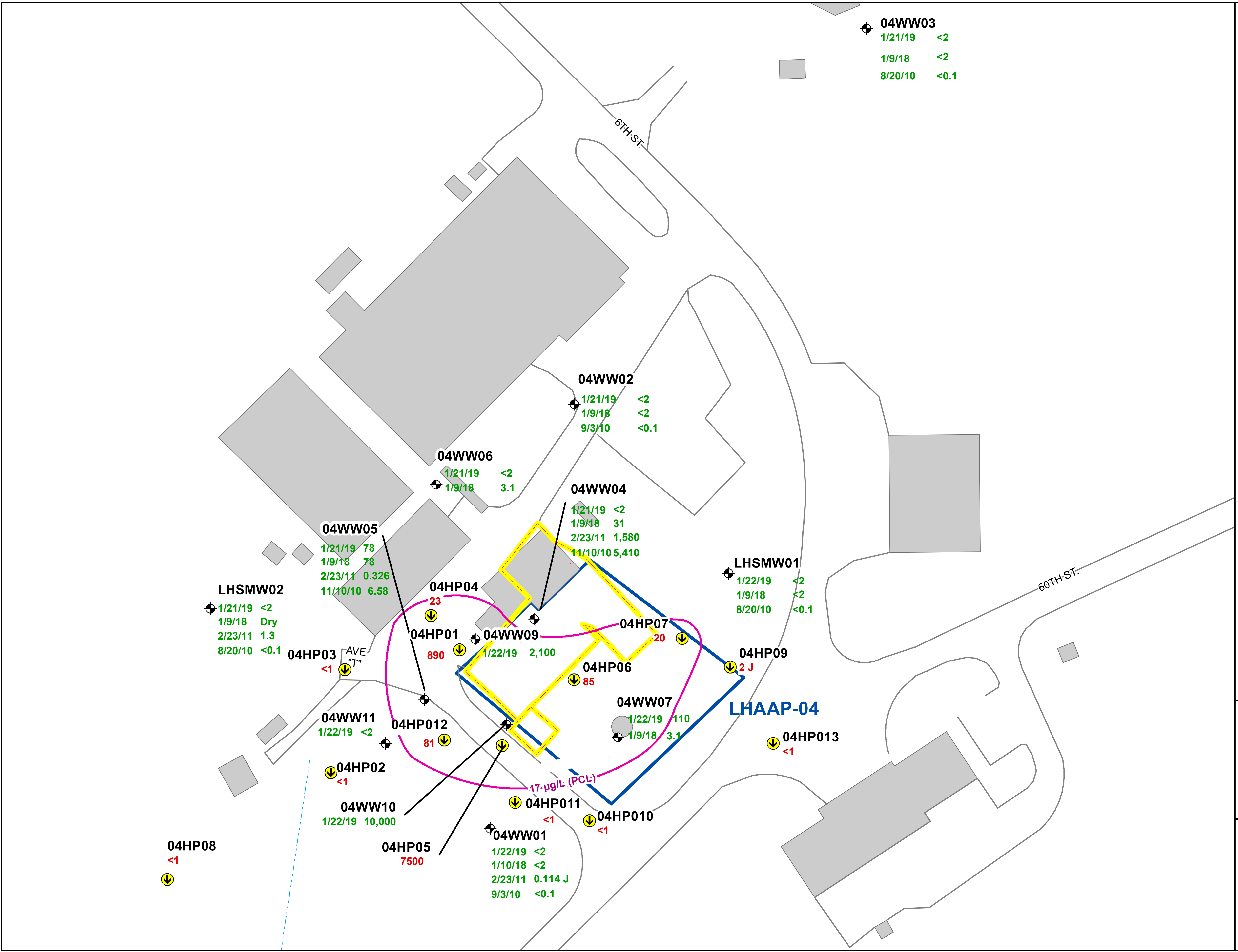
Figure 2-2

Site Vicinity Map
LHAAP-04
Remedial Design/Remedial Action Work Plan
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/7/2018

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\RD_RAWP\Fig1-3_SiteVicinityMap.mxd



⌖ Shallow Monitoring Well

Ⓥ Hydropunch Location

— Perchlorate Plume

- - - Stream

- - - Limits of Excavation at Surface (*Source: LHAAP-04 Final Completion Report, Shaw, 2011*)

— Road

▨ Building

▭ Site Boundary

Note:
1. Perchlorate concentrations reported in micrograms per liter (µg/L).
2. Plume boundaries based on most recent results available at each well (2018-2019).
3. PCL - Texas Risk Reduction Program Protective Concentration Level for Residential Groundwater
4. 85 = Hydropunch November-December 2018 data
110 = 2010, 2011, 2018, and 2019 monitoring well data

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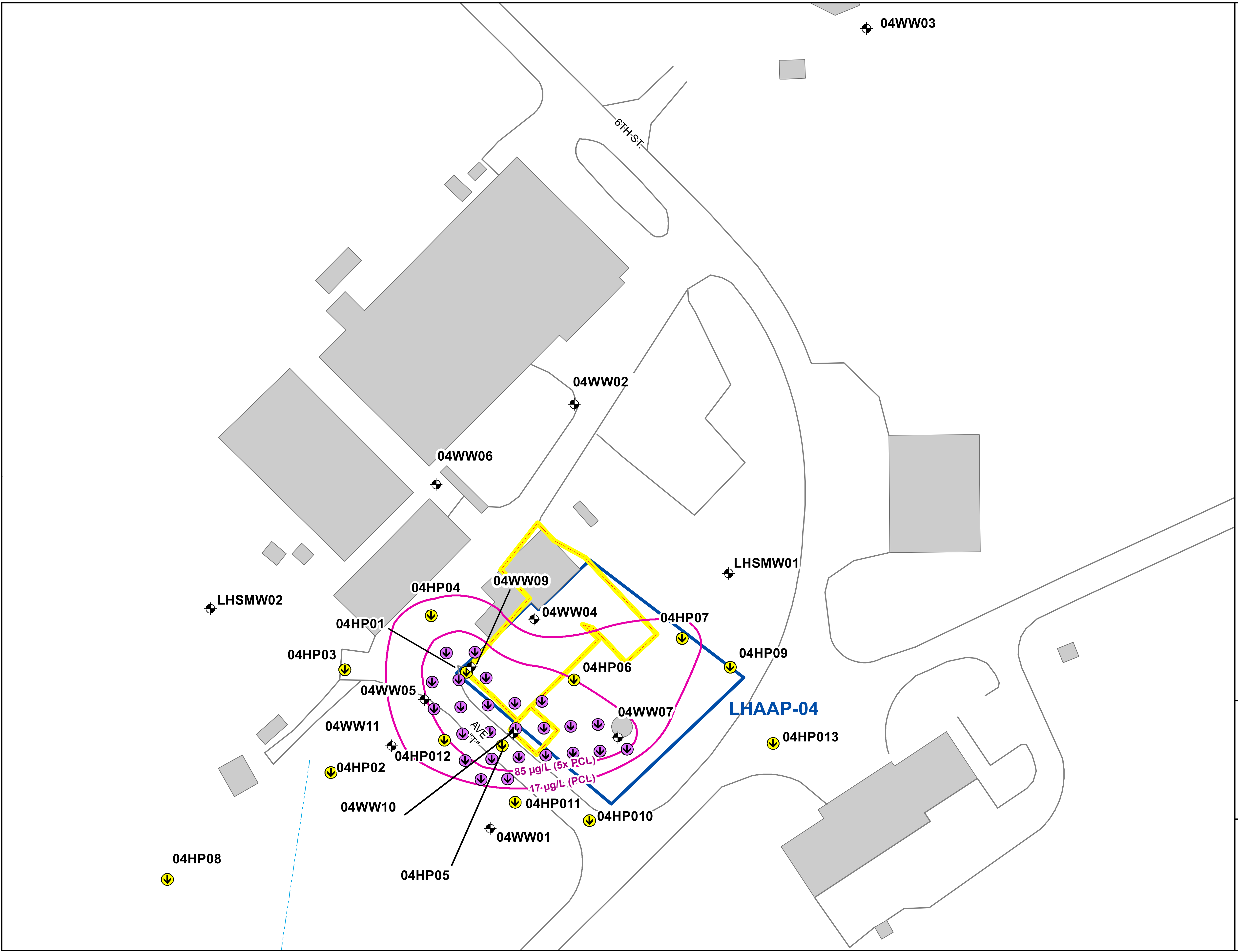
Figure 2-3

Perchlorate Concentrations in Shallow Groundwater at LHAAP-04

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 1/31/2019

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\TechMemo\LHAAP04_ProposedInjectionLocations.mxd



⌖ Shallow Monitoring Well

● Proposed Injection Location

● Hydropunch Location

— Perchlorate Plume

- - - Stream

--- Limits of Excavation at Surface (*Source: LHAAP-04 Final Completion Report, Shaw, 2011*)

— Road

▨ Building

☐ Site Boundary

Note:
1. Plume boundaries based on most recent results available at each well (2018).
2. PCL - Texas Risk Reduction Program Protective Concentration Level for Residential Groundwater
3. The injection pattern generally targets the area within the 85 µg/L contour, but has been shifted to the southwest to account for potential future migration.

N

0 50 100 Feet

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Figure 3-1

Proposed Injection Locations at LHAAP-04

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/14/2019

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\TechMemo\LHAAP04_ProposedInjectionLocations.mxd

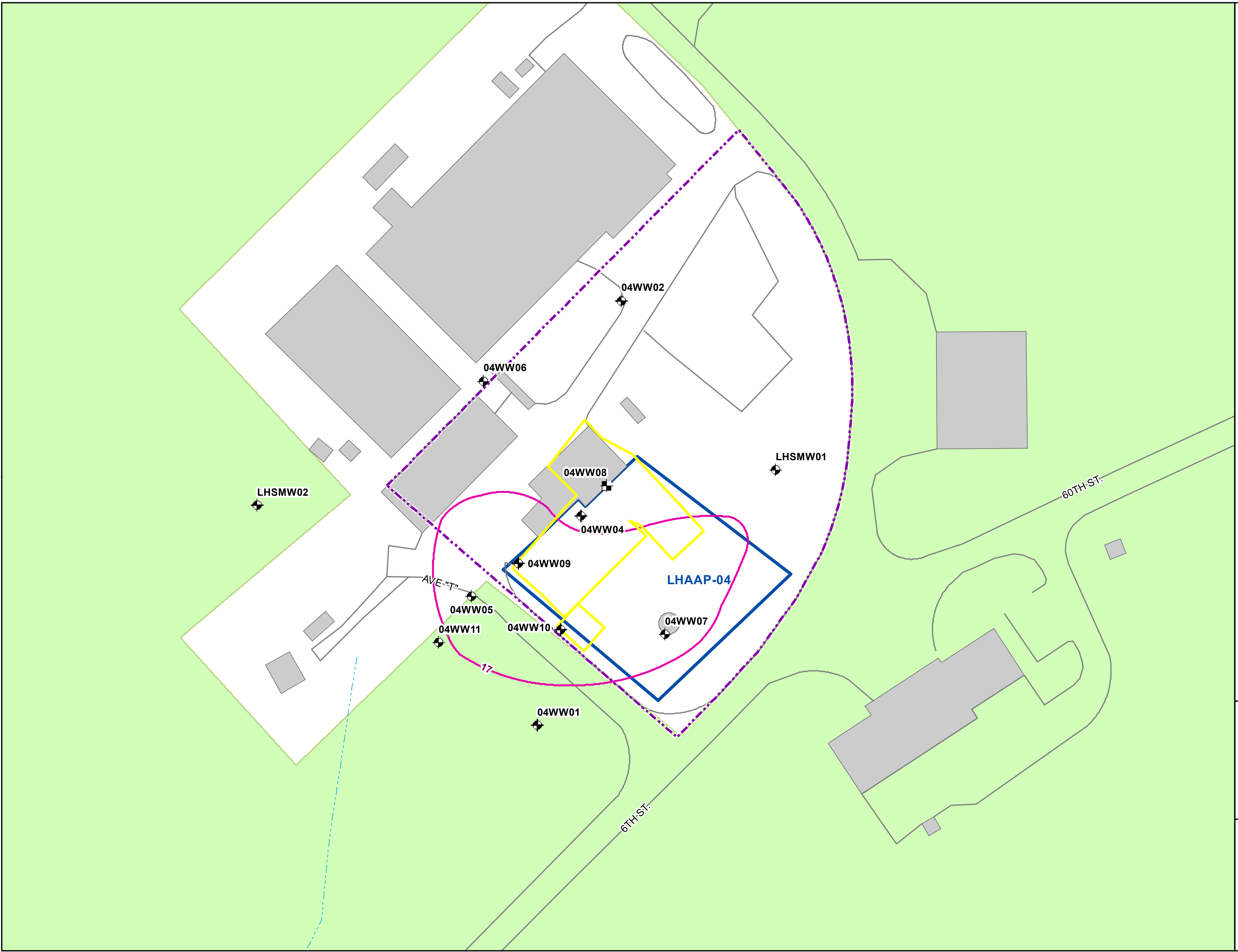

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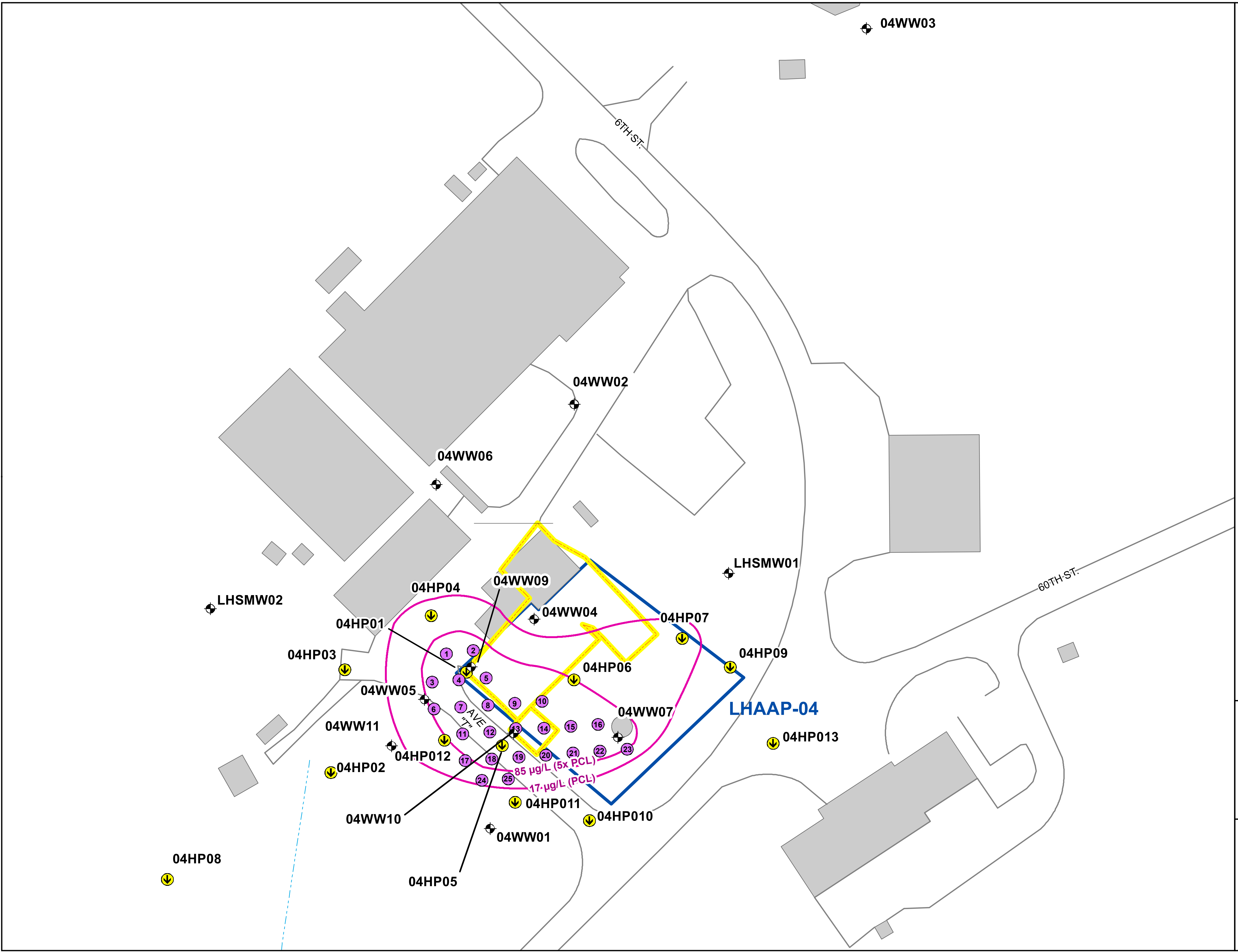
Figure 4-1

Preliminary LUC Boundary
LHAAP-04
Remedial Design/Remedial Action Work Plan
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/20/2019

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\RD_RAWP\LHAAP04_ProposedLUCBoundary.mxd



- ⊕ Shallow Monitoring Well
- ● Proposed Injection Location
- ● Hydropunch Location
- Perchlorate Plume
- Stream
- Limits of Excavation at Surface (*Source: LHAAP-04 Final Completion Report, Shaw, 2011*)
- Road
- ▨ Building
- ☐ Site Boundary

Note:
1. Plume boundaries based on most recent results available at each well (2018).
2. PCL - Texas Risk Reduction Program Protective Concentration Level for Residential Groundwater
3. The injection pattern generally targets the area within the 85 µg/L contour, but has been shifted to the southwest to account for potential future migration.

N

0 50 100 Feet

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Figure 5-1

Injection Plan
LHAAP-04

LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/14/2019

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\TechMemo\LHAAP04_ProposedInjectionLocations.mxd

NOTE:
1. EVO – EMULSIFIED VEGETABLE OIL.

LEGEND:
- |○| BALL VALVE (OPEN)
- |●| BALL VALVE (CLOSED)
- ECCENTRIC REDUCER
- CONCENTRIC REDUCER
- CAMLOCK QUICK DISCONNECT
- BALL LOCK QUICK DISCONNECT
- PNEUMATIC ACTUATOR
- SEAL
- FLEXHOSE
- PI PRESSURE INDICATOR
- FI FLOW INDICATOR

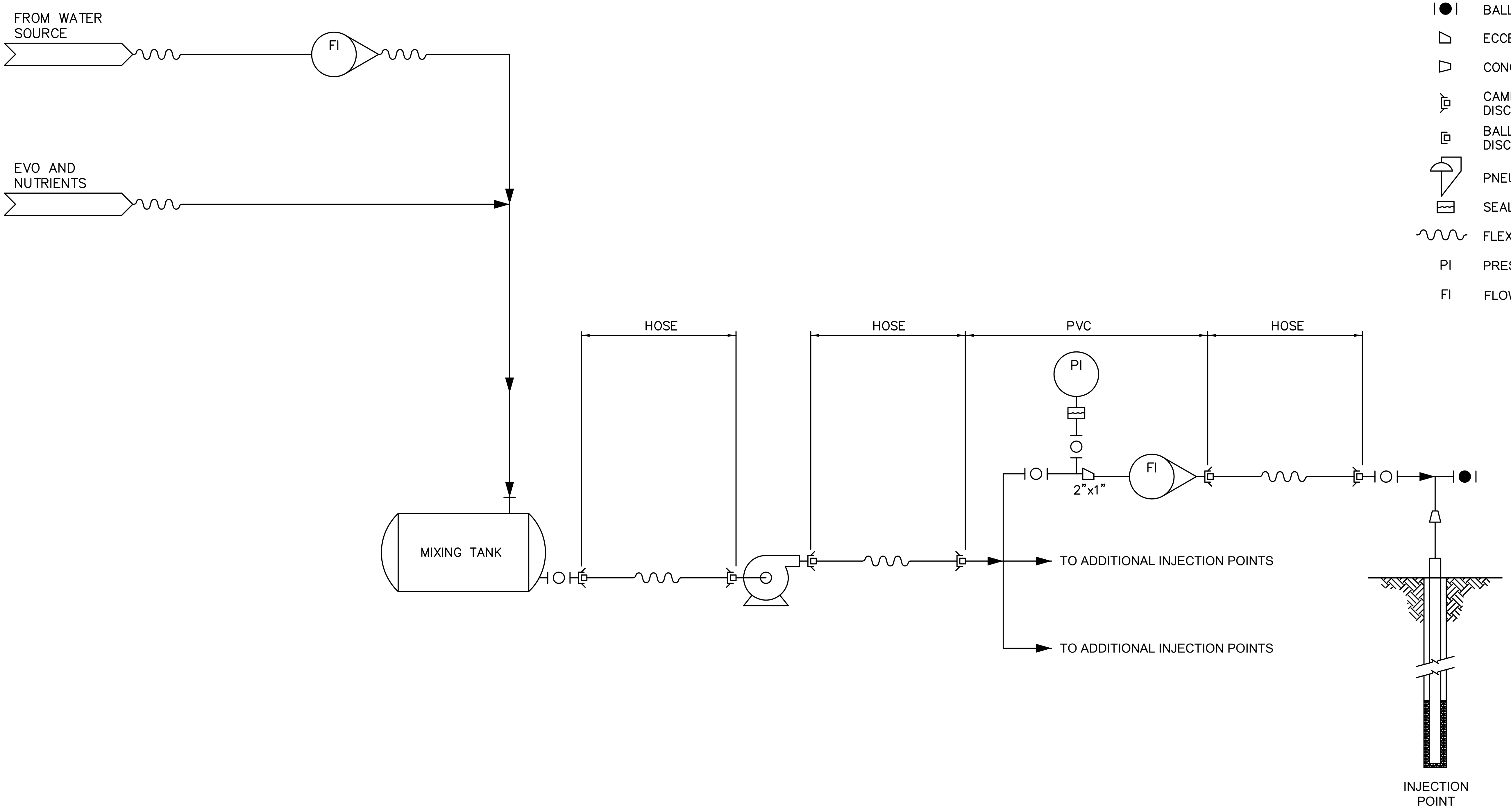

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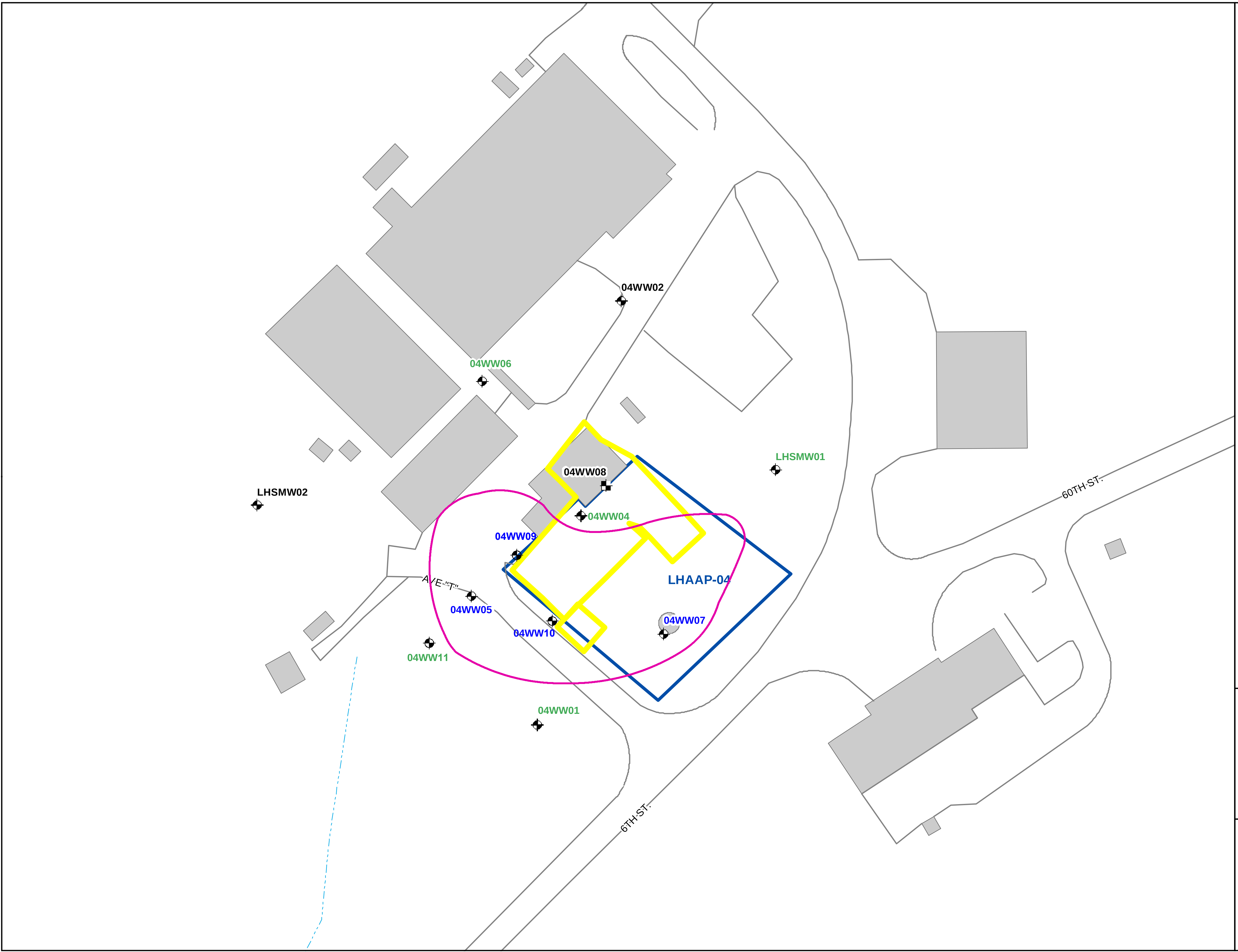
Figure 5-2
ISB DPT Injection System
LHAAP-04
Remedial Design/Remedial Action Work Plan
Longhorn Army Ammunition Plant
Karnack, Texas



- ⌖ Shallow Monitoring Well (Blue = Performance Well, Green = LTM Well, Black = Baseline Well)
- ⌖ Intermediate Monitoring Well
- — Perchlorate Plume Extent (PCL - 17 µg/L)
- - - Stream
- — Road
- ▨ Building
- ☐ Site Boundary
- ▬ Limits of Excavation at Surface (*Source: LHAAP-04 Final Completion Report, Shaw, 2011*)

N

0 35 70 Feet

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Figure 6-1

Performance and LTM Monitoring Network
LHAAP-04
Remedial Design/Remedial Action Work Plan
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Date: 2/9/2018

Document Path: G:\Longhorn\LHAAP\Documents\Mxd\LHAAP04\RD_RAWP\LHAAP04_ProposedLUCBoundary.mxd

Appendix A

Boring Logs and Monitoring Well Construction Forms for Newly Installed Monitoring Wells

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Drilling Log

Soil Boring **04HP01**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *18.0 ft.* North East
Top of Casing *NA* Water Level Initial *▽ 6.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-18')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/27/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 15.5'. Collect 04HP01-181127@1330.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0 2			▨	CL	**SANDY CLAY**; red (2.5YR 4/6), firm, moist, some silt, trace roots.
4			▨	CL	**SILTY CLAY**; reddish gray (5YR 5/2), stiff, damp, trace sand, trace brown mottling.
6 ▽			⁞	SM	**SILTY SAND**; red (10R 4/6), loose to firm, saturated, trace clay.
8 10			▨	CL	**SILTY CLAY**; light brown and gray (7.5YR 6/3), stiff, damp, trace sand, trace calcareous nodules.
			‖	ML	**SANDY SILT**; red (10R 5/6), loose, wet, trace clay.
12			▨	CL	**SILTY CLAY**; light brown (7.5YR 6/4), stiff, dry to damp, trace sand.
14			‖	ML	**CLAYEY SILT**; yellowish brown (10YR 5/4), soft, wet, some sand.
16			▨	CL	**SILTY CLAY**; SAA, soft to firm, moist, trace sand.
			▨	CL	**SANDY CLAY**; mottled dark grayish brown (10YR 2/2 and 4/2), hard, dry, some silt.
18					**END OF BORING AT 18 FEET.**
20					

APTIM

Drilling Log

Soil Boring 04HP02

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *14.0 ft.* North East
Top of Casing *NA* Water Level Initial ∇ *8.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-14')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/28/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 12'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0 2			▨	CL	**SILTY CLAY**; brown (10YR 4/3), soft, wet, some sand, some roots.
4			▨	CL	**SANDY CLAY**; light yellowish brown (10YR 6/4), firm, moist, trace silt.
6			▨	CL	**SILTY CLAY**; dark yellowish brown (10YR 4/6), stiff, moist, trace roots, trace ferrous iron (Fe) nodules.
8 ∇			▨	SC	**CLAYEY SAND**; pale brown (10YR 7/3), loose, saturated, trace silt.
10 12			▨	CL	**SANDY CLAY**; yellowish brown (10YR 5/8), firm to stiff, moist, trace silt, trace Fe staining. **SAA**; dark grayish brown (10YR 4/2); stiff, wet, trace silt, laminar appearance.
14 16 18 20					**END OF BORING AT 14 FEET.**

APTIM

Drilling Log

Soil Boring **04HP03**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *18.0 ft.* North East
Top of Casing *NA* Water Level Initial ▽ *7.5 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-18')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/28/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 17.5'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0					Topsoil
2				CL	**SANDY CLAY**;brown (7.5YR 5/3), firm, moist, small gravel and roots present.
4 6 ▽				SC	**CLAYEY SAND**; gray (7.5YR 6/1), loose to medium dense, moist to wet, trace Fe staining, trace roots.
8				CL	**SILTY CLAY**; light gray (7.5YR 7/1), firm to stiff, damp, trace Fe staining.
10				CL	**SANDY CLAY**; strong brown (7.5YR 5/6), firm, moist, trace silt.
12				CL	**SILTY CLAY**; yellowish brown (10YR 5/4), soft, moist, trace sand.
14				CL	**SANDY CLAY**; very dark brown (10YR 2/2), mottled with gray, firm, moist. **SAA**; color change to grayish brown (10YR 5/2).
16				CL	**SILTY CLAY**; dark grayish brown (10YR 4/2), stiff, damp, laminar appearance, trace sand.
18					**END OF BORING AT 18 FEET.**
20					

APTIM

Drilling Log

Soil Boring **04HP04**

Page: 1 of 1

Project: Longhorn Army Ammunition Plant
Owner: USACE
Location: LHAAP-04
Proj. No.: 501032
Surface Elev.: NA
Total Hole Depth: 20.0 ft.
North:
East:
Top of Casing: NA
Water Level Initial: ▽ 7.0 ft.
Static: NA
Diameter: 2 in.
Screen: Dia: 1 in.
Length: 10 ft.
Type/Size: Sch. 40 PVC/0.010 in.
Casing: Dia: 1 in.
Length: 5 ft.
Type: Sch. 40 PVC
Fill Material: Granular Bentonite
Rig/Core: Kubota Geoprobe
Drill Co.: Best Drilling
Method: Direct Push (0-20')
Driller: Ramon Gutierrez
Log By: Wesley Garcia
Date: 11/27/18
Driller #: NA
Checked By: Bill Foss
License No.: TX290

COMMENTS
Hydropunch to 17.1'. PVC screen set 5-15'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			▨	CL	**SANDY CLAY**; brown (10YR 5/3), firm, moist, trace roots, trace silt.
2			▨		
			▒	SC	**CLAYEY SAND**; dark grayish brown (10YR 4/2), dense, damp, trace gravel.
4			▨		**SANDY CLAY**; light gray (10YR 7/1), firm, moist, trace Fe staining, moisture increasing with depth, saturated at 7 feet.
6			▨	CL	
▽			▨		
8			▨		**SILTY CLAY**; grayish brown (10YR 5/2), firm, wet, trace sand.
10			▨	CL	**SAA**; color change to gray (10YR 501), moisture change to damp.
12			▥		**SANDY SILT**; pale brown (10YR 6/3), stiff, moist to wet, some clay.
			▥	ML	
14			▥		**SAA**; color change to yellowish brown (10YR 5/6), density change to firm.
			▨	CL	**SANDY CLAY**; light gray (10YR 7/2), stiff to hard, damp, trace gravel.
16			▨	CL	**SILTY CLAY**; brownish yellow (10YR 6/6), firm, moist, trace sand.
18			▨	CL	**SANDY CLAY**;dark gray (10yr 4/1), hard, damp, laminar appearance and crumbly texture.
20					**END OF BORING AT 20 FEET.**

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Drilling Log

Soil Boring 04HP05

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *20.0 ft.* North East
Top of Casing *NA* Water Level Initial ∇ *8.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *1 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *1 in.* Length *5 ft.* Type *Sch. 40 PVC*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-20')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/27/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 15'. PVC screen set to 5-15'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			↓		Asphalt & Gravel
			▨		**SILTY CLAY**; yellowish brown (10YR 5/6), soft to firm, moist, trace sand.
2			▨		
4			▨	CL	**SAA**; gray (10YR 6/1), firm, damp, trace Fe staining.
6			▨		
			▨		**CLAYEY SAND**; dark brown (10YR 3/3), firm, moist to wet, trace silt, trace Fe staining.
8 ∇			▨	SC	
			▨		**SILTY CLAY**; gray (10YR 5/1) with yellowish brown (10YR 5/6) mottles, firm to stiff, moist, trace sandy lenses.
10			▨	CL	
12			▨		**SANDY CLAY**; yellowish brown (10YR 5/4), firm to stiff, moist to damp, silt increasing with depth, color changing to gray (10YR 5/1) with depth.
14			▨		
16			▨	CL	**SAA**; dark gray (10YR 4/1), hard, damp, laminar appearance, blocky texture.
18			▨		
20					**END OF BORING AT 20 FEET.**

APTIM

Drilling Log

Soil Boring **04HP06**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *16.0 ft.* North East
Top of Casing *NA* Water Level Initial ∇ *7.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *1 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *1 in.* Length *4 ft.* Type *Sch. 40 PVC*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-16')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/27/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 14'. PVC screen set to 4-14'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0 2			▨	CL	Sandy Clay FILL
4 6 ∇			▨	CL	**SILTY CLAY**; dark grayish brown (10YR 4/2), firm, moist, trace sand, trace roots. **SAA**; yellowish brown (10YR 5/4), soft, moist, trace sand, trace plastic debris (possibly fill). **SAA**; light gray (10YR 7/1), firm, wet at 7 feet, trace Fe staining, trace sand.
8 10			▨	CL	**SANDY CLAY**; light gray (10YR 7/1), firm, wet, trace silt.
12			▨	CL	**SILTY CLAY**; light gray (10YR 7/1), soft, wet, some sand. **SAA**; light gray (10YR 6/1), stiff, moist, trace sand
14			▨	CL	**SANDY CLAY**; dark gray (10YR 4/1), stiff to hard, damp, laminar appearance.
16 18 20					**END OF BORING AT 16 FEET.**

APTIM

Drilling Log

Soil Boring **04HP07**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *20.0 ft.* North East
Top of Casing *NA* Water Level Initial ∇ *12.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-20')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/28/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 17'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			░		Topsoil (Sandy Clay)
2 4			▨	CL	**SANDY CLAY**; dark yellowish brown (10YR 4/4), soft to firm, moist, trace silt.
6			▨	CL	**SILTY CLAY**; yellowish brown (10YR 5/6), firm, damp, some Fe staining and calcareous nodules.
8 10			▨	CL	**SANDY CLAY**; gray (10YR 6/1), stiff to hard, damp, trace Fe staining, trace silt.
12 ∇			▨	SC	**CLAYEY SAND**; light yellowish brown (10YR 6/4), loose to medium dense, wet, trace silt.
14			▨	CL	**SANDY CLAY**; light gray (10YR 7/1), stiff, moist, trace silt.
16			▨	CL	**SILTY CLAY**; pale brown (10YR 7/4), mottled with gray, stiff, moist, trace Fe staining.
18			▨	CL	**SANDY CLAY**; grayish brown (10YR 5/2), grading to black at bottom (10YR 2/1), stiff, damp, laminar appearance.
20					**END OF BORING AT 20 FEET.**

APTIM

Drilling Log

Soil Boring **04HP08**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*

Location *LHAAP-04* Proj. No. *501032*

Surface Elev. *NA* Total Hole Depth *20.0 ft.* North ____ East ____

Top of Casing *NA* Water Level Initial ∇ *10.0 ft.* Static *NA* Diameter *2 in.*

Screen: Dia *1 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*

Casing: Dia *1 in.* Length *6 ft.* Type *Sch. 40 PVC*

Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*

Drill Co. *Best Drilling* Method *Direct Push (0-20')*

Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *11/28/18* Driller # *NA*

Checked By *Bill Foss* License No. *TX290*

COMMENTS

Hydropunch to 16'. PVC screen set to 6-16'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			▨	CL	**SANDY CLAY**; yellowish brown (10YR 5/4), soft, moist, trace roots, trace silt.
4					**SAA**; very pale brown (10YR 8/2), firm, damp, trace Fe staining, trace calcareous nodules.
10 ∇			▨	SC	**CLAYEY SAND**; very pale brown (10YR 8/2), loose, saturated, trace silt.
			▨	CL	**SILTY CLAY**; very pale brown (10YR 8/2), stiff, moist, trace sand.
16			▨	CL	**SANDY CLAY**; grayish brown (10YR 5/2), soft, moist, trace silt.
18					**SAA**; dark gray (10YR 4/1), hard, damp, laminar appearance.
20					**END OF BORING AT 20 FEET.**

APTIM

Drilling Log

Soil Boring **04HP09**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *19.0 ft.* North East
Top of Casing *NA* Water Level Initial ▽ *8.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-19')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *12/13/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 16.5'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			⁘		Topsoil (Sandy Clay)
2			▨		**SANDY CLAY**; yellowish brown (10YR 5/4), firm, moist, trace Fe staining.
4			▨		
			▨	CL	**SAA**; light gray (10YR 7/1), firm, damp, trace Fe staining, trace silt, trace calcareous nodules.
6			▨		
8 ▽			▨		**CLAYEY SAND**; dark gray (10YR 4/1), loose to medium dense, wet, density increasing with depth.
10			▨	SC	
12			▨	CL	**SANDY CLAY**; brownish yellow (10YR 6/8), firm, moist, trace silt.
14			▨	CL	**SILTY CLAY**; yellowish brown (10YR 5/8), soft, wet, sandy lenses, density increasing with depth.
16			▨		**SANDY CLAY**; dark grayish brown (10YR 4/2), firm, moist.
18			▨	CL	**SAA**; very dark gray (10YR 3/1), stiff, damp, laminar appearance.
					END OF BORING AT 19 FEET.
20					

APTIM

Drilling Log

Soil Boring **04HP10**

Page: 1 of 1

Project Longhorn Army Ammunition Plant
Owner USACE
Location LHAAP-04
Proj. No. 501032
Surface Elev. NA
Total Hole Depth 19.0 ft.
North
East
Top of Casing NA
Water Level Initial ▽ 8.0 ft.
Static NA
Diameter 2 in.
Screen: Dia NA
Length NA
Type/Size NA
Casing: Dia NA
Length NA
Type NA
Fill Material Granular Bentonite
Rig/Core Kubota Geoprobe
Drill Co. Best Drilling
Method Direct Push (0-19')
Driller Ramon Gutierrez
Log By Wesley Garcia
Date 12/13/18
Driller # NA
Checked By Bill Foss
License No. TX290

COMMENTS
Hydropunch to 15'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0					Topsoil (Sandy Clay)
2					
4				SC	**CLAYEY SAND**; brownish yellow (10YR 6/6), loose, moist, trace silt, trace roots.
6				CL	**SANDY CLAY**; light gray (10YR 7/1), firm, damp, trace calcareous nodules.
8 ▽				SC	**CLAYEY SAND**; brownish yellow (10YR 6/6), loose, saturated, trace calcareous nodules.
10				CL	**SANDY CLAY**; light gray (10YR 7/1), firm, moist, trace Fe staining.
12				SC	**CLAYEY SAND**; yellowish brown (10YR 5/6), medium dense, saturated, trace silt.
14					**SANDY CLAY**; gray (10YR 5/1), firm, damp, trace silt.
16				CL	
18					**SAA**; dark gray (10YR 4/1), stiff, damp, laminar appearance.
					END OF BORING AT 19 FEET.
20					

APTIM

Drilling Log

Soil Boring 04HP11

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *18.5 ft.* North East
Top of Casing *NA* Water Level Initial ▽ *7.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-18.5')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *12/13/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 15.5'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0					Topsoil (Sandy Clay)
					SANDY CLAY; yellowish brown (10YR 5/4), soft, moist, trace silt, trace roots.
2					
					SAA; color change to very pale brown (10YR 8/3).
4				CL	**SANDY CLAY**; light gray (7/1), with yellowish brown (10YR 5/8) mottles, firm, damp, trace silt.
6					
▽					
					CLAYEY SAND; pale brown (10YR 6/3), loose, saturated, decreased sand with depth, medium dense at 8 feet.
8					
10				SC	
12					**SANDY CLAY**; gray (10YR 6/1), firm to stiff, moist, silt increasing with depth.
				CL	
14					**SILTY CLAY**; yellowish brown (10YR 5/4), stiff, damp, trace sand.
				CL	
16					**SANDY CLAY**; very dark gray (10YR 3/1) with gray (10YR 5/1) laminations, hard, damp.
				CL	
18					
					END OF BORING AT 18.5 FEET.
20					

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Drilling Log

Soil Boring **04HP12**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *19.0 ft.* North ____ East ____
Top of Casing *NA* Water Level Initial ⊽ *9.0 ft.* Static *NA* Diameter *2 in.*
Screen: Dia *NA* Length *NA* Type/Size *NA*
Casing: Dia *NA* Length *NA* Type *NA*
Fill Material *Granular Bentonite* Rig/Core *Kubota Geoprobe*
Drill Co. *Best Drilling* Method *Direct Push (0-19')*
Driller *Ramon Gutierrez* Log By *Wesley Garcia* Date *12/13/18* Driller # *NA*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Hydropunch to 16.5'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0					Topsoil (Sandy Clay)
2				CL	**SANDY CLAY**; yellow (10YR 7/6), firm, moist, trace small gravel. **SAA**; yellowish brown (10YR 5/6), firm, damp, trace silt. **SAA**; yellow (10YR 7/6), firm, damp, trace silt, trace Fe staining, trace calcareous nodules.
8 ⊽					**SILTY CLAY**; interbedded brownish yellow (10YR 6/8) and light gray (10YR 7/1) layers, firm, wet at 9 feet, trace sand.
12				SC	**CLAYEY SAND**; yellowish brown (10YR 5/6), loose, saturated, trace silt.
				CL	**SILTY CLAY**; brownish yellow (10YR 6/6), stiff, moist, trace sand.
16				CL	**SANDY CLAY**; grayish brown (10YR 5/2) to gray (10YR 5/1), hard, damp, laminar appearance.
					END OF BORING AT 19 FEET.
20					

00920360

Drilling Log

Soil Boring 04HP13

Page: 1 of 1

Project Longhorn Army Ammunition Plant Owner USACE

Location LHAAP-04 Proj. No. 501032

Surface Elev. NA Total Hole Depth 18.0 ft. North East

Top of Casing NA Water Level Initial ∇ 12.0 ft. Static NA Diameter 2 in.

Screen: Dia NA Length NA Type/Size NA

Casing: Dia NA Length NA Type NA

Fill Material Granular Bentonite Rig/Core Kubota Geoprobe

Drill Co. Best Drilling Method Direct Push (0-18')

Driller Ramon Gutierrez Log By Wesley Garcia Date 12/13/18 Driller # NA

Checked By Bill Foss License No. TX290

COMMENTS
Hydropunch to 16'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			⁘		Topsoil (Sandy Clay)
2			▨	CL	**SANDY CLAY**; yellowish brown (10YR 5/8), firm, moist, some mottling with light brownish gray (10YR 6/2).
			▨	CL	**SILTY CLAY**; very dark gray (10YR 3/1), firm, damp, trace sand.
4			▨	CL	**SANDY CLAY**; very pale brown (10YR 8/4), stiff, damp, trace calcareous nodules.
6			▨	CL	**SILTY CLAY**; gray (5/1) with many calcareous nodules (10YR 8/1), stiff, damp, some Fe staining.
8					
10					
12 ∇			▨	SC	**CLAYEY SAND**; gray (10YR 6/1), loose, saturated, color grading to very pale brown (10YR 7/3) with depth, clay content increasing with depth.
14					
			▨	CL	**SANDY CLAY**; white to light gray (10YR 8/1 and 7/2), stiff, damp, slight laminar appearance.
16					
18					**END OF BORING AT 18 FEET.**
20					

APTIM

Drilling Log

Monitoring Well **04WW06**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *25.0 ft.* North *6959225.38 ft.* East *3305871.99 ft.*
Top of Casing *NA* Water Level Initial ∇ *10.5 ft.* Static *NA* Diameter *10.25 in.*
Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *4 in.* Length *15 ft.* Type *Sch. 40 PVC*
Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 75 Mobile Rig*
Drill Co. *Best Drilling* Method *Hand auger (0-5'); hollow stem auger (5-25')*
Driller *Sonny Tobola* Log By *D. Rowan* Date *12/12/17* Driller # *3026*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
4" PVC 0.010" slot screen set from 15-25'. 4" PVC casing 0-15'. 20/40 Sand at 12-25'. Bentonite at 10-12'. Grout 0-10'.

NOTE: First 48" using post hole digger for utility cleance, then probe to 60", boring drilled using ~10.25" diameter hollow stem augers, logged from split spoon at 2.5' intervals.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			▨	CL	**SANDY CLAY**; topsoil, some red silty clay.
2			▨	CL	**SILTY CLAY**; gray, firm to soft, moist, mottled orange Fe staining, slight plasticity, platy layers.
4			▨	CL	**SANDY CLAY**; tan, moist, soft, mottled orange Fe staining, few calciite nodules, few intermittent pebbles.
			▨	CL	**SILTY CLAY**; dark gray to black, very moist, lessening of sand concentration, orange Fe staining.
6					**SAA**; color change to light gray, orange Fe staining.
8					**SAA**; color change to gray, moist to very moist, interbedded sand lenses, few calcite nodules.
			▨	CL	**SANDY CLAY**; tan, interbedded gray clay lenses, very moist, slightly mottled orange Fe staining.sand.
10 ∇			▨	CL	**SILTY CLAY**; light gray, interbedded sand lenses, moist to damp, firm to soft, plastic when wet.
12					Same as above with the addition of interbedded orange Fe staining.
14					
16					
18					Same as above with the addition of interbedded black Fe staining.
20					**SILTY CLAY**; dark gray to black, interbedded tan sand, firm, damp
22					Same as above without sand.
24					
					END OF BORING AT 25 FEET.
26					

APTIM

Drilling Log

Monitoring Well 04WW07

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *20.0 ft.* North *6959038.63 ft.* East *3306006.11 ft.*
Top of Casing *NA* Water Level Initial *NA* Static *NA* Diameter *10.25 in.*
Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *4 in.* Length *10 ft.* Type *Sch. 40 PVC*
Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 75 Mobile Rig*
Drill Co. *Best Drilling* Method *Hand auger (0-5'); hollow stem auger (5-20')*
Driller *Sonny Tobola* Log By *D. Rowan* Date *12/12/17* Driller # *3026*
Checked By *Bill Foss* License No. *TX290*

COMMENTS

4" PVC screen set from 10-20'. 4" PVC casing 0-10'. 20/40 Sand at 7-20'. Bentonite from 5-7'. Grout 0-5'.

NOTE: First 48" using post hole digger for utility cleance, then probe to 60", boring drilled using ~10.25" diameter hollow stem augers, logged from split spoon at 2.5' intervals.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			░		Topsoil
			▨		**SILTY CLAY**; tan to gray with interbedded sand lenses, orange Fe staining with black Fe Mn or organic nodules, moist with area of very moist.
2			▨		Same as above with increase in Fe staining, higher concentration of sand in bottom 1.5'.
4			▨		
			▨		**SILTY CLAY**; firm, moist, plastic, mottled orange Fe staining, lessening silt concentration with depth, loss of sand.
6			▨		
8			▨		Same as above with some interbedded sand lenses.
			▨	CL	
10			▨		Same as above with lessening Fe staining.
12			▨		
			▨		**SILTY CLAY**; light gray to black with mottled orange Fe staining nodules, trace sand/silica throughout, firm to soft, moist to damp, little to no plasticity even when wet.
14			▨		
			▨		Same as above with black Fe Mn or organic nodules at 17', darkening of color at 16'.
16			▨		
18			▨	CL	**CLAY**; black, dry, few nodules of orange Fe staining.
			▨	CL	**SILTY CLAY**; black, dry, firm, very dense.
20					**END OF BORING AT 20 FEET.**

Drilling Log

Monitoring Well **04WW08**

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Project *Longhorn Army Ammunition Plant* Owner *USACE*

Location *LHAAP-04* Proj. No. *501032*

Surface Elev. *NA* Total Hole Depth *45.0 ft.* North *6959148.15 ft.* East *3305963.41 ft.*

Top of Casing *NA* Water Level Initial ∇ *32.5 ft.* Static *NA* Diameter *10.25 in.*

Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*

Casing: Dia *4 in.* Length *35 ft.* Type *Sch. 40 PVC*

Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 75 Mobile Rig*

Drill Co. *Best Drilling* Method *Hollow stem auger (0-45')*

Driller *Sonny Tobola* Log By *D. Rowan* Date *12/14/17* Driller # *3026*

Checked By *Bill Foss* License No. *TX290*

COMMENTS

Top 12' most likely backfill from excavation as noted on 04WW04 boring log.

12" PVC surface casing set in shallow zone from 0-23' on 12/12/2017. 4" PVC screen set from 31 to 41'. 20/40 Sand from 29-45'. Bentonite from 27-29'. Grout from 0-27'.

Hole diameter 0-23' is 14; from 23-45' hole diameter is 10.25'.

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
0			▨	CL	**SANDY CLAY**; topsoil, some silt, some red silty clay.
2 4			▥	ML	**SANDY SILT**; gray, clayey, increasing clay concentration and decreasing sand with depth.
6			▨	CL	**SANDY CLAY**; red, firm, moist, with depth there is increasing moisture content as well as decreasing sand concentration.
8 10 12 14 16			▨	CL	**SILTY CLAY**; red, soft, moist to very moist, trace orange Fe staining with some nodules of black Fe Mn or organics. **SILTY CLAY**; native gray, damp, trace sand, mottled orange Fe staining with interbedded black nodules of Fe Mn or organics. **SAA**; color change to gray, very firm, sheeted, plastic when wet, trace interbedded sand. Same as above with increasing trace of sand starting at 16', some orange Fe staining.
18 20			▨	CL	**CLAY**; light gray to dark gray with silt and trace sand, firm, moist, plastic when wet.

Continued Next Page

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Drilling Log

Monitoring Well **04WW08**

Page: 2 of 2

Project *Longhorn Army Ammunition Plant* Owner *USACE*

Location *LHAAP-04* Proj. No. *501032*

Depth (ft.)	PID (ppm)	Sample ID % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
					Continued
22 24			▨	CL	Same as above with some orange Fe staining.
26 28			▨	CL	**SILTY CLAY**; medium to dark gray, very firm, dense, dry, interbedded black organic nodules, increase in moisture to a moist consistency around 28.5' through rest of core, transition to light gray color at 29'.
30 32 ∇			▨	CL	**CLAY**; dark gray, moist, some orange Fe staining, firm to soft, plastic when wet. **SAA**; color change to black, with silt, dry, firm.
34					NO RECOVERY
36 38			▨	CL	**SILTY CLAY**; dark gray to black, from top to bottom saturated to moist, firm to stiff, slight plasticity.
40 42 44			▥	ML	**CLAYEY SILT**; light gray, clayey, damp, sheeted, firm to soft, no plasticity.
46 48					**END OF BORING AT 45 FEET.**

APTIM

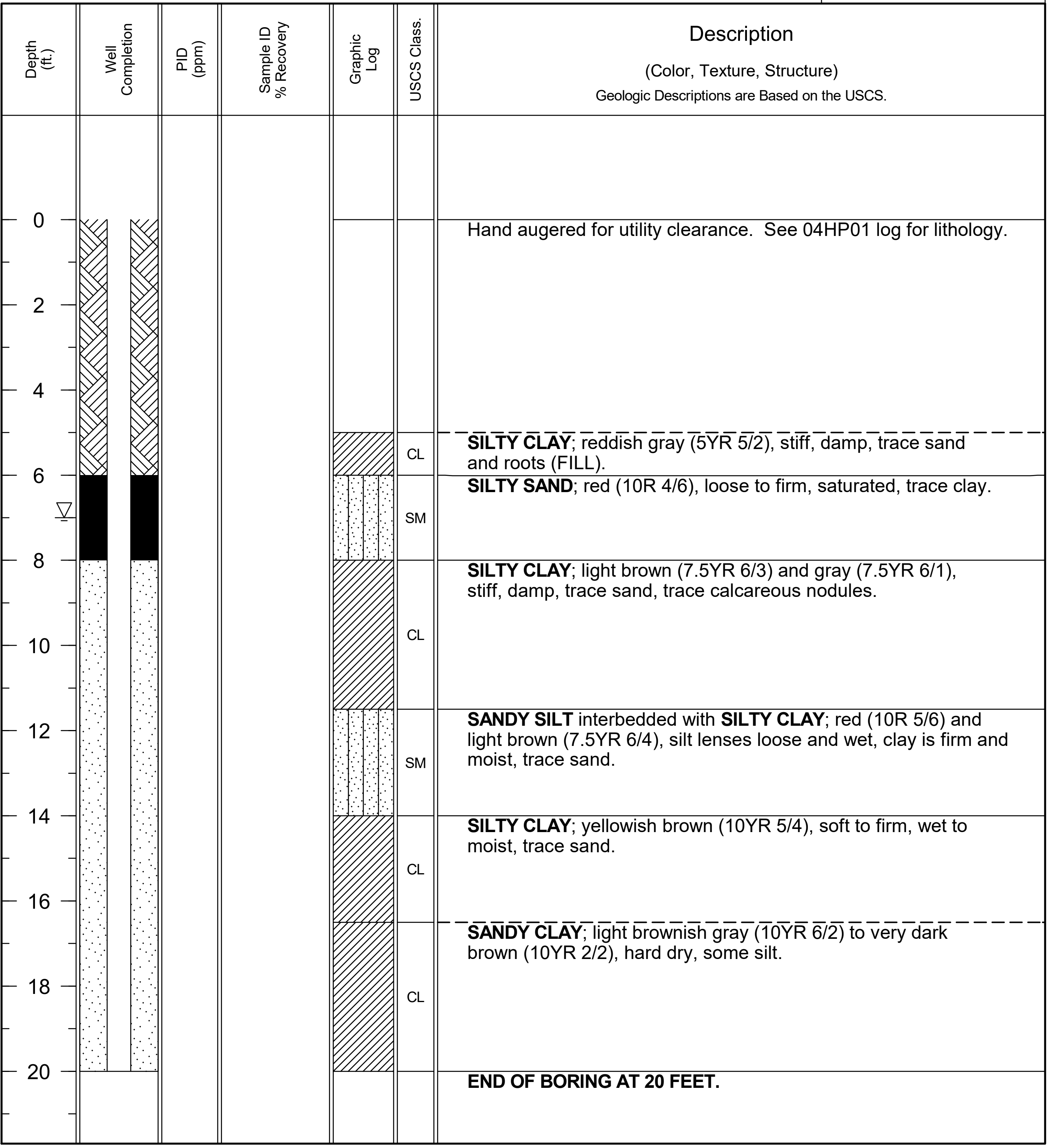
Drilling Log

Monitoring Well **04WW09**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *20.0 ft.* North East
Top of Casing *NA* Water Level Initial ▽ *7.0 ft.* Static *NA* Diameter *10.25 in.*
Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *4 in.* Length *10 ft.* Type *Sch. 40 PVC*
Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 55*
Drill Co. *ETTL* Method *Hand auger (0-5'); hollow stem auger (5-20')*
Driller *Rich Herman* Log By *Wesley Garcia* Date *1/15/19* Driller # *59385M*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
4" PVC well set at 20' with 10' of 0.010" slot screen. Filter pack 20/40 Sand at 8-20'. Bentonite chips 6-8' in 12" lifts, hydrated between lifts. Grout 0-5' placed 1/16/2019.



Description

(Color, Texture, Structure)

Geologic Descriptions are Based on the USCS.

USCS Class.	Description
	Hand augered for utility clearance. See 04HP01 log for lithology.
CL	**SILTY CLAY**; reddish gray (5YR 5/2), stiff, damp, trace sand and roots (FILL).
SM	**SILTY SAND**; red (10R 4/6), loose to firm, saturated, trace clay.
CL	**SILTY CLAY**; light brown (7.5YR 6/3) and gray (7.5YR 6/1), stiff, damp, trace sand, trace calcareous nodules.
SM	**SANDY SILT** interbedded with **SILTY CLAY**; red (10R 5/6) and light brown (7.5YR 6/4), silt lenses loose and wet, clay is firm and moist, trace sand.
CL	**SILTY CLAY**; yellowish brown (10YR 5/4), soft to firm, wet to moist, trace sand.
CL	**SANDY CLAY**; light brownish gray (10YR 6/2) to very dark brown (10YR 2/2), hard dry, some silt.
	END OF BORING AT 20 FEET.

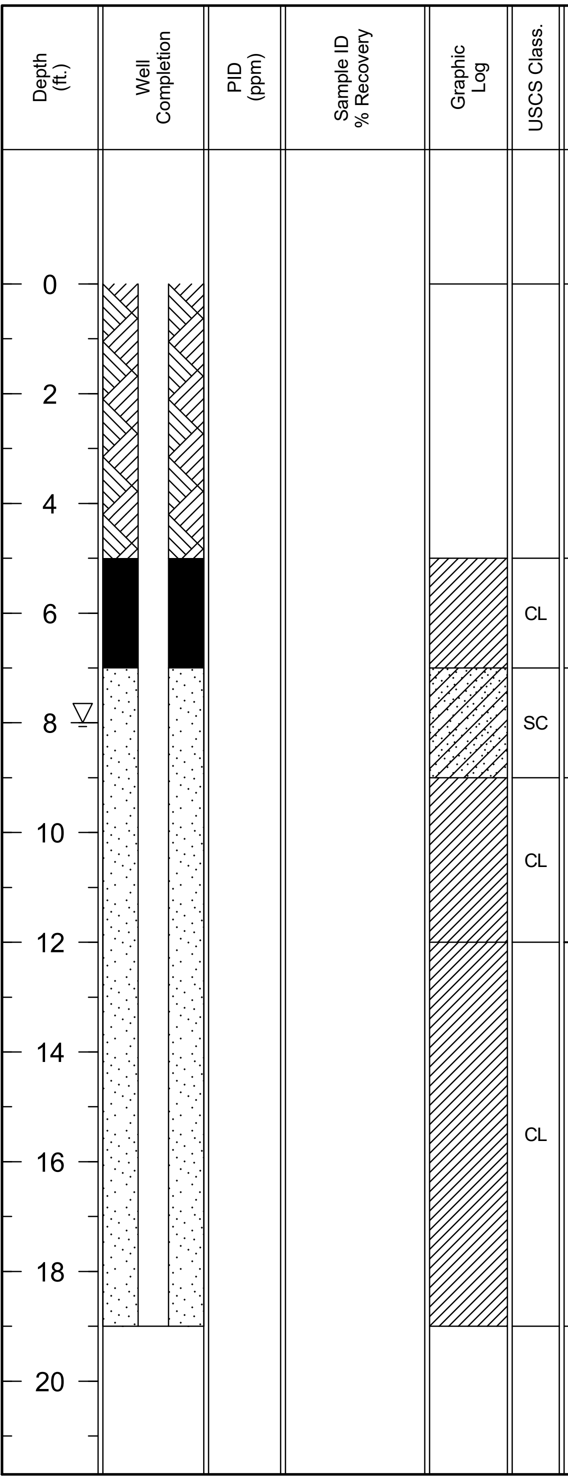
Drilling Log

Monitoring Well **04WW10**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *19.0 ft.* North ____ East ____
Top of Casing *NA* Water Level Initial ∇ *8.0 ft.* Static *NA* Diameter *10.25 in.*
Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *4 in.* Length *9 ft.* Type *Sch. 40 PVC*
Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 55*
Drill Co. *ETTL* Method *Hand auger (0-5'); hollow stem auger (5-19')*
Driller *Rich Herman* Log By *Wesley Garcia* Date *1/15/19* Driller # *59385M*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
4" PVC well set at 19' with 10' of 0.010" slot screen. Filter pack 20/40 Sand at 7-19'. Bentonite chips 5-7' in 12" lifts, hydrated between lifts. Grout 0-5' placed 1/16/2019.



Description

(Color, Texture, Structure)

Geologic Descriptions are Based on the USCS.

Hand augered for utility clearance. See 04HP05 log for lithology.

SILTY CLAY; gray (10YR 6/1), firm, damp, trace Fe staining.

CLAYEY SAND; dark brown (10YR 3/3), medium dense, moist to wet at 8 feet, trace silt, trace Fe staining.

SILTY CLAY; gray (10YR 5/1) with yellowish brown (10YR 5/6) mottles, firm to stiff, moist, trace sandy lenses.

SANDY CLAY; yellowish brown (10YR 5/4), firm to stiff, moist to damp, silt increasing with depth, color change fades to gray (10YR 5/1) with depth.

SAA; dark gray (10YR 4/1), hard, damp, laminar appearance, blocky texture.

END OF BORING AT 19 FEET.

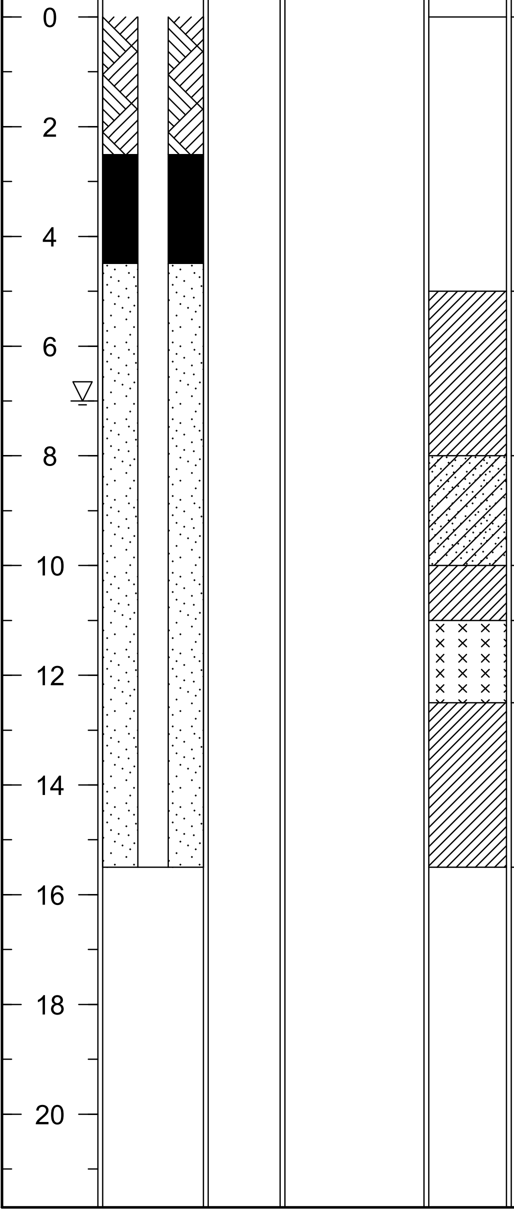
Drilling Log

Monitoring Well **04WW11**

Page: 1 of 1

Project *Longhorn Army Ammunition Plant* Owner *USACE*
Location *LHAAP-04* Proj. No. *501032*
Surface Elev. *NA* Total Hole Depth *15.5 ft.* North ____ East ____
Top of Casing *NA* Water Level Initial ∇ *7.0 ft.* Static *NA* Diameter *10.25 in.*
Screen: Dia *4 in.* Length *10 ft.* Type/Size *Sch. 40 PVC/0.010 in.*
Casing: Dia *4 in.* Length *5.5 ft.* Type *Sch. 40 PVC*
Fill Material *20/40 Sand; bentonite chips, grout* Rig/Core *CME 55*
Drill Co. *ETTL* Method *Hand auger (0-5'); hollow stem auger (5-15.5')*
Driller *Rich Herman* Log By *Wesley Garcia* Date *1/16/19* Driller # *59385M*
Checked By *Bill Foss* License No. *TX290*

COMMENTS
Auger refusal at 11'. Used mud bit inside auger to break through cemented layer. 4" PV well set at 15.5' with 10' of 0.010" slot screen. Filter pack of 20/40 Sand at 4.5-15.5'. Bentonite chips 2.5-4.5' in in 12" lifts, hydrated between lifts. Grout 0-2.5' placed2 hours after bentonite hydration.



USCS Class.	Description (Color, Texture, Structure) Geologic Descriptions are Based on the USCS.
	Hand augered for utility clearance. Lithology not recorded.
CL	**SILTY CLAY**; dark yellowish brown (10YR 4/6), stiff, moist, roots, trace Fe staining.
SC	**CLAYEY SAND**; pale brown (10YR 5/6), loose, saturated, trace silt.
CL	**SANDY CLAY**; yellowish brown (10YR 5/6), stiff, moist, silt, trace Fe staining.
	Cemented SILTSTONE; very dark gray (10YR 3/1), dry.
CL	**SANDY CLAY**; very dark gray (10YR 3/1), hard, dry, lighter gray laminations.
	END OF BORING AT 15.5 FEET.

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW01**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: 04WW01-190122

DATE/TIME: 1/22/2019 / 12:30

Pump Inlet Depth (ft): 22.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 7.33

Measured Depth of Well (ft): 27.28

Screen Interval (ft): 17.00 - 27.00

Pump Start Time: 1/22/2019 / 12:00

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 12:00

Purge End Date/Time: 1/22/2019 / 12:30

PID Reading: N/A

Sample Collection Log

Location ID: 04WW01 Sample No: 04WW01-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	12:05	100	0.50	7.41	3.13	16.26	6.83	22.0	319	0.80
1/22/2019	12:10	100	1.0	7.46	3.10	16.36	6.41	14.6	324	0.39
1/22/2019	12:15	100	1.5	7.50	3.10	16.36	6.20	11.8	326	0.16
1/22/2019	12:20	100	2.0	7.53	3.10	16.37	6.19	11.5	326	0.15
1/22/2019	12:25	100	2.5	7.55	3.10	16.38	6.18	11.1	327	0.16
1/22/2019	12:30	100	3.0	7.56	3.10	16.39	6.17	10.9	327	0.15

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW02**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Clear

SAMPLING INFORMATION

Sample No: 04WW02-190121

DATE/TIME: 1/21/2019 / 09:55

Pump Inlet Depth (ft): 21.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4"

Depth to Water - Initial (DTWi) (ft) 6.47

Measured Depth of Well (ft): 26.73

Screen Interval (ft): 16.00 - 26.00

Pump Start Time: 1/21/2019 / 09:25

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/21/2019 / 09:25

Purge End Date/Time: 1/21/2019 / 09:55

PID Reading: N/A

Sample Collection Log

Location ID: 04WW02 Sample No: 04WW02-190121

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	09:30	100	0.50	6.52	0.446	16.22	6.94	55.60	250	0.85
1/21/2019	09:35	100	1.0	6.58	0.435	16.70	6.62	20.0	230	0.63
1/21/2019	09:40	100	1.50	6.62	0.433	16.91	6.43	8.30	224	0.58
1/21/2019	09:45	100	2.0	6.65	0.432	16.99	6.42	6.0	223	0.57
1/21/2019	09:50	100	2.5	6.67	0.432	17.06	6.41	5.7	222	0.57
1/21/2019	09:55	100	3.0	6.69	0.432	17.13	6.40	4.50	221	0.56

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW03**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Clear

SAMPLING INFORMATION

Sample No: 04WW03-190121

DATE/TIME: 1/21/2019 / 09:00

Pump Inlet Depth (ft): 21.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4"

Depth to Water - Initial (DTWi) (ft) 6.57

Measured Depth of Well (ft): 26.88

Screen Interval (ft): 16.00 - 26.00

Pump Start Time: 1/21/2019 / 08:30

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/21/2019 / 08:30

Purge End Date/Time: 1/21/2019 / 09:00

PID Reading: N/A

Sample Collection Log

Location ID: 04WW03 Sample No: 04WW03-190121

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	08:35	100	0.50	6.63	1.17	12.15	7.33	29.5	299	3.68
1/21/2019	08:40	100	1.0	6.69	1.13	12.67	7.05	7.5	260	3.25
1/21/2019	08:45	100	1.5	6.73	1.13	12.95	7.04	3.9	256	3.19
1/21/2019	08:50	100	2.0	1.76	1.12	13.04	7.03	2.6	255	3.17
1/21/2019	08:55	100	2.5	6.78	1.12	13.12	7.03	2.0	254	3.15
1/21/2019	09:00	100	3.0	6.79	1.12	13.18	7.03	1.3	254	3.14

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW04**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Clear

SAMPLING INFORMATION

Sample No: 04WW04-190121

DATE/TIME: 1/21/2019 / 12:30

Pump Inlet Depth (ft): 16.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 2

Depth to Water - Initial (DTWi) (ft) 5.68

Measured Depth of Well (ft): 21.6

Screen Interval (ft): 11.00 - 21.00

Pump Start Time: 1/21/2019 / 12:00

Purging Method/Equipment: Bladder Pump

Purge Start Date/Time: 1/21/2019 / 12:00

Purge End Date/Time: 1/21/2019 / 12:30

PID Reading: N/A

APTIM

Sample Collection Log

Location ID: 04WW04   Sample No: 04WW04-190121

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	12:05	100	0.5	5.75	0.418	15.34	6.20	110	24	0.78
1/21/2019	12:10	100	1.0	5.81	0.419	16.30	6.33	93	2	0.39
1/21/2019	12:15	100	1.5	5.85	0.425	16.67	6.33	88.9	-6	0.15
1/21/2019	12:20	100	2.0	5.88	0.425	16.74	6.33	88.5	-7.0	0.15
1/21/2019	12:25	100	2.5	5.90	0.426	16.85	6.33	88.1	-8.0	0.16
1/21/2019	12:30	100	3.0	5.91	0.426	16.95	6.33	87.7	-8	0.15

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW05**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

SAMPLING INFORMATION

Sample No: 04WW05-190121

DATE/TIME: 1/21/2019 / 13:20

Pump Inlet Depth (ft): 24.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 2

Depth to Water - Initial (DTWi) (ft) 6.78

Measured Depth of Well (ft): 29.63

Screen Interval (ft): 19.00 - 29.00

Pump Start Time: 1/21/2019 / 12:50

Purging Method/Equipment: Bladder Pump

Purge Start Date/Time: 1/21/2019 / 12:50

Purge End Date/Time: 1/21/2019 / 13:20

PID Reading: N/A

Sample Collection Log

Location ID: 04WW05 Sample No: 04WW05-190121

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	12:55	100	0.50	6.85	0.577	16.93	6.43	39.3	73	2.12
1/21/2019	13:00	100	1.0	6.90	0.583	17.30	6.34	35.6	130	1.79
1/21/2019	13:05	100	1.5	6.94	0.583	17.57	6.27	33.5	160	1.65
1/21/2019	13:10	100	2.0	6.97	0.584	17.65	6.26	33.1	161	1.64
1/21/2019	13:15	100	2.5	6.99	0.584	17.70	6.26	32.8	162.0	1.63
1/21/2019	13:20	100	3.0	7.0	0.584	17.73	6.25	32.6	163	1.62

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW06**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Clear

SAMPLING INFORMATION

Sample No: 04WW06-190121

DATE/TIME: 1/21/2019 / 10:50

Pump Inlet Depth (ft): 23.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 5.53

Measured Depth of Well (ft): 28.14

Screen Interval (ft): 18.00 - 28.00

Pump Start Time: 1/21/2019 / 10:20

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/21/2019 / 10:20

Purge End Date/Time: 1/21/2019 / 10:50

PID Reading: N/A

Sample Collection Log

APTIM

Location ID: 04WW06 **Sample No: 04WW06-190121**

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	10:25	100	0.50	5.60	1.33	15.57	6.83	2.0	266	3.19
1/21/2019	10:30	100	1.0	5.65	1.36	15.98	6.80	1.9	263	3.0
1/21/2019	10:35	100	1.50	5.69	1.36	16.02	6.76	1.8	263	2.88
1/21/2019	10:40	100	2.0	5.72	1.37	16.10	6.75	2.0	264	2.85
1/21/2019	10:45	100	2.5	5.74	1.37	16.16	6.75	2.3	263	2.83
1/21/2019	10:50	100	3.0	5.75	1.37	16.20	6.75	2.1	264	2.82

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW07**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: 04WW07-190122

DATE/TIME: 1/22/2019 / 11:40

Pump Inlet Depth (ft): 17.50

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 6.63

Measured Depth of Well (ft): 22.7

Screen Interval (ft): 12.50 - 22.50

Pump Start Time: 1/22/2019 / 11:10

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 11:10

Purge End Date/Time: 1/22/2019 / 11:40

PID Reading: N/A

APTIM

Sample Collection Log

Location ID: 04WW07 Sample No: 04WW07-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	11:15	100	0.5	6.70	5.55	16.29	6.43	0.0	344	2.12
1/22/2019	11:20	100	1.0	6.75	4.30	16.72	6.34	0.0	341	1.94
1/22/2019	11:25	100	1.50	6.79	4.19	16.79	6.25	0.0	338	1.88
1/22/2019	11:30	100	2.0	6.81	4.18	16.86	6.24	0.0	337	1.86
1/22/2019	11:35	100	2.5	6.83	4.18	16.94	6.23	0.0	336	1.84
1/22/2019	11:40	100	3.0	6.84	4.17	17.0	6.22	0.0	336	1.83

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW09**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: 04WW09-190122

DATE/TIME: 1/22/2019 / 09:05

Pump Inlet Depth (ft): 18.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes: 04WW09-190122-FD Also Collected

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 6.5

Measured Depth of Well (ft): 23.53

Screen Interval (ft): 13.00 - 23.00

Pump Start Time: 1/22/2019 / 08:35

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 08:35

Purge End Date/Time: 1/22/2019 / 09:05

PID Reading: N/A

APTIM

Sample Collection Log

Location ID: 04WW09 Sample No: 04WW09-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	08:40	100	0.50	6.58	0.561	16.65	6.40	49.4	327	6.51
1/22/2019	08:45	100	1.0	6.64	0.563	17.40	6.10	17.8	327	6.05
1/22/2019	08:50	100	1.5	6.68	0.563	17.60	6.03	7.30	327	5.85
1/22/2019	08:55	100	2.0	6.71	0.562	17.68	6.02	5.9	327	5.83
1/22/2019	09:00	100	2.5	6.73	0.562	17.75	6.02	4.5	326	5.80
1/22/2019	09:05	100	3.0	6.74	0.562	17.81	6.02	3.2	326	5.78

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW10**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: 04WW10-190122

DATE/TIME: 1/22/2019 / 09:55

Pump Inlet Depth (ft): 17.00

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:	RELINQUISHED BY/AFFILIATION Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 6.79

Measured Depth of Well (ft): 22.53

Screen Interval (ft): 12.00 - 22.00

Pump Start Time: 1/22/2019 / 09:25

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 09:25

Purge End Date/Time: 1/22/2019 / 09:55

PID Reading: N/A

Sample Collection Log

Location ID: 04WW10 Sample No: 04WW10-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	09:30	100	0.50	6.87	1.12	15.48	6.27	7.50	325	4.14
1/22/2019	09:35	100	1.0	6.93	1.17	15.55	6.0	4.6	327	3.78
1/22/2019	09:40	100	1.5	6.98	1.17	15.56	5.66	4.1	331	3.65
1/22/2019	09:45	100	2.0	7.01	1.17	15.56	5.64	3.7	332	3.63
1/22/2019	09:50	100	2.5	7.03	1.17	15.57	5.63	3.2	332	3.61
1/22/2019	09:55	100	3.0	7.04	1.17	15.58	5.62	2.7	333	3.59

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **04WW11**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: 04WW11-190122

DATE/TIME: 1/22/2019 / 08:20

Pump Inlet Depth (ft): 13.50

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:	/ BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 5.13

Measured Depth of Well (ft): 18.53

Screen Interval (ft): 8.5 - 18.5

Pump Start Time: 1/22/2019 / 07:50

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 07:50

Purge End Date/Time: 1/22/2019 / 08:20

PID Reading: N/A

Sample Collection Log

Location ID: 04WW11 Sample No: 04WW11-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	07:55	100	0.50	5.20	0.747	13.60	6.13	11.6	334	2.24
1/22/2019	08:00	100	1.0	5.26	0.723	13.55	6.63	7.1	332	1.87
1/22/2019	08:05	100	1.5	5.30	0.717	13.57	6.91	6.2	325	1.62
1/22/2019	08:10	100	2.0	5.33	0.716	13.59	6.93	5.7	324	1.60
1/22/2019	08:15	100	2.5	5.35	0.716	13.60	6.94	5.3	323	1.58
1/22/2019	08:20	100	3.0	5.36	0.716	13.62	6.95	4.8	323	1.57

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **LHSMW01**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Cloudy

SAMPLING INFORMATION

Sample No: LHSMW01-190122

DATE/TIME: 1/22/2019 / 10:50

Pump Inlet Depth (ft): 12.50

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes: LHSMW01-190122-MS/MSD Also Collected

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012219	None	PERCHLORATE	6850

Sampler:		Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 4.45

Measured Depth of Well (ft): 18.03

Screen Interval (ft): 7.50 - 17.50

Pump Start Time: 1/22/2019 / 10:20

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/22/2019 / 10:20

Purge End Date/Time: 1/22/2019 / 10:50

PID Reading: N/A

Sample Collection Log

Location ID: LHSMW01 Sample No: LHSMW01-190122

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/22/2019	10:25	100	0.50	4.52	3.19	15.01	5.87	0.0	335	1.09
1/22/2019	10:30	100	1.0	4.57	2.98	15.16	5.50	0.0	348	0.40
1/22/2019	10:35	100	1.50	4.60	2.95	15.15	5.37	0.0	362	0.18
1/22/2019	10:40	100	2.0	4.62	2.95	15.14	5.36	0.0	363	0.18
1/22/2019	10:45	100	2.50	4.63	2.94	15.13	5.35	0.0	364	0.17
1/22/2019	10:50	100	3.0	4.63	2.94	15.13	5.34	0.0	365	0.17

APTIM

Sample Collection Log

Project Name: **Longhorn AAP**

Location ID: **LHSMW02**

Project No: **501032**

Sampler(s): **Scott Beesinger**

FIELD CONDITIONS

Sunny

SAMPLING INFORMATION

Sample No: LHSMW02-190121

DATE/TIME: 1/21/2019 / 11:40

Pump Inlet Depth (ft): 13.50

Sampling Method: Bladder Pump

Sample Purpose: REG

Sample Matrix: GW

Sample Notes:

Chain of Custody	COC Notes	**Analysis Group**	**Analytic Method**
ALSHT-012119	None	PERCHLORATE	6850

Sampler:	Scott Beesinger / BHATE	Scott Beesinger	
QC'ed By:		William A. Foss	2/12/2019

WELL AND PURGING INFORMATION

Measuring Point : Top of Casing

Casing ID (in.): 4

Depth to Water - Initial (DTWi) (ft) 12.22

Measured Depth of Well (ft): 19.08

Screen Interval (ft): 8.50 - 18.50

Pump Start Time: 1/21/2019 / 11:10

Purging Method/Equipment: Low Flow

Purge Start Date/Time: 1/21/2019 / 11:10

Purge End Date/Time: 1/21/2019 / 11:40

PID Reading: N/A

APTIM

Sample Collection Log

Location ID: LHSMW02   Sample No: LHSMW02-190121

Date of Reading	Time of Reading	Purge Rate	Total Purge	DTW	Cond.	Temp.	pH	Turbidity	ORP	DO
		(ml/min)	(L)	(ft)	(mS/cm)	(°C)		(NTU)	(mV)	(mg/L)
	Purge Stabilization Criteria	-	-	Drawdown limit 0.3 ft	±10%		±0.1 units	No criteria		± 10% or 0.2 mg/L
1/21/2019	11:15	100	0.5	12.30	0.307	13.48	6.87	39.9	276	3.45
1/21/2019	11:20	100	1.0	12.36	0.287	14.10	6.28	36.8	292	3.38
1/21/2019	11:25	100	1.5	12.39	0.279	14.14	6.12	31.7	297	3.30
1/21/2019	11:30	100	2.0	12.42	0.278	14.17	6.11	31.2	298	3.28
1/21/2019	11:35	100	2.5	12.44	0.278	14.20	6.10	30.9	299	3.27
1/21/2019	11:40	100	3.0	1246	0.278	14.24	6.09	30.5	299	3.26

LONGHORN ARMY AMMUNITION PLANT (LHAAP) - KARNACK, TEXAS

PREPARED FOR APTIM Federal Services, LLC.
2500 CityWest Blvd, Suite 1700
Houston, Texas 77042

TEXAS STATE PLANE COORDINATE SYSTEM
NORTH CENTRAL ZONE (4202), 1983 NORTH AMERICAN DATUM

MONITORING WELL	NORTHING	EASTING	NAVD 88 ELEVATION	
	TOP OF CASING	TOP OF CASING	TOP OF CASING	GROUND
04WW06	6959225.38	3305871.99	215.63	212.52
04WW07	6959038.63	3306006.11	214.64	211.66
04WW08	6959148.15	3305963.41	214.82	212.07
04WW09	6959090.67	3305897.71	214.61	211.47
04WW10	6959041.73	3305928.94	213.67	210.40
04WW11	6959032.36	3305839.02	212.01	209.31
17WW19	6952718.36	3315313.67	180.08	176.63
17PZ01	6952783.40	3315662.50	177.22	174.14
17PZ02	6952764.55	3315647.64	177.75	174.57
17PZ03	6952773.35	3115739.59	177.76	174.69
17WW20	6952980.24	3315580.24	180.02	177.13
FLOWLINE CREEK 1	6958236.20	3307772.02	198.47 TOP BANK	191.49 FLOWLINE
FLOWLINE CREEK 2	6958026.38	3308220.92	196.62 TOP BANK	189.16 FLOWLINE

DAVID R. COLLINS, JR. 6488

DAVID R. COLLINS, JR. R.P.L.S.#6488

SURVEY DATE: FEBRUARY 1, 2019

Appendix B

ISB Design Calculation Sheets

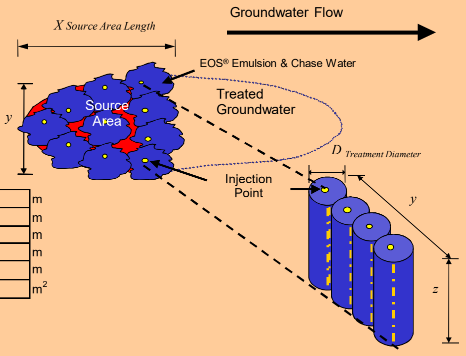
EOS Remediation, LLC

Help

EOS® SOURCE AREA & DNAPL DESIGN WORKSHEET

U.S. Version 2.1f, Rev. Date: June 18, 2008
www.EOSRemediation.com

Site Name:	Longhorn AAP	LHAAP04
Location:	Karnack, TX	
Project No.:	501032	



Step 1: Select a Substrate from the EOS® Family of Bioremediation Products

Substrate Selected (pick from drop down list) — EOS® 598B42 (Preferred for Chlorinateds)

For Product Literature Click Here

Step 2: EOS® Consumption During Contaminant Biodegradation / Biotransformation

Section A: Source Area Dimensions

Length of treatment area parallel to groundwater flow, "x"	105	ft	32.0	m
Width of treatment area perpendicular to groundwater flow, "y"	105	ft	32.0	m
Minimum depth to contamination	12	ft	3.7	m
Maximum depth of contamination	20	ft	6.1	m
Treatment thickness, "z"	8	ft	2.4	m
Treatment zone cross-sectional area, A = y * z	840	ft^2	78.0	m^2

Section B: Groundwater Flow Rate / Site Data

Soil Characteristics

Nominal Soil Type (pick from drop down list)	Silty Sand			
Total Porosity (accept default or enter *n*)	0.30	(decimal)		
Effective Porosity (accept default or enter n_e)	0.28	(decimal)		
Soil bulk density; (1-n)*2.65 g/cc (accept calculated or enter dry bulk density)	1.86	g/cc	116	lbs / ft^3
Fraction of organic carbon: foc	0.0050	range: 0.0001 to 0.01		

Hydraulic Characteristics

Hydraulic Conductivity (accept default or enter *K*)		0.099	ft/day	3.5E-05	cm/sec
Hydraulic Gradient (accept default or enter *i*)		0.028	ft/ft		

Note: Since the hydraulic gradient ($i = dh/dx$) is negative, we ask you to enter $-i$ in the EOS® Design Tool so that you can enter a positive number for convenience.

Non-reactive Transport Velocity, $V_x = -(K \times i) / n_e$	**LESS THAN**	0.01	ft/day	**LESS THAN**	0.003	m/day
Groundwater flow rate through treatment zone, $Q = -KiA$		17.42	gallons/day	**LESS THAN**	66.60	L/day

Section C: Calculated Contact Length

Contact time (τ) between oil and contaminants (accept default or enter τ)		60	typical values 60 to 180 days, see comment		
Calculated Contact Length $(x) = \tau * V_x$	**Suggested Minimum**	5.0	ft	1.5	m

Treatment zone volume	88,200	ft^3	2,498	m^3
Treatment zone groundwater volume (volume * porosity)	197,921	gallons	749,264	L

Section D: Design Lifespan For One Application

	5	year(s)	typical values 5 to 10 years	
Estimated total groundwater volume treated over design life	229,707	gallons	870,811	L

Section E: Electron Acceptors

Dissolved Phase Electron Donor Demand

Inputs		Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichiometry *Contaminant/ H_2 (wt/wt H_2)*	Hydrogen Demand *(g H_2)*
Dissolved Oxygen (DO)		0 to 8	3.59	32.0	4	7.94	393.8783374
Nitrate Nitrogen (NO_3^- - N)		1 to 10	10	62.0	5	12.30	707.7589029
Sulfate (SO_4^{2-})		10 to 500	20	96.1	8	11.91	1461.940169
Tetrachloroethene (PCE), C_2Cl_4				165.8	8	20.57	
Trichloroethene (TCE), C_2HCl_3				131.4	6	21.73	
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$				96.9	4	24.05	
Vinyl Chloride (VC), C_2H_3Cl				62.5	2	31.00	
Carbon tetrachloride, CCl_4				153.8	8	19.08	
Chloroform, $CHCl_3$				119.4	6	19.74	
sym- tetrachloroethane, $C_2H_2Cl_4$				167.8	8	20.82	
1,1,1-Trichloroethane (TCA), CH_3CCl_3				133.4	6	22.06	
1,1-Dichloroethane (DCA), CH_2CHCl_2				99.0	4	24.55	
Chloroethane, C_2H_5Cl				64.9	2	32.18	
Perchlorate, ClO_4^-			10	99.4	8	12.33	706.1846342
Hexavalent Chromium, Cr[VI]				52.0	3	17.20	
User added							
User added							
User added							

Sorbed Phase Electron Donor Demand

The concentration of the sorbed contaminant can be estimated by: $C_{SOIL} = K_{OC} \times f_{oc} \times C_{WATER}$

Where: K_{oc} is partition coefficient with respect to organic carbon.
f_{oc} (fraction organic carbon) is the mass of organic matter in soil divided by the total mass of soil
C_{WATER} is the concentration of the contaminant in the groundwater

Default values for Koc taken from: US EPA, Superfund Section, APPENDIX K, Soil Organic Carbon (Koc) / Water (Kow) Partition Coefficients (Average Value Used)

Inputs Adjust *Koc* as necessary to provide site specific estimates or enter sediment concentration (C_{SOIL})		K_{oc} (L/kg)	C_{SOIL} (mg/Kg)	Mass (g)	Hydrogen Demand *(g H_2)*
Tetrachloroethene (PCE), C_2Cl_4		272			
Trichloroethene (TCE), C_2HCl_3		97			
cis-1,2-dichloroethene (c-DCE), $C_2H_2Cl_2$		38			
Vinyl Chloride (VC), C_2H_3Cl		241			
Carbon tetrachloride, CCl_4		158			
Chloroform, $CHCl_3$		53			
sym- tetrachloroethane, $C_2H_2Cl_4$		79			
1,1,1-Trichloroethane (TCA), CH_3CCl_3		139			
1,1-Dichloroethane (DCA), CH_2CHCl_2		54			
User added					
User added					
User added					

Section F: Additional Hydrogen Demand and Carbon Losses

Generation (Potential Amount Formed)	Typical Value	GW Conc. (mg/L)	MW (g/mole)	e^- equiv./ mole	Stoichiometry *Contaminant / H_2*	Hydrogen Demand *(g H_2)*	DOC Released *(moles)*
Estimated Amount of $Fe2^+$ Formed	10 to 100	50	55.8	1	55.41	785.8272003	
Estimated Amount of Manganese (Mn^{2+}) Formed		5	54.9	2	27.25	159.760166	
Estimated Amount of CH_4 Formed	5 to 20	10	16.0	8	1.99	4376.798773	
Target Amount of DOC to Release	60 to 100	100	12.0				7250.11

Design Safety Factor: 2.0 typical values 1 to 3

Calculations assume:
1.) all reactions go to completion during passage through emulsified edible oil treated zone; and,
2.) perfect reaction stoichiometry.

EOS® Requirement Calculations Based on Hydrogen Demand and Carbon Losses

Stoichiometric Hydrogen Demand	37.9	pounds
DOC Released	827.8	pounds

EOS® Requirement Based on
Hydrogen Demand and Carbon Loss

1,000 lbs

Step 3: EOS® Requirement Based on Attachment by Aquifer Material

Soil Characteristics

Effective treatment thickness, "z_e" (typically less than 40%)	0.25	
Weight of sediment to be treated	2,553,475	lbs
Adsorptive Capacity of Soil (accept default or enter site specific value)	0.0020	lbs EOS® / lbs sediment

For Additional Information on Effective Thickness, Click Here

EOS® Attachment by Aquifer Material[1]
- Fine sand with some clay 0.001 to 0.002 lbs EOS® / lbs soil
- Sand with higher silt/clay content 0.002 to 0.004 lbs EOS® / lbs soil

[1]Default values provided based on laboratory studies completed by NCSU

For Additional Data, Click Here

EOS® Requirement Based on
Oil Entrapment by Aquifer Material

5,107 lbs

Summary – How much EOS® do you need?

Suggested Quantity of EOS®
for Your Project

13 drums

†Exclusive license agreement with Solutions-IES under U.S. Patent # 6,398,960, E.U. Patent # EP 1 315 675 and several other pending international patents.
††EOS® is a registered trademark of EOS Remediation, LLC

Nutrient Dosing Calculation Sheet

Site Name: Longhorn AAP
Location: LHAAP-04
Project No.: 501032

Carbon content of soybean oil

Major component is linoleic acid			
CH3(CH2)4CH=CHCH2CH=CH(CH2)7 CO2CH3, or C19H34O2			
Formula weight:	294.48	grams per mole	
Carbon content:	77.42%		

Carbon content of 93% soybean oil EVO

Density of EVO	8.10	pounds/gallon	
Mass of EVO	3,065	pounds	
Mass of EVO	1,390	killograms	
Volume of EVO	378	gallons	
55 gal drum of EVO	6.88	drums	
Grade of EVO	100%		
Mass of carbon	1,076.42	killograms	
Mass of carbon	2,368.13	pounds	

Nutrient demand based on 100C:10N:1P ratio

Carbon	2,368	pounds	
Nitrogen	237	pounds	
Phosphate	24	pounds	

Nutrient source required

DAP	**1,116**	lbs	

N & P content of nutrient sources

Diamoium Phosphate (DAP) solid (16-46-10)

	molecular wt.	atoms	total wt.	%
Nitrogen	14.0067	2	28.0134	21.21328922
Hydrogen	1.0079	9	9.0711	6.869136479
Phospate	30.9738	1	30.9738	23.45506713
Oxygen	15.9994	4	63.9976	48.46250717
		Total	**132.1**	**100**
		100lbs of DAP =21.2 lbs of N		
		4.71	lbs DAP for 1 lb N	

Accelerite®, liquid (JRW Bioremeiation)

5 gallons accelerite for 5.25 drums EVO	
0.95238	gal accelrite/drum EVO
9.2	lbs accelerite/gal

LHAAP-04 Treatment Area Calculation Worksheet

Site Parameters	**units**	**LHAAP 04**
Target Width	feet	105
Target Length	feet	105
Treatment Interval	feet	8
Target Area Volume	cubic feet	88,200
Effective Porosity		0.28
Target Area Water Volume	cubic feet	24,696
Target Area Water Volume	gallons	184,726
Injection Radius of Influence	feet	10
Target Injection Volume (20%)	gallons	36,945
Amendment Volume Requirements		
Emulsified Vegetable Oil	pounds	3,065
Emulsified Vegetable Oil	gallons	367
Emulsified Vegetable Oil	drums	7
Nutrients (DAP)	pounds	1,116
Water	gallons	36,578
Volumes per Point		
Emulsified Vegetable Oil	gallons	15
Nutrients (DAP)	gallons	6
Water	gallons	1,463
Injection Parameters		
Injection Spacing	feet	20
Target Depth	ft bgs	20-Dec
Thickness	feet	8
Total Volume per Point	gallons	1,478
Volume per foot		185
Injection Rate	gpm	3
Injection Pressure (not to exceed)	psi	40
Time per Point	hours	9
Simultaneous Points	points	3
Hours of Injection per day	hours	8
Gallons per day	gallons	4,320
Points to be Completed (Injection Wells)	points	25
Days of Injection	days	9

Notes:
ft bgs - Feet below ground surface.
psi - Pound per square inch.
gpm - Gallons per minute.

Appendix C

Product Specification and Safety Data Sheets

Tech Brief

Enhanced Anaerobic Bioremediation

Tersus Environmental
For every zone of your plume, we've got you covered!

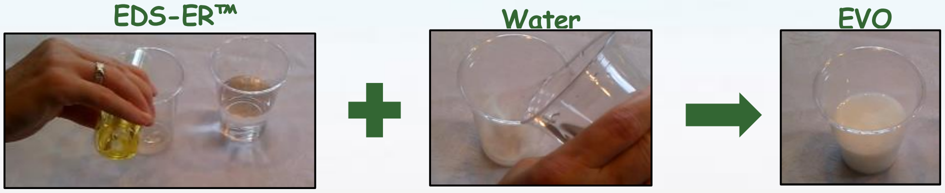
EDS-ER™

Electron Donor Solution – Extended Release

As delivered, the physical state of *EDS-ER™* (electron donor solution – extended release) by Tersus Environmental is significantly different than standard emulsified vegetable oil (EVO) products. Whereas other EVO products are concentrated emulsions containing water, *EDS-ER™* is a water-mixable oil; it contains no water. Thus, the costs for shipping EDS-ER are about 50% less than conventional products.

At room temperature, *EDS-ER™* is a liquid material with an appearance and viscosity roughly equivalent to vegetable oil. Unlike common EVO products, *EDS-ER™* will not separate, will not freeze, and has a shelf life of 2 years without spoilage.

Tersus Environmental is proud to announce that *EDS-ER™* does NOT contain ethoxylated surfactants. As you may know, many environmental remediation injectates, such as emulsified vegetable oils use biodegradable non-ionic surfactants. Unfortunately, ethoxylation, the manufacturing process that creates these surfactants (e.g., polysorbates) often results in these products containing 1,4-dioxane.



Purpose

EDS-ER™ is a simple, safe, low-cost solution for the bioremediation of halogenated compounds (e.g., PCE, TCE, DCE, VC, TCA, CT, etc.), perchlorate, explosives such as aromatic nitrates, energetic munitions residuals, nitrates, acids, radionuclides, select oxidized heavy metals, and other contaminants.

Benefits

- 100% fermentable and contains no water
- Because the product is completely water mixable, the number of necessary injection points for low permeability structures decreases
- Easily mixes with water, simplifying field operations
- Controlled release of electron donors for up to five years
- Food-grade carbon source
- Low total dissolved solids to comply with secondary water quality requirements for amendments with low salt content
- Conforms to EPA's EPP (Environmentally Preferable Purchasing) and USDA biobased criteria
- Neutral pH when mixed with water
- Clean, low-cost, non-disruptive application (e.g., direct-push, wells and excavations)
- Lowers transportation costs when compared to other electron donors
- Over two years shelf life
- Freezing Point is -4 °F (-20 °C)

Field Application Design

EDS-ER™ applications are easily tailored to meet site-specific conditions. Typical configurations consist of grid and barrier patterns and application in excavations or trenches. The product's low viscosity allows subsurface distribution through direct-push injection points, hollow-stem augers or pumped through existing wells.

Packaging Options

- 55-gallon poly drums
- 275-gallon IBC containers
- 3,000 - 5,000 gallon tankers

tersus environmental

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919.453.5577 • info@tersusenv.com

Rev: 2/11/2015

Material Safety Data Sheet

Electron Donor Solution

Section 1: Chemical Product and Company Identification

Product Name: Electron Donor Solution Extended Release
Catalog Codes: EDS-ER
CAS#: 8001-22-7
TSCA: TSCA 8(b) inventory: Soybean oil
HMIS Code: H F R P: 10 0 A
Trade Name and Synonyms: EDS-ER
Chemical Family: Glyceride Oils

Contact Information:
Tersus Environmental, LLC
109 E. 17th Street, Suite #3880
Cheyenne, WY 82001
Ph: 307.638.2822 • info@tersusenv.com
www.tersusenv.com
For emergency assistance, call: 919.638.7892

Section 2: Composition and Information on Ingredients

COMPONANT	CAS #	OSHA TWA	OSHA STEL	ACGIH TWA	ACGIH STEL
Soybean Oil	8001-22-7	---	10 mg/m^3	---	---
Vegetable Oil Derived Fatty Acid Esters	Confidential	---	---	---	---

HAZARDOUS INGREDIENTS: NONE AS DEFINED UNDER THE U.S. OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200) OR THE CANADIAN HAZARDOUS PRODUCTS. ACT S.C. 1987, C.30 (PART 1).

THE PRECISE COMPOSITION OF THIS PRODUCT IS PROPRIETARY INFORMATION. A MORE COMPLETE DISCLOSURE WILL BE PROVIDED TO A PHYSICIAN IN THE EVENT OF A MEDICAL EMERGENCY.

SARA HAZARD: NONE NOTED (SECTION 311/312) TITLE III SECTION 313 - NOT LISTED
All components of this product are listed on the TSCA registry.

Section 3: Physical/Chemical Characteristics

BOILING RANGE: Not applicable VAPOR DENSITY: Exceeds 1.0

SPECIFIC GRAVITY (H20=1.0): 0.92 - 0.925 VAPOR PRESSURE: Not applicable

PERCENT VOLATILE BY VOLUME: 0% SOLUBILITY IN WATER: Miscible

EVAPORATION RATE: Not applicable
APPEARANCE AND ODOR: A pale yellow, oily liquid - only a faint odor.
WEIGHT PER GALLON: 7.7 lbs. at 60F.

Section 4: Fire and Explosion Data

FLAMMABILITY CLASSIFICATION: Combustible Liquid - Class IIIB.
FLASHPOINT: Greater than 550 F (288 C).
METHOD USED: Tag Closed Cup.
EXTINGUISHING MEDIA: CO2, dry chemical, foam, sand.
SPECIAL FIREFIGHTING PROCEDURES: Avoid use of water as it may spread fire by dispersing oil. Use water to keep fire-exposed containers cool. Water spray may be used to flush spills away from fire.

UNUSUAL FIRE AND EXPLOSION HAZARDS: Rags soaked with any oil or solvent can present a fire hazard and should always be stored in UL Listed or Factory Mutual approved, covered containers. Improperly stored rags can create conditions that lead to oxidation. Oxidation, under certain conditions can lead to spontaneous combustion.

Section 5: Reactivity Data

STABILITY: Generally stable. Spontaneous combustion can occur. See Unusual Fire and Explosion Procedures, Section IV.

CONDITIONS TO AVOID: High surface area exposure to oxygen can result in polymerization and release of heat.

INCOMPATABILITY (MATERIALS TO AVOID): Avoid contact with strong oxidizing agents.

HAZARDOUS DECOMPOSITIONS OR BY-PRODUCTS: Decomposition may produce carbon dioxide and carbon monoxide.

HAZARDOUS POLYMERIZATION: Will not occur.

Section 6: Health Hazard Data

THRESHHOLD LIMIT VALUE: As a liquid - none. As oil mist - 10 mg/m3 total particulate.

INHALATION HEALTH RISKS AND SYMPTOMS OF EXPOSURE: Excessive inhalation of oil mist may affect the respiratory system. Oil mist is classified as a nuisance particulate by ACGIH.

SKIN ABSORPTION HEALTH RISKS AND SYMPTOMS OF EXPOSURE: Not classified as a primary skin irritant or corrosive material. Sensitive individuals may experience dermatitis after long exposure of oil on skin.

HEALTH HAZARDS (ACUTE AND CHRONIC): Acute: none observed by inhalation. Chronic: none reported.

EMERGENCY AND FIRST AID PROCEDURES FOR:

SKIN CONTACT: May be removed from skin by washing with soap and warm water.

EYE CONTACT: Immediately flush eyes with plenty of cool water for at least 15 minutes. Do NOT let victim rub eyes.

INHALATION: Immediately remove exposed individual to fresh air source. If victim has stopped breathing give artificial respiration, get medical attention immediately.

Section 7: Precautions for Safe Handling and Use

ENVIRONMENTAL PRECAUTIONS: Where large spills are possible, a comprehensive spill response plan should be developed and implemented.

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED: Wear appropriate respiratory protection and protective clothing as described in section VIII. Depending on quantity of spill: (a) Small spill - add solid adsorbent, shovel into disposable container and wash the area. Clean area with detergent. (b) Large spill - Squeegee or pump into holding container. Clean area with detergent. In the event of an uncontrolled release of this material, the user should determine if this release is reportable under applicable laws and regulations.

WASTE DISPOSAL METHOD: All recovered material should be packaged, labeled, transported, and disposed or reclaimed in accordance with local, state, and federal regulations and good engineering practices.

Section 8: Control Measures

RESPIRATORY PROTECTION: Not normally needed. A qualified health specialist should evaluate whether there is a need for respiratory protection under specific conditions.

VENTILATION: Handle in the presence of adequate ventilation. Intermittent clean air exchanges recommended, but not required.

PROTECTIVE GLOVES: Not normally needed. However, protective clothing is always recommended when handling chemicals.

EYE PROTECTION: Eye protection is always recommended when handling chemicals. Wear safety glasses meeting the specifications established in ANSI Standard Z87.1.

Section 9: Special Precautions

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORAGE: Store away from flame, fire, and excessive heat.

Section 10: Disposal Considerations

General Information: Do not discharge into drains, watercourses or onto the ground. Discharge, treatment, or disposal may be subject to national, state, or local laws. Empty containers may contain product residues.

Disposal Methods: No specific disposal method required.

Container: Since emptied containers retain product residue, follow label warnings even after container is emptied.

Section 11: Transportation Information

DOT Not regulated.
TDG Not regulated.
IATA Not regulated.
IMDG Not regulated.

Section 12: Other Information

Hazard Ratings

	Health Hazard	Fire Hazard	Instability	Special Hazard
NFPA	1	1	0	NONE

Hazard rating: 0 - Minimal; 1 - Slight; 2 - Moderate; 3 - Serious; 4 - Severe
NFPA Label colored diamond code: Blue - Health; Red - Flammability; Yellow - Instability; White - Special Hazards

	Health Hazard	Flammability	Physical Hazard	Personal Protection
HMIS	1	1	0	--

Hazard rating: 0 - Minimal; 1 - Slight; 2 - Moderate; 3 - Serious; 4 - Severe
HMIS Label colored bar code: Blue - Health; Red - Flammability; Orange - Physical Hazards; White - Special

Section 13: Disclaimer and/or Comments

We suggest that containers be either professionally reconditioned for re-use by certified firms or properly disposed of by certified firms to help reduce the possibility of an accident. Disposal of containers should be in accordance with applicable federal, state and local laws and regulations. "Empty" drums should not be given to individuals.

The conditions of handling, storage, use and disposal of the product are beyond our control and may be beyond our knowledge. For this and other reasons, we do not assume responsibility and expressly disclaim liability for loss, damage or expense arising out of or in any way connected with the handling, storage, use or disposal of the product.

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Tersus Environmental be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Tersus Environmental has been advised of the possibility of such damages.

Appendix D

Daily ISB Injection Log

APTIM

Drilling Company: ____________________
Area: __________
Injection Oversight: ____________________
Oversight Company: Aptim Federal Services, LLC
Injection Operator: ____________________

Injection Point	Date	Pressure (psi)	Total Volume (gal)	Flow Rate (gpm)	Start	End	Comments
LHAAP-04							
Total Volume 0							

Appendix E

LUC Inspection and Maintenance Checklist and Compliance Certification

Annual Land Use Control Compliance Certification Form

In accordance with the Remedial Design dated ________________ for LHAAP-04 an inspection of the site was conducted by _____________________ [indicate transferee] on ________________.

The land use control mechanisms are:

- Groundwater restrictions - prohibit access to the contaminated groundwater except for environmental monitoring and testing only until cleanup goals are met;
- Land use restrictions - restrict land use to nonresidential;
- Integrity of remedial and monitoring systems - maintain the integrity of any current or future remedial or monitoring systems until cleanup goals are met.

No unauthorized activities or uses have occurred. Compliance with land use controls and restrictions is as follows:

- No use of groundwater (other than environmental testing and monitoring), installation of new groundwater wells, or tampering with existing monitoring wells;
- No land use other than nonresidential; and
- No activities that would compromise the integrity of the remedial or monitoring systems.

I, the undersigned, do document that the inspection was conducted as indicated above, and that the above information is true and correct to the best of my knowledge, information, and belief.

Date: ____

Name/Title: ____

Signature: ____

Annual compliance certification forms shall be completed no later than March 1 of each year for the previous calendar year, retained in the file and provided to Army, EPA and TCEQ upon request.

RAO Inspection and Maintenance Checklist

General Information	
Project Name	RAO Inspection and Maintenance, LHAAP-04 Longhorn Army Ammunition Plant, Karnack, TX
Contractor	
Inspector's Name	
Inspector's Title	
Inspector's Signature	
Inspector's Contact Number	
Inspection Date	
Type of Inspection	☐ Quarterly ☐ Semiannual ☐ Annual ☐ Prior to forecast rain ☐ After a rain event ☐Other --------------------------------

A.	**Groundwater Monitoring Wells**					
D.1	Are the installed groundwater monitoring wells in poor condition?					
D.2	Is the well cleared of vegetation and accessible?					
D.3	Any other relevant observations?					
D.4	Are there any significant cracks present?					
D.5	Are there any damaged areas?					

00920408

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
LONGHORN ARMY AMMUNITION PLANT
POST OFFICE BOX 220
RATCLIFF, AR 72951

May 15, 2019

DAIM-ODB-LO

Mr. Rich Mayer
US Environmental Protection Agency
Federal Facilities Section R6
1445 Ross Avenue
Dallas, TX 75202-2733

Re: Final Five Year Review Report
Longhorn Army Ammunition Plant, Karnack, Texas, May 2019

Dear Mr. Mayer,

The above-referenced document has been revised to address your April 11, 2019 comments. It is transmitted to you for your file. In the following paragraphs, Longhorn presents additional response to some of EPA's comments on the Fourth Five Year Review Report.

EPA's comments, Nos. 13, 19, 23, 24, 98, 100, 142 and 143 for LHAAP-49 and LHAAP-004-R-01, include the statement that the remedies would not be protective in the long term without LUCs, since the sites do not meet unrestricted use/unrestricted exposure (UU/UE) conditions. This comment suggests that it is a matter of law that when not meeting UU/UE standards, LUCs are required. This is inaccurate; neither CERCLA nor the NCP require the selection of LUCs when not meeting UU/UE. The only statutory requirement is to conduct reviews no less than every 5 years, found in CERCLA §121(c) and 40 CFR 300.430(f)(4)(ii). The sites subject to these comments are protective in the short and long term without LUCs as a component of the remedy. The remedies were selected with reliance on the reasonably foreseeable future use, which is a non-residential wildlife refuge. This reasonably foreseeable future use is protected by the federal register notice establishing the Caddo Lake National Wildlife Refuge, which precludes or prohibits other uses incompatible with a wildlife refuge, such as residential use.

In Comment Nos. 51, 52, and 114, EPA states that the TRRP groundwater residential cleanup standards should be used as cleanup levels for non-MCL groundwater contaminants, in accordance with the dispute resolution agreement for the dispute covering RODs for LHAAP-16, LHAAP-17, LHAAP-001-R and LHAAP-003-R. The dispute resolution does not apply retroactively to sites that were not part of the dispute. These comments refer to sites with pre-dispute RODs. The cleanup levels for non-MCL groundwater contaminants of concern in these RODs are the industrial groundwater MSCs under the Risk Reduction Rules (RRR) and not the TRRP.

The point of contact for this action is the undersigned. I may be contacted at 479-635-0110, or by email at rose.m.zeiler.civ@mail.mil.

Sincerely,

Rose M. Zeiler

Rose M. Zeiler, Ph.D.
Longhorn AAP Site Manager

Attachments:
Final Five Year Review Report, May 2019
Responses to Comments Table

Copies furnished:
A. Palmie, TCEQ, Austin, TX
P. Bruckwicki, Caddo Lake NWR, TX
R. Smith, USACE, Tulsa District, OK
A. Williams, USACE, Tulsa District, OK
A. Maly, USAEC, San Antonio, TX
K. Nemmers, Bhate (for project files)

00920410

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

DEPARTMENT OF THE ARMY
LONGHORN ARMY AMMUNITION PLANT
POST OFFICE BOX 220
RATCLIFF, AR 72951

May 15, 2019

DAIM-ODB-LO

Ms. April Palmie
Texas Commission on Environmental Quality Superfund Section, MC-136
12100 Park 35 Circle, Bldg D
Austin, TX 78753

Re: Final Five-Year Review Report,
Longhorn Army Ammunition Plant, Karnack, Texas, May 2019

Dear Ms. Palmie,

The above-referenced document has been revised to address your April 5, 2019 comments on the Fourth Five Year-Review Report. It is transmitted to you for your file.

The point of contact for this action is the undersigned. I may be contacted at 479-635-0110, or by email at rose.m.zeiler.civ@mail.mil.

Sincerely,

Rose M. Zeiler

Rose M. Zeiler, Ph.D.
Longhorn AAP Site Manager

Attachments:
Final Five-Year Review Report, May 2019
Responses to Comments Table

Copies furnished:
R. Mayer, USEPA–Region 6, Dallas, TX
P. Bruckwicki, Caddo Lake NWR, TX
R. Smith, USACE, Tulsa District, OK
A. Williams, USACE, Tulsa District, OK
A. Maly, USAEC, San Antonio, TX
K. Nemmers, Bhate (for project files)

Memorandum

Date: **July 15, 2019**

To: **Richard Mayer, Environmental Protection Agency**

April Palmie, Texas Commission on Environmental Quality

CC: **Rose M. Zeiler, Ph.D., Longhorn AAP Site Manager**

From: **Aaron Williams, U.S. Army Corps of Engineers**

RE: **Errata to Final Fourth Five Year Review Report for Longhorn Army Ammunition Plant, Karnack, Texas, May 2019**

This memorandum presents corrections to errors in the Final Fourth Five Year Review Report that were identified by April Palmie of TCEQ (June 4, 2019 email) and Rich Mayer of EPA Region 6 (June 13, 2019 email).

The errors described in this memorandum, which is referred to herein as this Errata Memorandum, do not impact the overall protectiveness conclusions for each site as presented in the Final Fourth Five Year Review Report and the Report remains unchanged. This Errata Memorandum documents corrections to errors in the Report and will be used to ensure identified errors are not repeated during preparation of the Fifth Five Year Review Report. This Errata memorandum includes text and tables in attachments that are organized as follows:

- Revised Text. New updated abbreviations list.
- Updated Figure. ES Figure 1. Added reference to Landmark 2014a.
- Updated Table. ES Table 1. Added definition for 1,2-DCA.
- Revised Text. Section 2.4.3. Replaced “oil field” with “old field” and revised sentence to state “Harrison Bayou is considered a high quality natural area by the TCEQ and a wetland area of international importance by the International Ramsar Convention.”
- Revised Text. Section 6.5.1. Revised text to address incorrect statements about discharge limits and protocols.
- Updated Figure. Figure 22. Replaced figure with higher resolution figure.
- Updated Table. Table 23. Added Remedial Action Operation Report names and dates
- Updated Table. Table 34. Added Remedial Action Operation Report names and dates

Additional comments/revisions that were not incorporated in this Errata but need to be addressed during preparation of the Fifth Five Year Review include:

- Use of brighter colors in figures so that well numbers are easier to read
- Rename references in text to keep proper sequencing, for example references to AECOM documents should not begin with AECOMc
- Legends and Notes in Figures and Tables should be updated as new data from new sources is inserted and the purpose of the original figures or tables is changed

Attachment 1

Updated Abbreviations List

LIST OF ABBREVIATIONS AND ACRONYMS

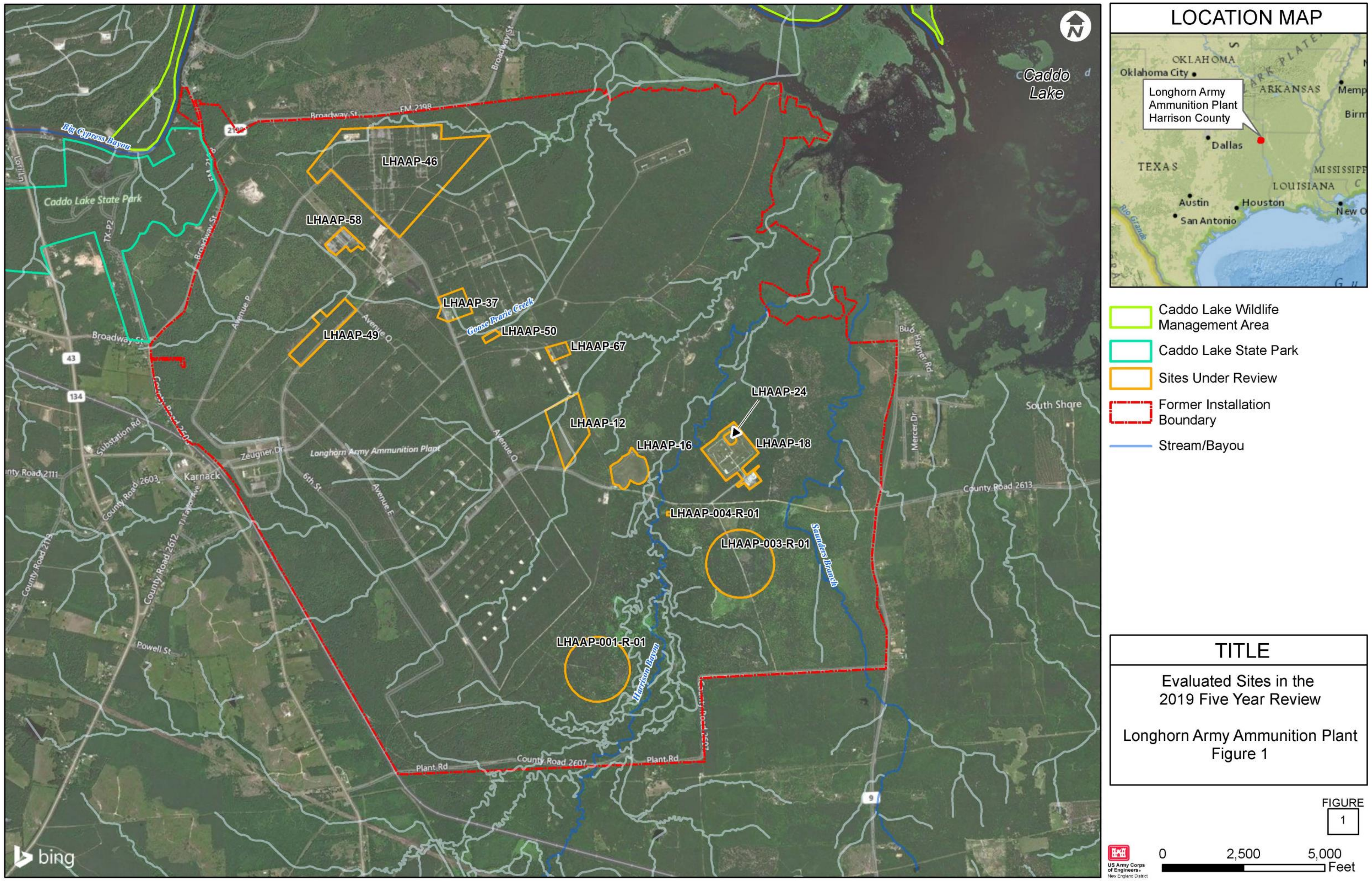
1,1-DCA	1,1-Dichloroethane
1,2-DCA	1,2-Dichloroethane
1,1-DCE	1,1-Dichloroethene
µg/L	micrograms per liter
§	Section
ACD	Air Curtain Destructor
AEC	Army Environmental Center
AECOM	AECOM Technical Services, Inc.
AEHA	United States Army Environmental Hygiene Agency
A/I	active/inactive
AMSL	Above mean sea level
AOC	area of concern
ARAR	applicable or relevant and appropriate requirements
Army	United States Department of Army
AST	above ground tank
BERA	Baseline Ecological Risk Assessment
BG3	Burning Ground Number 3
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-DCE	Cis-1,2-Dichloroethene
COC	contaminant of concern
COPC	chemical of potential concern
CSM	Conceptual Site Model
CTT	Closed, Transferring and Transferred
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	Dichloroethene
DERP	Defense Environmental Restoration Program
DNAPL	dense non-aqueous phase liquid
DOW	Dow Environmental, Inc.
EE/CA	Engineering Evaluation/Cost Analysis
EISB	Enhanced In Situ Bioremediation
EPS	Environmental Protection Systems
ESD	Explanation of Significant Differences
FBR	Fluidized Bed Reactor
FFA	Federal Facility Agreement
FS	Feasibility Study

FY	Fiscal Year
GAC	Granular Activated Carbon
GW-Ind	Groundwater-Industrial
gpm	gallons per minute
GWTP	groundwater treatment plant
ICT	interception collection trench
INF	Intermediate-Range Nuclear Forces
IRA	Interim Remedial Action
Jacobs	Jacobs Engineering Group, Inc.
LHAAP	Longhorn Army Ammunition Plant
LTM	Long-Term Monitoring
LTTD	low temperature thermal desorption
LUC	Land Use Control
LUCP	Land Use Control Plan
MC	methylene chloride
MCL	maximum contaminant level
MEC	Munitions and Explosives of Concern
mg/kg	milligrams per kilograms
MMRP	Military Munitions Response Program
MNA	monitored natural attenuation
MSC	medium specific concentration
Msl	mean sea level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
O&M	Operations and Maintenance
OB/OD	Open Burning/Open Dentonation
OM&M	Operations, Maintenance, and Monitoring
OPS	Operating Properly and Successfully
ORP	Oxidation-Reduction Potential
OSWER	Office of Solid Waste and Emergency Response
PCE	tetrachloroethene
PCL	Protective Concentration Level
PLC	Programmable Logic Controller
Plexus	Plexus Scientific Corp.
PSI	pounds per square inch
RA	Remedial Action
RAB	Restoration Advisory Board
RACR	Remedial Action Completion Report
Radian	Radian International, LLC.
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RFA	RCRA Facility Assessment

RI	Remedial Investigation
ROD	Record of Decision
SDWA	Safe Drinking Water Act
Shaw	Shaw Environmental, Inc.
SI	Site Inspection
SLERA	Screening-Level Ecological Risk Evaluation
STEP	Solutions To Environmental Problems, Inc.
TAC	Texas Administrative Code
TBC	to be considered
TCDD	tetrachlorodibenzo-p-dioxin
TCE	Trichloroethene
TCEQ	Texas Commission on Environmental Quality
TNRCC	Texas Natural Resource Conservation Commission
TNRIS	Texas Natural Resources Information System
TNT	Trinitrotoluene
TRRP	Texas Risk Reduction Program
TS	Treatability Study
UEP	Unlined Evaporation Pond
U.S.	United States
U.S. Army	U.S. Department of the Army
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
UUUE	Unlimited Use and Unrestricted Exposure
VC	vinyl chloride
VOC	volatile organic compound
WP	Work Plan

Attachment 2

Updated ES Figure 1.



ES Figure 1. **Twelve sites comprising the Fourth Five-Year Review at Longhorn Army Ammunition Plant, Karnack Texas (see Table ES-1 for details) (LHAAP, 2018a, US Army, 2016, Landmark Consultants, 2015a, b, c, 2014a, b, 2011a, b, 2006, EODT, 2009).**

Attachment 3

Updated ES Table 1.

ES Table 1. Information summary for the twelve sites comprising the Fourth Five-Year Review at Longhorn Army Ammunition Plant, Karnack Texas (see Figure ES-1) (AECOM, 2014a, US Army, 2016, 2010a-f, 2006, 1995a, b).

Site Number	Site Name	Description	ROD Date	Five-Year Review Iteration	COCs/Contaminants of Potential Concern (COPCs) (See Final ROD)	Selected Remedy(s)
LHAAP- 12	Landfill 12	Non-hazardous industrial waste disposal occurred between 1963 and 1994.	IRA - Sep 1995 Final - Apr 2006	4	TCE	Landfill cap, LUCs, and MNA. Estimated TCE cleanup time is 23 to 261 years.
LHAAP- 16	Old Landfill	Trinitrotoluene (TNT) red water ash disposal occurred from 1942 to 1944. Burn pits, waste storage, and landfill operations continued until 1980s.	IRA- Sep 1995 ROD-Aug 2016	4	None identified in the IRA CVOCs, perchlorate [a], and metals in groundwater	Landfill cap. Landfill cap, LUCs, bioremediation and biobarriers, and MNA with Five-Year Reviews. Estimated cleanup time is 280 years.
LHAAP - 18/24	Burning Ground No. 3 and Unlined Evaporation Pond (UEP)	Site 18 was used from approximately 1955 until 1984 for the treatment, storage, and disposal of pyrotechnic and combustible solvent wastes by open burning, incineration, evaporation, and burial. Site 24 was a UEP located within Site 18's former burning ground number 3 (BG3). The UEP was constructed in 1963 and used until 1984 for disposal of manufacturing plant waste.	IRA ROD May 1995	4	CVOCs and metals [a,b,c]	Extraction of shallow groundwater and treatment using metal precipitation, air stripping and off-gas treatment for VOCs, Excavation of source material and treatment using low thermal desorption and off-gas treatment for VOCs. Draft Proposed Plan is in review.
LHAAP-37	Chemical Laboratory	Also called Site 35B, the Chemical Laboratory area was used from 1953 to 1997.	ROD Jun 2010	1	CVOCs in shallow groundwater	Groundwater LUCs and MNA Bio plug study completed. Estimated cleanup time is 50 years.
LHAAP-46	Plant 2 Area	Pyrotechnic and illumination production area from 1952 until 1997.	ROD Sep 2010	1	CVOCs in shallow and intermediate groundwater	Groundwater LUC and MNA
LHAAP- 49	Former Acid Storage Area	This site was used from 1942 to 1945 formulation and storage of acid in support of TNT production.	ROD Aug 2010	2	None	No Action
LHAAP-50	Former Sump Water Tank	Former sump water above ground tank (AST) that received industrial wastewater from various LHAAP sumps between 1955 and 1988.	ROD Sep 2010	1	Perchlorate in soil and CVOCs and perchlorate in shallow groundwater	Perchlorate-contaminated soil excavation with offsite disposal, LUCs, and MNA for CVOCs. Estimated cleanup time is 50 years.
LHAAP-58	Shops Area	Also called Site 35B, the Shops Area was established in 1942 as part of the installation's initial construction. The facility provided plant-operated laundry, automotive, woodworking, metalworking, painting, refrigeration, and electrical services. The site became inactive in 1996-1997.	ROD Sep 2010	1	CVOCs in groundwater	Groundwater LUCs and EISB/MNA in eastern plume, and groundwater LUCs and MNA in western plume with Five-Year Reviews Eastern plume - estimated cleanup time is 200 years for MNA only, to be revised after implementing enhanced bioremediation option. Western plume – estimated vinyl chloride (VC) and 1,1-dichloroethene (1,1-DCE) cleanup times are 70 and 135 years, respectively.
LHAAP-67	Aboveground Storage Tank Farm	AST Farm consisting of seven former above ground tanks surrounded by earthen dikes, and used for bulk No. 2 fuel oil, kerosene, and solvents storage. Tank sizes and operation history are not known.	ROD Jun 2010	1	CVOCs in shallow groundwater	Groundwater LUCs and MNA. Estimated cleanup time for 1,1-DCE is 20 to 34 years, and for 1,2-dichloroethane (1,2-DCA) is 21-43 years.
LHAAP-001-R-01	South Test Area/Bomb Test Area	Testing M120A1 photoflash bombs produced at the facility until about 1956. During the early 1960s, detonation, and potentially white phosphorous munitions may have demilitarized leaking production items such as XM40E5 "button bombs".	ROD Aug 2016	1	MEC[d]	MEC removal, LUCs, and limited groundwater monitoring.

Site Number	Site Name	Description	ROD Date	Five-Year Review Iteration	COCs/Contaminants of Potential Concern (COPCs) (See Final ROD)	Selected Remedy(s)
LHAAP-003-R-01	Ground Signal Test Area	Beginning in April 1963, the range was used for aerial and on-ground testing and destruction of a variety of devices, including pyrotechnic signal devices, red phosphorus smoke wedges, infrared flares, illuminating mortar shells and cartridges, button bombs, and various types of explosive simulators. From late 1988 through 1991, the site was also used for burnout of Pershing missile rocket motors.	ROD Aug 2016	1	MEC[d]	MEC removal, LUCs, and limited groundwater monitoring.
LHAAP- 004-R-01	Pistol Range	This site was used between 1950 and 2004 for small arms target practice and qualifying tests.	ROD Aug 2010	2	None	No Action

Notes:

a	Perchlorate was identified at levels of concern following IRA implementation at LHAAP-16 and LHAAP-18/24	MNA	monitored natural attenuation
b	IRA specified discharge limits, not COCs	ROD	Record of Decision
c	Interim ROD only for LHAAP-18/24 at the time of the five year review	TCE	trichloroethene
d	Munitions and Explosives of Concern (MEC). This term, which distinguishes categories of military munitions that may pose unique explosives risks, means : (A) Unexploded Ordnance (UXO), as defined in 10 §101(e)(5); (B) Discarded military munitions (DMM), as defined in 10 U.S.C. §2710(e)(2); or (C) Munitions constituents (e.g., TNT, RDX), as defined in 10 U.S.C. §2710(e)(3), present in high enough concentrations to pose an explosive hazard.	UEP	unlined evaporation pond
COC	contaminant of concern	CVOC	Chlorinated volatile organic compound
COPC	chemical of potential concern	1,1-DCE	1,1-Dichloroethene
IRA	Interim Remedial Action	1,1-DCA	1,1-Dichloroethane
LUC	Land Use Control	1,2-DCA	1,2-Dichloroethane
ACD	Air Curtain Destructor	Cis-DCE	Cis-1,2-Dichloroethene
PLC	Programmable Logic Controller		

Attachment 4

Updated Section 2.4.3

2.4.3 Surface Water and Ecology

2.4.3.1 Surface Hydrology

The four natural drainage systems encompass approximately 1,133 acres of the installation (Harrison Bayou (475 acres), Goose Prairie Creek (246 acres), Central Creek (262 acres), and Saunders Branch (150 acres)) and drain north eastwardly to Caddo Lake. HUC12 Watershed boundaries place Harrison Bayou in the Harrison Bayou watershed, Goose Prairie Creek and Central Creek in the Kitchen Creek-Frontal Caddo Lake watershed, and Saunders Branch in the Watson Bayou-Frontal Caddo Lake watershed (Figure 3).

The surface area of Caddo Lake covers approximately 51 square miles and is a part of Big Cypress Bayou. The boundary of the installation along Caddo Lake is determined by the 169.27-foot lake elevation. Saunders Branch flows onto LHAAP near the southeastern corner of the installation and flows northward into Caddo Lake. Approximately 11 percent of the heavily wooded eastern section of the installation is drained by this system. Harrison Bayou enters LHAAP on the southern edge of the installation. The bayou carries 30 percent of the surface drainage of LHAAP and bisects the installation in a northeasterly direction. Central Creek enters LHAAP on its western edge just south of the town of Karnack, Texas and carries approximately 29 percent of the surface drainage from the installation to Caddo Lake. The headwaters of Goose Prairie Creek are located near the northwestern corner of the installation and consist of one larger creek and several smaller tributaries. Goose Prairie Creek flows across the northern edge of the installation and drains approximately 30 percent of LHAAP.

2.4.3.2 Ecology

LHAAP is part of the Cypress Bayou Basin and is within the Pineywoods ecological region of Texas. The Pineywoods is a deep inland extension of the Gulf Coastal Plain that extends into Texas, Louisiana, Arkansas, and Oklahoma. Caddo Lake in East Texas and Louisiana was designated a Wetlands of International Importance in 1993 by the Ramsar Convention on Wetlands and is home to numerous and unique species of fish, birds, and plants (Ramsar Sites Database, 2018) (Figure 3).

Mild temperatures, ample rainfall in the area and small elevation differences across the installation support an abundant and diverse plant community and provide a great diversity of habitats on the installation (Shaw, 2007c). Vegetation at the installation is dominated by mixed pine-hardwood forests that cover gently rolling to hilly terrain. Soil conditions at LHAAP range from moist to wet. The majority of soil is hydric or has hydric inclusions. Soils have good water-holding capacity. In the last decade, rainfall has been less abundant and temperatures higher, resulting in earlier seasonal dry down times and drought conditions during the later month of the summer season and autumn, however, the wetlands still receive enough rain and runoff to have pooled water and surface flow present every spring.

Uplands are broad and mostly flat with a gradation of habitats, from grassland/forbland and shrubland/old field habitats around developed areas, to moist upland pine forest, mixed forest, temporarily flooded bottomland forest, cypress swamp, and shallow water aquatic habitats in Caddo Lake (Shaw, 2007c). Habitat types include grassland/forbland, shrubland/old field, developed areas, pine forest, mixed pine/hardwood forest, upland hardwood forest, wetland/bottomland forest, and cypress swamp.

LHAAP supports hundreds of vertebrate species including mammals, birds, fish, amphibians, and reptiles. The site also supports federally listed species, State Listed species, State Species of Concern and State special Features/Natural Communities/Managed areas. Harrison Bayou is considered a high quality natural area by the TCEQ and a wetland area of international importance by the International Ramsar Convention. The bottomland area experiences flooding and waterlogged soils, which have prevented logging equipment access and allowed the Bayou to retain much of its integrity and ecological diversity. Harrison Bayou contains several species of oaks, pines and other trees that are generally large. Approximately one-half of Harrison Bayou is considered virgin forest. Photographs, maps, hydric soils information, and field observations indicate that the great majority of Harrison Bayou is jurisdictional wetland (Shaw, 2007c, USACE, 1987).

2.4.3.3 Risk Assessment for the Evaluated Sites

Both human health and ecological risk have been evaluated at LHAAP (US Army, 2016, 2010a-f, 2006, 1995a, b). Human health risk has been evaluated at the AOC level and ecological risk has been evaluated on a side-wide basis. As noted in the Final RODs for AOCs LHAAP-12, LHAAP-16, LHAAP-37, LHAAP-46, LHAAP-49, LHAAP-5-, LHAAP-58, LHAAP-67, LHAAP-001-R, LHAAP-003-R and LHAAP-004, no action is needed for the protection of ecological receptors. The early interim ROD for LHAAP-18/24, which predates the site wide BERA, states that the magnitude of ecological exposure and associated risk estimates are dependent upon further site characterization and will be addressed in the site risk assessment. The BERA, finalized in 2007 (Shaw, 2007c, d) included LHAAP-18/24 in the study area, making the conclusions and outcome from the BERA applicable for this AOC as well.

Attachment 5

Updated Section 6.5.1

6.3 Initial Response

No initial response actions occurred prior to the Interim ROD (US Army, 1995b).

6.4 Summary of Basis for Taking Action

The contaminants at the LHAAP-18/24 site are chlorinated solvents and metals. Prior to the IRA, concentrations of MC and TCE were higher in groundwater, and the plumes were presumably expanding. Because the site is located east of Harrison Bayou (which eventually discharges into Caddo Lake), and a portion of the site is within the 100-year flood plain, there were concerns about migration of contaminants from groundwater to surface water. The remedial objectives for the IRA were to eliminate or minimize the potential for exposure to human and ecological receptors. The interim remedy was selected to achieve this by reducing or preventing further migration of contaminants into deeper groundwater zones and possibly surface water bodies (US Army, 1995b). Groundwater monitoring well sampling criteria changed in late 2006 when the Army and the USEPA agreed and TCEQ concurred that only 15 of the previous 47 monitoring wells were necessary for monitoring contaminants on a semi-annual basis (Shaw, 2016). Since mid-2012, additional locations have been added to the sampling program and between 40 and 50 locations were sampled semi-annually since September 2012.

6.5 Remedial Actions

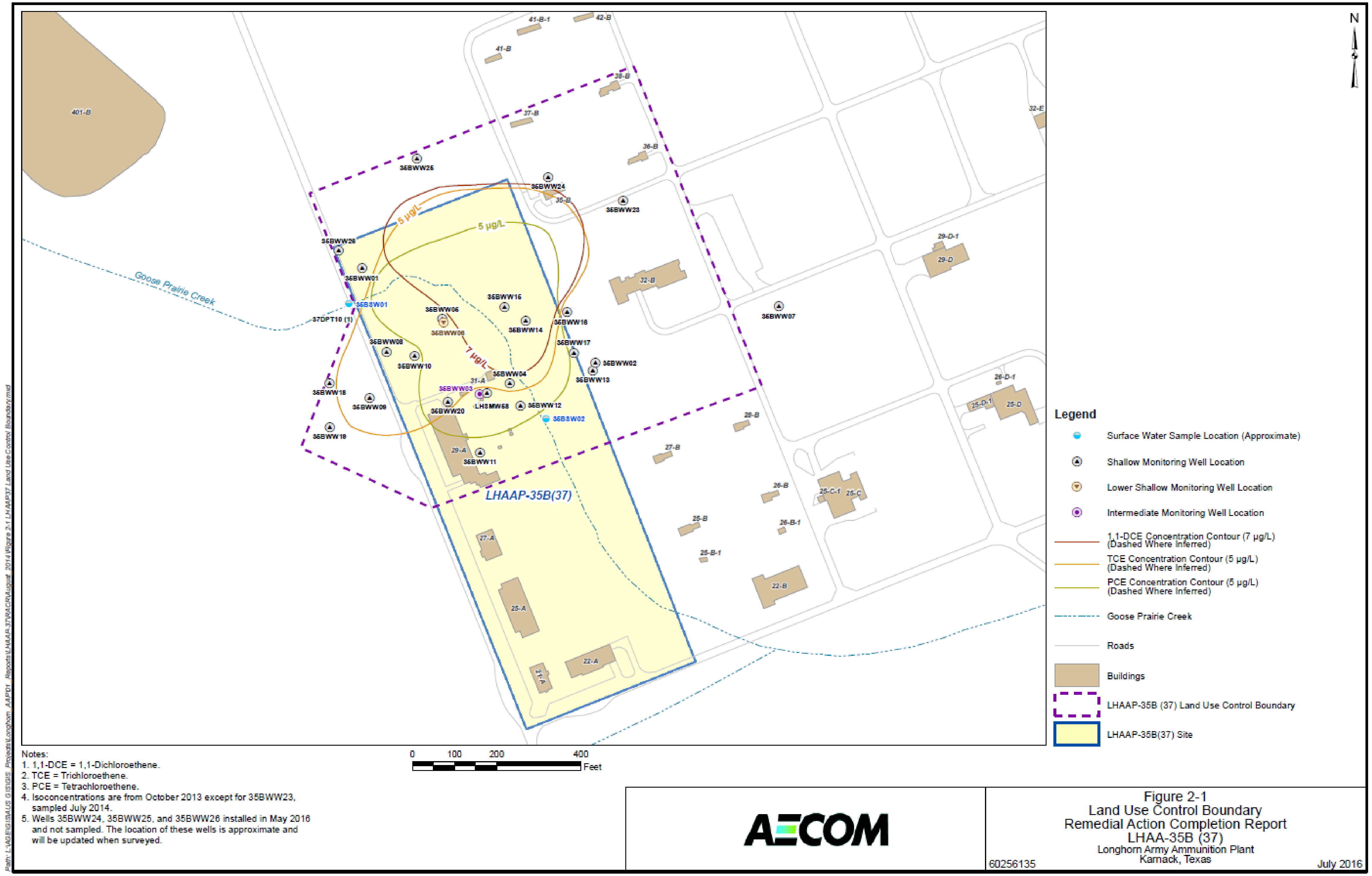
6.5.1 Remedy Selection

The selected LHAAP-18/24 remedy for addressing the site contaminants and meeting the remedial objectives of the IRA was a combination of soil removal/treatment and groundwater extraction and treatment. The Army issued the IRA ROD on April 18, 1995, which was approved by the USEPA on May 12, 1995 (US Army, 1995b). The interim ROD had no chemical-specific remedial goals. The IRA ROD required extracted groundwater to be treated to the levels established by TNRCC for discharge to the Harrison Bayou and/or Central Creek (US Army, May 1995). In a letter from TNRCC, dated January 8, 2002, perchlorate discharge was required to be less than 6 µg/L for the daily average and 13 µg/L for the daily maximum. A memorandum entitled Development of Proposed Discharge Limits for Perchlorate for the LHAAP GWTP dated May 9, 2017 and associated email approvals from TCEQ established the current discharge limits. The current allowable perchlorate discharge to the Harrison Bayou is 278 µg/L for a daily average and 589 µg/L for a daily maximum. A Final ROD and selected remedy have not been issued by the Army for LHAAP-18/24, so no chemical-specific remedial goals are available. LUCs will also be evaluated as a component of the final remedy.

The RAOs developed for the IRA were to eliminate or minimize the potential for exposure to human and ecological receptors. The interim remedy was selected to achieve this by reducing and/or preventing further migration of contaminants into deeper groundwater zones and possibly surface water bodies (US Army, 1995b). The IRA construction completion date was August 31, 1999 (Shaw, 2008).

Attachment 6

Updated Figure 22



Notes:
1. 1,1-DCE = 1,1-Dichloroethene.
2. TCE = Trichloroethene.
3. PCE = Tetrachloroethene.
4. Isoconcentrations are from October 2013 except for 35BWW23, sampled July 2014.
5. Wells 35BWW24, 35BWW25, and 35BWW26 installed in May 2016 and not sampled. The location of these wells is approximate and will be updated when surveyed.

Figure 2-1
Land Use Control Boundary
Remedial Action Completion Report
LHAA-35B (37)
Longhorn Army Ammunition Plant
Karnack, Texas
60256135
July 2016

Figure 22. LHAAP-37 MNA baseline footprints - 2013/2014, and selected posting of May 2018 COCs potentially affecting the extent of the footprints (AECOM, 2016e & Fourth Five-Year Review).

Attachment 7

Updated Table 23

Table 23. LHAAP-46 chronology of site events (AECOM, 2015e, 2012, Shaw, 2011a, 2009a, US Army, 2010c).

Event	Date
Plant 2 construction periods	1944 to early 1950s
Plant 2 operating period	1952-97
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8 1988
LHAAP placed on NPL	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Final Remedial Investigation Report for the Group 4 Sites, Sites 35A, 35B, 35C, 46, 47, 48, 50 60, and Goose Prairie Creek	January 2002
Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake),	June 2003
Data Gaps Investigation	April 2007
Final Baseline Ecological Risk Assessment	November 2007
Feasibility Study completed	October 2009
Proposed Plan	January 2010
Record of Decision	September 2010
Remedial Design	September 2011
Remedial Action Work Plan	December 2012
Remedial Action Completion Report	January 2015
Draft Final 1st Annual Remedial Action Operation Report for LHAAP-46	November 2015
Draft Final 2nd Annual Remedial Action Operation Report for LHAAP-46	May 2016
Draft Final 3rd Annual Remedial Action Operation Report for LHAAP-46	March 2017
Tech memo addressing dry wells and plan to proceed with MNA evaluation	March 2018

Attachment 8

Updated Table 34

Table 34. LHAAP-58 chronology of site events (Bhate, 2017, AECOM, 2016g, 2015f, US Army, 2010f).

Event	Date
Plant 3 operating period	1952-97
Shops Area Operations	1942-1997
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8 1988
LHAAP placed on NPL	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Remedial Investigation for the Group 4 Sites, Sites 35A, 35B, 35C, 46, 47, 48, 50 60, and Goose Prairie Creek	January 2002
Final Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake	June 2003
Data Gaps Investigation	April 2007
Feasibility Study completed	December 2009
Proposed Plan	January 2010
Record of Decision	September 2010
Remedial Design	September 2011
Remedial Action Work Plan	April 2013
Draft Final 1st Annual Remedial Action Operation Report for LHAAP-35A(58)	November 2015
Draft Final 2nd Annual Remedial Action Operation Report for LHAAP-35A(58)	May 2016
Remedial Action Completion Report	June 2016
Revised Remedial Action Work Plan Contingency Remedy for Western Plume	January 2018
Final Explanation of Significant Differences Record of Decision for Western Plume Contingency Remedy	March 2018
Draft Final 3rd Annual Remedial Action Operation Report for LHAAP-35A(58)	March 2018

US Army Corps
of Engineers ®

New England District
696 Virginia Road
Concord, Massachusetts
01742-2751

STAKEHOLDER COMMENTS

Location: Karnack, Harrison County, Texas

Reviewer: Various

Document Name: Draft – Five Year Review Longhorn Army Ammunition Plant (LHAAP)

Prepared By: NAE

No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
1.	General comment	The last Five-Year Review was about 450 pages and this one is about 850 pages. This Five-Year Review is too long, repetitive, and scholarly. It also includes too much non-essential information, which is already included in the site record.	Noted. This comment will be applied to the 2024 Five Year Review to eliminate repetition and non-essential information already in the record while following EPA and DoD guidance.
2.	Executive summary location	Please move this section so it is after the Table of Contents and between "List of Abbreviations" and "1.0 Introduction".	Executive Summary was moved to be located between the "List of Abbreviations" and "1.0 Introduction."
3.	Executive summary (and global edits)	LHAAP-12 – "Sanitary Fill Area" is not the description used for LHAAP-12 in previous records. Throughout the report (including tables and figures), replace the term "Sanitary Fill Area" with "Landfill 12" or "Sanitary Landfill". LHAAP-16 – While groundwater extraction is not a selected remedy for this site, it is a critical component for hydraulic control and surface water protection. In this section, protectiveness statement, and other LHAAP-16 discussions, please add information about groundwater extraction/hydraulic control.	"Sanitary Fill Area" was replaced with "Landfill 12" to be consistent with the site name identified in the ROD dated April 2006. Changes were made in the Executive Summary, text, tables, figure throughout the document. The protectiveness statement was revised in the executive summary, FYR Summary Form, and Section 5.12 to read: "The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the

No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
			2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs." In Section 5.9.1 in response to Question A and at the end of Section 5.9.2, the following sentence was added to the first paragraph: The IRA remedy is enhanced by a treatability study extraction system that serves to reduce contaminant transport and as well as the mass of contaminants in the groundwater. An issue was identified in the 2014 FYR: "Relatively high concentrations of TCE persist downgradient of the cap, suggesting that a continuing source may be present." This issue appears to be supported by the data review and technical assessment. Section 5.10 was revised and a table was added that identifies the issue as: “Relatively high concentrations of TCE persist downgradient of the cap, suggesting that a continuing source may be present.” Section 5.11 was revised to include the recommendation to address the identified issue. A table was added that identifies the recommendation as: “Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs.” An issues and Recommendations block was also added to the FYR Summary Form to capture the changes in Sections 5.10 and 5.11.

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No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
		FAA – Replace all "FAA" with "FFA".	"FAA" was replaced with "FFA" throughout the Executive Summary. A document search did not find "FAA" in any other locations within the document.
		Oscillate – please replace all use of "oscillate" with "vary", "change", or something similar.	"Oscillate" has been changed to "vary" or "change" throughout the entire document.
		LHAAP-50 – In this section and other LHAAP-50 discussions, revise statements about the contingency remedy to indicate the remedy will be implemented following the ESD to the ROD.	Concur. The text in the following Sections has been revised: Executive Summary Section 7 now reads: The contingency remedy to enhance MNA will be implemented following the ESD to the ROD and will address the elevated TCE concentrations and the increases in COC concentrations in leading edge wells Recommendations in the Summary Form was revised to read: "Implement the contingency remedy following the ESD to the ROD to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13." Last sentence of Question A in Section 10.10.1. Text now reads: MNA has been found to be effective, and according to the installation, the

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			contingency remedy to enhance MNA via in situ bioremediation will be implemented in FY 19 following the ESD to the ROD. Table 33 recommendations and follow up actions text now reads: Implement the contingency remedy following the ESD to the ROD to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.
4.	Figures and Tables	General comments follow regarding figures and tables. Titles – Consider revising the titles for figures and tables as shown in the examples below: Example 1 From draft (highlight added for emphasis) - Figure 1. LHAAP showing the location of the sites included in this review (LHAAP, 2018a, US Army, 2016, USGS, 2011, Landmark Consultants, 2015a, b, c, 2014, b, 2011a, b, 2006, EODT, 2009) (see Table 1) Suggested format - Figure 1. LHAAP showing the location of the sites included in this review	Figures and tables were generated using the citations listed. To accommodate this comment titles/headers were reformatted for clarity, but citations were retained for continuity.

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		Example 2: From draft (highlight added for emphasis) - Table 1. Five-Year Review status for sites included in the 2018 review (US Army, 2016, 2010a- f, 2006, 1995a, b) (see Figure 1) Suggested format – Table 1. Five-Year Review status for sites included in the 2018 review The remaining information (highlighted in original version examples) would be better presented as a note to the figure or table. When a figure or table from the site record has been modified for this report, the figure (or table assembly) should include notes to explain the changes. Examples follow: Figure 21, should have notes to discuss the additional call out boxes and any other changes Table 18, should have a list of the sources and explain the purpose of the table	

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		assembly and other features (such as arrows). This presentation format is difficult to interpret, and notes would help. Please make sure the imported figure and tables are legible. For example, the well names on Figure 22 are completely illegible.	
5.	2.1, 4	The topographic description was copied from previous documents, but it is inaccurate. Most of the site is 200 feet above MSL or higher. The site generally slopes from west to east, with the northwest corner the highest part of the site and boundary with Caddo Lake the lowest. The topographic maps for Karnack and Potters Point are very helpful.	Concur. The text beginning "The western end of the site is approximately 175 feet above mean sea … elevation increases by approximately 10 feet" was replaced with the following: "Surface elevations vary from 175 to 335 feet above mean sea level (MSL), with most of the site 200 feet or more above MSL. The site generally slopes from west to east."
6.	2.3.3, 8	Please revise this sentence as shown to remove inaccurate details: Caddo Lake ~~is the only natural lake in Texas, and~~ serves as the primary source of drinking water for several surrounding communities (e.g., Shreveport, LA) and provides recreational opportunities and lakeshore residential areas.	Inaccurate details were removed and statement was revised. Revised text reads: "Caddo Lake serves as the primary source of drinking water for several surrounding communities (e.g., Shreveport, LA) and provides recreational opportunities and lakeshore residential areas."

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		AOC – define this term or replace	AOC was defined as area of concern and added to the List of Abbreviations and Acronyms. Revised text reads: "The ecological risk evaluation is a site-wide finding and is not applicable at the area of concern (AOC) level."
7.	2.4.2, 11	Please revise this sentence as shown for clarity (replacement text highlighted): The third well is located immediately adjacent to the former LHAAP administration building, ~~and~~ which is currently used as the USFWS headquarters offices for the Caddo Lake Institute and the USFWS. Add the usage status for this well.	Sentence was revised. Revised text reads: "The third well is located immediately adjacent to the former LHAAP administration building, which is currently used as the USFWS headquarters offices for the Caddo Lake Institute and the USFWS." The usage status was added to second paragraph in Section 2.4.2 and reads: "This well is not currently used for drinking at LHAAP although it may supply water for non-potable uses."
8.	2.4.3.2, 13-14	3rd paragraph – "oilfield" is a typo. Please search for "oilfield" and replace with the term from BERA "old field" (or delete the term).	Revisions were made and "oilfield" was replaced with "oil field" throughout entire document. 3rd paragraph revised text reads: "Uplands are broad and mostly flat with a gradation of habitats, from grassland/forbland and shrubland/oil field habitats around developed areas, to moist upland pine forest, mixed forest, temporarily flooded bottomland forest, cypress swamp, and shallow water aquatic habitats in Caddo Lake (Shaw, 2007c). Habitat types include grassland/forbland, shrubland/oil field, developed areas, pine forest, mixed pine/hardwood forest, upland hardwood forest, wetland/bottomland forest, and cypress swamp."

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No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
		4th paragraph The sentence below seems to be paraphrasing a sentence from the BERA: TCEQ considers Harrison Bayou a high quality natural wetland area. Please revise to include the original sentence: From BERA - Harrison Bayou is considered a high quality natural area by the TCEQ and a wetland area of international importance by the International Ramsar Treaty. The following sentence should include pine trees: Harrison Bayou contains several species of oaks and other trees that are generally large.	Sentence was revised to include a statement from the BERA. Revised text reads: According to the Ramsar Convention, "Harrison Bayou is considered a high quality natural area by the TCEQ and a wetland area of international importance (Shaw, 2007c). " Sentence was revised to include pine trees. Revised text reads: "Harrison Bayou contains several species of oaks, pines and other trees that are generally large."
9.	Figure 7-9	In the legend area "Contaniment" is a repeated typo. This typo may apply to other figures too.	Figures 7-9 were revised.
10.	4.8.3	This sentence is in the interview section for each unit. Please revise this sentence	Sentence was revised throughout the entire document (Sections 4-15 interview sections). Revised text reads: "The USFWS and RAB representatives knew of no complaints regarding the site and the

No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
		in Sections 4-15 as shown for clarity (replacement text highlighted): The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that ~~though the length of time~~ it takes too long to complete phases of work ~~takes too long~~.	associated activities, but expressed the opinion that it takes too long to complete phases of work."
11.	5.5, 37	Please revise this sentence as shown for clarity (replacement text highlighted): This information is reported in monthly data packages and quarterly GWTP reports that were completed throughout the review period.	Sentence was revised. Revised text reads: "This information is reported in monthly data packages and quarterly GWTP reports that were completed throughout the review period."
12.	6.0, 43	Define first use of ACD and add to acronym list	Concur. The acronym for the Air Curtain Destructor (ACD) was added to the acronym list.
13.	Table 12, 47	2014 ESD is missing from the list.	Table 15 in Section 6.2 was revised to include the 2014 ESD. Text reads: "Final Explanation of Significant Differences (ESD) ROD for Early Interim Remedial Action at Burning Ground No. 3 LHAAP, February 2014"
14.	6.5.1, 49-50	2014 ESD should be included.	Section 6.5.1 was revised to include discussion of the 2014 ESD. Text now reads: "A Final Explanation of Significant Differences ROD for Early Interim Remedial Action at Burning Ground No. 3, Longhorn Army Ammunition Plant (AECOM, 2014e) was needed as a result of changes to the GWTP to remove the catalytic oxidation air emission control unit as a component of the Selected Remedy described in Section I of the Interim Remedial Action

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			Record of Decision (IRA ROD) (USACE, 1995). Because the Selected Remedy of extracting and air stripping VOCs from the groundwater remains in place and all ARARs will continue to be met without the catalytic oxidation unit, its deletion does not result in a fundamental change in the Selected Remedy requiring an IRA ROD amendment. All other GWTP system components remain unchanged and are not included in this ESD.”
15.	6.5.2.1, 50-51	First paragraph, please revise the following sentences (suggested replacement text highlighted): These elements of the IRA are shown on [Reference is missing]. The trenches extend approximately 25-55 feet deep to the confining clay layer of the Shallow Groundwater Zone, where present. [Or similar addition] Remove 2nd use of this statement before the numbered statements: The groundwater treatment system components are: (2) and (5) should include the 2014 ESD, which officially removed catalytic oxidizer.	Sentence was completed and now reads: “These elements of the IRA are shown on Plot 16 and Plot 17 in Appendix C, Section 3.0.” Text now reads: “The trenches extend approximately 25-55 feet deep to the confining clay layer of the Shallow Groundwater Zone, where present.” “The groundwater treatment system components are:” statement was removed prior to the numbered statements. The following was added to numbered statement 2: “In February 2014, a Final ESD, ROD for Early Interim Remedial Action at Burning Ground No. 3, LHAAP was needed as a result of changes to the GWTP to remove the catalytic oxidation air emission control unit as a component of the Selected Remedy described in Section I of the IRA ROD (AECOM, 2014e).”

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			A sentence was added before the end of numbered statement 5. The end of number statement 5 now reads: “Although neither of these criteria require the use of air emission control equipment, the 2014 ESD is required because the catalytic oxidation unit is identified as a remedy component of the Selected Remedy and there is no provision for removing the catalytic oxidation unit from the remedy if no longer required to meet the ARAR. The GWTP has been operating without air abatement since September 2012, meeting all the criteria set in the air-monitoring program (AECOM, 2014e)”
16.	6.7, 52	Replace BG3/UEP with LHAPP-18/24.	Replaced BG3/UEP with LHAAP-18/24. Revised text reads: “The LHAAP-18/24 OM&M activities are:”
17.	6.7.1, 54 and 6.7.2, 55	The following sentences should be revised to reference subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan. Pg 54 Extracted groundwater collected at the GWTP is treated to the levels established in the 1995 IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan. Pg. 55 As part of the GWTP operations, multiple samples from various sources or waste streams are collected and analyzed regularly for the parameters cited in the	Sentence was revised to include suggested revisions. Text now reads: “Extracted groundwater collected at the GWTP is treated to the levels established in the 1995 IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan.” Sentence was revised to include suggested revisions. Text now reads: “As part of the GWTP operations, multiple samples from various sources or waste streams are collected and analyzed regularly for the parameters

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<table>
<tr><th>No.</th><th>Ref.
Page / Para.</th><th>COMMENTS From TCEQ</th><th>Disposition</th></tr>
<tr><td></td><td></td><td>IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan ~~the TCEQ letter dated January 8, 2002.~~</td><td>cited in the IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan.”</td></tr>
<tr><td>18.</td><td>Figure 15, 56</td><td>Please check the 2017 costs.</td><td>Concur. The 2017 costs only captured 5 months of O&M and LTM, with the additional 7 months added, O&M Costs have been revised. Additionally in response to EPA comment #53, the LHAAP-12 costs were able to be extracted from the totals and all costs updated below:
<table>
<tr><th>Fiscal Year</th><th>O&M Costs ($)</th><th>LTM Costs ($)</th><th>Total ($)</th><th>Notes</th></tr>
<tr><td>2013</td><td>1,410,449.66</td><td>164,142.61</td><td>1,574,527</td><td>Upgrades and repairs to the aging GWTP</td></tr>
<tr><td>2014</td><td>574,627.64</td><td>492,427.84</td><td>1,067,055.48</td><td></td></tr>
<tr><td>2015</td><td>626,866.51</td><td>492,427.84</td><td>1,119,294.35</td><td></td></tr>
<tr><td>2016</td><td>626,866.51</td><td>369320.88</td><td>996,187.39</td><td></td></tr>
<tr><td>2017</td><td>848,952.01</td><td>157,760.46</td><td>1,006,712.47</td><td>Replace air compressor and PLC System</td></tr>
</table>
The text referencing LHAAP-12 costs was removed from all applicable sections of the report. Additionally, a sentence was added to state “The increased O&M costs for 2017 support replacement of air compressor and PLC system.”</td></tr>
</table>

No.	Ref. Page / Para.	COMMENTS From TCEQ	Disposition
			Section 5.6 was revised to remove discussion of LHAAP-12. Text now reads: "The costs for O&M and LTM activities at LHAAP-16, and LHAAP-18/24 are not subdivided into individual site estimates, thus assessment of individual site costs was not conducted." Section 5.11.1 was revised to remove discussion of LHAAP-12. Text now reads: "LHAAP-16 O&M costs are included with LHAAP-18/24. Track LHAAP-16 O&M costs separately from LHAAP-18/24." Section 6.7.4 was revised to remove discussion of LHAAP-12. Text now reads: "The O&M and LTM costs at LHAAP-16, and LHAAP- 18/24 are not subdivided into individual site values, thus assessment of individual site cost performance is not possible. The original O&M total cost estimate for LHAAP-12 and LHAAP- 16, and cost estimate for LHAAP-12 RAO LTM, was $75,000/year (US Army, 1995a). The original O&M total cost estimate for LHAAP-18/24 was $400,000/year (US Army, 1995b). The increased O&M costs for 2017 support replacement of air compressor and PLC system The combined approximate actual O&M and LTM costs for sites LHAAP-16, and LHAAP-18/24 are presented in Figure 15, including monitoring well maintenance activities." Section 6.12.1 was revised to remove discussion of tracking LHAAP18/24 costs separately from LHAAP-12 costs. Text now reads: "Track LHAAP-18/24 O&M costs separately from LHAAP-16."
19.	Table 15, 69 (and all sections)	Please check the "Oversight Agency" column in the recommendation tables in each section. Look for duplicated	The "Oversight Agency" column in the recommendation tables was checked for each section. Revisions were made to Tables 14, 16, 27, and

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		language, such as in Table 15. Also, some of these tables say USEPA & STATE, preference is that they all say USEPA & TCEQ.	45. Oversight agencies are listed as "USEPA & TCEQ" in all recommendation tables.
20.	7.0	In this section (and others) it should be clear that building have been removed. Suggest a global search for "buildings". In most cases it is appropriate to add or replace with "building foundation remnants". See example below: The surface features at LHAAP-35B (37) include a mixture of asphalt-paved roads and parking area, building foundation remnants from several administration buildings and the former Chemical Laboratory (Building 29-A), and a mixture of wooded and grassy vegetation-covered areas (US Army, 2010b).	A global search for "buildings" produced 6 results. Revisions were made to Section 7.0. Text now reads: "The surface features at LHAAP-35B (37) include a mixture of asphalt-paved roads and parking area, building foundation remnants from several administration buildings and the former Chemical Laboratory (Building 29-A), and a mixture of wooded and grassy vegetation-covered areas (US Army, 2010b)." Section 9.0 now reads: "The site is currently wooded and grassy with the exception of two concrete buildings, numerous building foundation remnants, and several concrete saddles and platforms previously used for the support of aboveground storage tanks."
21.	Figure 40	Title in the LHAAP-001-R-01 map incorrectly references "Former Pistol Range"	Figure 40 was revised.
22.	Appendix B, B-3	Correct Texas Risk Reduction Rule ~~Act~~	Searched the entire document and revised text on page B-3, no other revisions were necessary. Text on B-3 now reads: "Texas Risk Reduction Rule"
23.	Appendix B, B-4, Table 1	Sites are missing from the table – 16 and 18/24 for example.	Concur. The "date of last update" column was removed. The table was updated to include missing sites and location and action specific ARARs.

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		Suggest you delete the "date of last update" column. If you keep this information, please confirm dates. For example, Texas Surface Water Quality Standards have been revised several times since the date noted. The tables for location and action specific ARARs are missing.	
24.	Appendix D	The site inspection forms are too long and detailed. When there are so many check boxes and options the accuracy decreases. As a reviewer, I noticed many inconsistencies, but it was not possible to confirm the accuracy of about 200 pages of forms. This format is probably useful at a facility with one site/unit, but it is less useful as presented in this Five-Year Review with the entire form repeated for each site/unit. Please consider revising these forms so that each site/unit only includes the relevant sections. Please revise on all site inspection forms – April Palmie's phone number is 512-239-4152 and add Project Manager.	Agreed Appendix D is 243 pages long and repetitive, however this is how the field team filled out the site inspection forms. An effort will be made to optimize the format of the site inspection forms for the next Five Year Review inspection. All of April Palmie's information on site inspection forms now includes "Project Manager" and phone number of "512-239-4152"

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		D-26 Remedy box for landfill cover should be checked.	Revised. Box is now checked for landfill cover.
		D-52 Item 4, Add the following note to "remarks": Substantive requirements for monitoring and discharge are documented in the 2017 Final Revised Sampling and Analysis Plan.	The provided statement was added to the remarks for Item 4 on page D-52.
		D-183, XI A, Why does this statement reference the bio-plug pilot study? Beginning in 2020, bio-plug performance objectives will be re- evaluated, and the sampling program reduced to semi-annual until the 2024 five-year review, where monitoring effectiveness and needs will be reassessed.	The text has been revised to read : "Beginning in 2020, MNA performance objectives will be re-evaluated, and the sampling program reduced to semi-annual until the 2024 five-year review, where monitoring effectiveness and needs will be reassessed."
25.	Appendix E	E-2 April Palmie's title should be Project Manager. Please remove the rest - Project ~~and Grant~~ Manager~~, Superfund Section, Remediation Division~~	Revisions were made. Text now reads: "Project Manager" on page E-2 for April Palmie's title.

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		E-6 Please correct April Palmie's title and phone number. Mailing address should include MC-136 E-7 Revise A8 to include the correct name of the site.	Page E-6 text now reads: "Project Manager" as April Palmie's title and the phone number was corrected to be "(512) 239-4152". April Palmie's address was revised to include "MC-136". For page E-7 "LHAAP-12 (Sanitary Fill Area)" was revised to the correct site name of "LHAAP-12 (Landfill 12)".

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1.	General	There appears to be a somewhat random use of abbreviations. Suggest performing a technical edit to ensure that abbreviations are used consistently after first use of full terminology with abbreviations in parenthesis.	Noted. Abbreviations have been checked and added to the list of abbreviations as well.
2.	General	The brief summaries in the executive summary should include the identification of COCs for each site.	Concur. The Executive Summary was revised to include the identification of site COCs as per ES Table 1.
3.	General	The Five-Year Review Summary Form section appears to focus on “issues” – so only those sites with issues are included. It would be helpful to the reader to add a statement as to the purpose of this section, so that it will be clear to the reader that not all sites are to be listed in this section – just the ones with issues and recommendations.	The following text was added: “Of the 12 sites identified at LHAAP, only 7 had identified issues and are included in these five year review summary forms. Consequently, LHAAP-37, LHAAP-49, LHAAP-001-R-01, LHAAP-003-R-01, LHAAP-004-R-01, which have no identified issues are not included in these summary forms.”
4.	General	Please include a map that identifies all contaminated groundwater with the LUC boundaries identified? It would be helpful to see the groundwater LUCs holistically.	Exception. Please refer to Figure 1 of the Comprehensive Land Use Control (LUC) Management Plan which includes the groundwater use restriction areas. The document is updated annually.
5.	General	Why is there limited coverage of the sites in the analytical results (Appendix C) section?	The coverage of the sites in the analytical results reflects the scope of work defined in the work plans.

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6.	Page ES-1	The first use of USEPA, MNA, and COC. Please define.	USEPA, MNA, and COC were defined prior to the first use of each acronym. Text now reads: "United States Environmental Protection Agency (USEPA)", "monitored natural attenuation (MNA)", "contaminant of concern (COC)"
7.	Page ES-1/ Section 2	It is more accurate to state that "the interim landfill cap remedy is protective of human health and the environment in the short term, and it is anticipated that implementation of LUCs, EISB, bio-barriers, and MNA will be protective of human health and the environment in the long term. In the interim, unacceptable risks presented by groundwater and soil contamination are being controlled".	The statement was revised. Text now reads: "The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs."
8.	Page ES-2/ Section 3	Please be consistent with the acronym "COCs". Sometimes it is spelled in all capitalization "COCS".	A global search was done for "COCS" and all instances were replaced with "COCs" throughout the entire document.
9.	Page ES-2/ Section 3	The first use of ICT and GWTP, please define.	ICT and GWTP were defined prior to the first use of each acronym. Text now reads: "interception collection trench (ICT)" and "groundwater treatment plant (GWTP)"
10.	Page ES-2/ Section 4	Please include a clarification sentence on why it is too early to evaluate whether MNA is working at this site since the ROD was signed in 2010.	Concur. The sentence beginning "An insufficient amount of time…." was replaced with the following sentences: "Due to the implementation of a demonstration project which proved ineffective, the MNA remedy was delayed until late 2017. Because the first quarterly report was not completed within the review period, it is not possible to evaluate the MNA remedy, though it is noted that TCE concentrations in a perimeter well are slightly above the MCL."

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11.	Page ES-2/ Section 5	It appears that “COC’s” should be changed to “COCs”.	A global search for “COC’s” allow for correction to “COCs and “COCs’ ” where appropriate. Section 5.0 of the Executive summary was revised to state: “stabilized the COCs’ plumes”
12.	Page ES-2/ Section 5, Last Sentence	Please modify the last part of the last sentence to clarify that it is the shallow zone monitoring wells (being consistently dry for several sampling events) that are a concern at this site.	Last sentence in Section 5 was revised to clarify that the shallow zone monitoring wells are of concern. Text now reads: “However, in order for the remedy to be protective in the long-term, assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended.” Section 8.13 was also revised for consistency.
13.	Page ES-3/ Section 6 (LHAPP-49)	Is this site included in the overall LUC Management Plan Site? It appears that no LUCs are being implemented for this site. While this site may be protective in the short term, it would not be protective in the long term without LUCs, since the site does not meet unrestricted use/unrestricted exposure conditions. What is the Army’s plan to address this issue?	Do not concur. LUCs were not selected as part of the remedial response action in the ROD for LHAAP-49 and are not evaluated as part of this 5 year review. The NA decision remains protective in both the short-term and long-term.
14.	Page ES-3/ Section 8	The sentence providing, “[a]n insufficient amount of time has passed to assess the full impact of the EISB in the eastern	Concur. The sentence stating “an insufficient….in the eastern plume” was deleted.

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		plume" appears to be inconsistent with the fact that current performance monitoring shows some COCs are being reduced while other COCs concentrations are increasing. Please provide factually accurate information concerning, past performance monitoring, current performance monitoring, and future reports. EPA recommends deletion of the sentence concerning an "insufficient amount of time."	Information regarding the past performance monitoring, current performance monitoring and future reports is discussed in response to comment No. 121.
15.	Page ES-2/ Section 4/ Minor Typo	Please change FAA to FFA (Same with Sections 5, 6, 7, 8, 9, 10, 11, and 12). Also, first use of TCE and MCL, please define.	"FAA" was replaced with "FFA" throughout the entire document. TCE and MCL were defined prior to the first use. Text now reads: "trichloroethene (TCE)" and "maximum contaminant level (MCL)"
16.	Page ES-3/ Section 7	Please add CVOCs to abbreviation and acronym list or remove chlorinated and C from acronym and just use VOC in document. VOC is used later in document, so it needs to be consistent. The first use of DNAPL, so please define.	CVOC was added to the abbreviation and acronym list as "CVOC chlorinated volatile organic compound". DNAPL was defined prior to first use. Text now reads: "dense non-aqueous phase liquid (DNAPL)".
17.	Page ES-4/ Section 10	Please define and add TRRP and PCL to the abbreviation and acronym list.	TRRP and PCL were defined prior to first use and both were added to the abbreviation and acronym list. Text now reads: "Texas Risk Reduction Program (TRRP) Protective Concentration Level (PCL)"

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18.	Page ES-4/ Section 9	Please modify the last sentence to include the phrase, "the Army will evaluate the data in the north area of the plume …" Otherwise, the sentence is not clear.	Modification was made to the last sentence of Section 9. Text now reads: "However, in order for the remedy to be protective in the long-term, the Army will evaluate the data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system."
19.	Page ES-5/ Section 12 (LHAAP-001-R-01)	Is this site included in the overall LUC Management Plan for the site? It appears that no LUCs are being implemented for this site. While this site may be protective in the short term, it would not be protective in the long term without LUCs, since the site does not meet unrestricted use/unrestricted exposure conditions. What is the Army's plan to address this issue?	Do not concur. LUCs were not selected as part of the remedial response action in the ROD for LHAAP-004-R-01 and are not evaluated as part of this 5 year review. The NFA decision remains protective in both the short-term and long-term.
20.	Page ES-7 and ES-8/ Site Numbers LHAAP-001-R-01,N LHAAP-003-R-001, and LHAAP-004-R-01	These Sites fail to specify COCs and COPCs. Note that the Sites include munitions and explosives of concern and munitions constituents. As such, these munitions and explosives of concern/munitions constituents include either listed hazardous substances under CERCLA or are reactive or ignitable RCRA hazardous waste; and are therefore CERCLA hazardous substances. The COC/COPCs column should be modified to include the COCs and COPCs that created	The COC/COPCs column was modified to include MEC that may present an unacceptable explosive risk or safety hazard at the sites. A descriptive footnote was also added to the table. Footnote d reads: Munitions and Explosives of Concern (MEC). This term, which distinguishes specific categories of military Munitions that may pose unique explosives safety risks, means: (A) Unexploded Ordnance (UXO), as defined in 10 §101(e)(5); (B) Discarded military munitions (DMM), as defined in 10 U.S.C. §2710(e)(2); or (C) Munitions constituents (e.g., TNT, RDX), as defined in 10 U.S.C. §2710(e)(3), present in high enough concentrations to pose an explosive hazard.

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		an unacceptable explosive risk or hazard at the Sites.	No COCs are listed in the LHAAP-004-R-01 ROD which is a NFA ROD.
21.	Page ES-12/ LHAAP 16	It is more accurate to state that “the interim landfill cap remedy is protective of human health and the environment in the short term, and it is anticipated that implementation of LUCs, EISB, bio-barriers, and MNA will be protective of human health and the environment in the long term. In the interim, unacceptable risks presented by groundwater and soil contamination are being controlled.”	Concur with exception. The protectiveness determination was changed to short-term protective and the protectiveness statement was revised as follows: "The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs." Section 5.4.2 was revised to remove the statement: “In accordance with the IRA ROD, LUCs such as warning signage and maintenance and repair of the cap are currently in place. Routine maintenance (e.g., mowing, aerating, seeding, settlement, etc.) and erosion repair are also being performed to ensure that the integrity of the soil cover is maintained.” In Section 5.6 the 3rd bullet “Maintain LUCs” was removed. In Section 5.11.1, the first bullet was revised: “LUC inspection tables” was replaced with “Site inspection form”

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22.	Page ES-12/ LHAAP 18/24	It is more accurate to state that “the LHAAP 18/24 interim remedial action is protective of human health and the environment in the short term due to soil removal/treatment, groundwater extraction, groundwater monitoring, and the September 2020 implementation of a robust groundwater operation and maintenance program. It is anticipated that implementation of a final remedial action to be selected in the future will be protective of human health and the environment in the long term. In the interim, unacceptable risks presented by groundwater contamination are being controlled.”	Concur with exception. The protectiveness statement was revised as follows: The remedy at LHAAP-18/24 currently protects human health and the environment because soil removal/treatment, groundwater extraction, and groundwater monitoring have reduced and/or prevented further migration of contaminants of concern into deeper groundwater zones and surface water bodies, thereby eliminating or minimizing the potential for exposure to human and ecological receptors. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal." Table 18 was also revised to include the following as the recommendation : “Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.” Section 6.10.2 was revised for consistency and “since the final remedy has not been selected” was removed from the 1st sentence.

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23.	Page ES-13/ LHAAP 49	EPA believes that this site is only protective in the short term since there are no LUCs in place and the site does not meet unrestricted use/unrestricted exposure conditions. What is the Army's plan to address this issue?	Do not concur. See response to Comment No. 13.
24.	Page ES-13/ LHAAP-004-R-01	Same comment as the above comment pertaining to Site 49.	Do not concur. See response to Comment No. 19.
25.	Table 1	Please define UEP (i.e., under site name), and define and add 1,1-DCE, 1,2-DCA to the abbreviations/acronym list. First use of VC, please define.	UEP was defined prior to first use. Text in ES Table 1 now reads: "Unlined Evaporation Pond (UEP)" 1,1-DCE was defined prior to first use as 1,1-Dichloroethene. 1,1-DCE was added to the abbreviations table 1,1-DCA was defined prior to first use as 1,1-Dichlorethane. 1,1-DCA was added to the abbreviations table VC was defined prior to first use. Text in ES Table 1 now reads: "vinyl chloride (VC)"
26.	Page ix/ List of Tables	Table 6 is including information about J values in the main title. Please include the table title only. There are other tables that appear to have the same title issue.	Now Table 7. Method detection limit was removed from the title and changed to reporting limit. Table 7 Title now reads: "Table 7. 1,4-Dioxane in shallow LHAAP-12 groundwater in µg/L (USAEC, 2018). Blank-no sample collected, J-estimated, <1U-not detected above the 1 µg/L Reporting Limit."
27.	Page xiii	Please add the following abbreviations/acronyms that were used	The following were added to the abbreviations list: RA Remedial Action

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		and defined in text, but are not listed on page xiii: RA, FBR, MEC, LUCP, DERP, AST, CSM, RFA, WP, UUUE, PSI, MMR, CTT, OB/OD, AEC, and AMSL. Please remove the following since the abbreviation or acronym is not used in text: CES, CWA, HASP, HI, Jacobs, MCLG, PVC, RGO, RSL and SAI-Ind,	FBR fluidized bed reactor MEC Munitions and Explosives of Concern LUCP Land Use Control Plan AST above ground storage tank RFA RCRA Facility Assessment WP Work Plan UUUE Unlimited Use and Unrestricted Exposure PSI pounds per square inch MMRP Military Munitions Response Program CTT Closed Transferring and Transferred OB/OD Open Burning/Open Detonation AEC Army Environmental Command AMSL above mean sea level CDM was not found within the text DERP Defense Environmental Restoration Program and defined prior to first use in Section 4.8.1.1 The following were removed CES, HASP, HI, MCLG, PVC, RGO, RSL, and SAI-Ind CWA – was used in Table 1 of Appendix B
28.	Page 1/ Section 1.1	This Section (Introduction) should be modified as the authority for conducting the five-year review is provided in CERCLA Section 121(c), 42 U.S.C. § 9621(c), 40	Introduction (Section 1.1) was revised. Text now reads: "The United States Department of Army (Army) is the lead agency, and must comply with, manage, and execute site closure consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Section

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		C.F.R. §300.430(f)(4)(ii), EPA guidance – Comprehensive Five-Year Review Guidance (OSWER Directive 9355.7-03B-007, June 2001), and the December 1991 FFA. As such, the other authorities cited may be appropriate for other sections of this document such as the ARARs discussion section or TBC section, but not in this section. Please delete the references that do not authorize five-year reviews in this section, and include all authorizing references (CERCLA, C.F.R., EPA Guidance and the FFA) cited in this comment in the Introduction Section. This comment is consistent with Section 2.2 of this document	121(c), 42 United States Code (U.S.C.) §9621(c)), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations (CFR) §300.430(f) (4) (ii)), under the Defense Environmental Restoration Program (DERP) (10 U.S.C. Section 2701), . The trigger for this Five-Year Review is 15 May 2014, the signing date of the 2013 Five-Year Review (Department of Defense, 2014, AECOM, 2014a).”
29.	Page 1/ Section 1.1	The citation “part 300.430(f) (ii)” should be modified to “The NCP at 40 C.F.R. §300.430(f)(4)(ii) provides”.	The citation for “part 300.430(f) (ii)” was revised. Text now reads: “The NCP at 40 CFR §300.430(f) (4) (ii) provides:”
30.	Page 1/ Section 1.1	Please define CFR, first use.	CFR was defined prior to first use. Text now reads: “Code of Federal Regulations (CFR)”

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31.	Figure 1/ Minor Editorial	The reference on map title should be Landmark 2014a.	Figure title corrected to include Landmark 2014a, b.
32.	Page 4/ Section 2.1/ Second Paragraph	Please check Shaw 2008a reference. It probably should be 2008.	Shaw, 2008a has been replaced with Shaw, 2008 throughout the entire document.
33.	Page 4/ Section 2.2	The US Army 1991 reference is missing from the reference section. Please add.	Concur. The reference was included in the reference section as “US Army, 1995c” but has been revised to “US Army, 1991”. Text reference to US Army 1995c has also been corrected.
34.	Page 5/ Section 2.3.2	Please add Broom and Myers 1966 reference to the reference citations.	Broom and Myers 1966 was added to the references section as: United States Geological Survey (USGS), 1966. Ground-Water Resources of Harrison County, Texas, Report 27. Broom, M.E. and Myers, B.N. Prepared in Cooperation with Texas Water Development Board.
35.	Page 5/ Section 2.3.2.1	Please add Fryar and others, 2003 to the reference section.	Fryar and others, 2003 was added to the references section as: Fryar, D., Senger, R., Deeds, N., Pickens, J., Whallon, A., and Dean, K., 2003. Groundwater Availability Model for the Northern Carrizo-Wilcox Aquifer: Prepared by INTERA, Inc. and Parsons Corporation for the Texas Water Development Board, 529 p.
36.	Table 2	Please add Deeds and other, 2009 to the reference list.	Deeds and other, 2009 was added as to the references section as: Deeds, N.E., Fryar, D., Dutton, A., and Nicot, J.P., 2009. Hydrogeology of the Carrizo-Wilcox Aquifer, in Hutchison, W.R., Davidson, S.C., Brown, B.J., and Maces, R.E., eds, Aquifers of the Upper Coastal Plains of Texas, Texas Water Development Board Report 372, p. 35-60.

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37.	Figure 2	Please check TWDB 2018 reference. It is currently 2016 in the reference section.	TWDB, 2018 was added to the references section as: Texas Water Development Board, 2018. LHAAP Located Wells in Water Data Interactive. Available at https://www2.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer, downloaded April 2, 2018 by USACE-New England District.
38.	Page 8/ Section 2.3.3/ Second Paragraph, Last Sentence	Please add a space between the words Figure 4 and are.	Space was added between Figure 4 and are. Text now reads: "Unusually high flow rates shown in Figure 4 are from Gulf Coast storm remnants"
39.	Page 8/ Section 2.3.3/ Last Paragraph	Please define AOC and add it to the abbreviations/acronym list.	AOC was defined prior to first use and added to abbreviations/ acronym list. Text now reads: "area of concern (AOC)"
40.	Figure 3	Please add USFWS 2011 to the reference section.	USFWS, 2011 was added as:USFWS, 2011. Hiking Trails, available at https://www.fws.gov/gis/index.html, 03/21/2011, downloaded July 2018.
41.	Page 15/ Section 3.1 and Section 3.3.1	First use of BRAC, please define and add to abbreviations /acronym list. First use of ARARs, please define.	BRAC was defined prior to first use and added to abbreviations/ acronym list. Text now reads: "Base Realignment and Closure (BRAC)" ARAR was defined prior to first use. Text now reads: "applicable or relevant and appropriate requirements (ARAR)"

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42.	Page 12/ Section 2.4.2	Is this statement correct? “No USFWS or Army policy institutional controls are in place for regulating construction and operation of new and existing pumping wells (e.g., rig supply wells).” Despite this statement, LUCs are in place at LHAAP Sites with groundwater contamination (e.g., see p. 20 and the LUCs discussion for LHAAP-12; also see LHAAP 16 ROD that includes a performance objective prohibiting access to contaminated groundwater except for environmental monitoring and testing only). If the LUCs do not prohibit/control the drilling, and construction of groundwater wells into contaminated groundwater, then the LUCs should be modified to address risks (e.g., providing a channel for contaminated groundwater to impact other aquifers or surface water). These risks are addressed in the remedial action objectives for LHAAP Sites with groundwater contamination. This item should be included in the issues and recommendations for follow-up sections of this document.	The text was clarified by replacing “No USFWS or Army policy institutional controls are in place for regulating construction and operation of new and existing pumping wells (e.g., rig supply wells)” with the following sentence: Outside of groundwater use restrictions placed by Army on individual environmental sites, there are no provisions in place for regulating construction and operation of new and existing pumping wells (e.g., rig supply wells) located on the Refuge outside of these LUC boundaries.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
43.	Page 16/ Last Sentence	The first use of DCE and VC, please define.	Cis-DCE was defined as cis-1,2-dichloroethene prior to first use and added to the abbreviations table. VC was previously defined in ES Table 1 was also defined here as requested. Text now reads: “vinyl chloride (VC)”
44.	Table 3	The first use of LTM and FS, please define.	LTM and FS were defined prior to first use. Text now reads: “Long Term Monitoring (LTM)” and “Feasibility Study (FS)”
45.	Page 20/ Section 4.5.1	Please use this citation instead of the one used in the draft document “CERCLA Section 121(c), 42 U.S.C. § 9621(c)”.	Citation corrected. Text now reads: “CERCLA Section 121(c),42 U.S.C. §9621(c).”
46.	Page 20-21/ Section 4.5.1 and 4.6	Please provide/describe the LUC inspection results in the five-year report.	Concur. Text was added as a new paragraph before the last paragraph of Section 4.5.1. “Inspections to confirm no violations of the groundwater use restriction were conducted annually during the review period in 2013 and 2014 by Army and after transfer in 2014, by USFWS in 2015, 2016, and 2017. No use violations were noted during the review period. The landfill caps were inspected annually by Army to comply with cap maintenance LUCs. No violations were noted during the review period, however minor cap repairs were conducted. The annual LUC inspection documentation is presented in Appendix G. Text in Section 4.5.2 that reads “The site was transferred to the USFWS in May 2018” was corrected to state transfer to USFWS in March 2014. Text now reads: “The site was transferred to the USFWS in March 2014.”
47.	Page 19	The first use of RAO and OPS, please define.	RAO and OPS were defined prior to first use. Text now reads: “Remedial Action Objective (RAO)s” and “Operating Properly and Successfully (OPS)”

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STAKEHOLDER COMMENTS

Location: Karnack, Harrison County, Texas
Reviewer: Various
Document Name: Draft – Five Year Review Longhorn Army Ammunition Plant (LHAAP)
Prepared By: NAE

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
48.	Table 6	The Header states that <1 U is not detected above the 1 µg/L method detection limit. Should this be the reporting limit and not the method detection limit?	Now Table 7. Method detection limit was removed from the title and changed to reporting limit. Table 7. Title now reads: “Table 7. 1,4-Dioxane in shallow LHAAP-12 groundwater in µg/L (USAEC, 2018). Blank-no sample collected, J-estimated, <1U-not detected above the 1 µg/L Reporting Limit.”
49.	Page 24/ First Paragraph	Please define GW-Ind and add to the abbreviations/acronym list.	GW-Ind was defined prior to first use in section 4.8.1.1 as Groundwater Industrial. GW-Ind was added to the abbreviations list.
50.	Figure 7	EPA suggests using the same terminology for non-parametric statistical tests. The figure says Theil-Sen Trend test and in the text in Section 4.8.1.1 states O&M Mann-Kendall. Please clarify why O&M is listed before method here.	Descriptors such as O&M and Army were removed when referencing Mann-Kendall and Theil-Send Trend Analysis throughout the entire document.
51.	Page 24/ Section 4.8.1	This section shows the use of the Texas RRR groundwater industrial cleanup levels for 1,4-dioxane at 26 ug/L and EPA disagrees. EPA believes that the TRRP groundwater residential cleanup standard of 9.1 ug/L for 1,4-dioxane should be used until EPA finalizes an MCL. The site is currently not protective in the long term.	Do not concur. TRRP is not an ARAR for LHAAP-12.
52.	Page 28/ Section 4.8.3	EPA disagrees with the Army’s cleanup standard (Texas RRR groundwater industrial standards for 1,4 dioxane at 26 ug/L). EPA believes that the TRRP	Do not concur. See response to Comment No. 51.

<table>
<tr><th>No.</th><th>Ref.
Page / Para.</th><th>COMMENTS From EPA</th><th>Disposition</th></tr>
<tr><td></td><td></td><td>residential value of 9.1 ug/L should be used until EPA finalizes an MCL; otherwise, this site is not protected in the long-term. Also, please remove “USEPA is unsure” language.</td><td>The “USEPA is unsure” language has been removed.</td></tr>
<tr><td>53.</td><td>Page 29/ Section 4.9.1</td><td>Same comment as the above comment.

Also, this section should address the costs associated with LUCs implementation, cap operation and maintenance and MNA monitoring.</td><td>Please see the response to Comment No. 52.

Concur/Exception. The costs are more appropriately presented under section 4.6. A new section 4.6.1 was inserted and titled “Operations and Maintenance Costs” and the following text added:

“The original O&M total cost estimate for LHAAP-12 and LHAAP-16, and cost estimate for LHAAP-12 RAO LTM, was $75,000/year (US Army, 1995a). The approximate actual O&M and LTM cost estimates for site LHAAP-12 are presented in Table 5.”

<table>
<tr><th>Fiscal Year</th><th>O&M Costs ($)</th><th>LTM Costs ($)</th><th>Total ($)</th></tr>
<tr><td>2013</td><td>11,197.04</td><td>17,972.68</td><td>29,169.72</td></tr>
<tr><td>2014</td><td>11,197.04</td><td>17,972.68</td><td>29,169.72</td></tr>
<tr><td>2015</td><td>11,197.04</td><td>14,378.15</td><td>25,575.19</td></tr>
<tr><td>2016</td><td>11,197.04</td><td>7,189.07</td><td>18,386.11</td></tr>
<tr><td>2017</td><td>11,197.04</td><td>7,189.07</td><td>18,386.11</td></tr>
</table>
</td></tr>
<tr><td>54.</td><td>Page 16/ Site 12</td><td>The write-up is unclear as to how many wells are needed to address variability in</td><td>Concur. The last sentence of the protectiveness statement on in Section 2 of the ES, page ES-12 and in Section 4.12 was revised as follows:</td></tr>
</table>

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		flow based on season and water elevation, and to ensure that the "worst case" will be captured. In Table 5, it seems to imply that it is one well, but there are references to "well network". Please clarify the intent.	"Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast." The recommendations table in the Five Year Review Summary form and Section 4.11 was revised to match the recommendation provided at the end of the protectiveness statement for LHAAP-12.
55.	Page 31/ Section 5.0	The US Army is currently attempting to drill a shallow well on the east side of Harrison Bayou to determine if shallow groundwater contamination is on other side of Bayou. EPA (using a contractor) conducted a tree coring study and collected samples from trees across the Bayou and did not identify contamination (with one exception, one tree to the east of the bayou indicated some TCE contamination); however, EPA, agrees that at least one shallow well is needed in the area to bound the shallow groundwater table. Perchlorate was detected to the east of the bayou in a few cored trees. EPA has expressed concerns that if there is contamination migration to the east side of the Bayou it may also be in the intermediate zone based on intermediate zone contamination shown in wells west	Do not concur. The remedy is not yet fully implemented and is not the subject of the review. Evaluation of the data obtained during and after the implementation should provide insight for any future actions.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		of the Bayou. No intermediate zone wells are currently planned at this time, thus a potential plume bounding data gap. EPA suggests adding some text to the Five Year Review in this regard.	
56.	Page 35/ Section 5.4.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
57.	Page 37/ Section 5.5	The final remedy required a LUCs Remedial Design. There should be a description/statement in this section that identifies the LUC requirements and the time-frames for the implementation of LUCs.	Exception. The final remedy has not yet been fully implemented. However, initial notice of the LUCs and preliminary LUCs boundaries was provided within 90 days of ROD signature on December 8, 2016. A sentence will be added to the text in this section stating: Although the final remedy has not yet been fully implemented and, therefore, not the subject of this review, initial notice of the LUCs and preliminary boundaries was provided on December 8, 2016 within 90 days of ROD signature as required by the ROD to federal, state, and local officials including: Senators and Congressman, State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents and Boards of Directors, as well as the Caddo Lake NWR manager, the future transferee of the property.
58.	Page 37/ Section 5.5/ Second Paragraph	The first use of RACR, please define. Define O&M and make it consistent with acronym in the list (OM&M), unless there is a difference.	Terms were defined prior to first use. Text now reads: "Remedial Action Completion Report (RACR)" O&M was defined prior to first use as Operations and Maintenance in Section 4.6.1. O&M was added to the abbreviations list.

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STAKEHOLDER COMMENTS

Location: Karnack, Harrison County, Texas
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Prepared By: NAE

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
59.	Page 41/ Section 4.9.1	This section should address the costs associated with LUCs implementation, cap operation and maintenance.	Exception. The LHAAP-12 costs could be separated from LHAAP-16 and LHAAP-18/24 costs however, for this review period LHAAP-16 and LHAAP-18/24 O&M costs were grouped together and there is no means to separate the costs
60.	Pages 42/ Section 5.12/ Protectiveness Statement	It is more accurate to state that “the interim landfill cap remedy is protective of human health and the environment in the short term, and it is anticipated that implementation of LUCs, EISB, bio-barriers, and MNA will be protective of human health and the environment in the long term. In the interim, unacceptable risks presented by groundwater and soil contamination are being controlled.” There currently is insufficient data to evaluate protectiveness in the long term as the final remedies are not yet in place, given updates to system and lack of data to show functionality.	The statement was revised. Text now reads: The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs. The multi-layer landfill cap is in place, regularly inspected, and maintained, thereby ensuring no unacceptable exposure.
61.	Page 39/ Table 11	The RD Workplan for LHAAP 16 final remedial action should have a schedule for involving the O & M actions at each area of this Site. As such, the date of action column in this schedule should be determined already and not TBD.	Now Table 12. Sections 4.7, 5.0, and 7.0 of the RAWP, June 2018 present performance monitoring and O&M details. Action Taken will be revised to state: “O&M Plan documented in the Remedial Action Completion Report.” And Date of Action will be revised to “September 2020” Action taken.

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62.	Page 41/ Section 5.9.1	This section should address the LUCs. It should address and document the physical inspection and results concerning the LUCs implementation at LHAAP-16, in accordance with the LUCs interim remedial action workplan.	Concur. The following text was added to this section under Question A: *Requirements of the Interim ROD include warning signage and cap inspection, maintenance and repair. The inspections were conducted annually at a minimum during the review period. No major remedy deficiencies have been identified over the last five years. The only repairs necessary due to deficiencies noted in the inspection was placement of a small amount of soil and erosion control mat and then seeding in the south side of the site on the eastern slope, which was completed on August 15, 2013.The site is mowed annually at a minimum prior to the inspections, which includes evaluation of the landfill cap surface, animal burrows, erosion, monitoring wells, and site access. O&M of LHAAP-16 is documented in Section 1.2 of the Quarterly GWTP Report.*
63.	Page 43/ Section 6.0	The first use of ACD, please define and put into the abbreviation/acronyms list. First use of bgs, please define.	ACD was defined prior to first use as Air Curtain Destructor in Section 6.0. ACD was added to the list of abbreviations. bgs was defined prior to first use. Text now reads: “below ground surface (bgs)”
64.	Page 43	The first use of MC, please define.	Term was defined prior to first use. Text now reads: “methylene chloride (MC)”
65.	Figure 12	EPA recommends using a brighter color or bolder font for well numbers. It is difficult to read the well numbers. This comment is valid for additional figures and plots in the report as well.	Figure 12 was revised.
66.	Table 12	EPA recommends adding into the time line when water injection was stopped as well	Now Table 15. Concur. A line will be added to show that injections ceased on July 15, 2012. However, irrigation is still an option under the current

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Location: Karnack, Harrison County, Texas

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		as when irrigation of the treated water was stopped at the Site.	protocol and has not ceased. The last time irrigation of treated water occurred was December 12, 2016.
67.	Page 49/ Section 6.5.1	The description of the RAOs is confusing. Although there are no chemical-specific RAOs identified in the IRA (page 49) there is a discussion on an agreement regarding discharge of perchlorate (e.g., top of page 58 under 6.7.1) and a slightly different description on page 55 under 6.7.2. Please explain the discharge numbers for perchlorate, preferably where remedial actions are first introduced.	Concur. The following was included in Section 6.5.1: The IRA ROD required extracted groundwater to be treated to the levels established by TNRCC for discharge to the Harrison Bayou and/or Central Creek (US Army, May 1995). In a letter from TNRCC, dated January 8, 2002, perchlorate discharge was required to be less than 6 µg/L for the daily average and 13 µg/L for the daily maximum. A memorandum entitled Protocol for Discharging GWTP Effluent Longhorn Army Ammunition Plant, Karnack, TX was finalized on August 28, 2017 and established the current discharge protocol. This protocol increased the allowable effluent discharge for water to the Harrison Bayou to 278 µg/L for a daily average and 589 µg/L for a daily maximum.
68.	Page 49	Please check Shaw 2006a reference, there is only one Shaw 2006 reference in the references list.	Concur. The reference should be to Shaw, 2016 and will be corrected on Page 52 and on Page 203.
69.	Page 51/ Under Sludge Treatment	Please indicate how the sludge is disposed of (hazardous or non-hazardous).	Concur. The last sentence will state "the filter cake is shipped for disposal as non-hazardous waste."
70.	Page 50/ Section 6.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
71.	Page 50/ Second	Please add USACE 2010b to reference list and/or check for the correct reference.	Concur. Reference to USACE 2010b added as follows:

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	Paragraph and item 2	Please define PCE and add to the abbreviations/acronym list.	USACE, 2010b. Final Explanation of Significant Differences, Burning Ground 3 and Unlined Evaporation Pond (Designated as LHAAP-18/24) Interim Remedial Action Record of Decision Dated May 1995, AR 2010 Volume 8 of 19, B, 00088921-00088936, August. PCE was defined prior to first use as tetrachlorethene. PCE was also added to the list of abbreviations.
72.	Page 53/ Sections 6.7.1 and 3	Please define PLC, GAC and add them to the abbreviations/acronyms section.	PLC was defined prior to first use as Programmable Logic Controller. PLC was also added to the list of abbreviations. GAC was defined prior to first use and added to the list of acronyms. Text now reads: “Granular Activated Carbon (GAC)”
73.	Page 54/ Under Discharge of Treated Effluent	The bullets identify four, not three methods of discharge	The text was corrected to match the number of bullets. Text now reads: “The Army discharges the GWTP treated effluent using three methods in decreasing order of preference (AECOM, 2017g):” The fourth bullet inject has been deleted.
74.	Page 58/ Table 13	Some of the information in this table is outdated and needs to be updated.	Now Table 16. The action taken for the First Five Year Review Issues will be revised to both state “Remedial Design and Remedial Action Work Plan for the final remedy will evaluate.” The date of action for both will be revised to “deferred to final remedies.”
75.	Page 61/ Second Bullet	The text should probably indicate that the Wilcox wells are completed well below the ICT depths, thus the capture of the contamination from the treatment is unlikely even with some periodic upward	Exception. The text in the first paragraph of Section 6.5.2.1 describes the completion depths of the ICTs, noting that the ICTs extend approximately 25-55 feet deep to the confining clay layer of the Shallow Groundwater Zone. The 5th paragraph of Section 6.9.1.1 states that the extraction system appears to provide lateral capture of groundwater in the Shallow Groundwater Zone located within the boundaries of LHAAP18/24, though it

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		movement caused by the pumping system.	does not provide complete lateral or vertical capture of the footprints of the widespread COCs. No text change is required.
76.	Page 61/ Third Bullet	Please check accuracy that the highest level for MC was 1,000,000 ppb. EPA recalls the MC concentration might be as high 10,000,000 ppb prior to the IRA installation. Please note that 1,000,000 ppb value is also used throughout Appendix C.	Per the IRA, the highest MC concentration was 10,550 mg/L, near the center of the plume, as of April 1994. Therefore, the text in Section 6.9.1.5 and in Appendix C was corrected to 10,550,000 ppb for MC.
77.	Figure 17	The Figure is not mentioned in the text. Please mention in the text.	A new bullet was added Section 6.9.1.5, pg. 75 to provide text description of Figure 17. Text now reads: “Figure 17 depicts trend analysis results for abiotic CVOC degradation chemicals that are not part of the wide-spread risk driving COCs, but are presented for information purposes only. Increasing trends for single contaminants was indicated in the following monitoring wells: MW-14, AWD-1, and 17WW01.”
78.	Page 66/ Section 6.9.1.6/ Surface Water	This section should include an explanation and description concerning how the interim remedial action is satisfying the RAO to eliminate or minimize human and ecological receptors exposure to contaminants by reducing or preventing the migration of contaminants into the surface waters. It should also describe how the contaminants are not migrating	Concur. The following text was added to Section 6.9.1.6: The ICT and extraction well system is designed to capture the shallow groundwater plume thereby reducing or preventing further migration of contaminants from shallow groundwater to surface water and eliminating or minimizing the potential for exposure to the human and ecological receptors to contaminants. The effectiveness of the IRA is substantiated by the results of quarterly surface water sampling for perchlorate which indicate perchlorate is not reaching the nearby aquatic systems at unacceptable levels.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		from the groundwater to the surface water.	
79.	Page 68/ Section 6.10.1	This section should address the costs associated with groundwater treatment system operation and maintenance, and monitoring costs.	Concur. The following sentence will be added to the end of response to Question A: The costs for groundwater treatment system operation and maintenance have increased over the years to account for an aging GWTP system.
80.	Page 69/ Section 6.13/ Protectiveness Statement	It is more accurate to state that "the LHAAP 18/24 interim remedial action is protective of human health and the environment in the short term due to soil removal/treatment, groundwater extraction, groundwater monitoring, and the September 2020 implementation of a robust groundwater operation and maintenance program. It is anticipated that implementation of a final remedial action to be selected in the future will be protective of human health and the environment in the long term. In the interim, unacceptable risks presented by groundwater contamination are being controlled."	The statement was revised. Text now reads: "The remedy at LHAAP-18/24 currently protects human health and the environment because soil removal/treatment, groundwater extraction, and groundwater monitoring have reduced and/or prevented further migration of contaminants of concern into deeper groundwater zones and surface water bodies, thereby eliminating or minimizing the potential for exposure to human and ecological receptors. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.
81.	Page 70/ Section 7.1	All of the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section.	December 30, 1991 FFA added to Table 19. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		Also, please delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement "No enforcement orders have been issued at this site." has not been removed from section 7.1.
82.	Page 75/ Section 7.5.3/ Minor Editorial	Please add USACE, 2018 to the reference list.	The comment refers to the following sentence: *The MNA program began during the 2019 Five-Year Review site inspection. Cost data is not available (USACE, 2018)*. Citation was added as: USACE, 2018. Williams, Aaron K. "Re: LHAAP Data - Last Bits." Message to Drew Clemens. May 10, 2018. Email.
83.	Page 75/ Section 7.6	This section should provide more information concerning the Army LUCs implementation. What are the LUCs required and did the inspections find any violations with the LUCs.	The first paragraph of Section 7.6 was revised to state: "The groundwater use restriction against residential use of groundwater was implemented with the 2016 recordation of the restriction in Harrison County, Texas, and regular inspection commenced with the beginning of the RAO phase in November 2017. However, the first year RAO was still underway and not yet available at the close of the review period in May 2018." Note: Text in Section 7.5.2.1 is corrected to state that RAO began with the first RAO event in November 2017, not May 2018.
84.	Page 76/ Section 7.8.1.1/ Last Sentence	Please add Goose to Prairie Creek and provide the proper reference for Shaw 2007 (i.e., a, b, c, etc).	Goose was added to Prairie Creek and the reference was changed to US Army, 2010b.

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85.	Page 76/ Section 7.8.1.2	This section should include a table like Table 17, except this table would include the remedial cleanup/monitoring levels for the surface water COCs.	Concur with Exception. The ROD does not identify surface water COCs but it does identify ARARs that would be triggered in the event of remedy failure and a release to surface water. Table 20 in Section 7.5.1 was footnoted to indicate the cleanup table applies to surface water in the event of remedy failure. The following text was added to Section 7.8.1.2: The Record of Decision for LHAAP-37 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.
86.	Pages 81 and 82/ Sections 7.9.1 and 7.9.2	These sections should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs and the findings.	Concur. The first sentences of Question A in Section 7.9.1 (after "*Yes*" and Section 7.9.2 was replaced with the following: *The LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The restriction was recorded in Harrison County, Texas on December 9, 2014. Regular inspections of the groundwater use restriction commenced during the first year of the RAO phase which began in November 2017. Although reporting was not available at the close of the review period, no land use activities beyond wildlife refuge occur at the site.*
87.	Pages 81 and 82/ Sections 7.9.1 and 7.9.2	There should be statement indicating that the current MNA remedy is just being implemented due to a prior 2-year pilot study using bioplugs which were found not to be effective.	Concur. The following text was added to the response to Question A in Section 7.9.1: *Due to the implementation of a demonstration project which proved ineffective, implementation of the MNA remedy was delayed.*

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
			The last sentence in Section 7.9.2 was revised as follows: *Due to the implementation of a demonstration project which delayed implementation of the MNA remedy, an insufficient amount of time has passed to evaluate the MNA portion of the remedy, though TCE concentration in a perimeter well is slightly above the MCL.*
88.	Page 81/ Section 7.9.1	This Section states that the LHAAP 37 ROD "cleanup levels were not included in the Record of Decision." This is not correct, please change.	Concur. The text was changed to include the cleanup levels of the COCs, TCE, PCE, 1,1-DCE, thallium, and antimony.
89.	Pages ES-12/ LHAAP 37 and Page 82/ Section 7.12	These protectiveness statements (i.e., language providing that MNA ensures a stable and decreasing plume) are not consistent with the MNA language at Sections 7.9.1 and 7.9.2 (i.e., and insufficient amount of time has passed to evaluate MNA portion of the remedy, though TCE concentration in a perimeter well is slightly above the MCL). At best, it appears these protectiveness statements should state, "the LUCs and MNA remedy is protective of human health and the environment in the short term, and it is anticipated that further implementation and evaluation of MNA will be protective of human health and the environment in	Do not concur. Because this remedy has just been implemented, the expectation in the ROD is that it will be protective.

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		the long term by ensuring a stable and decreasing plume.”	
90.	Pages 83/ Section 8.1	All of the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section. Also, please delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	December 30, 1991 FFA added to Table 23. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement “No enforcement orders have been issued at this site.” has not been removed from section 8.1.
91.	Page 85/ Section 8.2	Please include a discussion describing how wastes were disposed of in the area and that the waste migrated from the soil to the groundwater.	Concur. The following text was added to the end of Section 8.2: *The original sources of contamination at LHAAP-46 were most likely small spills resulting from the services that occurred in support of the production of pyrotechnic and illumination devices. The spills would have resulted in minor soil contamination that would migrate, depending on the contaminants, through overland flow via surface runoff or through leaching to the groundwater. The forty six waste sumps and 13 waste racks formerly located at the site were not likely sources of contamination (Shaw, 2010e). All have been removed and addressed separately under LHAAP-35/36 (Jacobs, 2002c).* *Shaw, 2010e was added to the list of references which is the Final Record of Decision LHAAP-46, Longhorn Army Ammunition Plant, Karnack, Texas, September.*
92.	Page 87/ Section 8.6	This section should provide more information concerning the Army LUCs	Concur. The first paragraph of Section 8.6 was revised to state:

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		implementation performance and monitoring of such LUCs.	*The groundwater use restriction against residential use of groundwater was implemented with the December 2014 recordation of the restriction in Harrison County, Texas, with annual inspections commencing with the RAO phase in 2014. No violations were noted during the review period. The annual inspection forms are presented in Appendix G.*
		This section should also be modified to included language showing that the performance monitoring and evaluation program in place is both, currently being implemented and is consistent with the criteria outlined in, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, (OSWER 9200.4-17P, April 21, 1999).	Concur. The following sentences was added to the end of the second paragraph of Section 8.6: *MNA performance monitoring and evaluation takes place in accordance with the approved RD (Shaw, 2011a) and RACR (AECOM, 2015e), in which the MNA performance monitoring program for LHAAP-46 was designed to meet seven objectives from Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (USEPA, 1999). Ongoing implementation of performance monitoring is described in annual RAO reports for 2014 through 2017 of the review period.* USEPA, 1999 was added to the list of references: USEPA, 1999, Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites, Directive 9200.4-17P, U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, DC.
93.	Page 92/ Section 8.8.1.2	This section should include a table like Table 21, except this table would include	Concur with Exception. The ROD does not identify surface water COCs but it does identify ARARs that would be triggered in the event of remedy failure and a release to surface water. Table 24 in Section 8.5.1 was footnoted to

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		the remedial cleanup/monitoring levels for surface water COCs	indicate the cleanup table applies to surface water in the event of remedy failure. The following text was added to Section 8.8.1.2: *The Record of Decision for LHAAP-46 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.*
94.	Page 93/ Section 8.9.1	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. From reviewing this section, it is not clear what they are comprised of.	Concur. The first sentences of Question A in Section 8.9.1 was replaced with the following text: *Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The groundwater restriction was recorded in Harrison County, Texas on December 9, 2014. Inspections of the groundwater use restriction commenced on July 10, 2014 during the first year of the RAO phase. No land use activities beyond wildlife refuge occur at the site and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G.*
95.	Page 96/ Section 9.1	All the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section.	December 30, 1991 FFA added to Table 28. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement "No

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		Also, please delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	enforcement orders have been issued at this site." has not been removed from section 9.1.
96.	Page 98/ Section 9.3/ Second to Last Sentence	The mercury soil sampling was conducted by the USGS with the funding originating from the USFWS. The issue was that there was no soil confirmation sampling after soil removal. The USFWS and the public wanted confirmation since this area was located along an equestrian trail.	Concur. The sentence has been revised as follows: In September 2010, with funding provided by USFWS, USGS collected additional soil samples at the two sample locations to confirm the absolute removal of the mercury-impacted soil."
97.	Page 98/ Section 9.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
98.	Page 98/ Section 9.7	Is this site included in the overall LUC Management Plan Site? It appears that no LUCs are being implemented for this site. While this site may be protective in the short term, it would not be protective in the long term without LUCs, since the site does not meet unrestricted use/unrestricted exposure conditions. What is the Army's plan to address this issue?	Do not concur. Although the site is included in the Sitewide LUC Management Plan to document its suitability for nonresidential use, it does not have a LUC remedy. Please see RTC No. 13.
99.	Table 26/ Minor Editorial	No dates are provided for the RAO Reports	Concur. The following RA(O) Reports and dates will be added to Table 29: Draft Final 1st Annual Remedial Action Operation Report, LHAAP-50 - November 2016

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			Draft Final 2nd Annual Remedial Action Operation Report, LHAAP-50 – November 2016
100.	Page 101/ Item 9.12	EPA disagrees with protectiveness statement, which should be Short-Term Protective. Land Use Controls are needed to ensure long-term protectiveness. This was a no-action ROD, based on assumptions of future land use. Although the Army controls access in the short-term, to be protective in the long-term, LUCs should be implemented.	Do not concur. Please see RTC No. 13.
101.	Page 102/ Section 10.1	All the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section. Also, delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	December 30, 1991 FFA added to Table 29. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement “No enforcement orders have been issued at this site.” has not been removed from section 10.1
102.	Page 104/ Section 10.4	The first use of MSC, please define.	MSC was defined prior to first use. Text now reads: “Medium Specific Concentration (MSC)”
103.	Page 105/ Section 10.5.1	Table 27 only includes remedial cleanup levels for groundwater. There should also be a table for cleanup levels applicable for surface water consistent with Section 10.9.1.2.	Do not concur. Please see response to Comment No. 109.

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104.	Page 105/ Table 27	The perchlorate groundwater number should be the TRRP-Res at 17 ug/L.	Concur. The Record of Decision for LHAAP-50 identifies perchlorate as a groundwater COC with a cleanup level of 72 ug/L, however it is acknowledged that the RACR includes a perchlorate groundwater cleanup level of 17 ug/L. The 72 ug/L will be footnoted on the table to state that the cleanup level used was specified in the RACR to be 17 ug/L, the TRRP Tier 1 Residential Groundwater PCL.
105.	Page 106/ Section 10.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)."

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106.	Page 107/ Section 10.6	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. The section does not mention what the LUCs consist of and whether there were issues.	The first paragraph of Section 10.6 was revised to state that: *"A groundwater use restriction against the residential use of groundwater was implemented with the notification recorded in the Harrison County Courthouse in June 2015 and completion of the RACR in June 2016. Implementation of annual inspections commenced with the second year of RAO (establishment of the LUC boundary was delayed due to additional plume delineation) and the first annual LUC Compliance Certification Documentation dated July 4, 2015. LHAAP-50 has remained in compliance with land use and restriction covenants for the review period. The annual inspection forms are presented in Appendix G."*
107.	Page 113/ Minor Editorial/ Section 10.9.1.2/ Last Sentence	Please change BHATE, January 2018 to Bhate, 2018c.	Citation was revised. Text now reads: "(Bhate, 2018c)."

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108.	Table 31/ Minor Editorial	There are no dates provided for RAO Reports.	Now Table 34. Concur. The following RA(O) Reports and dates will be added to Table 34: Draft Final 1st Annual Remedial Action Operation Report for LHAAP-35A(58) – November 2015 Draft Final 2nd Annual Remedial Action Operation Report for LHAAP-35A(58) – May 2016
109.	Page 113/ Section 10.9.1.2	This section should include a table like Table 27, except that this table would include remedial cleanup/monitoring levels for surface water COCs.	Concur with Exception. The ROD does not identify surface water COCs but it does identify ARARs that would be triggered in the event of remedy failure and a release to surface water. Table 30 in Section 10.5.1 was footnoted to indicate the cleanup table applies to surface water in the event of remedy failure. The following text was added to Section 10.9.1.2: *The Record of Decision for LHAAP-50 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.*
110.	Page 114/ Section 10.10.1	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. What are the LUCs?	Concur. The first sentences of Question A in Section 10.10.1 was replaced with the following text: *Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited*

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		This Section should also specify the contingency remedy that will be implemented as identified in the LHAAP-50 ROD.	*exposure (UUUE). The restriction was recorded in Harrison County on June 18, 2015 (AECOM 2016f) and annual inspections of the groundwater use restriction commenced on July 4, 2015 during the second year of RAO (AECOM, 2016k), after completion of the RACR. No land use activities beyond wildlife refuge occurred at the site during the review period and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G.* Concur. The last sentence in the response to Question A will be revised to clarify: *"MNA has been found to be effective, and according to the installation, the contingency remedy to enhance MNA via in situ bioremediation will be implemented in FY 19 following the ESD to the ROD."*
111.	Page 115/ Sections 10.12 and 10.13	These sections should specify the name of the contingency remedy as provided in the ROD.	The recommendation component of the protectiveness statement was revised to the following: "Implement the contingency remedy to enhance MNA such as in situ bioremediation to address increasing trends of COCs near wells 50WW12 and 50WW13."

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			The Executive Summary Section 7, the five year review summary form, and Sections 10.12 and 10.13 were revised accordingly.
112.	Page 116/ Section 11.1	All of the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section. Also, delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	December 30, 1991 FFA added to Table 34. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement “No enforcement orders have been issued at this site.” has not been removed from section 11.1.
113.	Page 116/ Section 11.2	Please include a discussion describing how wastes were disposed of in the area and that they eventually migrated from the soil to the groundwater.	Concur. The following sentences was added to the section: “There were seven waste process sumps and one waste rack sump located within LHAAP-35A(58). There was a spray paint booth in Building 722-P that scrubbed its exhaust fumes; the wash water was collected in a sump. The sump overflowed to surface drainage while the solids were taken to the inert waste burning area (LHAAP-16) for disposal. Wastewater from the laundry (Building 723) was discharged through a mesh screen into a three-chambered tank. The tank discharged to a surface drainage. Boiler feed water was softened by two softeners, which were regenerated with salt brine. The backwash, rinse waters, and boiler blowdown were discharged to a surface drainage. Boiler additives included sulfites, hexametaphosphates, and Octameen (an organic amine sludge conditioner). Waste oil from the motor pool (Building 716) and roundhouse (Building 718-A) were collected from the sumps and taken to the explosive burning grounds for disposal.

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			Floor drains from the roundhouse and motor pool discharged to the sanitary sewer. Waste from the wash rack and steam cleaning area west of the motor pool discharged directly to the surface drainage (USAEHA, 1980b). The sumps and their contents were removed in 1996, mitigating the potential for continued migration of sump content contamination.” USAEHA, 1980b was added to the references: USAEHA (U.S. Army Environmental Hygiene Agency), 1980b. General Sanitary Engineering Survey No. 24-023-70, Longhorn Army Ammunition Plant, 5-8 January 1980
114.	Page 118/ Table 32	Please note that the Army is using GW-Ind for Chloroethane and 1,1, DCA. EPA believes it should it be GW-Res. Also, 1,4-dioxane should be included in the table. There are two wells that have been identified as having 1,4-dioxane above the TRRP GW-Res levels. For long-term protection, TRRP GW-Res PCLs should be required until an MCL is finalized.	Do not concur. TRRP is not an ARAR for LHAAP-58.
115.	Pages 119-120/ Sections 11.5.1 and 11.5.2.1	Please use this citation instead of the one used in the draft document “CERCLA Section 121(c), 42 U.S.C. § 9621(c)”.	Citation revised in sections 11.5.1 and 11.5.2.1. Text now reads: “CERCLA Section 121(c), 42 U.S.C. § 9621(c).”
116.	Page 120/ Section 11.5.2.2	Please define ORP and add to abbreviations list.	ORP was defined prior to first use and added to abbreviations list. Text now reads: “Oxidation-Reduction Potential (ORP)”

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117.	Page 120/ Section 11.6	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. Please specify the LUCs required and identify any issues noted.	The first paragraph of Section 11.6 was revised to state that: *"A groundwater use restriction against the residential use of groundwater was implemented with the notification recorded in the Harrison County Courthouse in March 2015 and completion of the RACR in April 2015 (AECOM, 2015f). Implementation of annual inspections commenced with the second year of RAO (establishment of the LUC boundary was delayed due to additional plume delineation required) and the first annual LUC Compliance Certification Documentation dated July 14, 2015. LHAAP-58 has remained in compliance with land use and restriction covenants for the review period. Copies of the annual LUC inspection forms are presented in Appendix G."*
118.	Page 121/ Section 11.9	The five-year review summary does not clearly articulate the issues in both the eastern and western plumes, which are distinct.	Concur. The following summary paragraphs was added to the beginning of section 11.9.1.1: "The eastern plume has a lateral extent of approximately 270,000 square feet (ft^2), and a vertical extent of approximately 5 feet. Assuming a total porosity of 0.3, the calculated volume of contaminated groundwater is 3.03 million gallons. The highest concentrations detected for PCE and TCE were 9,590 µg/L and 675 µg/L, respectively, from well 35AWW08, sampled in November 2008. The highest concentrations detected for 1,1-DCE and VC were 24 µg/L and 4.1 µg/L, respectively, from well 1004TW001, sampled in December 2003. Five shallow zone wells are within the eastern plume boundaries (35AWW08, 1004TW001, LHSMW04, LHSMW05, 03WW01), as well as one direct push data point (58DPT04)." "The western plume has a lateral extent of approximately 180,000 ft2, and a vertical extent of approximately 5 feet. Assuming a total porosity of 0.3, the

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			calculated volume of contaminated groundwater is 2.02 million gallons. In the sampling results from November 2008, the highest concentrations detected for TCE, 1,1-DCE, and VC were 25 µg/L, 576 µg/L, and 14.4 µg/L, respectively, from well LHSMW07; the highest concentration detected for PCE was 7.19 µg/L from well 35AWW06. Three shallow zone wells are within the western plume boundaries: LHSMW07, 35AWW06, and 1004TW006.”
119.	Page 128/ Section 11.9.1.2	This section should include a table like Table 32, except that this table would include remedial cleanup/monitoring levels for surface water COCs.	Concur with Exception. The ROD does not identify surface water COCs but it does identify ARARs that would be triggered in the event of remedy failure and a release to surface water. Table 35 in Section 11.5.1 was footnoted to indicate the cleanup table applies to surface water in the event of remedy failure. The following text was added to Section 11.9.1.2: The Record of Decision for LHAAP-35A(58) does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.
120.	Page 129/ Section 11.10.1	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. The section does not mention what the LUCs consist of.	Concur. The first sentences of Question A in Section 11.10.1 was replaced with the following text: Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). LUC Implementation began with the recordation in Harrison County on March 16, 2015 (AECOM, 2015f) and annual inspections

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			of the groundwater use restriction commenced on July 14, 2015 during the second year of the RAO after completion of the RACR (AECOM, 2015f). No land use activities beyond wildlife refuge occurred at the site during the review period and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G.
121.	Page 130	EPA disagrees with the technical assessment that the remedy is operating as intended. Please more clearly explain.	Exception/Concur. The statement included: *“EISB remedy in the eastern plume may be functioning as intended by the ROD.”* The statement in Section 11.10.2 was further clarified by adding the following: “*While there are significant decreasing trends in the EISB target area in the eastern plume, there are also increasing trends in downgradient well 35AWW09. The plume footprint remains unchanged and groundwater monitoring will continue to evaluate remedy effectiveness*.”
122.	Page 132/ Section 12.1	All the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section. Also, delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	December 30, 1991 FFA added to Table 40. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement “No enforcement orders have been issued at this site.” has not been removed from section 12.1
123.	Page 132/ Section 12.2	There should also be a discussion describing how wastes were disposed of in	Exception. No wastes were generated at this tank farm site and there are no known releases (Jacobs, 2002e), however, it is likely that spills occurred during transfer of fuels and solvents to and from the tanks, resulting in

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		the area and how contaminants eventually migrated to the groundwater.	releases to soil with migration into groundwater. The following text will be added as a new fourth sentence: Although there is no information related to a known release in the record, It is likely that incidental spills occurred during transfer of fuels and solvents to and from the tanks resulting in releases to soil and migration to groundwater. New Citation of Jacobs, 2002e was added to the references list as Jacobs, 2002e. Final Remedial Investigation Addendum for the Group 4 Sites (Sites 04, 08, 67) at the Longhorn Army Ammunition Plant, Karnack, Texas, February.
124.	Page 135/ Section 12.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C § 9621(c)"
125.	Page 136/ Section 12.6	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. The section does not mention what the LUCs consist of and whether there were issues.	Concur. The first paragraph of Section 12.6 was revised to state: The groundwater use restriction against residential use of groundwater was recorded in Harrison County, Texas on December 9, 2014 with annual inspections having already commenced in July 2014 during the first year of RAO. No violations were noted during the review period. The annual inspection forms are presented in Appendix G.
126.	Page 142/ Section 12.9.1.2	This section should include a table like Table 38, except this table would include the remedial cleanup/monitoring levels for surface water COCs.	Do Not Concur. The ROD does not identify surface water COCs although it does identify ARARs that would be triggered in the event of remedy failure and a release to surface water. However, after more information became available during the RAWP and RACR (AECOM, 2016i), it was agreed among the FFA representatives that potential discharge to surface water in Central Creek was an incomplete exposure pathway and surface water sampling was no longer necessary.

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			The following text was added to Section 12.9.1.2: Although the Record of Decision for LHAAP-67 provided ARARs that would be triggered in the event of remedy failure followed by a release to surface water, it was agreed among the FFA representatives that potential discharge to surface water in Central Creek was an incomplete exposure pathway and surface water sampling was no longer necessary (AECOM, 2017j).
127.	Page 142/ Section 12.10.1	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. The section does not mention what the LUCs consist of.	Concur. The first sentences of Question A in Section 12.10.1 was replaced with the following text: Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). Inspections of the groundwater use restriction commenced in July 2014 with the first year of the RAO phase. No land use activities beyond wildlife refuge occur at the site and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G.
128.	Page 144/ Section 12.12/ First Sentence	Please see format typo and fix.	Table Format typo was corrected.
129.	Page 145/ Section 13.1	All the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section.	December 30, 1991 FFA added to Table 46. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections. Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement “No

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		Also, delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	enforcement orders have been issued at this site." has not been removed from section 13.1
130.	Page 147	Please define WP and include in the abbreviations/acronym list. First use of EE/CA, please define. EPS, 2004 reference is missing from reference list.	EE/Ca was defined prior to first use. Text now reads: "Engineering Evaluation/Cost Analysis (EE/CA)" WP was defined as work plan and added to the list of abbreviations. Instances of WP in Section 13.2 were removed and changed to "white phosphorus". EPS, 1984 was added to the references section as: Environmental Protection Systems, Inc. (EPS), 1984. Longhorn Army Ammunition Plant Contamination Survey, June.
131.	Page 148/ Section 13.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
132.	Page 149/ Section 13.6	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. Please specify the LUCs required and identify any issues noted.	Concur. The following text was added to Section 13.6: The LUCs include MEC warning signage and restrictions against digging and residential use. These LUCs were recorded in Harrison County, Texas on April 19, 2018. As required by the ROD, within 90 days of ROD signature, preliminary notice of LUCs was provided, to federal, state, and local officials including: State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents, as well as the Caddo Lake NWR manager, the future transferee of

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			the property. A second notice was transmitted on May 9, 2018 to the same parties with finalization of the LUC RD/RACR (Bhate, 2018e). The LUC RD/RACR calls for annual inspections and maintenance of signage. Although the LUC RD/RACR was not in place during the review period, inspection and maintenance of signage was conducted. This included mowing around the signs so that they remained visible one to the next, and repairing signposts and damaged signs as needed. It was noted in 2017 that sign visibility from one to the next was compromised by brush growth. Major brush-clearing was conducted at LHAAP-001-R in 2017 to maintain sign visibility from one to the next and to improve access to signage. Of the 64 signs present at the site, faded "Danger" decals were replaced on 34 signs, and 5 sign posts and 4 signs were replaced entirely.
133.	Page 151/ Section 13.10.1	Same comment as above, other than no issues were found	Concur. The following text was added under Question A: Although the LUC RD/RACR was not in place, inspection and maintenance of signage took place during the review period. This included mowing around the 64 signs so that they remained visible one to the next, and repairing signs as needed. Major brush-clearing was conducted at LHAAP-001-R in 2017 to maintain sign visibility from one to the next and to improve access to signage. Of the 64 signs present at the site, faded "Danger" decals were replaced on 34 signs, and 5 sign posts and 4 signs were replaced entirely. No unauthorized use, such as digging or residential use, was noted during maintenance and well sampling activities throughout the review period.
134.	Page 153/ Section 14.1	All of the Site Chronology tables should include the December 30, 1991 FFA as a listed item. See December 1991 FFA Scope of Agreement Section.	December 30, 1991 FFA added to Table 50. All Site Chronology Tables were checked to ensure the FFA was listed. The FFA was added to site chronology tables in sections.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		Also, delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site.	Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement "No enforcement orders have been issued at this site." has not been removed from section 14.1
135.	Page 155	The Shaw, 2016 reference is missing from reference list.	Concur. The text is referring to the 2016 ROD, which is incorrectly cited. Shaw, 2016 has been corrected in the text to U.S. Army, 2016.
136.	Figures 40, 41, and 42/ Minor Editorial	These map keys indicate a lot of features that are not located on the map. Please remove the ones not on the map.	Figures 40, 41, and 42 were revised.
137.	Page 156/ Section 14.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
138.	Page 156/ Section 14.6	This section should provide more information concerning the Army LUCs implementation performance and monitoring of such LUCs. Please specify the LUCs required and identify any issues noted.	Concur. The following text was added to Section 14.6: The LUCs include MEC warning signage and restrictions against digging and residential use. These LUCs were recorded in Harrison County, Texas on April 19, 2018. As required by the ROD, within 90 days of ROD signature, preliminary notice of LUCs was provided, to federal, state, and local officials including: State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents, as well as the Caddo Lake NWR manager, the future transferee of the property. A second notice was transmitted on May 9, 2018 to the same parties with finalization of the LUC RD/RACR (Bhate, 2018e). The LUC RD/RACR calls for annual inspections and maintenance of signage. Although the LUC RD/RACR was not in place during the review period, inspection and maintenance of signage took place. This included mowing

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
			around the 64 signs so that they remained visible one to the next, and repairing signposts and damaged signs as needed. In 2017, faded "Danger" decals were replaced on 18 signs at LHAAP-003-R and brush clearing between signposts was conducted to improve visibility.
139.	Page 158/ Section 14.10.1	Same comment as above, other than no issues were noted in this section.	Concur. The following text was added under Question A: Although the LUC RD/RACR was not in place, inspection and maintenance of signage took place during the review period. This included mowing around the 64 signs so that they remained visible one to the next, and repairing signs as needed. In 2017, faded "Danger" decals were replaced on 18 signs at LHAAP-003-R and brush clearing between signposts was conducted to improve visibility. No unauthorized use, such as digging or residential use, was noted during maintenance and well sampling activities throughout the review period.
140.	Page 160/ Section 15.1	Please delete the no enforcement orders have been issued at this Site language. The FFA applies to this Site. See December 1991 FFA Scope of Agreement Section.	Do not concur. Federal Facility Agreements are required for federal facilities on the NPL, the requirement is found in Sec. 120(e)(2).The statement "No enforcement orders have been issued at this site." has not been removed from section 15.1
141.	Page 162/ Section 15.5.1	Please use this citation instead of the one used in the draft document "CERCLA Section 121(c), 42 U.S.C. § 9621(c)".	Citation was revised. Text now reads: "CERCLA Section 121(c), 42 U.S.C. § 9621(c)"
142.	Page 163/ Section 15.7	Is this site included in the overall LUC Management Plan Site? It appears that no LUCs are being implemented for this site. While this site may be protective in the	Do not concur. Please see response to Comment No. 19.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		short term, it would not be protective in the long term without LUCs, since the site does not meet unrestricted use/unrestricted exposure conditions. What is the Army's plan to address this issue?	
143.	Page 165/ Section 15.13	EPA disagrees with protectiveness statement, which should be Short-term Protective. Land Use Controls are needed to ensure long-term protectiveness. This was a no-action ROD, based on assumptions of future land use. Although the Army controls access in the short-term, to be protective in the long-term, LUCs should be implemented.	Do not concur. Please see response to Comment No. 19.
144.	Page 167/ References	The following references are listed in reference section but were not located by reviewer in the report. Please remove the following or place in text if needed: AECOM 2013d, AECOM 2015g, AECOM 2016a, AECOM 2017b, APTIM 2018, Becher 2012, Caddo Lake Institute 2018, Complete Environmental Services 2002, Jacobs 2001a, Jacobs 2001b, Jacobs 2002b, Jacobs 2002c, National Geodetic Survey 2018, Nuclear Waste Isolation Feasibility Studies 2014, Shaw 2005a and	The following were removed: AECOM, 2013d; AECOM 2015g ; AECOM 2016a; AECOM 2017b; APTIM 2018; Becher 2012; Caddo Lake Institute 2018; Complete Environmental Services 2002; Jacobs 2001a, Jacobs 2001b, Jacobs 2002b, National Geodetic Survey 2018, Nuclear Waste Isolation Feasibility Studies 2014, Shaw 2005a and b, Shaw 2007e, Shaw 2007g, Shaw 2009c, Shaw 2010a, Shaw 2010c, Shaw 2010d, US Army 2005, US Army 2009, USACE 1989, USACE and ALL 2006, U.S. Army Environmental Hygiene Agency 1980, USEPA 2002, USEPA 2009, USEPA 2011, USEPA 2012a and b, USEPA 2014, USEPA 2015, and Wilson 2003. Jacobs 2002c and Shaw 2009a were referenced in the text.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		b, Shaw 2007e, Shaw 2007g, Shaw 2009a, Shaw 2009c, Shaw 2010a, Shaw 2010c, Shaw 2010d, US Army 2005, US Army 2009, USACE 1989, USACE and ALL 2006, U.S. Army Environmental Hygiene Agency 1980, USEPA 2002, USEPA 2009, USEPA 2011, USEPA 2012a and b, USEPA 2014, USEPA 2015, and Wilson 2003.	
145.	Page 171/ References	Caddo Lake, Louisiana and Texas, ……1998 is not properly referenced and does not appear to be in report. Proper reference would be USGS, 1998. Please remove if not used in the report.	Reference was changed to be: United States Geological Survey (USGS), 1998. Caddo Lake, Louisiana and Texas, August and September 1998. Department of the Interior, USGS Water-Resources Investigations Report 99-4217.
146.	General Comment	Does the current LUCs in place encompass all the soil and/or groundwater contamination found at the Site at actionable levels? On at least one or more of the maps with LUCs (see pp. 71, 84, 89 – 91, 103, 110 – 112, 117, 123 - 125, 133, 139 – 141, 146, 154), it appears that LUCs may not encompass all the soil and/or groundwater contamination at the Site. If not, the LUCs need to be revised to include areas with soil and/or groundwater contamination above actionable levels	Concur. Note that the page numbers are not the same in the revised document, but the figure numbers are the same. Pages 71 (Figure 19), 133 (Figure 36), 139-141 (Figures 37-39): The LUC boundaries are incorrectly labeled the site boundary LUC, but correctly reflect the LUC boundaries. The legends will be changed to Land Use Control - Groundwater Restriction and site boundaries will be added to the figures. Pages 84 (Figure 23), 89-91 (Figures 24-26), 103 (Figure 28), 110-112 (Figures 29-31), 117 (Figure 32), 123-125 (Figures 33-34): The LUC boundaries are correctly depicted, but the legends will be revised to Land Use Control - Groundwater Restriction.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
			Pages 146 (Figure 40) and 154 (Figure 41) – The Site Boundary and the LUC boundary are co-located at both MMRP sites. The legends will be revised to show both the same color. The label of the LUC will be Land Use Control - MEC Warning, Dig and Residential Use Restrictions.
147.	Page B-4	The first use of TBC and USC, please define.	TBC was defined prior to first use. Text now reads: "to Be Considered (TBC)" USC was replaced to be U.S.C. which was previously defined in the text. Text now reads: "U.S.C."
148.	Appendix/ Page B-4/ Table 1	The ARARs/TBC table fails to include the Texas Risk Reduction Program (TRRP) groundwater residential standards and TRRP PCLs under 30 TAC § 350, Subchapter D.	Do not concur. None of the RODs for the sites in this review include the TRPP PCL as an ARAR. Further, it has not been presented as an ARAR for recent (post-dispute) RODs in deference to EPA Region 6 position that the TRRP PCL is not an ARAR.
149.	Page B-7	The references listed below in table 2 need to be added to reference list. Also, what does the light pink bolding indicate in Table 2 (pages 6-7)?	There is no light pink bolding in Table 2 of Appendix B in the working copy of the document. No changes were made. The references for the historic toxicity values were collected from 2010 LHAPP-35A ROD and Jacobs Engineering Group (Jacobs), Inc, 2003 Final Baseline Human Health and Screening Ecological Risk Assessment; these are listed in the reference section. Table 2 in Appendix B has been updated to clarify this. The following reference was added to the reference list: USEPA, 2018, Integrated Risk Information System, https://www.epa.gov/iris
150.	Page C-5/ Section 4/	EPA is not familiar with the Thiel-Sen analysis, but if the method detection limits	The Theil Sen test was conducted using the EPA's Pro-UCL 5.0 software and is a non-parametric trend estimator.

STAKEHOLDER COMMENTS

Location: Karnack, Harrison County, Texas
Reviewer: Various
Document Name: Draft – Five Year Review Longhorn Army Ammunition Plant (LHAAP)
Prepared By: NAE

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
	Part b/ General Comment	were used as concentrations on the low end this would potentially bias the data slightly high, the since real value is somewhere between the mdl and zero. Looking into statistical analysis with data that includes non-detections it appears that that Akritas-Theil-Sen would help eliminate bias. Please see http://www.practicalstats.com/nada/nadatext.html. Also, there are multiple reporting limits (ex. 1, .25. .5) and estimated J values so how where those values handled? Is the scale on the right site of plot 1 correct? It appears the lowest value on the concentration is -36.? In addition, the text could use better clarification on when Mann-Kendall and Thiel-Sol trends tests were used and why. The statistical trend tests add great value to the FYR and is greatly appreciated.	Concentrations below the detectable limit (MDL) always require additional evaluation, as MDLs sometimes decrease over the historic data record. To avoid biasing the evaluation either high or low, the trend tests were run for the large LHAAP data set on unique location/constituent records with 8 or more values, and with a maximum concentration greater than 10-times the MCL. Estimated concentrations (i.e. "J" qualified data) and MDL concentrations were used without adjustment for all Theil-Sen evaluations. All resulting trends produced from these test conditions (inclusion of data well below the 10-times MCL threshold) were given a second round of evaluation to determine the appropriateness of their inclusion in the Thiel Sen trend analysis.
151.	General Comment/ Appendix C	The data analysis conducted for LHAAP 18/24 (and other sites) was very well done and provided some interesting information that has not been provided in the past. The capture zone analysis along with vertical gradient is very interesting and provided some additional analysis	The comment is noted. Some discussion among the FFA representatives may be beneficial as the final remedy decision approaches – the draft ROD will be submitted this fiscal year – keeping in mind the FFA representatives' uniform goal of maximizing the use of in situ treatment, as ex situ is diminished.

No.	Ref. Page / Para.	COMMENTS From EPA	Disposition
		that could be beneficial to help optimize the system. EPA recommends further discussion of these findings with Army, USACE, BHATE, EPA, and TCEQ.	
152.	Page C-161/ Plot 135	The plot needs more detail in explanation such as green is the GW elevation and not for sure what is the orange color on the bottom represents.	Figure extracted from Appendix F of Bhate, 2018c. Third Annual Remedial Action Operation Report, LHAAP-50 Former Sump Water Tank, Longhorn Army Ammunition Plant, Karnack, Texas. Original figure did not include green and orange colors in legend.
153.	General Comment	The use of trend in figures and plots needs to be consistent. Bhate and other older Longhorn documents typically called time series plots trends; however, those are not statistically viable trends. Bhate and USACE conducted actual statistical trend analysis for many of the wells and those are trends. Suggest changing figures that show time series plots to indicate a time series plot (i.e., plot 138, page C-164).	The titles of figures and plots in the Fourth Five Year Review are consistent with earlier Five Year Reviews. No changes were made to the document.
154.	Page 1 (Page 769 in document): Summary of COCs Concentrations	EPA recommends adding a column for units, the use significant figures for average, and add a code key to table (in the header is preferable or at the end of the table).	Concentration units were added in. J and U codes were defined at the bottom of the table as: U = Not Detected: The analyte was analyzed for, but not detected. J = Estimated Value: The analyte was positively identified, the result is an estimation due to discrepancies in certain analyte-specific quality control criteria.

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US Army Corps of Engineers®

FINAL FOURTH FIVE-YEAR REVIEW REPORT

FOR

ON THE LINE

LONGHORN ARMY AMMUNITION PLANT

TOWN OF KARNACK
HARRISON COUNTY, TEXAS

US Army Corps
of Engineers®

FINAL FOURTH FIVE-YEAR REVIEW REPORT

FOR

LONGHORN ARMY AMMUNITION PLANT

TOWN OF KARNACK
HARRISON COUNTY, TEXAS

Approved by:

Rose M - Zeiler

Rose Zeiler, PhD
LHAAP Site Manager

Date:

May 15, 2019

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LIST OF ABBREVIATIONS AND ACRONYMS

1,1-DCA	1,1-Dichloroethane
1,1-DCE	1,1-Dichloroethene
µg/L	micrograms per liter
§	Section
ACD	Air Curtain Destructor
AEC	Army Environmental Center
AECOM	AECOM Technical Services, Inc.
AEHA	United States Army Environmental Hygiene Agency
A/I	active/inactive
Amsl	Above mean sea level
AOC	area of concern
ARAR	applicable or relevant and appropriate requirements
Army	United States Department of Army
AST	above ground tank
BERA	Baseline Ecological Risk Assessment
BG3	Burning Ground Number 3
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
BRAC	Base Realignment and Closure
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cis-DCE	Cis-1,2-Dichloroethene
COC	contaminant of concern
COPC	chemical of potential concern
CTT	Closed, Transferring and Transferred
CVOC	chlorinated volatile organic compound
CWA	Clean Water Act
DCE	Dichloroethene
DERP	Defense Environmental Restoration Program
DNAPL	dense non-aqueous phase liquid
DOW	Dow Environmental, Inc.
EE/CA	Engineering Evaluation/Cost Analysis
EISB	Enhanced In Situ Bioremediation
EPS	Environmental Protection Systems
ESD	Explanation of Significant Differences
FBR	Fluidized Bed Reactor
FFA	Federal Facility Agreement
FS	Feasibility Study
FY	Fiscal Year
GAC	Granular Activated Carbon
GW-Ind	Groundwater-Industrial
gpm	gallons per minute
GWTP	groundwater treatment plant
ICT	interception collection trench
INF	Intermediate-Range Nuclear Forces
IRA	Interim Remedial Action
Jacobs	Jacobs Engineering Group, Inc.

LHAAP	Longhorn Army Ammunition Plant
LTM	Long-Term Monitoring
LTTD	low temperature thermal desorption
LUC	Land Use Control
LUCP	Land Use Control Plan
MC	methylene chloride
MCL	maximum contaminant level
MEC	Munitions and Explosives of Concern
mg/kg	milligrams per kilograms
MMRP	Military Munitions Response Program
MNA	monitored natural attenuation
MSC	medium specific concentration
Msl	mean sea level
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NPL	National Priorities List
O&M	Operations and Maintenance
OB/OD	Open Burning/Open Dentonation
OM&M	Operations, Maintenance, and Monitoring
OPS	Operating Properly and Successfully
ORP	Oxidation-Reduction Potential
OSWER	Office of Solid Waste and Emergency Response
PCE	tetrachloroethene
PCL	Protective Concentration Level
PLC	Programmable Logic Controller
Plexus	Plexus Scientific Corp.
PSI	pounds per square inch
RA	Remedial Action
RAB	Restoration Advisory Board
RACR	Remedial Action Completion Report
Radian	Radian International, LLC.
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RD	Remedial Design
RFA	RCRA Facility Assessment
RI	Remedial Investigation
ROD	Record of Decision
SDWA	Safe Drinking Water Act
Shaw	Shaw Environmental, Inc.
SI	Site Inspection
SLERA	Screening-Level Ecological Risk Evaluation
STEP	Solutions To Environmental Problems, Inc.
TAC	Texas Administrative Code
TBC	to be considered
TCDD	tetrachlorodibenzo-p-dioxin
TCE	Trichloroethene
TCEQ	Texas Commission on Environmental Quality
TNRCC	Texas Natural Resource Conservation Commission
TNRIS	Texas Natural Resources Information System

TNT	Trinitrotoluene
TRRP	Texas Risk Reduction Program
TS	Treatability Study
UEP	Unlined Evaporation Pond
U.S.	United States
U.S. Army	U.S. Department of the Army
USACE	U.S. Army Corps of Engineers
U.S.C.	United States Code
USEPA	U.S. Environmental Protection Agency
USFWS	U.S. Fish and Wildlife Service
UUUE	Unlimited Use and Unrestricted Exposure
VC	vinyl chloride
VOC	volatile organic compound
WP	Work Plan

EXECUTIVE SUMMARY

This report documents the results of the five-year review of Remedial Actions (RAs) implemented at twelve sites located at Longhorn Army Ammunition Plant (LHAAP) in Karnack, Texas (Figure ES-1, Table ES-1). The trigger for this Five-Year Review is 15 May 2014, the signing date of the previous Five-Year Review. The United States (US) Department of the Army (Army) conducted the review as required by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The Army conducted a Site Inspection 21-24 May 2018 to support this review. According to United States Environmental Protection Agency (USEPA) guidance, Five-Year Reviews are either statutory or policy; this review for LHAAP contains both statutory reviews and policy reviews. The purpose of the Five-Year Review is to evaluate whether the Interim Remedial Action (IRA) or final RAs implemented at twelve LHAAP sites are or remain protective of human health and the environment.

This report includes a detailed evaluation for the twelve response action sites with either an IRA or final remedy in place (see Figure ES-1 and Table ES-1):

1. LHAAP-12 (Landfill 12)

The Army and USEPA signed an Interim Removal Action Record of Decision (IRA ROD) in September 1995 with the Texas Commission on Environmental Quality (TCEQ) concurrence. The interim remedy was a landfill cap and land use controls (LUCs). The final ROD was signed in April 2006 formalizing LUCs and adding monitored natural attenuation to the remedy. The Army transferred LHAAP-12 to the US Fish and Wildlife Service (USFWS) in May 2014. LUCs remain in place and are functioning as intended. The cap and site access controls continue to be well maintained and the groundwater is not used. The monitored natural attenuation (MNA) remedy appears to be functioning as intended along the northeast-trending contaminant of concern (COC) plume, as defined by the current monitoring network; therefore, the remedy is functioning as intended in the ROD. Field investigations conducted subsequent to the issuance of the ROD determined that groundwater flow could occur to the southeast. When groundwater trends toward the southeast, the MNA network does not bind the plume. An additional well is required to define the limit of the plume in the southeast. The COC at LHAAP-12 is trichloroethene (TCE). The LHAAP-12 remedy currently protects human health and the environment because the landfill cap is well maintained, LUCs are in place and long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness: Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast.

2. LHAAP-16 (Old Landfill)

The Federal Facility Agreement (FFA) parties signed an IRA ROD in September 1995, with the remedy being a landfill cap. It was later augmented by an extraction system installed by the Army as a treatability study. The final ROD was signed in August 2016 with TCEQ concurrence, formalizing LUCs, enhanced in situ bioremediation (EISB) in a target area, biobarriers, and MNA. Implementation of the final remedy is underway. The multilayer cap is functioning to meet the objectives of the IRA. The cap and signage require minor maintenance. The COCs identified in the final ROD for LHAAP-16 are chlorinated volatile organic compounds

(CVOCs), perchlorate, and metals in groundwater. The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs.

3. LHAAP-18/24 (Burning Ground No. 3 and Unlined Evaporation Pond)

The Interim Remedial Action's (IRA's) ROD was signed in May 1995, with the remedy being source material thermal treatment and groundwater extraction and treatment with the goal of reducing or preventing further migration of contaminants from source material and shallow groundwater into deeper groundwater zones, and possibly surface water bodies. The COCs identified for LHAAP-18/24 are CVOCs and metals. The interim remedy resulted in significant reduction in concentrations of COCs and mass loading into the deeper groundwater zones and surface water bodies. However, capture zone analysis suggests that the interim remedy does not totally prevent the COCs impacted shallow groundwater from migrating outside the treatment zone. In addition, there have been problems with the treatment system, primarily related to the treatment of perchlorate, and maintenance of the acid tank. Treatment plant and the extraction system upgrades and maintenance took place under the AECOM contract (2012-2017), including repair and replacement of interception collection trench (ICT) pumps, the addition of an in-line ion exchange system and work on the plant continues through the new contract (Bhate) with a complete overhaul of the fluidized bed reactor (FBR) and upgrade of the ion exchange system. The Proposed Plan is in agency review. According to the installation, a smaller more efficient groundwater treatment plant (GWTP) is included as a possibility in the draft Proposed Plan for this site. Although a final remedial action has not been implemented, the IRA remedy is protective of human health and the environment because groundwater extraction and long-term monitoring occurs. Recommendations include implementing a proactive maintenance program and restoring FBR performance to ensure the perchlorate discharge threshold is not exceeded. The final remedy will address long-term protectiveness. The remedy at LHAAP-18/24 currently protects human health and the environment because soil removal/treatment, groundwater extraction, and groundwater monitoring have reduced and/or prevented further migration of contaminants of concern into deeper groundwater zones and surface water bodies, thereby eliminating or minimizing the potential for exposure to human and ecological receptors. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.

4. LHAAP-35B (37) (Chemical Laboratory)

The FFA parties signed the ROD in June 2010 with TCEQ concurrence, selecting groundwater LUCs and MNA as the remedy. LUCs are in place and functioning as intended and, the groundwater use restriction is being followed. Due to the implementation of a demonstration project which proved ineffective, the MNA remedy was delayed until late 2017. Because the first quarterly report was not completed within the review period, it is not possible to evaluate the MNA remedy, though it is noted that trichloroethene (TCE) concentrations in a perimeter well are slightly above the maximum contaminant level (MCL). The COCs identified for LHAAP-37 are CVOCs in shallow groundwater. The LHAAP-35B (37) remedy is protective of human health and the environment because LUCs are in place and MNA long-term monitoring occurs.

5. LHAAP-46 (Plant 2 Area)

The FFA parties signed the ROD in September 2010 with TCEQ concurrence, selecting groundwater LUCs and MNA with a contingency remedy to enhance MNA, if MNA proved ineffective. LUCs are in place and functioning as intended, for the groundwater use restriction is followed. Available analytical data indicates that MNA appears to have stabilized the COCs' plumes. Contaminants of concern identified at LHAAP-46 are CVOCs in shallow and intermediate groundwater. Numerous monitoring network wells could not be sampled because they were dry due to many years of drier than normal conditions. Although the drought eased in the last few years, most wells in the shallow zone are still dry. In a technical memo presented to regulators in January 2018, the Army stated that the lack of water might be due to a regional decline in groundwater elevations and/or the cessation of plant activities that would have contributed water to a shallow zone. Approval was received from the regulators to begin the MNA evaluation for the site based on a reduced set of wells. The LHAAP-46 remedy currently protects human and the environment health because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended.

6. LHAAP-49 (Former Acid Storage Area)

The FFA parties signed the ROD in August 2010 with TCEQ concurrence, determining that no remedial action would be required but Five-Year Reviews would be required because hazardous substances, pollutants, contaminants remain at the site above levels that allow for unlimited use and unrestricted exposure (UUUE). The LHAAP-49 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.

7. LHAAP-50 (Former Sump Water Tank)

The FFA parties signed the ROD in September 2010 with TCEQ concurrence, selecting groundwater LUCs and MNA with a contingency remedy if MNA proved ineffective as the remedy for chlorinated volatile organic compounds (CVOCs) and perchlorate, and soil removal and offsite disposal for perchlorate. The COCs identified at LHAAP-50 are CVOCs and perchlorate in shallow groundwater and perchlorate in soil. LUCs are in place and functioning as intended. Although groundwater COC plume footprints vary with time, MNA appears to stabilize the extent of the plumes. COC increases are noted in some wells, but it is not certain whether the trends in some of the wells are potentially due to a COC slug released during soil excavation or seasonal variation. Indication of increasing trend for perchlorate at the leading edge of the plume, and localized, elevated TCE concentrations possibly suggest the presence of residual dense non-aqueous phase liquid (DNAPL). The contingency remedy to enhance MNA will be implemented following the ESD to the ROD and will address the elevated TCE concentrations and the increases in COC concentrations in leading edge wells. The LHAAP-50 remedy currently protects human health and the environment because LUCs are in place and MNA long-term monitoring occurs. However, for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness: Implement the contingency remedy to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.

8. LHAAP-35A (58) (Shops Area)

The FFA parties signed the ROD in September 2010 with TCEQ concurrence, selecting groundwater LUCs and EISB followed by MNA for the eastern plume, and MNA for the western plume with a contingency remedy for MNA if found to be ineffective. Groundwater LUCs are in place and functioning as intended. The COCs identified at LHAAP-58 are CVOCs in groundwater.

EISB remedy in the eastern plume appears to be functioning as intended by the ROD by reducing the concentration and mass loading of COCs from the center of the plume. However, COCs concentrations immediately downgradient and side gradient of the plume’s center show increasing trends. Currently the extent of the COCs plume exceeding the MCL is bounded with the available network of perimeter wells, where concentrations remain below the detection limits. The effectiveness will be further evaluated in future reports.

MNA appears to be ineffective in the western plume, because the lateral extent of the COCs exceeding MCL is no longer bounded by perimeter wells and the plume appears to be extending laterally. The MNA contingency remedy for the western plume was implemented in March and April 2018. The LHAAP-35A (58) remedy currently protects human health and the environment because LUCs are in place, EISB has been implemented in the eastern and western plumes, and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement EISB performance monitoring and assess if additional monitoring wells are required to delineate the plume to the south and southwest.

9. LHAAP-67 (Aboveground Storage Tank Farm)

The FFA parties signed the ROD in June 2010 with TCEQ concurrence, selecting groundwater LUCs and MNA as the remedy. The groundwater LUCs are in place and functioning as intended. The COCs identified at LHAAP-67 are CVOCs in shallow groundwater. Although the COC footprints appear to be stable, the COCs plumes redistribute with shifting groundwater flow directions resulting in contaminant migration outside the current MNA monitoring network. A redefinition of the plume extent requires additional well installation. The LHAAP-67 remedy currently protects human health in the short-term because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the Army will evaluate the data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system.

10. LHAAP-001-R-01 (South Test Area/Bomb Test Area)

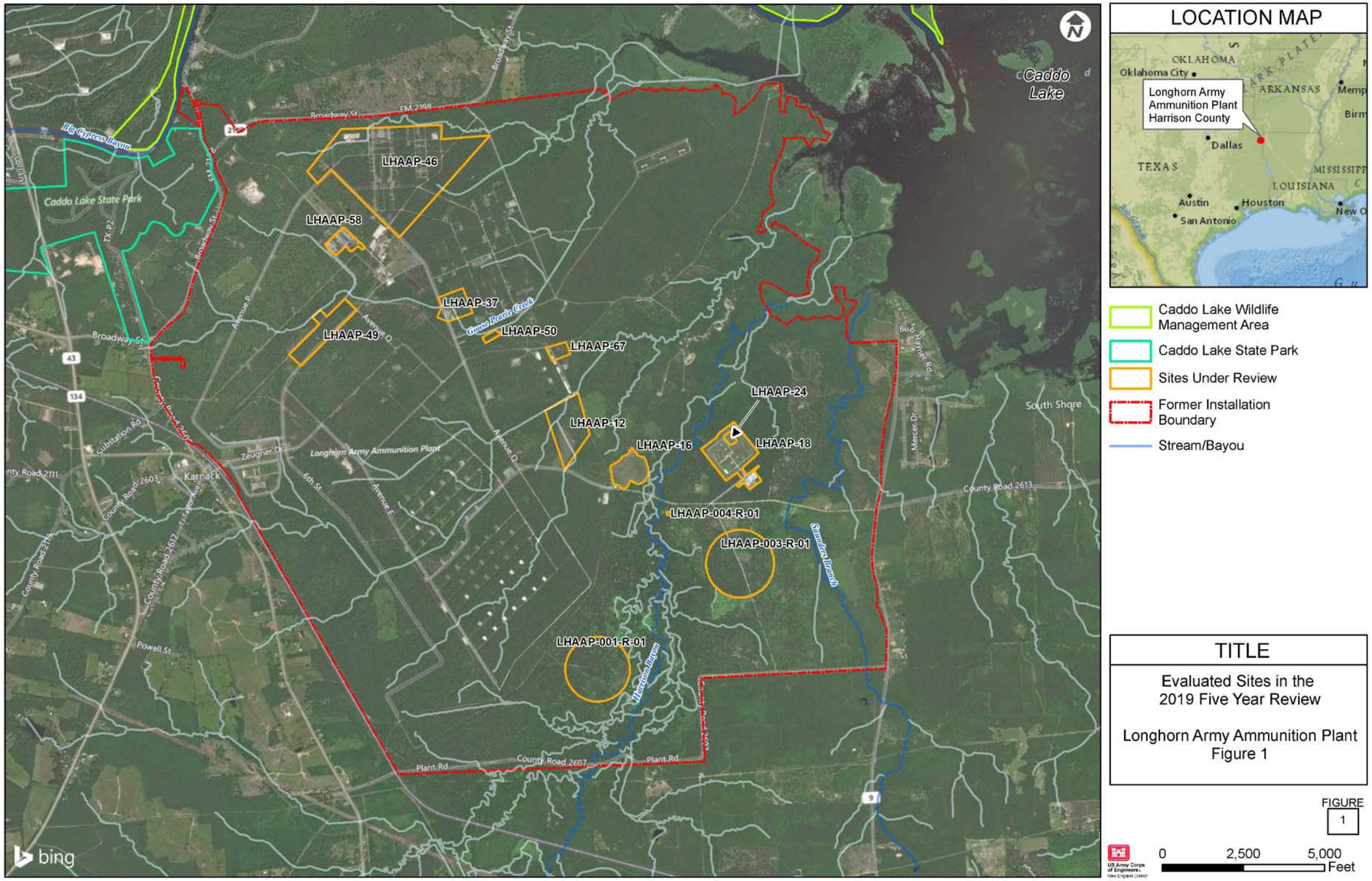
The FFA parties signed the ROD in August 2016 with TCEQ concurrence, selecting LUCs with limited perchlorate sampling as the remedy (Munitions and Explosives of Concern (MEC) removal was completed in November 2009). Groundwater perchlorate concentrations are below the 17 µg/L Texas Risk Reduction Program (TRRP) Protective Concentration Level (PCL) residential groundwater cleanup level. The institutional controls are implemented in accordance with the land use control plan (LUCP), maintaining non-residential land use, and preventing exposure to MEC. The COC identified at LHAAP-001-R-01 was MEC. The LHAAP-001-R-01 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.

11. LHAAP-003-R-01 (Ground Signal Test Area)

The FFA parties signed the ROD in August 2016 with TCEQ concurrence, selecting LUCs with limited perchlorate sampling as the remedy (MEC removal was completed in November 2009). Groundwater perchlorate concentrations are below the 17 µg/L TRRP PCL residential groundwater cleanup level. The institutional controls are implemented in accordance with the LUCP, maintaining non-residential land use, and preventing exposure to MEC. The COC identified at LHAAP-003-R-01 was MEC. The LHAAP-001-R-03 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.

12. LHAAP-004-R-01 (Former Pistol Range)

The FFA parties signed the ROD in August 2010 with TCEQ concurrence, selecting the No Action decision with Five-Year Reviews because site contaminants are above levels that allow for unrestricted use and unrestricted exposure. Land use assumptions that formed the basis of the risk evaluation have not changed since the 2013 Five-Year Review. The LHAAP-004-R-01 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.



ES Figure 1. **Twelve sites comprising the Fourth Five-Year Review at Longhorn Army Ammunition Plant, Karnack Texas (see Table ES-1 for details) (LHAAP, 2018a, US Army, 2016, Landmark Consultants, 2015a, b, c, 2014, b, 2011a, b, 2006, EODT, 2009).**

ES Table 1. Information summary for the twelve sites comprising the Fourth Five-Year Review at Longhorn Army Ammunition Plant, Karnack Texas (see Figure ES-1) (AECOM, 2014a, US Army, 2016, 2010a-f, 2006, 1995a, b).

Site Number	Site Name	Description	ROD Date	Five-Year Review Iteration	COCs/Contaminants of Potential Concern (COPCs) (See Final ROD)	Selected Remedy(s)
LHAAP- 12	Landfill 12	Non-hazardous industrial waste disposal occurred between 1963 and 1994.	IRA - Sep 1995 Final - Apr 2006	4	TCE	Landfill cap, LUCs, and MNA. Estimated TCE cleanup time is 23 to 261 years.
LHAAP- 16	Old Landfill	Trinitrotoluene (TNT) red water ash disposal occurred from 1942 to 1944. Burn pits, waste storage, and landfill operations continued until 1980s.	IRA- Sep 1995 ROD-Aug 2016	4	None identified in the IRA CVOCs, perchlorate[a], and metals in groundwater	Landfill cap. Landfill cap, LUCs, bioremediation and biobarriers, and MNA with Five-Year Reviews. Estimated cleanup time is 280 years.
LHAAP - 18/24	Burning Ground No. 3 and Unlined Evaporation Pond (UEP)	Site 18 was used from approximately 1955 until 1984 for the treatment, storage, and disposal of pyrotechnic and combustible solvent wastes by open burning, incineration, evaporation, and burial. Site 24 was a UEP located within Site 18's former burning ground number 3 (BG3). The UEP was constructed in 1963 and used until 1984 for disposal of manufacturing plant waste.	IRA ROD May 1995	4	CVOCs and metals[a,b,c]	Extraction of shallow groundwater and treatment using metal precipitation, air stripping and off-gas treatment for VOCs, Excavation of source material and treatment using low thermal desorption and off-gas treatment for VOCs. Draft Proposed Plan is in review.
LHAAP-37	Chemical Laboratory	Also called Site 35B, the Chemical Laboratory area was used from 1953 to 1997.	ROD Jun 2010	1	CVOCs in shallow groundwater	Groundwater LUCs and MNA Bio plug study completed. Estimated cleanup time is 50 years.
LHAAP-46	Plant 2 Area	Pyrotechnic and illumination production area from 1952 until 1997.	ROD Sep 2010	1	CVOCs in shallow and intermediate groundwater	Groundwater LUC and MNA
LHAAP- 49	Former Acid Storage Area	This site was used from 1942 to 1945 formulation and storage of acid in support of TNT production.	ROD Aug 2010	2	None	No Action
LHAAP-50	Former Sump Water Tank	Former sump water above ground tank (AST) that received industrial wastewater from various LHAAP sumps between 1955 and 1988.	ROD Sep 2010	1	Perchlorate in soil and CVOCs and perchlorate in shallow groundwater	Perchlorate-contaminated soil excavation with offsite disposal, LUCs, and MNA for CVOCs. Estimated cleanup time is 50 years.
LHAAP-58	Shops Area	Also called Site 35B, the Shops Area was established in 1942 as part of the installation's initial construction. The facility provided plant-operated laundry, automotive, woodworking, metalworking, painting, refrigeration, and electrical services. The site became inactive in 1996-1997.	ROD Sep 2010	1	CVOCs in groundwater	Groundwater LUCs and EISB/MNA in eastern plume, and groundwater LUCs and MNA in western plume with Five-Year Reviews Eastern plume - estimated cleanup time is 200 years for MNA only, to be revised after implementing enhanced bioremediation option. Western plume – estimated vinyl chloride (VC) and 1,1-dichloroethene (1,1-DCE) cleanup times are 70 and 135 years, respectively.
LHAAP-67	Aboveground Storage Tank Farm	AST Farm consisting of seven former above ground tanks surrounded by earthen dikes, and used for bulk No. 2 fuel oil, kerosene, and solvents storage. Tank sizes and operation history are not known.	ROD Jun 2010	1	CVOCs in shallow groundwater	Groundwater LUCs and MNA. Estimated cleanup time for 1,1-DCE is 20 to 34 years, and for 1,2-DCA is 21-43 years.
LHAAP-001-R-01	South Test Area/Bomb Test Area	Testing M120A1 photoflash bombs produced at the facility until about 1956. During the early 1960s, detonation, and potentially white phosphorous munitions may have demilitarized leaking production items such as XM40E5 "button bombs".	ROD Aug 2016	1	MEC[d]	MEC removal, LUCs, and limited groundwater monitoring.

Site Number	Site Name	Description	ROD Date	Five-Year Review Iteration	COCs/Contaminants of Potential Concern (COPCs) (See Final ROD)	Selected Remedy(s)
LHAAP-003-R-01	Ground Signal Test Area	Beginning in April 1963, the range was used for aerial and on-ground testing and destruction of a variety of devices, including pyrotechnic signal devices, red phosphorus smoke wedges, infrared flares, illuminating mortar shells and cartridges, button bombs, and various types of explosive simulators. From late 1988 through 1991, the site was also used for burnout of Pershing missile rocket motors.	ROD Aug 2016	1	MEC[d]	MEC removal, LUCs, and limited groundwater monitoring.
LHAAP- 004-R-01	Pistol Range	This site was used between 1950 and 2004 for small arms target practice and qualifying tests.	ROD Aug 2010	2	None	No Action

Notes:

a	Perchlorate was identified at levels of concern following IRA implementation at LHAAP-16 and LHAAP-18/24
b	IRA specified discharge limits, not COCs
c	Interim ROD only for LHAAP-18/24 at the time of the five year review
d	Munitions and Explosives of Concern (MEC). This term, which distinguishes categories of military munitions that may pose unique explosives risks, means : (A) Unexploded Ordnance (UXO), as defined in 10 §101(e)(5); (B) Discarded military munitions (DMM), as defined in 10 U.S.C. §2710(e)(2); or (C) Munitions constituents (e.g., TNT, RDX), as defined in 10 U.S.C. §2710(e)(3), present in high enough concentrations to pose an explosive hazard.
COC	contaminant of concern
COPC	chemical of potential concern
IRA	Interim Remedial Action
LUC	Land Use Control
ACD	Air Curtain Destructor
PLC	Programmable Logic Controller

MNA	monitored natural attenuation
ROD	Record of Decision
TCE	trichloroethene
UEP	unlined evaporation pond
CVOC	Chlorinated volatile organic compound
1,1-DCE	1,1-Dichloroethene
1,1-DCA	1,1-Dichloroethane
Cis-DCE	Cis-1,2-Dichloroethene

FIVE-YEAR REVIEW SUMMARY FORM

SITE IDENTIFICATION		
Site Name: Longhorn Army Ammunition Plant		
EPA ID: TX6213820529		
Region: 6	**State:** TX	**City/County:** Karnack/Harrison

SITE STATUS	
NPL Status: Final	
Multiple OUs? Yes	**Has the site achieved construction completion?** No

REVIEW STATUS
Lead agency: Other Federal Agency **If "Other Federal Agency" was selected above, enter Agency name:** United States Army
Author name (Federal or State Project Manager): Rose Zeiler
Author affiliation: US Army
Review period: 17 April 2018 – 15 May 2019
Date of site inspection: 21-24 May 2018
Type of review: Statutory
Review number: 4
Triggering action date: 15 May 2014
Due date *(five-years after triggering action date)*: 15 May 2019

Five-Year Review Summary Form (continued)

Issues and Recommendations Identified in the Fourth Five-Year Review:

Of the 12 sites identified at LHAAP, only 7 had identified issues and are included in these five year review summary forms. Consequently, LHAAP-37, LHAAP-49, LHAAP-001-R-01, LHAAP-003-R-01, LHAAP-004-R-01, which have no identified issues are not included in these summary forms.

OU(s): LHAAP-12	**Issue Category: Changed Site Conditions**			
	Issue: Changes in groundwater flow direction result in contaminant migration outside the current MNA monitoring network.			
	Recommendation: Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Implementing Party**	**Oversight Party**	**Milestone Date**
No	Yes	U.S. Army	EPA/State	Sep 2020

OU(s): LHAAP-16	**Issue Category: Changed Site Conditions**			
	Issue: Relatively high concentrations of TCE persist downgradient of the cap, suggesting that a continuing source may be present.			
	Recommendation: Implement the remedy selected in the 2016 ROD consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs.			
Affect Current Protectiveness	**Affect Future Protectiveness**	**Implementing Party**	**Oversight Party**	**Milestone Date**
No	Yes	U.S. Army	EPA/State	Sep 2020

<table>
<tr><td rowspan="3">OU(s): LHAAP-18/24</td><td colspan="4">Issue Category: Operations and Maintenance</td></tr>
<tr><td colspan="4">Issue: Groundwater treatment plant operation experiences frequent breakdowns resulting in excessive down time, reduced mass removal, increasing potential impacts to Harrison Bayou.</td></tr>
<tr><td colspan="4">Recommendation: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>Yes</td><td>U.S. Army</td><td>EPA/State</td><td>Sep 2020</td></tr>
</table>

<table>
<tr><td rowspan="3">OU(s): LHAAP-46</td><td colspan="4">Issue Category: Changed Site Conditions</td></tr>
<tr><td colspan="4">Issue: It is uncertain if the declining trends in TCE concentrations are maintained when groundwater elevation are recovered during high recharge periods.</td></tr>
<tr><td colspan="4">Recommendation: Assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>Yes</td><td>U.S. Army</td><td>EPA/State</td><td>Sep 2020</td></tr>
</table>

<table>
<tr><td rowspan="3">OU(s): LHAAP-50</td><td colspan="4">Issue Category: Monitoring</td></tr>
<tr><td colspan="4">Issue: TCE and Perchlorate trends are increasing across part of the site.</td></tr>
<tr><td colspan="4">Recommendation: Implement the contingency remedy following the ESD to the ROD to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>Yes</td><td>U.S. Army</td><td>EPA/State</td><td>Oct 2024</td></tr>
</table>

<table>
<tr><td rowspan="3">OU(s): LHAAP-58</td><td colspan="4">Issue Category: Remedy Performance</td></tr>
<tr><td colspan="4">Issue: EISB implementation requires performance monitoring to establish effectiveness.</td></tr>
<tr><td colspan="4">Recommendation: Implement EISB performance monitoring and assess if additional monitoring wells are required to delineate the plume to the south and southwest.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>Yes</td><td>U.S. Army</td><td>EPA/State</td><td>Sep 2020</td></tr>
</table>

<table>
<tr><td rowspan="3">OU(s): LHAAP-67</td><td colspan="4">Issue Category: Monitoring</td></tr>
<tr><td colspan="4">Issue: Changes in groundwater flow direction result in contaminant migration outside the current MNA monitoring network.</td></tr>
<tr><td colspan="4">Recommendation: Evaluate data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system.</td></tr>
<tr><td>Affect Current Protectiveness</td><td>Affect Future Protectiveness</td><td>Implementing Party</td><td>Oversight Party</td><td>Milestone Date</td></tr>
<tr><td>No</td><td>Yes</td><td>U.S. Army</td><td>EPA/State</td><td>Sep 2020</td></tr>
</table>

Protectiveness Statements

Operable Unit: LHAAP-12 (Landfill 12)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The LHAAP-12 remedy currently protects human health and the environment because the landfill cap is well maintained, LUCs are in place and long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness: Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast.

Operable Unit: LHAAP-16 (Old Landfill)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs.

Operable Unit: LHAAP-18/24 (Burning Ground No. 3 and Unlined Evaporation Pond)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The remedy at LHAAP-18/24 currently protects human health and the environment because soil removal/treatment, groundwater extraction, and groundwater monitoring have reduced and/or prevented further migration of contaminants of concern into deeper groundwater zones and surface water bodies, thereby eliminating or minimizing the potential for exposure to human and ecological receptors. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.

Operable Unit: LHAAP-35B (37) (Chemical Laboratory)	*Protectiveness Determination:* Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The LHAAP-35B (37) remedy is protective of human health and the environment. LUCs ensure there is no exposure, and MNA ensures a stable or decreasing plume.

Operable Unit: LHAAP-46 (Plant 2 Area)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The LHAAP-46 remedy currently protects human and the environment health because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended.

Operable Unit: LHAAP-49 (Former Acid Storage Area)	*Protectiveness Determination:* Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The LHAAP-49 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.

Operable Unit: LHAAP-50 (Former Sump Water Tank)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.

Protectiveness Statement:
The LHAAP-50 remedy currently protects human health and the environment because LUCs are in place and MNA long-term monitoring occurs. However, for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness: Implement the contingency remedy to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.

Operable Unit: LHAAP-35A (58) (Shops Area	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.
Protectiveness Statement: The LHAAP-35A (58) remedy currently protects human health and the environment because LUCs are in place, EISB has been implemented in the eastern and western plumes, and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement EISB performance monitoring and assess if additional monitoring wells are required to delineate the plume to the south and southwest.		

Operable Unit: LHAAP-67 (Aboveground Storage Tank Farm)	*Protectiveness Determination:* Short-term Protective	*Addendum Due Date (if applicable):* Click here to enter date.
Protectiveness Statement: The LHAAP-67 remedy currently protects human health in the short-term because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the Army will evaluate the data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system.		

Operable Unit: LHAAP-001-R-01 (South Test Area/Bomb Test Area	*Protectiveness Determination:* Protective	*Addendum Due Date (if applicable):* Click here to enter date.
Protectiveness Statement: The LHAAP-001-R-01 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.		

Operable Unit: LHAAP-003-R-01 (Ground Signal Test Area)	*Protectiveness Determination:* Protective	*Addendum Due Date (if applicable):* Click here to enter date.
Protectiveness Statement: The LHAAP-001-R-03 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.		

Operable Unit: LHAAP-004-R-01 (Former Pistol Range)	*Protectiveness Determination:* Protective	*Addendum Due Date (if applicable):* Click here to enter date.
Protectiveness Statement: The LHAAP-004-R-01 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.		

1.0 INTRODUCTION

1.1 Regulatory Background

LHAAP in Karnack, Texas, is TX6213820529 on the National Priorities List (NPL). The United States Department of Army (Army) is the lead agency, and must comply with, manage, and execute site closure consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (Section 121(c), 42 United States Code (U.S.C.) §9621(c)), the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) (40 Code of Federal Regulations (CFR) §300.430(f) (4) (ii)), under the Defense Environmental Restoration Program (DERP) (10 U.S.C. Section 2701). The trigger for this Five-Year Review is 15 May 2014, the signing date of the 2013 Five-Year Review (Department of Defense, 2014, AECOM, 2014a).

CERCLA §121(c) states:

> *If the President selects a remedial action that results in any hazardous substances, pollutants, or contaminants remaining at the site, the President shall review such remedial action no less often than each five-years after the initiation of such remedial action to assure that human health and the environment are being protected by the remedial action being implemented. In addition, if upon such review it is the judgment of the President that action is appropriate at such site in accordance with section [104] or [106], the President shall take or require such action. The President shall report to the Congress a list of facilities for which such review is required, the results of all such reviews, and any actions taken as a result of such reviews.*

The NCP at 40 CFR §300.430(f) (4) (ii) provides:

> *If a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the site above levels that allow for unlimited use and unrestricted exposure, the lead agency shall review such action no less often than every five-years after the initiation of the selected remedial action.*

This review has been prepared due hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unlimited use and unrestricted exposure.

1.2 Purpose of the Five-year Review

The purpose of this Five-Year Review is to determine whether the LHAAP remedies are protective of human health and the environment for each of the twelve evaluated sites (Figure 1).

1.3 Personnel Conducting the Review

The United States Army Corps of Engineers (USACE) completed the review, and visited 21-24 May 2018. USACE site visit team included Drew Clemens (Geologist), Chris Kilbridge (Hydrogeologist), and Dr. Lily Sehayek (Environmental Engineer). The remaining team members included Dr. Ken Heim (Hydrologist), Cynthia Auld (Human Risk Assessor), Dr. Cheryl R. Montgomery (Research Biologist/Ecological Risk Assessor), and Olivia Beaulieu (editing).

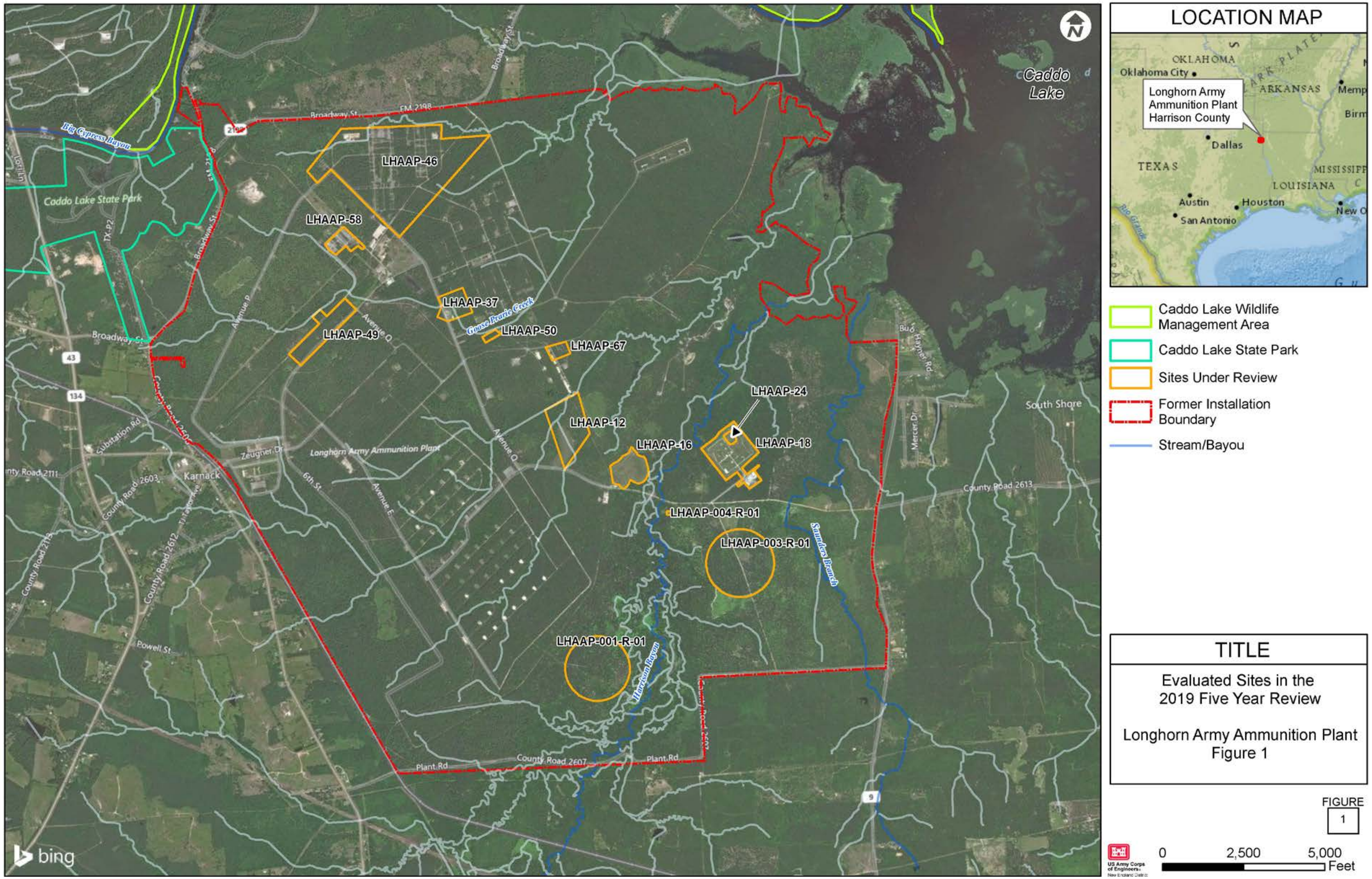


Figure 1. LHAAP showing the location of the sites included in this review
(LHAAP, 2018a, US Army, 2016, USGS, 2011, Landmark Consultants, 2015a, b, c, 2014a, b, 2011a, b, 2006, EODT, 2009) (see Table 1).

1.4 Review Status

Table 1. Five-Year Review status for sites included in the 2018 review (US Army, 2016, 2010a-f, 2006, 1995a, b) (see Figure 1).

Site	Description	ROD Date	Five-Year Review Iteration
LHAAP- 12	Non- hazardous industrial waste disposal occurred between 1963 and 1994.	IRA - Sep 1995 Final - Apr 2006	4
LHAAP- 16	Trinitrotoluene (TNT) red water ash disposal occurred from 1942 to 1944. Burn pits, waste storage, and landfill operations continued until 1980s.	IRA- Sep 1995 Final-Aug 2016	4
LHAAP - 18/24	Site 18 was used from approximately 1955 until 1984 for the treatment, storage, and disposal of pyrotechnic and combustible solvent wastes by open burning, incineration, evaporation, and burial. Site 24 was a UEP located within Site 18's former burning ground number 3 (BG3). The UEP was constructed in 1963 and used until 1984 for disposal of manufacturing plant waste.	IRA ROD May 1995	4
LHAAP-37	Also known as Site 35B, the Chemical Laboratory area was used from 1953 to 1997.	ROD Jun 2010	1
LHAAP-46	Pyrotechnic and illumination production area from 1952 until 1997.	ROD Sep 2010	1
LHAAP- 49	This site was used from 1942 to 1945 formulation and storage of acid in support of TNT production.	Sep 2010	2
LHAAP-50	Former sump water above ground tank (AST) that received industrial wastewater from various LHAAP sumps between 1955 and 1988.	ROD Sep 2010	1
LHAAP-58	Also known as Site 35B, the Shops Area was established in 1942 as part of the installation's initial construction. The facility provided plant-operated laundry, automotive, woodworking, metalworking, painting, refrigeration, and electrical services. The site became inactive in 1996-1997.	ROD Jun 2010	1
LHAAP-67	AST Farm used for solvent storage.	ROD Jun 2010	1
LHAAP-001-R-01	South Test Area/Bomb Test Area	ROD Aug 2016	1
LHAAP-003-R-01	Ground Signal Test Area	ROD Aug 2016	1
LHAAP- 004-R-01	The Pistol Range was used between 1950 and 2004 for small arms target practice and qualifying tests.	ROD Aug 2010	2

2.0 LHAAP BACKGROUND

Site-wide background, physical characteristics, and site history for the LHAAP are presented here. Site-specific background information (e.g., history of contamination, initial response, and basis for taking RA) for each response action site undergoing detailed review is presented in Sections 4.0 through 15.0.

2.1 Physical Characteristics

The LHAAP is an inactive, government-owned, formerly contractor-operated and maintained industrial facility located in central-east Texas in the northeastern corner of Harrison County. The facility occupies approximately 1,300 of its former 8,416 acres located between State Highway 43 in Karnack, Texas, and the western shore of Caddo Lake (Figure 1).

Most of LHAAP consists of mixed pine-hardwood forests that cover a flat to gently rolling terrain with an average slope of 3 percent or less. Surface elevations vary from 175 to 335 feet above mean sea level (MSL), with most of the site 200 feet or more above MSL. The site generally slopes from west to east. Surface water at LHAAP drains to the northeast into Caddo Lake via four drainage systems known as Goose Prairie Creek, Central Creek, Harrison Bayou, and Saunders Branch (Shaw, 2008).

2.2 History

LHAAP was established in 1942 to produce trinitrotoluene (TNT) for use in World War II. Production of TNT was discontinued in 1945, but the facility was later used for production of pyrotechnic ammunition, rocket motor production, static firing, and elimination of rocket motors. The plant was deactivated and declared excess to the Army's needs in 1997. In December 1991, the State of Texas, USEPA, and the Department of Defense, entered into a Federal Facility Agreement (FFA) to address the contamination at LHAAP. Proposed actions are carried out under CERCLA (as implemented through the NCP) with the Army as the lead agency, in conformity with the FFA (US Army 1991). The entire installation was under the control of the Army until May 5, 2004, when approximately two-thirds of the property was transferred to the United States Fish and Wildlife Service (USFWS). The property transfer process is continuing as remedies are put in place at smaller parcels of land. Site LHAAP-12 and LHAAP-49 have transferred out of Army control to the USFWS (Figure 1).

2.3 Location and Hydrology

2.3.1 Location

LHAAP is located near the unincorporated community of Karnack, Texas. Karnack is a rural community with a population of 2,703 people. The incorporated community of Uncertain, Texas, population of 94, is a local resort area located to the northeast of LHAAP on the edge of Caddo Lake and an access point to Caddo Lake. The industries in the surrounding area consist of agriculture, timber, oil and natural gas production, and recreation.

2.3.2 Regional and Local Groundwater Hydrology

Regional and LHAAP stratigraphy, structure, aquifer classification and interconnectivity understanding has undergone several changes since Broom and Myers' 1966 Groundwater Resources of Harrison County (USGS, 1966).

2.3.2.1 Geologic Setting

The Midway Formation is the lowermost regional fresh water aquitard in northeast Texas, and is comprised of marine shale interbedded with a few local sandstone and limestone beds (Table 2) (Warwick, 2017, Bech and others, 2016, Fryar and others, 2003). The younger Wilcox Formation fills a paleo stream channel underlying LHAAP-16, where it bends northeast toward LHAAP-18/24 and underlies Caddo Lake (Figure 2) (Fryar and others, 2003, USACE, 2001, Albertson, 1992).

The younger upper Wilcox Formation, Reklaw Formation (leaky aquitard), Carrizo Sand, and Queen City Formation are not present within or near LHAAP (Fryar and others, 2003). Historic hydrogeology and site investigation reports speculated these units were present, but recent stratigraphic and geophysical logging data has shown these units are not present.

Regional Quaternary alluvium consists of two units: a lower, sand and gravel unit, grading into an upper, silt and clay unit (Boswell and others, 1968). The shallow alluvium is predominantly clay or silt. The basal part of the lower unit is usually composed of coarse sand and gravel. The relative thickness of the two units is extremely variable. At LHAAP, all sites except LHAAP-49 are underlain by Quaternary depositional terrace deposits unconformably overlying the Tertiary middle and lower Wilcox Formation units (Albertson and Dunbar, 1993, Albertson, 1992). These terrace deposits are flat or gently inclined surfaces between the valley slopes and the floodplains of the respective drainage basins, and exceed 60 ft thick at the LHAAP eastern boundary (Albertson, 1992). Buried stream channels and natural levees likely trend northeast-southwest across LHAAP, with site-scale directional variations possible.

2.3.2.2 Hydrogeology

The Tertiary Wilcox Formation forms the largest regulated aquifer in East Texas, but only the lower and middle members underlie LHAAP. Local windows within the Yoakum Clay, such as those identified at LHAAP-18/24 (see Section 6), create vertical flow across the otherwise regional confining unit. Wilcox Formation horizontal groundwater flow is governed by:

- Channel in the Midway Group (Figure 2). The channel is a preferential groundwater flow pathway in the lower and possibly middle Wilcox Formation. Low angle folds parallel to the arms of Caddo Lake and several stream channels may also affect groundwater flow direction (e.g., Matson, 1916).
- Sabine Uplift. The Wilcox Formation dips about 0.2° northwestward, so regional groundwater flows north-northwest toward the East Texas Embayment where not affected by missing confining units or eroded channels in the Midway Group (Matson, 1916, Kreitler and others, 1980, Hosman and others, 1968). This is observed at LHAAP-46's Deep Groundwater Zone wells near the installation's northern border (Figure 2).

Table 2. Summary of the hydrogeologic units underlying LHAAP, and their correlation to pre- and post-2012 conceptual hydrogeologic models (CSM)
(AECOM, 2017a, George, 2009, Deeds and others, 2009, and Fryar and others, 2003, Boswell and others, 1968).

Age	Unit	Subunit	Notes	Pre-2012 CSM	Post 2012 CSM used at LHAAP-18/24
Quaternary	Bayou Channel and Terrace Deposits	None	Interfingering stream channels, flood, and slack water deposits near Big Cypress Creek, and older terrace deposits covering most of LHAAP.	Shallow Groundwater Zone Intermediate Groundwater Zone	Referred to as Shallow, Shallow/Intermediate and intermediate Groundwater Zone
Tertiary	Wilcox Formation	Middle Wilcox	Middle and Lower Wilcox subunits are often merged together unless geophysical logging data show Yoakum Shale (top of Middle Wilcox) and Big Shale (bottom of Middle Wilcox) marker beds. Uniform channel sands are associated laterally with levee silt are associated laterally with levee silt deposits, local and thin sand splays, extensive interfingering channel or overbank muds, and numerous lignite seams.	Deep Groundwater Zone?	Deep Groundwater Zone
		Clay	Big Shale (Louisiana), a marine shale bed locally extensive but extent under LHAAP has not been verified with geophysical logs.		
		Lower Wilcox	Middle and Lower Wilcox subunits frequently merged unless geophysical logging data Big Shale marker bed. Contains a coarsening upward sequence of delta plain, delta front, and prodelta sequences (medium to fine grain), varying degrees of cementation, deposited onto the Medway Formation’s eroded surface.	Deep Groundwater Zone?	Deep Groundwater Zone?
	Midway Formation	Not Applicable	Regional marine clay and related rocks. Upper contact incised with N-S trending stream channels.		

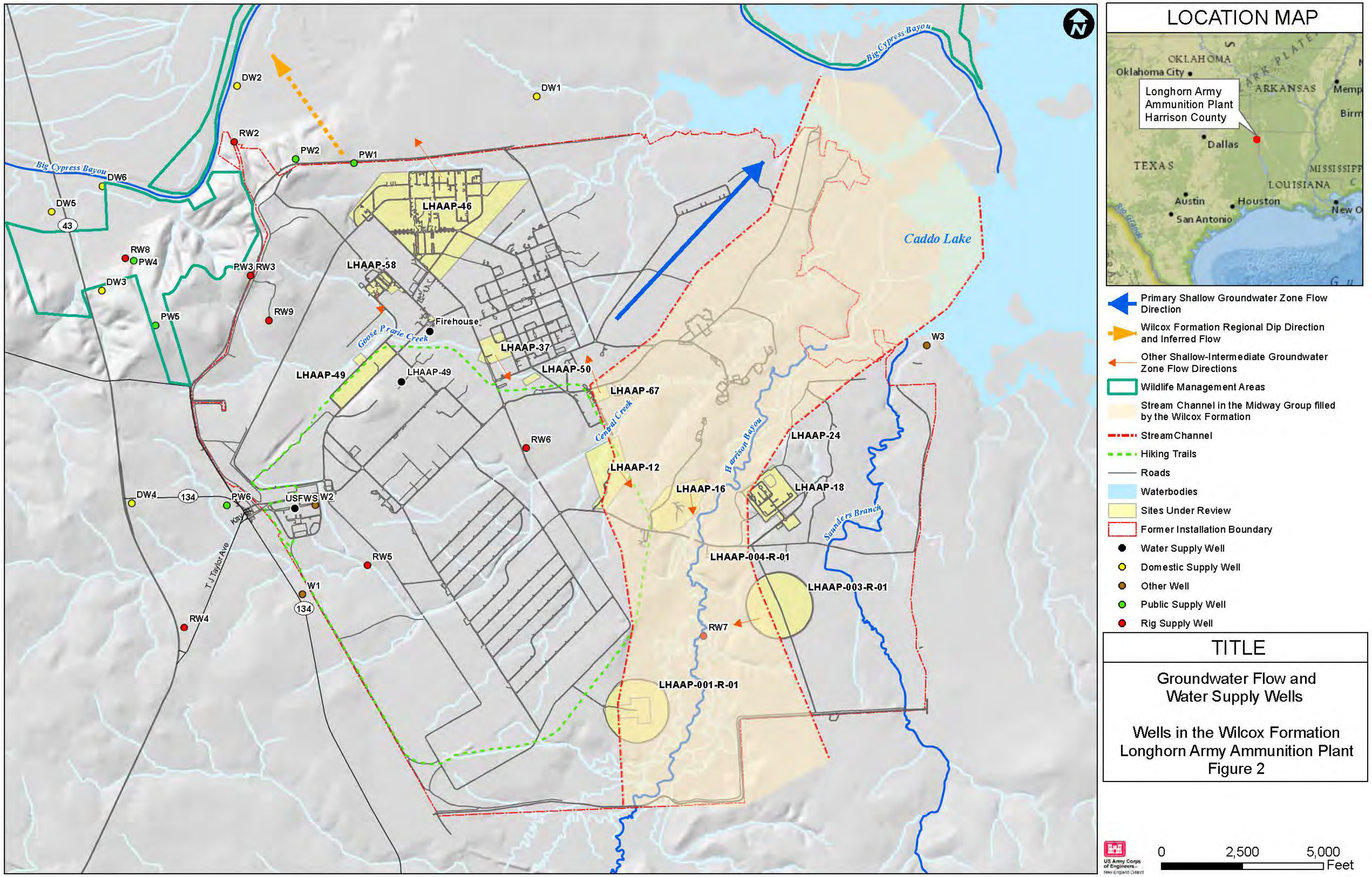


Figure 2. Groundwater flow directions and water supply wells within the Wilcox Formation, the major aquifer underlying the site, and the inferred direction of groundwater flow along depositional dip (LHAAP, 2018a, TCEQ, 2018, TWDB, 2018, US Army, 2016, AECOM, 2013a, USGS, 2011, 2006, Landmark Consultants, 2015a, b, c, 2014, b, 2011a, b, 2006, EODT, 2009).

Regional and local groundwater data show LHAAP area groundwater flow direction within the Quaternary deposits is northeast and east toward Caddo Lake (Fryar, 2003). Local flow directions change more than 90° to the southeast or northwest during high groundwater conditions (see section 2.2.3 and peak discharge/gage heights in Figure 4). The terrace deposits and younger stream channel deposits form perched-on-perched aquifer systems with small, seasonal yields and are not regulated aquifers. Water levels from these perched systems may introduce error when interpreting local and regional groundwater flow directions. Contaminant distribution data within the suggest concentrations are stable or reducing in the Quaternary terrace deposits.

2.3.3 Regional and Local Surface Water Hydrology

Caddo Lake serves as the primary source of drinking water for several surrounding communities (e.g., Shreveport, LA) and provides recreational opportunities and lakeshore residential areas. The lake is less than 10 feet in depth on the Texas side (Ensminger, 1999). Due to the uncertainty regarding the extent and integrity of the Yoakum Shale and Big Shale units under Caddo Lake, it is not clear how much groundwater discharge it receives from the lower and middle Wilcox formation, and where it occurs.

Big Cypress Creek is recharged during low flow conditions from the Wilcox Formation (Speer and others, 1968) (Figure 3). Its seasonal low flow/low staff gage periods (base flow or low groundwater conditions) show the region had higher base flow elevations in the fourth five-year review period compared to the 2013 five-year review period (Figure 4) (USGS, 2019, 2018). Increased base flow rates combined with more recharge than in the 2013 five-year review period (below normal discharge occurred between 2011 and 2014) caused groundwater flow conditions to change 90-180 degrees from the regional northeast flow direction (Figure 2, Figure 4). The increased recharge may have contributed to increased volume of water treated at the groundwater treatment plant supporting LHAAP-16 and LHAAP-18/24. This recharge is locally reduced or eliminated where Quaternary deposits or regional shale units underlie the stream channel (Kreitler and others, 1980). Unusually high flow rates shown in Figure 4 are from Gulf Coast storm remnants.

Streamflow conditions during the fourth five-year review period are similar to those in the 2008 five-year review period and when many of the evaluated site's RODs were signed (Figure 4). The Army completed base-wide ecological risk assessment (BERA) field sampling at the end of a dry period similar to those observed during the fourth five-year review period (Figure 4) (Shaw, 2007d). Based upon these findings, ecological risk findings at the time of this Five-Year Review would be equivalent to or less than the findings of risk the site-wide BERA in approved in 2008. The ecological risk evaluation is a site-wide finding and is not applicable at the area of concern (AOC) level.

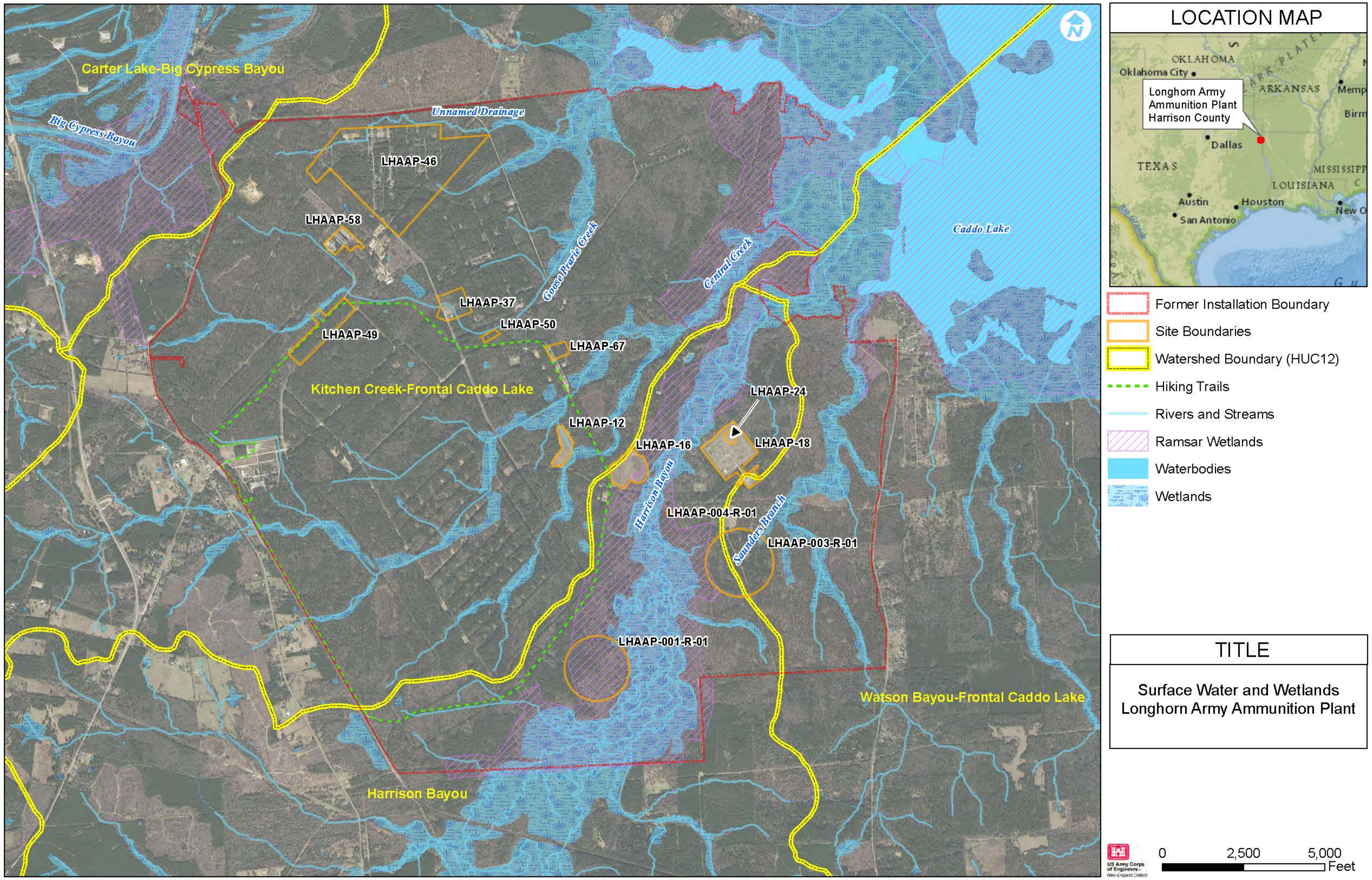


Figure 3. **Surface water features, wetlands, and watersheds within and near LHAAP (LHAAP, 2018a, US Army, 2016, TNRIS, 2015, USFWS, 2011, USGS, 2011, Landmark Consultants, 2015a, b, c, 2014, b, 2011a, b, 2006, EODT, 2009).**

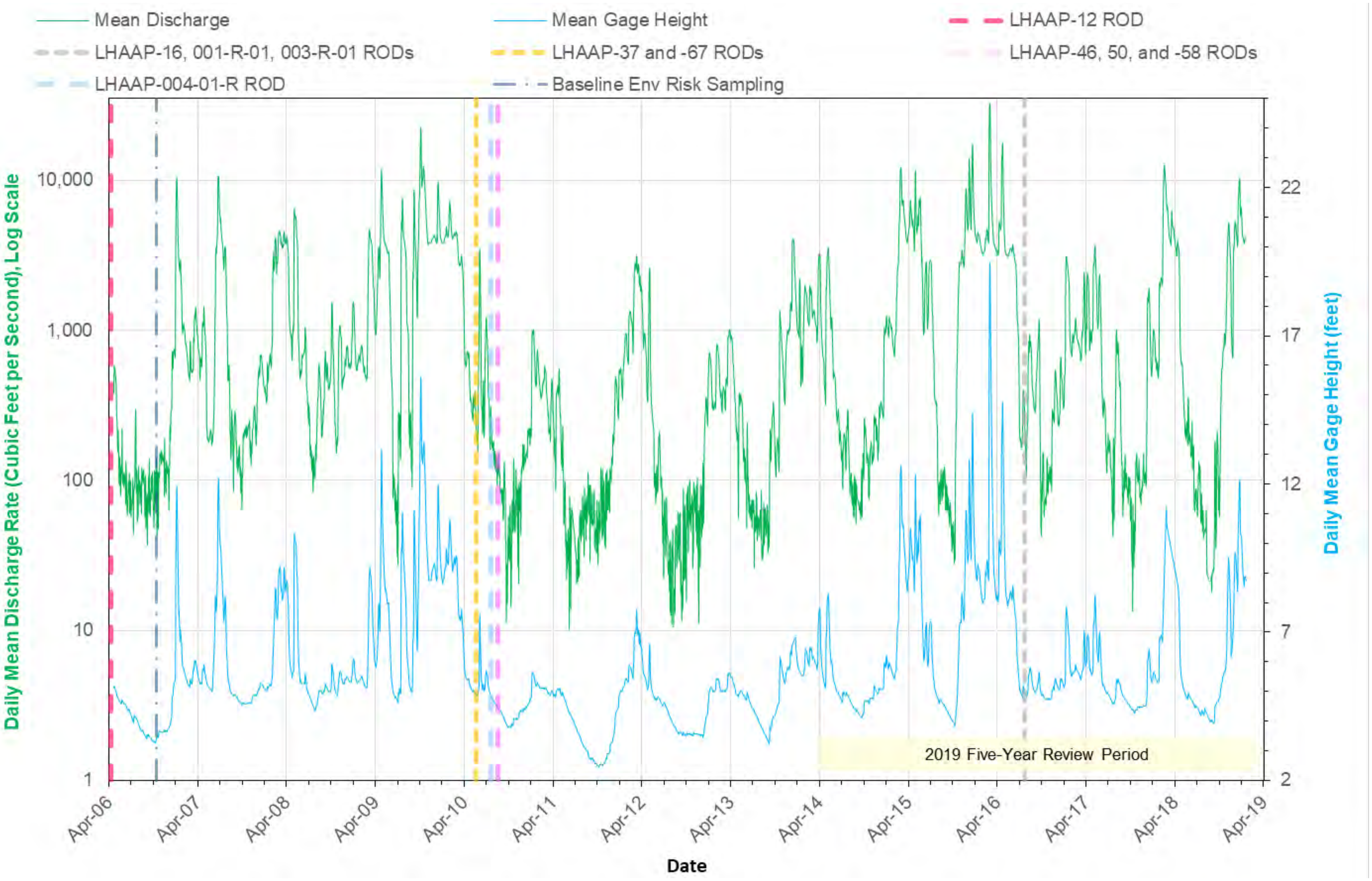


Figure 4. Big Cyprus Creek mean flow and mean gage height, located 8 miles northwest of LHAAP (USGS, 2019), with evaluated site's ROD and baseline environmental risk assessment sampling dates (US Army, 2016, 2010a-f, 2006, 1995a, b).

2.4 Land and Resource Use

2.4.1 Land Use

LHAAP has been an industrial facility since 1942. Significant production activities continued until the facility was determined to be in excess of the Army's needs in 1997. The plant area is now inactive. Approximately two-thirds of the former plant area is administered by the USFWS Caddo Lake Wildlife Refuge, and is largely accessible to the public. Portions of LHAAP within the refuge still requiring remediation or maintenance are surrounded by fences and warning signs (except on the border with Caddo Lake) to preclude unlimited public access. The reasonably foreseeable anticipated future use of the entire facility is as a wildlife refuge.

2.4.2 Groundwater Use

All of the groundwater above the Midway Formation is considered fresh water in Harrison County (Bech and others, 2016). The county is within the Texas Water Development Board's (TWDB) Groundwater Management Area 11, and is not part of a groundwater conservation district (TWDB, 2016). Sabine Uplift area water levels are generally constant over the period of record (+/- 15 ft) to 1989 (Fryar and others, 2003). From 1995-2015, Harrison County water levels fell 0-5 feet for each 5 year period except for 2000-2005, where they were 0-5 ft above those measured in 1995-2000. Total regional decline is less than 50 feet for the combined Carrizo-Wilcox Aquifer unit, but the regional decline near LHAAP is unknown.

Three water supply wells are located on LHAAP (Figure 5). One well near the Fire Station (north of Goose Prairie Creek) is used to supply water to the GWTP.A second well directly south of LHAAP-58 is believed to be inactive. The third well is located immediately adjacent to the former LHAAP administration building, which is currently used as the USFWS headquarters offices for the Caddo Lake Institute and the USFWS. This well is not currently used for drinking at LHAAP although it may supply water for non-potable uses. Two additional wells that previously supplied water to the installation have been plugged and abandoned.

Public, private, and agricultural water supply wells continue to be drilled or deepened on the western and northern borders of LHAAP. Three water supply wells were drilled or modified during the review period, compared to eight in the previous review period (Figure 5). This includes the Town of Karnack deepening its water well during the May 2018 Site Inspection and a new domestic supply well near Big Cyprus Creek. During the last review period, a 342-ft deep livestock well was drilled near the LHAAP eastern boundary; close the northeast-southwest deep channel in the top of the Midway Formation/deep section of the lower Wilcox Formation (Figure 2). Due to the low permeabilities estimated for the Wilcox Formation underlying LHAAP, it is unlikely that pumping wells located west of the installation boundary could affect contaminant distribution. Evaluations on the wells near LHAAP-46 determined that the plume is not affected by these pumping wells. It is unknown if pumping wells located downgradient of LHAAP-18-24 (e.g., Figure 2, W3) have any effect on the middle or lower Wilcox Formation aquifer gradients and flow directions.

Several rig supply wells have been drilled within LHAAP to support local oil and gas well drilling and hydrocarbon recovery (all outside groundwater use restriction areas). Natural gas production wells in the Haynesville Shale (10,000-12,000 ft deep) and Cotton Valley Group (7,500 to 10,000 ft deep) spurred drilling ten hydrocarbon exploration and recovery wells within

LHAAP (RCT, 2018, Van Bersel, 2009, Dyman and Condon, 2006). These wells require a large, steady supply of fresh water for drilling and hydraulic fracture stimulation in an area where a large volume of water can be difficult to secure outside the alluvial valleys (Van Bersel, 2009). A rig supply well supporting a new Haynesville Shale well will produce 1.05*10^6 gallons for drilling one well, and 3.15*10^6 gallons for fracturing in this same well. Rig supply well pumping only occurs during well construction and operation and when economically feasible, but the effects on horizontal or vertical plume migration the lower or middle Wilcox Formation, and any cross connections to the Quaternary terrace deposits where the Yoakum Clay is absent, has not been assessed. Outside of groundwater use restrictions placed by Army on individual environmental sites, there are no provisions in place for regulating construction and operation of new and existing pumping wells (e.g., rig supply wells) located on the Refuge outside of these LUC boundaries.

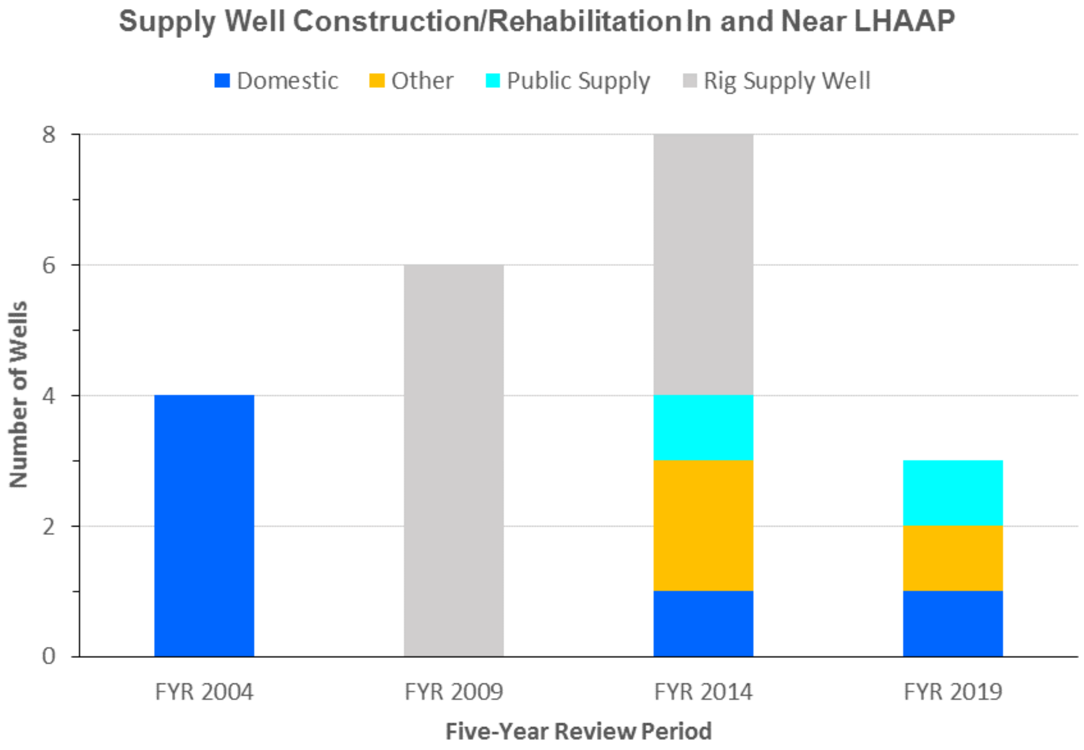


Figure 5. Water supply well construction by type in the current and previous five-year review periods (TCEQ, 2018, TWDB, 2018, RCT, 2018).

2.4.3 Surface Water and Ecology

2.4.3.1 Surface Hydrology

The four natural drainage systems encompass approximately 1,133 acres of the installation (Harrison Bayou (475 acres), Goose Prairie Creek (246 acres), Central Creek (262 acres), and Saunders Branch (150 acres)) and drain north eastwardly to Caddo Lake. HUC12 Watershed boundaries place Harrison Bayou in the Harrison Bayou watershed, Goose Prairie Creek and Central Creek in the Kitchen Creek-Frontal Caddo Lake watershed, and Saunders Branch in the Watson Bayou-Frontal Caddo Lake watershed (Figure 3).

The surface area of Caddo Lake covers approximately 51 square miles and is a part of Big Cypress Bayou. The boundary of the installation along Caddo Lake is determined by the 169.27-foot lake elevation. Saunders Branch flows onto LHAAP near the southeastern corner of the installation and flows northward into Caddo Lake. Approximately 11 percent of the heavily wooded eastern section of the installation is drained by this system. Harrison Bayou enters LHAAP on the southern edge of the installation. The bayou carries 30 percent of the surface drainage of LHAAP and bisects the installation in a northeasterly direction. Central Creek enters LHAAP on its western edge just south of the town of Karnack, Texas and carries approximately 29 percent of the surface drainage from the installation to Caddo Lake. The headwaters of Goose Prairie Creek are located near the northwestern corner of the installation and consist of one larger creek and several smaller tributaries. Goose Prairie Creek flows across the northern edge of the installation and drains approximately 30 percent of LHAAP.

2.4.3.2 Ecology

LHAAP is part of the Cypress Bayou Basin and is within the Pineywoods ecological region of Texas. The Pineywoods is a deep inland extension of the Gulf Coastal Plain that extends into Texas, Louisiana, Arkansas, and Oklahoma. Caddo Lake in East Texas and Louisiana was designated a Wetlands of International Importance in 1993 by the Ramsar Convention on Wetlands and is home to numerous and unique species of fish, birds, and plants (Ramsar Sites Database, 2018) (Figure 3).

Mild temperatures, ample rainfall in the area and small elevation differences across the installation support an abundant and diverse plant community and provide a great diversity of habitats on the installation (Shaw, 2007c). Vegetation at the installation is dominated by mixed pine-hardwood forests that cover gently rolling to hilly terrain. Soil conditions at LHAAP range from moist to wet. The majority of soil is hydric or has hydric inclusions. Soils have good water-holding capacity. In the last decade, rainfall has been less abundant and temperatures higher, resulting in earlier seasonal dry down times and drought conditions during the later month of the summer season and autumn, however, the wetlands still receive enough rain and runoff to have pooled water and surface flow present every spring.

Uplands are broad and mostly flat with a gradation of habitats, from grassland/forbland and shrubland/oil field habitats around developed areas, to moist upland pine forest, mixed forest, temporarily flooded bottomland forest, cypress swamp, and shallow water aquatic habitats in Caddo Lake (Shaw, 2007c). Habitat types include grassland/forbland, shrubland/oil field, developed areas, pine forest, mixed pine/hardwood forest, upland hardwood forest, wetland/bottomland forest, and cypress swamp.

LHAAP supports hundreds of vertebrate species including mammals, birds, fish, amphibians, and reptiles. The site also supports federally listed species, State Listed species, State Species of Concern and State special Features/Natural Communities/Managed areas. According to the Ramsar Convention, “Harrison Bayou is considered a high quality natural area by the TCEQ and a wetland area of international importance (Shaw, 2007c)”. The bottomland area experiences flooding and waterlogged soils, which have prevented logging equipment access and allowed the Bayou to retain much of its integrity and ecological diversity. Harrison Bayou contains several species of oaks, pines and other trees that are generally large. Approximately one-half of Harrison Bayou is considered virgin forest. Photographs, maps, hydric soils information, and field observations indicate that the great majority of Harrison Bayou is jurisdictional wetland (Shaw, 2007c, USACE, 1987).

2.4.3.3 Risk Assessment for the Evaluated Sites

Both human health and ecological risk have been evaluated at LHAAP (US Army, 2016, 2010a-f, 2006, 1995a, b). Human health risk has been evaluated at the AOC level and ecological risk has been evaluated on a side-wide basis. As noted in the Final RODs for AOCs LHAAP-12, LHAAP-16, LHAAP-37, LHAAP-46, LHAAP-49, LHAAP-5-, LHAAP-58, LHAAP-67, LHAAP-001-R, LHAAP-003-R and LHAAP-004, no action is needed for the protection of ecological receptors. The early interim ROD for LHAAP-18/24, which predates the site wide BERA, states that the magnitude of ecological exposure and associated risk estimates are dependent upon further site characterization and will be addressed in the site risk assessment. The BERA, finalized in 2007 (Shaw, 2007c, d) included LHAAP-18/24 in the study area, making the conclusions and outcome from the BERA applicable for this AOC as well.

3.0 FIVE-YEAR REVIEW PROCESS

3.1 Administrative Components

Army Base Realignment and Closure (BRAC) notified members of the Federal and State regulatory agencies of the initiation of the five-year review in the fall of 2017. The USACE Fourth Five-Year Review Team was led by Drew Clemens, PG with member expertise in hydrogeology (Chris Kilbridge, PG), human risk assessment (Cindy Auld), ecological risk assessment (Dr. Cheryl Montgomery), and environmental engineering (Dr. Lily Sehayek).

3.2 Community Involvement

The public notice was published in the Marshall News Messenger on 11 May 2018 (Appendix A). When the Five-Year Review report is finalized, another notice will be published announcing the report is available to the public at the Marshall Public Library (300 South Alamo Boulevard in Marshall, Texas 75670).

3.3 Document Review

3.3.1 Background Documents Review

Site-related documents reviewed as part of Fourth Five-Year Review are listed in Section 17.

Review of applicable or relevant and appropriate requirements (ARAR), Toxicity, and Chemical Characteristics is in Appendix B.

3.3.2 Site Inspections

Representatives of the USEPA, the TCEQ, US Fish and Wildlife Service (USFWS), and/or Bhate Environment & Infrastructure accompanied the USACE Five-Year Review site inspection team, Tulsa District and Army BRAC on its site inspections 22-23 May 2018. Inspection results are discussed with each site, with maps, forms, and photographs presented in Appendix D.

3.3.3 Interviews

Interviews were conducted on site and via email with representatives of the USEPA, the Texas Commission on Environmental Quality (TCEQ), USACE Tulsa District, US Fish and Wildlife Service (USFWS), Restoration Advisory Board (RAB). Interview summaries are included with each site, and the Interview Record forms and memorandums for record are in Appendix E.

4.0 LHAAP-12 LANDFILL 12

The LHAAP-12 Landfill 12 is a capped landfill encompassing approximately 7 acres, and is located in the central portion of LHAAP, approximately 1,700 feet east-northeast of the intersection of Pennington Street and Avenue Q (Figure 6). The site is an open area of grass bounded by heavy timber. Central Creek, which eventually drains into Caddo Lake, is located approximately 500 feet northwest of LHAAP-12. The site was transferred by the Army to the USFWS in 2014 and is being managed as part of the Caddo Lake National Wildlife Refuge.

A stream channel survey conducted in 2004 suggested the shallow groundwater potentiometric surface might be several feet below the bottom of Central Creek during the dry season, making Central Creek a losing stream during low flow conditions (Figure 4). Conversely, groundwater may discharge into Central Creek and Harrison Bayou during high flow/high recharge conditions.

4.1 Site Chronology

Significant site events and dates are in Table 3. No enforcement orders have been issued for the Site.

4.2 History of Contamination

Disposal at the LHAAP-12 landfill began in 1963 (US Army, 2006). The landfill was used intermittently for the disposal of industrial solid waste, possibly containing small quantities of hazardous constituents, generated at LHAAP. Disposal began in the upstream end of a diversion ditch that traversed the site from Central Creek and one of its principal tributaries (Figure 6). By December 1978, a previously undisturbed hillside adjoining the ditch had become another location for waste disposal. The hillside subsequently became the northeast boundary of the site. In the early 1980s, a large area alongside the southeastern margin of the former diversion ditch was cleared for waste disposal and was used for this purpose until closure of the site in 1994.

4.3 Initial Response

No initial response actions occurred at LHAAP-12 beyond CERCLA investigations listed in Table 3.

4.4 Basis for Taking Action

The potential exists for groundwater contaminants to pose an unacceptable human health risk to an industrial worker and to discharge to nearby surface water bodies, which could ultimately affect Caddo Lake (US Army, 2006). The basis for taking action was presence of TCE, cis-1,2-dichloroethene (cis-DCE), and vinyl chloride (VC) in groundwater at concentrations posing an unacceptable risk to an industrial worker.

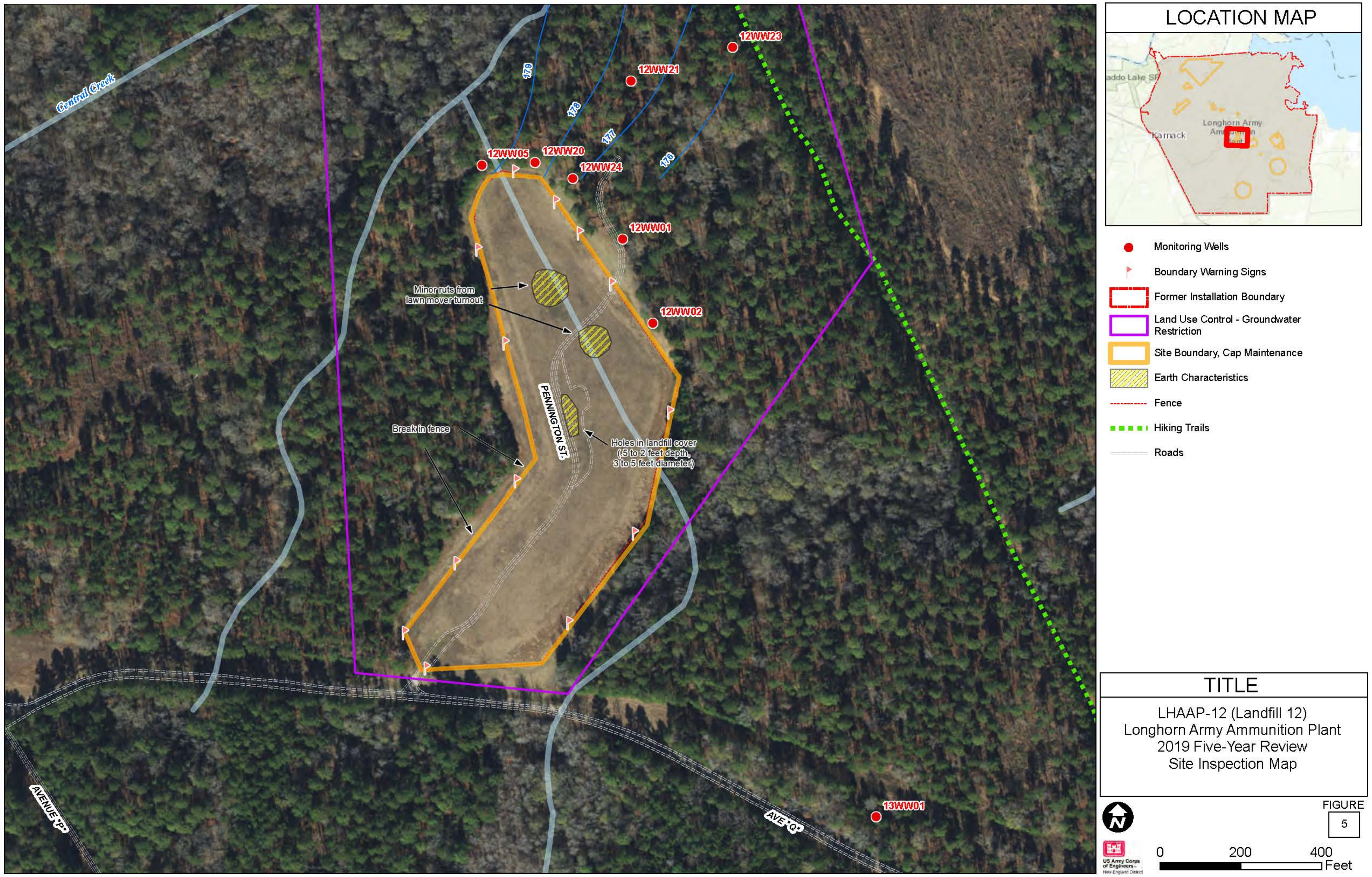


Figure 6. LHAAP-12 site map showing 2018 Site Inspection features and land use controls (LHAAP, 2018a, TNRIS, 2015, USGS, 2011, Landmark Consultants, 2006).

Table 3. LHAAP-12 chronology of site events (AECOM, 2014a, US Army, 2006).

Event	Date
First use of landfill	1963
Land Disposal Study No. 38-26-01014-81. UNITED STATES Army Environmental Hygiene Agency (AEHA) installs and samples four monitoring wells at Active Landfill (Site 12)	1980
Environmental Protection Systems (EPS) installs two monitoring wells and samples all six wells	1982
Installation Resource Conservation and Recovery Act (RCRA) Facility Assessment (RFA) reviewed all Sites at LHAAP and assigned numbers currently in use to identify them	April 8, 1988
LHAAP placed on NPL	August 29, 1990
LHAAP, Texas Water Commission (later Texas Natural Resource Conservation Commission [TNRCC] and now Texas Commission on Environmental Quality [TCEQ]), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30,1991
RCRA Part B Permit signed.	February, 1992
Phase I Field Investigation installed seven additional monitoring wells and collected soil, sediment, groundwater, and surface water samples	1993
Landfill formally closed	March 1994
Phase II Field Investigation installed five additional monitoring wells and collected soil, sediment, groundwater, and surface water samples	1995
Final Report-LHAAP Installation Restoration Program, Sites 12 and 16 IRA Focused Feasibility Study (FS), recommends cap design for Sites 12 and 16	March 1995
Final ROD for Early IRA at Landfill Sites 12 and 16	September 1995
Final Project Work Plans (WPs), IRA Landfill 12 and 16	June 10, 1996
IRA Construction start date	October 25, 1996
2,000 cubic yards of treated soil placed in landfill	1997
Early IRA Completed (Landfill Cap Construction completed)	October 1997
Landfill Cap Long Term Monitoring (LTM) started	1998
Phase III Field Investigation installed seven monitoring wells and collected soil, sediment, groundwater, and surface water samples	1998
Final Construction Completion Report, IRA, Landfills 12 and 16 Cap Construction, LHAAP	December 1998
Final Remedial Investigation (RI) Report for Site 12, LHAAP (Group 2 Report)	April 2001
Second Quarter Data Summary for Perchlorate Investigation	March 2001
First Five-Year Review for Sites 18 & 24 (BG3/UEP), Site 16 (Old Landfill), and Site 12 (Sanitary Landfill)	August 2002
Final Group 2 Sites Baseline Human Health Risk Assessment (BHHRA) and Screening Ecological Risk Assessment (Sites 12, 17, 18/24, 29, 32, 49, Harrison Bayou, and Caddo Lake)	August 2002
Plant-wide perchlorate investigations are implemented, including sampling at LHAAP-12 (Solutions to Environmental Problems (STEP), 2005)	2002
Screening-Level Ecological Risk Evaluation (SLERA) for Site 12 Soil	September 2004
Final FS, Site 12 Group 2	January 2005
Environmental Site Assessment, Phase I and II Report, Final	February 2005
Addendum to Final FS, Site 12 Group 2 (Revision 2)	March 2005
Final Proposed Plan for Landfill 12 (LHAAP-12). The proposed plan recommends final remedy consisting of monitored natural attenuation (MNA) with Land Use Controls (LUCs) that consist of cap protection provisions and groundwater	March 2005

Event	Date
restrictions.	
Final Plant-wide Perchlorate Investigation for the LHAAP. For perchlorate in groundwater at LHAAP-12, the report recommends monitoring but “no further remedial measures”	April 2005
Final ROD for Landfill 12 (LHAAP-12)	April 2006
Final Remedial Design (RD) Addendum, Landfill 12 (LHAAP-12); document includes Groundwater Monitoring Plan	June 2007
Final Natural Attenuation Evaluation LHAAP-12, 35B(37), and 67	June 2007
Final Operating Properly and Successfully (OPS) Demonstration Report, Landfill 12 (LHAAP-12), LHAAP	September 2007
Final Baseline Ecological Risk Assessment	November 2007
Second Five-Year Review for LHAAP-12, LHAAP-16 and LHAAP-18/24	October 2008
Final ROD for Final Remedy at LHAAP-12	April 2006
Final RD Addendum, LHAAP-12	June 2007
Third Five-Year Review for LHAAP-12, LHAAP-16 and LHAAP-18/24	May 2014
Transferred to USWFS	May 2018

4.5 Remedial Actions

4.5.1 Remedy Selection

The Army issued the Final Interim ROD on September 27, 1995, with the selected interim remedy of capping of the landfill (US Army, 1995a). The Interim ROD’s Remedial Action Objective (RAO)s included:

- Minimize long-term vertical infiltration through the landfill.
- Minimize contaminant transport.

The final ROD for LHAAP-12 was issued by the Army in April 2006 (US Army, 2006), with the selected final remedy being Monitored Natural Attenuation (MNA) and Land Use Controls (LUCs). The RAOs (existing and new) to meet the ROD’s remediation goals (Table 4):

- Protection of human health by preventing human exposure to TCE contaminated groundwater.
- Protection of human health and the environment by reducing the leaching and migration of landfill hazardous substances into the groundwater.
- Protection of human health and the environment by preventing TCE contaminated groundwater from migrating into nearby surface water.

Table 4. LHAPP-12 groundwater chemicals of concern and remedial goals based on the maximum contaminant level (MCL)
(US Army, 2006).

Chemical	Remedial Goal, micrograms per liter (µg/L)	Basis
Trichloroethene	5	MCL
cis—1,2-Dichloroethene	70	MCL
Vinyl chloride	2	MCL

Due to the potential for TCE-contaminated groundwater to migrate, MNA is included as a component in the final remedy and to evaluate the effectiveness of the existing cap and to assure that the plume does not migrate to nearby surface water at levels that may present an unacceptable risk to human health and the environment.

Inspections to confirm no violations of the groundwater use restriction were conducted annually during the review period in 2013 and 2014 by Army and after transfer in 2014, by USFWS in 2015, 2016, and 2017. No use violations were noted during the review period. The landfill caps were inspected annually by Army to comply with cap maintenance LUCs. No violations were noted during the review period, however minor cap repairs were conducted. The annual LUC inspection documentation is presented in Appendix G.

Because the LHAAP-12 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c),42 U.S.C. §9621(c).

4.5.2 Remedy Implementation

Consistent with the IRA ROD and approved design, a multilayer cap was constructed overlying the source area of LHAAP-12 and completed in 1998 (US Army, 2006). The cap consists of a low permeability cover of a sodium bentonite geocomposite liner placed over a foundation soil layer used to provide proper grading of the landfill surfaces. A second low permeability layer consisting of a geosynthetic membrane liner was placed over the sodium bentonite layer. The cap consisted of a soil cover with adequate slopes and a vegetative cover with perimeter berms and drainage swales to control surface drainage. The multilayer cap reduces the potential for vertical migration of contaminants via rainfall infiltration through the landfill. During cap construction, monitoring wells within the landfill limit were plugged and abandoned.

Following cap construction, administrative LUCs were implemented to restrict access and usage to maintain the integrity of the landfill cap. Periodic inspections of the landfill cap have been performed since June 2000, shortly after the official date for cap construction completion (August 31, 1999) (Shaw, 2007a).

The final remedy is currently in the operating phase in accordance with the Remedial Design (RD) completed in June 2007 (Shaw, 2007b). The LUC and maintenance area associated with the landfill cap is approximately seven acres and comprises the landfill cap, extending to the surrounding fence (Figure 6). The LUC area associated with the groundwater use restriction extends beyond the cap area encompassing approximately 46 acres in a downgradient direction toward Central Creek (Figure 3). As part of LUCs, specific measures were implemented to restrict access and limit exposure to contaminated groundwater. These measures include incorporating the LUCs in the Site-wide LUC Management Plan, annual physical inspections, and cap maintenance. The site was transferred to the USFWS in March 2014. The Army may, as a condition of property transfer, require the transferee to assume responsibility for various implementation actions, but will retain responsibility for remedy integrity. The LUCs will remain in effect until the Army and USEPA agree and TCEQ concurs that contaminant concentrations at the site have been reduced to levels that allow for unlimited use and unrestricted exposure and the remedy is complete.

The LUC boundary was surveyed in 2006, defining the area restricting groundwater use to environmental purposes (Landmark Consultants, 2006). The Texas Department of Licensing and Regulation was notified of the groundwater restriction (US Army, 2007).

The groundwater-monitoring network consists of three on-site monitoring wells (12WW20, 12WW21, and 12WW24) and two downgradient compliance wells (12WW22 and 12WW23) (Figure 6). These wells are screened in the Shallow Groundwater Zone. Groundwater monitoring and MNA evaluation are being conducted following the Final RD Addendum, Landfill 12 (Shaw, 2007b).

4.6 Compliance Monitoring

The LHAAP-12 groundwater monitoring and site inspection (SI) program consists of annual SIs, annual groundwater monitoring. The Army inspects all land use restrictions and controls specified in the ROD (such as in conjunction with mowing which is completed at least annually) to determine the effectiveness and compliance with these restrictions and controls. The inspections include determining any violations of the LUCs, as well as indicators of cap degradation, maintenance issues, trespass, and incompatible use. Inspection activities include the following:

- Visual inspection of the cap and the vegetative cover;
- Visual inspection of monitoring wells and signage;
- Visual inspection to ensure that no water wells have been installed and land use/groundwater use remain consistent with that mandated by the Final ROD;
- Completion of visual inspection activities by walking through the site. During the inspection, field notes, a checklist, and a photographic log are maintained to document observed conditions.

Damage or irregularities to the wellheads are reported at the time they are identified and recorded in field notes or on sampling forms, and repaired or scheduled for repair when needed. Groundwater sampling is completed annually. Specific results from each inspection are documented in the site's Remedial Action Operations Report.

The Army conducts yearly groundwater monitoring to evaluate effectiveness of the cap, track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs.

4.6.1 Operations and Maintenance Costs

The original Operations and Maintenance (O&M) total cost estimate for LHAAP-12 and LHAAP-16, and cost estimate for LHAAP-12 RAO LTM, was $75,000/year (US Army, 1995a). The approximate actual O&M and LTM cost estimates for site LHAAP-12 are presented in Table 5.

Table 5. LHAAP-12 Operations, maintenance and monitoring costs by year through 2017 (USACE, 2018).

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)	Notes
2013	11,197.04	17,972.68	29,169.72	
2014	11,197.04	17,972.68	29,169.72	
2015	11,197.04	14,378.15	25,575.19	
2016	11,197.04	7,189.07	18,386.11	
2017	11,197.04	7,189.07	18,386.11	

4.7 Progress since the 2014 Five-Year Review

This is the fourth five-year review for LHAAP-12.

4.7.1 Protectiveness Statements from the 2014 Review

The Final LHAAP-12 remedial action (cap, LUCs and MNA) currently protects human health and the environment by reducing the leaching and migration of hazardous substances, preventing contaminated groundwater from migrating to surface water, and preventing human exposure to contaminated groundwater. Replacement of 12WW24 and an evaluation of whether expansion of the current monitoring well network and re-evaluation of possible seasonal effect on VOC concentrations and groundwater flow will enhance long-term protectiveness.

4.7.2 Status of Recommendations and Follow-Up Actions from the 2013 Review

All but two issues identified in the 2013 Five-Year Review were resolved during the fourth five-year review period (Table 5).

4.7.3 Status of Other Prior Issues

The Army addressed the last two issues identified in previous Five-Year Reviews during the fourth five-year review period.

Table 6. LHAAP-12's 2014 Five-Year Review Recommendations and Follow-Up Actions addressed by the Army in the fourth five-year review period. All other issues were addressed before the previous five-year review period was signed in May 2014 (AECOM, 2014a).

Issue	Recommendation/ Follow-up Action	Affects Current Protectiveness?	Affects Future Protectiveness?	Action Taken	Date of Action
Water level measurements from current network of five wells might not adequately depict groundwater gradient and flow direction	Add older wells into the water elevation data set for an expanded picture of groundwater gradient and flow direction.	No	Yes	Added older wells into the water elevation data set beginning with the 2014 RAO Report.	October 2014
♦ Well within the plume found dry during December 2012 sampling event. ♦ MNA evaluation is limited to one well within the plume ♦ Possible seasonal effects on VOC concentrations in groundwater and groundwater elevation drop in the plume area	♦ Install well adjacent to the dry well ♦ Re-evaluate the LHAAP-12 MNA Network ♦ Re-evaluate the LHAAP-12 MNA Network	No	Yes	Attempted to install one additional well within the plume ~50 feet downgradient of the well within the plume, however when the DPT result came back clean the team decided not to install well.	August 2014

4.8 Five-year Review Process

4.8.1 Data Review

Data analysis to support the Fourth Five-Year Review is in Appendix C, with the summaries presented below by media. Summary data and statistical tables are in Appendix F.

4.8.1.1 Groundwater

TCE is the only COC encountered in only one MNA monitoring well, 12WW24 (perchlorate was removed from the sampling program after three non-detect events (US Army, 2006)). The Fourth Five-Year Review and the Mann-Kendall analysis indicates a statistically decreasing trend at the 95% confidence level for TCE concentrations in plume center monitoring well 12WW24, located immediately downgradient of Landfill (Figure 7, Plot 4 , and Appendix F). Although the overall trend of TCE concentration decreased between 2006 and 2017, concentrations increased significantly in 2013 after a prolonged drought of 2012, decreasing thereafter (Appendix C and Plot 4). Temporal trend of groundwater elevations and TCE concentrations indicates an inverse relationship (e.g., concentration of TCE increasing with decrease in groundwater elevation and vice versa). The increase in concentration appears to be associated with a shift in groundwater flow regime from the southeast, when the flow toward 12WW24 is from an un-impacted upgradient groundwater, to the east/northeast, when the flow is from the suspected source (capped landfill) toward well 12WW24 and remaining to the east/northeast for a prolonged period. The overall decreasing trend in concentrations of TCE is attributed to dilution/dispersion as well as reductive dechlorination, as is evident by the presence of biodegradation byproducts (cis-1,2-DCE and VC, Appendix C Plot 7).

Reductive dechlorination is taking place at 12WW24. However, the groundwater conditions are not optimal for this decay mechanism as is evident by the low site-specific first-order decay rate of 6.2E-04 per day (Biochlor, March 2002). Restoration times ranging between 19 and 80 years are estimated based on site specific first-order decay rates of 6.2E-04 and 1.5E-04 per day, respectively, and initial concentration of 396 µg/L (e.g., maximum TCE concentration reported in December 2006). Restoration times ranging between 12 and 51 years are estimated based on first-order decay rates of 6.2E-04 per day and 1.5E-04 per day, respectively, and an initial concentration of 83 µg/L, the most recent TCE concentration reported in December 2017. Restoration times estimated based on the most recent TCE concentration reported in December 2017 are in line with ROD’s restoration time range of 23 to 261 years expected for MNA (US Army, 2006).

The decreasing temporal trend in contaminant concentrations combined with the lack of detected VOCs in adjacent wells provide evidence that the plume is stable where delineated and natural attenuation is occurring, resulting in an overall decrease in TCE concentration in groundwater over time. The presence of cis-1,2-DCE and VC in this well since December 2006 also indicates that biodegradation has been occurring. However, the extent of the plume to the southeast is not delineated. The groundwater flow regime in the ROD and in subsequent RA(O) is predominantly to the east/northeast with occasional shift to the southeast. Investigation conducted as a result of the 2013 Five-Year Review indicates that groundwater flow to the southeast can take place over extended periods including the winter, spring and early summer and, at times portions of the fall as well.

In accordance with DoD Policy Memorandum, 22 Aug 2016, "Revised Site Management Procedures -Update to DoD Manual 4715.20" on procedures for addressing emerging contaminants at Defense Environmental Restoration Program (DERP) sites, the Army will continue to sample for 1,4-dioxane during Five-Year Reviews. However, the ROD and remedy will not be amended until it is shown that the emerging contaminant presents an unacceptable risk. For the fourth five-year review period, the maximum detection at LHAAP-12 was 20.5 µg/L (Table 6) and the applicable clean-up goal is the Texas Risk Reduction Rule Groundwater-Industrial (GW-Ind) concentration of 26 µg/L. So, no detections greater than the clean-up goal were observed during this five-year review period. Therefore, a ROD amendment does not need to be considered. Sampling will continue to support future five-year reviews.

Table 7. 1,4-Dioxane in shallow LHAAP-12 groundwater in µg/L (USAEC, 2018). Blank-no sample collected, J-estimated, <1U-not detected above the 1 µg/L Reporting Limit.

Location ID	2013	2015	2017
12WW01	8.26 J	8.14	
12WW24	19.2 J	20.5	4.8
12WW20		1.02 J	1.7
12WW21		< 1 U	1.6
12WW23		<1 U	

4.8.1.2 Surface Water

Surface water sampling is not conducted in Central Creek or the surface water feature 200 feet northwest of 12 WW22 (Figure 3, Figure 7 through Figure 9). A channel topography survey conducted in 2004 (USACE, 2006) suggested Central Creek would not receive groundwater or be a losing stream or have no water during low flow conditions (e.g., August through October on Figure 4). Groundwater discharge into Central Creek, or gaining stream conditions, are possible during high flow conditions (e.g., March through May periods on Figure 4).

4.8.2 Site Inspection

The site inspection was conducted on 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary (Figure 6). Gates and signage are in good condition.

The site inspection identified the following issue: Well 12WW-22 was reported under water.

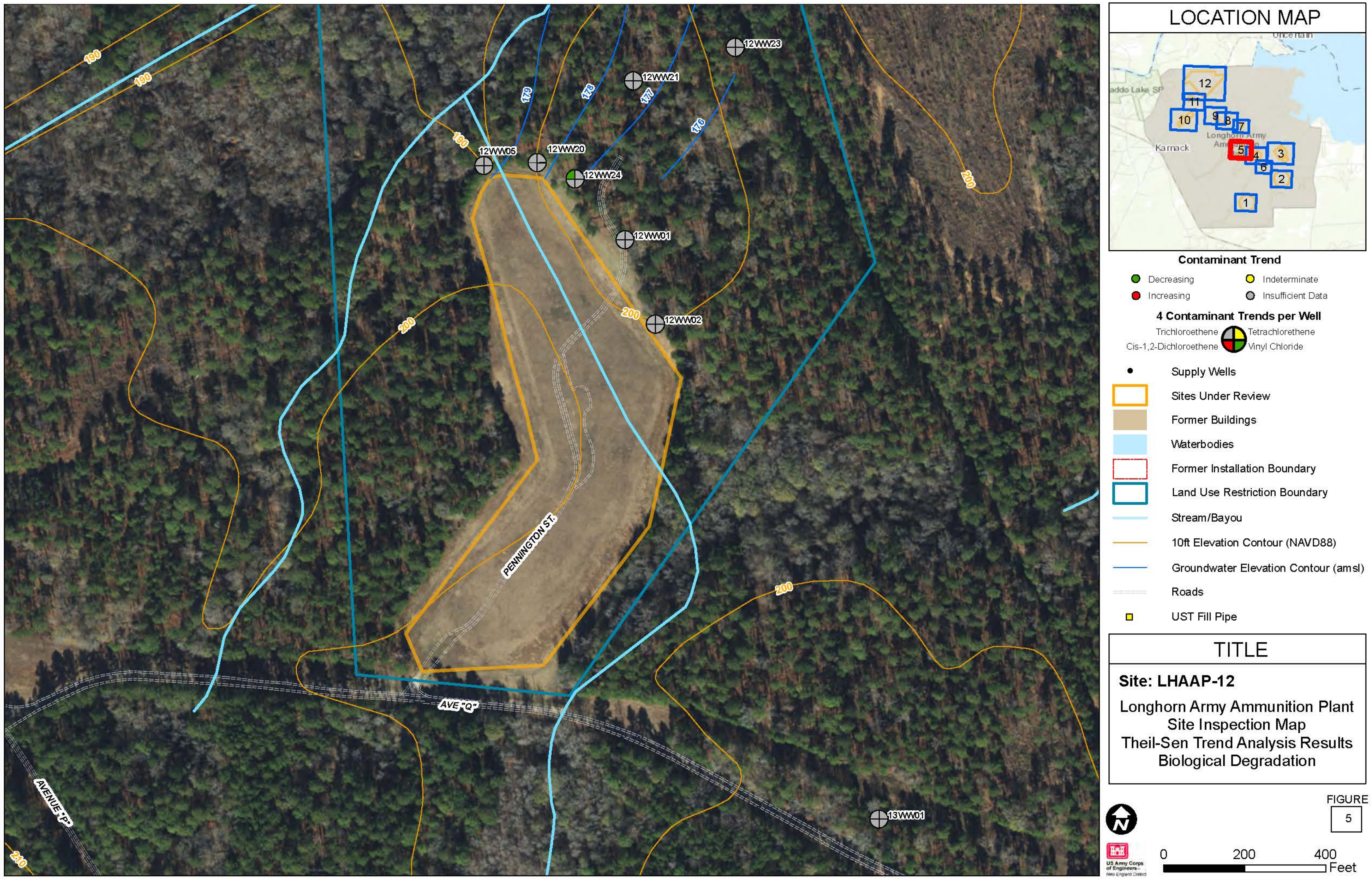


Figure 7. LHAAP-12 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006, Landmark Consultants, 2006).

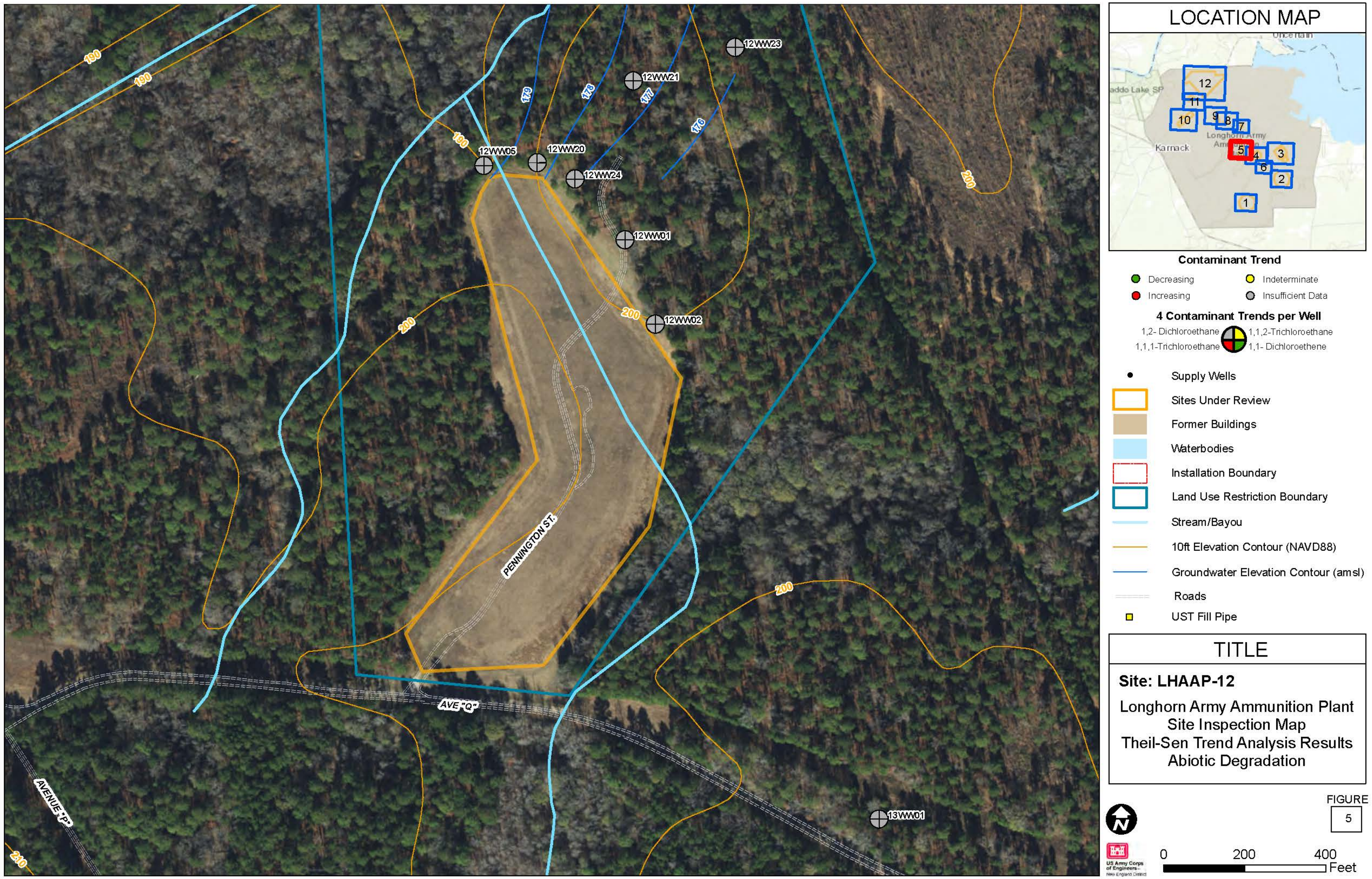


Figure 8. LHAAP-12 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006, Landmark Consultants, 2006).

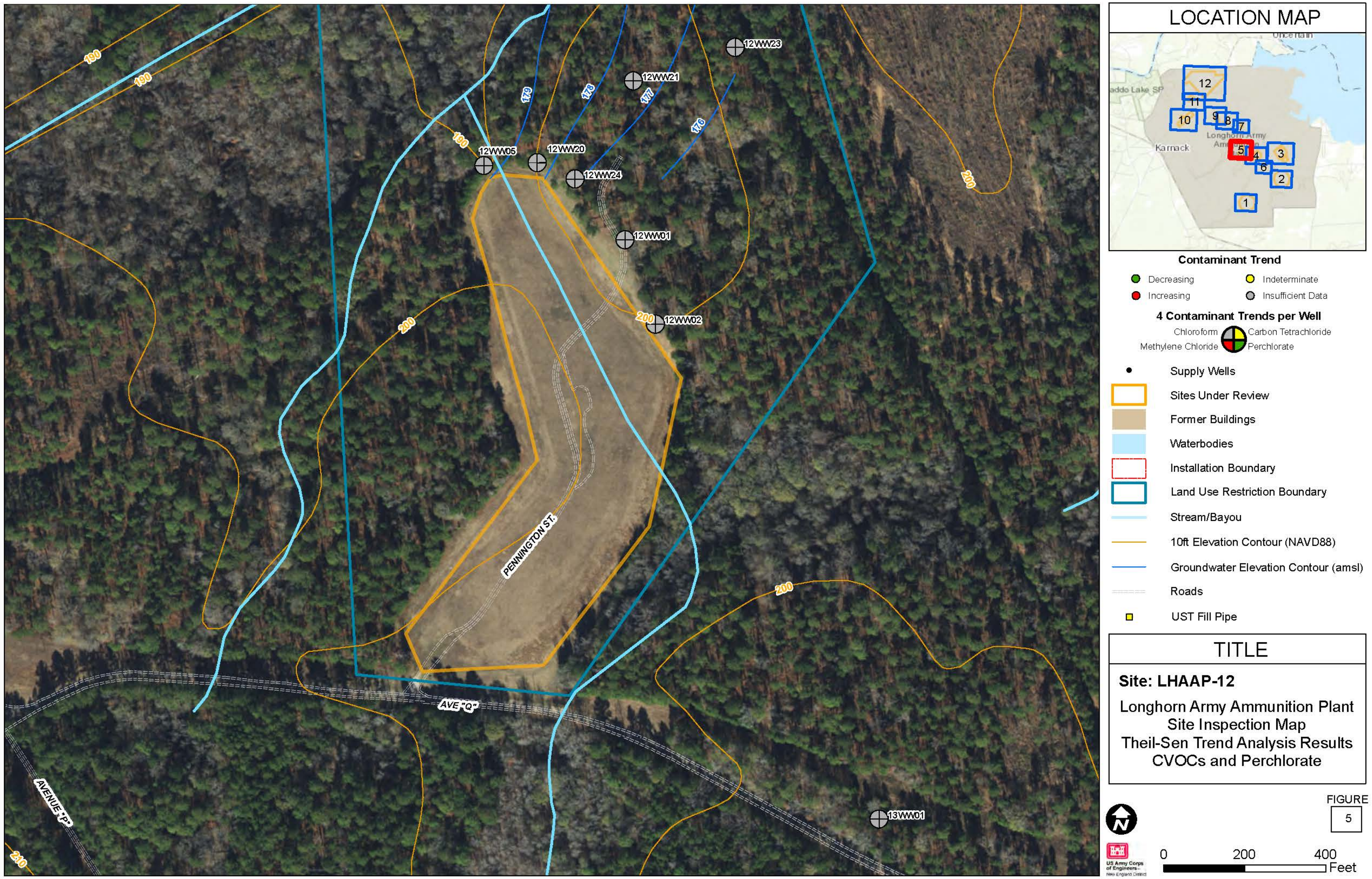


Figure 9. LHAAP-12 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006, Landmark Consultants, 2006).

4.8.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 five-year review period. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

One site-specific issue was raised by USEPA:

1,4-dioxane found on sites with existing RODs. Existing RODs before the 2011 dispute have industrial drinking water levels for contaminants without an MCL. Pre-dispute ROD Sites 35A (58) and Site 12 have found 1,4-dioxane as a new contaminant. The Army has initially indicated that because 1,4-dioxane has no MCL they will require an industrial drinking water standard instead of a residential one.

4.9 Technical Assessment

4.9.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (EPA, 2001):
Question A:Is the remedy functioning as intended by the decision document?

Yes. LUCs are in place and functioning as intended, for the landfill cap and site access controls continue to be well maintained, and the groundwater use restriction is followed. The MNA remedy appears to be functioning as intended along the COC plume, oriented to the northeast/east, as defined by the current monitoring network.

The available information indicates that the TCE plume footprint is stable and limited to one well, 12WW24, and that MNA's restoration times are within the period anticipated in the ROD.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced. In addition, emerging contaminant 1,4-dioxane analytical results collected during this five-year review period did not demonstrate an exceedance of the Texas Risk Reduction Rule Industrial Groundwater Medium Specific Concentration of 26 ug/L (Table 6).

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

4.9.2 Summary of the Technical Assessment

Land use controls (LUCs) are in place and functioning as intended, for the cap and site access controls continue to be well maintained and the groundwater use restriction is followed. The MNA remedy appears to be functioning as intended along the northeast-trending COC plume, as defined by the current monitoring network. Although the remedy is currently effective, to assure future protectiveness, the network requires an additional well to the southeast.

4.10 Issues

This Five-Year Review identified one issue listed in Table 7 below.

Table 8. LHAAP-12 issues identified in the Fourth Five-Year Review.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
Changes in groundwater flow direction result in contaminant migration outside the current MNA monitoring network.	No	Yes

4.11 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 8. Other Findings are noted below.

Table 9. LHAAP-12 Recommendations and Follow-up Actions.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
Changes in groundwater flow direction result in contaminant migration outside the current MNA monitoring network.	Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast.	US Army	USEPA & TCEQ	Sep 2020	No	Yes

4.11.1 Other Findings

- Identify the coordinates and dimensions of settlement, burrows, and minor erosion on the annual report's maps to allow problem identification.
- Verify well 12WW22 top of casing relative to surface water elevation. If near or under water may limit access or potentially compromise water quality results. Modify or abandon 12WW22.

4.12 Protectiveness Statement

The LHAAP-12 remedy currently protects human health and the environment because the landfill cap is well maintained, LUCs are in place and long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness: Establish a well network that captures seasonal and spatial variations in COC-impacted groundwater flow direction, by adding a well to the southeast.

5.0 LHAAP-16 OLD LANDFILL

LHAAP-16, a capped landfill, is located in the south-central portion of LHAAP and covers an area of approximately 20 acres (Figure 10) (US Army, 2016). Harrison Bayou runs along the northeastern edge of LHAAP-16. The landfill was established in the 1940s and was used for the disposal of solid and industrial wastes until the 1980s when disposal activities were terminated.

5.1 Site Chronology

Significant site events and dates are in Table 9. No enforcement orders have been issued for the Site.

Table 10. LHAAP-16 chronology of site events (US Army, 2016, 2010, AECOM, 2017e, 2014a).

Event	Date
Land Disposal Study No. 38-26-0104, LHAAP. AEHA installed and sampled three monitoring wells at Old Landfill (Site 16)	1980
EPS installed one monitoring well (MW-122) and collected groundwater and soil samples.	1987
RFA reviewed all sites at LHAAP and assigned numbers currently in use to identify them.	April 8,1988
LHAAP placed on NPL	August 29, 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30,1991
RCRA Part B Permit signed.	February, 1992
Phase I Field Investigation installed eleven monitoring wells, seven soil borings and collected sediment, groundwater, and surface water samples	1993
Phase II Field Investigation installed seven monitoring wells, drilled ten soil borings, and collected twenty-one Geoprobe samples	1995
USACE begins quarterly sampling of surface water	1995
Final Report-LHAAP Installation Restoration Program, Sites 12 and 16 IRA Focused FS, recommends cap design for Sites 12 and 16	March 1995
Final ROD for Early IRA at Landfill Sites 12 and 16	September 1995
Post-Phase II investigation, collecting surface water and installing two extraction wells and twelve piezometers	August 1995
Two pilot extraction wells and twelve piezometers installed by Sverdrup as part of Groundwater Treatability Study (TS)	February 1996
Final Project WPs, IRA Landfill 12 and 16	June 10, 1996
IRA Construction start date	October 25, 1996
As part of Phase III investigation, installed eight piezometers and twenty monitoring wells. Six more extraction wells were installed under the Accelerated RI to contain contamination seeping from groundwater into Harrison Bayou. Water to be piped to the GWTP. Groundwater, soil, surface, and sediment samples collected.	June 1997
35,840 cubic yards of treated soil placed in landfill from LHAAP-18/24 and capped	1997

Event	Date
Geoprobe and groundwater samples	1998
Landfill Cap LTM started	1998
Final Sampling and Data Results Report, Site 16 Phase III RI/FS and Groundwater TS, LHAAP	December 1998
Final Construction Completion Report, IRA, Landfills 12 and 16 Cap Construction, LHAAP	December 1998
IRA Construction completion date	August 31, 1999
Site 16 Draft RI/FS	August 1999
Final Human Health Risk Assessment	June 2001
Final FS for Site 16	March 2002
Second Quarter Data for Perchlorate Investigation	2002
First Five-Year Review for Sites 18 & 24 (BG3), Site 16 (Old Landfill), and Site 12 (Sanitary Landfill)	August 2002
Final Group 2 Sites Baseline Human Health and Screening Ecological Risk Assessment (Sites 12, 17, 18/24, 29, 32, 49, Harrison Bayou, and Caddo Lake)	August 2002
Three additional monitoring events	2003-2004
Study of enhanced in-situ bioremediation of perchlorate at LHAAP-16	2003-2005
Environmental Site Assessment, Phase I and II Report, Final	February 2005
Final Plant-Wide Perchlorate Investigation for the LHAAP. For the groundwater at LHAAP-16, the report recommends continuation of monitoring and consideration of remedial measures to reduce the levels of perchlorate.	April 2005
Draft Final MNA Plan, LHAAP-16	March 2007
Final Addendum 11 MNA Sampling LHAAP-16, -17, -29, -46, -47, -50, -35A(58), Final Installation-Wide Work Plan	May 2007
Installation and Sampling of Wells near Harrison Bayou	2007
Final Baseline Ecological Risk Assessment	November 2007
Sampling and Analysis for Metals, Perchlorate, and VOCs	2009
Second Five-Year Review Report for LHAAP-12, LHAAP-16 and LHAAP-18/24	October 2008
Final Addendum to Final FS	March 2010
Proposed Plan	September 2010
Third Five-Year Review Report for LHAAP-12, LHAAP-16 and LHAAP-18/24	May 2014
Dispute Resolution	2011-2014
Final ROD, LHAAP-16 Landfill 16	August 2016
Final Remedial Design	January 2017

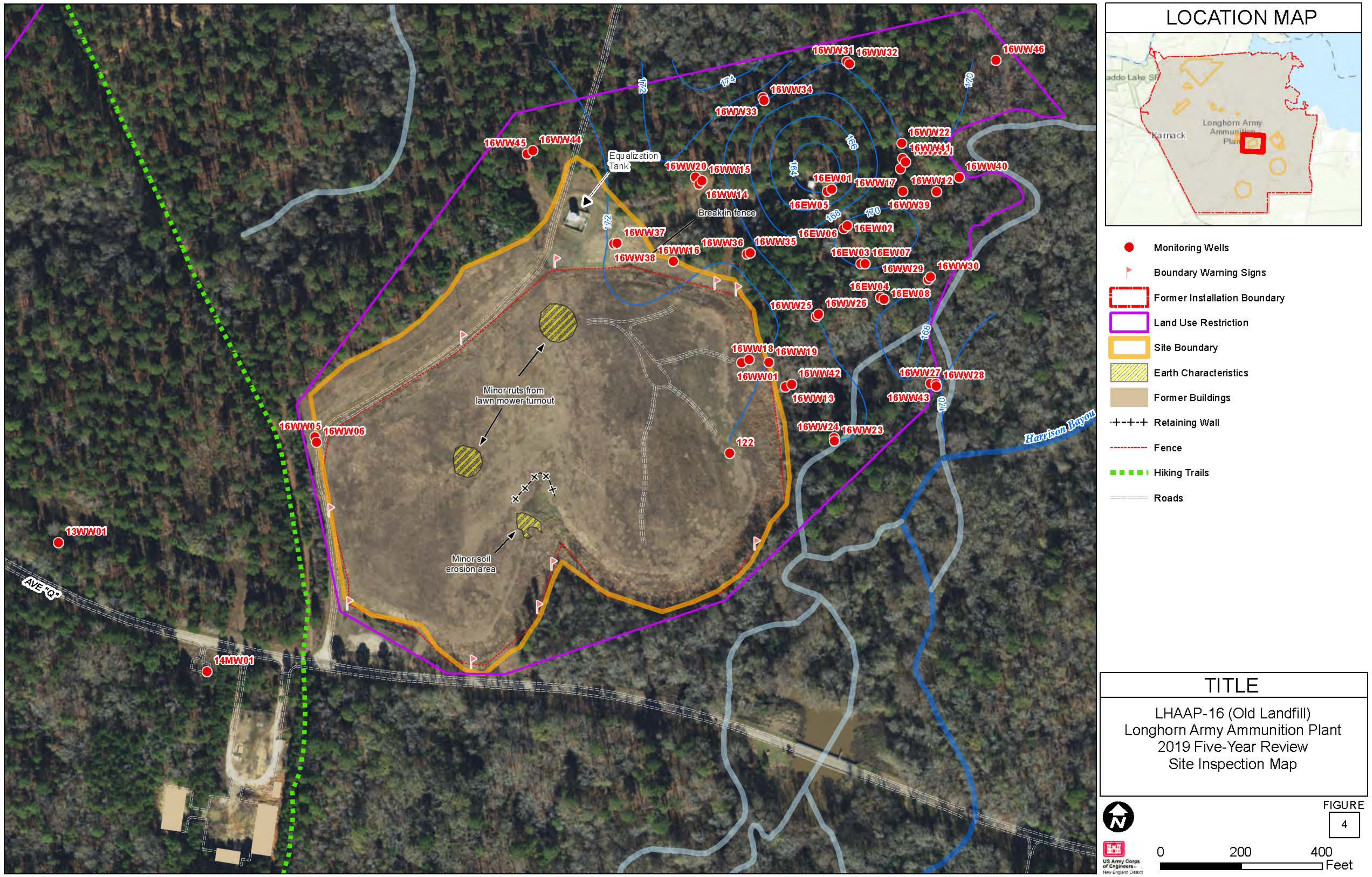


Figure 10. LHAAP-16 site map showing 2018 site inspection features (LHAAP, 2018a, US Army, 2016, TNRIS, 2015, USGS, 2011).

5.2 History of Contamination

LHAAP-16, the Old Landfill was originally used from 1942 to 1944 for the disposal of TNT red water ash (Figure 10). The central section of the site was reportedly used as an all-purpose junkyard for disposal of such materials as substandard TNT, barrels of chemicals, oil, paint, scrap iron, and wood. In the mid to late 1950s, rocket motor casings were reportedly burned and possibly buried at the site. Burn pits, waste storage, and landfill operations continued as waste disposal and treatment activities until sometime in the 1980s. As early as 1980, an AEHA land disposal study recommended changes in disposal practices due to leachate escaping from the landfill. Leachate from the landfill is considered the source of groundwater contamination by VOCs and perchlorate at LHAAP-16 (Shaw, 2008).

5.2.1 Initial Response

No removal actions occurred prior to the Interim ROD (US Army, 1995a).

5.3 Summary of Basis for Taking Action

The basis for taking action was low to moderate concentrations of chlorinated solvents, explosives, and heavy metals in the shallow groundwater, and buried waste with a landfill cover conducive to the infiltration of rainwater and contaminant migration to groundwater.

5.4 Remedial Actions

5.4.1 Remedy Selection

An Early Interim Remedial Action (IRA) ROD (US Army, 1995a) was finalized in September 1995, directing the capping of the landfill with the remedial objectives of minimize long-term vertical infiltration of water through the landfill; and minimize contaminant transport (U.S. Army 1995a). Approximately 35,840 cubic yards of treated soil from LHAAP-18/24 Thermal Desorbers was placed in LHAAP-16 as a grading layer of the cap (Shaw, 2008, Green and Marr, 1990). The cap was completed in 1999, the site was fenced with barbed wire, and warning signs were placed around the landfill. In addition, at the request of the regulatory authorities, but not pursuant to a decision document (e.g., a record of decision or consent order), a groundwater extraction system was voluntarily installed by the US Army in 1996 and 1997 as a treatability study to prevent the groundwater plume from migrating to Harrison Bayou. This extraction system has been operating for over 20 years. The Interim ROD did not have any chemical-specific remedial goals.

Since the 2013 Five-year review, the ROD and remedial design were finalized in 2016 and 2017, respectively (US Army, 2016, AECOM, 2017e). The final selected remedy for LHAAP-16 protects human health and the environment by preventing human exposure to the landfill waste and contaminated groundwater, and preventing groundwater contaminated with chemicals of concern (COC) from migrating into nearby surface water. The RAOs to meet the final ROD's remediation goals (Table 10) are (US Army, 2016):

- Protection of human health and the environment by preventing exposure to landfill contents
- Protection of human health and the environment by reducing leaching and migration of landfill hazardous substances into the groundwater

- Protection of human health by preventing human exposure to the contaminated groundwater
- Protection of human health and the environment by preventing COCs and COC by-products from migrating into Harrison Bayou at levels that cause surface water in Harrison Bayou to exceed surface water criteria
- Return of groundwater to its potential beneficial uses as drinking water, wherever practicable

Table 11. LHAPP-16 final ROD's groundwater chemicals of concern and remedial goals use the federal MCL and the Texas Risk Reduction Program Tier 1 Groundwater Residential Protective Concentration Level (TRRP-GW-PCL) (US Army, 2016)

Chemical	Remedial Goal (µg/L)	Basis
1,2-Dichloroethane	5	MCL
1,1-Dichloroethene	7	MCL
cis—1,2-Dichloroethene	70	MCL
Methylene Chloride	5	MCL
Perchlorate	17	TRRP-GW PCL
1,1,2-Trichloroethane	5	MCL
Trichloroethene	5	MCL
Vinyl chloride	2	MCL
Arsenic	10	MCL
Chromium	100	MCL
Manganese	1,100	TRRP-GW PCL
Nickel	490	TRRP-GW PCL
Thallium	2	MCL

The final ROD's selected remedy elements include (Figure 11):

- Maintenance and repair of the existing landfill cap
- In situ enhanced bioremediation in the most contaminated portion of the Shallow and Intermediate Groundwater Zones
- Installation of biobarriers at Harrison Bayou and at the edge of the landfill
- MNA
- LUCs.

Because the LHAAP-16 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

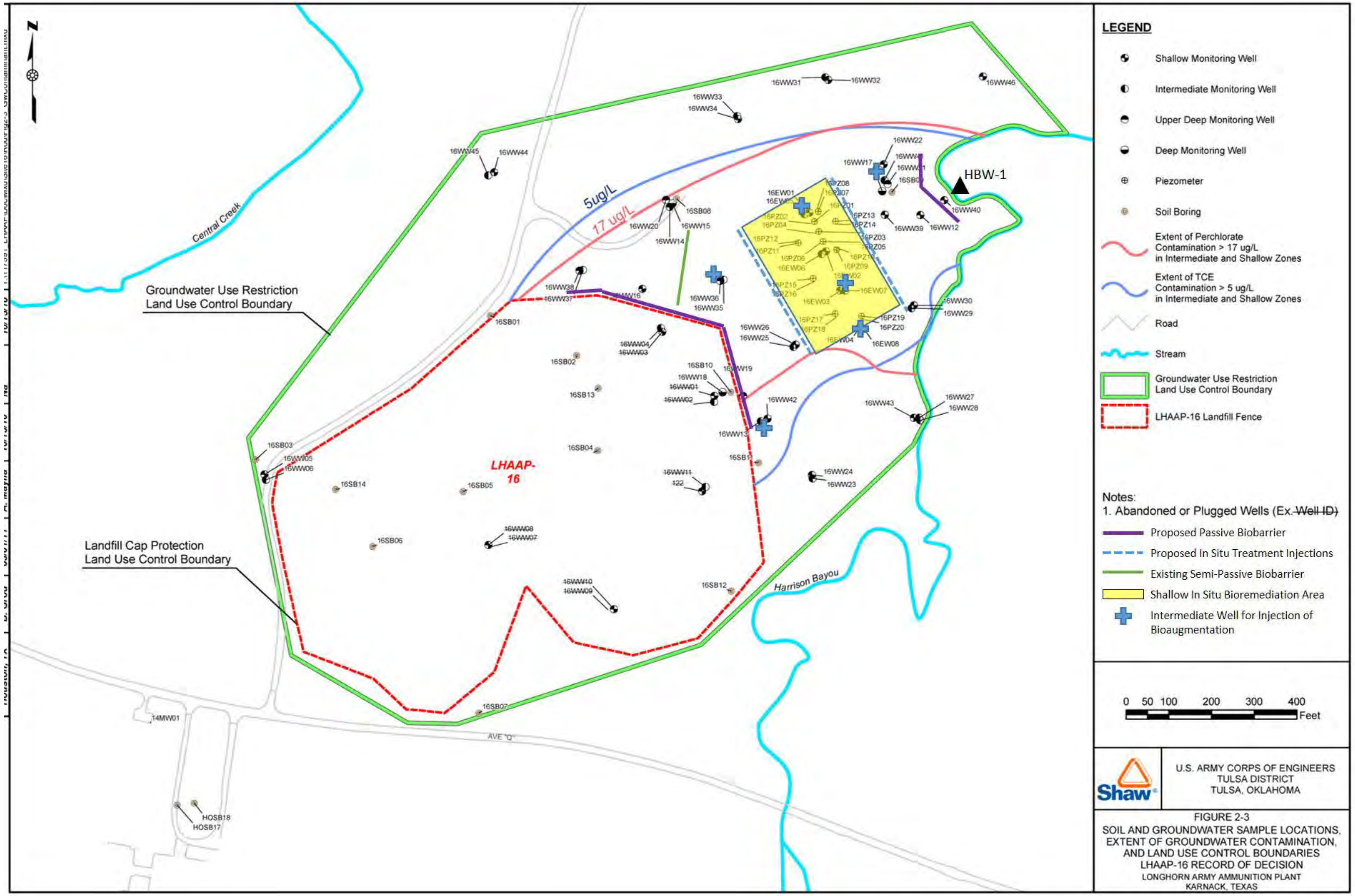


Figure 11. LHAAP-16 final remedial design remedial design with site and land use control boundaries (AECOM, 2017e; 2016b, US Army, 2016).

5.4.2 Remedy Implementation for 1995 IRA

Maintenance/repair of the existing cap instituted during the IRA have been implemented. The IRA included the construction of a landfill cap, now considered a component of the final remedy at LHAAP-16. Construction of the 13-acre multilayer cap was completed in 1999. Since June 2000, the cap has been monitored, maintained, and repaired, as necessary, to ensure its long-term effectiveness (Shaw, 2008).

A groundwater extraction system was voluntarily installed by the Army in 1996 and 1997 as a treatability study (TS). The groundwater extraction system consists of eight wells screened in the Shallow and Intermediate Groundwater Zones and has been in operation since 1996. The original objective of the extraction system was to operate as a temporary (24 month) TS to prevent the COCs from migrating into Harrison Bayou (Figure 11). The extraction wells were installed as four pairs (“nests”), each consisting of a shallow well (wells 16EW01-16EW04) installed to a depth of approximately 35 feet and screened in the shallow saturated zone, and an intermediate well (wells 16EW05-16EW08) installed to a depth of approximately 55 feet and screened in the intermediate saturated zone. These extraction wells are located in the most contaminated portion of the Shallow and Intermediate Groundwater Zones. Although the extraction wells were designed for an optimum combined flow rate of 8 gpm, historically they have produced a combined average total of about 2 gpm (Jacobs, 2000).

This groundwater extraction system was not part of the 1995 IRA and is not a component of the final remedy. Based on the Draft Final Remedial Design (Bhate, 2017), the existing Shallow Zone extraction system will be shut down prior to implementation of the final remedy. The existing Intermediate Zone extraction wells will continue to be pumped during implementation of the ISB to recirculate the amendment, and then will be shut down immediately after injection is complete to prevent extraction of the injected substrate.

5.5 Compliance Monitoring

Groundwater monitoring is conducted in accordance with the Sampling and Analysis Plan (SAP) Groundwater Treatment Plant and Well Fields (AECOM, 2017c). Groundwater monitoring consists of monthly water levels and annual extraction well sampling (16EW01-16EW-08). Samples are analyzed for VOCs, perchlorate, and chloride. In addition, groundwater elevations are measured from twenty piezometers. Monitoring data are uploaded in the project database, as available.

The Army performs annual inspections including determining indications of any unauthorized access through the landfill fence, indicators of cap degradation, maintenance issues, trespass, and incompatible use. The final remedy LUCs will be finalized and recorded in the county with production of the Remedial Action Completion Report (RACR).

Landfill signage inspection and repair and cap maintenance are routinely performed at LHAAP-16 in conjunction with the O&M activities at LHAAP-18/24. As part of the landfill inspections, wells are visually inspected during sampling activities and mowing, weeding, and brush clearing activities are completed. This information is reported in monthly data packages and quarterly GWTP reports that were completed throughout the review period. The extraction system is not part of the IRA but acts to enhance the effectiveness of the cap in controlling migration of contaminated groundwater.

Although the final remedy has not yet been fully implemented and, therefore, not the subject of this review, initial notice of the LUCs and preliminary boundaries was provided on December 8, 2016 within 90 days of ROD signature as required by the ROD to federal, state, and local officials including: Senators and Congressman, State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents and Boards of Directors, as well as the Caddo Lake NWR manager, the future transferee of the property.

5.6 System Operations and Maintenance

The primary O&M activities for the landfill cap are as follows:

- Maintain the signs and mow the associated areas
- Inspect the cap and perform repairs as required

The costs for O&M and LTM activities at LHAAP-16, and LHAAP- 18/24 are not subdivided into individual site estimates, thus assessment of individual site costs was not conducted.

5.7 Progress since the 2014 Five-Year Review

This is the fourth five-year review for LHAAP-16.

5.7.1 Protectiveness Statements from the 2014 Review

The IRA remedy at LHAAP-16 currently protects human health and the environment because the cap prevents direct exposure pathway to landfill material, reduces contaminant transport and mass of contaminants in the groundwater. The final remedy documented in the Final ROD inclusive of the IRA cap, in- situ bioremediation/biobarriers, and LUCs such as groundwater use restrictions is expected to be protective of human health and the environment upon completion. In-situ bioremediation/biobarriers in the final remedy will mitigate the potential for contaminants to seep into Harrison Bayou surface water at unacceptable levels.

5.7.2 Status of Recommendations and Follow-Up Actions from the 2014 Review

All but two issues identified in the 2013 Five-Year Review were resolved during the Fourth Five-Year Review period (Table 11).

5.7.3 Status of Other Prior Issues

The second Five-Year Review recommended the piezometer network be assessed, repaired/redeveloped, replaced, or abandoned as part of the final remedy (Shaw, 2008). This and the landfill cap O&M manual preparation will occur after completing monitoring well installation as part of the remedial design implementation (AECOM, 2017e).

Table 12. LHAAP-16's 2014 Five-Year Review Recommendations and Follow-Up Actions addressed by the Army in the fourth five-year review period. All other issues were addressed before the previous Five-Year Review was signed in May 2014 (AECOM, 2014a).

Issue	Recommendation/ Follow-up Action	Affects Current Protectiveness?	Affects Future Protectiveness?	Action Taken	Date of Action
Need separate O&M plan for cap	Prepare O&M Plan for the landfill cap	No	No	O&M Plan documented in the Draft Final Remedial Action Completion Report.	September 2020
Relatively high concentrations of TCE downgradient of the cap were detected at 16EW02 (33,400 µg/L), 16EW03 (31,400 µg/L) and 16EW04 (53,500 µg/L) during December 2012 sampling event, suggesting that a continuing source may be present unless high concentrations of TCE had already migrated to the aquifer prior to capping.	Implement Final Remedy once ROD is approved. The final remedy will address continuing sources.	No	Yes	ROD finalized in 2016. Remedy Implementation underway.	TBD

5.8 Five-year Review Process

5.8.1 Data Review

Data analysis conducted by USACE to support the Fourth Five-Year Review is in Appendix C, with the summaries presented below by remediation system and by media. Summary data and statistical tables are in Appendix F.

5.8.1.1 Groundwater

The extraction system will be shut down in 2019 following installation of in-situ bioremediation injection wells perpendicular to northeast groundwater flow (biobarriers). Monthly groundwater flow directions have been to the southeast since May 2017 (remedial design finalized January 2017).

5.8.1.2 Surface Water

Surface water sampling on Harrison Bayou is not a requirement of the IRA. The Army currently samples Harrison Bayou quarterly for perchlorate, and has had no detections since 2009.

5.8.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater associated with the final remedy is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary. Signage is in good condition. A potentially orphan monitoring well with a rusted protective casing located near the 16WW14/15/20 cluster was observed during the site inspection.

5.8.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program has improved since the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.
The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

5.9 Technical Assessment

5.9.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes. The multilayer cap component of the Interim Remedial Action (IRA) is functioning to meet the objectives of the IRA. Requirements of the Interim ROD include warning signage and cap inspection, maintenance and repair. The inspections were conducted annually at a minimum during the review period. No major remedy deficiencies have been identified over the last five years. The only repairs necessary due to deficiencies noted in the inspection was placement of a small amount of soil and erosion control mat and then seeding in the south side of the site on the eastern slope, which was completed on August 15, 2013. The site is mowed annually at a minimum prior to the inspections, which includes evaluation of the landfill cap surface, animal burrows, erosion, monitoring wells, and site access. O&M of LHAAP-16 is documented in Section 1.2 of the Quarterly GWTP Report. The cap and signage continue to be maintained. The IRA remedy is enhanced by a treatability study extraction system that serves to reduce contaminant transport as well as the mass of contaminants in the groundwater.

High concentrations of TCE are still present, higher in the Shallow Groundwater Zone (over 10,000 µg/L) than the intermediate groundwater zone (less than 10,000 µg/L) based on annual sampling performed on the eight extraction wells. Perchlorate also remains above the state standard of 17 µg/L in some of the extraction wells. Groundwater flow has not been perpendicular to the extraction system since May 2017.

The final remedy has been selected but is not fully constructed. The final remedy includes a groundwater and surface water program, which is absent from the IRA's program, Therefore, long-term protectiveness cannot be evaluated at this time.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

5.9.2 Summary of the Technical Assessment

The Fourth Five-Year Review concludes the current IRA is meeting short-term protectiveness to minimize vertical infiltration of water through the landfill due to the presence of the multilayer cap installed in 1998, and to a lesser extent is minimizing the migration of contaminated Shallow and Intermediate Groundwater Zone groundwater to discharge into Harrison Bayou. The IRA remedy is enhanced by a treatability study extraction system that serves to reduce contaminant transport and as well as the mass of contaminants in the groundwater.

5.10 Issues

This Five-Year Review identified one issue listed in Table 13below.

Table 13. LHAAP-16 issues identified in the Fourth Five-Year Review.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
Relatively high concentrations of TCE persist downgradient of the cap, suggesting that a continuing source may be present..	No	Yes

5.11 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 14. Other Findings are noted below.

Table 14. LHAAP-16 Recommendations and Follow-up Actions.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
Relatively high concentrations of TCE persist downgradient of the cap, suggesting that a continuing source may be present.	Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs.	US Army	USEPA & TCEQ	Sep 2020	No	Yes

5.11.1 Other Findings

- Landfill cap inspection results are not located on site inspection maps, so trends in minor maintenance problems cannot be evaluated and addressed before becoming costly issues later. Require all observations noted on the Site Inspection Form to be located on current imagery (e.g., Google Earth).
- The perimeter fence that holds the signs needs to be mended in one place, and the overgrown southwestern part of the fence cut back to show warning signs and reduce fence maintenance costs.
- A potentially orphan monitoring well with a rusted protective casing is located near the 16WW14/15/20 cluster. Assess and repair or abandon well as needed.

- LHAAP-16 O&M costs are included with LHAAP-18/24. Track LHAAP-16 O&M costs separately from LHAAP-18/24.

5.12 Protectiveness Statement

The interim remedy at LHAAP-16 currently protects human health and the environment because the landfill cap prevents unacceptable exposure to landfill contents, and the cap minimizes vertical infiltration of water through the landfill and, augmented by the treatability study extraction system, minimizes contaminant transport. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the remedy selected in the 2016 ROD, consisting of landfill cap maintenance and repair, in situ enhanced bioremediation, biobarriers, MNA, and LUCs. The multi-layer landfill cap is in place, regularly inspected, and maintained, thereby ensuring no unacceptable exposure.

6.0 LHAAP-18/24 BURNING GROUND NO. 3/UNLINED EVAPORATION POND

The LHAAP-18/24 site is a 34.5 acre fenced, cleared area located in the southeastern portion of LHAAP, between Avenue Q to the southeast and Harrison Bayou to the northwest (Figure 12) (AECOM, 2017a). LHAAP-18/24 includes the area formerly designated as Burning Ground No. 3 (BG3, designated LHAAP-18) and the Unlined Evaporation Pond (UEP, designated LHAAP-24). LHAAP-18/24 is mostly vegetated with grass and weeds and is crossed by a number of paved roads. It is situated on a natural topographic high slightly west of the crest of a small topographic divide between Harrison Bayou and Sander's Branch (Figure 3). The site's topography has been greatly altered by operations over the past 40 years. LHAAP-18/24 is mostly level, with more relief near the western corner that contained the Air Curtain Destructor (ACD) until 2003, and near the northern corner that contains the mounded surface of the former UEP (AECOM, 2017a).

The pre-June 2012 CSM described three groundwater zones that were identified jointly by the FFA parties for LHAAP-18/24: shallow, intermediate, and deep (Section 2.2.2, Table 2) (US Army, 1991). The CSM updated on October 18, 2012 recognized only two groundwater zones at LHAAP-18/24: a "Shallow Groundwater Zone" extending from the surface to a depth of approximately 45 ft below ground surface (bgs) (likely Pleistocene terrace deposits), and the middle Wilcox Formation below the Shallow Groundwater Zone. These two units are separated by a clay layer that is present across most of site except in the area to the west and northwest towards Harrison Bayou (AECOM, 2017a) (Figure 13).

6.1 Site Chronology

Significant LHAAP-18/24 site events and dates are in Table 15. No enforcement orders have been issued for the Site.

6.2 History of Contamination

As early as 1955, the former BG3 area was used for the treatment, storage, and disposal of pyrotechnic and combustible solvent wastes by open burning, incineration, evaporation and burial (Figure 14). Waste management units included the UEP, open burning pits, stockpiles of solvent-soaked sawdust, and suspected burial pits. The UEP began operating in 1963 as a holding pond to store wastes from the washout of rocket motor casings, and in 1973 began receiving wash-water containing solvent residues and solids from pyrotechnic material preparation and mixing. These residues and solids commonly contained metallic cations (aluminum, barium, cadmium, chromium, iron, lead, magnesium, sodium, strontium, and zinc), nonmetallic anions (nitrite, nitrate, and phosphate), arsenic, and organic solvents (acetone, ethyl alcohol, methyl ethyl ketone, methylene chloride (MC), TCE, and toluene). Sawdust soaked with MC and other solvents used to clean and scour illuminant mixers, was stockpiled along the southern berm of the UEP, and burned in trenches in the western portion of BG3. An Air Curtain Destructor was built in 1979 in the western corner for burning explosive-contaminated wastes. Use of the burn pits, trenches, and the UEP were all reportedly discontinued in 1984. When groundwater beneath the site was found contaminated, the UEP was closed in 1986 by removing the waste and capping. To accommodate Intermediate-Range Nuclear Forces (INF) Treaty activities, a cage for the open burning of Pershing II missile motors operated from 1989 to 1993 at the INF Pond (Figure 14) (US Army, 1995b).

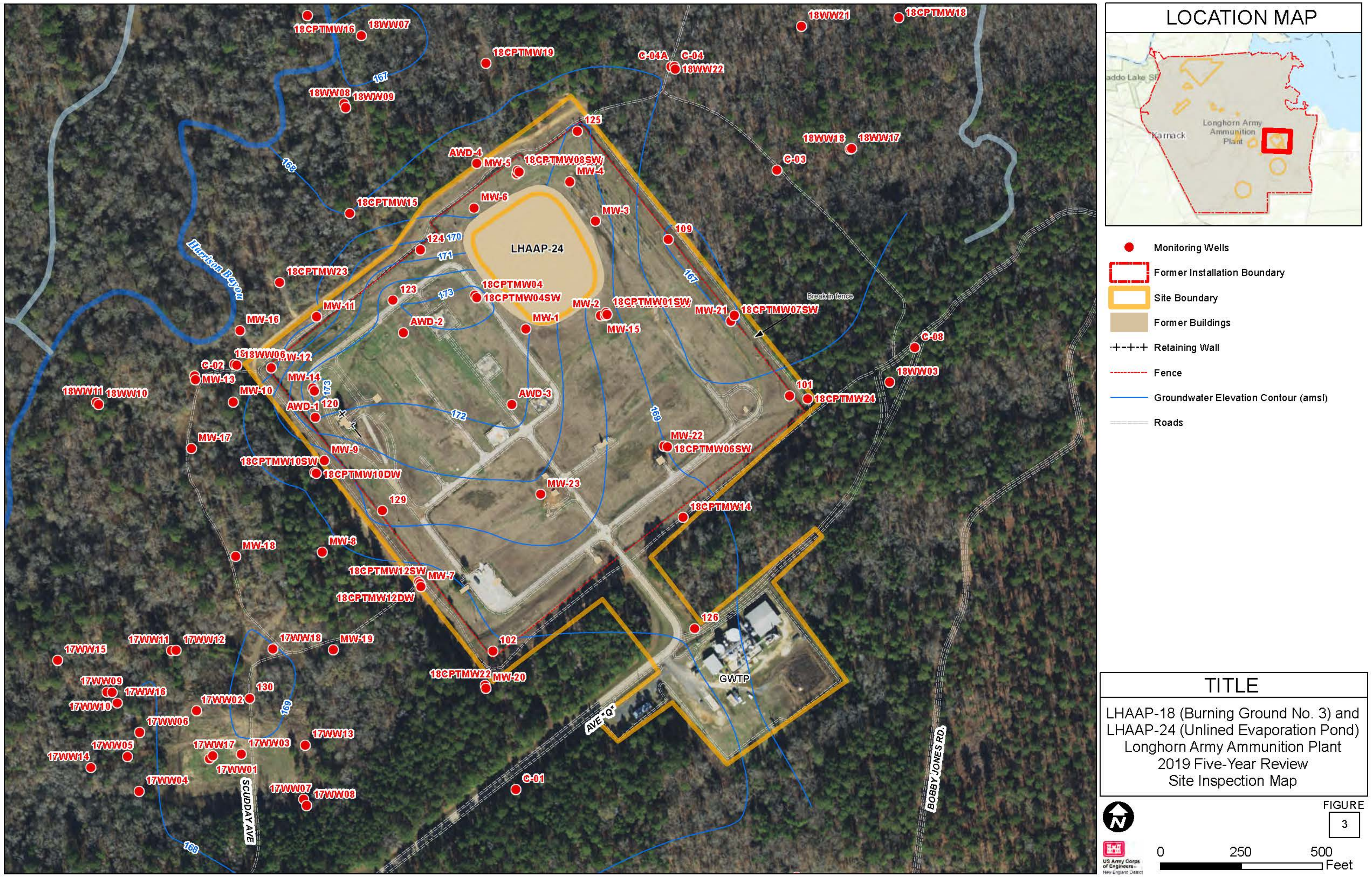


Figure 12. LHAAP-18/24 site map showing 2018 site inspection features (LHAAP, 2018a, TNRIS, 2015, USGS, 2011).

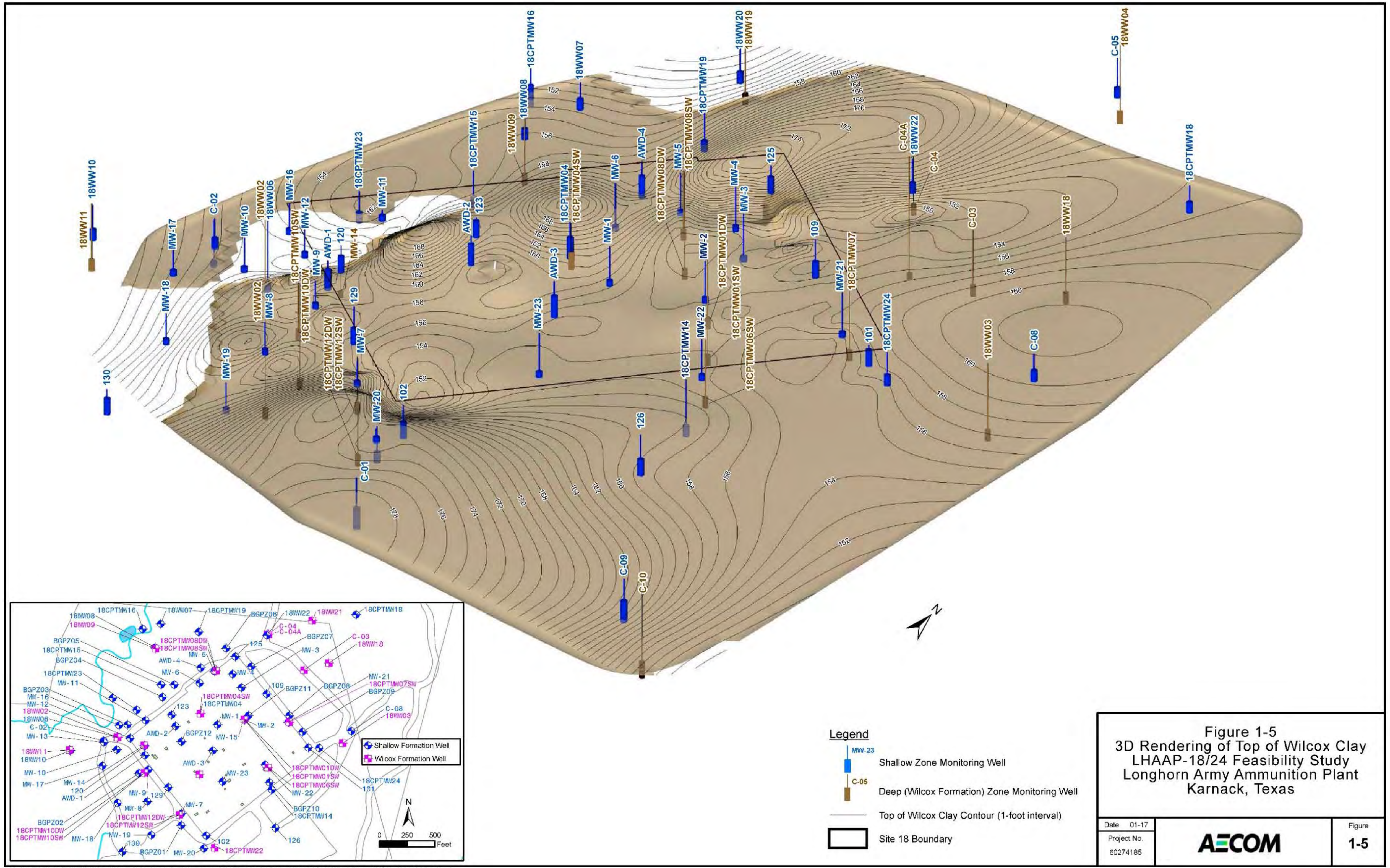


Figure 13. Topography of clay layer (Yoakum Shale) separating the shallow Pleistocene deposits from the deeper middle Wilcox Formation/aquifer (see Section 2.3.2.2) (figure from AECOM, 2017a).

Table 15. LHAAP-18/24 chronology of site events (AECOM, 2017a, 2014a).

Event	Date
BG3 begins operation for disposal of wastes associated with pyrotechnics, explosives, and propellant production.	1955
UEP constructed for disposal of manufacturing plant wastewaters.	1963
AEHA Water Quality Special Study first identifies contamination at the UEP (Site 24) within the boundaries of BG3 (Site 18).	August 2 - 10, 1976
Land Disposal Study No. 38-26-0104-81, LHAAP: AEHA installs thirteen monitoring wells and finds groundwater contamination at UEP (Site 24) in BG3 (Site 18).	January 23 - February 8, 1980
EPS installs nine monitoring wells and samples twenty-two monitoring wells.	1982
Hazardous Waste Management Special Study No. 39-26-147-83, DARCOM Open Burning/Open Detonation Grounds Evaluation.	September 1, 1983
Waste disposal terminated at UEP.	June 1, 1984
EPS collects groundwater samples from three wells.	1987
Closure Report for UEP.	June 1, 1986
RFA reviewed all sites at LHAAP and assigned identification numbers that are currently in use.	April 8, 1988
Compliance groundwater monitoring wells installed by USACE at LHAAP 18 & 24 as a RCRA Facility Investigation (RFI).	1989
LHAAP placed on NPL	August 29, 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
RCRA Part B Permit signed.	February, 1992
IRA Design Initiated for LHAAP-18/24.	1994
Interim Risk Assessment for BG3 and UEP (LHAAP-18/24).	January 18, 1994
Final ROD for Early IRA at BG3 (LHAAP-18/24).	May 12, 1995
Phase II Field Investigation by Sverdrup installed eighteen additional monitoring wells and collected soil, sediment, groundwater, and surface water samples.	1995
Start of construction on extraction and treatment system for metals and organic contamination at LHAAP-18/24.	March 1995
Final WP for Phase III IRA at BG3.	January 3, 1996
IRA construction starts date.	October 25, 1996
GWTP approved and began operating with approximately 5,000 linear feet of ICT to control migration of contaminated groundwater.	January 1997
Start date for the excavation of 37,840 cubic yards of soil and treatment of the soil in low temperature thermal desorption (LTTD) unit.	February 12, 1997
Proof of Performance test conducted for soil treatment plant	February 13-15, 1997
Proof of Performance test conducted at GWTP.	March 24, 1998
Phase III Field Investigation by Sverdrup collected groundwater, sediment, and surface water samples.	1998
Closure of burning cages at BG3.	1998
Perchlorate discovered in groundwater at LHAAP-18/24.	April 1999
IRA construction completion date.	August 31, 1999
United States Army, USEPA, and TNRCC (now TCEQ) agree to establish discharge limits for perchlorate in effluent from the GWTP.	December 2, 1999
Second Quarter Data Summary for Perchlorate Investigation.	March 2001

Event	Date
Fluidized Bed Reactor (FBR) for treatment of perchlorate goes online at GWTP.	April 2001
Final RI Report for LHAAP-18/24.	April 2001
First Five-Year Review for Sites 18 & 24 (BG3), Site 16 (Old Landfill), and Site 12 (Sanitary Landfill).	August 2002
Final Group 2 Sites Baseline Human Health and Screening Ecological Risk Assessment (Sites 12, 17, 18/24, 29, 32, 49, Harrison Bayou, and Caddo Lake).	August 2002
Final WP, Groundwater Data Gaps Investigation, Groups 2 and 4.	February 2004
Environmental Site Assessment, Phase I and II Report, Final.	February 2005
STEP issues Final Plant-Wide Perchlorate Investigation for LHAAP. For perchlorate at LHAAP-18/24, the report concludes that further remediation of soil is unnecessary, but that groundwater monitoring should continue until “further remedial measures are implemented.”	April 2005
TCEQ approves use of irrigation system at LHAAP-18/24 as an alternative to Harrison Bayou for discharge of effluent from the GWTP during dry periods.	August 26, 2005
Draft Final BERA was submitted to regulatory agencies for approval.	March 2007
Data Gaps Investigation Report	April 2007
Injection in ICTs-6 and 9 began.	September 17, 2007
Injection Sumps 1, 3, 5, 10 and 12A deactivated.	September 2007
Final Baseline Ecological Risk Assessment	November 2007
Second Five-Year Review Report for LHAAP-12, LHAAP-16 and LHAAP-18/24.	October 2008
Start withdrawals, vertical extraction Well EW-1 and converted Monitoring Well 18WW17 for groundwater withdraws during high water.	October 2008
Final Explanation of Significant Differences (ESD) for LHAAP-18/24 submitted by USACE.	August 2010
Approval Letter from TCEQ for changes to interim remedy presented in ESD.	February 12, 2010
Irrigation Sprinklers installed in eastern Section BG3 to help induce groundwater capture.	May 2007
GWTP Inoperable Scrubber Unit, Injection in ICTs-6 and 9 ended.	May 21, 2012
Water injections ceased	July 15, 2012
Final Explanation of Significant Differences (ESD) ROD for Early Interim Remedial Action at Burning Ground No. 3 LHAAP	February 2014
ICT 12A restarted, withdrawing groundwater.	December 2012
Final Feasibility Study	January 2017

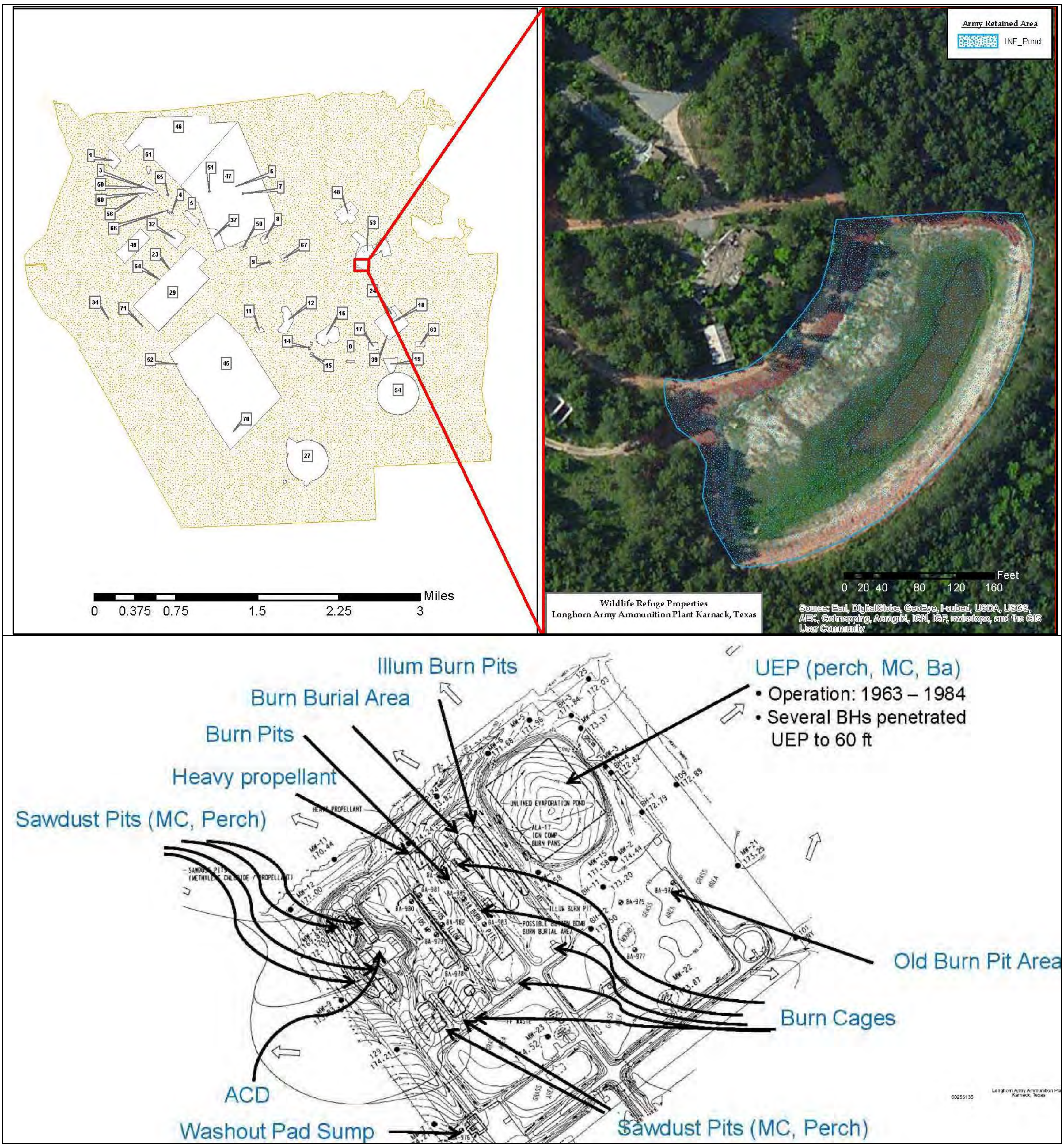


Figure 14. Location of INF Pond and former disposal areas at LHAAP-18/24 (after AECOM, 2017a).

6.3 Initial Response

No initial response actions occurred prior to the Interim ROD (US Army, 1995b).

6.4 Summary of Basis for Taking Action

The contaminants at the LHAAP-18/24 site are chlorinated solvents and metals. Prior to the IRA, concentrations of MC and TCE were higher in groundwater, and the plumes were presumably expanding. Because the site is located east of Harrison Bayou (which eventually discharges into Caddo Lake), and a portion of the site is within the 100-year flood plain, there were concerns about migration of contaminants from groundwater to surface water. The remedial objectives for the IRA were to eliminate or minimize the potential for exposure to human and ecological receptors. The interim remedy was selected to achieve this by reducing or preventing further migration of contaminants into deeper groundwater zones and possibly surface water bodies (US Army, 1995b). Groundwater monitoring well sampling criteria changed in late 2006 when the Army and the USEPA agreed and TCEQ concurred that only 15 of the previous 47 monitoring wells were necessary for monitoring contaminants on a semi-annual basis (Shaw, 2016). Since mid-2012, additional locations have been added to the sampling program and between 40 and 50 locations were sampled semi-annually since September 2012.

6.5 Remedial Actions

6.5.1 Remedy Selection

The selected LHAAP-18/24 remedy for addressing the site contaminants and meeting the remedial objectives of the IRA was a combination of soil removal/treatment and groundwater extraction and treatment. The Army issued the IRA ROD on April 18, 1995, which was approved by the USEPA on May 12, 1995 (US Army, 1995b). The interim ROD had no chemical-specific remedial goals. The IRA ROD required extracted groundwater to be treated to the levels established by TNRCC for discharge to the Harrison Bayou and/or Central Creek (US Army, May 1995). In a letter from TNRCC, dated January 8, 2002, perchlorate discharge was required to be less than 6 µg/L for the daily average and 13 µg/L for the daily maximum. A memorandum entitled Protocol for Discharge GWTP Effluent Longhorn Army Ammunition Plant, Karnack, TX was finalized on August 28, 2017 and established the current discharge protocol. This protocol increased the allowable effluent discharge for water to the Harrison Bayou to 278 µg/L for a daily average and 589 µg/L for a daily maximum. A Final ROD and selected remedy have not been issued by the Army for LHAAP-18/24, so no chemical-specific remedial goals are available. LUCs will also be evaluated as a component of the final remedy.

The RAOs developed for the IRA were to eliminate or minimize the potential for exposure to human and ecological receptors. The interim remedy was selected to achieve this by reducing and/or preventing further migration of contaminants into deeper groundwater zones and possibly surface water bodies (US Army, 1995b). The IRA construction completion date was August 31, 1999 (Shaw, 2008).

The interim remedy consists of:

- Extraction of shallow groundwater followed by treatment using metal precipitation, air stripping, and off-gas treatment for VOCs. After treatment, the effluent is discharged to Harrison Bayou
- Excavation of 32,000 cubic yards of soil source material and treatment using low temperature thermal desorption (LTTD) and off-gas treatment for VOCs. Treated soils were used as fill at the LHAAP-012 and LHAAP-016 landfills

Because the LHAAP-18/24 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

Further details on the treatment systems are presented in Appendix C. Differences in the treatment system from that specified in the IRA ROD are discussed in the 2008 Five-Year Review (Shaw, 2008) and the Explanation of Significant Differences (ESD) document (USACE 2010b).

A Final Explanation of Significant Differences ROD for Early Interim Remedial Action at Burning Ground No. 3, Longhorn Army Ammunition Plant (AECOM, 2014e) was needed as a result of changes to the GWTP to remove the catalytic oxidation air emission control unit as a component of the Selected Remedy described in Section I of the Interim Remedial Action Record of Decision (IRA ROD) (USACE, 1995). Because the Selected Remedy of extracting and air stripping VOCs from the groundwater remains in place and all ARARs will continue to be met without the catalytic oxidation unit, its deletion does not result in a fundamental change in the Selected Remedy requiring an IRA ROD amendment. All other GWTP system components remain unchanged and are not included in this ESD.

6.5.2 Remedy Implementation

6.5.2.1 Groundwater Extraction and Treatment

The GWTP and approximately 5,000 feet of ICTs began operating in January 1997. These elements of the IRA are shown on Plot 16 and Plot 17 in Appendix C, Section 3.0. Details of the extraction component of the remedial system include 14 ICTs ranging in length from approximately 100 to 1,300 feet, located within and around three sides of the former burning ground. The trenches extend approximately 25-55 feet deep to the confining clay layer of the Shallow Groundwater Zone, where present. After construction, piezometers were installed to evaluate ICT effectiveness. Water levels within the trenches are controlled using water level probes, set at various levels to activate or deactivate the twenty-eight sump pumps. These maximize groundwater capture and remove the groundwater from the ICT sections through dual wall containment piping, which leads to a 300,000-gallon influent equalization-holding tank at the GWTP (Shaw, 2008). The GWTP components are (see Appendix C Section 3.2 and 3.3):

1. Pretreatment: Removes excessive scaling and fouling chemicals dissolved in the groundwater, as well as heavy metals (antimony, arsenic, barium, chromium, manganese, thallium, nickel, silver, selenium, and lead). These chemicals are removed through pH adjustment, polymer addition, flocculation, and precipitation. Precipitation occurs in a plate clarifier. The water is then gravity-fed to a sand filter.

2. Air Stripping: Following pretreatment, an 80-foot tall air stripper is utilized to remove volatile contaminants (tetrachloroethene (PCE), TCE and daughter products, MC, chloroform, 1,2-DCE, and 1,1,2-trichloroethane) from the water. The water is fed into the top of the air-stripping tower, which contains a packing material that provides the proper environment for the transfer of VOCs from the water to the air stream. An air supply of 4,600 cubic feet per minute is fed into the bottom of the air stripper and flows upward through the tower. The air vents to a catalytic oxidizer. The metals and VOC treatment are operated in batch mode as needed to fill the FBR influent tank to ensure the FBR operated continuously. In February 2014, a Final ESD, ROD for Early Interim Remedial Action at Burning Ground No. 3, LHAAP was needed as a result of changes to the GWTP to remove the catalytic oxidation air emission control unit as a component of the Selected Remedy described in Section I of the IRA ROD (AECOM, 2014e).
3. Carbon Columns: Two Calgon carbon columns are utilized to polish the water that has been treated for metals and VOCs. The carbon columns are in series and each contains 10,000 pounds of carbon.
4. FBR & Ion Exchange: The FBR was installed following the carbon columns at the GWTP in 2001, after perchlorate was discovered in the groundwater (STEP 2005). The FBR is a 21-foot tall by 5-foot diameter column that contains a carbon bed. The circulation of water upward through the bed fluidizes the carbon. The FBR is fed a nutrient stream and an electron donor. A biomass grows on the carbon bed and consumes perchlorate in the influent water stream. The FBR process takes place as the last treatment step in the water treatment process prior to discharge. In April 2017, Ion Exchange units were added to address perchlorate exceedances.
5. Catalytic Oxidation and Vent Scrubbing: The VOCs in the air stream from the air stripper are routed to a thermal catalytic oxidizer. The VOCs are converted to carbon dioxide, water, and hydrogen chloride gases. These gases are then scrubbed using water to produce a very dilute acid stream. The dilute acid is then used in the water treatment. An interim air monitoring plan was approved to enable operation without the Catalytic Oxidation system in September 2012 and weekly air monitoring since that time has identified that air emissions meet IRA ROD discharge criteria (Texas requirements) without treatment. Interim air emission monitoring (discussed in Section 3.1) following the air stripper breakdown confirms that the air stripping unit at the GWTP can reliably achieve air emissions significantly below the action-specific ARAR (i.e., 30 TAC §106.533 and/or former 30 TAC §116.211(a)) without the catalytic oxidation unit. Although neither of these criteria require the use of air emission control equipment, the 2014 ESD is required because the catalytic oxidation unit is identified as a remedy component of the Selected Remedy and there is no provision for removing the catalytic oxidation unit from the remedy if no longer required to meet the ARAR. The GWTP has been operating without air abatement since September 2012, meeting all the criteria set in the air-monitoring program (AECOM, 2014e).
6. Sludge Treatment - Sludge from pretreatment is first processed in thickeners with devolatilization. Upon thickening and devolatizing, the sludge is fed through a belt press where filter cake is generated. The filter cake is transferred to a roll-off box. When the roll-off box is full, the filter cake is shipped for disposal as non-hazardous waste.

The contaminated groundwater from the sumps is treated at the GWTP and discharged to Harrison Bayou, per the guidelines presented in the 1995 IRA ROD. The rate at which treated water can be discharged to Harrison Bayou depends on the flow in the bayou. Historically there have been extended periods when the lack of flow in Harrison Bayou does not allow the discharge of treated water. During these frequent periods, the treated water is diverted to the

INF lined holding pond for temporary storage. During extended dry periods, when the INF pond reaches capacity, sprinklers distribute treated water within the containment area (Shaw, 2008).

6.5.2.2 Source Material Excavation and Treatment

From February 22 through December 10, 1997, extensive soil excavation and treatment was conducted. Prior to the excavation activities and after initial mobilization and set-up, soil dewatering and storage pads were constructed. Details regarding system set-up are presented in the Final General WP IRA for BG3 (Dow Environmental, Inc. [Dow] 1995) and performance testing of the LTTD soil treatment system (February 13 to 15, 1997) is presented in the LTTD Proof of Performance Test Results document (Radian 1998).

Soil, including 30,000 cubic yards of source material, 1,029 cubic yards of material from the ICT trenches, 105 cubic yards of material from the burning cages, and 1,157 cubic yards of material from storage and treatment area floors was removed. Treated soils were used as fill at the LHAAP-12 and LHAAP-16 landfills. Confirmation soil sampling was reportedly conducted, as well as drilling of 20 soil borings to investigate the potential presence of additional source material. The site was then restored by backfilling the excavations with clean fill, repairing utility lines, etc. (Shaw, 2008).

Waste removal and RAs at LHAAP-18/24 began after the May 1995 IRA ROD for soil remediation and groundwater extraction/treatment was signed (Shaw, 2008). From February 22 through December 10, 1997, extensive soil excavation and treatment was conducted. Soil removal included 30,000 cubic yards of source material, 1,029 cubic yards of material from the interception collection trenches (ICTs), 105 cubic yards of material from the burning cages, and 1,157 cubic yards of material from storage and treatment area floors. Perimeter air monitoring was conducted during the operations and the treated soils were used as fill at the LHAAP-12 and LHAAP-16 landfills (Shaw, 2008). The GWTP, including approximately 5,000 feet of ICT began operating in January 1997, and a fluidized bed reactor (FBR) began treating perchlorate at the GWTP in April 2001 (Shaw, 2008). Figure 5-5 shows the LHAAP-18/24 area with the layout of the ICTs and the location of the GWTP.

6.6 Compliance Monitoring

Compliance monitoring at site LHAAP-18/24 consists of inspections; air, influent, and effluent monitoring at the GWTP; monitoring well and piezometer groundwater elevation surveys; and monitoring well sampling. All the sampling requirements are summarized in the Revised Sampling and Analysis Plan for the GWTP and well fields (AECOM, 2017c). Results of the GWTP monitoring over the past five-year period are presented in quarterly monitoring reports.

Historically, groundwater contaminants at the site were monitored quarterly between 1986 and 1994 and have been monitored semi-annually since 1997, with directed sampling events occasionally occurring (Shaw, 2008). Based on evaluation of historical results and the monitoring well locations, the number of wells sampled was reduced from 47 to 15 in 2007 (Shaw, 2008). Groundwater levels are measured monthly in the original forty-seven monitoring wells and twelve piezometers, and frequently there are additional monitoring well water levels measured. The data are maintained on-site at the GWTP and are tabulated and presented in plan- view figures, as well as time-trend graphs in monthly and quarterly reports that are submitted to the regulatory agencies. These data are used to monitor the hydraulic effectiveness of groundwater extraction and to confirm that contaminants do not discharge into Harrison Bayou at concentrations exceeding ARARs. It should be noted that the majority of groundwater contour maps presented over the past five-years were generated using water levels from the shallow monitoring wells with fewer intermediate and deep groundwater contour maps produced. Contaminant concentrations in the ICTs are measured annually. Since mid-2012, additional locations have been added to the sampling program and between 40 and 50 locations were sampled semi-annually since September 2012.

6.7 Operations, Maintenance, and Monitoring

The LHAAP-18/24 OM&M activities are:

- Collection of monitoring well and piezometer water-level measurements, and groundwater samples. Wells are maintained and repaired as needed.
- Maintenance, compliance monitoring, system adjustments, evaluation, and optimization of the ICT/groundwater extraction system
- Chemical monitoring of the ICTs and influent and effluent results
- GWTP air, influent, and effluent compliance monitoring
- Maintenance and operation of the GWTP, including all influent and effluent components
- Data compilation, records upkeep, and submittal of reports on GWTP operations and sampling results
- Maintenance of all on-site equipment, including fences and signs, and routine maintenance activities (mowing, etc.).

6.7.1 Treatment or Other System Processes

The groundwater treatment process was modified in April 2017 when two ion exchange units were placed between the discharge pumps and the flow meter to address the exceedance of the perchlorate discharge above 13 µg/L in the effluent noted in 2015 and 2016 (Figure 15). The available quarterly evaluation reports (AECOM, 2017c-m, 2016b-d, 2015b-d, 2013a-c, and Bhate, 2018a, b) indicate that there were no violations of the perchlorate discharge limit, subsequent to the installation of the ion exchange units. However, the ion exchange resin limited the flow that can be treated by the system. In 4th quarter 2017, the average discharge flow rate from the GWTP was calculated as 10 gpm. Key maintenance issues are described in detail in the following paragraphs:

1. Pretreatment: On December 12, 2016, flange bolts at TK-380 failed and allowed hydrochloric acid (HCl) to drain into the sump. The containment area was washed down and the sump contents were transferred into a TK-140 Equalization Tank. Because of the acid release, extraction of groundwater from ICTs was halted, and the GWTP was put into recycle mode (effluent sent back as influent) until the acid was neutralized and perchlorate, metals, and VOCs were below discharge criteria on March 17, 2017. During the site, inspection of May 2017, USACE noted corrosion and leaking liquids at the same flange bolts (Appendix D LHAAP 18/24 Site Inspection Photo 9). Mr. Beesinger indicated that the current leak from the acid tank (Site Inspection Photo 9) occurs at the same location as the spill of the hydrochloric acid reported in December 2016. In 2016, the pump operated automatically and the spilled acid was returned into the influent, which adversely affected the treatment system. As a preventive measure with the current newly installed Programmable Logic Controller (PLC), the pump will cease when acid is spilled.

2. Air Stripping: On September 2015, the blower on the air stripper malfunctioned during routine operation. Two days later, the wiring on the blower was repaired and the blower operated for less than 2 hours, when the blower malfunctioned again. It was determined that the blower needed to be replaced, and groundwater extraction and operation of the GWTP ceased beginning September 18, 2015, as the influent equalization tank became full. Beginning on October 2, 2015 it was determined that the GWTP could operate without the blower at a reduced extraction rate. The operation of the GWTP allowed extraction of groundwater from ICTs 12E, 13A, 13B and 13C (13C was changed to ICT 13E on October 12, 2015), which were considered critical ICTs to prevent migration of contaminants to Harrison Bayou. Groundwater extraction was switched frequently between ICTs 12E, 13A, 13B and 13E to ICTs 14B, 14C and 14D beginning December 14, 2015. On January 2016, the blower was replaced but an attempt to return the GWTP to continuous operation was not successful. The treatment plant operated in batch mode. The metals and VOC treatment are operated in batch mode as needed to fill the FBR influent tank to ensure the FBR operated continuously.
3. Carbon Columns: Given the frequent idle status of the metals and VOC portion of the plant, these Granular Activated Carbon (GAC) units are subject to biofouling due to bacterial growth.
4. FBR & Ion Exchange: In April 2017, Ion Exchange units were added to address perchlorate exceedances. During the May 2018 site inspection, Mr. Beesinger indicated there were no violations for effluent discharge. However, he did indicated that the fluidized bed reactor (FBR) had breakthrough of carbon and biomass. The site supervisor tried to address this issue by installing filters before the ion exchange vessel. Initially, the operator tried installing a 10-micron filter prior to the ion exchange, however, the filter clogged in one day; subsequently they tried a 100-micron filter that clogged in four days. The subcontractor troubleshot the FBR issue and found that the lateral nozzles were clogged (though the inductor functioned properly). The plan is to replace the lateral and nozzle. The site supervisor indicated that they would use ion exchange to remove perchlorate while the FBR is bypassed and taken off-line for repair.

During the site visit of May, 2018 Mr. Beesinger (supervisor) was being acquainted with the new PLC system. Bhate believes this system will enable prompt identification of maintenance issues and responses.

Extracted groundwater collected at the GWTP is treated to the levels established in the 1995 IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan. Prior to the discharge of GWTP effluent to the bayou, the flow in the stream is manually measured. The calculated discharge is then compared to chloride and sulfide concentrations from a surface water sample collected at the same time and analyzed at the GWTP. These calculations are then referenced on a graph to determine if the GWTP effluent can be discharged to the bayou. A licensed contractor takes precipitated metals off-site for disposal at an approved/licensed non-hazardous waste facility. The Army discharges the GWTP treated effluent using three methods in decreasing order of preference (AECOM, 2017g):

- Discharge to Harrison Bayou
- If Harrison Bayou is not flowing, discharge to INF Pond (Figure 14) for temporary storage until Harrison Bayou flow resumes. The INF Pond has a flexible membrane liner protected by a soil cover with a gravity discharge pipe (and valve) to Harrison Bayou. The INF Pond has a nominal capacity of 3 million gallons (2013 Five-Year Review).

- Discharge as irrigation water within LHAAP-18 (last resort). The layout of the irrigation lines are on Plot 77. The state approved use of irrigation as a means of discharge at LHAAP-18/24 in August 2005.

A Remediation System Operations Plan for Groundwater Treatment Plant and Well fields is maintained on-site (AECOM, 2017c). The plan consists of written procedures, plans, permits, records, equipment, database descriptions, etc.

Records pertaining to compliance of the GWTP, such as sampling and analysis records, and discharge flow calculations are maintained at the site and the collected data (including analytical) are maintained in a variety of file formats, databases and spreadsheet files. The volume of water removed from the ICTs is measured monthly. The volumes of groundwater treated and associated concentrations are presented in monthly and quarterly reports that are also provided to the regulatory agencies. GWTP reports are provided to the Army on a weekly, monthly, and quarterly basis (Beesinger, Scott, personal communication January 24, 2013 [Beesinger 2013]). These reports summarize the compliance monitoring events and operations, including the GWTP air, influent, and effluent sampling results. The GWTP monitoring is performed following the guidelines presented in the 2017 Sample and Analysis Plan (AECOM, 2017c), in compliance with requirements established in the IRA ROD, and as modified in subsequent arrangements with the regulatory agencies.

6.7.2 Groundwater Treatment Plant Sampling and Analysis

As part of the GWTP operations, multiple samples from various sources or waste streams are collected and analyzed regularly for the parameters cited in the IRA ROD and subsequent revisions documented in the 2017 Final Revised Sampling and Analysis Plan. Besides the ROD sampling requirement, additional sample analyses are performed on the influent and effluent samples to monitor the effectiveness of the FBR process. Sampling of the effluent for VOCs, anions, perchlorate, and metals is conducted on a biweekly basis, and the results have consistently been below the discharge limits. As per the revised sampling and analysis plan (AECOM, 2017c), monthly metals sampling is reported in biweekly sampling results presented in the biweekly tables in the quarterly reports. Monthly sampling for selenium and silver was continued and the results are presented in the biweekly tables. Sampling of the effluent for VOCs, anions, chemical oxygen demand, oil and grease, perchlorate, and metals is conducted on a quarterly basis and has consistently been below the discharge limits. Additionally, weekly samples are analyzed for perchlorate. While perchlorate has occasionally exceeded its discharge criteria (6 µg/L daily average and 13 µg/L daily maximum before 2017, and 278 µg/L daily average and 589 µg/L daily maximum), this has had little to no impact on protectiveness for the following reasons:

- There are relatively few exceedances above the perchlorate effluent criterion. During the 2008-2012 review period, there were 792 perchlorate analyses of GWTP effluent (including QC), of which only 5 grab samples exceeded the daily average criterion of 6 µg/L and only one composite sample exceeded the daily maximum criteria of 13 µg/L. Of the six exceedances, discharge was being completed to Harrison Bayou on only one of these occasions
- The purpose of the interim remedy is to contain the groundwater at LHAAP-18/24. The remedy has successfully done this, thus preventing water with very high perchlorate concentrations (e.g., groundwater at MW01 or MW03) from reaching surface water.

- When the flow in Harrison Bayou is low, the effluent is not discharged to the bayou, but is returned to the site as irrigation or discharged to the INF pond (Figure 14). Thus the concentration in the bayou is always much lower than the effluent concentration.

6.7.3 Groundwater Monitoring

Water levels from 65 monitoring wells and 12 piezometers are collected monthly to generate groundwater elevation maps to monitor the effectiveness of the groundwater extraction in the Shallow Groundwater Zone and Wilcox formation.

6.7.4 Operations, Maintenance, and Monitoring Costs

The O&M and LTM costs at LHAAP-16, and LHAAP- 18/24 are not subdivided into individual site values, thus assessment of individual site cost performance is not possible. The original O&M total cost estimate for LHAAP-12 and LHAAP- 16, and cost estimate for LHAAP-12 RAO LTM, was $75,000/year (US Army, 1995a). The original O&M total cost estimate for LHAAP-18/24 was $400,000/year (US Army, 1995b). The increased O&M costs for 2017 support replacement of air compressor and PLC system The combined approximate actual O&M and LTM costs for sites LHAAP-16, and LHAAP-18/24 are presented in Figure 15, including monitoring well maintenance activities.

From 2013 through 2017, the annual operations and maintenance costs are higher than the previous Five-Year Review (Figure 15). The increased costs for 2013 support upgrades and repairs to the aging GWTP.

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)	Notes
2013	1,410,449.66	164,142.61	1,574,592.27	Upgrades and repairs to the aging GWTP
2014	574,627.64	492,427.48	1,067,055.48	
2015	626,866.51	492,427.84	1,119,294.35	
2016	626,866.51	369,320.88	996,187.39	
2017	848,952.01	157,760.46	1,006,712.47	Replace air compressor and PLC System

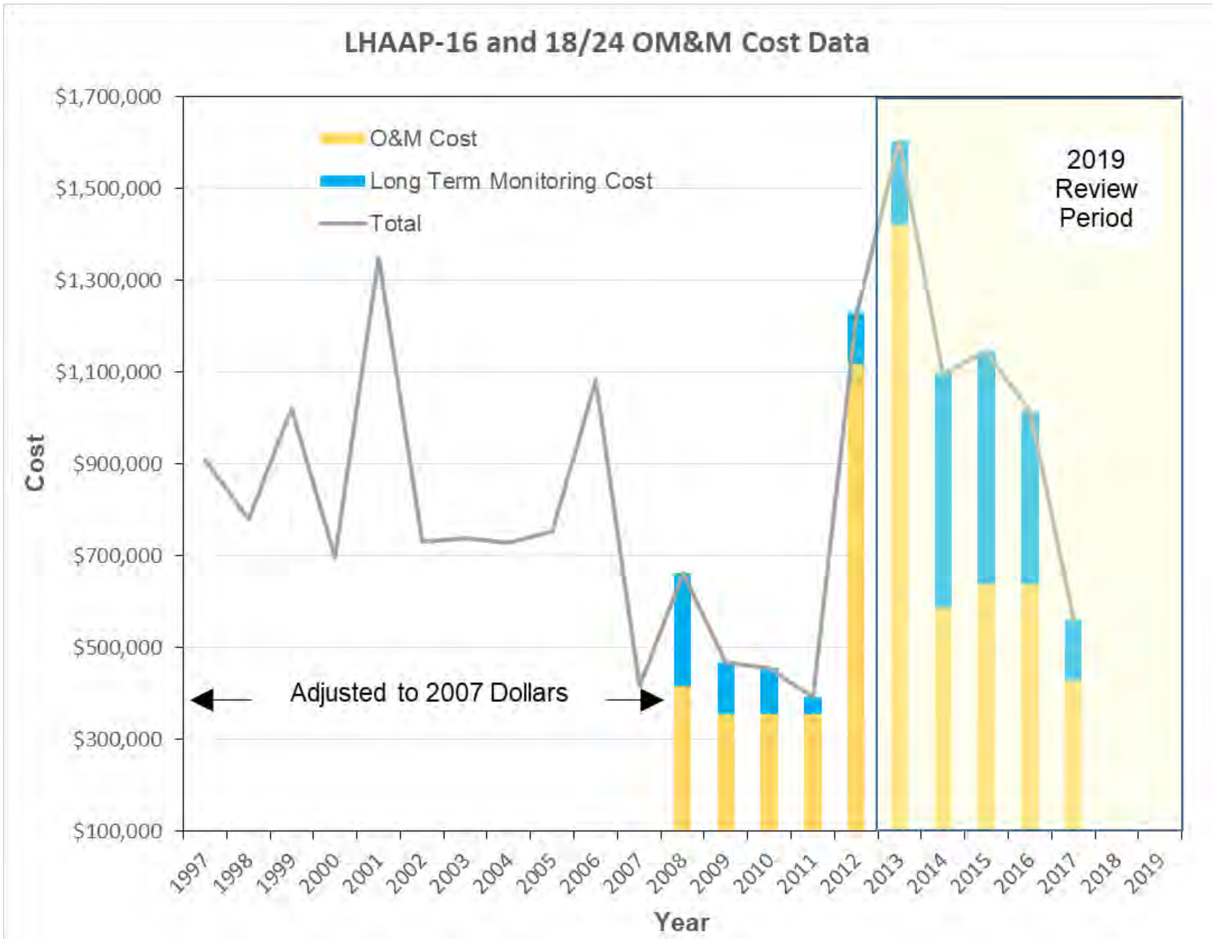


Figure 15. LHAAP-18/24 operations, maintenance, and monitoring costs by calendar year through 2017 (USACE, 2018, AECOM, 2014a, Shaw, 2008). Some LHAAP-16 costs are included in the 2019 review period.

6.8 Progress since the 2014 Five-Year Review

This is the fourth five-year review for LHAAP-18/24.

6.8.1 Protectiveness Statements from the 2014 Review

The IRA at LHAAP-18/24 currently protects human health and the environment because the excavation of source material has removed the source, and the extraction and treatment of groundwater mitigates plume migration and has resulted in reductions in contaminant levels since implemented.

6.8.2 Status of Recommendations and Follow-Up Actions from the 2014 Review

All were addressed before the 2014 Five-Year Review was signed in May2014.

6.8.3 Status of Other Prior Issues

See Table 16.

6.9 Five-year Review Process

6.9.1 Data Review

Data analysis conducted by USACE to support the Fourth Five-Year Review is in Appendix C, with the summaries presented below by remediation system and by media. Summary data and statistical tables are in Appendix F.

Table 16. LHAAP-18/24 status of first and second Five-Year Review's Recommendations and Follow-Up Actions.

Issue	Recommendation/Follow-up Action	Party Responsible	Oversight Agency	Milestone Date	Affects Current Protectiveness	Affects Future Protectiveness?	Action Taken	Date of Action
Status of Recommended Actions from First Five-Year Review								
Metal precipitation process may not be required	Review data and monitoring information	USACE	USEPA & TCEQ	11/30/02	No	No	Remedial Design and Remedial Action Work Plan for the final remedy will evaluate.	Deferred to final remedies
Contamination at Northwest of burning ground outside of ICT capture zone.	Further study to determine if groundwater extraction from area is required.	USACE	USEPA & TCEQ	11/30/02	No	Yes	Remedial Design and Remedial Action Work Plan for the final remedy will evaluate.	Deferred to final remedies
Status of Recommended Actions from Second Five-Year Review								
No groundwater use restrictions are in place.	Address as part of final remedy implementation of each site.	Army	USEPA & TCEQ	To be determined in site-specific RI/FS documents	No	Yes	Groundwater use restrictions will be addressed as part of the final remedy for each site. Final remedies will be determined via the CERCLA RI/FS/PP/ROD process. The draft final LHAAP-16 FS Addendum and the draft LHAAP-18/24 FS have been issued and both documents include LUCs that restrict groundwater use.	In progress.
Contamination northwest of burning ground.	Address as part of final remedy implementation of the site.	Army	USEPA & TCEQ	Per LHAAP-18/24 RI/FS schedule	No	Yes	Contamination northwest of the Burning Ground will be addressed in the LHAAP-18/24 FS. The draft FS has been issued and comments are being resolved.	In progress.
Age and condition of piezometers	Inspect condition of piezometers during monitoring activities and, when applicable, identify for repair, replacement, or abandonment	Army	USEPA & TCEQ	12/31/08	No	No	Due to lack of information about their construction, the degree of silting at the piezometers cannot be determined. Given the concerns about their condition, the Contractor has stopped using the piezometers for potentiometric surface maps. Water levels were measured monthly through April 2009, but Contractor no longer measures water depths at the piezometers. The piezometers will be abandoned when the final remedies are implemented at LHAAP-16 and -18/24.	Deferred to final remedies.

6.9.1.1 Extraction System

The RAO for the IRA were to eliminate or minimize the potential for exposure to human and ecological receptors by reducing or preventing further migration of contaminants from source material and shallow groundwater into deeper groundwater zones, and possibly surface water bodies. Although the GWTP removed mass flux of COCs from groundwater and overall stabilized the widespread risk driving COCs footprints (report section 4.5.2), the system does not fully provide lateral or vertical capture of the entire footprints of COCs (e.g., MW-16).

When there is no interruption due to maintenance issues, fluctuation in total monthly recovery rate is predominantly influenced by meteorological conditions (Plot 19). Higher extraction rates are achieved after a prolonged recharge from precipitation and low extraction rates are associated with periods of low recharge.

ICT flows are controlled by controlling the water elevations to minimize the number of times the pumps start and stop. In the summer time, the level is held low at approximately 40 feet below ground elevation and in the winter, the level is held high at approximately 22 feet below ground elevation. The trend in total monthly recovery rates in the last five-years does not show monotonic decline of flow (recovery rate volumes), indicating that, overall, the recovery rates are not limited by loss of efficiency of the system, but by other factors. Major factors include meteorological conditions and the treatment volume capacity (e.g., flow limited by residence time required in the ion exchange system) and operation and maintenance of the treatment system. Temporal variation of total quarterly recovery rates (Plot 20) support that the trend in total recovery rate does not show a monotonic decrease with time.

Mass removal rate's analysis from each recovery point conducted by Fourth Five-Year Review using monthly extraction flow data available for February/March 2015 and concentrations of COCs sampled at ICT and recovery wells at the end of February (Plot 21), 2016 indicates that:

- Relatively high groundwater extraction and high mass removal rates are encountered at ICT 4, 8, 11, 13A, 14D, 14E.
- Relatively high extraction rates and low mass removal rate are encountered at ICT 2, 13B, 13C.
- Relatively low extraction rates and high mass removal rates are encountered 18WW17, ICT 12B, 12C, 12D, 12E.

The GWTP removed COCs mass from groundwater and stabilized the COCs footprints. The extraction system appears to provide lateral capture of groundwater in the Shallow Groundwater Zone located within the boundaries of LHAAP18/24, though it does not provide complete lateral or vertical capture of the footprints of the widespread COCs. Although the system does not provide complete lateral and vertical capture of the footprints of the widespread COCs, it meets the IRA RAOs in that it reduces the mass loading leaving the perimeters of LHAAP18/24.

Regular maintenance of the groundwater extraction system includes cleaning of submersible pumps. In some of the ICTs, due to iron precipitation, especially at ITC No. 13A, 13B, and 13C, pumps are removed every 3-4 months to be cleaned. In these locations, submersible pumps are replaced typically after the third cleaning (about every year). To date, no attempts have been made to assess the conditions of the media in the trench outside the ICT lateral pipe to determine, if iron fouling of the trench itself was occurring, which could be reducing the efficiency of hydraulic control of the IRA.

6.9.1.2 Treatment System

Key maintenance issues that lead to interruptions in system operation in the last five-years are summarized below. These are described in details in section 6.7.1 and Appendix C (see Plot 19).

- Release of hydrochloric acid due to failure of flange bolt that occurred on December 12, 2016.
- Malfunction of air stripper's blower noted in September 2015.
- Exceedance of perchlorate in the effluent.
- FBR's breakthrough of carbon and biomass.
- Failure of the main transformer during the severe storm of August 12, 2017.

6.9.1.3 Effluent Discharge

As of May 2017, treatment plant effluent is discharged according the following protocol in decreasing order of preference:

- Discharge to Harrison Bayou provided surface water quality parameters are suitable and if there is minimum natural flow in Harrison Bayou to provide dilution of GWTP effluent. Discharge to the creek is dependent on having some flow in the creek, and meeting sulfate and chloride water quality criteria.
- If Harrison Bayou is not flowing, discharge to Intermediate-Range Nuclear Forces (INF, Plot 76) Pond for temporary storage until Harrison Bayou flow resumes. The INF Pond has a flexible membrane liner protected by soil cover with a gravity discharge pipe (and valve) to Harrison Bayou. The INF Pond has a nominal capacity of 3 million gallons.
- Discharge as irrigation water (Plot 77) within LHAAP-18 as a last resort. Concerns have been expressed that irrigation may facilitate downward migration of COCs into the deeper Wilcox Formation.

6.9.1.4 Compliance Monitoring

Compliance monitoring air and treated groundwater effluent indicates that:

- All air analytical sample results are below requirements for site COCs.
- No exceedances of VOCs or metals are in the system effluent, though in most monitoring events Selenium and Silver reporting limits were greater than the Daily Average and Maximum Limit.
- Periodic perchlorate exceedances occur above the discharge criteria of daily maximum concentrations of 13 µg/L (see Appendix C Section 3.3.1). Perchlorate exceedances above the discharge criteria occurred in the first three quarters of 2016. The majority of exceedances occurred during the 1st quarter of 2016 when the FBR was running in batch mode or nutrient levels were low resulting from a broken feed pump. In the 2nd and 4th quarter of 2017, after the two ion exchange resins were added to the treatment system, perchlorate did not exceed the discharge criteria.

6.9.1.5 Effectiveness of IRA in Meeting ROD's RAO

The IRA is meeting the RAO intent by removing COC mass and reducing COC areal extent, and has stabilized the footprints of the TCE, MC, and perchlorate in the Shallow Groundwater Zone and the Wilcox Formation (numerous wells showing a decline in temporal concentrations). Compliance monitoring suggests the IRA is meeting the RAO intent for reducing COC impacts to Harrison Bayou.

Spatial and temporal trends of COCs (TCE, MC, and perchlorate) concentrations were evaluated in order to determine whether the IRA is meeting the ROD's remedial action objective. Summary of the analysis leading to the conclusion that the IRA is meeting the remedial action objectives is provided below:

- TCE concentrations in the Shallow Groundwater Zone along the southeast corner of the UEP declined from levels that were within the solubility limit (as high as 1,000,000 ppb) in 1994, to levels that are ~ 1% solubility limit (i.e. ~ 10,000 ppb) in June 2016. The large areal extent of the Shallow Groundwater Zone's footprint of TCE with concentration above the 1% solubility limits which covered the UEP, burn pits area, and the ACD has decreased significantly between 1994 and June 2016, and in 2017 was limited to one well located at the ACD (along the northwest corner of LHAAP18/24 property's boundary. Analysis of the 2014 through 2017 COCs contours indicates the presence of two primary source areas (possibly DNAPL in the ACD area), one at MW-2 (located near the former UEP), and the second at 120(located near the former ACD operations). Results of trend analysis documented in AECOM, 2017a, and results of trend analysis performed by the Fourth Five-Year Review, are described in details in Appendix C Section 3.5.2. Overall, TCE attenuation (as is defined, in general, by wells with stable trends and stable footprints of the TCE plumes) outside the capture/containment area is taking place east, north, and west of the capture zone/containment boundary. However, the available data for MW16, located downgradient of the ACD, and adjacent to the stream (Figure 16) indicates an increasing TCE trend by order of magnitude since the last Five-Year Review (Plot 81). There are two wells (109 and 18CPTMW04, Figure 16) with increasing TCE trends (where concentrations increased by several orders of magnitude) within the capture zone/ containment area. Both wells are located in the proximity of the UEP. Wells with decreasing TCE trends (MW-06, MW-01, and MW-04) are present between the two wells with the increasing TCE trends. This pattern provides the line of evidence that the increase in TCE within the capture zone/containment boundary is likely due to plume redistribution in response to the operation of the recovery system.
- Figure 17 depicts trend analysis results for abiotic CVOC degradation chemicals that are not part of the wide-spread risk driving COCs, but are presented for information purposes only. Increasing trends for single contaminants was indicated in the following monitoring wells: MW-14, AWD-1, and 17WW01.
- There are two TCE plumes in the middle Wilcox Formation (Plot 61 through Plot 63). The centers of these plumes coincide with the centers of the shallow TCE plumes. TCE's trend analysis conducted by O&M (AECOM, 2017) indicates increasing trends in the plume's center well, MW-14, located in the ACD area along the northwest property boundary (Plot 47). The Fourth Five-Year Review trend analysis indicates that the available data did not meet the criteria to conduct a trend analysis.

- Time series of MC concentrations contours in the Shallow Groundwater Zone indicate that MC concentrations along the southeast corner of the UEP declined from levels as high as 10,550,000 ppb (Plot 50) in 1994, to around 100,000 ppb (Plot 54 through Plot 56) in 2017. The 1994 large areal extent of the Shallow Groundwater Zone's footprint of MC with concentration 100,000 ppb covering the UEP, burn pits area, and the ACD decreased, and in 2017 was limited to one well located at the south east corner of the UEP (Plot 56). Analysis of the 2014 through 2017 MC contours indicates the presence of two primary source areas (possibly DNAPL in the southeast corner of the UEP area), one at MW-2 located near the former UEP, and the second at 120 located near the former ACD operations. Results of a trend analysis performed by O&M (AECOM, 2017a) depicted in Plot 54, and results of trend analysis performed by the Fourth Five-Year Review, depicted in (Figure 18), are described in details in Appendix C Section 3.5.2.
- Time series of perchlorate concentrations in the Shallow Groundwater Zone indicate that increasing in trends of perchlorate concentrations are only noted within the containment area (Plot 72). Perchlorate trends in wells located outside the containment are either declining or indeterminate (Figure 18). Although perchlorate concentration in 18WW08, located ~ 150 feet upgradient of Harrison Bayou and downgradient of the northwest perimeter of the site is declining, recently, the fluctuation in concentration ranged between ND and 2400 µg/L (Plot 75).
- Perchlorate in the middle Wilcox Formation include three high perchlorate concentration areas (MW-14 located near the former ACD (MW-14) where concentrations are > 100,000 ppb, near the former UEP (18CPTMW08SW) where concentrations are > 10,000 ppb, and outside of the containment on the south corner of the site (18CPTMW22SW) where concentrations are > 10,000 ppb (Plot 72). The footprints of these plumes appear stable.

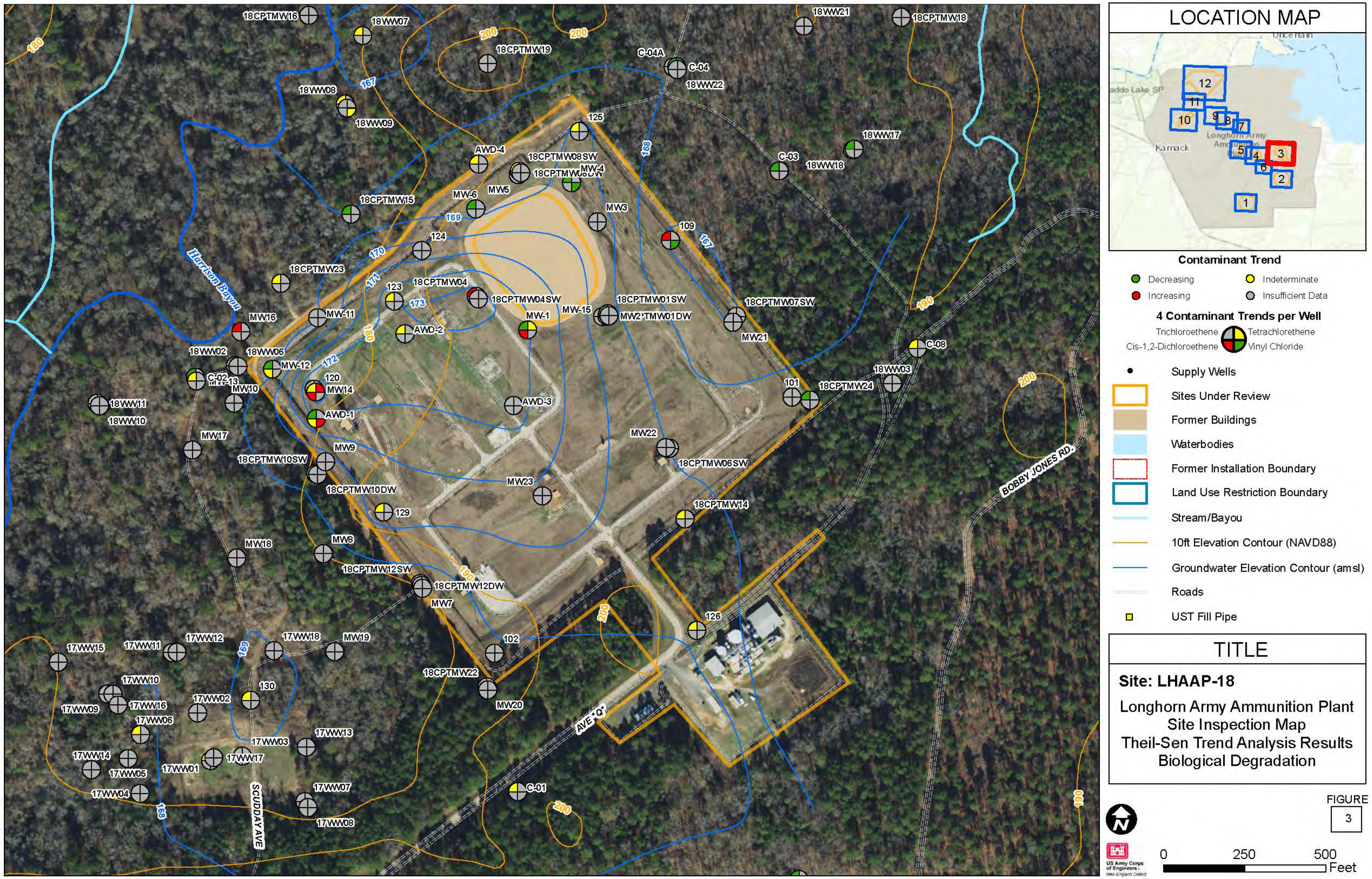


Figure 16. LHAAP-18/24 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006).

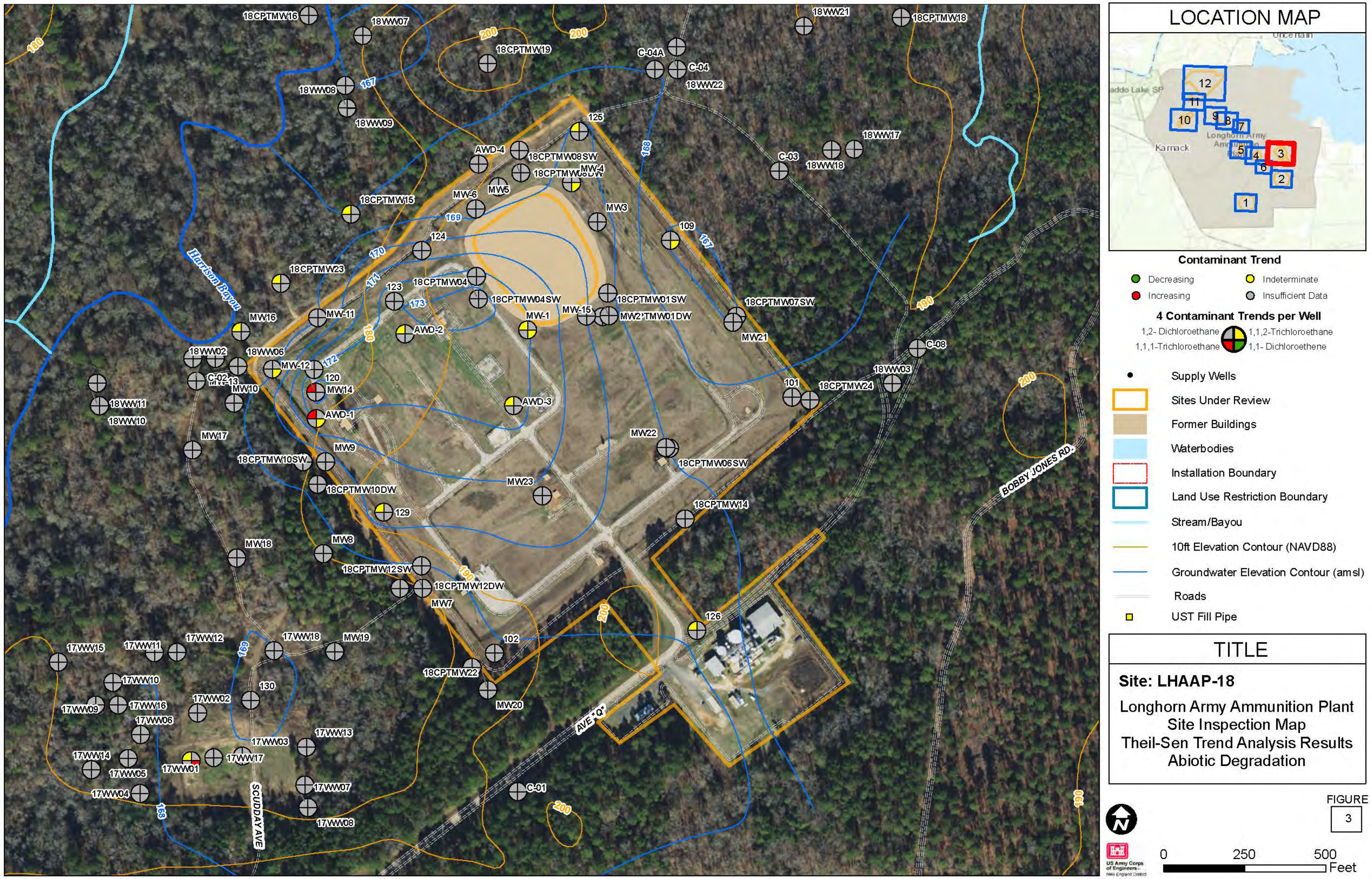


Figure 17. LHAAP-18/24 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006).

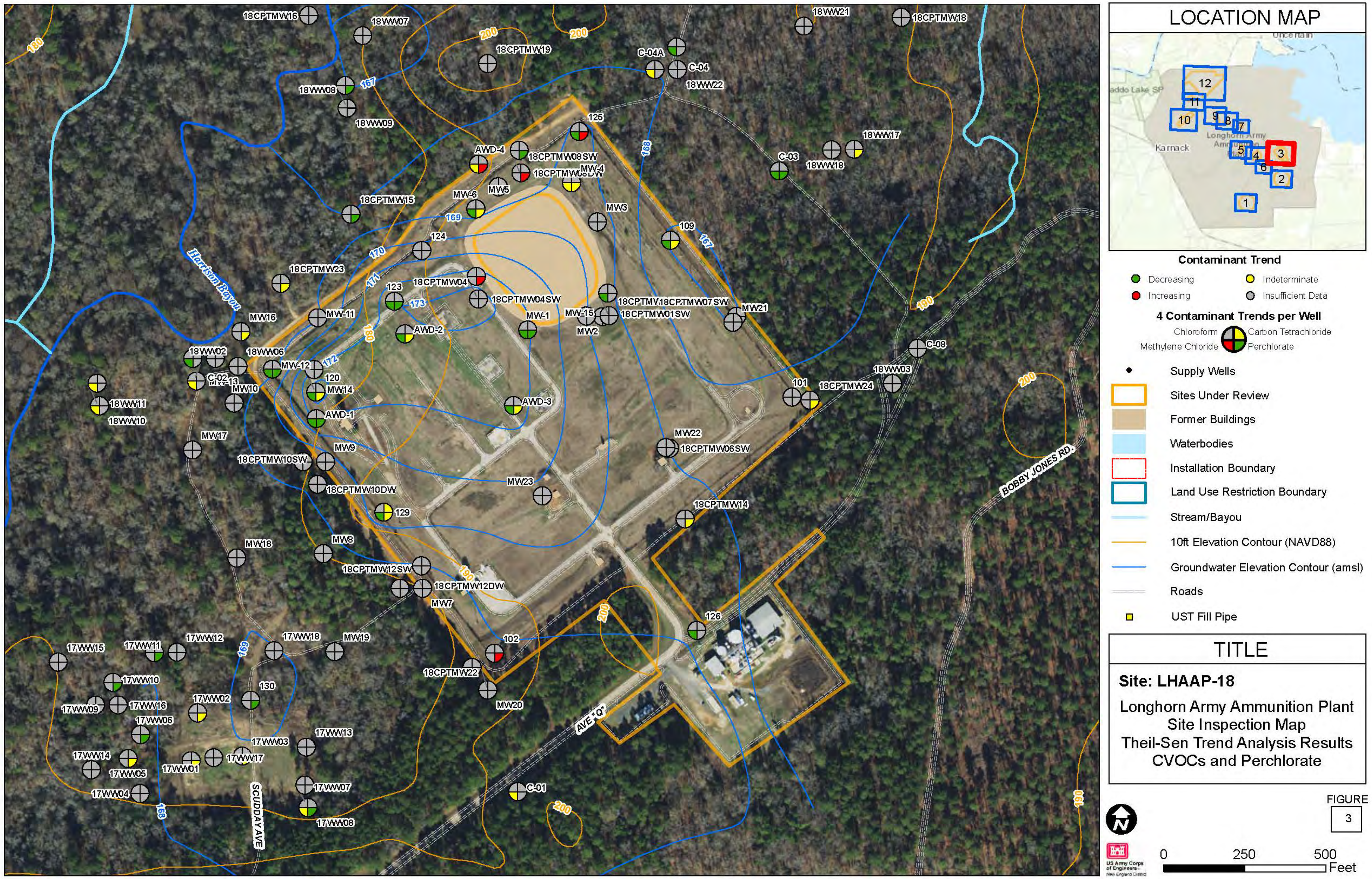


Figure 18. LHAAP-18/24 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (LHAAP, 2018a, USAEC, 2018, TNRIS, 2015, USGS, 2011, 2006).

6.9.1.6 Surface Water

Surface water sampling is not part of compliance monitoring for the IRA. However, as the result of a dispute resolution decision with the State of Texas in the 1990s, the Army collects surface water samples quarterly from three locations on Harrison Bayou (HBW-1, HBW-7, HBW-10), and two locations on Goose Prairie Creek (GPW-1, GPW-2), shown on Plot 25. Surface water samples are analyzed for perchlorate, the results are reported to the State and USEPA, and distributed to the public at the quarterly Restoration Advisory Board (RAB) meetings (surface water sampling results are in Appendix C Section 3.6).

Groundwater concentrations in Shallow Groundwater Zone monitoring wells have indicated elevated concentrations of perchlorate, up to 2,400 µg/L (December 2017) in 18WW08 located about 160 feet southeast of Harrison Bayou. Trend analysis of perchlorate in 18WW08 indicates a declining trend with recent fluctuation from levels that are lower than the PCL of 17 µg/L to 2400 µg/L. Another Shallow Groundwater Zone well, 18CPTMW23, located between the northwest corner of the containment area and the Harrison Bayou (about 150 feet east of the Bayou), has had fluctuating perchlorate concentrations from levels that are lower than the PCL to levels as high as 3,220 µg/L (June 2017).

The close proximity of Shallow Groundwater Zone wells with area of periodic elevated concentrations of perchlorate over two orders of magnitude higher than the Residential Protective Concentration Level (PCL) of 17 µg/L is of concern, due to its the proximity to Harrison Bayou. The ICT and extraction well system is designed to capture the shallow groundwater plume thereby reducing or preventing further migration of contaminants from shallow groundwater to surface water and eliminating or minimizing the potential for exposure to human and ecological receptors to contaminants. The effectiveness of the IRA is substantiated by the results of quarterly surface water sampling for perchlorate which indicate perchlorate is not reaching the nearby aquatic systems at unacceptable levels. Compliance monitoring suggests the IRA is meeting the RAO intent for reducing COC impacts to Harrison Bayou.

6.9.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). No water or rig supply wells have been drilled within the groundwater use restriction/site boundary. The site inspection identified the following issues:

- Performance-based extraction well redevelopment does not appear to be occurring, leading to increased pump maintenance and replacement. Poor extraction well yield increases the risk of contaminated groundwater entering Harrison Bayou under drought recovery or high gradient conditions (Figure 4).
- It is not clear if the GWTP will again experience significant repair periods and downtime as in FY 2013. Issues to date and system age suggest major repairs will be an ongoing issue as long as the current system is used.

- The interviewees noted that there have been a high frequency of unscheduled repairs, due to breakthrough of carbon media and biomass from the fluidized bed reactor (FBR), corrosion of fittings that released acid from the pH control tank, the frequent need to clean submersible pumps at the ICTs, and vertical extraction pipe cleaning due to iron precipitation fouling; etc. In addition, the system is old and has had a high frequency of electrical component failures. Typically, these equipment failures are fixed prior to the interim remedy shutdown period resulting in a compromise of protectiveness.
- It is not known how much water line condition is limiting well field yield.

6.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The proper operation and successfulness determination for several remedies has not yet been determined.
- Concerns were expressed about contaminated groundwater entering Caddo Lake.

Site-specific issues raised during the interviews are:

- GWTP Operations. The groundwater treatment plant continues to have problems treating perchlorate and has had several excursions. The system is old and for many years, the plant was not kept up or maintained as needed. The Army contractors were lax with the upkeep of the plant.
- Two GWTP shutdowns that raised concern. Both stemmed from problems with the FBR, which has not performed as designed. The first related to a higher concentration acetic acid feed that resulted from a drum shipped to the plant that was mislabeled, and the second was an acid release (into a containment system) that made its way into the treatment system through the sump system. Both issues were resolved without compromising surface water. More intensive FBR maintenance is expected to improve perchlorate treatment efficiency.

6.10 Technical Assessment

6.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes. The interim remedy is functioning as intended, reducing migration of contaminant from the source material into the deeper groundwater zones and possibly into surface water bodies. The remedial objectives for the Early Interim Remedial Action were to eliminate or minimize the potential for exposure to human and ecological receptors by reducing or preventing further migration of contaminants from source material and shallow groundwater into deeper groundwater zones, and possibly surface water bodies." The capture zone analysis for Site 18/24, using groundwater potentiometric contour maps and trends of water quality in the monitoring well network, suggests that hydraulic control may not be achieved to the extent previously thought. This is due to the following: 1) persistence of downward hydraulic gradients inside the containment area, and 2) fluctuating trends in wells such as MW-16 (TCE) and 18WW08 (perchlorate) where concentrations of COCs can become elevated by several orders of magnitude above the cleanup concentration in Shallow Groundwater Zone monitoring wells nearest to Harrison Bayou. The costs for groundwater treatment system operation and maintenance have increased over the years to account for an aging GWTP system.

The IRA effectively reduced the high concentrations and/or the areal extent of the high concentrations of widespread COCs; in addition, the IRA in general has stabilized the footprints of the TCE, MC, and Perchlorate in the shallow and Wilcox formation, with numerous wells showing a decline in temporal concentrations. Although perchlorate concentrations in two wells located adjacent to Harrison Bayou show decreasing trends, the concentrations are periodically elevated and may be of concern at the Bayou. TCE concentrations in one well (MW-16) located adjacent to the Bayou has increased from ND in 1994 to levels that have recently fluctuated between 200 and 700 µg/L.

Although there is limited evidence of natural attenuation through biological processes, it is believed that the decline in COCs' concentrations is due to pumping rather than natural attenuation (NA) mechanisms. The IRA was shut down, or its mode of operation was changed to address several malfunctions. The causes for system shutdown and/or change in mode of operation and the duration are summarized in Plot 19. It is anticipated that the newly installed PLC will improve response to system malfunction. Although the IRA meets the ROD's RAO, the system does not provide lateral or vertical capture of the footprint of the widespread COCs. The IRA captures the Shallow Groundwater Zone within the boundaries of LHAAP18/24.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. The cleanup levels and RAOs have not been formally set in a final Record of Decision. However, Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced. The emerging contaminant 1,4-Dioxane will be monitored in the future because of its detection in several wells across the site above the Industrial Groundwater Medium Specific Concentration of 26 µg/L.

Question C: *Has any other information come to light that could call into question the protectiveness of the remedy?*

Yes. Periodic elevated concentrations of perchlorate and the increasing trend in wells located near Harrison Bayou are of concern. In addition, the elevated perchlorate plume extending outside the boundaries of LHAAAP18/24 to the east to well 18WW17 and the low recovery rate at this well is of concern. Increase in TCE concentrations from ND in 1994 to levels recently measured (ranges of 200 and 700 µg/L) in a well located 77 ft. upgradient of Harrison Bayou is of concern.

6.10.2 Summary of the Technical Assessment

Based on the reviewed data, site inspection, and interviews, the interim remedy is functioning as intended only for the short-term, since the final remedy has not been selected. The system will likely have additional avoidable shutdowns unless performance monitoring with effective data management, and acid tank leaks, are addressed.

6.11 Issues

The Fourth Five-Year Review has identified one issue listed in Table 17.

Table 17. Issues at LHAAP 18/24, Karnack, TX.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
Groundwater treatment plant operation experiences frequent breakdowns resulting in excessive down time, reduced mass removal, increasing potential impacts to Harrison Bayou.	No	Yes

6.12 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 18.

Table 18. LHAAP 18/24 Recommendations and Follow-up Actions.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
Groundwater treatment plant operation experiences frequent breakdowns resulting in excessive down time, reduced mass removal, increasing potential impacts to Harrison Bayou.	♦ Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.	US Army	USEPA & TCEQ	Sep 2020	No	Yes

6.12.1 Other Findings

- GAC is redundant. Consider removing GAC from the treatment train.
- Track LHAAP-18/24 O&M costs separately from LHAAP-16.

6.13 Protectiveness Statement

The remedy at LHAAP-18/24 currently protects human health and the environment because soil removal/treatment, groundwater extraction, and groundwater monitoring have reduced and/or prevented further migration of contaminants of concern into deeper groundwater zones and surface water bodies, thereby eliminating or minimizing the potential for exposure to human and ecological receptors. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness: Implement the preferred alternative identified in the 2019 Proposed Plan, consisting of enhanced groundwater extraction and treatment, Land Use Controls (LUCs), enhanced in-situ bioremediation (EISB) inside and outside of the containment area in the shallow zone and in the Wilcox Formation, unsaturated soil excavation and off-site disposal, and thermal dense non-aqueous phase liquid (DNAPL) removal.

7.0 LHAAP-37 CHEMICAL LABORATORY

LHAAP-35B (37) Chemical Laboratory encompasses about 12.2-acres in the central part of the former LHAAP Plant 3, located south of the intersection of Avenue P and 59th Street (Figure 19). The surface features at LHAAP-35B (37) include a mixture of asphalt-paved roads and parking area, building foundation remnants from several administration buildings and the former Chemical Laboratory (Building 29-A), and a mixture of wooded and grassy vegetation-covered areas (US Army, 2010b). The topography in this area is relatively flat with the surface drainage flowing into Goose Prairie Creek. The creek runs perpendicular to the western border of the site and then turns south through the east central portion of the site and eventually drains into Caddo Lake.

7.1 Site Chronology

Significant site events and dates are in Table 19. No enforcement orders have been issued for the Site.

Table 19. LHAAP-37 chronology of site events (AECOM, 2016e, ABS, 2015, US Army, 2010b).

Event	Date
Plant 3 became operational	December 1954
Chemical Laboratory construction	1953-1955
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP, and assigned numbers currently in use to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Staging area for site investigations.	1998
Remedial Investigation completed	January 2002
Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake),	June, 2003
Feasibility Study completed	October 2005
Final Baseline Ecological Risk Assessment	November 2007
Proposed Plan	June 2008
Record of Decision	June 2010
Remedial Action Work Plan	June 2013
bio plug Pilot Study Final Report	June 2015
Remedial Action Completion Report	September 2016

7.2 History of Contamination

The Chemical Laboratory was built during the construction of Plant 3 (1953-1955) and was originally used to support the production activities at LHAAP. These support activities included research and testing of materials used in the production processes and quality assurance testing. One waste rack sump was located at the site.

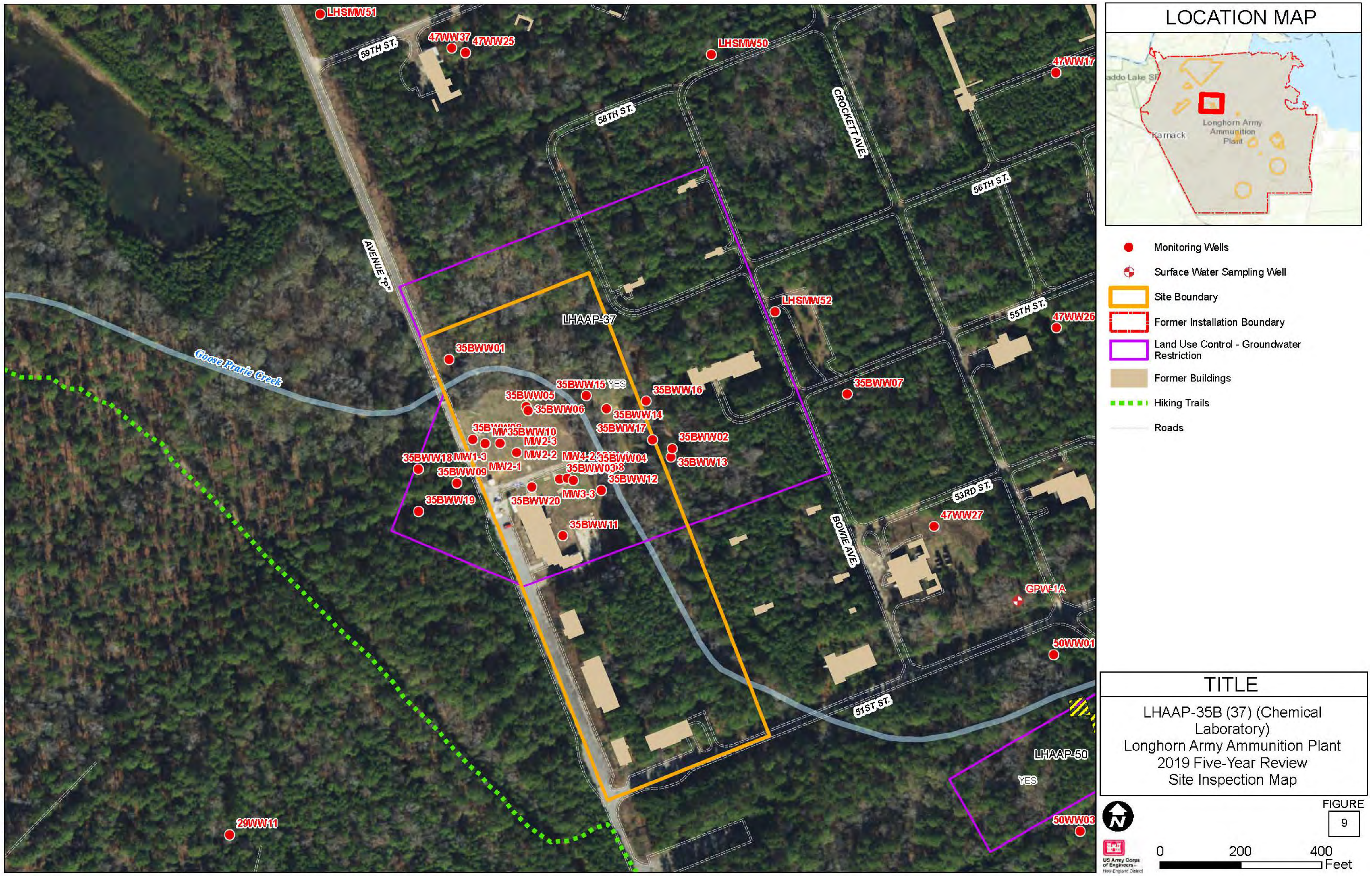


Figure 19. LHAAP-37 Site map showing 2018 site inspection observations (LHAAP, 2018a, Landmark Consultants, 2015a, TNRIS, 2015, USGS, 2011).

7.3 Initial Response

No initial response actions occurred at LHAAP-37 beyond CERCLA investigations listed in Table 16.

7.4 Summary of Basis for Taking Action

The LHAAP-37 investigations and risk assessments identified TCE, PCE, and 1,1-DCE as the primary COCs at the Site, broken down by media below (US Army, 2010, Shaw, 2007c, d, Jacobs, 2003). Groundwater was determined by the baseline risk assessment to pose an unacceptable risk or hazard to a hypothetical future maintenance worker at LHAAP-35B (37) under an industrial scenario (Jacobs, 2003). The primary COCs for LHAAP-35B (37) groundwater are TCE, PCE, and 1,1-DCE due to their significant contribution to the total risk. Additionally, hazardous substances present in LHAAP-35B (37) groundwater could also potentially discharge to surface water in Goose Prairie Creek, which flows to Caddo Lake, a drinking water supply. The basis for taking action was presence of 1,1-DCE, PCE, TCE, 2,3,7,8-tetrachlorodibenzop-dioxin (TCDD)and two inorganics (thallium and antimony) in groundwater at concentrations posing an unacceptable risk to an industrial worker.

7.5 Remedial Actions

7.5.1 Remedy Selection

The selected LHAAP-37 remedy for addressing the site contaminants and meeting the remedial objectives of the ROD was a combination of groundwater land use controls and MNA (US Army, 2010b). The RAOs to meet the ROD's remediation goals (Table 20) are:

- Protection of human health by preventing human exposure to the contaminated groundwater;
- Protection of human health and the environment by preventing contaminated groundwater from migrating into nearby surface water; and,
- Return of groundwater to its potential beneficial use as drinking water, wherever practicable.

Table 20. LHAPP-37 groundwater chemicals of concern and remedial goals (AECOM, 2016c, US Army, 2010b).

Chemical	Remedial Goal (µg/L)	Basis
1,1-Dichloroethene	7	MCL
Tetrachloroethene	5	MCL
Trichloroethene	5	MCL

Table 20 applies to surface water in the event of remedy failure.

The remedy consists of (US Army, 2010b):

- Groundwater LUC. Ensure protection of human health by restricting the use of groundwater exceeding cleanup levels to environmental monitoring and testing only. The LUC will remain in effect until the Army, and USEPA agree and TCEQ concurs that the concentrations of COCs have met cleanup levels.
- MNA. Passive remedial action that relies on natural biological, chemical, and physical processes that act to reduce the mass and concentrations of groundwater COCs under favorable conditions. A program of MNA will be implemented to establish confidence in

attenuation trends and verify that the plume is stable and will not migrate to nearby surface water at levels that may present an unacceptable risk to human health or the environment. Natural attenuation is expected to reduce contaminant concentrations to their respective clean-up levels, and return groundwater to its beneficial use, wherever practicable. Performance objectives for the MNA program will be re-evaluated after two years of groundwater monitoring following completion of an ongoing bio plug demonstration study. During those two years, groundwater monitoring will be performed on a quarterly basis.

- Long-term Monitoring: LTM will begin at a semiannual frequency after the first two years until the CERCLA Five-Year Review. In subsequent years, LTM will be performed annually until the following CERCLA Five-Year Review. The LTM associated with this remedy will be used to track the continued effectiveness of MNA and will continue at least once every five-years until the cleanup levels are achieved. The need for continued monitoring will be evaluated every five-years during the CERCLA Five-Year Review.

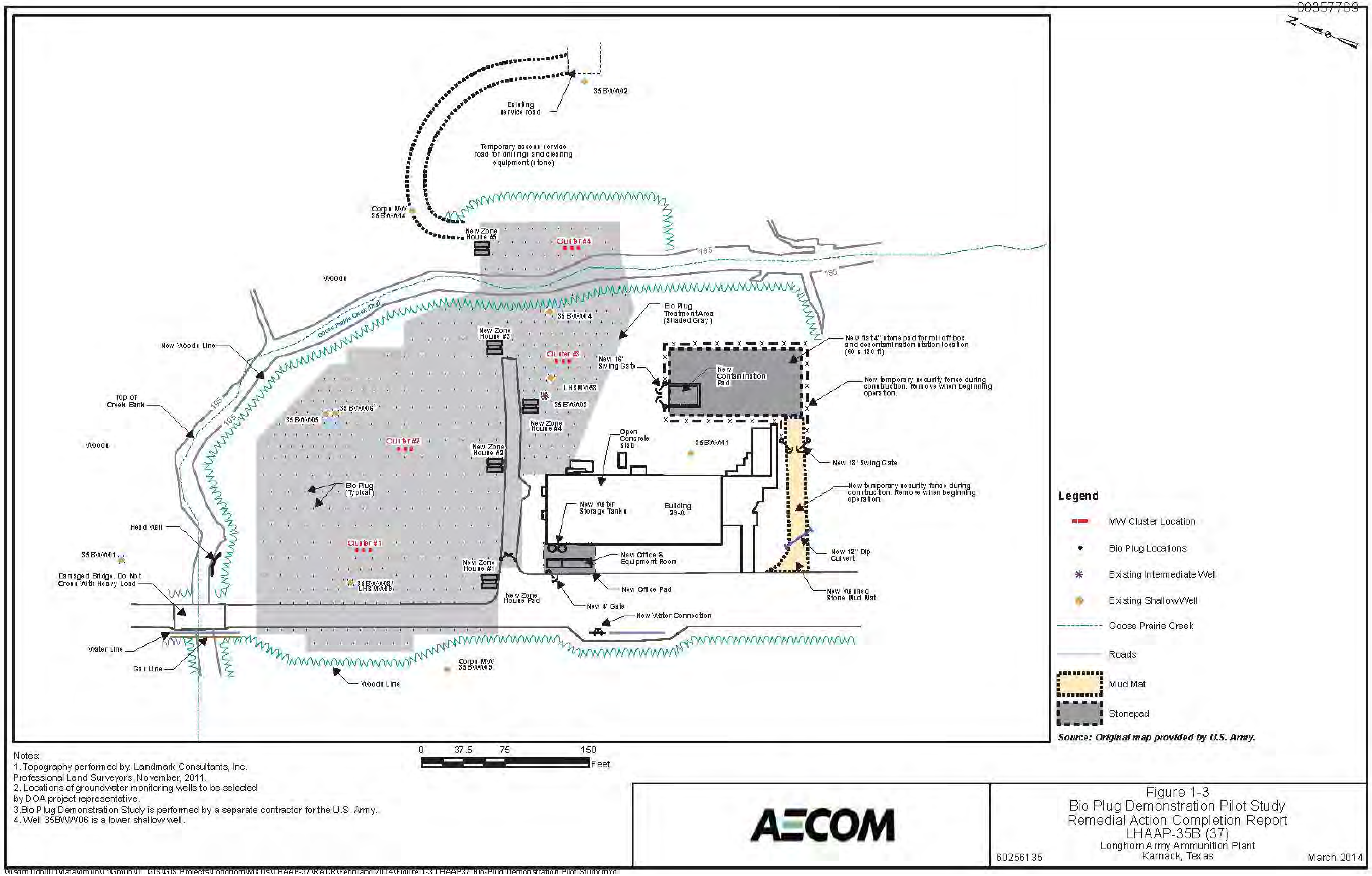
Because the LHAAP-37 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA §121(c), U.S. Code (U.S.C.) Title 42 §9621(c).

7.5.2 Remedy Implementation

7.5.2.1 MNA

Field demonstration pilot study of a bio plug technology was initiated at the LHAAP-35B (37) site in September 2012 delaying implementation of the MNA remedy. The bio plug technology at Site 37 was a method of augmenting and enhancing aerobic in-situ biological degradation of chlorinated organic contaminants. Figure 20 depicts the array of bio plug wells installed across the LHAAP-35B (37) site and the monitoring wells installed for performance monitoring during the bio plug demonstration study. After completion of the demonstration study, aquifer conditions were allowed to return to baseline before initiating the MNA remedy.

Initial plume delineation activities were performed from July through September 2013 and May through July 2014 to refine the extent of contamination in the Shallow Groundwater Zone. Based on the results of these initial plume delineation activities, it was determined additional control was required for long-term delineation of the VOC plume in the north and northwestern portion of the site. In May 2016, three additional Shallow Groundwater Zone monitoring wells were installed in the north and northwestern portion of the site to evaluate the effectiveness of MNA in that area. The first MNA monitoring event took place in November 2017, so remedy implementation evaluation using chemistry data trends will be done in the 2024 Five-Year Review.



Source: Original map provided by U.S. Army.

Notes:
1. Topography performed by: Landmark Consultants, Inc. Professional Land Surveyors, November, 2011.
2. Locations of groundwater monitoring wells to be selected by DOA project representative.
3. Bio Plug Demonstration Study is performed by a separate contractor for the U.S. Army.
4. Well 35BWW06 is a lower shallow well.

Figure 1-3
Bio Plug Demonstration Pilot Study
Remedial Action Completion Report
LHAAP-35B (37)
Longhorn Army Ammunition Plant
Karnack, Texas
60256135
March 2014

Figure 20. LHAAP-37 Bio Plug locations – Shallow Groundwater Zone (AECOM, 2016e).

Groundwater models suggest groundwater may discharge to Goose Prairie Creek under normal or high conditions (Shaw, 2009). Surface water is to be sampled only when the groundwater elevation in the Shallow Groundwater Zone well 35BWW05 and 35BWW12 are at or above the creek bottom elevation at surface water sampling points 35BSW01 and 35BSW02, respectively. The first surface water sampling took place in 2018, so remedy implementation evaluation of groundwater and surface water link will be done in the 2018 RAO report.

7.5.2.2 Land Use Controls

The LHAAP-37 LUC objectives are to prevent human exposure to Shallow Groundwater Zone contamination presenting an unacceptable risk to human health and ensure that there is no withdrawal or use of groundwater beneath the site for anything other than environmental monitoring and testing until the cleanup levels are attained. Notification of the groundwater use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566 (US Army, 2015a). The Army provided a survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map to the Texas Department of Licensing and Regulation in hard and electronic copy.

The LUC boundary was surveyed in September 2015, defining the area restricting groundwater use to environmental purposes (Landmark Consultants, 2015a). The groundwater use restriction has been filed with Harrison County.

7.5.3 Operations, Maintenance, and Monitoring

LHAAP-37 OM&M activities are:

- Collection of monitoring well and piezometer water-level measurements and groundwater samples
- Data compilation, records upkeep, and submittal of reports
- Maintenance of monitoring well network and routine maintenance activities (mowing, etc.)

The MNA program began during the Fourth Five-Year Review site inspection. Cost data is not available (USACE, 2018).

7.6 Compliance Monitoring

The groundwater use restriction against residential use of groundwater was implemented with the 2016 recordation of the restriction in Harrison County, Texas, and regular inspection commenced with the beginning of the RAO phase in November 2017. However, the first year RAO was still underway and not yet available at the close of the review period in May 2018.

The Army conducts groundwater and surface water monitoring to track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs (AECOM, 2014c).

7.7 Progress since the Last Five-Year Review

This is the first five-year review for LHAAP-37.

7.8 Five-year Review Process

7.8.1 Data Review

A long-term monitoring program has been implemented to monitor the natural attenuation of Site-related contamination, as required by the ROD. Data for each media are summarized below. Summary data and statistical tables are in Appendix F.

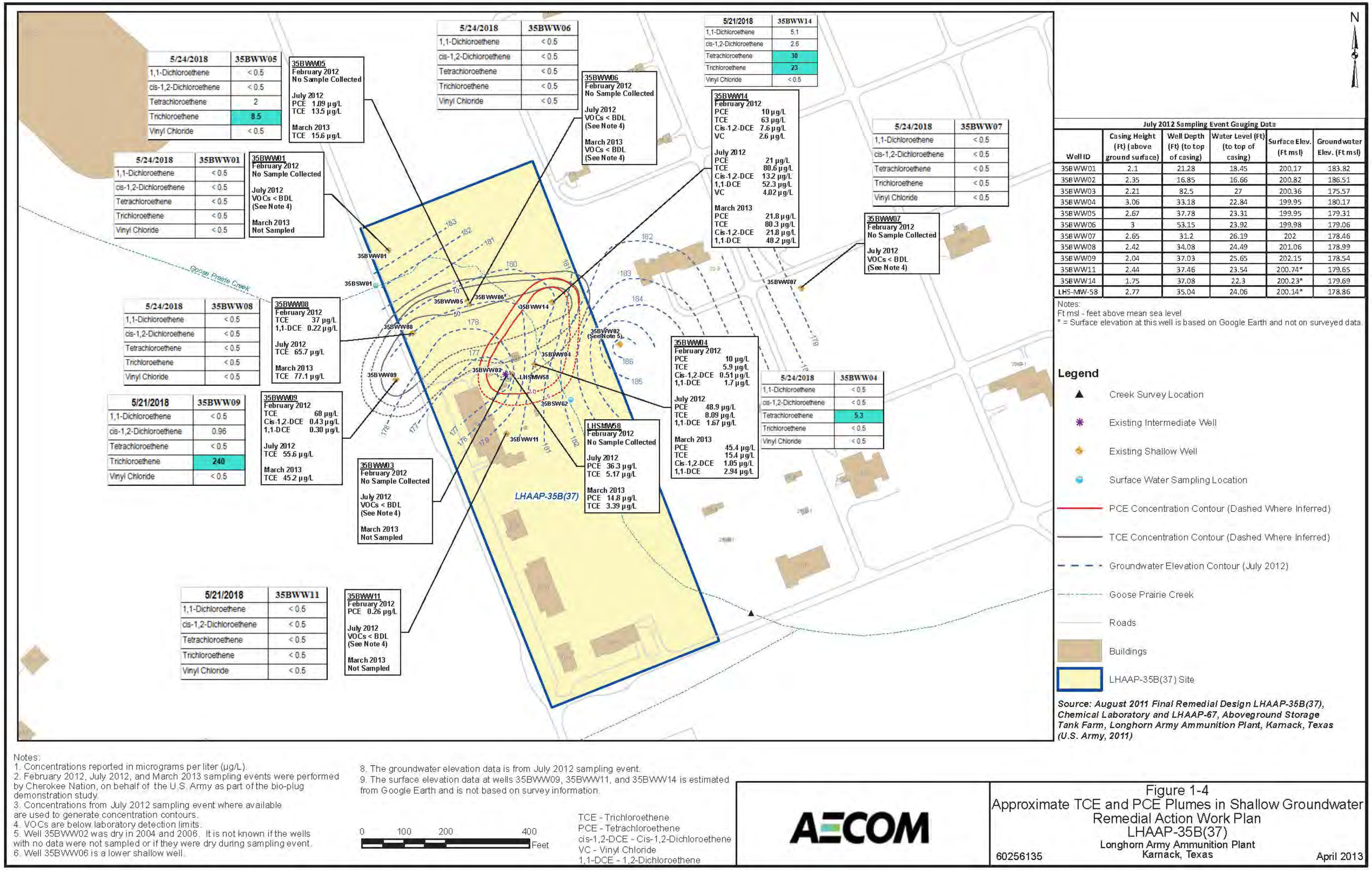
7.8.1.1 Groundwater

PCE, TCE and 1,1-DCE are the Shallow Groundwater Zones COCs in LHAAP-35(B) 37 (Figure 21). COCs were not encountered in the lower interval of the Shallow Groundwater Zone or in the Intermediate Groundwater Zone. These findings are based on data gathered from one location in each zone paired with shallow zone wells with VOCs above the MCL. The footprints of PCE and 1,1-DCE in the Shallow Groundwater Zone have been delineated in the baseline 2013 sampling event (Figure 21). However, it is uncertain that the footprint of the TCE is delineated to the north. TCE concentration of 5.5 µg/L, in perimeter well located along the north is slightly above the MCL (Figure 22, Table 21 and Table 22). The north perimeter well was installed subsequent to the 2013 delineation of the baseline COCs footprints, and was only sampled once. The first sampling event for evaluation of MNA performance took place in May 2018, allowing sufficient time for conditions in groundwater to restore to those existing prior to the bio plug study. Therefore, the available data are insufficient to evaluate trends or MNA performance.

Groundwater flow directions in the shallow zone and intermediate zones are to the south-southeast, although the shallow groundwater flow direction may vary locally during high water table conditions due to the influence of Goose Prairie Creek (Figure 2, Figure 3, and Figure 4). Under high groundwater conditions, shallow groundwater may discharge into Goose Prairie Creek and Caddo Lake (US Army, 2010b).

7.8.1.2 Surface Water

VOCs above laboratory detection limits were not detected in the baseline surface water sampling event of October 17, 2013. The Record of Decision for LHAAP-37 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.



5/24/2018	35BWW05
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	2
Trichloroethene	8.5
Vinyl Chloride	< 0.5

35BWW05
February 2012
No Sample Collected

July 2012
PCE 1.09 µg/L
TCE 13.5 µg/L

March 2013
TCE 15.6 µg/L

5/24/2018	35BWW01
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

35BWW01
February 2012
No Sample Collected

July 2012
VOCs < BDL
(See Note 4)

March 2013
Not Sampled

5/24/2018	35BWW06
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

35BWW06
February 2012
No Sample Collected

July 2012
VOCs < BDL
(See Note 4)

March 2013
VOCs < BDL
(See Note 4)

5/21/2018	35BWW14
1,1-Dichloroethene	5.1
cis-1,2-Dichloroethene	2.6
Tetrachloroethene	30
Trichloroethene	23
Vinyl Chloride	< 0.5

35BWW14
February 2012
PCE 10 µg/L
TCE 63 µg/L
Cis-1,2-DCE 7.6 µg/L
VC 2.6 µg/L

July 2012
PCE 21 µg/L
TCE 80.6 µg/L
Cis-1,2-DCE 13.2 µg/L
1,1-DCE 52.3 µg/L
VC 4.02 µg/L

March 2013
PCE 21.8 µg/L
TCE 80.3 µg/L
Cis-1,2-DCE 21.8 µg/L
1,1-DCE 48.2 µg/L

5/24/2018	35BWW07
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

35BWW07
February 2012
No Sample Collected

July 2012
VOCs < BDL
(See Note 4)

5/24/2018	35BWW08
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

35BWW08
February 2012
TCE 37 µg/L
1,1-DCE 0.22 µg/L

July 2012
TCE 65.7 µg/L

March 2013
TCE 77.1 µg/L

5/21/2018	35BWW09
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	0.96
Tetrachloroethene	< 0.5
Trichloroethene	240
Vinyl Chloride	< 0.5

35BWW09
February 2012
TCE 68 µg/L
Cis-1,2-DCE 0.43 µg/L
1,1-DCE 0.30 µg/L

July 2012
TCE 55.6 µg/L

March 2013
TCE 45.2 µg/L

35BWW03
February 2012
No Sample Collected

July 2012
VOCs < BDL
(See Note 4)

March 2013
Not Sampled

5/21/2018	35BWW11
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

35BWW11
February 2012
PCE 0.26 µg/L

July 2012
VOCs < BDL
(See Note 4)

March 2013
Not Sampled

35BWW04
February 2012
PCE 10 µg/L
TCE 5.9 µg/L
Cis-1,2-DCE 0.51 µg/L
1,1-DCE 1.7 µg/L

July 2012
PCE 48.9 µg/L
TCE 8.09 µg/L
1,1-DCE 1.67 µg/L

March 2013
PCE 45.4 µg/L
TCE 15.4 µg/L
Cis-1,2-DCE 1.05 µg/L
1,1-DCE 2.94 µg/L

5/24/2018	35BWW04
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	5.3
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

LHSMW58
February 2012
No Sample Collected

July 2012
PCE 36.3 µg/L
TCE 5.17 µg/L

March 2013
PCE 14.8 µg/L
TCE 3.39 µg/L

July 2012 Sampling Event Gauging Data

Well ID	Casing Height (Ft) (above ground surface)	Well Depth (Ft) (to top of casing)	Water Level (Ft) (to top of casing)	Surface Elev. (Ft msl)	Groundwater Elev. (Ft msl)
35BWW01	2.1	21.28	18.45	200.17	183.82
35BWW02	2.35	16.85	16.66	200.82	186.51
35BWW03	2.21	82.5	27	200.36	175.57
35BWW04	3.06	33.18	22.84	199.95	180.17
35BWW05	2.67	37.78	23.31	199.95	179.31
35BWW06	3	53.15	23.92	199.98	179.06
35BWW07	2.65	31.2	26.19	202	178.46
35BWW08	2.42	34.08	24.49	201.06	178.99
35BWW09	2.04	37.03	25.65	202.15	178.54
35BWW11	2.44	37.46	23.54	200.74*	179.65
35BWW14	1.75	37.08	22.3	200.23*	179.69
LHS-MW-58	2.77	35.04	24.06	200.14*	178.86

Notes:
Ft msl - feet above mean sea level
* = Surface elevation at this well is based on Google Earth and not on surveyed data.

Legend
▲ Creek Survey Location
✳ Existing Intermediate Well
◆ Existing Shallow Well
● Surface Water Sampling Location
— PCE Concentration Contour (Dashed Where Inferred)
— TCE Concentration Contour (Dashed Where Inferred)
- - Groundwater Elevation Contour (July 2012)
---- Goose Prairie Creek
— Roads
▨ Buildings
▭ LHAAP-35B(37) Site

Source: August 2011 Final Remedial Design LHAAP-35B(37), Chemical Laboratory and LHAAP-67, Aboveground Storage Tank Farm, Longhorn Army Ammunition Plant, Karnack, Texas (U.S. Army, 2011)

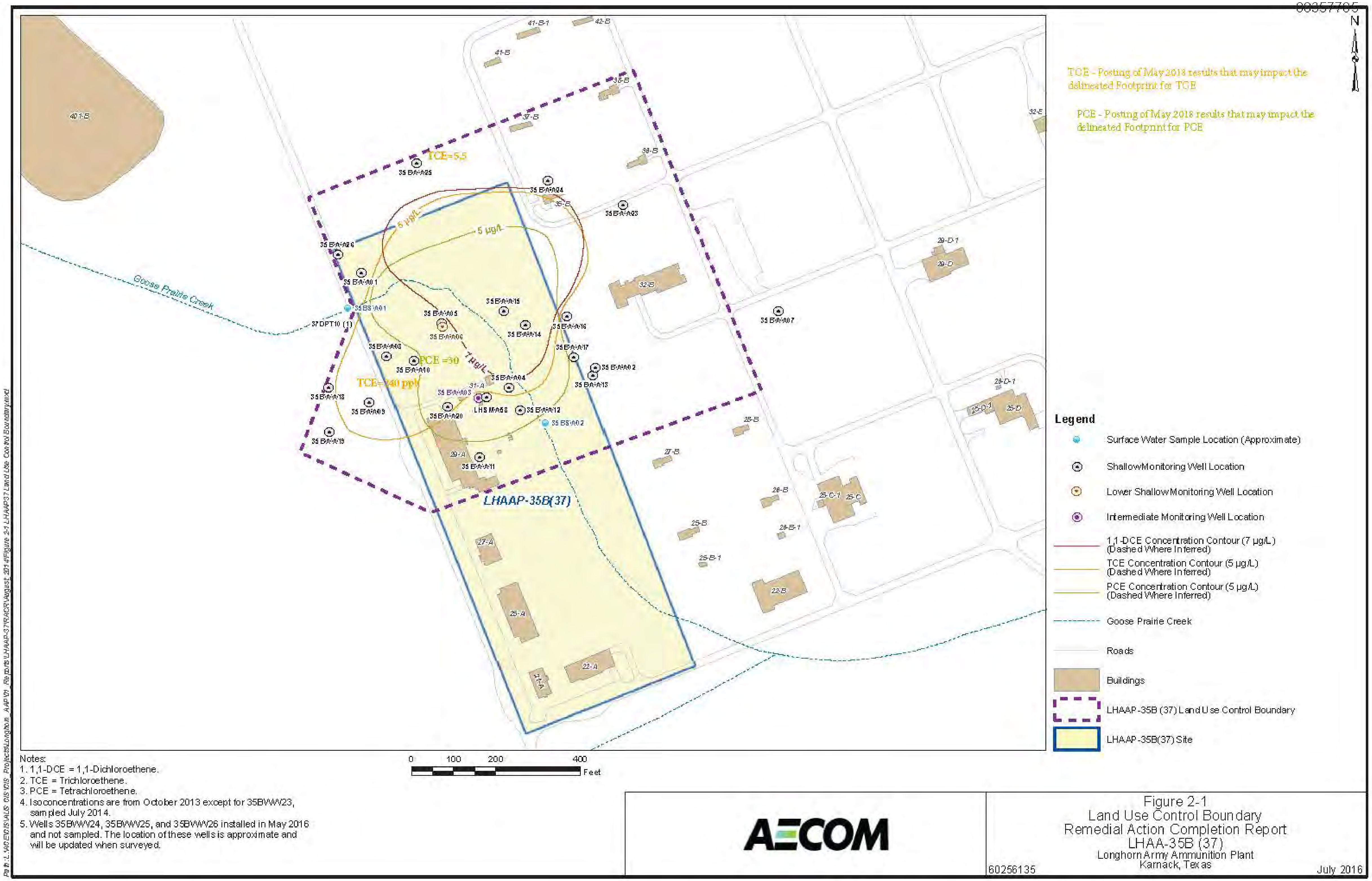
Notes:
1. Concentrations reported in micrograms per liter (µg/L).
2. February 2012, July 2012, and March 2013 sampling events were performed by Cherokee Nation, on behalf of the U.S. Army as part of the bio-plug demonstration study.
3. Concentrations from July 2012 sampling event where available are used to generate concentration contours.
4. VOCs are below laboratory detection limits.
5. Well 35BWW02 was dry in 2004 and 2006. It is not known if the wells with no data were not sampled or if they were dry during sampling event.
6. Well 35BWW06 is a lower shallow well.
8. The groundwater elevation data is from July 2012 sampling event.
9. The surface elevation data at wells 35BWW09, 35BWW11, and 35BWW14 is estimated from Google Earth and is not based on survey information.

TCE - Trichloroethene
PCE - Tetrachloroethene
cis-1,2-DCE - Cis-1,2-Dichloroethene
VC - Vinyl Chloride
1,1-DCE - 1,2-Dichloroethene

AECOM

Figure 1-4
Approximate TCE and PCE Plumes in Shallow Groundwater
Remedial Action Work Plan
LHAAP-35B(37)
Longhorn Army Ammunition Plant
Karnack, Texas
60256135
April 2013

Figure 21. LHAAP-37 COCs concentration pre Bio Plug, 2012 – Intermediate Groundwater Zone (35BWW03), Lower Interval Shallow Groundwater Zone (35BWW06), and Shallow Groundwater Zone (AECOM, 2013h).



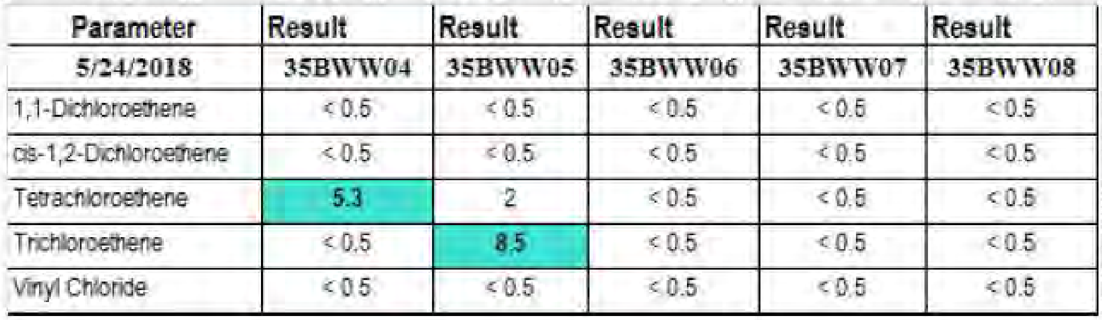
Notes:
1. 1,1-DCE = 1,1-Dichloroethene.
2. TCE = Trichloroethene.
3. PCE = Tetrachloroethene.
4. Isoconcentrations are from October 2013 except for 35BWW23, sampled July 2014.
5. Wells 35BWW24, 35BWW25, and 35BWW26 installed in May 2016 and not sampled. The location of these wells is approximate and will be updated when surveyed.

Figure 2-1
Land Use Control Boundary
Remedial Action Completion Report
LHAA-35B (37)
Longhorn Army Ammunition Plant
Karnack, Texas
60256135
July 2016

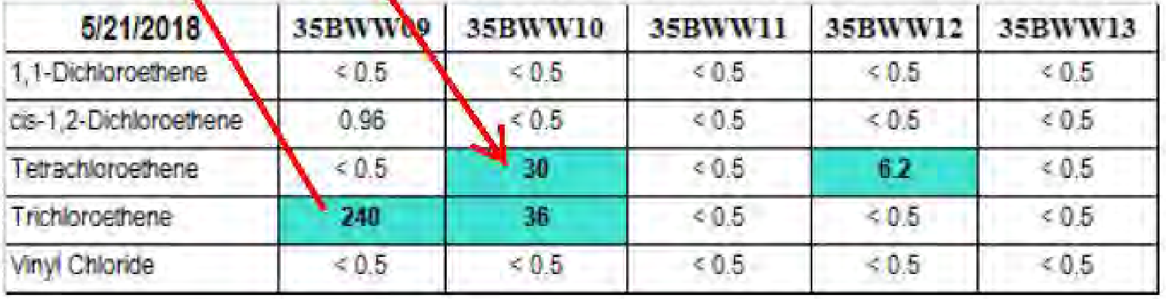
Figure 22. LHAAP-37 MNA baseline footprints - 2013/2014, and selected posting of May 2018 COCs potentially affecting the extent of the footprints (AECOM, 2016e & Fourth Five-Year Review).

Table 21. LHAAP-37 baseline COCs (2013) & first MNA sampling event (May 2018) (AECOM, 2016e & Fourth Five-Year Review).

Location ID: Sample Date:	Units	Cleanup Level(1)	35BWW03-100513 10/5/2013	35BWW04-100313 10/3/2013	35BWW05-100413 10/4/2013	35BWW06-100413 10/4/2013	35BWW07-100513 10/5/2013	35BWW08-100913 10/9/2013	35BWW09-100813 10/8/2013	35BWW10-100413 10/4/2013	35BWW10FD-100413 10/4/2013	35BWW11-100813 10/8/2013	35BWW12-100313 10/3/2013	35BWW13-100713 10/7/2013
Volatile Organic Compounds (8260B)														
1,1-Dichloroethene	µg/L	7	<1 U	2.3 J	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U
cis-1,2-Dichloroethene	µg/L	70	<0.5 U	0.673 J	0.295 J	<0.5 U	<0.5 U	<0.5 U	0.529 J	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U
Tetrachloroethene	µg/L	5	<0.5 U	66.5 J	1.57	<0.5 U	<0.5 U	<0.5 U	<0.5 U	4.45	4.52	0.252 J	15.3	4.14
trans-1,2-Dichloroethene	µg/L	100	<0.5 U	<0.5 UJ	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U
Trichloroethene	µg/L	5	<0.5 U	11.4 J	14	<0.5 U	<0.5 U	43.8	49	56.3	56.9	<0.5 U	2.04	1.84
Vinyl Chloride	µg/L	2	<0.5 U	<0.5 UJ	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U



Parameter 5/24/2018	Result 35BWW04	Result 35BWW05	Result 35BWW06	Result 35BWW07	Result 35BWW08
1,1-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
cis-1,2-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Tetrachloroethene	5.3	2	< 0.5	< 0.5	< 0.5
Trichloroethene	< 0.5	8.5	< 0.5	< 0.5	< 0.5
Vinyl Chloride	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5



5/21/2018	35BWW09	35BWW10	35BWW11	35BWW12	35BWW13
1,1-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
cis-1,2-Dichloroethene	0.96	< 0.5	< 0.5	< 0.5	< 0.5
Tetrachloroethene	< 0.5	30	< 0.5	6.2	< 0.5
Trichloroethene	240	36	< 0.5	< 0.5	< 0.5
Vinyl Chloride	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

Analytes in **bold** are Constituents of Concern (COCs). Analytes in *italic* are degradation products of some of the COCs (as a result of biological degradation pathway).

(1) - Cleanup level is based on United States Environmental Protection Agency Maximum Contaminant Level (MCL).

(2) - Samples were not collected for wells 35BWW01 and 35BWW02 as they were dry. Wells 35BWW15 and 35BWW17 were previously purged prior to sampling in October 2013; however, the turbidity in these wells remained high. As such these wells were not sampled at that time. Well 35BWW15 was sampled in January 2014 and well 35BWW17 was sampled in February 2014.

(3) 35BWW23 installed in May 2014 and sampled in July 2014.

(4) Wells 35BWW21 and 35BWW22 were intermediate zone wells planned for installation under the RAWP conditional upon impacted DPT grab groundwater samples. The DPT groundwater samples were not impacted, so these wells were not installed.

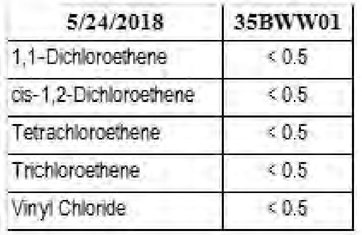
Blue highlighting indicates analyte detected above cleanup level.

J - estimated concentration

U - below laboratory reporting limit

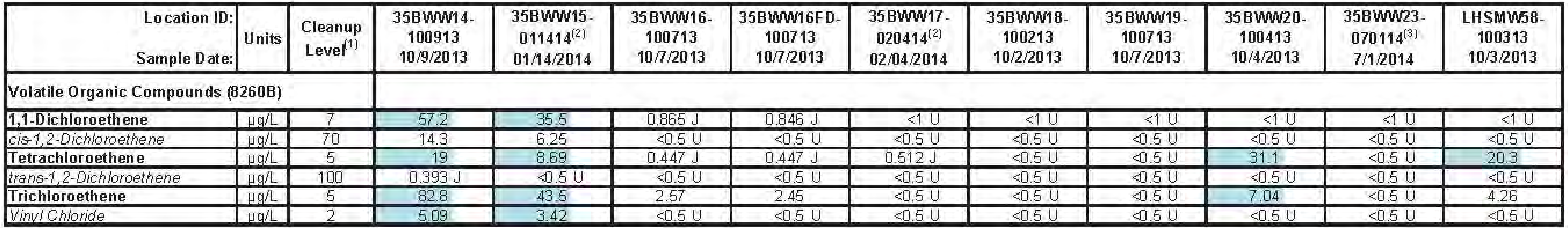
µg/L - microgram per liter

UJ - The analysis was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample. 'UJ' not detects are not definite; the analyte may be present.



5/24/2018	35BWW01
1,1-Dichloroethene	< 0.5
cis-1,2-Dichloroethene	< 0.5
Tetrachloroethene	< 0.5
Trichloroethene	< 0.5
Vinyl Chloride	< 0.5

Table 22. LHAAP-37 baseline COCs (2013 & 2014) & first MNA sampling event (May 2018) (AECOM, 2016e & Fourth Five-Year Review).



Location ID: Sample Date:	Units	Cleanup Level(1)	35BWW14-100913 10/9/2013	35BWW15-011414(2) 01/14/2014	35BWW16-100713 10/7/2013	35BWW16FD-100713 10/7/2013	35BWW17-020414(2) 02/04/2014	35BWW18-100213 10/2/2013	35BWW19-100713 10/7/2013	35BWW20-100413 10/4/2013	35BWW23-070114(3) 7/1/2014	LHSMW58-100313 10/3/2013
Volatile Organic Compounds (8260B)												
1,1-Dichloroethene	µg/L	7	57.2	35.5	0.865 J	0.846 J	<1 U	<1 U	<1 U	<1 U	<1 U	<1 U
cis-1,2-Dichloroethene	µg/L	70	14.3	6.25	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U
Tetrachloroethene	µg/L	5	19	8.69	0.447 J	0.447 J	0.512 J	<0.5 U	<0.5 U	31.1	<0.5 U	20.3
trans-1,2-Dichloroethene	µg/L	100	0.393 J	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U
Trichloroethene	µg/L	5	82.8	43.5	2.57	2.45	<0.5 U	<0.5 U	<0.5 U	7.04	<0.5 U	4.26
Vinyl Chloride	µg/L	2	5.09	3.42	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U	<0.5 U

Analytes in **bold** are Constituents of Concern (COCs). Analytes in *italic* are degradation products of some of the COCs (as a result of biological degradation pathway).

(1) - Cleanup level is based on United States Environmental Protection Agency Maximum Contaminant Level (MCL).

(2) - Samples were not collected for wells 35BWW01 and 35BWW02 as they were dry. Wells 35BWW15 and 35BWW17 were previously purged prior to sampling in October 2013; however, the turbidity in these wells remained high. As such these wells were not sampled at that time. Well 35BWW15 was sampled in January 2014 and well 35BWW17 was sampled in February 2014.

(3) 35BWW23 installed in May 2014 and sampled in July 2014.

(4) Wells 35BWW21 and 35BWW22 were intermediate zone wells planned for installation under the RAWP conditional upon impacted DPT grab groundwater samples. The DPT groundwater samples were not impacted, so these wells were not installed.

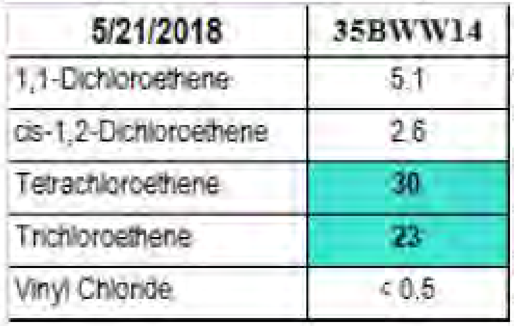
Blue highlighting indicates analyte detected above cleanup level.

J - estimated concentration

U - below laboratory reporting limit

µg/L - microgram per liter

UJ - The analysis was not detected above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample. 'UJ' not detects are not definite; the analyte may be present.



5/21/2018	35BWW14
1,1-Dichloroethene	5.1
cis-1,2-Dichloroethene	2.6
Tetrachloroethene	30
Trichloroethene	23
Vinyl Chloride	< 0.5

5/21/2018	35BWW15	35BWW16	35BWW17	35BWW18	35BWW19	35BWW20	35BWW23
1,1-Dichloroethene	3.4	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
cis-1,2-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Tetrachloroethene	13	7.8	< 0.5	< 0.5	< 0.5	29	< 0.5
Trichloroethene	13	4	< 0.5	< 0.5	< 0.5	6.3	< 0.5
Vinyl Chloride	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5

5/23/2018	35BWW24	35BWW25	35BWW26	LHSMW58
1,1-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5
cis-1,2-Dichloroethene	< 0.5	< 0.5	< 0.5	< 0.5
Tetrachloroethene	< 0.5	< 0.5	< 0.5	12
Trichloroethene	< 0.5	5.5	< 0.5	1.4
Vinyl Chloride	< 0.5	< 0.5	< 0.5	< 0.5

7.8.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

7.9 Technical Assessment

7.9.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The restriction was recorded in Harrison County, Texas on December 9, 2014. Regular inspections of the groundwater use restriction commenced during the first year of the RAO phase which began in November 2017. Although reporting was not available at the close of the review period, no land use activities beyond wildlife refuge occur at the site. Due to the implementation of a demonstration project which proved ineffective, implementation of the MNA remedy was delayed. An insufficient amount of time has passed to evaluate the MNA portion of the remedy, though TCE concentration in a perimeter well is slightly above the MCL.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. The cleanup levels identified in the Record of Decision were MCLs for groundwater and listed as: TCE (5 µg/L), PCE (5 µg/L), 1,2-DCE (7 µg/L), thallium (2 µg/L), and antimony (6 µg/L) (US Army, 2010b). Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water bodies. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

7.9.2 Summary of the Technical Assessment

The LUC portion of the remedy, a restriction against residential use of groundwater is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The restriction was recorded in Harrison County, Texas on December 9, 2014. Regular inspections of the groundwater use restriction commenced during the first year of the RAO phase which began in November 2017. Due to the implementation of a demonstration project which delayed implementation of the MNA remedy, an insufficient amount of time has passed to evaluate the MNA portion of the remedy, though TCE concentration in a perimeter well is slightly above the MCL.

7.10 Issues

None. The available data are insufficient to evaluate the MNA remedy.

7.11 Recommendations and Follow-Up Actions

The MNA remedy will be evaluated in the 2024 Five-Year Review.

7.11.1 Other Findings

None.

7.12 Protectiveness Statement

The LHAAP-35B (37) remedy is protective of human health and the environment. LUCs ensure there is no exposure, and MNA ensures a stable or decreasing plume.

8.0 LHAAP-46 PLANT 2 AREA

LHAAP-46, also known as the Plant 2 Area, is located in the north-central portion of LHAAP within the Goose Prairie Creek water shed, and covers approximately 190 acres (Figure 3, Figure 23). The surface features at the site are a mixture of asphalt-paved roads, parking areas, building foundation remnants, old buildings, and overgrown wooded and grassy vegetation-covered areas. There are no notable subsurface features. The topography in this area is relatively flat with the surface drainage flowing east into tributaries of Goose Prairie Creek, which eventually flows into Caddo Lake. The lake is a source of drinking water for several neighboring communities in Louisiana. LHAAP-46 has no known areas of archaeological or historical importance (US Army, 2010c).

8.1 Site Chronology

Significant events relevant to combined site LHAAP-46 are presented in Table 23. No enforcement orders have been issued for the Site.

Table 23. LHAAP-46 chronology of site events (AECOM, 2015e, 2012, Shaw, 2011a, 2009a, US Army, 2010c).

Event	Date
Plant 2 construction periods	1944 to early 1950s
Plant 2 operating period	1952-97
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8 1988
LHAAP placed on NPL	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Final Remedial Investigation Report for the Group 4 Sites, Sites 35A, 35B, 35C, 46, 47, 48, 50 60, and Goose Prairie Creek	January 2002
Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake),	June 2003
Data Gaps Investigation	April 2007
Final Baseline Ecological Risk Assessment	November 2007
Feasibility Study completed	October 2009
Proposed Plan	January 2010
Record of Decision	September 2010
Remedial Design	September 2011
Remedial Action Work Plan	December 2012
Remedial Action Completion Report	January 2015
RA(O) Reports	March 2018
Tech memo addressing dry wells and plan to proceed with MNA evaluation	March 2018

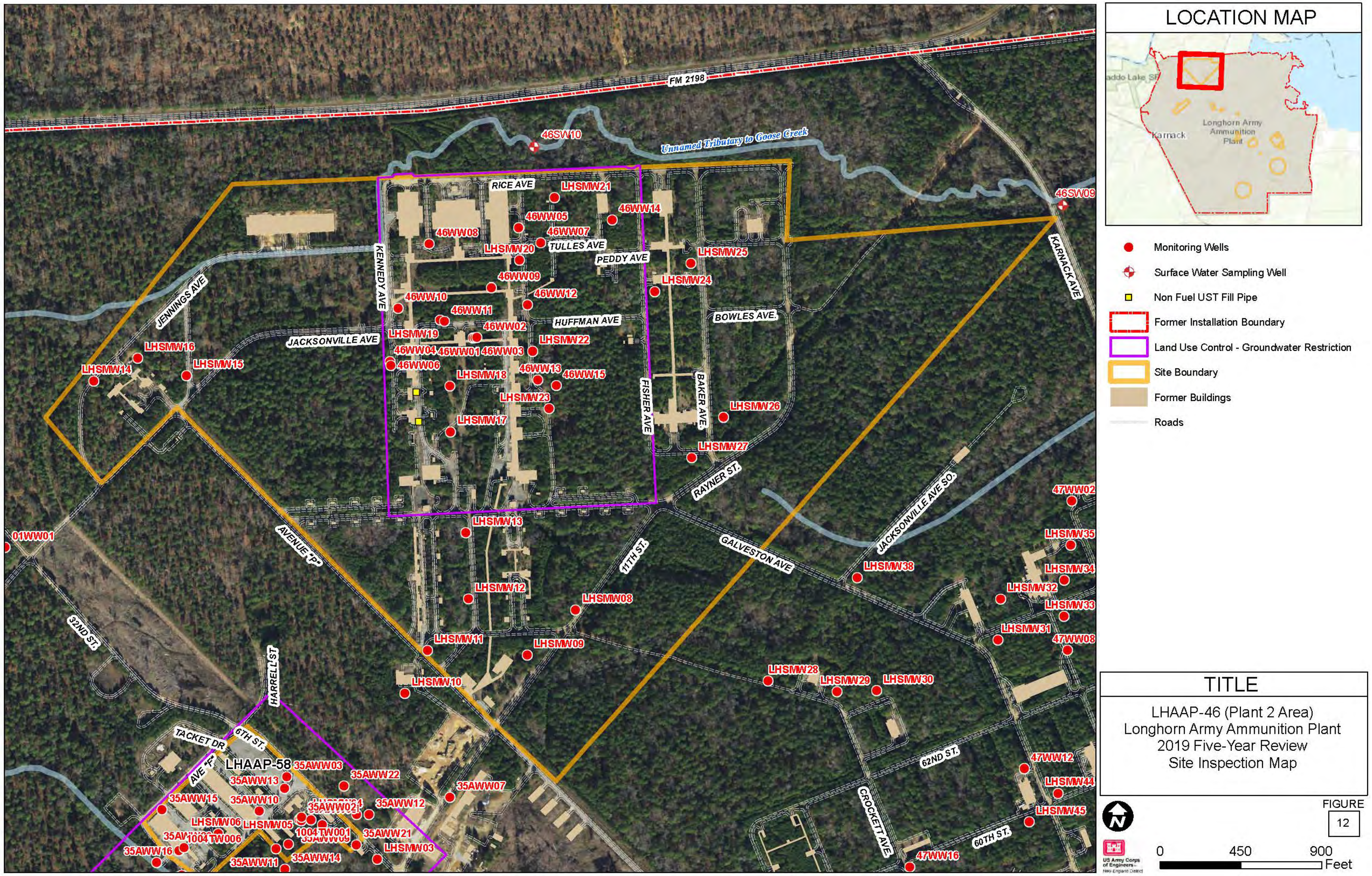


Figure 23. LHAAP-46 showing 2018 site inspection observations and groundwater land use control boundary (LHAAP, 2018a, AECOM, 2015e, TNRIS, 2015, Landmark Consultants, 2014, USGS, 2011).

8.2 History of Contamination

LHAAP was established in December 1941 and had three plants that manufactured a variety of ammunition and explosives at various times, among other industrial activities (US Army, 2010c). LHAAP-46 is the current designation of the former Plant 2 Area. Construction of facilities for producing JB-2 propellant fuel at Plant 2 began in 1944, but construction was halted in 1945 with the end of World War II. Plant 2 was used to produce pyrotechnic ammunition, such as photoflash bombs, simulators, hand signals, and tracers for 40 mm ammunition from 1952 to 1956. Plant 2 was reactivated to produce pyrotechnic and illuminating devices from 1964 to 1997. LHAAP, including Plant 2, operated until 1997 when it was placed on inactive status and classified by the U.S. Army Armament, Munitions, and Chemical Command as excess property. The original sources of contamination at LHAAP-46 were most likely small spills resulting from the services that occurred in support of the production of pyrotechnic and illumination devices. The spills would have resulted in minor soil contamination that would migrate, depending on the contaminants, through overland flow via surface runoff or through leaching to the groundwater. The forty six waste sumps and 13 waste racks formerly located at the site were not likely sources of contamination (Shaw, 2010e). All have been removed and addressed separately under LHAAP-35/36 (Jacobs, 2002c).

8.3 Initial Response

No initial response actions occurred at LHAAP-46 beyond CERCLA investigations listed in Table 20.

8.4 Summary of Basis for Taking Action

The basis for taking action was presence of TCE, DCE, VC and three inorganics (thallium, antimony, and manganese) in groundwater at concentrations posing an unacceptable risk to an industrial worker.

8.5 Remedial Actions

8.5.1 Remedy Selection

The selected LHAAP-46 remedy for addressing the site contaminants and meeting the remedial objectives of the ROD was a combination of groundwater land use controls and MNA (US Army, 2010c). The RAOs to meet the ROD's remediation goals (Table 24) are:

- Protection of human health by preventing human exposure to the contaminated groundwater;
- Protection of human health and the environment by preventing contaminated groundwater from migrating into nearby surface water; and
- Return of groundwater to its potential beneficial uses as drinking water, wherever practicable.

Table 24. LHAPP-46 groundwater chemicals of concern and remedial goals (US Army, 2010c).

Chemical	Remedial Goal (µg/L)	Basis
cis-1,2-Dichloroethene	70	MCL
Trichloroethene	5	MCL
Vinyl chloride	2	MCL

Table 24 applies to surface water in the event of remedy failure.

The remedy consists of (AECOM, 2015e):

- Groundwater LUC. LUC in the impacted area ensures protection of human health by restricting the use of groundwater to environmental monitoring and testing only. The LUC will remain in effect until the Army and USEPA agree and TCEQ concurs that COC concentrations have met cleanup levels.
- MNA.
  - Verify that the TCE plume is stable and will not migrate to nearby surface water at levels that may present an unacceptable risk to human health and the environment. MNA will return groundwater to its potential beneficial use, wherever practicable.
  - Performance Objectives. The MNA program performance objectives will be evaluated after two years of groundwater monitoring. During those two years, groundwater monitoring will be performed on a quarterly basis.
- Long-term Monitoring. MNA will be performed for two years, after which LTM will be continued at a semiannual frequency for the following three years (until the Five-Year Review). In subsequent years, LTM will be performed annually until the next 2024 Five-Year Review. LTM associated with this remedy will be used to track the continued effectiveness of MNA and will continue once every five-years until the cleanup levels are achieved. Based on the calculated attenuation rates for LHAAP-46, groundwater cleanup levels are expected to be attained through natural attenuation in approximately 23 years (Shaw, 2009). Considering the lithologic variability, particularly the lateral and vertical change from sand to clay, the time to MCL may vary by an order of magnitude.

Because the LHAAP-46 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA §121(c), U.S. Code (U.S.C.) Title 42 §9621(c).

8.5.2 Remedy Implementation

8.5.2.1 MNA

MNA at the LHAAP-46 site is implemented to monitor COCs and ensure protection of human health and the environment. Performance monitoring to evaluate remedy effectiveness includes groundwater and surface water monitoring. The groundwater monitoring program is designed to evaluate and monitor natural attenuation of COCs in both Shallow and Intermediate Groundwater Zone groundwater. The surface water monitoring program is designed to monitor potential migration of contaminated groundwater to surface water.

The monitoring program is intended to meet the following objectives:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (e.g., geochemical, hydrogeological, etc.) that may reduce the efficacy of any of the natural attenuation processes;

- Identify potentially toxic and/or mobile transformation products;
- Verify that the plumes are not expanding;
- Verify no unacceptable impact to down gradient receptors;
- Detect new releases of contaminants to the environment that could impact effectiveness of the natural attenuation remedy; and,
- Verify attainment of the remediation objectives.

The monitoring program monitors the suspected source area and downgradient directions in the Shallow and Intermediate Groundwater Zones.

8.5.2.2 Land Use Controls

The LHAAP-46 LUC objectives are to prevent human exposure to Shallow Groundwater Zone contamination presenting an unacceptable risk to human health and ensure that there is no withdrawal or use of groundwater beneath the site for anything other than environmental monitoring and testing until the cleanup levels are attained. Notification of the groundwater use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566. The survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map, have been provided to the Texas Department of Licensing and Regulation in hard and electronic copy (US Army, 2015b).

The Army and regulators will confer to determine appropriate actions should there be a failure of a LUC objective at the site after it has been transferred.

8.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. The groundwater use restriction against residential use of groundwater was implemented with the December 2014 recordation of the restriction in Harrison County, Texas, with annual inspections commencing with the RAO phase in 2014. No violations were noted during the review period. The annual inspection forms are presented in Appendix G.
The Army conducts groundwater and surface water monitoring to track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs (AECOM, 2014c). MNA performance monitoring and evaluation takes place in accordance with the approved RD (Shaw, 2011a) and RACR (AECOM, 2015e), in which the MNA performance monitoring program for LHAAP-46 was designed to meet seven objectives from Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites (USEPA, 1999). Ongoing implementation of performance monitoring is described in annual RAO reports for 2014 through 2017 of the review period.

8.7 Operations, Maintenance, and Monitoring

LHAAP-46 OM&M activities are:

- Collection of monitoring well and piezometer water-level measurements and groundwater samples

- Data compilation, records upkeep, and submittal of reports
- Maintenance of all well protective casings and pads, and mowing well access roads

8.7.1 Groundwater Monitoring

Thirty-one wells are in the maintenance and groundwater monitoring program. Not all of these wells are sampled due to drought conditions causing some wells in the Shallow and Intermediate Groundwater Zones to be dry during sampling events (see Section 2.2.4 and Figure 4).

8.7.2 Operations, Maintenance, and Monitoring Costs

From 2014 through 2016, the annual costs are stable and below those estimated in the ROD (Table 25) (US Army, 2010c). The contractor weighted the final year cost of LTM heavier than the previous years to display the contractor's commitment to completing the contract resulting in the sharp increase in monitoring costs in 2017.

Table 25. LHAAP-46 operations, maintenance, and monitoring costs by fiscal year (USACE, 2018).

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)
2013	0	0	0
2014	0	19,546	19,546
2015	0	19,546	19,546
2016	0	19,546	19,546
2017	0	39,091	39,091

8.8 Five-year Review Process

8.8.1 Data Review

Data analysis conducted by the Fourth Five-Year Review is in Appendix C, with the summaries presented below by media. Summary data and statistical tables are in Appendix F.

8.8.1.1 Groundwater

TCE and its initial breakdown products are the only wide spread COCs in the Shallow Groundwater Zone. Spatial distribution of trend analysis results (AECOM, 2017l) and COCs contours are depicted in Plot 90. TCE concentrations in wells LHSMW18 (in-plume well) and 46WW19 (in-plume well) decreased below MCL (Appendix F). TCE concentrations at 46WW11 (in-plume well, Plot 87) may drop below MCL in 8 years (well below the 23 to 230 years assumed for the MNA remedial action in the ROD), if the declining trend in concentrations is maintained. Neither the trend in well 46WW13, located east of the plume center Plot 87), nor the extent of the plume downgradient of this well could be determined because this well, located immediately east of the TCE plume center (Plot 82 and Plot 86) and other wells located east of the TCE plume center were dry since 2013 (Plot 86). Although direction of groundwater flow is toward the east, the unnamed tributary to Goose Prairie Creek (Figure 24 to Figure 26, Appendix C Plot 86), is along the northern perimeter of the plume, has not been routinely monitored due to it being dry, or the dry wells next to the tributary (LHSMW20, 46WW12, and LHSMW21).

TCE and its initial breakdown products are the only wide spread COCs in the Intermediate Groundwater Zone. Two separate footprints of TCE have been delineated in the Intermediate Groundwater Zone, one centered around 46WW02, and one centered on 46WW05 (Plot 87). Concentrations of TCE have not increased with distance from the most impacted TCE plume centered wells, 46WW02 and 46WW05 (Plot 87), and no new detections of COCs at boundary area wells have been reported, indicating no plume migration. First order decay rate for TCE estimated for the intermediate well with declining TCE concentration is identical to that estimated for the Shallow Groundwater Zone, providing the line of evidence that attenuation is occurring in part through reductive dechlorination, even though geochemical conditions are not optimal for complete reductive dechlorination (for details see Appendix C Section 5.2.2). In addition, the presence of degradation byproduct cis-1,2-DCE and VC provide additional line of evidence that reductive dechlorination is taking place (Figure 24 to Figure 26). Restoration time in one plume defined by the well showing a declining TCE trend, 46WW05, is 8 years, well below the lower range of 23 to 230 years estimated for the MNA remedial action in the ROD.

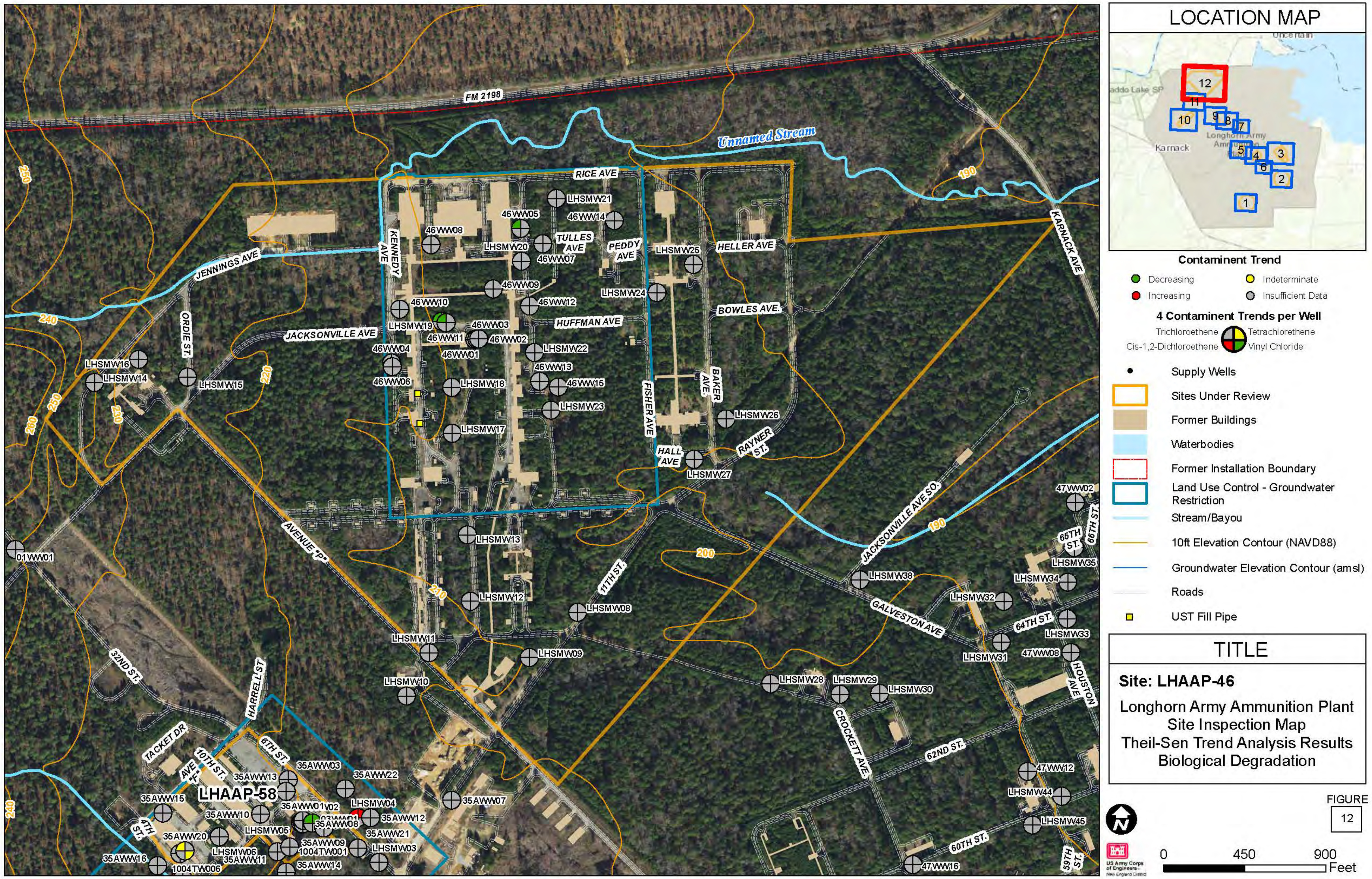


Figure 24. LHAAP-46 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2014, USGS, 2011, 2006).

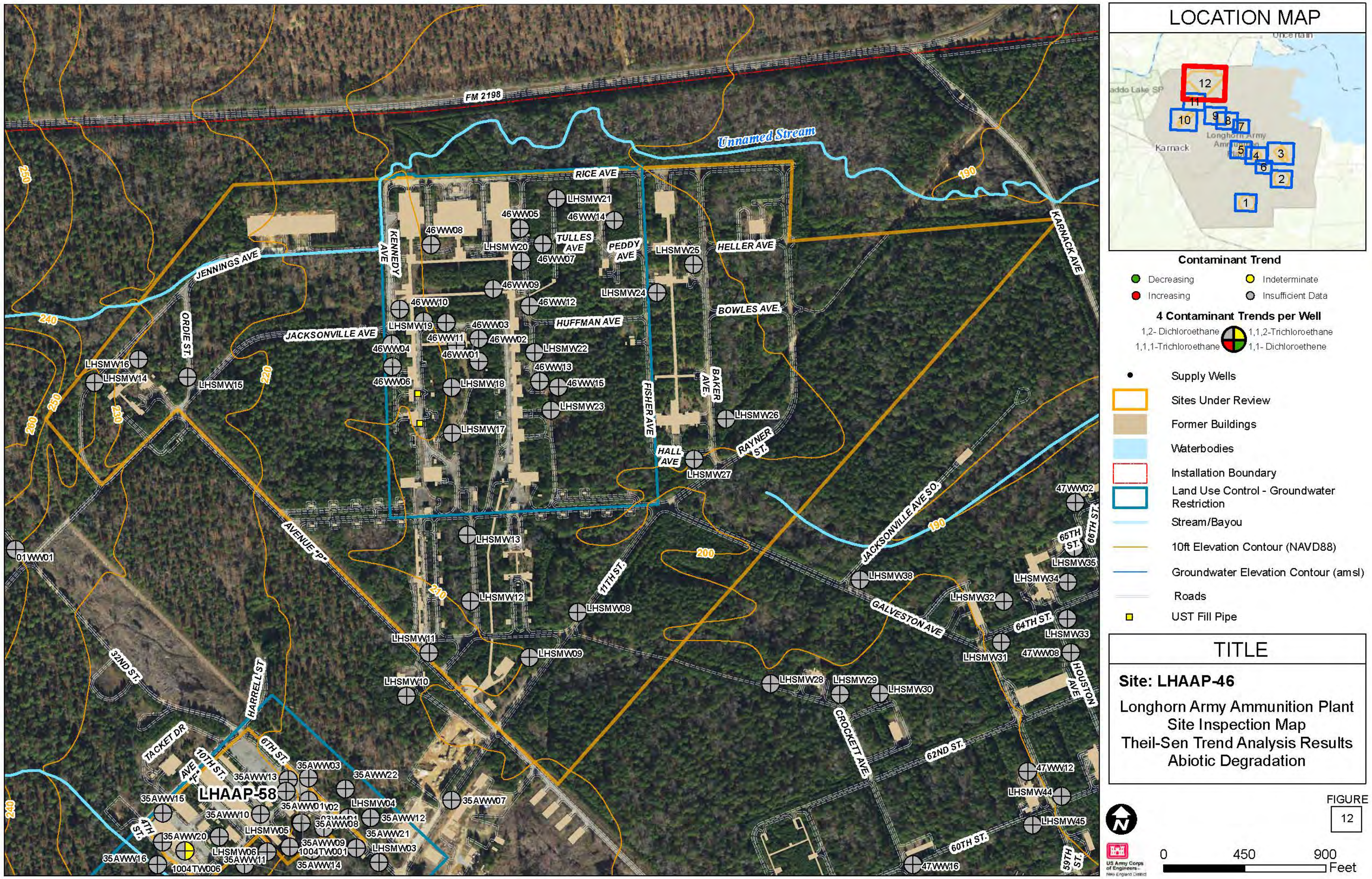


Figure 25. LHAAP-46 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2014, USGS, 2011, 2006).

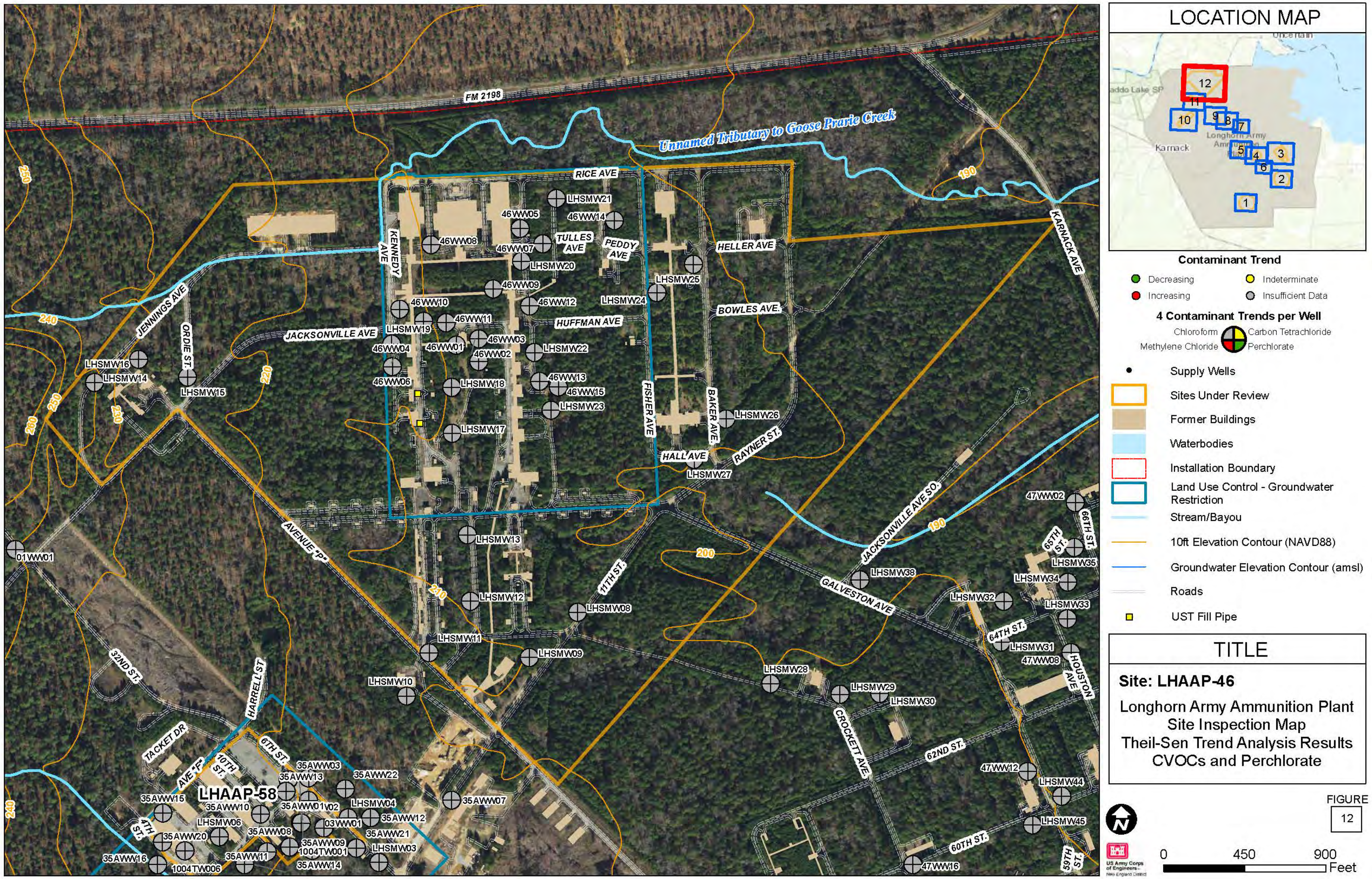


Figure 26. LHAAP-46 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2014, USGS, 2011, 2006).

Restoration time in the plume centered on 46WW02 cannot be calculated from temporal trends until the Mann-Kendall analyses show statistically declining trends at 95% confidence.

8.8.1.2 Surface Water

Surface water samples were initially (2013 and 2014) taken from 46SW09, located in Goose Prairie Creek adjacent to LHAAP-46, and were later collected from 46SW09 and 46SW10. Surface water sample 46SW10 is located in the tributary to Goose Prairie Creek (AECOM, 2015e). Sample location 46SW10 is downgradient of the Intermediate Groundwater Zone's groundwater plume but is cross gradient from the Shallow Groundwater Zone's groundwater plume (Figure 23, Plot 82, and Plot 83). No VOCs were detected in the surface water samples. The Record of Decision for LHAAP-46 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.

The pathway from groundwater to surface water is currently incomplete because the footprints of COCs do not extend to surface water bodies and because the COC plumes at LHAAP-46 appear to be stable or decreasing and are not migrating under the current meteorological conditions.

8.8.2 Site Inspection

A site inspection was conducted on 23 May 2018, which included visual inspection of the site's access roads, a subset of the monitor wells, and the western and eastern load lines (Appendix D). Drew Clemens, Chris Kilbridge, and Lily Sehayek from USACE performed the site inspection, accompanied by the USFWS refuge manager.

Land use continues to be non-residential. No signs of vandalism or dumping, and no water supply wells constructed on or near the site.

Issues identified during the Site Inspection are discussed below.

8.8.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

8.9 Technical Assessment

8.9.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The groundwater restriction was recorded in Harrison County, Texas on December 9, 2014. Inspections of the groundwater use restriction commenced on July 10, 2014 during the first year of the RAO phase. No land use activities beyond wildlife refuge occur at the site and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G. MNA appears to have stabilized the COCs' plumes. However, numerous monitoring network wells could not be sampled because they were dry. Although the drought eased in the last few years, the dry wells in the shallow zone are still dry. According to the installation "In a technical memo presented to regulators in January 2018, it is stated that the lack of water may be due to a regional decline in groundwater elevations and/or the cessation of plant activities which would have contributed water to a shallow zone. Approval was received from the regulators to begin the MNA evaluation for the site based on a reduced set of wells".

TCE concentrations in several wells located in the Shallow and Intermediate Groundwater Zones show declining trends with restoration times lower than the lower range stated in the ROD. However, there is one well with insufficient number of samples required to establish a trend, and one well where the trend cannot be established with 95% confidence. It is not known if the declining trend in TCE noted in several monitoring wells will be maintained if and when groundwater elevations are recovered during high recharge periods.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water bodies. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

8.9.2 Summary of the Technical Assessment

LUCs are in place and functioning as intended, for the groundwater use restriction is followed. MNA appears to have stabilized the COCs' plumes. However, numerous monitoring network wells that could not be sampled since they were dry. According to the installation, "the regulators have accepted the contractor's rationale that the water levels are not likely to achieve pre-drought levels and that evaluation of MNA should proceed with the current well system". TCE concentrations in several wells located in the Shallow and Intermediate Groundwater Zones show declining trends with restoration times lower than that of the lower range stated in the ROD. However, it is not known if the declining trend in TCE noted in several monitoring wells will be maintained if/when groundwater elevations are recovered during high recharge periods.

8.10 Issues

The Fourth Five-Year Review has identified one issue listed in Table 26.

Table 26. Issues at LHAAP-46, Karnack, TX.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
It is uncertain if the declining trends in TCE concentrations are maintained when groundwater elevation are recovered during high recharge periods.	No	Yes

8.11 Other Findings

- Confirm the extent of the footprint to the north by sampling LHSMW21 if 46WW12 and LHSMW20 are dry.
- Assess the two potential UST fill pipes found during the site inspection.

8.12 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 27.

Table 27. Recommendations and Follow-up Actions for LHAAP-46.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
It is uncertain if the declining trends in TCE concentrations are maintained when groundwater elevation are recovered during high recharge periods	Assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended	US Army	USEPA & TCEQ	Sep 2020	No	Yes

8.13 Protectiveness Statement

The LHAAP-46 remedy currently protects human and the environment health because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, assessment of whether declining trends (consistently dry for several sampling events) in the shallow zone monitoring wells are maintained during high recharge period, and sampling of monitoring wells when groundwater elevations are recovered is recommended.

9.0 LHAAP-49 FORMER ACID STORAGE AREA

The former Acid Storage Area is a 30-acre site situated in the west-central portion of LHAAP (Figure 27), and is the only evaluated site directly overlying the Wilcox Formation aquifer (US Army, 2010d, Albertson, 1992). The topography is relatively flat with approximately 3 to 5 feet of elevation increase from west to east. The site is currently wooded and grassy with the exception of two concrete buildings, numerous building foundation remnants, and several concrete saddles and platforms previously used for the support of aboveground storage tanks. Runoff from the site eventually enters Caddo Lake via Goose Prairie Creek.

9.1 Site Chronology

Significant site events and dates are in Table 28. No enforcement orders have been issued for the Site.

Table 28. LHAAP-49 chronology of site events (AECOM, 2014a).

Event	Date
Use of LHAAP-49 formulation and storage of acids and acid mixture.	1942 to 1945
Installation Remedial Facility Assessment reviewed all sites at LHAAP and assigned numbers to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29, 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
RCRA Part B Permit signed.	February, 1992
Initial investigation including Phase III RI to identify potential site contamination at LHAAP-49.	1998-2000
Final RI Report Addendum for the Group 2 Sites RI Report, Site 49.	February 2002
Final Group 2 Sites Baseline Human Health and Screening Ecological Risk Assessment (Sites 12, 17, 18/24, 29, 32, 49, Harrison Bayou, and Caddo Lake)	August 2002
Additional soil sampling focused primarily on lead and mercury contamination.	2002-2004
Additional groundwater sampling to address metals and nitrate/nitrite contamination in groundwater.	2005-2009
Final Baseline Ecological Risk Assessment	November 2007
Final Site Evaluation Report recommending No Action decision for LHAAP-49.	June 2009
Final ROD for LHAAP-49, and transfer to USFWS	September, 2010
Notice of Nonresidential Land Use	January 2012
First Five-Year Review	May 2014

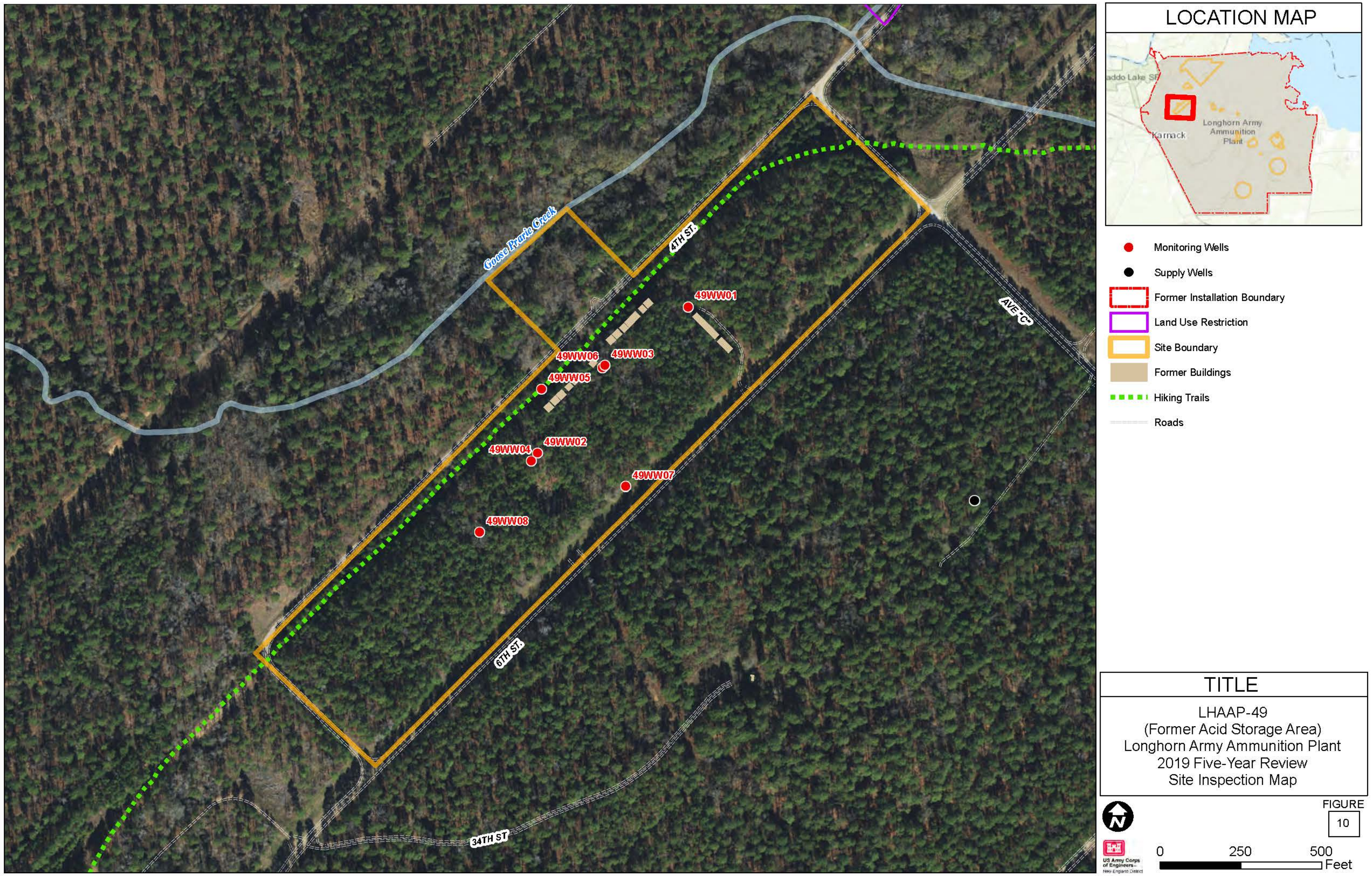


Figure 27. LHAAP-49 site map showing 2018 site inspection observations showing current conditions (LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2011a, USGS, 2011).

9.2 History of Contamination

The former Acid Storage Area or the Acid Area was used from 1942 to 1945 for the formulation and storage of acids and acid mixtures in support of TNT production during World War II (US Army, 2010d, Shaw, 2009b). Nitric acid and sulfuric acids were manufactured and handled in large quantities in this area. No known process releases occurred at LHAAP-49; however, spills could have occurred around the tanks, lines, or buildings. The original sources of contamination at LHAAP-49 probably included the buildings, piping, and tanks that were associated with on-site operations for the formulation, transfer, and storage of acids. These features may have included some components that were manufactured using lead or installed using lead-based solder. The floors of some buildings were reportedly covered with lead sheeting (Plexus, 2005). It is also possible that some of the facilities at LHAAP-49 included instrumentation (e.g., pressure gauges, thermometers) that contained mercury that was spilled during operations or demolition.

9.3 Initial Response

During the 2004 RI sampling, two soil sample locations at LHAAP-49 were found to have mercury concentrations that were markedly higher than soil samples elsewhere within LHAAP-49 (Shaw, 2007c, d). In 2008, to address TCEQ hotspot concerns, a voluntary soil removal was conducted outside the RIFS decision process by Shaw E&I. Soil near these two sample locations was removed to a depth of 1.0-foot bgs and backfilled the area with clean soil. Shaw completed these activities in October 2008 (Shaw, 2009b). In September 2010, with funding provided by USFWS, USGS collected additional soil samples at the two sample locations to confirm the absolute removal of the mercury-impacted soil. The confirmation sample results indicated that any remaining mercury concentrations were low, at or below 27 µg/kg.

No LHAAP-49 groundwater COCs were identified.

9.4 Summary of Basis for Taking No Action

The determination for the No Action decision for LHAAP-49 was based on the RI (Jacobs, 2002d), BBHRA (Jacobs 2002a), and BERA (Shaw 2007c, d). The BHHRA was performed using data from the RI, and determined that the site is suitable for nonresidential use (Jacobs, 2002a). Further, the risk evaluation, which was based on the reasonably anticipated future use as non-residential, does not address unrestricted use.

9.5 Remedial Actions

9.5.1 Remedy Selection

The ROD selected the No Action decision for LHAAP-49 (US Army, 2010d). Because hazardous substances, pollutants, or contaminants remain at the site above levels that allow for unlimited use and unrestricted exposure, a Five-Year Review will be conducted every five years to ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c). Although not a remedy, the LHAAP-49 land use assumption forms the basis for the remedy (AECOM, 2016f). The future use of the site as part of a national wildlife refuge is consistent with an industrial risk exposure scenario. Notification of the land use assumption of this site was recorded in Harrison County records stating that the site is suitable for nonresidential use in accordance with Texas Administrative Code (TAC) Title 30 §335.566 was submitted January 19 2012 (US Army, 2012).

This is a No Action decision; so RAOs do not apply and there are no chemical-specific remedial goals (US Army, 2010d).

9.5.2 Remedy Implementation

The No Action decision was selected in 2010 (US Army, 2010d).

9.6 Compliance Monitoring

Compliance monitoring does not occur at this site.

9.7 Operations, Maintenance, and Monitoring

Operations and maintenance activities do not occur at this site.

9.8 Progress since the 2014 Five-Year Review

This is the second five-year review for LHAAP-49.

9.8.1 Protectiveness Statements from the 2014 Review

Not applicable.

9.8.2 Status of Recommendations and Follow-Up Actions from the 2014 Review

None reported in the 2013 Five-Year Review.

9.8.3 Status of Other Prior Issues

None reported in the 2013 Five-Year Review.

9.9 Five-year Review Process

9.9.1 Data Review

A Google Earth imagery review showed no residential activities occurred on the site since the 2013 Five-Year Review.

9.9.2 Site Inspection

A site inspection was conducted on 23 May 2018, which included visual inspection of the site and photo documentation (Appendix D). Drew Clemens, Chris Kilbridge, and Lily Sehayek from USACE performed the site inspection, working with the USFWS.

No issues or other findings were found during the site walk and road tour. The former water supply well potentially associated with the former facility is outside the site boundary and not evaluated (Figure 2).

9.9.3 Interviews

Interview results no issues or concerns. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

9.10 Technical Assessment

9.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, with no land use activities beyond wildlife refuge occurring at the site.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

9.10.2 Technical Assessment Summary

No land use activities beyond wildlife refuge occurred at the site during the review period. The exposure assumptions, COC toxicity, and cleanup levels for soil and groundwater have not changed since the removal action and the ROD.

9.11 Issues and Recommendations

No issues were identified.

9.12 Protectiveness Summary

The LHAAP-49 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.

10.0 LHAAP-50 FORMER SUMP WATER TANK

The LHAAP-50 site (former sump water tank) is in the north-central portion of LHAAP and covers about 1 acre (Figure 28) (US Army, 2010e). The northeastern half of the LHAAP-50 is an open area of grass and brush that is bounded by South Crocket Avenue to the northeast, a drainage ditch to the west, a railroad spur to the south, and Goose Prairie Creek to the north. Runoff is collected by a drainage ditch to the northeast that runs parallel to South Crockett Avenue and eventually joins Goose Prairie Creek and Caddo Lake.

The Pleistocene terrace deposits underlying LHAAP-50 consist primarily of silty clay with thin lenses of sand (Albertson 1992). The site hydrogeology was revised in the Remedial Action Construction Report (RACR) from that used in previous documents including the ROD as follows (AECOM, 2016f):

Pre-RACR	Post RACR
Shallow Groundwater Zone	Upper Shallow Groundwater Zone (11 Wells)
Intermediate Groundwater Zone	Lower Shallow Groundwater Zone (5 wells)
Deep Zone	Intermediate Groundwater Zone (not monitored)

10.1 Site Chronology

Significant site events and dates are in Table 29. No enforcement orders have been issued for the Site.

Table 29. LHAAP-50 chronology of site events (AECOM, 2016f, US Army, 2010e).

Event	Date
Plant 3 operating period	1952-97
AST received LHAAP sump waste water	1955-1988
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8 1988
LHAAP placed on NPL	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Remedial Investigation completed	January 2002
Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake),	June 2003
Data Gaps Investigation	April 2007
Final Baseline Ecological Risk Assessment	November 2007
Feasibility Study completed	December 2009
Proposed Plan	January 2010
Record of Decision	September 2010
Remedial Design	September 2011
Remedial Action Work Plan	April 2013
Perchlorate-contaminated soil removal	August 2013
Remedial Action Completion Report	June 2016

Event	Date
Draft Final 1st Annual Remedial Action Operation Report, LHAAP-50	November 2016
Draft Final 2nd Annual Remedial Action Operation Report, LHAAP-50	November 2016

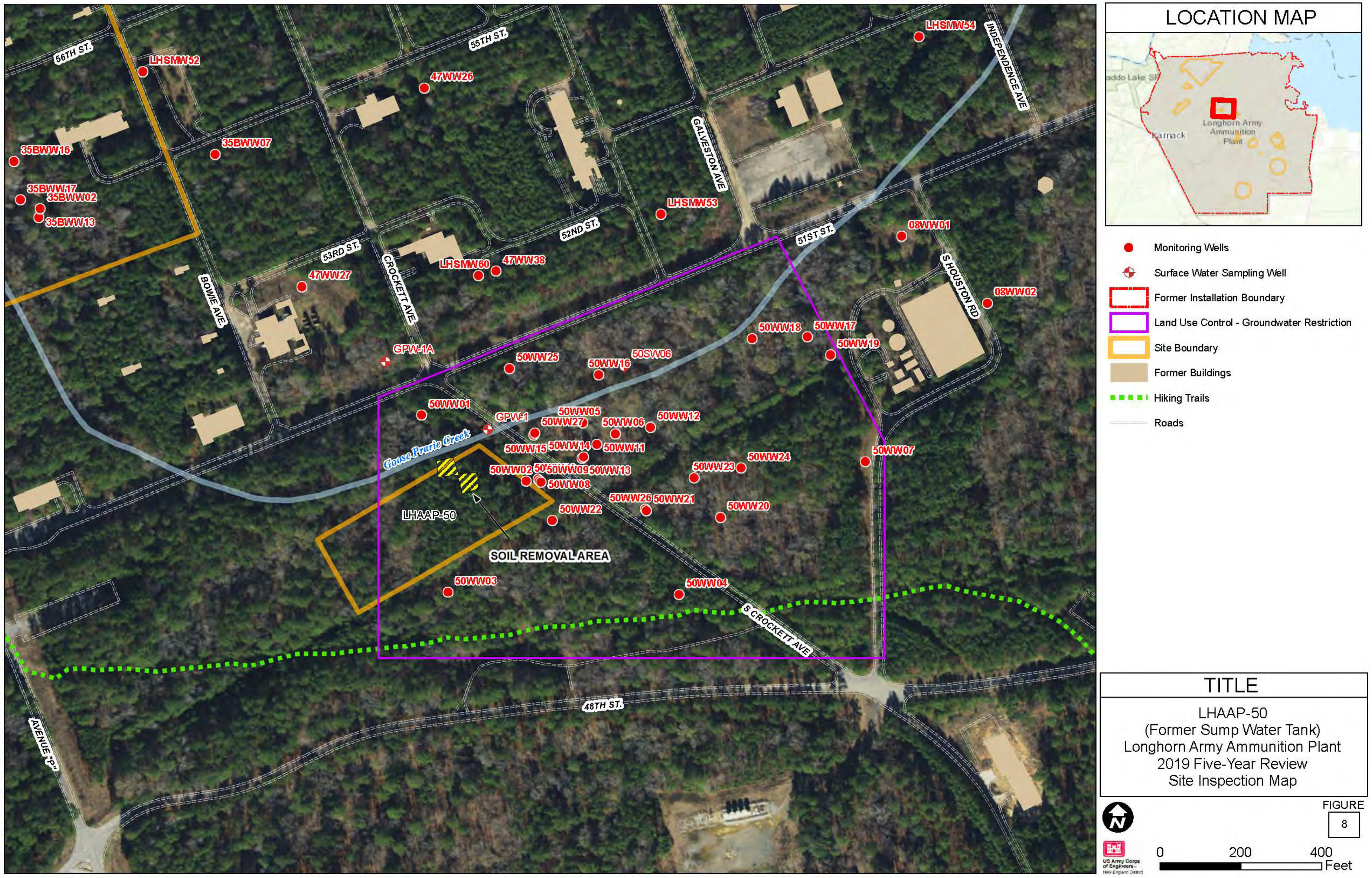


Figure 28. LHAAP-50 with Land Use Control Boundary, and nearby LHAAP-35B (37), surface water, and nearby hiking trail (LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2015b, USGS, 2011).

10.2 History of Contamination

LHAAP-50 contained a 47,000-gallon capacity aboveground storage tank (AST) which received industrial wastewater from various industrial waste production sumps throughout LHAAP from 1955 to 1988 (Shaw, 2010b). After the solids were filtered, the storage tank contents were discharged up stream of the bridge on Crockett Avenue, south of 51st Street into Goose Prairie Creek (Figure 28). The flow in the creek was sufficient to dilute the water to safe levels (Jacobs, 2003). If natural flow in the creek was considered insufficient, clean water was apparently pumped into the creek to dilute the contents.

The AST was the most likely source of contaminants being released into the environment. Because the AST has been removed, there is no longer a potential release mechanism for leaks or spills. Perchlorate and VOCs were probably released via overflows, spills, and discharges to the soil and adjacent surface water. Sufficient perchlorate levels remain in the saturated soil to act as an ongoing source of groundwater contamination or to be potentially released into surface waters during storm events. The area of perchlorate contamination in the saturated soil is very small, and the concentrations of perchlorate do not pose an unacceptable risk to human health (hypothetical future maintenance worker) or ecological receptors.

10.3 Initial Response

No initial response actions occurred at LHAAP-50 beyond CERCLA investigations listed in Table 29.

10.4 Summary of Basis for Taking Action

The basis for taking action was presence of perchlorate, TCE, VC, 1,1-DCE, and 1,2-DCA in groundwater at concentrations posing an unacceptable risk to an industrial worker. Even though the risk assessment did not conclude that exposure to soil would cause risk, additional evaluation was conducted of the soil as potential soil-to-surface water and soil-to groundwater pathways for the emerging contaminant perchlorate. The maximum concentration of perchlorate in the surface soil between 0 to 0.5 feet bgs was detected at 45,600 micrograms per kilogram (µg/kg) which exceeds the TCEQ soil Medium Specific Concentration (MSC) for industrial use based on groundwater protection (GWP-Ind) for perchlorate of 7,200 µg/kg (TCEQ, 2006). Thus, perchlorate in soil poses unacceptable risk to groundwater. Based on protection of groundwater, perchlorate was identified as a COC in soil.

10.5 Remedial Actions

10.5.1 Remedy Selection

The selected LHAAP-50 remedy for addressing the site contaminants and meeting the remedial objectives of the ROD was a combination of groundwater land use controls and MNA (US Army, 2010e). The RAOs to meet the ROD's remediation goals (Table 30) are:

- Protection of human health by preventing human exposure to the contaminated groundwater;
- Protection of human health by preventing further potential degradation of groundwater and surface water from contaminated soil;

- Protection of human health and the environment by preventing contaminated groundwater from migrating into nearby surface water; and
- Return of groundwater to its potential beneficial uses as drinking water, wherever practicable.

Table 30. LHAPP-50 chemicals of concern and remedial goals (US Army, 2010e). TCEQ groundwater (GW-Ind) and soil (GWP-Ind) medium-specific concentration for industrial use for groundwater protection, or use based on groundwater protection, respectively.

Chemical	Remedial Goal	Basis
GROUNDWATER	**(µg/L)**	
1,2-Dichloroethane	5	MCL
1,1-Dichloroethene	7	MCL
cis-1,2-Dichloroethene	70	MCL
Perchlorate	72[a]	GW-Ind
Tetrachloroethene	5	MCL
Trichloroethene	5	MCL
Vinyl chloride	2	MCL
SOIL	**(µg/Kg)**	
Perchlorate	7,200	GWP-Ind

a – The cleanup level was specified in the RACR to be 17 µg/L, the TRRP Tier 1 Residential Groundwater PCL.

Table 30 applies to surface water in the event of remedy failure.

The remedy consists of (AECOM, 2016f, US Army, 2010e):

- Soil Removal. Excavation and off-site disposal of perchlorate-contaminated soil.
- Groundwater LUC. LUC in the impacted area ensures protection of human health by restricting the use of groundwater to environmental monitoring and testing only. The LUC will remain in effect until the Army and USEPA agree and TCEQ concurs that COC concentrations have met cleanup levels.
- MNA.
  - o Program. Establish confidence in attenuation trends, verify that the perchlorate and VOC plumes are stable or shrinking, and will not migrate to surface water at levels that may present an unacceptable risk to human health or the environment. Natural attenuation is expected to reduce contaminant concentrations to their respective clean-up levels, and return groundwater to its beneficial use, wherever practicable.
  - o Performance Objectives. Re-evaluated after two years of groundwater monitoring. During those two years, groundwater monitoring will be performed on a quarterly basis. If MNA is found to be ineffective, a contingency remedy to enhance MNA will be implemented.
- Long-term Monitoring. If MNA is found to be effective at the end of the initial two-year monitoring period, LTM will continue at a semi-annual frequency for the following three years (until the first CERCLA Five-Year Review). In subsequent years, LTM will be performed annually until the next CERCLA Five-Year Review. The LTM associated with this remedy will be used to track the continued effectiveness of MNA. The need for continued monitoring and any reductions in the monitoring frequency will be evaluated every five-years during the CERCLA Five-Year Review. However, at a minimum, the LTM will continue once every five-years until the cleanup levels are achieved. Based on the calculated attenuation rates for the LHAAP-50 site, groundwater cleanup levels are

expected to be met through natural attenuation in approximately 50 years (Shaw, 2010b). This time frame will be re-evaluated as part of the MNA evaluation and periodic reviews.

Because the LHAAP-50 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

Although not a remedy, the land use assumption for LHAAP-50 forms the basis for the remedy (AECOM, 2016f). The future use of the site as part of a national wildlife refuge is consistent with an industrial risk exposure scenario. Notification of the land use assumption of this site is recorded in the Harrison County Courthouse in accordance with TAC Title 30, §335.566 and will be made in transfer documentation.

10.5.2 Remedy Implementation

10.5.2.1 Soil Removal

The planned total volume of perchlorate-contaminated soils excavated was approximately 150 cubic yards, with the actual final excavated volume being 183 cubic yards (Figure 28) (AECOM, 2016f). Excavation was performed to a minimum depth of 12 inches over the 4,000 square ft area; however, most of the area was excavated to approximately 18 inches. Confirmation samples were collected from excavation floor and sidewalls. Five-point composite soil samples were collected from areas of the excavation floor measuring approximately 750 square ft each, for six excavation floor composite samples. A single grab sample was collected from each sidewall of the excavation, for eight sidewall samples.

Results from all confirmation samples were less than the 7,200 µg/kg Texas GWP-Ind for perchlorate. Following completion of soil excavation and documentation of clean confirmation samples, the area was backfilled with clean soil to match surrounding grade. Certified clean backfill material was provided from a commercial off-site source.

10.5.2.2 Potential Perchlorate Source Area Investigation

Historical groundwater sampling information from well 50WW06 identified relatively high concentrations of perchlorate on the east side of South Crockett Avenue (Figure 28) (AECOM, 2016f). To assess whether unsaturated soils in this area constituted a perchlorate source requiring excavation, 50DPT03 was advanced with soil samples collected from the ground surface (0-0.5 ft bgs), 2.5 ft bgs, 5.0 ft bgs and 10.0 ft bgs depths. Results from all samples were less than the laboratory detection limit, with the exception of the 10 ft bgs sample result of 19.8 µg/kg, well below the Texas GWP-Ind for perchlorate of 7,200 µg/kg.

10.5.2.3 Land Use Controls

The LHAAP-50 LUC objectives are to prevent human exposure to Shallow Groundwater Zone contamination presenting an unacceptable risk to human health and ensure that there is no withdrawal or use of groundwater beneath the site for anything other than environmental monitoring and testing until the cleanup levels are attained. A restriction against residential use of groundwater will remain in effect until the levels of COCs in groundwater and soil allow unrestricted use and unlimited exposure (UUUE). Notification of the groundwater use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566 (US Army, 2015b). The Army provided a survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map to the Texas Department of Licensing and Regulation in hard and electronic copy.

The Army and regulators will confer to determine appropriate actions should there be a failure of a LUC objective at the site after it has been transferred.

10.5.2.4 Monitored Natural Attenuation

MNA component of the remedy at the LHAAP-50 site is implemented to monitor COCs and ensure protection of human health and the environment (AECOM, 2016f). Performance monitoring is used to evaluate remedy effectiveness. Performance monitoring includes groundwater and surface water monitoring. The groundwater monitoring program is designed to evaluate and monitor natural attenuation of COCs in the Shallow Groundwater Zone. The surface water monitoring program is designed to evaluate the effectiveness of the soil removal action to eliminate any contribution of perchlorate to surface water from runoff of the perchlorate-impacted soil and monitor potential migration of contaminated groundwater to surface water. The combined monitoring program shall meet the following objectives:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (e.g., geochemical, hydrogeologic etc.) that may reduce the efficacy of any of the natural attenuation processes;
- Identify potentially toxic and/or mobile transformation products;
- Verify that the plumes are not expanding;
- Verify no unacceptable impact to down gradient receptors;
- Detect new releases of contaminants to the environment that could impact effectiveness of the natural attenuation remedy; and,
- Verify attainment of the remediation objectives.

10.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. A groundwater use restriction against the residential use of groundwater was implemented with the notification recorded in the Harrison County Courthouse in June 2015 and completion of the RACR in June 2016. Implementation of annual inspections commenced with the second year of RAO (establishment of the LUC boundary was delayed due to additional plume delineation) and the first annual LUC Compliance Certification Documentation dated July 4, 2015. LHAAP-50 has remained in compliance with land use and restriction covenants for the review period. The annual inspection forms are presented in Appendix G.

The Army conducts groundwater and surface water monitoring to track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs (AECOM, 2014c).

10.7 Operations, Maintenance, and Monitoring

LHAAP-50 OM&M activities are:

- Collection of monitoring well water-level measurements, surface water and groundwater samples
- Data compilation, records upkeep, and submittal of reports
- Maintenance of all well protective casings and pads, and well access.

10.7.1 Groundwater and Surface Water Monitoring

Water levels from 28 monitoring wells and samples from 27 monitor wells were collected semi-annually. Surface water samples were to be collected quarterly for two years at GPW-1 or GPW-1A (Figure 28).

10.7.2 Operations, Maintenance, and Monitoring Costs

From 2014 through 2016, the annual costs shown in Table 31 are stable and below those estimated in the ROD (Shaw, 2010b). The contractor weighted the final year cost of LTM heavier than the previous years to display the contractor's commitment to completing the contract resulting in a sharp increase in costs in 2017.

Table 31. LHAAP-50 operations, maintenance, and monitoring costs for 2013-2017 (USACE, 2018).

Calendar Year	O&M Costs ($)	LTM Costs ($)	Total ($)
2013	-	-	-
2014	-	24,463	24,463
2015	-	24,463	24,463
2016	-	24,463	24,463
2017	-	48,927	48,927

10.8 Progress since the Last Five-Year Review

This is the first Five-Year Review for LHAAP-50.

10.9 Five-year Review Process

10.9.1 Data Review

Data analysis conducted by the Fourth Five-Year Review is in Appendix C, with the summaries presented below by media. Summary data and statistical tables are in Appendix F.

10.9.1.1 Groundwater

Data analysis indicates that, although the footprints of COCs vary with time, the areal extent of the footprints remained stable. Concentrations of COCs in perimeter wells located hydraulically downgradient (e.g., northeast) of the plumes remained non-detect. The center of the predominant COCs plumes are oriented along the major groundwater flow direction (e.g., to the northeast). Temporal variation of COCs in wells located within the center of the plume correlates to fluctuation in groundwater elevations. In most wells, peak COC concentrations coincided with low groundwater elevation and vice versa. However, in one location, 50WW12, with the highest perchlorate concentrations, peaks in concentrations coincide with peaks in groundwater elevation, with peak concentrations increasing with time to levels of 87,800 ppb (Plot 136). Although O&M and the Fourth Five-Year Review's trend analysis of perchlorate at this location indicate no trend, visual inspection indicates that the peak concentrations of perchlorate increase with time (Bhate, 2018c).

Spatial distribution of O&M's (Bhate, 2018c) trend analysis results and plumes contours are depicted in Plot 111. Mann-Kendall analysis indicated an increase in TCE concentrations at 95% confidence in two in plume wells (50WW09 (Plot 120) and 50WW12 (Plot 124) located immediately downgradient of the excavated impacted soil), and an increase in perchlorate at 95% confidence in one downgradient/leading edge well (50WW06, Plot 117) to levels as high as 5240 ppb (Bhate, 2018c). The Fourth Five-Year Review's trend analysis (Figure 31), which includes all the data collected to date, indicates that the data for TCE in in-plume well 50WW09 did not meet the criteria for trend analysis, but confirms the increasing trend for TCE noted at in-plume well 50WW12, and for perchlorate, noted at leading edge well 50WW06. In addition, the Fourth Five-Year Review's trend analysis indicates increases in TCE trends in leading edge well 50WW06, located adjacent to 50WW12.

A source of TCE is suspected at 50WW13. This is based on results from vertical profile investigation showing TCE concentrations at 1% solubility (indicative of the presence of residual non-aqueous phase liquid. Highest TCE concentrations (as high as 13,000 ppb) were reported at this well.

Limited TCE daughter compounds, cis-1,2-DCE and VC, indicate that reductive dechlorination is occurring in some locations within the Shallow Groundwater Zone plume, but geochemical conditions (for details information see Appendix C Section 6.2.1) are not favorable and that complete dechlorination within the plume is not taking place (Figure 29 to Figure 31). The Army recommended implementing the ROD contingency to enhance MNA by creating conditions that are conducive for reductive dechlorination (Bhate, 2018c).

TCE restoration times of less than 20 years were estimated in locations where Mann-Kendall analyses show declines in concentration with 95% confidence (Bhate, 2018c). In these locations, MNA meets the lower range of the ROD's estimated clean up time of 50 years. Since in most locations temporal variation in COCs show no trend (either with stable or not stable data), it is not possible at this time to estimate restoration times from concentrations trends throughout the plume. According to the ROD, due to heterogeneity in the formation, restoration time could be one order of magnitude higher than the 50 years estimate (i.e., 500 years) (US Army, 2010e). Therefore, with time it is expected that the source(s) will be depleted through natural attenuation, leading to declining trends in COCs throughout the plumes.

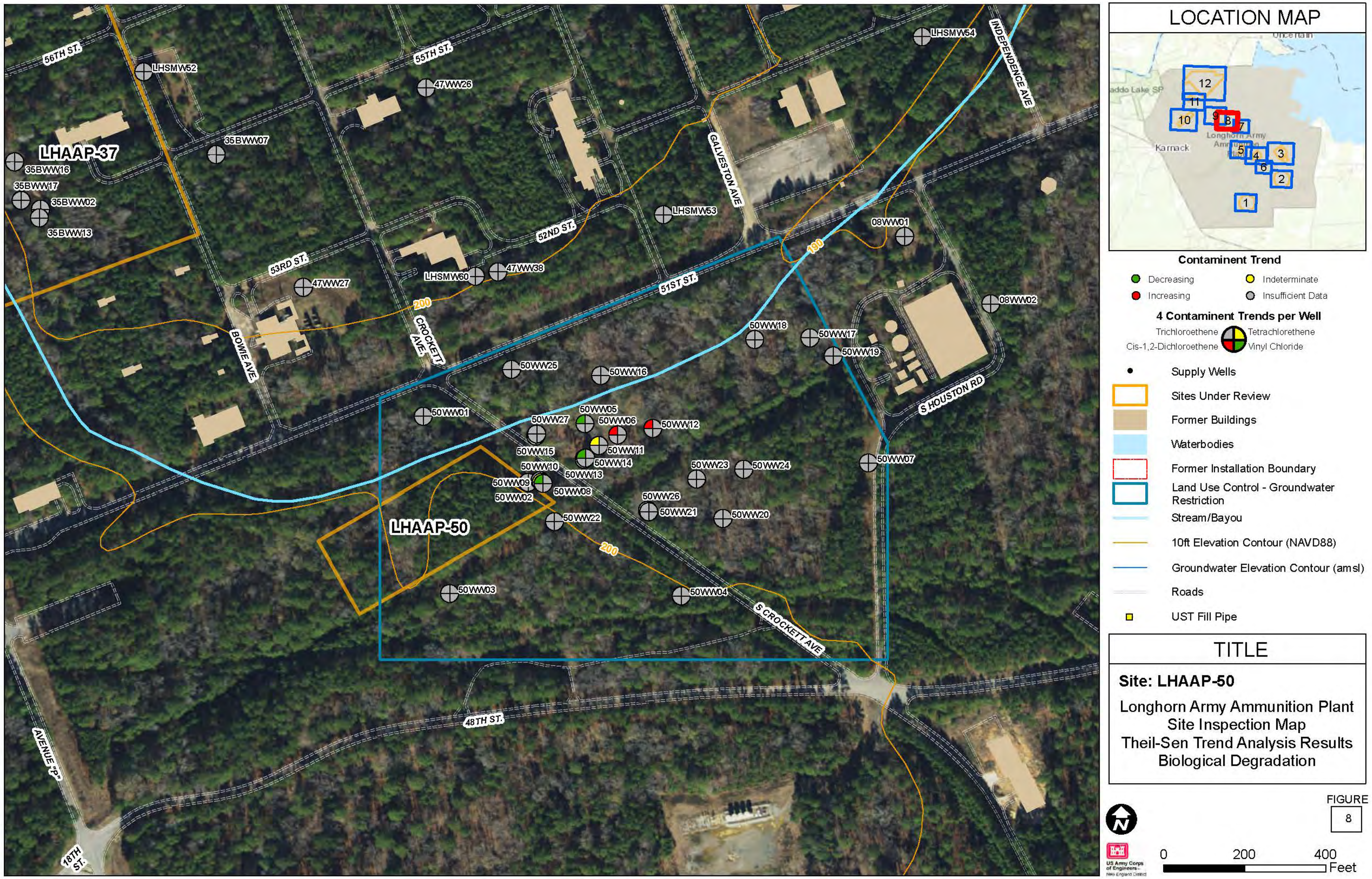


Figure 29. LHAAP-50 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2015b, USGS, 2011, 2006).

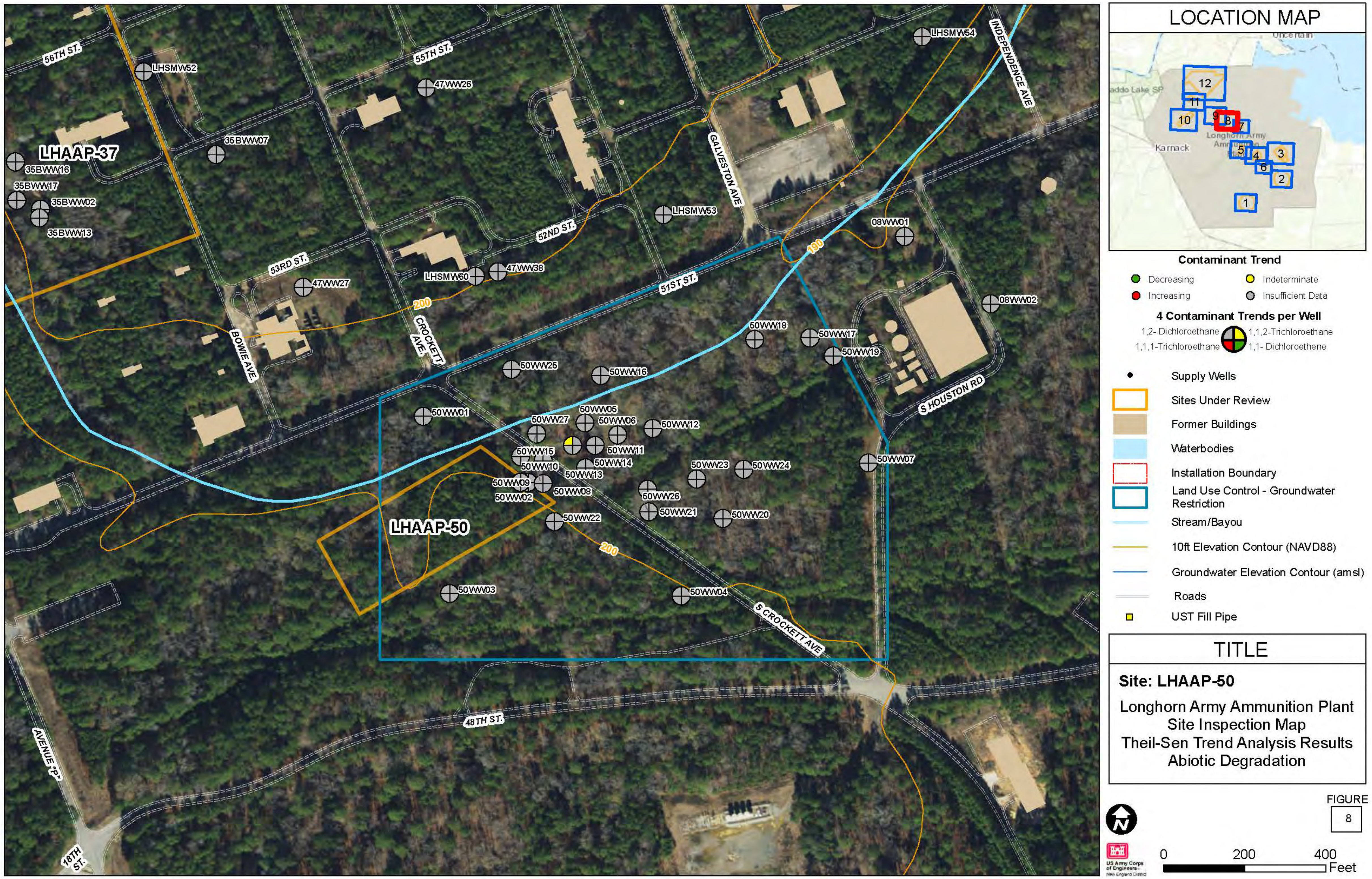


Figure 30. LHAAP-50 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2015b, USGS, 2011, 2006).

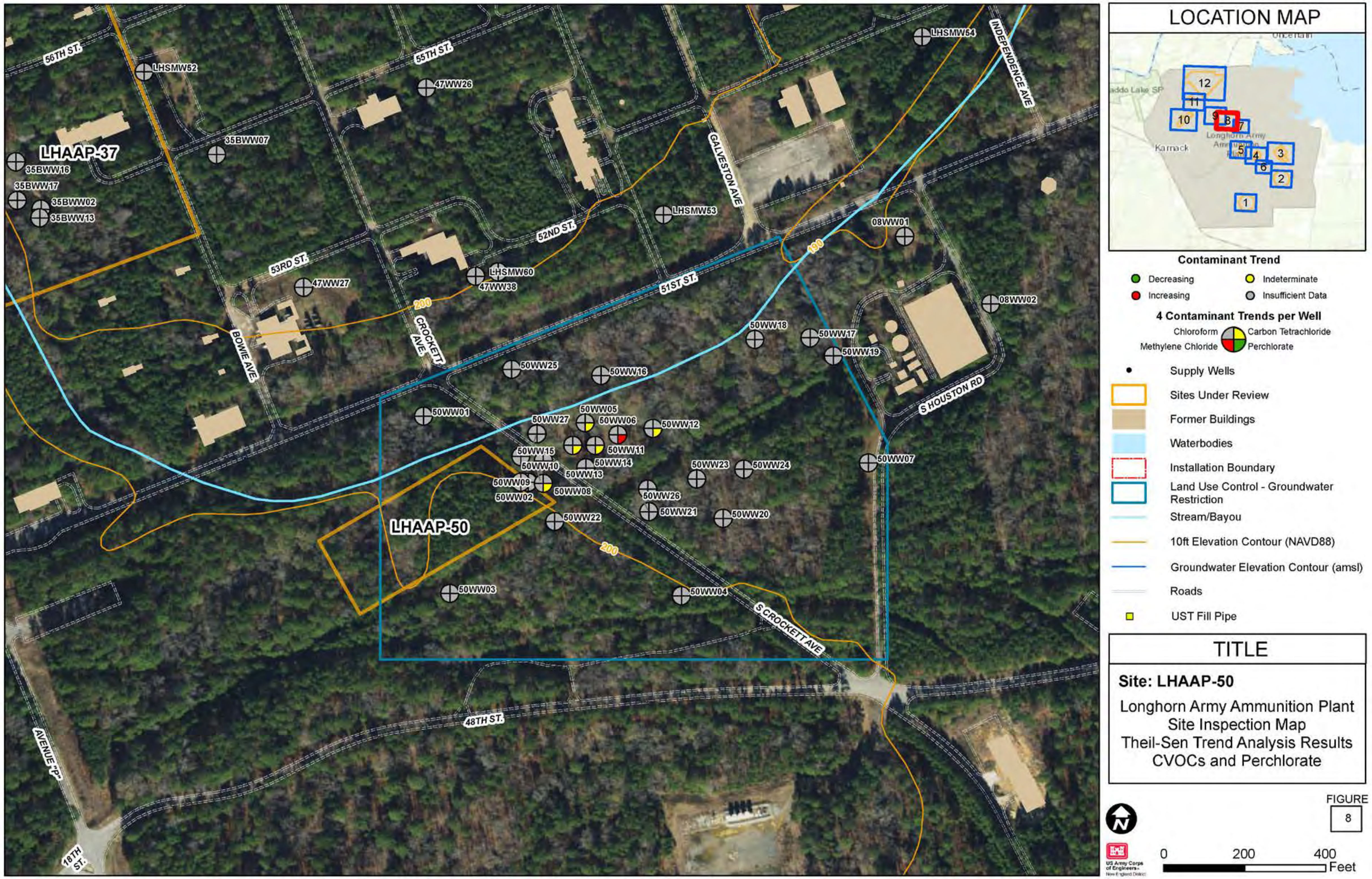


Figure 31. LHAAP-50 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2015b, USGS, 2011, 2006).

10.9.1.2 Surface Water

LHAAP-50 surface water sampling locations are shown in Figure 28 and described below. These locations include:

- GPW-1 – Located adjacent to the perchlorate contaminated soil excavation area (Plot 103). Designed to monitor for contaminant contributions from soil runoff from the perchlorate-contaminated portion of LHAAP-50, two years following perchlorate contaminated soil excavation, which took place in fall 2013.
- GPW-1A – Located in a ditch at the upgradient end of a culvert in LHAAP-47 to monitor for contaminant contributions in runoff from the perchlorate-contaminated portion of LHAAP-47.
- 50SW06 – Located in Goose Prairie Creek Designed to monitor for potential discharge points for groundwater to surface water contamination.

Analytical results for the samples collected in 2015 from 50SW06, GPW-1, and GPW-1A were below MCLs/PCL for all COCs except for perchlorate in one historical sample. One perchlorate concentration of 38.2 µg/L, which exceeds the perchlorate PCL of 17 µg/L, was reported in the sample from GPW-1A collected on February 17, 2015.

Analytical results for the samples collected in 2016 from GPW-1, and GPW-1A were below detection limits for all COCs. Perchlorate was detected but was at concentrations below the PCL of 17 µg/L in the four GPW-1 samples and in the GPW-1A sample. The highest perchlorate concentration was detected in May 2016 at GPW-1 at 6.59 µg/L below the PCL of 17 µg/L.

Limited analytical data were available for surface water station, 50SW06, located in Goose Prairie Creek and used to monitor for potential contaminated groundwater discharge to surface water (three quarters in 2015). Perchlorate at maximum level of 1.44 µg/L, lower than the cleanup level of 17 µg/L, is the only COCs detected at this surface water station. The 2016 analytical results for the surface water sample 50SW06 were either not present or were addressed in the third annual RA(O) report for LHAAP50 (Bhate, 2018c).

The Record of Decision for LHAAP-50 does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the same as those for groundwater.

10.9.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary.

10.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

10.10 Technical Assessment

10.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). The restriction was recorded in Harrison County on June 18, 2015 (AECOM, 2016f) and annual inspections of the groundwater use restriction commenced on July 4, 2015 during the second year of RAO (AECOM, 2016k), after completion of the RACR. No land use activities beyond wildlife refuge occurred at the site during the review period and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G. Although groundwater COC plume footprints vary with time, MNA appears to stabilize the extents of the plumes. TCE and perchlorate increases in some wells, but it is not certain whether the trends in some of the wells are temporary (potentially due to a COC slug released during soil excavation or seasonal variation). MNA has been found to be effective, and according to the installation, the contingency remedy to enhance MNA via in situ bioremediation will be implemented in FY 19 following the ESD to the ROD.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

10.10.2 Summary of the Technical Assessment

LUCs are in place and functioning as intended, for the groundwater use restriction is followed. While MNA appears to control and in the short term stabilize the oscillating COCs, there are locations where COCs concentrations are increasing with time.

10.11 Issues

The Fourth Five-Year Review identified one issue listed in Table 32.

Table 32. Issues at LHAAP-50, Karnack, TX.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
TCE and Perchlorate trends are increasing across part of the site.	No	Yes

10.12 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 33.

Table 33. Recommendations and Follow-up Actions for LHAAP-50.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
TCE trends are increasing across part of the site.	Implement the contingency remedy following the ESD to the ROD to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.	US Army	USEPA & TCEQ	Oct 2024	No	Yes

10.13 Protectiveness Statement

The LHAAP-50 remedy currently protects human health and the environment because LUCs are in place and MNA long-term monitoring occurs. However, for the remedy to be protective in the long-term, the following action needs to be taken to ensure protectiveness:

- Implement the contingency remedy to enhance MNA (such as in situ bioremediation) to address increasing trends of COCs near wells 50WW12 and 50WW13.

11.0 LHAAP-58 SHOPS AREA

The LHAAP-35A (58) site, also known as the Shops Area, is located in the north-central portion of LHAAP and currently covers an area of approximately 11 acres (Figure 32) (US Army, 2010f). The surface features are a mixture of asphalt-paved roads, a parking area, and areas of wooded and grassy vegetation. The topography is relatively flat with the surface drainage flowing into the tributaries of Goose Prairie Creek. Runoff from the site enters Caddo Lake via Goose Prairie Creek.

11.1 Site Chronology

Significant events relevant to combined site LHAAP-58 are presented in Table 34. No enforcement orders have been issued for the Site.

Table 34. LHAAP-58 chronology of site events (Bhate, 2017, AECOM, 2016g, 2015f, US Army, 2010f).

Event	Date
Plant 3 operating period	1952-97
Shops Area Operations	1942-1997
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8 1988
LHAAP placed on NPL	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Remedial Investigation for the Group 4 Sites, Sites 35A, 35B, 35C, 46, 47, 48, 50 60, and Goose Prairie Creek	January 2002
Final Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake	June 2003
Data Gaps Investigation	April 2007
Feasibility Study completed	December 2009
Proposed Plan	January 2010
Record of Decision	September 2010
Remedial Design	September 2011
Remedial Action Work Plan	April 2013
Draft Final 1st Annual Remedial Action Operation Report for LHAAP-35A(58)	November 2015
Draft Final 2nd Annual Remedial Action Operation Report for L:HAAP-35A(58)	May 2016
Remedial Action Completion Report	June 2016
Revised Remedial Action Work Plan Contingency Remedy for Western Plume	January 2018
Final Explanation of Significant Differences Record of Decision for Western Plume Contingency Remedy	March 2018
RA(O) Reports	

11.2 History of Contamination

The Shops Area now designated as LHAAP-35A (58) was established in 1942 as part of the installation’s initial construction (US Army, 2010f). The facility was used to provide plant-operated laundry, automotive, woodworking, metalworking, painting, refrigeration, and electrical services. The site was active throughout LHAAP’s mission and was deactivated along with the rest of the installation in 1996-1997. There were seven waste process sumps and one waste rack sump located within LHAAP-35A(58). There was a spray paint booth in Building 722-P that scrubbed its exhaust fumes; the wash water was collected in a sump. The sump overflowed to surface drainage while the solids were taken to the inert waste burning area (LHAAP-16) for disposal. Wastewater from the laundry (Building 723) was discharged through a mesh screen into a three-chambered tank. The tank discharged to a surface drainage. Boiler feed water was softened by two softeners, which were regenerated with salt brine. The backwash rinse waters, and boiler blowdown were discharged to a surface drainage. Boiler additives included sulfites, hexametaphosphates, and Octameen (an organic amine sludge conditioner). Waste oil from the motor pool (Building 716) and roundhouse (Building 718-A) were collected from the sumps and taken to the explosive burning grounds for disposal. Floor drains from the roundhouse and motor pool discharged to the sanitary sewer. Waste from the wash rack and steam cleaning area west of the motor pool discharged directly to the surface drainage (USAEHA, 1980b). The sumps and their contents were removed in 1996, mitigating the potential for continued migration of sump content contamination. The site and land use control boundary contain nineteen other sites addressed by other investigation.

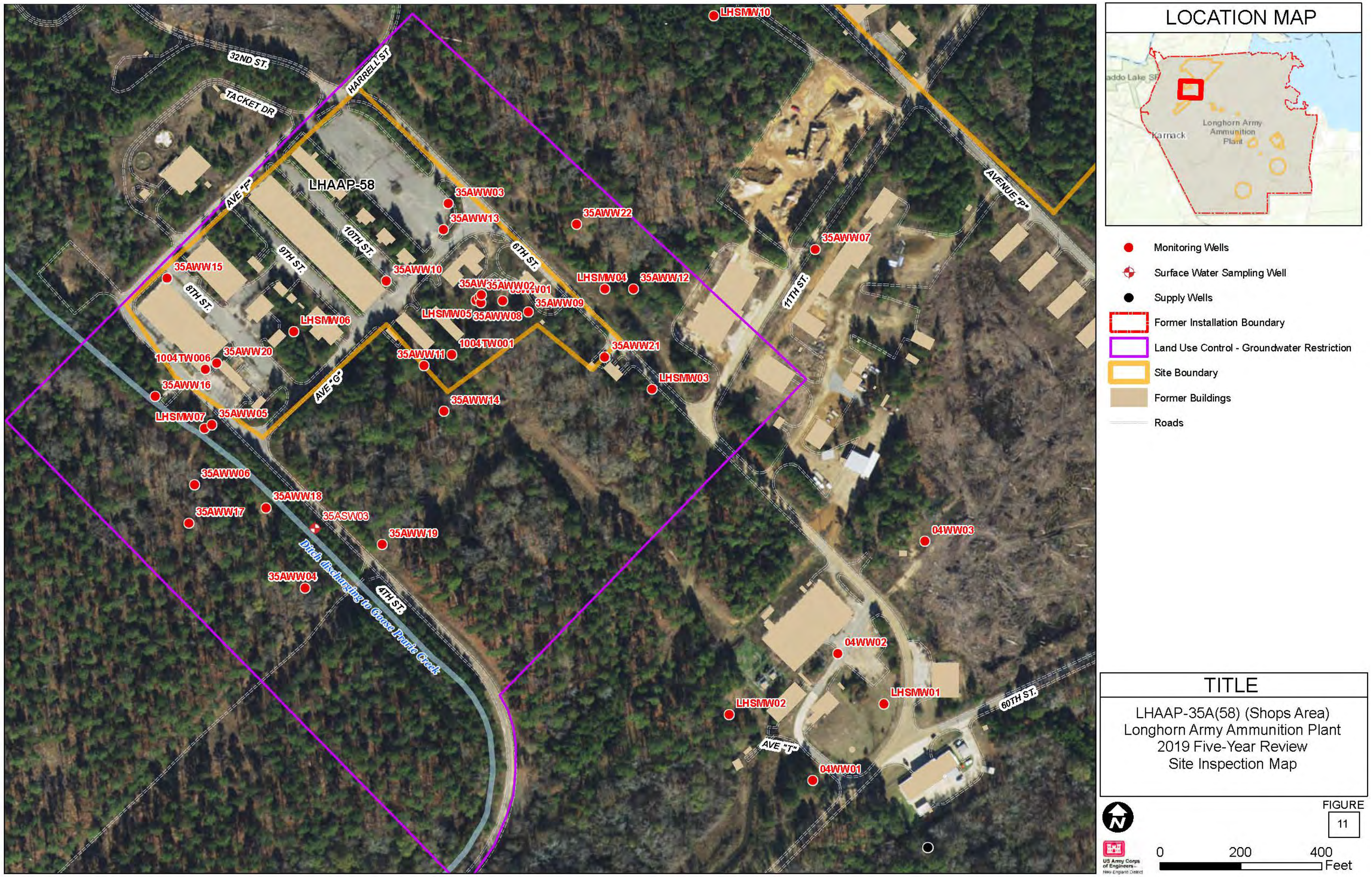


Figure 32. LHAAP-58 site map showing the groundwater land use control boundary, groundwater and surface water locations (LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2015c, USGS, 2011).

11.3 Initial Response

No initial response actions occurred at LHAAP-58 beyond CERCLA investigations listed in Table 31.

11.4 Summary of Basis for Taking Action

The basis for taking action was presence of PCE and 1,1-DCE in groundwater at concentrations posing an unacceptable risk to an industrial worker.

11.5 Remedial Actions

11.5.1 Remedy Selection

The selected LHAAP-58 remedy for addressing the site contaminants and meeting the remedial objectives of the ROD was a combination of groundwater land use controls, MNA, Five-Year Reviews, and enhanced in-situ bioremediation for the eastern plume area (US Army, 2010f). The RAOs to meet the ROD's remediation goals (Table 35) are:

- Protection of human health by preventing human exposure to the contaminated groundwater;
- Protection of human health and the environment by preventing contaminated groundwater from migrating into nearby surface water; and
- Return of groundwater to its potential beneficial uses as drinking water, wherever practicable.

Table 35. LHAPP-58 chemicals of concern and remedial goals (US Army, 2010f). TCEQ groundwater (GW-Ind) medium-specific concentration for industrial use for groundwater protection.

Chemical	Remedial Goal (µg/L)	Basis
Chloroethane	41,000	GW-Ind
cis-1,2-Dichloroethene	70	MCL
trans-1,2-Dichloroethene	100	MCL
1,1-Dichloroethane	10,000	GW-Ind
1,1-Dichloroethene	7	MCL
Trichloroethene	5	MCL
1,1,2-Trichloroethene	5	MCL
Tetrachloroethene	5	MCL
Vinyl chloride	2	MCL

Table 35 clean up levels apply to surface water in the event of a remedy failure.

The remedy consists of (AECOM, 2016g, h):

- Groundwater LUC. LUC in the impacted area ensures protection of human health by restricting the use of groundwater to environmental monitoring and testing only. The LUC will remain in effect until the Army and USEPA agree and TCEQ concurs that COC concentrations have met cleanup levels.
- Enhanced In-Situ Bioremediation (EISB). EISB technology involves biological degradation of contaminants in groundwater via respiratory or metabolic processes through appropriate microbes. The EISB treatment involves injection of carbon substrates (electron donor), nutrients, and, if needed, microbial cultures, into the subsurface. EISB was implemented in the eastern plume area only, as the COC levels in this area represented highest concentrations in the Shallow Groundwater Zone at the site and warranted active treatment MNA.
    - Program. Establish attenuation trends, verify that the VOC plumes are stable or shrinking, and will not migrate to nearby surface water at levels that may present an unacceptable risk to human health or the environment. MNA is expected to return groundwater to acceptable quality.
    - Performance Objectives. Re-evaluated after two years of groundwater monitoring. During those two years, groundwater monitoring will be performed on a quarterly basis. If MNA is found to be ineffective, a contingency remedy to enhance MNA will be implemented.
- Long-term Monitoring.
    - Evaluation. MNA will be evaluated for two years, and if it is verified to be effective, LTM will begin at a semiannual frequency for the following three years (until the first CERCLA Five-Year Review). In subsequent years, LTM will be performed annually until the next CERCLA Five-Year Review. The LTM associated with this remedy will be used to track the continued effectiveness of MNA. The need for continued monitoring and any reductions in the monitoring frequency will be evaluated every five-years during the CERCLA Five-Year Review. However, at a minimum, the LTM will continue once every five-years until the cleanup levels are achieved.
    - Treatment Timeframe Estimates. Based on the previously performed groundwater modeling for the LHAAP-35A (58) western plume area, MCLs are expected to be met through natural attenuation in approximately 200 years. This timeframe will be re-evaluated as part of the MNA evaluation and periodic reviews. The cleanup time for the eastern plume is expected to be similar to that for the western plume, and will be reevaluated following EISB implementation and subsequent data collection.

Because the LHAAP-58 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

Although not a remedy, the land use assumption for LHAAP-58 forms the basis for the remedy (AECOM, 2016g). The future use of the site as part of a national wildlife refuge is consistent with an industrial risk exposure scenario. Notification of the land use assumption of this site is recorded in the Harrison County Courthouse in accordance with TAC Title 30, §335.566 and will be made in transfer documentation.

11.5.2 Remedy Implementation

11.5.2.1 Land Use Controls

The LHAAP-58 LUC objectives are to prevent human exposure to groundwater contamination presenting an unacceptable risk to human health and ensure that there is no withdrawal or use of groundwater beneath the site for anything other than environmental monitoring and testing until the cleanup levels are attained. A restriction against residential use of groundwater will remain in effect until the levels of COCs in groundwater and soil allow unrestricted use and unlimited exposure (UUUE). Notification of the groundwater use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566 (US Army, 2015c). The Army provided a survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map to the Texas Department of Licensing and Regulation in hard and electronic copy.

The Army and regulators will confer to determine appropriate actions should there be a failure of a LUC objective at the site after it has been transferred.

Because contaminants remain above levels that allow for unlimited use and unrestricted exposure, Five-Year Reviews will continue to be conducted to ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

11.5.2.2 EISB

EISB treatment was specified to treat COCs in the eastern plume area to enhance their biological degradation and create subsurface conditions favorable for MNA after completion of the EISB treatment (AECOM, 2015f). EISB implementation included selection of carbon substrate, mixing and injection procedures, a baseline sampling event, bioaugmentation (injections of microbial culture), post injection monitoring and analysis of data. Prior to the EISB treatment, an underground injection control substantive requirements notification was submitted to the TCEQ in September 2013, to comply with the substantive requirements for construction, operation, and closure under 30 TAC §331, Subchapters A, C, and H (the Applicable or Relevant and Appropriate Requirements for underground injection control).

August and October 2013 injections targeted the depth interval of approximately 23 to 30 feet bgs at each point. The injection flow rates ranged from 4 to 6 gallons per minute (gpm) and the injection pressures were between 25 and 30 pounds per square inch (psi). Follow-on bioaugmentation injections were done in October 2013.

MNA analysis consisted of theoretical behavior of the MNA parameters in a reductive dechlorination conducive setting, ranges of values detected, and occasionally what the values may suggest about site biochemical processes. Oxidation-Reduction Potential (ORP) was not converted to the Standard Hydrogen Electrode reference, which adds 150+ mV to the field reading making marginally anaerobic values very aerobic. No assessment was made of what parameters supported site monitoring and which did not provide value.

11.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. A groundwater use restriction against the residential use of groundwater was implemented with the notification recorded in the Harrison County Courthouse in March 2015 and completion of the RACR in April 2015 (AECOM, 2015f). Implementation of annual inspections commenced with the second year of RAO (establishment of the LUC boundary was delayed due to additional plume delineation required) and the first annual LUC Compliance Certification Documentation dated July 14, 2015. LHAAP-58 has remained in compliance with land use and restriction covenants for the review period. Copies of the annual LUC inspection forms are presented in Appendix G.

The Army conducts groundwater and surface water monitoring to track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs (AECOM, 2014c).

11.7 Operations, Maintenance, and Monitoring

LHAAP-58 OM&M activities are:

- Collection of monitoring well water-level measurements and groundwater samples
- Data compilation, records upkeep, and submittal of reports
- Maintenance of all monitoring wells.

11.7.1 Groundwater Monitoring

VOC samples and water levels from 25 monitoring wells are collected quarterly to semi-annually. MNA parameters are collected from nine wells.

11.7.2 Operations, Maintenance, and Monitoring Costs

From 2014 through 2016, the annual costs shown in Table 36 are stable and below those estimated in the ROD (US Army, 2010f). The contractor weighted the final year cost of LTM heavier than the previous years to display the contractor’s commitment to completing the contract resulting in the sharp increase in monitoring costs in 2017.

Table 36. LHAAP-58 operations, maintenance, and monitoring costs for 2013-2017 (USACE, 2018).

Calendar Year	O&M Costs ($)	LTM Costs ($)	Total ($)
2013	-	-	-
2014	-	13,033	13,033
2015	-	13,033	13,033
2016	-	13,033	13,033
2017	-	26,066	26,066

11.8 Progress since the Last Five-Year Review

This is the first Five-Year Review for LHAAP-58.

11.9 Five-year Review Process

11.9.1 Data Review

Data analysis conducted by the Fourth Five-Year Review is in Appendix C, with the summaries presented below by media. Summary data and statistical tables are in Appendix F.

11.9.1.1 Groundwater

The eastern plume has a lateral extent of approximately 270,000 square feet (ft^2), and a vertical extent of approximately 5 feet. Assuming a total porosity of 0.3, the calculated volume of contaminated groundwater is 3.03 million gallons. The highest concentrations detected for PCE and TCE were 9,590 µg/L and 675 µg/L, respectively, from well 35AWW08, sampled in November 2008. The highest concentrations detected for 1,1-DCE and VC were 24 µg/L and 4.1 µg/L, respectively, from well 1004TW001, sampled in December 2003. Five shallow zone wells are within the eastern plume boundaries (35AWW08, 1004TW001, LHSMW04, LHSMW05, 03WW01), as well as one direct push data point (58DPT04).

The western plume has a lateral extent of approximately 180,000 ft^2, and a vertical extent of approximately 5 feet. Assuming a total porosity of 0.3, the calculated volume of contaminated groundwater is 2.02 million gallons. In the sampling results from November 2008, the highest concentrations detected for TCE, 1,1-DCE, and VC were 25 µg/L, 576 µg/L, and 14.4 µg/L, respectively, from well LHSMW07; the highest concentration detected for PCE was 7.19 µg/L from well 35AWW06. Three shallow zone wells are within the western plume boundaries: LHSMW07, 35AWW06, and 1004TW006.

EISB was implemented in the eastern plume in September 23 to 25, 2013. The remedy comprised of injecting 2,200 gallons of sodium lactate solution via direct push (Plot 151) is described in detail in Appendix C Section 7.2.2. EISB in the eastern plume appears to be effective only in the area where the amendments were applied, reducing the concentration and hence the mass loading of COCs. However, the footprints of the plumes appeared to increase in size. Although the footprints of the plumes increased, concentrations of COCs in downgradient perimeter wells remain non-detect (for details see Appendix C sections 7.2.1 and 8.2.3).Restoration time of parent compounds (PCE and TCE) is reduced due to the reduction in concentration and mass of these compounds in the Shallow Groundwater Zone.

MNA in the western COCs plumes does not appear to be an effective remedy, as is evident by the increase in size of the COCs footprints (for details see Appendix C sections 7.3.1 and 7.3.2). Several of the downgradient perimeter wells have COCs concentrations greater than the MCL; therefore, according to the installation, the contingency plan for enhanced MNA was implemented in March and April 2018. Although the COCs footprint increased in size, the available analytical results from surface water monitoring are below the MCL.

- Eastern Plume

EISB treatment in the eastern plume area appears to be effectively reducing the VOC concentrations within the EISB treatment area only. COCs concentrations in historical plume center well 03WW01 were reduced by orders of magnitudes to non-detect three years after implementation of EISB. Since the last Five-Year Review, PCE concentrations decreased from ~ 400 ppb to < 5 ppb in 2017. TCE (daughter product) decreased from ~ 70 ppb to < 5 ppb while cis-1,2-Dichloroethene (daughter product) increased from < 5 ppb to ~ 100 ppb in 2016, subsequently decreasing to < 5 ppb. VC (daughter product) remains ND (with detection levels ranging between 0.625 to 50 ppb) in all sampling events. Although orders of magnitudes reduction in PCE (from ~ 1500 ppb in 2013 to 12 ppb in 2017) and TCE (from ~ 550 ppb in 2013 to ~ 30 ppb in 2017) were observed in historical plume center well 35AWW08, PCE and TCE concentrations at the end of the reporting period (October 2016) remained above the MCL. VC was detected in April and October 2016 (at a maximum level of 14.2 ppb with a J qualifier in April 2016, and at 7.46 ppb with J qualifier in October 2016) at 35AWW08, indicating limited degradation of cis-1,2-DCE. Additional monitoring will be required to evaluate whether complete reductive dechlorination will occur, and to look for potential rebound. For details on spatial and temporal variation of COCs in the eastern plume, see sections 8.2.1 and 8.2.2.

The center of the eastern COCs plumes shifted from 03WW01/35AWW08 to 35AWW09/ LHSMW04 due to migration of COCs. Although concentrations of PCE and TCE immediately downgradient (35AWW09) and cross-gradient (LHSMW04) of the eastern COCs plumes' centers have increased (Figure 33) by orders of magnitude, the mass loading of COCs from the plume center decreased. This is due to the several orders of magnitude decrease in the maximum concentration of the parent COCs (PCE from level > 1500 µg/L to levels of 400 µg/L). For details on spatial and temporal variation of COCs in the eastern plume, see Appendix C sections 7.2.1 and 7.2.2.

Geochemical parameters indicate that reductive dechlorination is taking place in the EISB treatment area. Alkalinity, methane and chloride levels are elevated in the EISB area, while ORP levels are depressed. In 2016, microbial counts were high within the EISB area, and TOC remained elevated above the threshold criteria for reductive dechlorination. However, complete reductive dechlorination to final end products is limited. Ethene was detected at low levels in only one plume center well, and ethane was nondetect for all samples. For a detailed analysis of geochemical parameters, see Appendix C section 7.2.4.

Figure 33. **LHAAP-58 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2015c TNRIS, 2015, USGS, 2011, 2006).**

Figure 34. LHAAP-58 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2015c TNRIS, 2015, USGS, 2011, 2006).

Figure 35. LHAAP-58 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2015c TNRIS, 2015, USGS, 2011, 2006).

Although the footprints of the eastern COCs plumes as delineated by the contoured MCLs shifted and appear to increase, the available network of monitoring wells are sufficient to define the extent of the COCs plumes exceeding the MCL. COCs in perimeter wells remain below the detection limits. COCs plumes do not extend to surface water bodies and restoration times of parent compounds (PCE and TCE) have been reduced due to the reduction in concentration and mass of these compounds.

- Western Plume

Spatial and temporal variations in the COCs in the western plume are provided in details in Appendix C sections 7.3.1 and 7.3.2.

Concentrations of COCs in perimeter wells, 35AWW15, 35AWW16, 35AWW17, and 35AWW18, located away from the most impacted plume center well 35AWW20, and cross gradient well LHSMW07, remained non-detect. However, concentrations of 1,1-DCE in downgradient perimeter wells 35AWW14 and 35AWW19, increased from below the MCL of 7 ppb in October 2013 to a maximum level of ~ 17 ppb, slightly above the MCL, in October 2016, indicating plume expansion in the downgradient direction. Based on the interpreted southeastern groundwater flow direction, COC levels have generally increased with distance from the plume center. According to the 3rd year monitoring results, the lateral extent of the western plume is no longer defined in the area of downgradient perimeter wells 35AWW14 and 35AWW19.

The plume center well (35AWW20) exhibits the highest levels of COCs, which first increased then decreased over the 3-year RA(O) monitoring period, except for VC, which exhibited an overall increasing trend. The concentrations of COCs in cross gradient well LHSMW07 have increased (e.g. since the last Five-Year Review TCE concentrations increased from ~ 20 in 2013 to values ranging between ~ 40 and 120 ppb between 2015 and 2016). The increase in concentrations of COCs in cross gradient well LHSMW07 indicates likely migration of COCs from the upgradient area of plume center well 35AWW20, to the area of cross gradient well LHSMW07. LHSMW07 is located adjacent to the surface water sampling location 35ASW03, potential exposure point. Concentrations of COCs in surface water samples were below MCLs. Analytical results from 35ASW03 during the 1st, 2nd, and 3rd Year RA(O)s were below MCLs for all COCs that were detected in groundwater at the site. According to the RA(O), the surveyed bottom of the ditch at the lowest point is 213.58 ft above msl, while the gauged water level in nearest upgradient monitoring well (35AWW18) in April 2016 was 195.35 ft above msl. Therefore, the RA(O) recommended sampling surface water only if the groundwater elevation is at or above the bottom of the ditch.

The qualitative assessment of geochemical indicators and the absence of dechlorinating bacteria in the Shallow Groundwater Zone (outside of EISB zone) at LHAAP-35A (58) indicate aerobic conditions with elevated ORP, relatively low levels of methane, and TOC slightly above the Threshold value of 20 mg/L, adequate to support microbial activities (for details see Appendix C section 7.3.3). Therefore, current naturally occurring geochemical conditions are not optimal for MNA. Although, degradation products (1,1-DCE in 35AWW09; 1,1-DCE, cis-1,2-DCE, and VC in plume center well 35AWW20; and 1,1-DCE and VC in cross gradient well LHSMW07) have been detected in the western plume, conditions that currently exist within the impacted area do not sustain complete reductive dechlorination.

In order to address the noted increases in COCs trends in the western plume, the installation implemented the ROD’s contingency remedial action plan to enhance MNA in March and April 2018. A report that describes the implemented contingency remedial action plan or data was not available for the Fourth Five-Year Review.

In accordance with DoD Policy Memorandum, 22 Aug 2016, "Revised Site Management Procedures -Update to DoD Manual 4715.20" on procedures for addressing emerging contaminants at DERP sites, the Army will continue to sample for 1,4-dioxane during Five-Year Reviews. However, the ROD and remedy will not be amended until it is shown that the emerging contaminant presents an unacceptable risk. For this five-year review period, there were 30 results and 4 results were greater than the applicable Texas Risk Reduction Rule Industrial Groundwater Medium Specific Concentration of 26 ug/L (Table 37). While the maximum 1,4-dioxane detection at LHAAP-58 was 120 µg/L, the average detection was less than 11 µg/L. Sampling will continue to support the five-year review process.

Table 37. 1,4-Dioxane in shallow (s) and intermediate (i) aquifer LHAAP-58 units in µg/L (USAEC, 2018). Blank-no sample collected, J-estimated, <1U-not detected above the 1 µg/L method detection limit.

Location ID	Aquifer	2013	2015	2017
03WW01	s	<1 U	35.5 J	1.4
35AWW08	s	<1 U	2.45 J	1.2
35AWW06*	s	<1 U		< 0.20
35AWW20	s		56.8	28
35AWW21	s		0.814 J	1.8
35AWW11	s			1.6
LHSMW07	s			120
35AWW17	s			0.70
35AWW18	s			1.3
35AWW05	i			1.9
35AWW16	s			1.2
35AWW16	s			1.5
35AWW09	s			1.6
35AWW10	s			< 0.20
35AWW10	s			0.13
35AWW19	s			< 0.10
LHSMW06	s			0.99
35AWW14	s			4.1
35AWW22	s			0.63
35AWW15	s			0.86
35AWW01	i			0.99
35AWW13	s			1.2
35AWW12	s			0.20

11.9.1.2 Surface Water

The Remedial Action Work Plan (AECOM, 2013e) specifies that surface water monitoring for VOCs (1,1,2-TCA; 1-1-dichloroethane (1,1-DCA); 1,1-DCE; 1,2-dichloroethane; benzene; cis-1,2-DCE; TCE; PCE; and VC) will be performed at 35ASW03 located in a ditch parallel to 4th Street, on the western boundary of the site and adjacent to the western groundwater plume (Figure 32). Analytical results from 35ASW03 during the 1st, 2nd, and 3rd Year RA(O)s were below MCLs for all COCs that were detected in groundwater at the site.

According to the RA(O), the surveyed bottom of the ditch at the lowest point is 213.58 ft above msl, while the gauged water level in nearest upgradient monitoring well (35AWW18) in April 2016 was 195.35 ft above msl. Therefore, the RA(O) recommended sampling surface water only if the groundwater elevation is at or above the bottom of the ditch. The Record of Decision for LHAAP-35A(58) does not identify COCs in surface water at this site, but does provide ARARs that would be triggered in the event of remedy failure followed by a release to surface water. In the event of remedy failure, the surface water COCs and cleanup levels would be the sample as those for groundwater.

11.9.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary.

11.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

Only one site-specific issues was raised during the interviews – The MNA remedy was not working, so additional in situ remedies have been applied to this site. A contingency remedy for the western plume was recently implemented.

11.10 Technical Assessment

11.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). LUC Implementation began with the recordation in Harrison County on March 16, 2015 (AECOM, 2015f) and annual inspections of the groundwater use restriction commenced on July 14, 2015 during the second year of the RAO after completion of the RACR (AECOM, 2015f). No land use activities beyond wildlife refuge occurred at the site during the review period and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G. EISB remedy in the eastern plume may be functioning as intended by the ROD reducing the concentration and mass loading of COCs from the center of the plume, thereby reducing aquifer restoration time and the future maximum extent of the COCs footprints. However, MNA does not appear to be functioning as intended by the ROD in the western plumes, because the lateral extent of the COCs exceeding MCL can no longer be defined by perimeter wells, and there are statistically significant increasing trends of COCs in wells located within the plumes and along the perimeter of the plumes. Although the footprint of the COCs plume increased with time and there was a statistically increasing trend of COCs concentration in LHSMW07, located adjacent to the surface water sampling location 35ASW03, concentrations of COCs in surface water samples were below MCLs. According to the installation, the MNA contingency remedy for the western plume was implemented in March and April 2018.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced. In addition, the emerging contaminant 1,4-dioxane analytical results collected during this five-year review period did include some exceedances of Texas Risk Reduction Rule Industrial Groundwater Medium Specific Concentration of 26 ug/L, but the average result was less than 11 µg/L (Table 34). The remedy is still protective and there is not an unacceptable risk to receptors.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

11.10.2 Summary of the Technical Assessment

Based on the reviewed data, site inspection, and interviews, the LUCs are in place and functioning as intended, for the groundwater use restriction is followed. EISB remedy in the eastern plume may be functioning as intended by the ROD reducing the concentration and mass loading of COCs from the center of the plume. While there are significant decreasing trends in the EISB target area in the eastern plume, there are also increasing trends in downgradient well 35AWW09. The plume footprint remains unchanged and groundwater monitoring will continue to evaluate remedy effectiveness. MNA did not appear to be functioning as intended by the ROD in the western plume, because the lateral extent of the COCs exceeding MCL can no longer be defined by perimeter wells, and there were statistically significant increasing trends of COCs in wells located within the plumes and along the perimeter of the plumes. According to the installation, the MNA contingency remedy for the western plume was implemented in March and April 2018.

11.11 Issues

The Fourth Five-Year Review has identified one issue listed in Table 38.

Table 38. Issues at LHAAP-58, Karnack, TX.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
EISB implementation requires performance monitoring to establish effectiveness.	No	Yes

11.12 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 39.

Table 39. Recommendations and Follow-up Actions for LHAAP-58.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
EISB implementation requires performance monitoring to establish effectiveness.	Implement EISB performance monitoring and assess if additional monitoring wells are required to delineate the plume to the south and southwest.	US Army	USEPA & TCEQ	Sep 2020	No	Yes

11.12.1 Other Findings

- Assess effectiveness of EISB in attenuating the eastern plume. It is recommended that the effectiveness of EISB/ MNA, including the maximum extent of the COCs footprint, be determined.

11.13 Protectiveness Statement

The LHAAP-35A (58) remedy currently protects human health and the environment because LUCs are in place, EISB has been implemented in the eastern and western plumes, and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the following actions need to be taken to ensure protectiveness:

- Implement EISB performance monitoring and assess if additional monitoring wells are required to delineate the plume to the south and southwest.

12.0 LHAAP-67 ABOVEGROUND STORAGE TANK FARM

LHAAP-67 site is a former aboveground storage tank (AST) farm located at the southeast corner of 48th Street and Ignatius Avenue in the central portion of LHAAP (Figure 36). The site covers approximately 1.9 acres. The site topography slopes toward the southeast toward Central Creek, the nearest significant surface water body located approximately 870 feet (ft) from LHAAP-67. Central Creek eventually flows into Caddo Lake.

12.1 Site Chronology

Significant events relevant to combined site LHAAP-67 are presented in Table 40. No enforcement orders have been issued for the Site.

Table 40. LHAAP-67 chronology of site events (AECOM, 2016i, US Army, 2010b).

Event	Date
Plant 3 became operational	December 1954
U.S. Army Toxic and Hazardous Material Agency records search	February 1980
U.S. Army Environmental Hygiene Agency contamination survey	May 1987
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
Staging area for site investigations.	1998
Remedial Investigation completed	January 2002
Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake)	June 2003
Feasibility Study completed	October 2005
Final Baseline Ecological Risk Assessment	November 2007
Proposed Plan	June 2008
Record of Decision	June 2010
Remedial Action Work Plan	June 2013
Remedial Action Completion Report	July2016
1st RA(O) Report	January 2017
2nd RA(O) Report	February 2017
3rd RA(O) Report	March 2017

12.2 History of Contamination

When operational, LHAAP-67 consisted of seven aboveground storage tanks used for storing No. 2 fuel oil, kerosene, and solvents. The size of the tanks is unknown. The tanks were surrounded by earthen dikes designed to contain potential spills. The ASTs have been removed and the only structure remaining at the site is a railroad bed (USACE, 2010a). Although there is no information related to a known release in the record, It is likely that incidental spills occurred during transfer of fuels and solvents to and from the tanks resulting in releases to soil and migration to groundwater (Jacobs, 2002e).

12.3 Initial Response

No initial response actions occurred at LHAAP-67 beyond CERCLA investigations listed in Table 40.

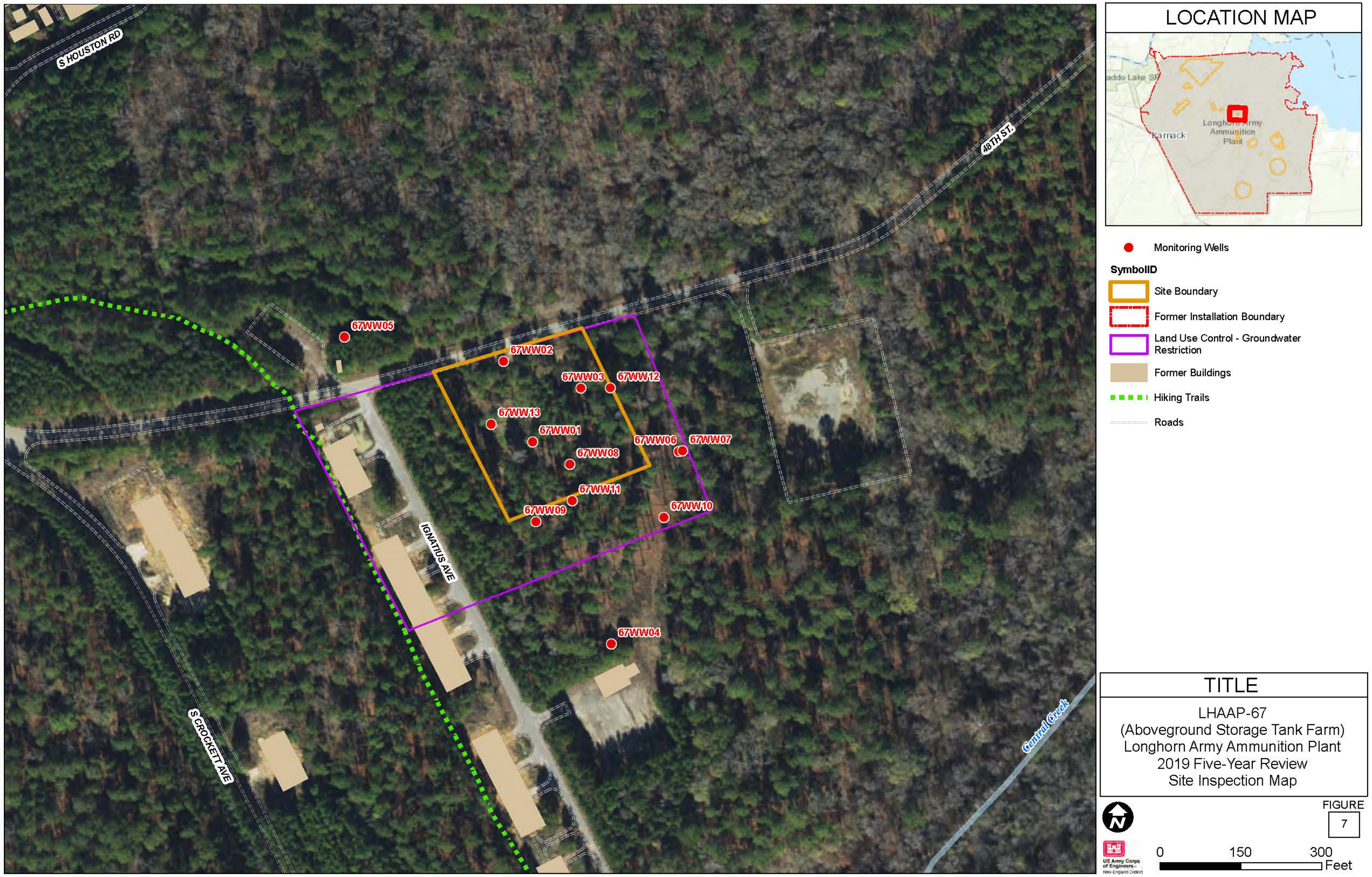


Figure 36. LHAAP-67 site map showing 2018 site inspection observations (LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2014b, USGS, 2011).

12.4 Summary of Basis for Taking Action

The basis for taking action was presence of 1,1-DCE, PCE, TCE, and 2,3,7,8-TCDD and two inorganics (thallium and antimony) in groundwater at concentrations posing an unacceptable risk to an industrial worker. Hazardous substances present in LHAAP-67 groundwater could potentially discharge to surface water in Central Creek, which flows to Caddo Lake, a drinking water source.

12.5 Remedial Actions

12.5.1 Remedy Selection

The ROD's selected LHAAP-67 remedy for addressing the site contaminants and meeting the remedial objectives of the ROD was a combination of groundwater land use controls and MNA (US Army, 2010b). The RAOs to meet the ROD's remediation goals (Table 41) are:

- Protection of human health by preventing human exposure to the contaminated groundwater;
- Protection of human health and the environment by preventing contaminated groundwater from migrating into nearby surface water; and,

Return of groundwater to its potential beneficial use as drinking water, wherever practicable.

Table 41. LHAPP-67 chemicals of concern and remedial goals (AECOM, 2016i, US Army, 2010b).

Chemical	Remedial Goal (µg/L)	Basis
1,2-Dichloroethane	5	MCL
1,1-Dichloroethene	7	MCL
1,1,1-Trichloroethane	200	MCL
1,1,2-Trichloroethane	5	MCL
Trichloroethene	5	MCL

The remedy consists of (AECOM, 2016i, US Army, 2010b):

- Groundwater LUC. Ensure protection of human health by restricting the use of groundwater exceeding cleanup levels to environmental monitoring and testing only. The LUC will remain in effect until the Army and USEPA agree and TCEQ concurs that the concentrations of COCs have met cleanup levels.
- MNA. Passive remedial action that relies on natural biological, chemical, and physical processes that act to reduce the mass and concentrations of groundwater COCs under favorable conditions. A program of MNA will be implemented to establish confidence in attenuation trends and verify that the plume is stable and will not migrate to nearby surface water at levels that may present an unacceptable risk to human health or the environment. Natural attenuation is expected to reduce contaminant concentrations to their respective clean-up levels, and return groundwater to its beneficial use, wherever practicable. Performance objectives for the MNA program will be evaluated after two years of groundwater monitoring. During those two years, groundwater monitoring will be performed on a quarterly basis.
- Long-term Monitoring: LTM will begin at a semiannual frequency after the first two years until the CERCLA Five-Year Review. In subsequent years, LTM will be performed annually until the following CERCLA Five-Year Review. The LTM associated with this

remedy will be used to track the continued effectiveness of MNA and will continue at least once every five-years until the cleanup levels are achieved. The need for continued monitoring will be evaluated every five-years during the CERCLA Five-Year Review.

Because the LHAAP-67 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C § 9621(c).

12.5.2 Remedy Implementation

12.5.2.1 MNA

MNA at the LHAAP-67 site is implemented to monitor COCs and ensure protection of human health and the environment. Performance monitoring to evaluate remedy effectiveness includes groundwater and surface water monitoring. The groundwater monitoring program is designed to evaluate and monitor natural attenuation of COCs in Shallow Groundwater Zone. The surface water monitoring program is designed to monitor potential migration of contaminated groundwater to surface water.

The monitoring program is intended to meet the following objectives:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (e.g., geochemical, hydrogeological, etc.) that may reduce the efficacy of any of the natural attenuation processes;
- Identify potentially toxic and/or mobile transformation products;
- Verify that the plumes are not expanding;
- Verify no unacceptable impact to down gradient receptors;
- Detect new releases of contaminants to the environment that could impact effectiveness of the natural attenuation remedy; and,
- Verify attainment of the remediation objectives.

Between 2013 and 2015, soil borings, direct push, and new monitor well tasks were completed to meet the above objectives.

12.5.2.2 Land Use Controls

The LHAAP-67 LUC objectives are to prevent human exposure to Shallow Groundwater Zone contamination presenting an unacceptable risk to human health and ensure that there is no withdrawal or use of groundwater beneath the site for anything other than environmental monitoring and testing until the cleanup levels are attained (AECOM, 2016i). A restriction against residential use of groundwater will remain in effect until the levels of COCs in groundwater and soil allow unrestricted use and unlimited exposure (UUUE). Notification of the groundwater use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566 (US Army, 2014). The Army provided a survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map to the Texas Department of Licensing and Regulation in hard and electronic copy.

The Army and regulators will confer to determine appropriate actions should there be a failure of a LUC objective at the site after it has been transferred.

12.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. The groundwater use restriction against residential use of groundwater was recorded in Harrison County, Texas on December 9, 2014 with annual inspections having already commenced in July 2014 during the first year of RAO. No violations were noted during the review period. The annual inspection forms are presented in Appendix G

The Army conducts groundwater and surface water monitoring to track MNA progress, and to ensure that contaminants do not discharge to nearby surface water bodies at concentrations exceeding their respective groundwater ARARs (AECOM, 2014c).

12.7 Operations, Maintenance, and Monitoring

LHAAP-67 OM&M activities are:

- Collection of monitoring well and piezometer water-level measurements and groundwater samples
- Data compilation, records upkeep, and submittal of reports
- Maintenance of monitoring well network, and routine maintenance activities (mowing, etc.)

12.7.1 Operations, Maintenance, and Monitoring Costs

No operations and maintenance occurs at LHAAP-67, so the only annual costs are monitoring and related well maintenance (Table 42). From 2013 through 2016, the annual estimates are stable. The contractor weighted the final year cost of LTM heavier than the previous years to display the contractor’s commitment to completing the contract resulting in a sharp increase of costs in 2017.

Table 42. LHAAP-67 operations, maintenance, and monitoring costs for 2013-2017 (USACE, 2018).

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)	Notes
FY13	-	-	-	Remedy not implemented
FY14	-	21,305	21,305	
FY15	-	21,305	21,305	
FY16	-	21,305	21,305	
FY17	-	42,609	42,609	

12.8 Progress since the Last Five-Year Review

This is the first Five-Year Review for LHAAP-67.

12.9 Five-year Review Process

12.9.1 Data Review

Data analysis conducted by the Fourth Five-Year Review is in Appendix C, with the summaries presented below by media. Summary data and statistical tables are in Appendix F.

12.9.1.1 Groundwater

Three primary widespread COCs are at LHAAP67: 1,1-DCE and 1,2-DCA, and to a lesser extent VC. 1,1-DCE is suspected to be an abiotic degradation byproduct of 1,1,1-TCA, which has been detected in groundwater in 1998. 1,1,1-TCA is no longer being detected in groundwater, possibly due to the fast degradation rate through hydrolysis to 1,1-DCE. The small footprint of VC encountered within the COCs plume center is possibly due to reductive dechlorination of 1,1-DCE. 1,2-DCA is suspected to be an abiotic degradation by-product of 1,1,2-DCA. Low levels of 1,1,2-DCA are still being detected in groundwater (Figure 37 and Figure 39).

The footprints of the primary widespread COCs appear to redistribute with shifts in groundwater flow directions from the north/northeast to the north/northwest. Although the footprints of the 1,1-DCE and 1,2-DCA redistribute, they appear to remain stable within their historical footprints. COCs are non-detect in upgradient perimeter wells located along the southern perimeter of the plumes, and in cross gradient/downgradient perimeter wells located to the east/northeast and northwest. However, 1,1-DCE and 1,2-DCA above their respective MCL were encountered in a cross gradient perimeter well located along the western perimeter of the plume and in a downgradient perimeter well located north of the plume. This was found, subsequent to a prolonged high recharge period or return to non-drought conditions (Figure 4) and subsequent to a shift in the groundwater flow direction from northeast to northwest. In the most recent sampling events of November 2017, COCs were below their respective MCL in all perimeter wells.

Mann-Kendall analysis conducted with data collected through 2016 indicated increasing trends in 1,1-DCE and 1,2-DCA in two plume center wells, and the Fourth Five-Year Review trends analysis confirms the increasing trends of COCs in one of these wells (Figure 40). However, correlation of the trend patterns with the shift in the groundwater flow regime, COC trends that includes the 2017 recent sampling results, and meteorological conditions, indicates the increasing COC trends appear to be temporary and perhaps due to a prolonged period of high recharge. The drop in concentrations of COCs encountered in 2017 is attributed to a prolonged period of low recharge (Figure 4). For details, see Appendix C section 8.2.1.

The qualitative assessment of geochemical indicators during the three-year RA(O) period in the Shallow Groundwater Zone at LHAAP-67 indicates current geochemical conditions are not optimal for MNA. Redox condition shifts from aerobic to anaerobic, presence of dissolved iron, and TOC at concentrations above the threshold value considered adequate to support reductive dechlorination may indicate that, at times, conditions could favor natural attenuation. Degradation by-products including 1,2-DCA and 1,1- DCE have been detected in the plume monitoring wells. Adequate conditions within the impacted area currently do not exist to sustain complete reductive dechlorination (for detailed see section 9.2.3).

Multiple groundwater contours generated using gauging that includes new Shallow Groundwater Zone monitoring wells show that (Figure 3) Central Creek is upgradient from LHAAP-67. The VOC plume is now delineated within the LUC boundary. Therefore, concurrence was obtained not to sample surface water from Central Creek.

The groundwater flow direction in the ROD was assumed to the southeast toward Central Creek, located 870 feet away from the site. Based on data gathered from more than 15 wells the groundwater flow direction was revised to be to the north/northeast between 2013 and December 2014, switching to the north/northwest between May 2014 and 2016. There are no other surface water bodies downgradient or in close proximity to the LHAAP-67 site from which to collect an appropriate surface water sample. Based on the large distance to potential discharge points and the limited extent of the footprints of the widespread COCs, TCEQ, USEPA and other stakeholders concurred that there was no complete exposure pathway and that there was no need to sample and monitor surface water at the LHAAP-67 site.

In accordance with DoD Policy Memorandum, 22 Aug 2016, "Revised Site Management Procedures -Update to DoD Manual 4715.20" on procedures for addressing emerging contaminants at DERP sites, the Army will continue to sample for 1,4-dioxane during Five-Year Reviews. However, the ROD and remedy will not be amended until it is shown that the emerging contaminant presents an unacceptable risk. For this five-year review period, there were 23 results and three results were greater than the applicable Texas Risk Reduction Rule Industrial Groundwater Medium Specific Concentration of 26 ug/L (Table 43). While the maximum 1,4-dioxane detection at LHAAP-67 was 54.1 µg/L, the average detection was less than 10 µg/L. Sampling will continue to support the five-year review process.

Table 43. 1,4-Dioxane in shallow (s) and intermediate (i) LHAAP-67 aquifer units in µg/L (USAEC, 2018). Blank-no sample collected, NS-not sampled, J-estimated, <1U-not detected above the 1 µg/L method detection limit.

Location ID	Aquifer	2013	2015	2017
67WW01	s	4.15		17
67WW02	s	1.7 J	2.75	0.26
67WW03	s	NS, dry		
67WW06	s	<1 U	<1 U	1.7
67WW12	s		<1 U	0.6
67WW13	s		51.4	36
67WW09	s			1.2
67WW11	s			18
67WW14	s			17
67WW15	s			12
67WW05	s			0.53
67WW08	s			22
67WW08	s			29
67WW07	s			0.53
67WW09A	s			3.6
67WW10	s			0.23
67WW16I	i			0.33

Figure 37. LHAAP-67 Thiel-Sen Trend Analysis results-biological CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2014b, TNRIS, 2015, USGS, 2011, 2006).

Figure 38. LHAAP-67 Thiel-Sen Trend Analysis results-abiotic CVOC degradation (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2014b, TNRIS, 2015, USGS, 2011, 2006).

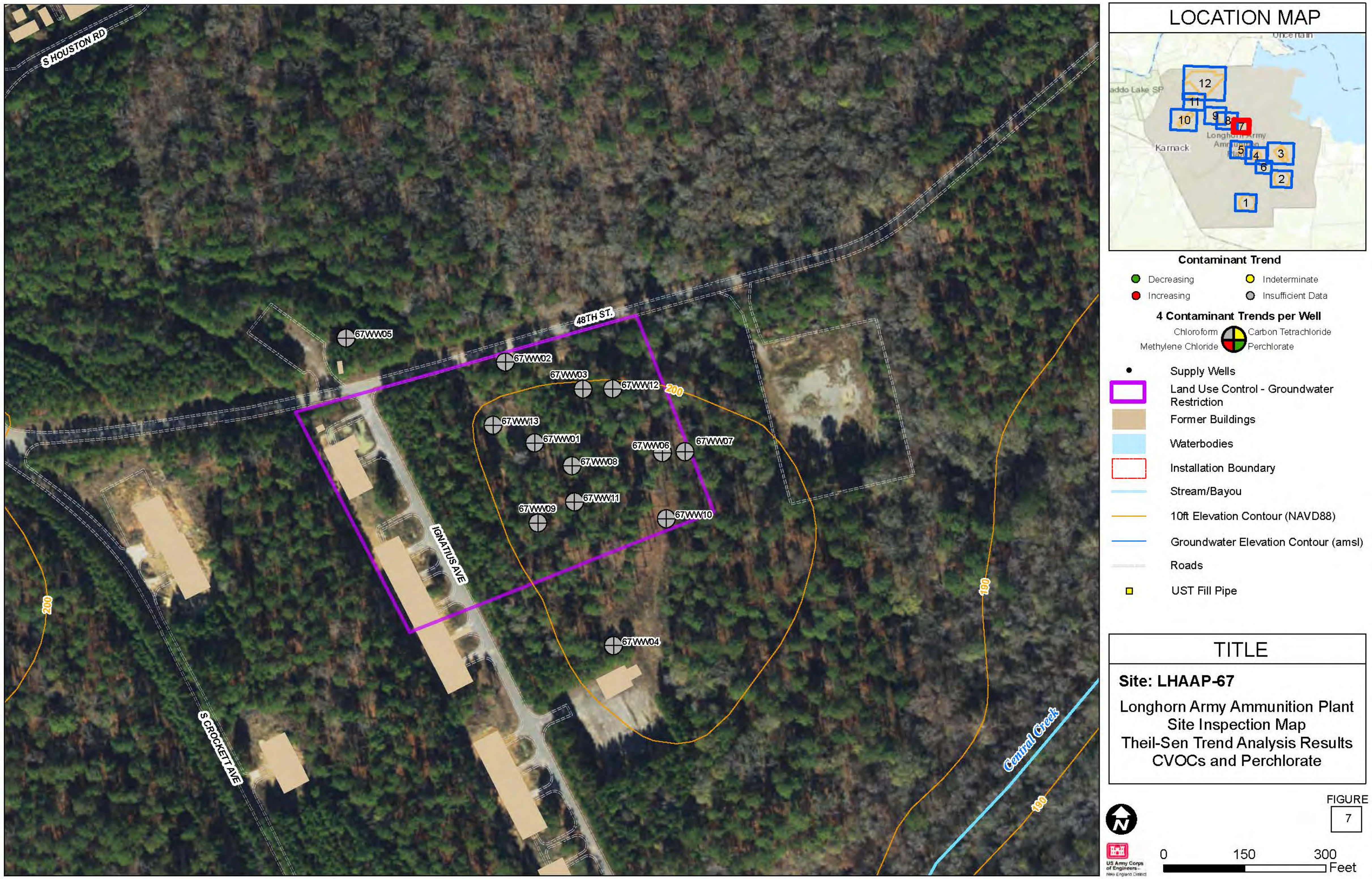


Figure 39. LHAAP-67 Thiel-Sen Trend Analysis results-other CVOCs and perchlorate (see Appendix C for details) (USAEC, 2018, LHAAP, 2018a, Landmark Consultants, 2014b, TNRIS, 2015, USGS, 2011, 2006).

12.9.1.2 Surface Water

Semi-annual sampling of surface water from one location in Central Creek was planned (AECOM, 2017h-j). The Central Creek surface water sampling location was dry during the baseline groundwater monitoring event and no surface water sample was collected.

As documented in Appendix C, the addition of multiple new Shallow Groundwater Zone monitoring wells has resulted in more clearly defining the groundwater potentiometric surface for the site. The Shallow Groundwater Zone flow direction suggests that Central Creek does not receive recharge from the LHAAP-67 area, and was used to justify not sampling surface water. Although the Record of Decision for LHAAP-67 provided ARARs that would be triggered in the event of remedy failure followed by a release to surface water, it was agreed among the FFA representatives that potential discharge to surface water in Central Creek was an incomplete exposure pathway and surface water sampling was no longer necessary (AECOM, 2017j).

12.9.2 Site Inspection

The site inspection was conducted 23 May 2018 (maps, forms, and photographs presented in Appendix D). Land use restriction for groundwater is properly implemented, for no water or rig supply wells have been drilled within the groundwater use restriction/site boundary.

12.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:
- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

12.10 Technical Assessment

12.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the LUC portion of the remedy, a restriction against residential use of groundwater, is in place and functioning as intended. It will remain in effect until the levels of COCs in groundwater allow unrestricted use and unlimited exposure (UUUE). Inspections of the groundwater use restriction commenced in July 2014 with the first year of the RAO phase. No land use activities beyond wildlife refuge occur at the site and no access to groundwater has occurred beyond environmental monitoring and testing. The annual inspection forms are included in Appendix G. Although the COCs plumes redistribute with shifting groundwater flow directions, the footprints appear to be stable. Subsequent to prolonged periods of precipitation when the groundwater flow direction shifts to the north/northwest, the footprint of the COCs exceeding MCL, temporarily, cannot be defined by the western and northern perimeter wells.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. The cleanup levels were not included in the Record of Decision; they were included in the Remedial Action Completion Report (AECOM, 2016i). Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

The emerging contaminant 1,4-dioxane analytical results collected during this five-year review period did include some exceedances of the Texas Risk Reduction Rule Industrial Groundwater Medium Specific Concentration of 26 ug/L, but the average result was less than 10 µg/L (Table 40). The remedy is still protective.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the 2019the Fourth Five-Year Review calls into question the protectiveness of the remedy.

12.10.2 Summary of the Technical Assessment

Based on the reviewed data, site inspection, and interviews, the LUCs are in place and functioning as intended, for the groundwater use restriction is followed. Although the COC footprints appear to be stable, the COCs plumes redistribute with shifting groundwater flow directions.

12.11 Issues

The Fourth Five-Year Review has identified one issue listed in Table 44.

Table 44. Issues at LHAAP-67, Karnack, TX.

Issues	Affects Current Protectiveness	Affects Future Protectiveness
Changes in groundwater flow direction result in occasional contaminant migration outside the current MNA monitoring network	No	Yes

12.11.1 Other Findings

The qualitative assessment of geochemical indicators during the three year RA(O) period in the Shallow Groundwater Zone at LHAAP-67 indicates current geochemical conditions are not optimal for MNA (AECOM, 2017h-j). Because these conditions are anticipated to remain relatively stable, it is recommended that sampling for these indicators be terminated.

12.12 Recommendations and Follow-Up Actions

In response to the issues noted above, recommended actions are listed in Table 45.

Table 45. Recommendations and Follow-up Actions for LHAAP-67.

Issue	Recommendations and Follow-up Actions	Party Responsible	Oversight Agency	Milestone Date	Affects Protectiveness	
					Current	Future
Changes in groundwater flow direction result in contaminant migration outside the current MNA monitoring network	Evaluate data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system	US Army	USEPA & TCEQ	Sep 2020	No	Yes

12.13 Protectiveness Statement

The LHAAP-67 remedy currently protects human health in the short-term because LUCs are in place and MNA long-term monitoring occurs. However, in order for the remedy to be protective in the long-term, the Army will evaluate the data in the north area of the plume to determine if temporary exceedances indicate plume migration or require extension of the plume boundary well monitoring system.

13.0 LHAAP-001-R-001 (SITE 27) SOUTH TEST AREA/BOMB TEST AREA

LHAAP-001-R is located near the southern boundary of LHAAP, and consists of a deteriorated asphalt and gravel road running from the entrance to the test pad (Figure 40). Concrete bunkers and the site of the demolished former observation building are located alongside the road about halfway between the entrance and the test pad. A circular, 50-foot (ft) wide fire lane with a 2,000-ft diameter is centered at the test pad. The site, formerly cleared areas near the test pad, and alongside the access road are overgrown with vegetation.

13.1 Site Chronology

Significant events relevant to combined site 001-R-001 (SITE 27) are presented in Table 46. No enforcement orders have been issued for the Site.

Table 46. LHAAP-001-R-01 (Site 27) chronology of site events (Bhate, 2018e, AECOM, 2017n, US Army, 2016, Shaw, 2011b, EODT, 2009, Cape, 2007).

Event	Date
Illuminating signal devices were demilitarized within pits excavated near the site's test pad.	1950s
Site constructed by Universal match Corporation and used to test M120A1 photoflash bombs.	1954-1956
Button bombs and white phosphorous items may have been demilitarized at the site. Occasional leaking white phosphorous items were burned.	1960s
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
US Army CTT Range/Site Inventory designate the Ground Signal Area LHAAP-003-R-01	September 2002
USFWS LHAAP investigation	March 2003
Military Munitions Response Program (MMRP) Site Investigation (SI) completed	2004
Engineering Evaluation/Cost Analysis identified Munitions and Explosives of Concern (MEC) at the site	August 2007
Final Baseline Ecological Risk Assessment	November 2007
MEC Removal Action completed	November 2009
Proposed Plan	June 2011
Dispute Resolution	2011-2014
Record of Decision	August 2016
Perchlorate Sampling	September 2016
Perchlorate Sampling	November 2017
Land Use Control Remedial Design/Remedial Action Construction Report	May 2018

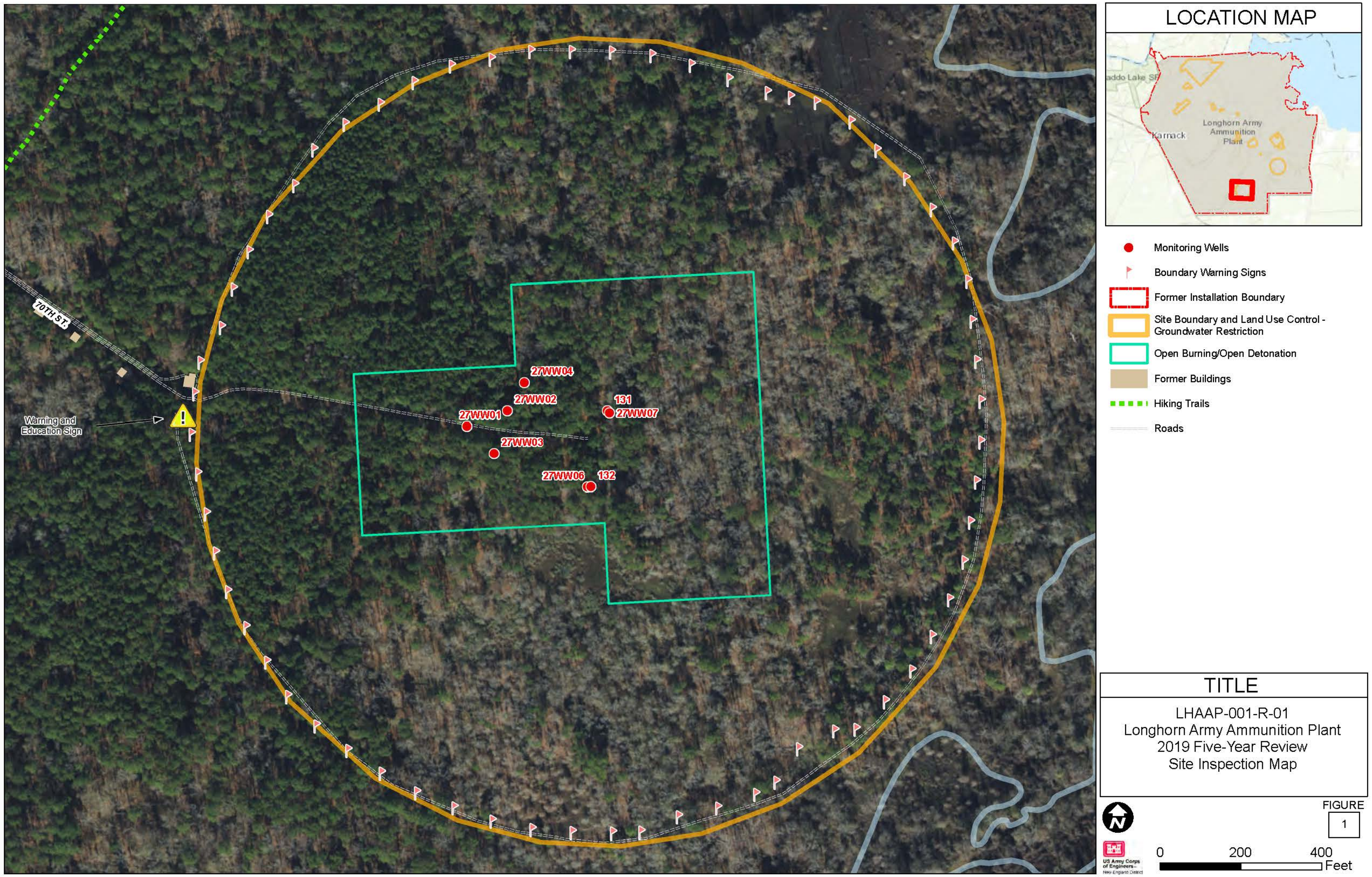


Figure 40. LHAAP-001-R-01 (Site 27) site map showing 2018 site inspection observations (LHAAP, 2018a, TNRIS, 2015, USGS, 2011, EODT, 2009).

13.2 History of Contamination

The LHAAP-001-R site was constructed in 1954 and used by Universal Match Corporation for testing M120A1 photoflash bombs produced at the facility until about 1956. The bombs were tested by exploding them in the air over an elevated, semi-elliptical earthen test pad. Bombs awaiting testing were stored in three earth-covered concrete bunkers. The bombs tested were 150-pound M120/M120A photoflash bombs filled with photoflash powder and containing a black powder booster charge for bursting the bomb and a timed nose fuse

During the late 1950s, illuminating signal devices were also demilitarized within pits excavated near the test pad at the site. During the early 1960s, leaking production items such as XM40E5 “button bombs” may have been demilitarized by detonation in the South Test Area/Bomb Test Area (LHAAP-001-R) or the Ground Signal Test Area (LHAAP-003-R). The XM40E5 is a small (approximately 1- by 1.25-inch) anti-intrusion mine also referred to as a "Gravel" Mine, which explodes on impact. It is believed that leaking white phosphorus munitions were disposed of in this area although no primary source documentation concerning this effort was located. Occasional leaking white phosphorus munitions were burned at the site as a demilitarization activity. Other sources indicate that possibly 3- to 4-pound canisters of white phosphorus were demilitarized near the test pad. The 1984 LHAAP Contamination Survey (Environmental Protection Systems, Inc. (EPS, 1984) stated the area has been relatively inactive since the early 1960s and no disposal or testing activities were carried out in this area.

The site was identified in the Army Closed, Transferring, and Transferred (CTT) Range/Site Inventory as 6.75 acres in size. A 1981 aerial photograph, historical records, a site visit, and a teleconference on 17 May and 18 May 2005 between USACE and the Army Environmental Center (AEC) indicated the site should be 79 acres including Demolition Sub Areas 1, 2 and 3.

13.3 Initial Response

The 2002-2004 MMRP SI identified MEC and scrap at the site, possible source areas, and a white phosphorous soil analysis data gap (US Army, 2016). An Engineering Evaluation/Cost Analysis (EE/CA) was conducted in 2007, where nineteen of 21 MEC and MPPEH items were recovered at the surface or within the top 6 inches of the soil in LHAAP-001-01-R’s open burning/open detonation (OB/OD) area (Cape. 2007). Post-removal soil sampling showed no detections of explosives that would pose a risk to human health and safety, and no detections of white phosphorous. The EE/CA recommended MEC surface clearance, subsurface clearance in the OB/OD area, and LUCs to reduce risk within LHAAP-001-R.

The 2009 MEC removal action found and removed 308 items (14 were inert), over 15,397 lbs. of munitions debris, and over 1,722 lbs. of metallic cultural debris (EODT, 2009). After completing site restoration activities, an LUC program was instituted consisting of intrusive activity restriction, installing perimeter signs, and instituting an MEC-avoidance education program for future refuge visitors

13.4 Summary of Basis for Taking Action

Through the 2008 surface removal action, MEC items were located and removed over the entire LHAAP-001-R-01 site, reducing the risk to the future land user. However, because there is a reasonable potential some MEC remained after the removal action, there is a potential risk to the public. The basis for taking action (i.e., implementation of LUCs) is to promote ongoing protection of human safety against potential explosive hazards that may have remained at the site.

13.5 Remedial Actions

13.5.1 Remedy Selection

The selected LHAAP-001-R-01 remedy for addressing the low MEC risk and site contaminants to meet RAOs was a combination of land use controls and limited perchlorate groundwater monitoring (US Army, 2016). The LHAAP-001-R ROD for the former South Test Area/Bomb Test Area was issued August 2016. The decision was based on the Administrative Record for this site, including the Final EE/CA (Cape, 2007), Final MEC removal (EODT, 2009), and Final Proposed Plan (U.S. Army 2011).

EPA (Region 6) and the TCEQ are the regulatory agencies providing technical support, project review and comment, and oversight of the U.S. Army cleanup program. The USEPA agreed to the selected remedy with TCEQ concurrence.

The LHAAP-001-R RAOs are protection of human health and safety from explosive hazards that may have remained at the sites after the MEC removal action, and confirmation that perchlorate is present in groundwater at levels below the chemical specific criterion (Table 47).

Table 47. LHAPP-01-R-001 and LHAAP-01-R-003 groundwater chemical of concern and remedial goal (US Army, 2016).

Chemical	Remedial Goal (µg/L)	Basis
Perchlorate	17	TRRP-GW PCL

The remedy consists of:

- LUC Implementation. This includes a completed legal description and plat in accordance with TAC § 335.569, Appendix III to include perimeter signage warning of potential UXO and prohibiting intrusive activities, and an education program for future refuge visitors, staff, and volunteers (Bhate, 2018e, US Army, 2016, 2013). LUCs to be verified by Five-Year Reviews.
- Three rounds of perchlorate sampling to verify groundwater is below the 17 µg/L TRRP PCL residential groundwater cleanup level.

Because the LHAAP-01-R-001 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

13.5.2 Remedy Implementation

The signage and education program established as part of the EE/CA (EODT, 2009) are now part of the ROD's land use control program for this site (US Army, 2013).

13.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. The LUCs include MEC warning signage and restrictions against digging and residential use. These LUCs were recorded in Harrison County, Texas on April 19, 2018. As required by the ROD, within 90 days of ROD signature, preliminary notice of LUCs was provided, to federal, state, and local officials including: State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents, as well as the Caddo Lake NWR manager, the future transferee of the property. A second notice was transmitted on May 9, 2018 to the same parties with finalization of the LUC RD/RACR (Bhate, 2018e).

The LUC RD/RACR calls for annual inspections and maintenance of signage. Although the LUC RD/RACR was not in place during the review period, inspection and maintenance of signage was conducted. This included mowing around the signs so that they remained visible one to the next, and repairing signposts and damaged signs as needed. It was noted in 2017 that sign visibility from one to the next was compromised by brush growth. Major brush-clearing was conducted at LHAAP-001-R in 2017 to maintain sign visibility from one to the next and to improve access to signage. Of the 64 signs present at the site, faded "Danger" decals were replaced on 34 signs, and 5 sign posts and 4 signs were replaced entirely.

13.7 Operations, Maintenance, and Monitoring

LHAAP-001-R-01 OM&M activities are:

- Collect three rounds of perchlorate groundwater samples to confirm perchlorate levels are below the TRRP Tier 1 Groundwater Residential PCL (17 µg/L).
    - Data compilation, records upkeep, and submittal of reports
    - Maintenance of MEC signs

13.7.1 Groundwater Monitoring

Two rounds were completed in September 2016 and February 2017 (USAEC, 2018).

13.7.2 Operations, Maintenance, and Monitoring Costs

From FY 2013 through 2017, the annual OM&M costs are stable (Table 48).

Table 48. Breakdown of LHAAP-001-R-01 operations and maintenance costs by fiscal year (USACE, 2018).

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)
FY13 Actuals	$568.31	$0	$568.31
FY14 Actuals	$568.31	$0	$568.31
FY15 Actuals	$568.31	$0	$568.31
FY16 Actuals	$568.31	$0	$568.31
FY17 Actuals	$568.31	$0	$568.31

13.8 Progress since the Last Five-Year Review

This is the first Five-Year Review for LHAAP-001-R-01.

13.9 Five-year Review Process

13.9.1 Data Review

Both groundwater data sets show perchlorate concentrations are below the 17 µg/L TRRP PCL residential groundwater cleanup level (Table 46). Sampling spans both wet and dry seasons (high and low base flow conditions, Figure 4) with no significant changes, suggesting no shallow residual perchlorate source is present. Summary data and statistical tables are in Appendix F.

Table 49. LHAAP-001-R perchlorate concentrations summary in groundwater (28-29 September 2016, and 20-21 November 2017), Longhorn Army Ammunition Plant, Karnack, TX (USAEC, 2018) (Figure 40). ND = non-detect.

Chemical	**Perchlorate**	
Cleanup Goal	**17 µg/L**	
Well ID	**Range**	**Most Recent**
27WW01	ND	ND
27WW02	ND- 0.705 –	0.705
27WW03	ND	ND
27WW04	ND	ND
131	ND	ND

13.9.2 Site Inspection

A site inspection was conducted on 22 and 23 May 2018, which included visual inspection of site land use and signage (Appendix D). Drew Clemens, Chris Kilbridge, and Lily Sehayek from USACE performed the site inspection. USFWS, USACE Tulsa District, USEPA Region 6, and TCEQ accompanied the team.

The land use control plan is being followed, and institutional controls have successfully maintained land use as non-residential. Maintenance continues for the warning signs posted as part of the 2009 MEC removal. Education programs and warning signs have kept people from digging holes. No changes in land use within the site or abutting land.

13.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

13.10 Technical Assessment

13.10.1 Technical Assessment Questions

This section addresses the three technical assessment questions identified in the USEPA's Five-Year Review guidance document as noted below (USEPA, 2001):

Question A:Is the remedy functioning as intended by the decision document?

Yes, the institutional controls portion of the remedy is functioning as intended. The first two sampling rounds showed below the 17 µg/L TRRP PCL residential groundwater cleanup level. Although the LUC RD/RACR was not in place, inspection and maintenance of signage took place during the review period. This included mowing around the 64 signs so that they remained visible one to the next, and repairing signs as needed. Major brush-clearing was conducted at LHAAP-001-R in 2017 to maintain sign visibility from one to the next and to improve access to signage. Of the 64 signs present at the site, faded "Danger" decals were replaced on 34 signs, and 5 sign posts and 4 signs were replaced entirely. No unauthorized use, such as digging or residential use, was noted during maintenance and well sampling activities throughout the review period.

Question B: *Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?*

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: *Has any other information come to light that could call into question the protectiveness of the remedy?*

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

13.10.2 Summary of the Technical Assessment

Based on the reviewed data, site inspection, and interviews, the institutional controls are implemented in accordance with the Site Wide LUC Management Plan, maintaining non-residential land use, preventing exposure to MEC.

13.11 Issues

The Fourth Five-Year Review identified no issues.

13.12 Recommendations and Follow-Up Actions

None.

13.13 Protectiveness Statement

The LHAAP-001-R-01 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.

14.0 LHAAP-003-R-01 GROUND SIGNAL TEST AREA

The LHAAP-003-R site is in the southeast part of LHAAP, and includes an asphalt road (Haystack Road) that intersects Long Point Road just east of its intersection with Avenue Q (Figure 41). The area is currently undeveloped and has become overgrown with woody vegetation since clearing was done in 2009 (US Army, 2016, EODT, 2009). The site straddles the divide separating Saunders Branch (east) and Harrison Bayou (west). Both Saunders Branch and Harrison Bayou flow into Caddo Lake. Surface water runoff from the site is towards drainage ditches located alongside the circular dirt road forming the outer margin of the site. The ditches converge to the northeast and the southwest directing surface water to Saunders Branch and Harrison Bayou, respectively.

14.1 Site Chronology

Significant site events and dates are in Table 50. No enforcement orders have been issued for the Site.

Table 50. LHAAP-003-R-01 chronology of site events (Bhate, 2018e, AECOM, 2017n, US Army, 2016, 2011, EODT, 2009, Cape, 2007).

Event	Date
Beginning of intermittent ground and aerial testing, device destruction, and rocket motor burnout	April 1963
Burnout of Pershing missile rocket motors	1988-1991
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA	December 30, 1991
US Army CTT Range/Site Inventory designate the Ground Signal Area LHAAP-003-R-01	September 2002
USFWS LHAAP investigation	March 2003
Military Munitions Response Program (MMRP) Site Investigation (SI) completed	2004
Engineering Evaluation/Cost Analysis identified Munitions and Explosives of Concern (MEC) at the site	August 2007
Final Baseline Ecological Risk Assessment	November 2007
MEC removal completed	November 2009
Proposed Plan	June 2011
Dispute Resolution	2011-2014
Record of Decision	August 2016
Perchlorate Sampling	September 2016
Groundwater Sampling Methodology and Perchlorate Analytical Results for September 2016, LHAAP-003-R	February 2017
Perchlorate Sampling	June 2017
Land Use Control Remedial Design/Remedial Action Construction Report	May 2018

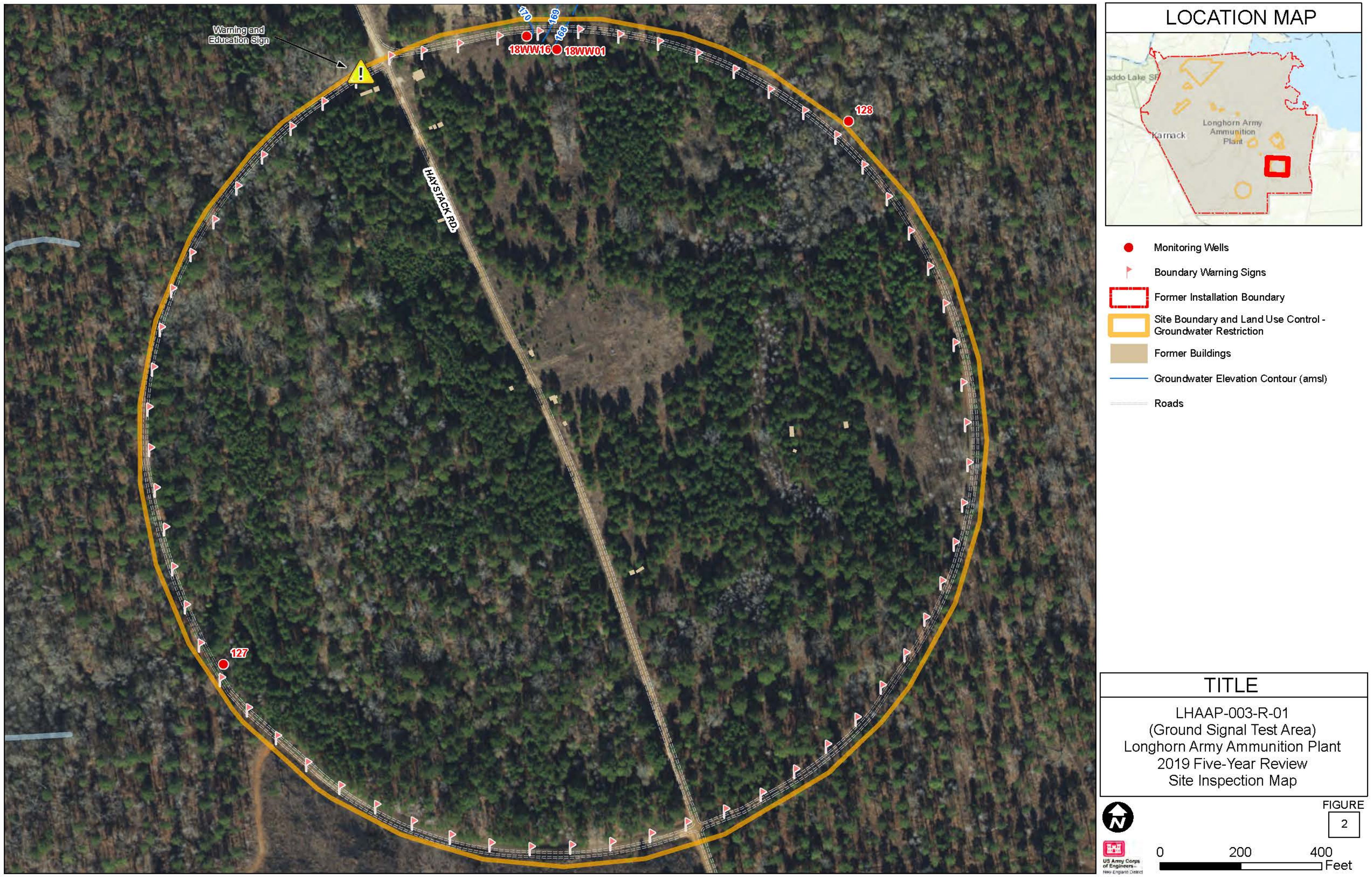


Figure 41. LHAAP-003-R-01 site map showing 2018 site inspection observations (LHAAP, 2018a, TNRIS, 2015, USGS, 2011, EODT, 2009).

14.2 History of Contamination

LHAAP-003-R, the Ground Signal Test Area, is co-located with IRP site LHAAP-54 (U.S. Army, 2016, Cape, 2007). LHAAP-003-R was used intermittently starting in April 1963 for aerial and on-ground testing and destruction of a variety of devices, including pyrotechnic signal devices, red phosphorus smoke wedges, infrared flares, illuminating mortar shells and cartridges, button bombs, and various types of explosive simulators. The site was also used intermittently over a 20-year period for testing and burnout of rocket motors. From late 1988 through 1991, the site was also used for burnout of Pershing missile rocket motors. Occasionally, leaking white phosphorous munitions were burned at the site as a demilitarization activity Initial Response Co-located IRP Site 54 underwent phased investigations between 1982 and 1996, and a No Further Action (NOFA) ROD was signed in January 1998 (Shaw, 2011b). The LHAAP Closed, Transferring and Transferred Range/Site Inventory report designated the Ground Signal Test Area LHAAP-003-01-R a separate site (U.S. Army, 2016). The USFWS collected soil samples from two locations along the surface drainage flowing toward Saunders Branch on the east side of the site. Analytical results showed low-level metals contamination, and no perchlorate (USFWS, 2003 reported in US Army, 2016). The 2003 MMRP SI identified white phosphorous as a soil data gap.

14.3 Initial Responses

The 2002-2004 MMRP SI identified MEC and scrap at the site, possible source areas, and a white phosphorous soil analysis data gap (US Army, 2016). An EE/CA was conducted in 2007, where fourteen MEC and MPPEH items were recovered at the surface or within the top 6 inches of the soil in LHAAP-003-01-R’s Mortar Test Area (Cape. 2007). Post-removal soil sampling showed no detections of white phosphorous or explosives. The EE/CA recommended MEC surface clearance and LUCs to reduce risk within LHAAP-003-R.

The 2009 MEC removal action found and removed 13 items (one was inert), over 6,880 pounds of munitions debris and over 5,981 pounds of metallic cultural debris (EODT, 2009). A previous demolition site was found, yielding 13 expended (inert) M485, 155mm illumination projectiles and numerous expended illumination canisters. After completing site restoration activities, an LUC program was instituted consisting of intrusive activity restriction, installing perimeter signs, and instituting an MEC-avoidance education program for future refuge visitors.

14.4 Summary of Basis for Taking Action

Through the 2008 surface removal action, MEC items were located and removed over the entire site thereby reducing the risk to the future land user. Because there is a reasonable potential some MEC remained after the removal action, a potential risk to the public exists. The basis for taking action (i.e., implementation of LUCs) is to promote ongoing protection of human safety against potential explosive hazards that may have remained at the site.

The LHAAP-003-R-01 investigations summarized in Table 47 found no COCs related to the site. MEC is the primary risk driver, and is ranked low for this site due to the two removals.

14.5 Remedial Actions

14.5.1 Remedy Selection

The selected LHAAP-003-R-01 remedy for addressing the low MEC risk and site contaminants while meeting the RAOs was a combination of land use controls and limited perchlorate groundwater monitoring (US Army, 2016). The LHAAP-003-R ROD for the former Ground Signal Test Area was issued August 2016. The decision was based on the Administrative Record for this site, including the Final EE/CA (Cape, 2007), Final MEC removal (EODT, 2009), and Final Proposed Plan (U.S. Army 2011). The decision was made in accordance with CERCLA, as amended by SARA, and, to the extent practicable, the NCP.

The August 2016 ROD was issued by the U.S. Army, who is the lead agency for this installation (US Army, 2016). USEPA (Region 6) and the TCEQ are the regulatory agencies providing technical support, project review and comment, and oversight of the U.S. Army cleanup program. The USEPA agrees with the selected remedy with TCEQ concurrence.

The LHAAP-003-R RAOs are protection of human health and safety from explosive hazards that may have remained at the sites after the MEC removal action, and confirmation that perchlorate is present in groundwater at levels below the chemical specific criterion (Table 51).

Table 51. LHAPP-001-R-001 and LHAAP-01-R-003 groundwater chemical of concern and remedial goal (US Army, 2016).

Chemical	Remedial Goal (µg/L)	Basis
Perchlorate	17	TRRP-GW PCL

The remedy consists of:

- LUC Implementation. This includes a completed legal description and plat in accordance with TAC § 335.569, Appendix III to include perimeter signage warning of potential UXO and prohibiting intrusive activities, and an education program for future refuge visitors, staff, and volunteers (Bhate, 2018e, US Army, 2016, 2013). LUCs to be verified by Five-Year Reviews.
- One round of perchlorate sampling from 18WW16, MW127, and MW128 to verify groundwater concentrations are below the 17 µg/L TRRP PCL residential groundwater cleanup level.

Because the LHAAP-01-R-003 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

14.5.2 Remedy Implementation

The signage and education program established as part of the EE/CA (EODT, 2009) are now part of the ROD's land use control program for this site (US Army, 2013).

14.6 Compliance Monitoring

The Army inspects all land use restrictions and controls specified in the ROD to determine the effectiveness and compliance with these restrictions and controls (US Army, 2013). The inspections include determining any violations of the LUCs, maintenance issues, trespass, and incompatible use. The LUCs include MEC warning signage and restrictions against digging and residential use. These LUCs were recorded in Harrison County, Texas on April 19, 2018. As required by the ROD, within 90 days of ROD signature, preliminary notice of LUCs was provided, to federal, state, and local officials including: State Representatives, the Harrison County Judge, the City of Uncertain Mayor, and Caddo Lake and Leigh Water Supply Corporations' Presidents, as well as the Caddo Lake NWR manager, the future transferee of the property. A second notice was transmitted on May 9, 2018 to the same parties with finalization of the LUC RD/RACR (Bhate, 2018e).

The LUC RD/RACR calls for annual inspections and maintenance of signage. Although the LUC RD/RACR was not in place during the review period, inspection and maintenance of signage took place. This included mowing around the 64 signs so that they remained visible one to the next, and repairing signposts and damaged signs as needed. In 2017, faded "Danger" decals were replaced on 18 signs at LHAAP-003-R and brush clearing between signposts was conducted to improve visibility.

14.7 Operations, Maintenance, and Monitoring

LHAAP-003-R-01 OM&M activities are:

- Collect one round of perchlorate groundwater samples
- Data compilation, records upkeep, and submittal of reports
- Maintenance of all wells and MEC signs

From FY 2013 through 2017, the annual OM&M costs are stable (Table 52). The increased costs for FY2016 are due to perchlorate sampling at three wells.

Table 52. LHAAP-003-R-01 operations, maintenance, and monitoring costs by fiscal year] (USACE, 2018).

Fiscal Year	O&M Costs ($)	LTM Costs ($)	Total ($)	Notes
FY13 Actuals	$568.31	$0	$568.31	
FY14 Actuals	$568.31	$0	$568.31	
FY15 Actuals	$568.31	$0	$568.31	
FY16 Actuals	$568.31	$11,004	$11,572.31	ROD Signed Aug 2016, wells sampled Sep 2017
FY17 Actuals	$568.31	$0	$568.31	

14.8 Progress since the Last Five-Year Review

This is the first Five-Year Review for LHAAP-003-R-01.

14.9 Five-year Review Process

14.9.1 Data Review

Both groundwater data sets show perchlorate concentrations are below the 17 µg/L TRRP PCL residential groundwater cleanup level (Table 53). Sampling spans both wet and dry seasons (high and low base flow conditions, Figure 4) with no significant changes, suggesting no shallow residual perchlorate source is present. Summary data and statistical tables are in Appendix F.

Table 53. LHAAP-003-1-R perchlorate concentrations summary in groundwater, Longhorn Army Ammunition Plant, Karnack, TX (USAEC, 2018). ND = non-detect. Cleanup goal is 17 17 µg/L.

Location ID	29 September 2016
18WW16	5.32
127	ND
128	ND

14.9.2 Site Inspection

A site inspection was conducted on 22 and 23 May 2018, which included visual inspection of site land use, access roads, and signage (Appendix D). Drew Clemens, Chris Kilbridge, and Lily Sehayek from USACE performed the site inspection. USFWS, USACE Tulsa District, USEPA Region 6, and TCEQ accompanied the team.

The land use control plan is being followed, and institutional controls have successfully maintained land use as non-residential. Maintenance continues for the warning signs posted as part of the 2008-2009 MEC removal. Education programs and warning signs have kept people from digging holes. No changes in land use within the site or abutting land.

14.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.

The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

14.10 Technical Assessment

14.10.1 Technical Assessment Questions

The following discussion details how each question has been answered based on the findings of the Fourth Five-Year Review using the 2001 USEPA guidance (USEPA, 2001).

Question A:Is the remedy functioning as intended by the decision document?

Yes, the institutional controls portion of the remedy is functioning as intended. Although the LUC RD/RACR was not in place, inspection and maintenance of signage took place during the review period. This included mowing around the 64 signs so that they remained visible one to the next, and repairing signs as needed. In 2017, faded "Danger" decals were replaced on 18 signs at LHAAP-003-R and brush clearing between signposts was conducted to improve visibility. No unauthorized use, such as digging or residential use, was noted during maintenance and well sampling activities throughout the review period.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced.

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

14.10.2 Summary of the Technical Assessment

Based on the reviewed data, site inspection, and interviews, the institutional controls are implemented in accordance with the LUCP, maintaining non-residential land use, preventing exposure to MEC and exposure to subsurface soil and groundwater.

14.11 Issues

The Fourth Five-Year Review identified no issues.

14.12 Recommendations and Follow-Up Actions

None.

14.13 Protectiveness Statement

The LHAAP-001-R-03 remedy is protective of human health and the environment. LUCs—including perimeter signage, prohibitions on intrusive activities and land development, and an educational awareness program—prevent exposure to MEC, and groundwater monitoring has confirmed that perchlorate remains below the remedial goal.

15.0 LHAAP-004-R-01 PISTOL RANGE

The former Pistol Range is located in the southeastern portion of LHAAP, approximately 280 feet south of Avenue Q at the end of Robert Avenue (Figure 42) (US Army, 2011). The site is the eastern portion of a rectangular field and is approximately 110 feet north to south by 150 feet east to west (approximately 0.4 acres). The former Pistol Range was used by LHAAP security personnel for small arms target qualification and recertification. The former Pistol Range was established in the 1950s and was used intermittently through 2004.

15.1 Site Chronology

Significant site events and dates are in Table 54. No enforcement orders have been issued for the Site.

Table 54. LHAAP-004-R-01 chronology of events (AECOM, 2014a, US Army, 2011).

Event	Date
Former Pistol Range established for small target practice and qualifying tests.	1950-2004
Installation Remedial Facility Assessment reviewed all Sites at LHAAP and assigned numbers currently in use to identify them.	April 8, 1988
LHAAP placed on NPL.	August 29, 1990
LHAAP, Texas Water Commission (later TNRCC and now TCEQ), and USEPA enter into a CERCLA Section 120 Agreement for remedial activities at LHAAP, referred to as the FFA.	December 30,1991
RCRA Part B Permit signed.	February, 1992
A few soil samples collected from the Former Pistol Range.	1995
Pistol Range officially closed by the U.S. Army.	2005
Comprehensive site investigation at the Former Pistol Range.	2006-2007
Non-time critical removal action at the Former Pistol Range.	2009
Final Baseline Ecological Risk Assessment	November 2007
Final Engineering Evaluation/Cost Analysis (EE/CA) Report.	January 2010
Final Proposed Plan for the Former Pistol Range.	January 2010
Final ROD, Former Pistol Range.	August 2010
First Five-Year Review	May 2014

15.2 History of Contamination

The Pistol Range at LHAAP was established before 1954 and was used by LHAAP security personnel for small arms target practice and qualifying tests (Figure 42). The range was designated as an active/inactive (A/I) range during the Army range inventory process, which culminated in the LHAAP A/I Range Inventory conducted in March 2001 by the Army Materiel Command. The reason for the A/I classification was that the range was being used once a year by contract security for qualification/certification. The Pistol Range was used through 2003 and into 2004 for qualifying and recertification by security guards. The Pistol Range was officially closed by Army in 2005.

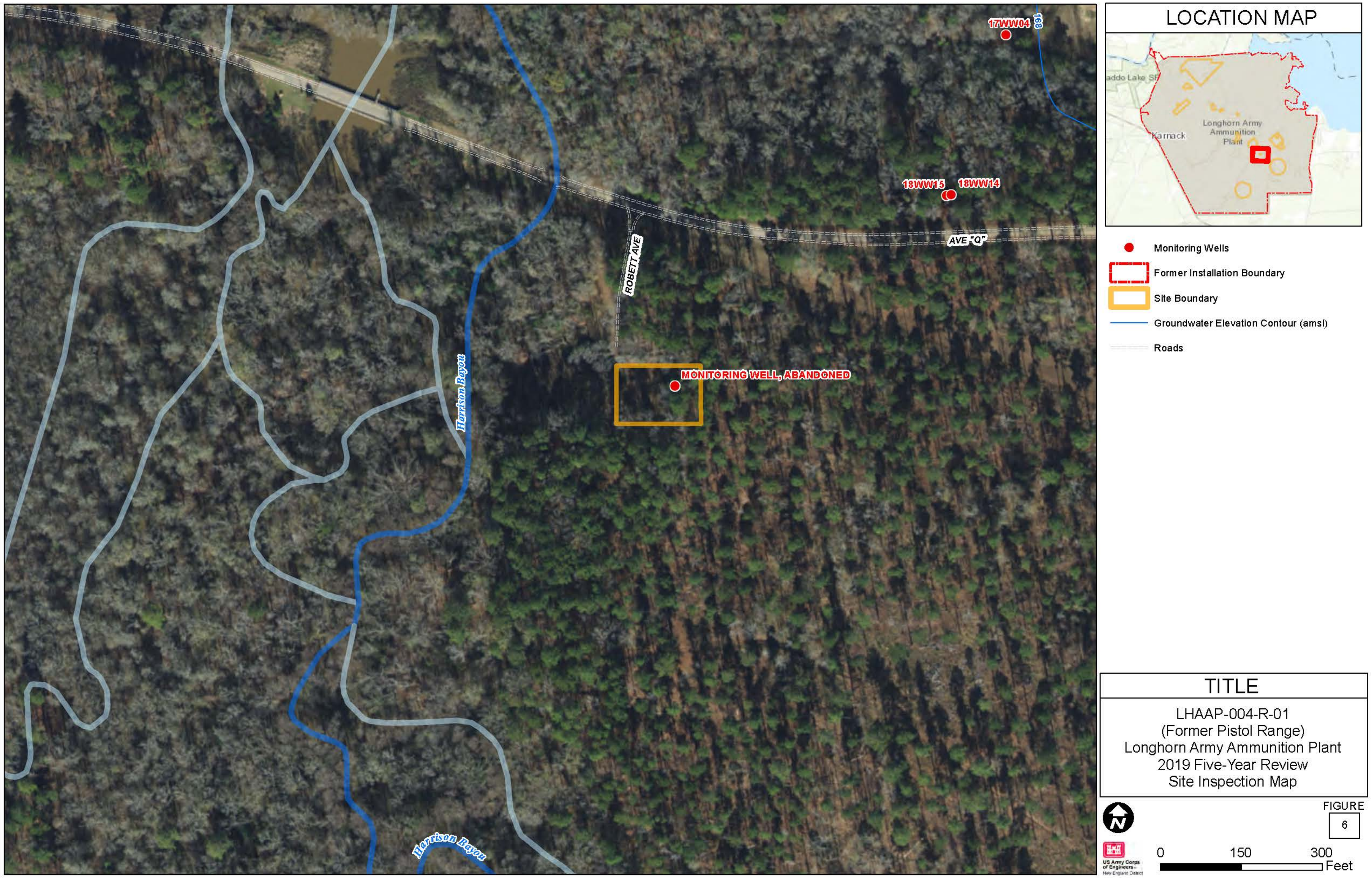


Figure 42. LHAAP-004-R-01 site map showing 2018 site inspection observations showing 2018 site inspection observations (LHAAP, 2018a, TNRIS, 2015, Landmark Consultants, 2011b, USGS, 2011).

According to the Draft Historical Records Review for Other Than Operational Ranges at LHAAP, 1 June 2004, the Pistol Range was a small arms range. The Final Environmental Site Assessment, Phase I and II Report, Production Areas, Longhorn Army Ammunition Plant (Plexus 2005) provides a summary of historical aerial photographs and notes the Pistol Range is present in photographs from 1954 and 1955. In the 2001 inventory, the size was indicated as 0.15 acres, which is an area approximately equivalent to the northeastern portion of the range from the firing line to the target embankment. There is no visual evidence or historical record of the Pistol Range used as anything other than a small arms firing range (Shaw, 2009d).

15.3 Initial Response

Evaluation of the data collected in those investigations showed that lead contamination in surface and near surface soil was the only environmental concern at the site (Shaw, 2009d). A non-time critical removal action was implemented at the former Pistol Range in 2009 to address a potential threat to public health through exposure to high levels of lead in soil. The potential threat was eliminated through soil removal. Soil with lead concentrations exceeding 1,000 milligrams per kilograms (mg/kg) was excavated and disposed of offsite (Shaw, 2009e).

15.4 Summary of Basis for Taking Action

The results of the 2006 and 2007 investigations demonstrated that sediment and surface water were not impacted by the site (Shaw, 2009d, e). As a result, no removal action was necessary to ensure protection of human health and the environment under the industrial land use scenario.

15.5 Remedial Actions

15.5.1 Remedy Selection

The ROD selected the No Action decision for LHAAP-004-01-R (US Army, 2010g). Although not a remedy, the LHAAP-49 land use assumption forms the basis for the remedy (AECOM, 2016f). The future use of the site as part of a national wildlife refuge is consistent with an industrial risk exposure scenario. Notification of the land use assumption of this site was recorded in Harrison County records stating that the site is suitable for nonresidential use in accordance with Texas Administrative Code (TAC) Title 30 §335.566 was submitted January 19 2012 (US Army, 2012).

This is a No Action decision site, so RAOs do not apply and there are no remedial goals.

Because the LHAAP-01-R-004 remedy does not restore the site to unrestricted use/unrestricted exposure conditions, five-year reviews are required ensure protection of human health and the environment under CERCLA Section 121(c), 42 U.S.C. § 9621(c).

15.5.2 Remedy Implementation

Notification of the nonresidential land use restriction accompanying all transfer documents was recorded at the Harrison County Courthouse in accordance with the Texas Administrative Code (TAC) Title 30, §335.566 (US Army, 2012). The Army provided a survey plat, legal boundary, and description of the groundwater restriction, in conjunction with a locator map to the Texas Department of Licensing and Regulation in hard and electronic copy.

15.6 Compliance Monitoring

None is conducted at this site.

15.7 Operations, Maintenance, and Monitoring

None are conducted at this site.

15.8 Progress since the 2014 Five-Year Review

This is the second five-year review for LHAAP-004-R-01.

15.8.1 Protectiveness Statements from the 2014 Review

Not Applicable.

15.8.2 Status of Recommendations and Follow-Up Actions from the 2014 Review

None reported in the 2014 Five-Year Review.

15.9 Five-year Review Process

15.9.1 Data Review

Surveyed site boundaries were verified to be correct and site maps updated (see Appendix C).

15.9.2 Site Inspection

A site inspection was conducted on 22 May 2018, which included visual inspection of former target berm and the soil remediation area (Appendix D). Drew Clemens, Chris Kilbridge, and Lily Sehayek from USACE performed the site inspection. USFWS, USACE Tulsa, Army BRAC, USEPA Region 6, and TCEQ accompanied the team.

No issues or other findings were identified during the site inspection. Land use has not changed since the 2013 Five-Year Review, nor is it anticipated to change before the 2024 Five-Year Review (AECOM, 2014a).

15.9.3 Interviews

Interview results indicate implementation of the selected remedy has proceeded without significant issue or concern. USEPA and TCEQ stated the LHAAP program is proceeding much better than during the 2013 Five-Year Review. All noted that no trespassing or vandalism activities occurred during this or the 2013 Five-Year Review. The USFWS and RAB representatives knew of no complaints regarding the site and the associated activities, but expressed the opinion that it takes too long to complete phases of work.
The following general items, questions, concerns were brought up:

- Future land use offsite includes USFWS acquiring abutting properties as they become available.
- The operating properly and successfully determination for several remedies has not yet been determined.
- Concerned about contaminated groundwater entering Caddo Lake.

No site-specific issues were raised during the interviews.

15.10 Technical Assessment

15.10.1 Technical Assessment Questions

The following discussion details how each question has been answered based on the findings of the Fourth Five-Year Review using the 2001 USEPA guidance (USEPA, 2001).

Question A:Is the remedy functioning as intended by the decision document?

Yes. The No Action decision is functioning as intended, for intended land use has not changed.

Question B: Are the exposure assumptions, toxicity data, cleanup levels, and remedial action objectives (RAOs) used at the time of remedy selection still valid?

Yes. Human health exposure assumptions and toxicity factors, as well as cleanup levels and the RAOs were reviewed and details are provided in Appendix B. While some exposure and toxicity factors did change since the completion of the BHHRA, the cumulative BHHRA site risk estimates, which risk management used to develop and evaluate cleanup levels and RAOs, are still valid because the changes are balanced. The wildlife refuge exposure assumptions, cleanup levels, and remedial action objectives remain the same since the ROD (Appendix B).

Question C: Has any other information come to light that could call into question the protectiveness of the remedy?

No. The Fourth Five-Year Review identified no human or ecological targets. Surface water samples analyzed found no contamination of surface water. No weather-related events have affected the protectiveness of the remedy. No other information analyzed during the Fourth Five-Year Review calls into question the protectiveness of the remedy.

15.10.2 Summary of the Technical Assessment

Contaminated soil was removed and disposed of offsite in 2009. Confirmatory soil sampling showed the remedial action reduced lead contamination below the nonresidential use cleanup levels. The Fourth Five-Year Review found no changes to current or future intended land use.

15.11 Issues

The Fourth Five-Year Review identified no issues.

15.12 Recommendations and Follow-Up Actions

None.

15.13 Protectiveness Statement

The LHAAP-004-R-01 No Action decision is protective of human health and the environment. There have been no changes in land use or other assumptions that would affect protectiveness.

16.0 NEXT REVIEW

The next Five-Year Review report for Longhorn Army Ammunition Plant is required five-years from the completion date of this review.

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APPENDIX A - PUBLIC NOTICE

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ANNOUNCEMENTS

LEGAL NOTICES

NOTICE TO CREDITORS

Notice is hereby given that original Letters Testamentary for the Estate of JAMES RICHARD SWILLEY, Deceased, were issued on January 29, 2018, in Cause No. 2017-17,706-CCL, pending in the County Court at Law of Harrison County, Texas, to: JANICE MARIE SWILLEY.

All persons having claims against this Estate which is currently being administered are required to present them to the undersigned within the time and in the manner prescribed by law.

c/o: **STEVEN G. SHAW**
Attorney at Law
304 N. Walnut Street
Jefferson, Texas 75657

DATED the 9th day of May, 2018.

STEVEN G. SHAW
Attorney for JANICE MARIE SWILLEY
State Bar No.: 18152530
304 N. Walnut Street
Jefferson, Texas 75657
Telephone: (214) 679-5383
E-mail: Lawyerlawman@yahoo.com

NOTICE TO CREDITORS

Notice is hereby given that original Letters of Administration for the Estate of JOHN TIMOTHY DUMOLT, Deceased, were issued on May 4, 2018, in Cause No. 2018-17,779-CCL, pending in the County Court at Law of Harrison County, Texas, to: SHERRY R. DUMOLT.

All persons having claims against this Estate which is currently being administered are required to present them to the undersigned within the time and in the manner prescribed by law.

c/o: Ronald Ned Dennis
Attorney at Law
308 W. Houston
P.O. Box 299
Marshall, Texas 75671-0299

DATED the 7th day of May, 2018.
Respectfully submitted,
Ronald Ned Dennis
Attorney at Law
P.O. Box 299
Marshall, Texas 75671-0299
903/938-3746
903/938-6012 (fax)
State Bar No. 05753000
dennislawmtx@gmail.com

Notice of Sale at A&O Self Storage, 1007 Indian Springs, will be held at 9 a.m. on Tuesday, May 22, 2018.

MANAGEMENT

DISTRICT MANAGER

The Longview News-Journal is looking for an individual with leadership ability. This position will oversee independent contractors (newspaper carriers) in a designated area of the community, provide customer service, identify growth opportunities, recruit and train independent contractors and oversee down route maintenance. This an entry level management position with nights and weekends mandatory
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Longview News-Journal

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3 blocks from Travis Elementary
Sat. May 12, 8am-2pm
Major downsizing sale: clothes (ladies' plus & men's reg), kitchen/household items, decor, twin bed, office furniture

GARAGE SALE
2814 Mary Mack
Thurs & Fri/8am-3pm
Lots of household goods, Corelle Dishes, tables & more.

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MARSHALL

Garage Sale
4404 Bridle Path
Off Hwy 80, N on Jasper, Right on Bridle Path, @ end of street
Saturday, May 12th, 7 AM
Toys, excersaucer, rocker, pack-n-play, car seat. $1 clothes Girls NB-2T, Boys 2T-5(SX), Shoes, Adult clothes. Utility cart, Bball goal, Bike Trlr, bike, pool.

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Living & Bedroom Furniture, small appliances, scrubs & lots of misc.

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Household items, toys, lots of clothing, furniture and lots of misc.

YARD SALE
52 Linwood Dr
Off Victory Drive and Murray
Friday, May 11th 8a - 2p
Saturday, May 12th 8a - 2p
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NOTICE OF APPLICATION FOR OIL AND GAS WASTE DISPOSAL WELL PERMIT

Brooks Petroleum Company: 100 Independence Place, Suite 404, Tyler, TX 75703

Is applying to the Railroad Commission of Texas for a permit to dispose of produced salt water or other oil and gas waste by well injection into a formation not productive to oil and gas. The applicant proposes to inject oil and gas waste into the Blossom/Tokio formations, Allen #1 "Whelan (Travis Peak)". The proposed injection well is located 4.6 Miles SW of Harleton, J.D. Moore Survey, A-451, Harrison County. Fluid waste will be injected into strata in the subsurface depth interval from 3000' to 3400'.

LEGAL AUTHORITY: Chapter 27 of the Texas Water Code, as amended, Title 3 of the Texas Natural Resources Code, as amended and the Statewide Rules of the Oil and Gas Division of the Railroad Commission of Texas.

Requests for a public hearing from persons who can show they are adversely affected or requests for further information concerning any aspect of the application should be submitted in writing within fifteen days of publication, to the Environmental Services Section, Oil and Gas Division, Railroad Commission of Texas, P.O. Box 12967, Austin, Texas 78711 (Telephone 512-463-6792)

The US Army is conducting a five-year review of twelve sites at Longhorn Army Ammunition Plant near Karnack Texas (see below). The review will focus on remedy implementation, progress, and protectiveness. Anyone having questions about the remedies or the five-year review process can contact Army site manager, Ms. Rose Zeiler at 479-635-0110. The five-year review is scheduled to be completed in October 2018.

LHAAP-12 (Sanitary Fill Area)
LHAAP-16 (Old Landfill)
LHAAP-18/24 (Burning Ground No. 3 and Unlined Evaporation Pond)
LHAAP-35B(37) (Chemical Laboratory)
LHAAP-46 (Plant 2 Area)
LHAAP- 49 (Former Acid Storage Area)
LHAAP-50 (Former Sump Water Tank)
LHAAP-35A(58) (Shops Area)
LHAAP-67 (Aboveground Storage Tank Farm)
LHAAP-001-R-01 (South Test Area/Bomb Test Area)
LHAAP-003-R-01 (Ground Signal Test Area)
LHAAP-004-R-01 (Former Pistol Range)

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APPENDIX B – ARAR, RISK ASSESSMENT ASSUMPTIONS, AND TOXICITY REVIEW

1.0 SITE-WIDE RISK ASSESSMENT SUMMARY

1.1 Human Risk Assessment

A base-wide Human Health Risk Assessment (BHHRA) was completed in 2002 (Jacobs, 2002a) for CERCLA hazardous substances and another evaluation for two MMRP sites was completed in 2007 (USACE, 2007). The CERCLA HTRW risk assessment included an evaluation of risks to a current trespasser's exposure to soil and potential future maintenance worker's exposure to soil and groundwater. The MEC and MC risk assessment included an evaluation of risk for a trespasser's exposure to MC in soil and groundwater as well as ordinance. Area-specific summaries of BHHRA results are provided under the section for each area. Appendix B provides information and an evaluation of the historic risk assessment assumptions, exposure factors, and toxicity factors.

1.2 Ecological Risk Assessment

The Baseline Ecological Risk Assessment (BERA) reported in 2007 (Shaw, 2007d) was based upon a Screening Levels Ecological Risk Assessment (SLERA) (Shaw, 2007c) that concluded the potential for adverse ecological risk existed for terrestrial and aquatic receptors, and that a more thorough assessment was warranted (Shaw, 2007c). Using a variety of measurement endpoints for higher trophic level terrestrial and aquatic systems, such as uptake by plants and invertebrates, food chain modelling, toxicity testing etc., the BERA showed some receptors to be at risk and derived Preliminary Remediation Goals (PRGs) for them. Following selected remediation in the upland areas, Five-Year Reviews indicated that ecological risk was not considered a risk driver (Shaw, 2008, AECOM, 2014a).

The hydrogeological evaluation (Section 2) indicates that currently on average, site-wide COC concentrations in groundwater are either equivalent to or less than concentrations at the time the site-wide BERA was performed. Based upon these findings, ecological risk findings at the time of this Five-Year Review would be equivalent to or less than the findings of risk the site-wide BERA in 2008.

2.0 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS, RISK ASSUMPTIONS AND TOXICITY REVIEW

This section provides a review of the site-wide Applicable or Relevant and Appropriate Requirements (ARARs), risk assessment assumptions, exposure factors as well as the cleanup levels and toxicity values for the Contaminants of Concern.

2.1 Review of ARARs

The NCP defines two ARAR components: (1) applicable requirements, and (2) relevant and appropriate requirements. These definitions and their functions in the remedy selection process must be considered when evaluating ARARs.

CERCLA considers applicable requirements to include cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site.

Relevant and appropriate requirements include those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws. While these are not “applicable” to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, they address problems or situations sufficiently similar to those encountered at the CERCLA site such that their use is well suited to the particular site.

CERCLA considers three types of ARARs:

- Location-specific ARARs are requirements driven by the geographical or physical position of the site, rather than by the nature of the chemicals of concern or the actions at the site. Location-specific ARARs are typically restrictions or requirements placed on the concentration of hazardous substances or the conduct of activities solely because they occur in a specific location.
- Chemical-specific ARARs are laws and regulations that identify health- or risk-based numerical values that, when applied to site-specific conditions, result in the establishment of concentration cleanup limits for specific hazardous substances. These limits establish the acceptable amount or concentration of a chemical that may be found in, or discharged to, the environment.
- Action-specific ARARs are requirements that define acceptable performance, design, or other similar controls or restrictions imposed on particular kinds of activities. Action-specific ARARs are usually technology- or activity-based requirements.

In general, chemical- and location-specific ARARs provide a basis for determining the objectives and goals of remedial action for the site, whereas action-specific ARARs provide a basis for determining how the remedial action will be implemented.

LHAAP ARARs were identified in the RODs are shown in Table 1 below and include the following:

- Safe Drinking Water Act (SDWA)
- Texas Risk Reduction Rule
- Resource Conservation and Recovery Act (RCRA)
- Texas Regulations for the Well Drilling Industry

Since the finalization of the RODs, Texas Risk Reduction Rule groundwater concentrations and the drinking water standards pertinent to this site remain the same. Since the RODs, Federal MCLs also have not been changed for COCs at the LHAAP sites. In 2002, the arsenic MCL was the last changed.

The SDWA was last amended in 1996. With respect to site-related contaminants of concern (COCs) in groundwater, no changes have been promulgated since 1997 in the Federal Review of ARARs for sites covered in this Five-Year Review did not identify any new requirements.

Table 1. Chemical-Specific ARARs

Source	Standard, Requirement, Criteria/Limitation	Scope	ARAR/To Be Continued (TBC) Status	Requirement/Action
Chemical Specific ARARs				
Federal Safe Drinking Water Act	40 CFR Part 141 42 U.S.C. 300g-1	Sites 12, 37, 46, 50 and 67.	Relevant and appropriate for water that could potentially be used for human consumption.	Water designated as a current or potential source of drinking water must not exceed drinking water standard, the MCLs.
State of Texas Primary Drinking Water Standards	30 TAC 290, Subchapter F	Site 58	Applicable to drinking water for a public water system - relevant and appropriate for water that could potentially be used for human consumption.	Must not exceed groundwater standard for water designated as a current or potential source of drinking water.
State of Texas Risk Reduction Standards	30 TAC 335.558 and 35.559(d)(2) as updated in the Texas Commission on Environmental Quality memorandum July 23, 1998	Site 46, 50 and 58	Applicable to industrial drinking water - relevant and appropriate for potential hypothetical future maintenance worker exposure to groundwater consumption.	If no Maximum Contaminant Level has been promulgated, groundwater must not exceed the industrial medium-specific concentration.
Early IRA ROD Discharge Criteria	Table 2 of IRA ROD Early Interim Action at Burning Grounds 3, Army, May 1995 and Protocol for Discharging GWTP Effluent (August 28, 2017)	Site 18/24	Relevant and appropriate for water discharge from the plant to Harrison Bayou following treatment.	Comparison table for analytical data to enable monitoring of quality of water returned to Harrison Bayou or INF Pond.

Source	Standard, Requirement, Criteria/Limitation	Scope	ARAR/TBC Status	Requirement/Action
Location-Specific ARARs				
National Historic Preservation Act of 1966 and Texas Preservation Trust Fund	36 CFR 60, 36 CFR 65 and 36 CFR 800 13 TAC 16, 17 and 25	No known historic locations are present at any of the subject sites	Applicable if remediation activities are located near historic locations.	Current activities are not expected to disturb any additional land although Site 18/24 may have future remedy activities that could be impacted. Any historic resource must be identified, designated and protected.
Floodplain Management and Protection	40 CFR 264.18	Site 16, 18/24	Applicable for activities located near the 100-year flood plain or designated wetlands.	Parts of the burning ground,LHAAP-18/24 and LHAAP-16 are within the 100 year floodplain. Minimal impact is expected based on limited ongoing ground-disturbing activities. Avoid, to the extent possible, the long- and short-term adverse effects associated with modification of floodplains. Minimize destruction, loss or degradation to any wetlands.

Source	Standard, Requirement, Criteria/Limitation	Scope	ARAR/TBC Status	Requirement/Action
Action-Specific ARARs				
National Pollution Discharge Elimination System	40 CFR Part 125 and 30 TAC	Site 18/24	Applicable if water is discharged to a surface water body or wetland	Discharges to waters of the State must meet the NPDES requirements.
Post Closure Care Requirements for Hazardous Waste Landfills	40 CFR 264.310(b) and 30 TAC 335.174(b)	Sites 12 and 16	Relevant and appropriate to post closure under CERCLA of landfills containing RCRA hazardous waste. Currently Sites 12 and 16.	Owner or operator must: • maintain the effectiveness and integrity of the final cover including making repairs to the cap as necessary; • prevent run-on and run-off from eroding or otherwise damaging the final cover; and • maintain and monitor a groundwater monitoring system.
Clean Water Act (CWA)	40 CFR Parts 133 and 230 and 33 CFR Parts 320-330	Sites 12 and 16	Relevant and appropriate	Applies to construction of a fill in a wetlands area.
State of Texas Air Emissions (Permit by Rule)	30 TAC 116	Site 18/24	Relevant and appropriate	Air emissions from groundwater treatment process will be in accordance with 30 TAC 116 (now Permit by Rule).

3.0 RISK ASSESSMENT ASSUMPTIONS AND EXPOSURE FACTORS

Human Health risk assessment assumptions at the time of the RODs were for a current on-site trespasser and hypothetical future maintenance worker under an industrial scenario. These exposure scenarios remain valid potential exposures for human health risk.

Since the RODs were signed, some exposure factors used in the risk assessment they were based on have changed. The body weight and skin surface area for the outdoor worker increased, but the soil adherence factor decreased. Most default exposure factors for the two receptors evaluated in the HHRA, same such as those for the outdoor worker exposure frequency and duration, remain the same as at those used at the time of the HHRA evaluation. Application of current exposure factor default values to the HHRA would not change the risk conclusions.

4.0 REVIEW OF TOXICITY FACTORS

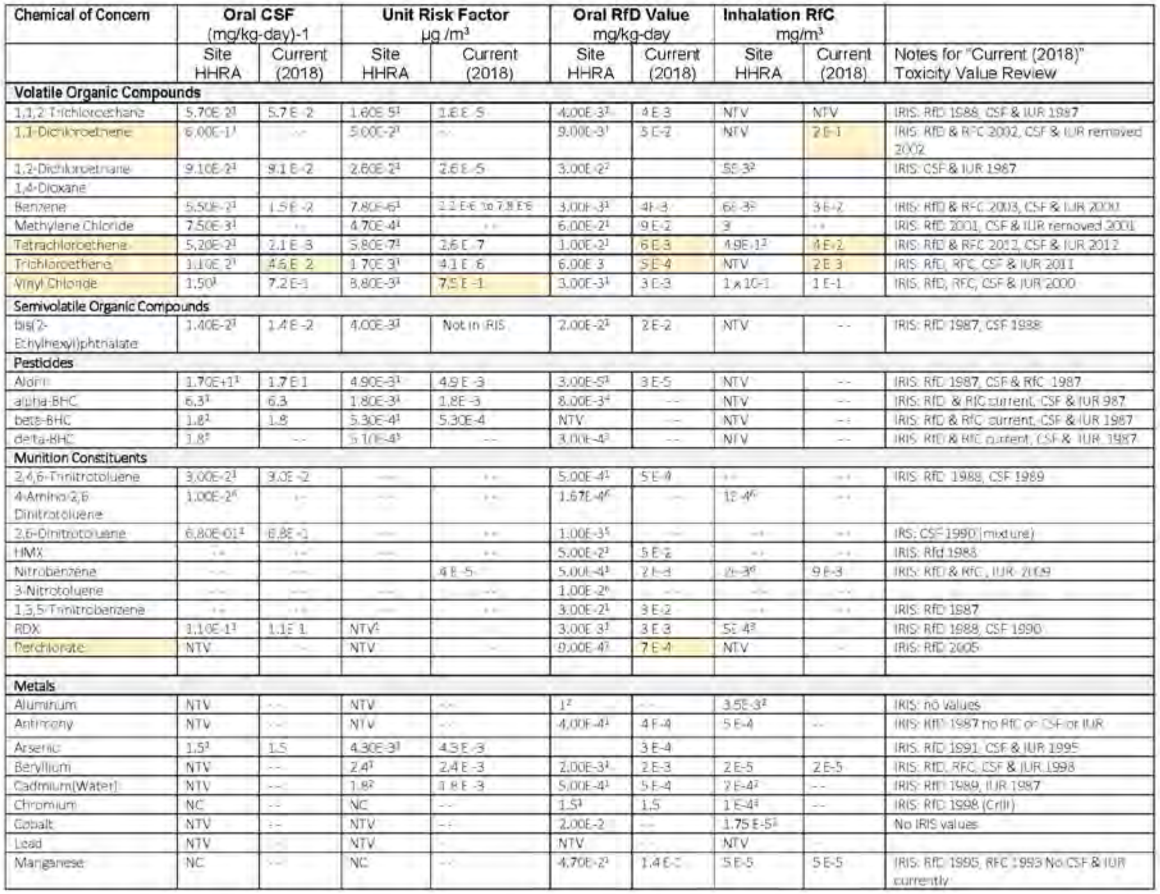
Toxicity factors used in the human health risk assessments (HHRAs) for the site were reviewed and compared to currently available toxicity factors. Table 2 shows all the toxicity values for oral and inhalation routes of exposure for cancer and noncancer adverse health effects. With the exception of the following compounds, all the following toxicity factors are currently the same or would be associated with a lower risk estimate:

- 1,1-Dichloroethene
- Tetrachloroethene
- Trichloroethene
- Vinyl Chloride
- Perchlorate

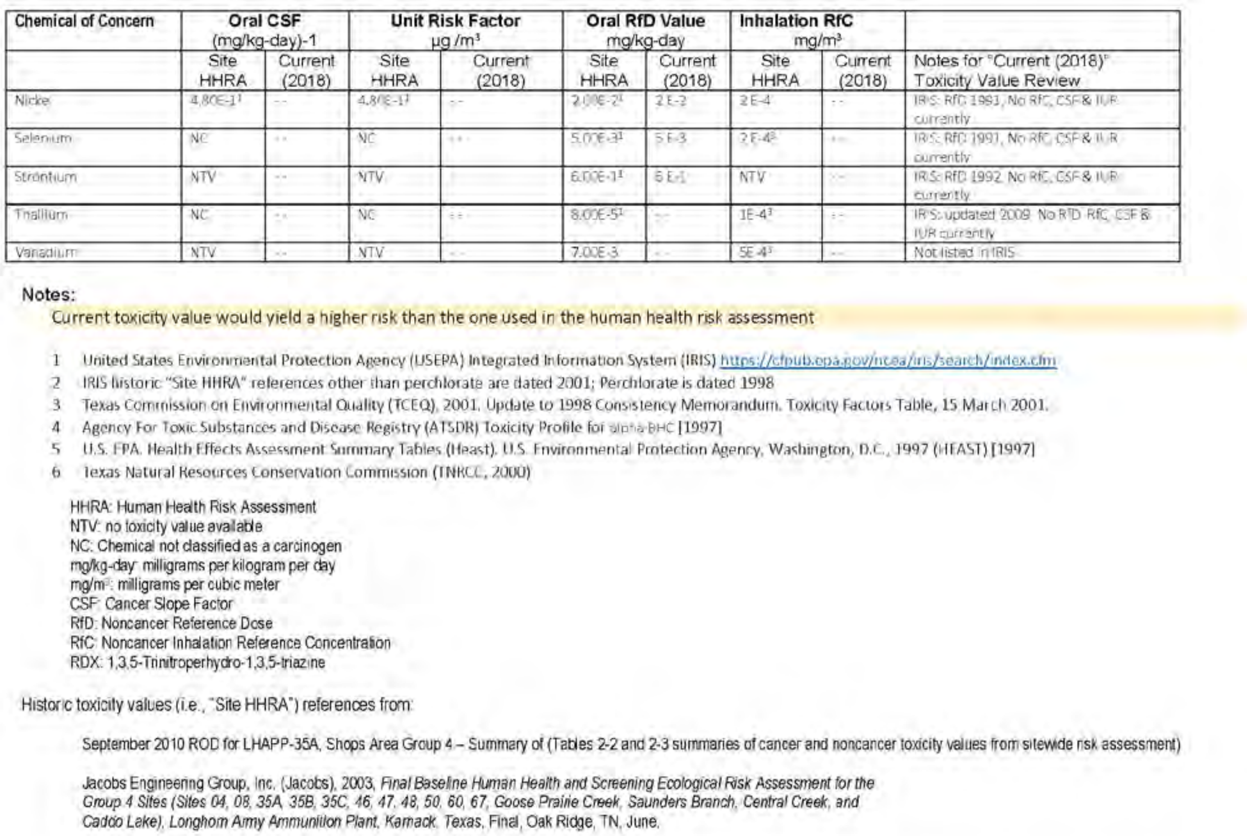
1,1-Dichloroethene, tetrachloroethene, and trichloroethene have lower noncancer inhalation toxicity factors (which means the risk would be higher), but because these chemicals are in groundwater from which there are no residential exposures and the incremental risk change is small, the change does not affect protectiveness. Likewise, the change in cancer inhalation risk for vinyl chloride also does not affect protectiveness. Perchlorate, tetrachloroethene, and trichloroethene also had small changes in the noncancer ingestion toxicity factors. No one drinks the water and the groundwater is being monitored, so these changes do not effect protectiveness. Trichloroethene’s cancer oral ingestion toxicity factor also changed minimally (within the same order of magnitude), so that change does not affect protectiveness. Finally, the changes in several other toxicity factors would lower the risk and some compounds no longer have toxicity factors for some routes of exposure, so the overall effect of the toxicity factors likely lowers the total site risk. Therefore, the remedial goals based on cumulative risk in place at the time of the Records of Decision (RODs) are still protective.

While the emerging contaminant 1,4-dioxane has been detected in site groundwater, the remedy is still protective. In accordance with DoD Policy Memorandum, 22 Aug 2016, "Revised Site Management Procedures -Update to DoD Manual 4715.20" on procedures for addressing emerging contaminants at DERP sites, the Army will continue to sample for 1,4-dioxane during Five-Year Reviews, however, the ROD and remedy will not be amended until it is shown that the emerging contaminant presents an unacceptable risk.

Table 2. Comparison of Toxicity Values from time of Record of Decision with Current Toxicity Values



Chemical of Concern	Oral CSF (mg/kg-day)-1		Unit Risk Factor µg /m^3		Oral RfD Value mg/kg-day		Inhalation RfC mg/m^3		
	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Notes for "Current (2018)" Toxicity Value Review
Volatile Organic Compounds									
1,1,2-Trichloroethane	5.70E-2^1	5.7 E-2	1.60E-5^1	1.6 E-5	4.00E-3^1	4 E-3	NTV	NTV	IRIS: RfD 1988, CSF & IUR 1987
1,1-Dichloroethene	6.00E-1^1	--	5.00E-2^1	--	9.00E-3^1	5 E-2	NTV	2 E-1	IRIS: RfD & RFC 2002, CSF & IUR removed 2002
1,2-Dichloroethane	9.10E-2^1	9.1 E-2	2.60E-2^1	2.6 E-5	3.00E-2^2		5E-3^2		IRIS: CSF & IUR 1987
1,4-Dioxane									
Benzene	5.50E-2^1	1.5 E-2	7.80E-6^1	2.2 E-6 to 7.8 E-6	3.00E-3^1	4 E-3	6E-3^2	3 E-2	IRIS: RfD & RFC 2003, CSF & IUR 2000
Methylene Chloride	7.50E-3^1	--	4.70E-4^1	--	6.00E-2^1	9 E-2	3	--	IRIS: RfD 2001, CSF & IUR removed 2001
Tetrachloroethene	5.20E-2^1	2.1 E-3	5.80E-7^1	2.6 E-7	1.00E-2^1	6 E-3	4.9E-1^2	4 E-2	IRIS: RfD & RFC 2012, CSF & IUR 2012
Trichloroethene	1.10E-2^1	4.6 E-2	1.70E-3^1	4.1 E-6	6.00E-3	5 E-4	NTV	2 E-3	IRIS: RfD, RFC, CSF & IUR 2011
Vinyl Chloride	1.50^1	7.2 E-1	8.80E-3^1	7.5 E-1	3.00E-3^1	3 E-3	1 x 10-1	1 E-1	IRIS: RfD, RFC, CSF & IUR 2000
Semivolatile Organic Compounds									
bis(2-Ethylhexyl)phthalate	1.40E-2^1	1.4 E-2	4.00E-3^1	Not in IRIS	2.00E-2^1	2 E-2	NTV	--	IRIS: RfD 1987, CSF 1988
Pesticides									
Aldrin	1.70E+1^1	1.7 E1	4.90E-3^1	4.9 E-3	3.00E-5^1	3 E-5	NTV	--	IRIS: RfD 1987, CSF & RfC 1987
alpha-BHC	6.3^1	6.3	1.80E-3^1	1.8E-3	8.00E-3^4	--	NTV	--	IRIS: RfD & RfC current, CSF & IUR 987
beta-BHC	1.8^1	1.8	5.30E-4^1	5.30E-4	NTV	--	NTV	--	IRIS: RfD & RfC current, CSF & IUR 1987
delta-BHC	1.8^3	--	5.10E-4^3	--	3.00E-4^3	--	NTV	--	IRIS: RfD & RfC current, CSF & IUR 1987
Munition Constituents									
2,4,6-Trinitrotoluene	3.00E-2^1	3.0E-2	--	--	5.00E-4^1	5 E-4	--	--	IRIS: RfD 1988, CSF 1989
4-Amino-2,6-Dinitrotoluene	1.00E-2^6	--	--	--	1.67E-4^6	--	1E-4^6	--	
2,6-Dinitrotoluene	6.80E-01^1	6.8E-1	--	--	1.00E-3^5	--	--	--	IRS: CSF 1990 (mixture)
HMX	--	--	--	--	5.00E-2^1	5 E-2	--	--	IRIS: Rfd 1988
Nitrobenzene	--	--		4 E-5	5.00E-4^1	2 E-3	2E-3^6	9 E-3	IRIS: RfD & RfC, IUR 2009
3-Nitrotoluene	--	--	--	--	1.00E-2^6	--	--	--	
1,3,5-Trinitrobenzene	--	--	--	--	3.00E-2^1	3 E-2	--	--	IRIS: RfD 1987
RDX	1.10E-1^1	1.1E 1	NTV^1		3.00E-3^1	3 E-3	5E-4^3		IRIS: RfD 1988, CSF 1990
Perchlorate	NTV	--	NTV	--	9.00E-4^7	7 E-4	NTV	--	IRIS: RfD 2005
Metals									
Aluminum	NTV	--	NTV	--	1^2	--	3.5E-3^2		IRIS: no values
Antimony	NTV	--	NTV	--	4.00E-4^1	4 E-4	5 E-4	--	IRIS: RfD 1987 no RfC or CSF or IUR
Arsenic	1.5^1	1.5	4.30E-3^1	4.3 E-3		3 E-4			IRIS: RfD 1991, CSF & IUR 1995
Beryllium	NTV	--	2.4^1	2.4 E-3	2.00E-3^1	2 E-3	2 E-5	2 E-5	IRIS: RfD, RFC, CSF & IUR 1998
Cadmium(Water)	NTV	--	1.8^2	1.8 E-3	5.00E-4^1	5 E-4	2 E-4^2	--	IRIS: RfD 1989, IUR 1987
Chromium	NC	--	NC	--	1.5^1	1.5	1 E-4^2	--	IRIS: RfD 1998 (CrIII)
Cobalt	NTV	--	NTV	--	2.00E-2	--	1.75 E-5^2		No IRIS values
Lead	NTV	--	NTV	--	NTV	--	NTV	--	
Manganese	NC	--	NC	--	4.70E-2^1	1.4 E-1	5 E-5	5 E-5	IRIS: RfD 1995, RFC 1993 No CSF & IUR currently



Chemical of Concern	Oral CSF (mg/kg-day)-1		Unit Risk Factor µg /m³		Oral RfD Value mg/kg-day		Inhalation RfC mg/m³		
	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Site HHRA	Current (2018)	Notes for "Current (2018)" Toxicity Value Review
Nickel	4.80E-1[1]	--	4.80E-1[1]	--	2.00E-2[1]	2 E-2	2 E-4	--	IRIS: RfD 1991, No RfC, CSF & IUR currently
Selenium	NC	--	NC	--	5.00E-3[1]	5 E-3	2 E-4[3]	--	IRIS: RfD 1991, No RfC, CSF & IUR currently
Strontium	NTV	--	NTV		6.00E-1[1]	6 E-1	NTV	--	IRIS: RfD 1992, No RfC, CSF & IUR currently
Thallium	NC	--	NC	--	8.00E-5[1]	--	1E-4[3]	--	IRIS: updated 2009. No RfD, RfC, CSF & IUR currently
Vanadium	NTV	--	NTV	--	7.00E-3	--	5E-4[3]	--	Not listed in IRIS

Notes:

Current toxicity value would yield a higher risk than the one used in the human health risk assessment

1 United States Environmental Protection Agency (USEPA) Integrated Information System (IRIS) https://cfpub.epa.gov/ncea/iris/search/index.cfm
2 IRIS historic "Site HHRA" references other than perchlorate are dated 2001; Perchlorate is dated 1998
3 Texas Commission on Environmental Quality (TCEQ), 2001. Update to 1998 Consistency Memorandum. Toxicity Factors Table, 15 March 2001.
4 Agency For Toxic Substances and Disease Registry (ATSDR) Toxicity Profile for alpha-BHC [1997]
5 U.S. EPA. Health Effects Assessment Summary Tables (Heast). U.S. Environmental Protection Agency, Washington, D.C., 1997 (HEAST) [1997]
6 Texas Natural Resources Conservation Commission (TNRCC, 2000)

HHRA: Human Health Risk Assessment
NTV: no toxicity value available
NC: Chemical not classified as a carcinogen
mg/kg-day: milligrams per kilogram per day
mg/m³: milligrams per cubic meter
CSF: Cancer Slope Factor
RfD: Noncancer Reference Dose
RfC: Noncancer Inhalation Reference Concentration
RDX: 1,3,5-Trinitroperhydro-1,3,5-triazine

Historic toxicity values (i.e., "Site HHRA") references from:

September 2010 ROD for LHAPP-35A, Shops Area Group 4 – Summary of (Tables 2-2 and 2-3 summaries of cancer and noncancer toxicity values from sitewide risk assessment)

Jacobs Engineering Group, Inc. (Jacobs), 2003, *Final Baseline Human Health and Screening Ecological Risk Assessment for the Group 4 Sites (Sites 04, 08, 35A, 35B, 35C, 46, 47, 48, 50, 60, 67, Goose Prairie Creek, Saunders Branch, Central Creek, and Caddo Lake), Longhorn Army Ammunition Plant, Karnack, Texas*, Final, Oak Ridge, TN, June.

5.0 REVIEW OF CLEANUP LEVELS

In Table 3, cleanup goals from RODs are summarized and compared to current standards and regulations from the same federal or Texas programs. The standards and regulations are from the following programs:

- Federal Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs),
- Texas Risk Reduction Rule (TRRR) MSC (Medium Specific Concentrations) and risk-based screening levels
- Texas April 2018 Texas Risk Reduction Program (TRRP) Tier 1 protective concentration levels (PCLs)

There have been no changes in the chemical concentration regulations or standards since the RODs were written.

6.0 SUMMARY AND CONCLUSIONS

The evaluation of current ARARs, risk assessment, and exposure factor assumptions did not reveal any changes that would affect the conclusions of the HHRA used for the determination of taking action. Further, the cleanup goals are based on either federal or Texas regulations or standards and those regulations and standards remain the same. Those cleanup goals were based on the SDWA ARAR and two Texas groundwater ARARS. One Texas ARAR related to the cleanup goals is updated annually and the standards and regulations the applicable to LHAPP cleanup goals remain valid. Other than a wastewater discharge ARAR and the Endangered Species Acts, most other ARARs have not been updated or changed significantly since the interim or final RODs were signed.

Based on the risk evaluation presented in this appendix, there are no changes in ARARs, risk assumptions, exposure or toxicity factors that call into question the results of the risk assessments. The cleanup goals were based on federal and state drinking water and industrial standards and regulations that are the same, so the cleanup goals also remain valid.

Table 3. Cleanup goals from records of decision compared to current regulations and standards.

Chemical of Concern	Record of Decision Cleanup Level		Current (August 2018)	
	Concentration	Regulatory Basis	Concentration	
Groundwater (μg/L)				
Chloroethane	41,000	GW-Ind	41,000	GW-Ind
1,1-Dichloroethane	10,000	GW-Ind	10,000	GW-Ind
1,2-Dichloroethane	5	MCL	5	MCL
cis-1,2-Dichloroethene	70	MCL	70	MCL
trans-1,2-Dichloroethene	100	MCL	100	MCL
1,1-Dichloroethene	7	MCL	7	MCL
Methylene Chloride	5	MCL	5	MCL
1,1,2-Trichloroethane	5	MCL	5	MCL
Trichloroethene	5	MCL	5	MCL
Tetrachloroethene	5	MCL	5	MCL
Vinyl Chloride	2	MCL	2	MCL
Arsenic	10	MCL	10	MCL
Chromium (total)	100	MCL	100	MCL
Manganese	1,100	TRRP PCL	1,100	TRRP PCL (residential)
Nickel	490	TRRP PCL	490	TRRP PCL (residential)
Thallium	2	MCL	2	MCL
1,4-dioxane*	**Emerging Contaminant**			
Perchlorate	17	TRRP PCL	17	TRRP PCL (residential)
Perchlorate	72	GW-Ind	51	GW-Ind
Soil (μg/kg)				
Perchlorate	7,200	GWP-Ind	7,200	GWP-Ind

Notes:

- GW-Ind: Texas Risk Reduction Rule (TRRR) MSC (Medium Specific Concentrations) and risk-based screening levels table: https://www.tceq.texas.gov/remediation/rrr.html/#topic1. This rule was last updated March 2006.
- TRRP PCL: Texas April 2018 Texas Risk Reduction Program (TRRP) Tier 1 protective concentration levels (PCLs): https://www.tceq.texas.gov/remediation/trrp/trrppcls.html
- MCL: United States Environmental Protection Agency (EPA) Maximum Contaminant Level are chemical concentrations in primary drinking water sources and are enforceable as the National Primary Drinking Water Regulations promulgated under a process in the Safe Drinking Water Act.
- *No current cleanup goal documented but 1,4-Dioxane is being monitored. USEPA Fact Sheet: https://www.epa.gov/sites/production/files/2014-03/documents/ffrro_factsheet_contaminant_14-dioxane_january2014_final.pdf

APPENDIX C – DATA ANALYSIS

DATA ANALYSIS TABLE OF CONTENTS

1.0 DATA ANALYSIS METHODS

1.1 Positional Accuracy and Datums

1.1.1 Horizontal Data

Horizontal data was evaluated using ArcGIS by overlaying the surveyed LUC and site boundary data onto rectified imagery projected onto the Texas-North state plane NAD83 datum. All boundary data measured by a Texas-licensed surveyor included with deed notices has suitable horizontal accuracy for the Fourth Five-Year Review (errors greater than 2 feet were not apparent).

1.1.2 Vertical Data

Due to the relatively flat water table and shallow groundwater gradients, small differences in groundwater elevation can have significant impacts on interpreted groundwater flow. Given the criticality of groundwater level measurement for analyzing flow direction and discharge locations, the Fourth Five-Year Review team evaluated the vertical data. All LHAAP vertical data (well measuring points, groundwater contours) are referenced to the tidal datum "above mean sea level" (amsl) instead of an established vertical datum (Bhate, 2017, Marcy, 2017, AECOM, 2014c). The fourth five-year review team assumed the elevation data was internally consistent and referenced to a local control point within each site following USACE guidance (USACE, 2010a, 2007).

The available digital elevation model was used to show site-wide topographic trends, for it was not high enough resolution to conduct site-level (e.g., drainage) analysis (USGS, 2013).

1.2 Chemistry Database Integration and Trend Analysis

Historical groundwater quality data collected at the Longhorn sites since 1980 were summarized to highlight the sample collection periods of COCs and contaminants of interest at select monitoring wells, surface water and miscellaneous sampling points. Monitoring points of interest were defined as being those sampled at least once during the five-year review period (since October 2013). Trend analysis was conducted using ProUCL 5.0 (Mann-Kendall and Theil-Sen analysis) and ArcGIS 10.4 using the following steps.

1. Combine and process available data sets (USAEC, 2018, USACE, 2018, LHAAP, 2018b)
    a. Available datasets were combined and duplicates were removed to develop a single dataset.
    b. Combined data was processed to resolve several inconsistencies (e.g., misspellings, missing names, concatenation of concentrations and qualifiers, multiple names for same analyte).
    c. Highlight only analytes that were identified as COCs

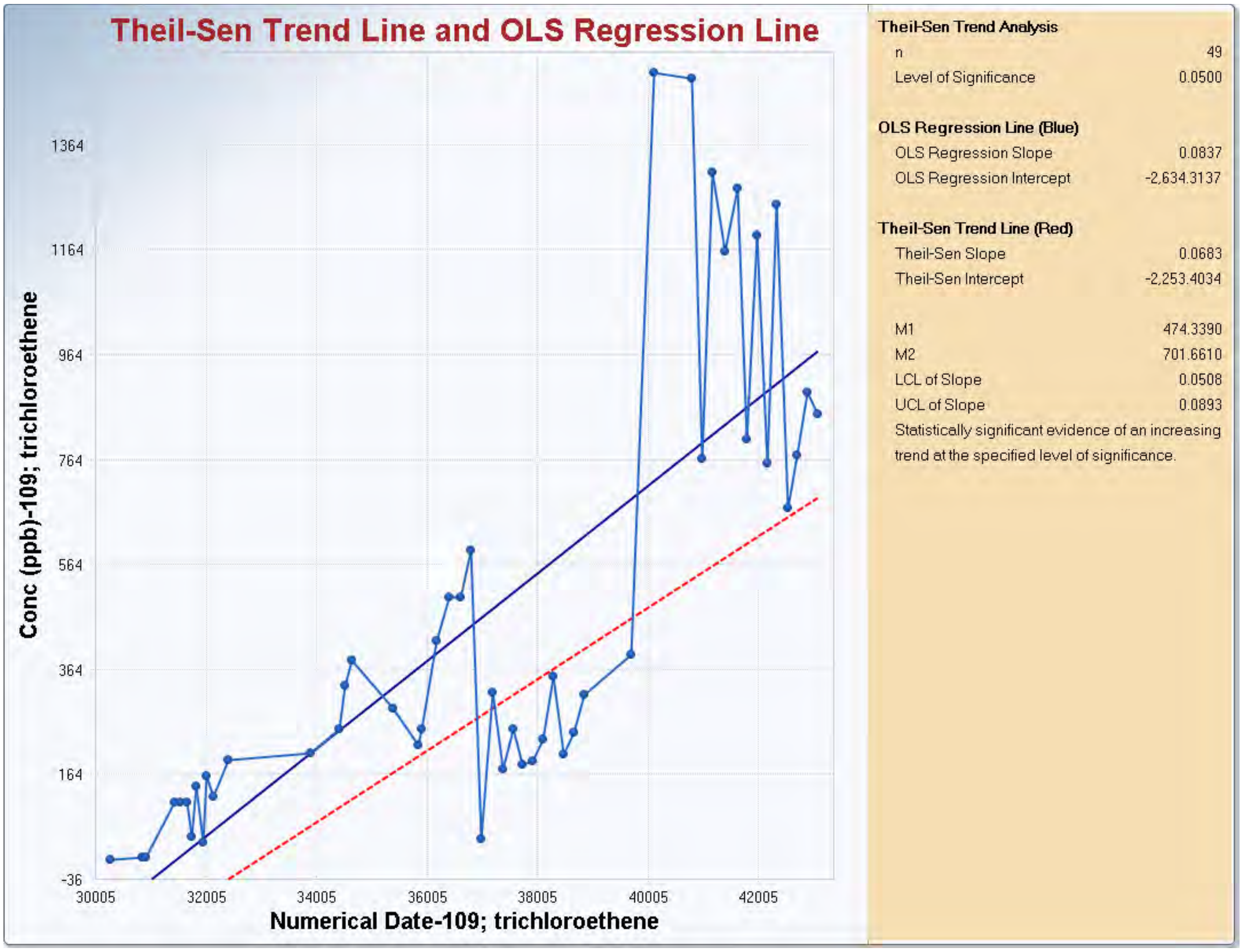
2. Summarize data
    a. Group data by unique location and COC identifier
    b. Determine several statistics including period of record, number of samples, minimum, maximum, and average.
    c. Create a single summary table for all locations-COCs pairs

3. Prepare data for ProUCL trend analysis
    a. Filter out wells that have not been sampled since 2012 to eliminate an evaluation of wells that are presumably no longer in the sampling program.
    b. Filter out constituents with period of record maximum concentrations that were either "ND" or were less than 10 times their respective MCL to eliminate 1) the evaluation of data that may be skewed due to elevated detection limits and 2) the evaluation of relatively low concentration data and reduction in the overall number of ProUCL evaluations.
    c. Filter to consider wells with at least eight samples as a way of evaluating data with an adequate data history, similar to CERCLA recommendations for evaluation of data for development of a long-term monitoring plan.

4. Trend evaluation using ProUCL
    a. Prepared and filtered data was formatted for use by ProUCL to determine trend evaluations for 512 unique location-COC pairs (ProUCL can only be used for a limited number of location-COC pairs and needed to be run multiple times).
    b. Mann-Kendall and Theil-Sen analysis were conducted using the detection limit for concentrations reported as non-detect (ProUCL does not differentiate between measurable and non-detect concentrations) and at a 95% probability to determine if the data was “Increasing”, “Decreasing”, or if there was “Insufficient” data to identify a trend (see Plot 1 for an example).
        i. Mann-Kendall Analysis. Run on data with monotonic trends and no seasonal variability.
        ii. Theil-Sen Analysis. Run on data with monotonic, linear trends.

5. Summarize Trend Results-ProUCL and Geospatial Analysis
    a. ProUCL output data was combined and processed to complete a tabular summary of location-COC results using the following categories:
        i. N/A, which indicates 1) not sampled, 2) maximum POR concentration was "ND", 3) maximum POR concentration <10 times MCL, or 4) <8 Samples
        ii. Increasing Trend, which indicates that an increasing trend was identified by ProUCL
        iii. Decreasing Trend, which indicates that a decreasing trend was identified by ProUCL
        iv. Insufficient Data, which indicates there was not enough data for ProUCL to determine a trend.
    b. ArcGIS was used to provide a visual means of presenting the VOC, perchlorate, and 1,4-Dioxane ProUCL trend analyses by showing COCs as quadrants within well symbols and then color-coding the quadrant based on the ProUCL result.

Once the list of LHAAP wells of interest was compiled, water quality data for the 21 identified COCs or contaminants of interest was summarized to include the sample collection period, number of samples collected, and the average, minimum, and maximum concentrations (Appendix F).



```
Theil-Sen Trend Analysis
   n                                        49
   Level of Significance                0.0500

OLS Regression Line (Blue)
   OLS Regression Slope                 0.0837
   OLS Regression Intercept        -2,634.3137

Theil-Sen Trend Line (Red)
   Theil-Sen Slope                      0.0683
   Theil-Sen Intercept             -2,253.4034

   M1                                 474.3390
   M2                                 701.6610
   LCL of Slope                         0.0508
   UCL of Slope                         0.0893
   Statistically significant evidence of an increasing
   trend at the specified level of significance.
```

Plot 1. Sample data set processed using ProUCL showing Theil-Sen trend line.

2.0 LHAAP-12

2.1 MNA Performance

Groundwater at the site generally occurs under unconfined conditions and flows to the east and northeast away from the landfill (Plot 2) (US Army, 2006). Since the ROD was signed in 2006 (US Army, 2006) TCE exceeding the MCL has been encountered in only one well, 12WW24 (Plot 4). The footprint of TCE in groundwater at LHAAP-12 remains localized around well 12WW24 (Plot 5).

The MNA evaluation completed as part of the 2013 Five-Year Review (AECOM, 2014a) concluded that TCE degradation was occurring via anaerobic reductive dechlorination, as is evident by the presence of cis-1,2-DCE and VC.

2.1.1 Monitoring Network Locations and Frequency

The 2013 Five-Year Review recommended expanding the MNA network to include installing at least one additional well in the plume, re-evaluating and expanding wells where water level measurements are taken, and re-evaluating the MNA network (AECOM, 2014a). The Army installed a direct push boring 50 feet down-gradient/east of plume well 12WW24 (see 12WW25 in Plot 5). The boring was advanced to a depth of 35 feet, with visibly wet soils encountered starting at 25 feet below ground surface (bgs) and an assemblage of sands from 15 – 30 feet bgs. A grab groundwater sample was collected from this boring to confirm its location within the plume. Analytical results identified low levels of COCs TCE (0.317 micrograms per liter [µg/L]) and cis-1,2-DCE (0.402 µg/L) below the MCL, along with similar levels of methylene chloride, benzene, chlorobenzene and 1,4 dichlorobenzene. Based on these results the Army, USEPA and TCEQ concurred that the plume at LHAAP-12 is limited and therefore there was no need to install the additional well. According to the installation: “This was done in the context of an ongoing drought. The sample was collected from the base of the interval of interest where there was sufficient water. The Army included a task for additional well installation at Site 12 in the 2017 Bhate contract.”

Longhorn was already aware that groundwater changed direction at certain elevations. Cross sections and structural maps (bottom of sand, clay barrier, etc.) were provided to the regulators and the contractor by Longhorn demonstrating the issue before the 2014 well installation attempt.”

Groundwater sampling of monitoring wells (12WW20, 12WW21, and 12WW24) and compliance monitoring wells (12WW22 and 12WW23), has been conducted annually beginning in the third year of the RA(O) through the 2014 RA(O) (AECOM, 2015a, Shaw, 2007f). In the 2014 RA(O), recommendations were made to reduce the frequency of sampling of monitoring well 12WW22 to one every five-years and to eliminate collection of groundwater samples from monitoring wells 12WW23. The rationale for reducing the frequency of sampling of 12WW22 was based on the conceptualization that 12WW22 is an upgradient well, located at a great distance from the landfill. The proposal to eliminate 12WW23 was made because this well is located further downgradient from the landfill relative to 12WW21 (Plot 2) in an area which remains unimpacted. In the 2015 RA(O), compliance monitoring wells 12WW22 and 12WW23 were not sampled. Based on comprehensive groundwater elevation data collected monthly, for 15 months, from eight wells the 2015 RA(O) it was determined that 12WW22, which was changed into 5 years sampling period, could be considered a downgradient well (Plot 2). Although 12WW22 was no longer considered an upgradient well, the 2015 RA(O) recommended keeping the frequency of sampling this well to once every five years because 12WW20 located upgradient of 12WW22 (Plot 2), is unimpacted and since 12WW22 was always unimpacted (Plot 4).

Since the 2013 Five-Year Review, although an increasing trend in TCE concentration was observed in well 12WW24 in December 2013 and January 2015, a decreasing trend has been observed over the past three sampling events, December 2015, December 2016, and December 2017 (Plot 4 and Plot 6). Trend of TCE concentrations and groundwater elevations in 12WW24 indicate that when the water table is high, TCE concentrations appear to be lower, and vice versa (Plot 6). The inverse relationship between groundwater elevations and concentrations of TCE and its bio-degradation byproduct (Plot 4, Plot 6, and Plot 7) are likely due to the change in groundwater flow directions. Groundwater flow direction shifts from east and northeast to the southeast when groundwater elevation increases (Plot 3 vs. Plot 2). When groundwater flow direction is to the east/northeast, the flow is from the capped landfill towards well 12WW24, however, when the flow is to the southeast, groundwater flows toward 12WW24 from an un-impacted upgradient groundwater (Plot 3). Therefore, it is apparent that the fluctuation in concentrations of TCE and its biodegradation byproduct are influenced by the change in direction of the groundwater flow as it relates to the location of the suspected source and the only impacted well, 12WW24. Temporal change in concentration of TCE is attenuated by enhanced biodegradation through reductive dechlorination and by changes in the groundwater flow regime. There is an observed increase in concentrations when the groundwater flow direction shifts to the northeast for a prolonged period (i.e. groundwater flow from the landfill towards 12WW24 occurs over a prolonged period), thereby leading to slower overall decreasing trend in TCE concentrations.

The increase in TCE concentrations in well 12WW24 in 2013 after the drought and the potential impact in the change in the groundwater flow regime on the trend and distribution of the TCE and its biodegradation byproducts require re-evaluation of the MNA monitoring network. It is noted that an attempt to locate a well east of 12WW24 (Plot 5) was abandoned in 2014 after a grab sample collected from a boring drilled to a depth of 35 feet using direct push technology showed TCE and cis-1,2-DCE levels below MCL.

2.1.2 Trend Analysis

Statistical analysis of the concentration profile for TCE in 12WW24 using the Mann-Kendall trend analysis was completed (Bhate, 2018d) for the data collected through the 10th year RA(O) period (i.e., data collected between 2006 and 2017 (Plot 4)). The results indicated a statistically. Decreasing trend at the 95% confidence level for TCE concentrations in monitoring well 12WW24, located immediately downgradient of the suspected source. A drought that persisted between 2011 and 2012 resulted in decreased groundwater levels and well 12WW24 going dry and not sampled in 2012 (Plot 4). However, after the groundwater level in 12WW24 had recovered from being dry, TCE concentrations increased during the December 2013 and January 2015 sampling events, before declining during the December sampling events in 2015, 2016, and 2017.

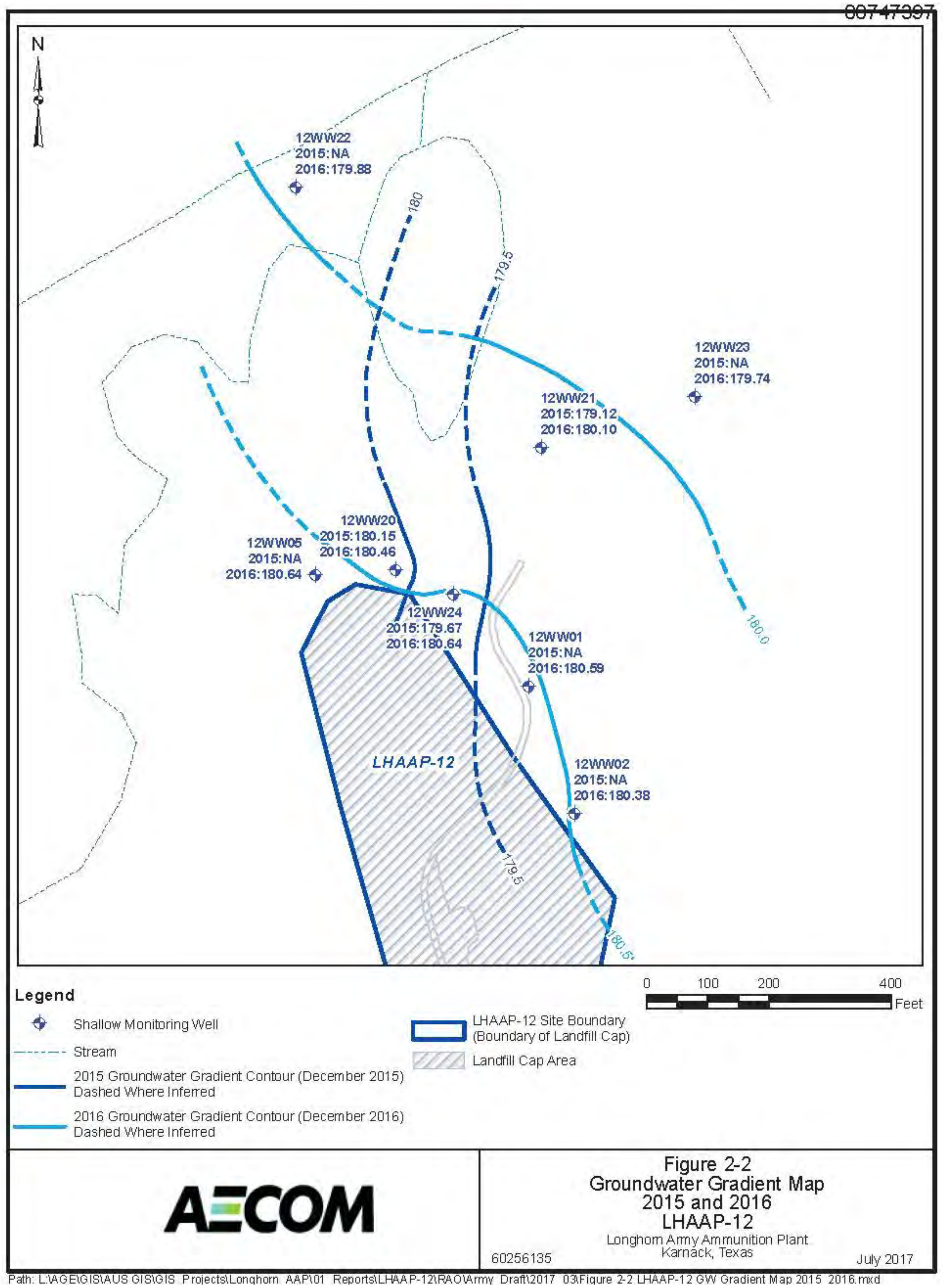
First order decay rates of 1.5 E-04 per day was estimated (Bhate, 2018d) using the entire TCE concentrations data set (e.g., the data recorded between 2006 and 2017). According to the literature, TCE decay rates through reductive dechlorination range between 8.2E-04 and 8.7E-03 per day (Biochlor, March 2002). The first order decay rate of 6.2E-04 per day, calculated without taking into account the impact of changing groundwater flow directions and the additional mass loading of TCE to 12WW24 suspected to occur during the drought year, is slightly below the lower range of first order decay rate for reductive dechlorination reported in the literature. Therefore, while reductive dechlorination is taking place at 12WW24 the groundwater conditions are not optimal for this decay mechanism. Although biogeochemical conditions are not optimal for reductive dechlorination, TCE and its bio-degradation byproducts are limited in extent and appear to be stable, attenuating through dilutions/dispersion and biodegradation.

2.1.3 Time to Restoration

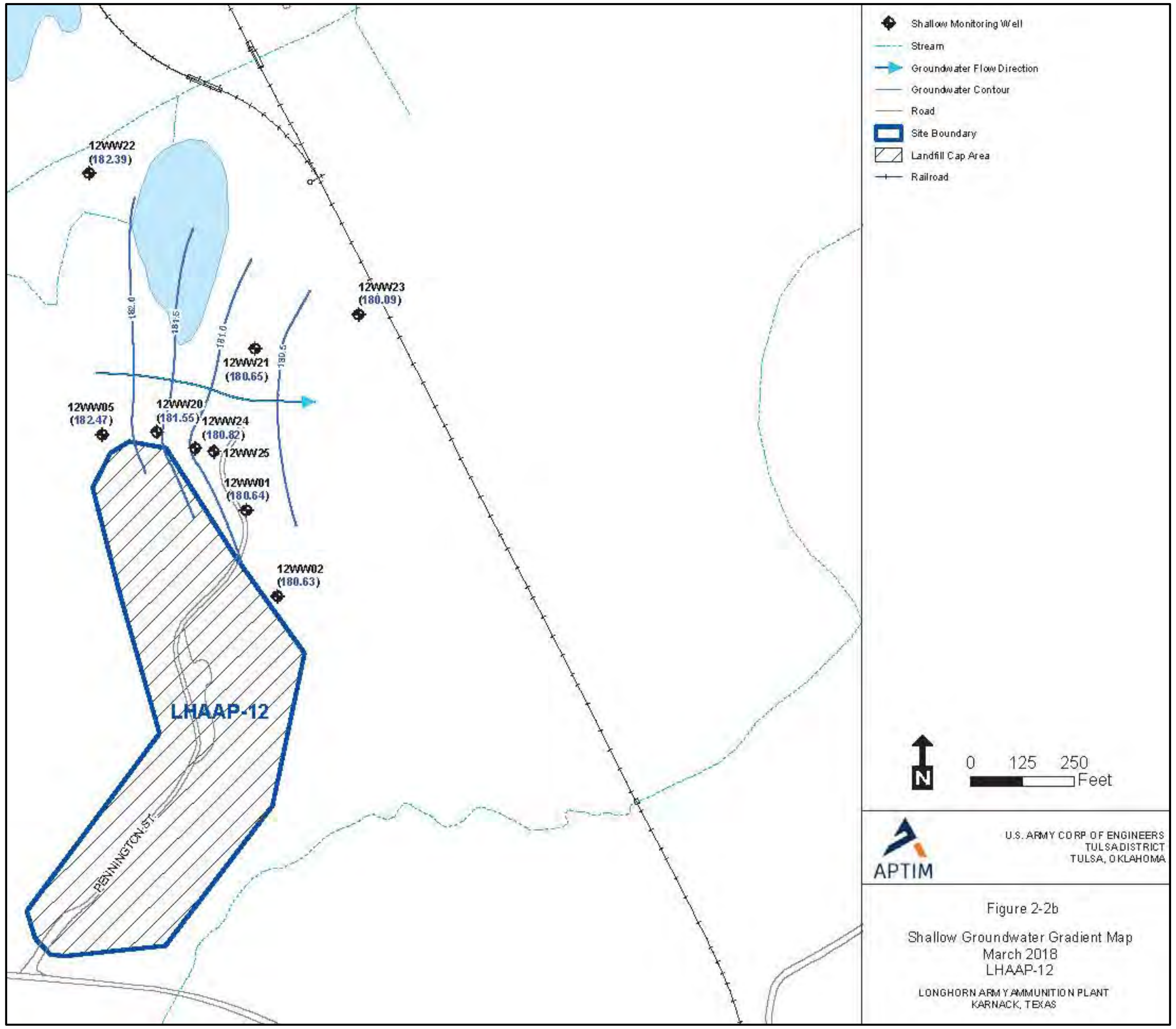
Restoration times ranging between 80 and 19 years are estimated based on site specific first order decay rates of 1.5E-04 and 6.2E-04 per day, respectively, and initial concentration of 396 µg/L (e.g., maximum TCE concentration reported in December 2006). Estimated restoration times ranging between 51 and 12 years are based on first order decay rates of 1.5E-04 and 6.2E-04 per day, respectively, and initial concentration of 83 µg/L (e.g., most recent TCE concentration reported in December 2017). Restoration time estimated based on the most recent TCE concentration reported in December 2017 are in line with ROD's restoration time range of 23 to 261 years expected for MNA (US Army, 2006).

2.2 Data Analysis Summary

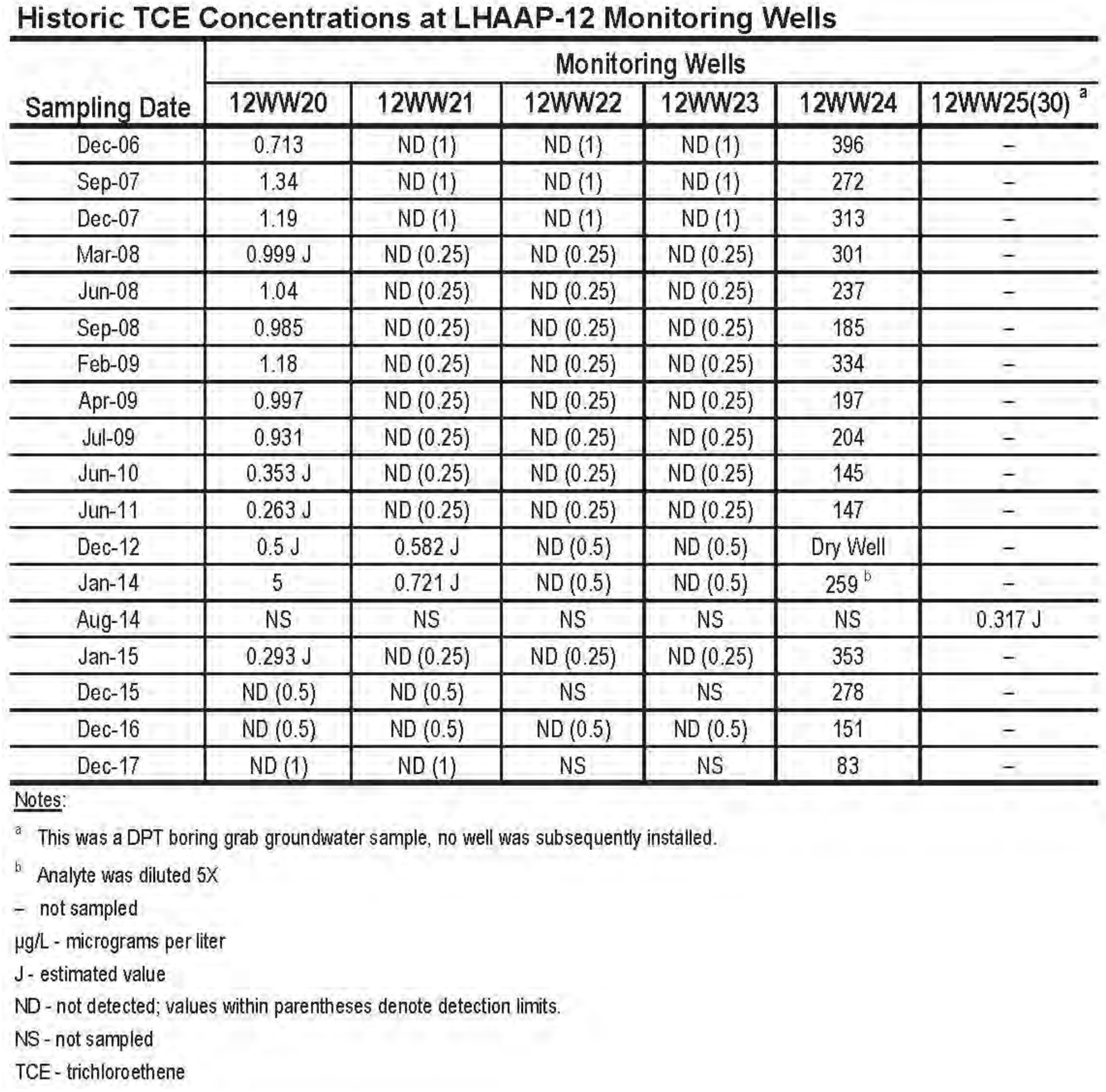
Using the methods and limitations discussed in Appendix C Section 1, the Fourth Five-Year Review concludes the decreasing trend in contaminant concentrations combined with the lack of detected VOCs in adjacent wells provide evidence that the plume is stable and natural attenuation is occurring, resulting in an overall decrease in TCE concentration in groundwater over time. The presence of cis-1,2-DCE and VC in this well since December 2006 also indicates that biodegradation is occurring. Restoration times appear to be in agreement with previous analysis.



Plot 2. LHAAP-12 Groundwater Contours – December 2015 & December 2016 (AECOM, 2017d).



Plot 3. LHAAP-12 Groundwater Contours – March 2018 (Bhate 2018d).



Historic TCE Concentrations at LHAAP-12 Monitoring Wells

Sampling Date	Monitoring Wells					
	12WW20	12WW21	12WW22	12WW23	12WW24	12WW25(30) [a]
Dec-06	0.713	ND (1)	ND (1)	ND (1)	396	–
Sep-07	1.34	ND (1)	ND (1)	ND (1)	272	–
Dec-07	1.19	ND (1)	ND (1)	ND (1)	313	–
Mar-08	0.999 J	ND (0.25)	ND (0.25)	ND (0.25)	301	–
Jun-08	1.04	ND (0.25)	ND (0.25)	ND (0.25)	237	–
Sep-08	0.985	ND (0.25)	ND (0.25)	ND (0.25)	185	–
Feb-09	1.18	ND (0.25)	ND (0.25)	ND (0.25)	334	–
Apr-09	0.997	ND (0.25)	ND (0.25)	ND (0.25)	197	–
Jul-09	0.931	ND (0.25)	ND (0.25)	ND (0.25)	204	–
Jun-10	0.353 J	ND (0.25)	ND (0.25)	ND (0.25)	145	–
Jun-11	0.263 J	ND (0.25)	ND (0.25)	ND (0.25)	147	–
Dec-12	0.5 J	0.582 J	ND (0.5)	ND (0.5)	Dry Well	–
Jan-14	5	0.721 J	ND (0.5)	ND (0.5)	259 [b]	–
Aug-14	NS	NS	NS	NS	NS	0.317 J
Jan-15	0.293 J	ND (0.25)	ND (0.25)	ND (0.25)	353	–
Dec-15	ND (0.5)	ND (0.5)	NS	NS	278	–
Dec-16	ND (0.5)	ND (0.5)	ND (0.5)	ND (0.5)	151	–
Dec-17	ND (1)	ND (1)	NS	NS	83	–

Notes:

[a] This was a DPT boring grab groundwater sample, no well was subsequently installed.

[b] Analyte was diluted 5X

– not sampled

µg/L - micrograms per liter

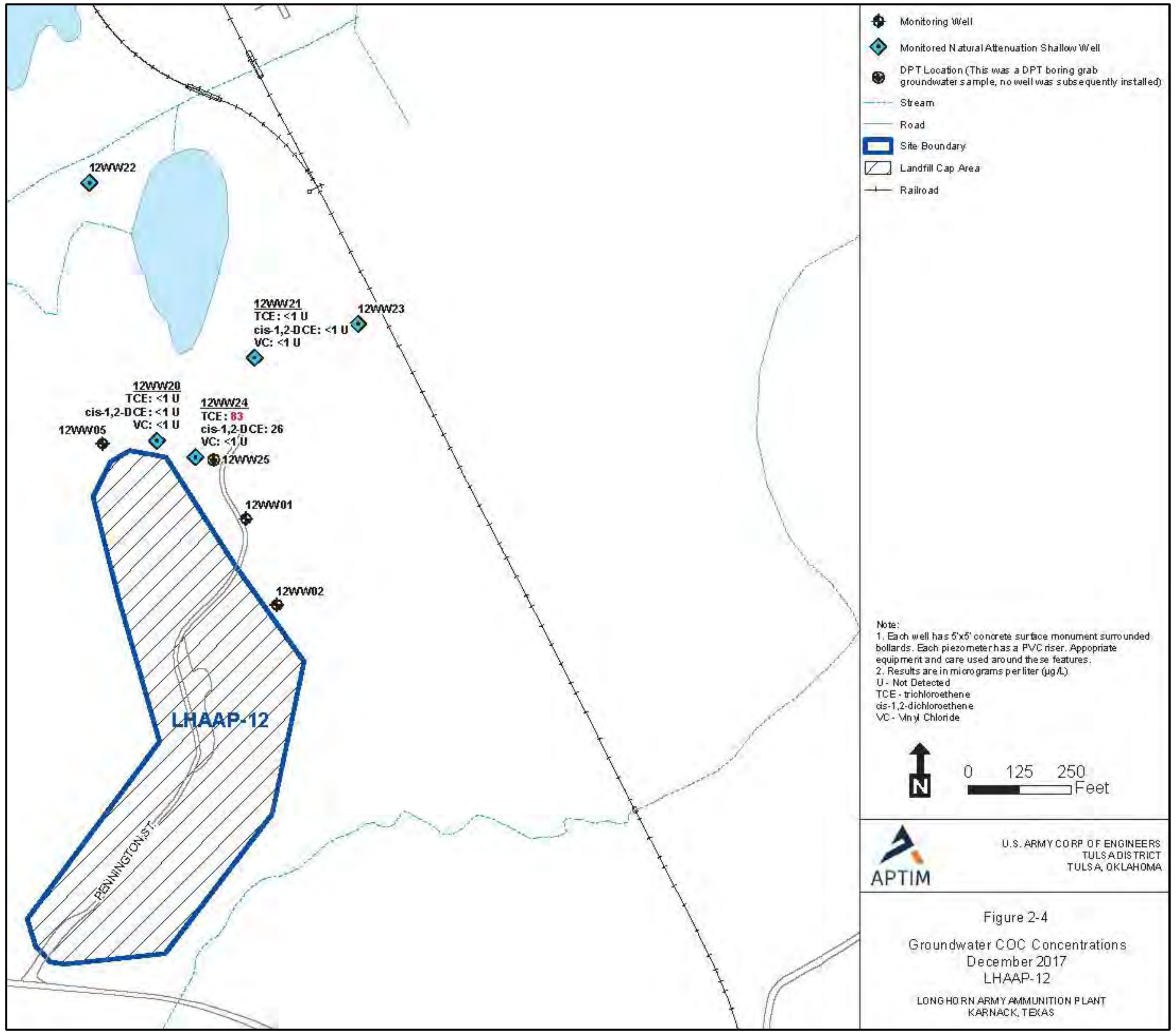
J - estimated value

ND - not detected; values within parentheses denote detection limits.

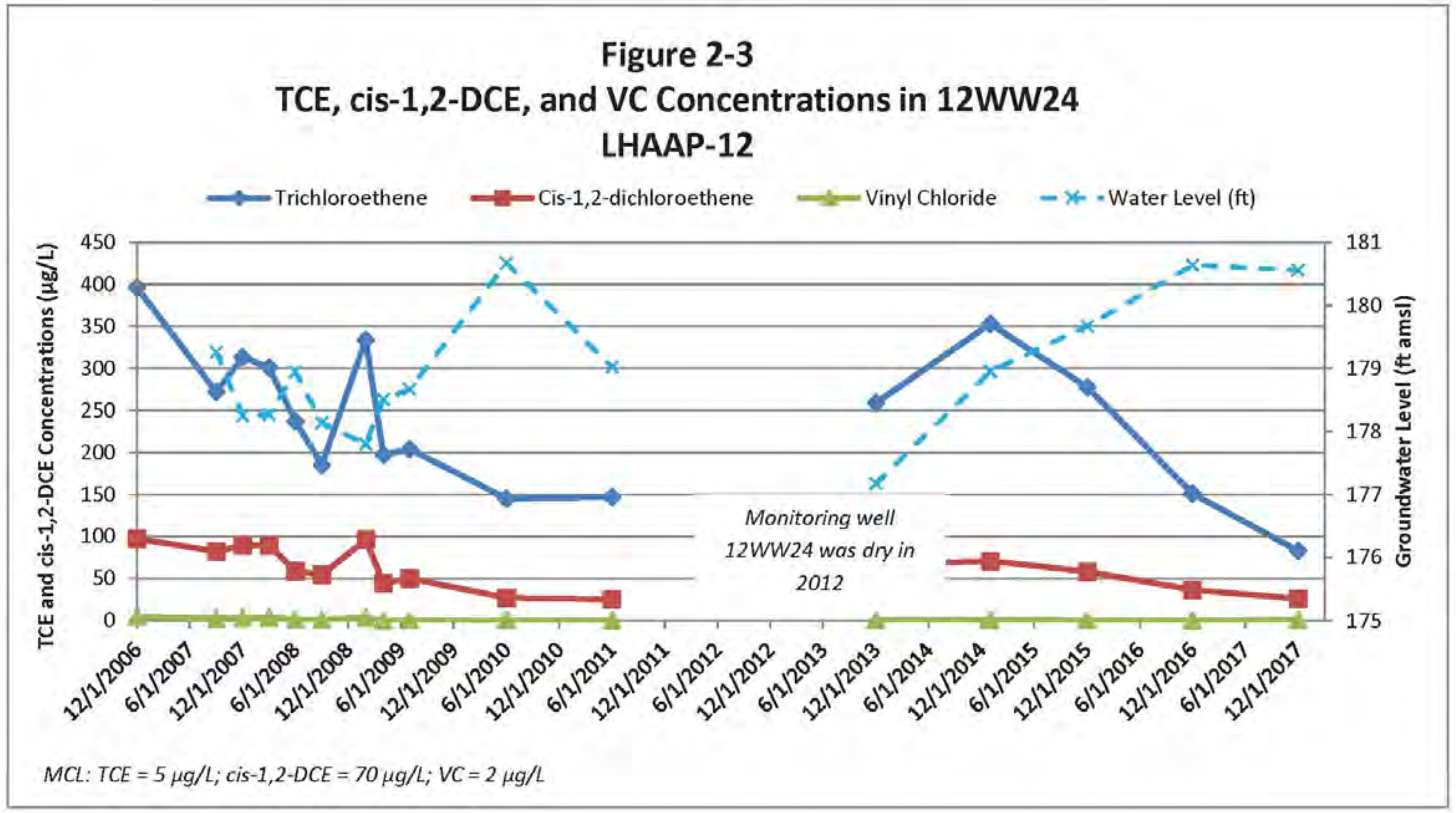
NS - not sampled

TCE - trichloroethene

Plot 4. LHAAP-12 TCE Concentration (µg/L) – 2006 through 2017 (Bhate, 2018d).



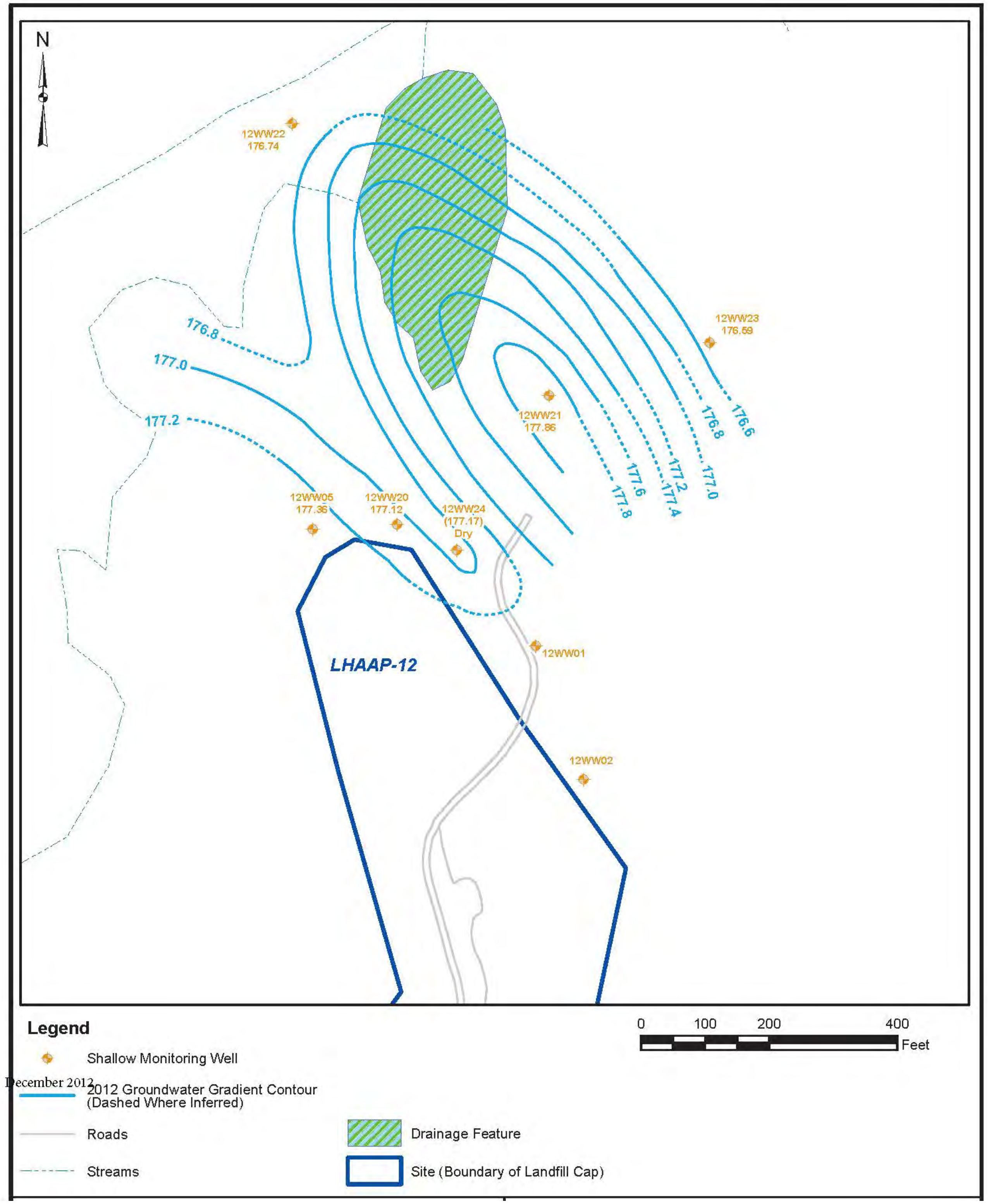
Plot 5. LHAAP-12 TCE (µg/L) Footprint – December 2017 (Bhate, 2018d).



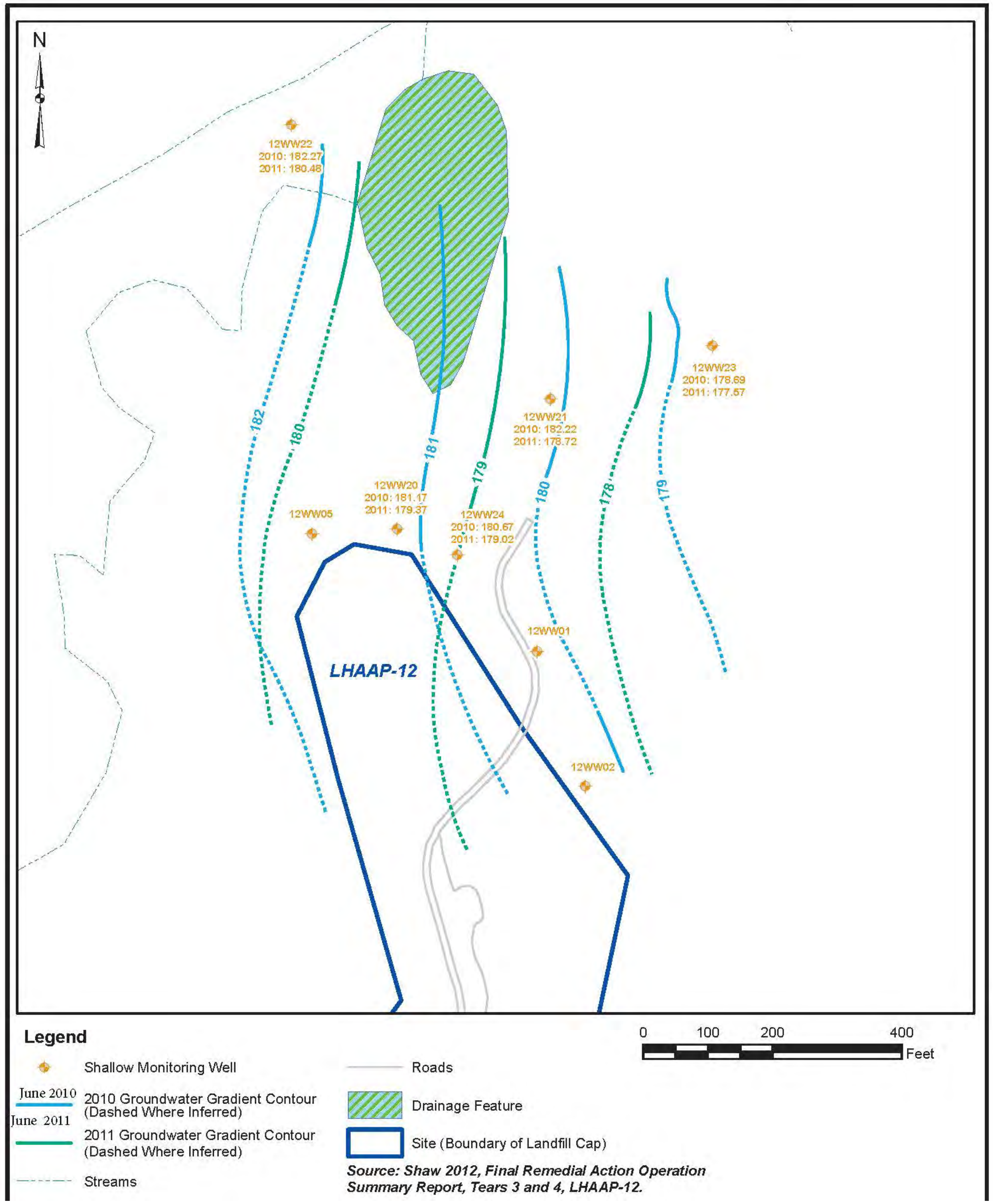
Plot 6. LHAAP-12 well 12WW24 trend of groundwater elevations, TCE, cis-1,2-DCE, and VC Concentrations – 2006 through 2017 (Bhate, 2018d).

12WW01	6/13/1993	Trichloroethene	27	
12WW01	4/20/1995	Trichloroethene	5	U
12WW01	7/15/1998	Trichloroethene	1	U
12WW01	8/11/2006	TRICHLOROETHENE	5	U
12WW01	12/19/2006	TRICHLOROETHENE	5	U
12WW02	6/14/1993	Trichloroethene	5	U
12WW02	4/19/1995	Trichloroethene	5	U
12WW02	7/15/1998	Trichloroethene	1	U
12WW02	8/11/2006	TRICHLOROETHENE	5	U
12WW02	12/19/2006	TRICHLOROETHENE	5	U
12WW10	4/19/1995	Trichloroethene	5	U
12WW10	7/15/1998	Trichloroethene	1	
12WW10	2/27/2003	trichloroethene	14.5	
12WW10	2/19/2004	trichloroethene	1.84	
12WW10	12/8/2004	trichloroethene	6.96	
12WW01	6/13/1993	cis-1,2-Dichloroethene	5	U
12WW01	7/15/1998	cis-1,2-Dichloroethene	1	U
12WW01	2/27/2003	cis-1,2-Dichloroethene	1	U
12WW01	8/11/2006	CIS-1,2-DICHLOROETHENE	10	U
12WW01	12/19/2006	CIS-1,2-DICHLOROETHENE	10	U
12WW02	6/14/1993	cis-1,2-Dichloroethene	5	U
12WW02	7/15/1998	cis-1,2-Dichloroethene	0.65	J
12WW02	2/27/2003	cis-1,2-Dichloroethene	3.33	
12WW02	8/11/2006	CIS-1,2-DICHLOROETHENE	1.77	J
12WW02	12/19/2006	CIS-1,2-DICHLOROETHENE	1.39	J
12WW10	7/15/1998	cis-1,2-Dichloroethene	1	U
12WW10	2/27/2003	cis-1,2-Dichloroethene	2.91	
12WW01	6/13/1993	Vinyl Chloride	10	U
12WW01	4/20/1995	Vinyl Chloride	10	U
12WW01	7/15/1998	Vinyl Chloride	1	U
12WW01	8/11/2006	VINYL CHLORIDE	0.575	J
12WW01	12/19/2006	VINYL CHLORIDE	10	U
12WW02	6/14/1993	Vinyl Chloride	10	U
12WW02	4/19/1995	Vinyl Chloride	10	U
12WW02	7/15/1998	Vinyl Chloride	2.1	
12WW02	2/27/2003	Vinyl chloride	7.24	
12WW02	2/19/2004	Vinyl chloride	5.34	
12WW02	12/8/2004	Vinyl chloride	3.75	
12WW02	8/11/2006	VINYL CHLORIDE	6.88	J
12WW02	12/19/2006	VINYL CHLORIDE	4.3	J
12WW10	4/19/1995	Vinyl Chloride	10	U
12WW10	7/15/1998	Vinyl Chloride	1	U
12WW10	2/27/2003	Vinyl chloride	2.46	

Plot 7. LHAAP-12 TCE, 1,2 cis-DCE, and VC Concentrations (µg/L) – Wells 12WW01, 12WW02, and 12WW10 - 1993 through 2006.

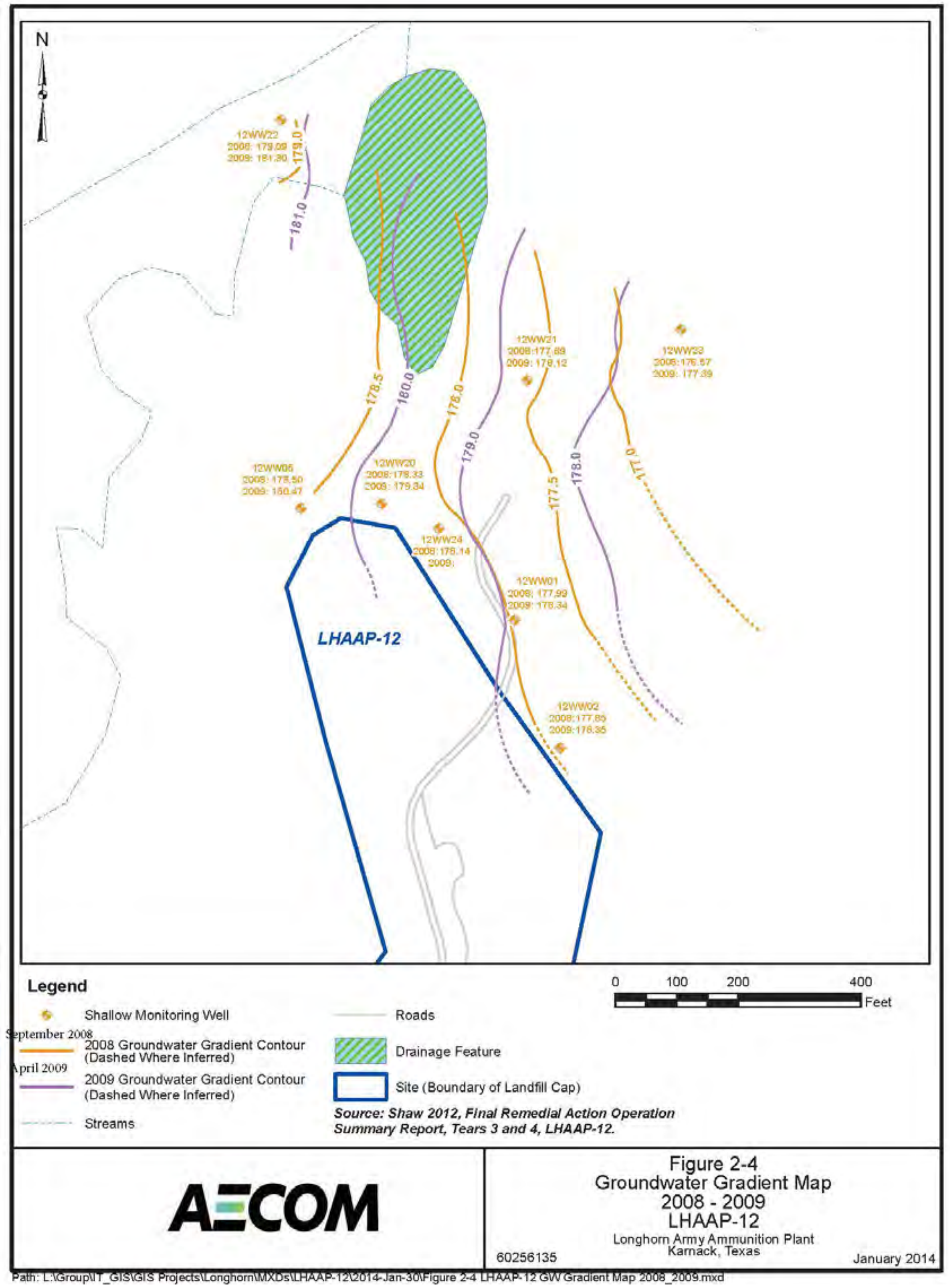


Plot 8. LHAAP-12 Groundwater Contours – December 2012 (AECOM, 2014d).



Source: Shaw 2012, Final Remedial Action Operation Summary Report, Tears 3 and 4, LHAAP-12.

Plot 9. LHAAP-12 Groundwater Contours – June 2010 & June 2011 (AECOM, 2014d).



Source: Shaw 2012, Final Remedial Action Operation Summary Report, Tears 3 and 4, LHAAP-12.

Plot 10. LHAAP-12 Groundwater Contours – September 2008 & April 2009 (AECOM, 2014d).

12WW12	7/15/1998	cis-1,2-Dichloroethene	110	
12WW12	2/26/2003	cis-1,2-Dichloroethene	144	
12WW12	4/20/1995	Trichloroethene	495	
12WW12	7/15/1998	Trichloroethene	420	
12WW12	2/26/2003	trichloroethene	334	
12WW12	2/20/2004	trichloroethene	429	
12WW12	12/8/2004	trichloroethene	480	
12WW12	12/9/2004	trichloroethene	464	
12WW12	4/20/1995	Vinyl Chloride	10	U
12WW12	7/15/1998	Vinyl Chloride	8	U
12WW12	2/26/2003	Vinyl chloride	5.65	
12WW12	2/20/2004	Vinyl chloride	4.03	
12WW12	12/8/2004	Vinyl chloride	2.22	
12WW12	12/9/2004	Vinyl chloride	2.05	

Plot 11. LHAAP-12 TCE, 1,2 cis-DCE, and VC Concentrations (µg/L) – Well 12WW012 - 1995 through 2004.

3.0 LHAAP-18/24

3.1 Background

Groundwater at LHAAP-18/24 generally occurs under unconfined conditions and the elevation fluctuates with seasonal variations in rainfall. Groundwater is encountered at depths of 11 – 30 ft bgs at LHAAP-18/24 (AECOM, 2013f), and flows generally toward the northeast, except near Harrison Bayou or where influenced by the extraction system (AECOM, 2014a). The Shallow Groundwater Zone is comprised of about 45 ft of Pleistocene terrace deposits on top of a clay layer that is discontinuous near the Harrison Bayou west and northwest of the site (Plot 12, Plot 13, and Plot 14). The Tertiary middle Wilcox Formation underlies the terrace and clay layer deposits, and is part of the regulated Wilcox Formation aquifer (see report section 2.3.2).

Groundwater investigations have identified three areas with high perchlorate concentrations. These areas include the area south of the former Unlined Evaporation Pit (UEP) (Plot 29) where the highest concentrations have been detected near MW21, MW2 and MW15. Relatively high concentrations are also present in MW-3 and MW-5, which are located on the perimeter of the NE quadrant of UEP and indicate the UEP being the principal source for perchlorate contamination. A second high contamination area is located near the former ACD where high concentrations extend away from the source in a southward and westward oriented plume (Plot 15).

3.2 Capture Zone Analysis Approach

Groundwater divides (stagnation zones) and groundwater flow direction vectors were delineated on existing potentiometric contour maps to manually create a general flow net. The limits of the groundwater capture zone, or the groundwater flow region that represents the general zone of groundwater flowing through the site under evaluation, was delineated manually on selected monthly potentiometric surface maps. The monthly potentiometric surface maps were selected based on variations of regional precipitation as measured at NOAA weather stations in the Shreveport Area (https://w2.weather.gov/climate/xmacis.php?wfo=shv) and O&M conditions for the groundwater extraction (pump and treat) systems. The regional climate and aquifer recharge condition with respect to being “wet” or “dry” was also evaluated by reviewing a USGS stream gage #07346080 located on the Big Cypress Creek northwest of the LHAAP site near Karnack, TX (Figure 4) (USGS, 2019).

Capture Zone maps were prepared for wet and dry conditions based on regional precipitation data. The analysis selected monthly water level gaging events when extraction equipment was operating under as full capacity as practicable, and avoided periods of total system shutdown due to pumping equipment or GWTP system malfunction.

Horizontal gradients and groundwater flow direction were determined by inspection of the monthly potentiometric contours depicted on the maps prepared by the LHAAP Contractor that were included in the GWTP evaluation reports. Vertical gradients at nested well sites were calculated to assess magnitude and whether upward or downward vertical gradients could be interpreted. Well pairs utilized for vertical gradient calculations inside the ICT containment area or immediately outside the ICT area consisted of water levels in wells that were well couplets designed to monitor the shallow and Wilcox Formation groundwater zones, or wells screened in these zones that were nearest neighbors and could be separated by more than 10-20 feet laterally. Upward gradient may indicate capture from deeper zones below the intake. Downward gradients may indicate vertical migration from shallow to deeper zones.

Due to the relative complexity of the extraction structures consisting of lateral ICTs with impermeable barriers on the downgradient sides of some of the ICTs, the extraction system was not simulated in an analytical or numerical groundwater model. The limitations of budget, schedule, and available data that would be required to perform such computational simulations of the LHAAP-18/24 extraction system also precluded designing a groundwater model of the LHAAP-18/24 groundwater extraction system. However, the empirical approach applied to delineate observed capture zones using actual water level data is interpreted to be a reasonable approach to estimate adequacy of the extraction system performance under actual operational conditions.

3.3 Groundwater Extraction System – Configuration, Performance, and Maintenance

3.3.1 Configuration and Historical Operation

A groundwater extraction system consisting of about 5,000 linear feet (ft) of interceptor collection trenches (ICT) and two extraction wells, and a groundwater treatment plant (GWTP) and ICTs began operating in January 1997 (AECOM, 2014a). The extraction component of the remedial system includes 14 ICTs ranging in length from approximately 100-1,300 feet, and is located within and around three sides of the former burning ground (Plot 16). The trenches extend approximately 25-55 feet deep to the confining clay layer of the Shallow Groundwater Zone. After construction, piezometers were installed to evaluate ICT effectiveness. Water levels within the trenches are controlled using water level probes, set at various levels to activate or deactivate the twenty-eight sump pumps. These maximize groundwater capture and remove the groundwater from the ICT sections through dual wall containment piping, which leads to a 300,000-gallon influent equalization holding tank at the GWTP (AECOM, 2014a).

Liner material was installed on the down gradient side of the trenches on the north and west sides of the site (Plot 16) to further restrict groundwater flow towards the Harrison Bayou.

3.3.2 Performance

Total monthly groundwater recovery rates from LHAAP1-18/24 and LHAAP-16 recorded between September 2012 and March 2018 are shown in Plot 18. When there is no interruption due to maintenance issues, fluctuation in total monthly recovery rate is predominantly influenced by meteorological conditions (Plot 19). Higher extraction rates are achieved after a prolonged recharge from precipitation and low extraction rates are associated with periods of low recharge. According to the GWTP supervisor (Mr. Beesinger, May 2018 Site Inspection Form), the flow from the ICT is controlled by controlling the water elevations in the ICT to minimize the number of times the pumps start and stop. In the summer time, the level is held low at approximately 40 feet below ground elevation and in the winter, the level is held high at approximately 22 feet below ground elevations. The trend in total monthly recovery rates in the last five-years does not show an overall decline in recovery rates indicating that recovery of groundwater is not limited by loss of efficiency of the system, but by meteorological conditions, the flow capacity of the treatment system, and the operation and maintenance of the system.

Minimum and maximum recovery rates at each ICT and recovery wells are shown in Plot 17.

Mass removal rate analysis from each recovery point conducted by the Fourth Five-Year Review used monthly extraction flow data available for February/March 2015 and concentrations of COCs sampled at ICT and recovery wells at the end of February (Plot 21), 2016. This analysis indicates that:

- Relatively high groundwater extraction and high mass removal rates are encountered at ICT 4, 8, 11, 13A, 14D, 14E.
- Relatively high extraction rates and low mass removal rates are encountered at ICT 2, 13B, 13C.
- Relatively low extraction rates and high mass removal rates are encountered at 18WW17, ICT 12B, 12C, 12D, 12E.

3.3.3 Maintenance

According to the GWTP supervisor (Mr. Beesinger, Appendix D, Mr. Williams, Appendix E), iron precipitation, especially at ITC No. 13A, 13B, and 13C causes pumps in these locations to be removed every 3-4 months to be cleaned. Submersible pumps have to be replaced, typically after the third cleaning.

3.4 GWTP – Treatment Process, Maintenance, and Performance

3.4.1 Treatment Process and Maintenance

The groundwater treatment process diagram (Plot 22) was modified in April 2017 when two ion exchange units were placed between the discharge pumps and the flow meter to address the exceedance of the perchlorate discharge limit of 13 µg/L in the effluent noted in 2015 and 2016 (Plot 22). Key maintenance issues with treatment units described above are depicted graphically in Plot 19. The operation of the GWTP was interrupted by these maintenance issues and by failure of the main transformer. The main transformer that failed during the severe storm of August 12, 2017 was replaced on September 12, 2017.

During the site visit of May, 2018 Mr. Beesinger (supervisor) was reviewing the new PLC system. This system will enable prompt identification of maintenance issues and responses.

3.4.1.1 Performance

The criteria used to evaluate performance of the groundwater treatment system takes into consideration all of the routine monitoring and sampling conducted as part of the Sampling and Analysis Plan (SAP) (AECOM, 2017c). These criteria include volumes of groundwater treated, regulatory compliance, and temporal impact on the footprints of the widespread COCs.

3.4.1.2 Quantity of Groundwater Treated

Plot 23 depicts the monthly total volume of groundwater treated from the ICTs and extraction wells at LHAAP-18/24 and LHAAP-16 from January 2012 through October 2017. Plot 24 depicts the monthly volume treated between 2012 and 2017. Plot 23 also includes the monthly total volume of groundwater treated, the monthly precipitation rate, and key maintenance events. Precluding the period of key maintenance events the trend in volume of groundwater treated is predominantly influenced by meteorological conditions with higher flow treated after a prolonged period of recharge. The volume of water treated is predominantly a function of the meteorological system and the capacity of the treatment system (e.g., the flow rate that the ion exchange system can handle).

3.4.1.3 Regulatory Compliance

Compliance monitoring at site LHAAP-18/24 consists of inspections; air, influent, and effluent monitoring at the GWTP; monitoring well and piezometer groundwater elevation surveys; and monitoring well sampling. All the sampling requirements from the IRA ROD, General WP for IRA (Dow 1995), as well as various regulatory approval letters and memoranda, were brought together in the 2017 Sample and Analysis Plan for the GWTP and well fields.

Based on the analytical reports of samples collected from the system effluent ports, there have been no exceedances of VOCs or metals in the system effluent, though in most monitoring events Selenium and Silver reporting Limits were greater than the Daily Average and Maximum Limit . There are periodic perchlorate exceedances above the discharge criteria of 13 µg/L. A majority of the exceedances occurred during the 1st quarter of 2016 when the FBR was running in batch mode or nutrient levels were low resulting from a broken feed pump. Because of the periodic perchlorate exceedances, two ion exchange vessels were added to the FBR effluent as a polishing step. Perchlorate did not exceed the perchlorate discharge criteria in the 2nd and 4th quarter of 2017, after the two ion exchange resins were added to the treatment system. However, as described in the previous section, due to recent maintenance events with the FBR, additional measures are being taken including replacing the lateral and nozzle feeding the FBR.

In 2017 the discharge criteria for perchlorate was changed to 278 µg/L daily average and 589 µg/L daily maximum. Discharge to the INF Pond is limited to 17 µg/L.

Air samples collected from the air exhaust stacks of the groundwater remediation systems and the downwind ambient air near the property boundary were collected quarterly. All air analytical sample results are below requirements for site COCs.

3.4.1.4 Temporal Impact of the GWTP on the footprints of the widespread COCs

The widespread risk driving COCs in the shallow and Wilcox formation at LHAAP18/24 include TCE, MC, and perchlorate. In addition 1,4-dioxane is an emerging contaminant found at the site.

TCE and MC were identified as COCs in the IRA's ROD (EPA, May 1995). Perchlorate was discovered in groundwater at LHAAP-18/24, and subsequently was added as a COC. A FBR was added to the treatment train in April 2001, to address perchlorate. 1,4-Dioxane has been added as a COC in the recent FS (AECOM, 2017a) because of its detection in several wells across the site above the TRRP PCL. This section does not include evaluation of the impact of the GWTP on the footprint of 1,4-Dioxane due to the limited historical data available for this compound.

The footprints of the TCE, MC, and perchlorate in the shallow and Wilcox formation appear to have stabilized because of the implementation of the IRA, with numerous wells showing a decline in temporal concentrations. A summary of the analysis leading to this conclusion is provided below.

TCE in Shallow Formation

The plumes and footprints of TCE in the shallow formation as depicted in April 1994, December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 37 through Plot 43. Comparison of the shallow formation TCE plume depicted in 1994, prior to the implementation of the IRA, to the TCE plumes depicted between 2014 and 2017, indicated that the wide spread contours with concentrations of 1,000,000 (which ~ solubility limit of TCE) and 100,000 µg/L (10% solubility limit of TCE indicative of DNAPL) indicative of DNAPL, are no longer present. The shallow formation TCE plumes are relatively stable between 2014 and 2017. During this time period the TCE plumes include, at most, include two 10,000 µg/L (1% solubility of TCE which may be indicative of DNAPL) contour lines, one centered on MW-2 and one centered on MW-120.

Contamination comprises a southeasterly trending plume defined by MW-2 and MW21 as well as wells surrounding the UEP. Comparison of plume over time indicates that TCE concentrations at MW-2 and MW-120 decreased with time (Plot 42). While the TCE trend in MW-2 decreases with time, the trend at MW21 is increasing with time, probably due to redistribution of the plume. The other area evaluated is the ACD which has created a southerly trending plume which appears to include wells 120, and AWD1 located to the south of the source, as well as MW7, MW8 and MW9 which are located along the SW boundary of the site. TCE concentrations in 120, AWD1, MW-7, and MW-8 show declining trends (Plot 41). The center of the TCE plume downgradient of lined ICT 13# (Plot 16) and upgradient of the stream appears to have shifted in 2014 from 18CPTMW04 located between the UEP and ACD, to 18CPTMW23, in 2015 through 2017, located closer to the ACD. The elevated TCE concentrations downgradient of ICT#13, in particular at MW-16 (Plot 32) may be of concern as they are located upgradient/adjacent to surface water body monitored by HBW-1 and HBW7 (Plot 25). An in depth, evaluation of trend analysis is discussed in section 4.5.

TCE in Wilcox Formation

The plumes and footprints of TCE in the Wilcox formation as depicted in December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 44 through Plot 49.

Two separate TCE plumes are encountered in the Wilcox formation. One stable TCE plume is centered at MW-14 where concentrations over time remain stable at approximately 10,000 µg/L (~ 1% of TCE solubility limit, which could imply the presence of DNAPL). This plume is near shallow well, 120, located near the former ACD operations, which display a similar magnitude of TCE concentrations. Because the vertical gradient in this location is predominantly downward (see capture zone analysis, section 4.6), and because the clay layer is missing in this area (Plot 12, Plot 13, and Plot 14) it is possible that the source of the TCE in the Wilcox could be from the shallow aquifer as opposed to DNAPL in the Wilcox. The second TCE plume in the Wilcox formation with concentration well below the, 1% solubility of TCE, may originate from the vicinity of MW-2 located near the UEP. In December 2017, maximum concentration of 90 µg/L was encountered at the center of this plume in the well located adjacent to MW-2. The direction of the vertical gradient in the vicinity of MW-2 fluctuates (see section 4.6) with a predominant upward direction; therefore, the mass flux from the shallow aquifer to this plume is limited as well as attenuated by the clay (Plot 13) layer located between the shallow and Wilcox formation.

Methylene Chloride in Shallow Formation

The plumes and footprints of MC in the shallow formation, as depicted in April 1994, December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 50 through Plot 56. Comparison of the shallow formation's MC plume depicted in 1994, prior to the implementation of the IRA, to the MC plumes depicted between 2014 and 2017, indicated that the maximum strength of the plume (of ~ 1,000,000 µg/L, approximately the solubility of MC) and areal extent has significantly declined since 1994. Between 2014 and 2017, the MC plume appear to be limited in extent mainly confined to well, MW-2, where concentrations in 2017 were 140,000 µg/L (~ 10% solubility of MC, indicative of the presence of DNAPL).

Another limited area of elevated methylene chloride occurs near the ACD in the western corner of the site, where concentrations are < 100 µg/L.

Analysis of temporal MC concentrations in all Shallow Groundwater Zone monitoring wells show declining trends (Plot 54). See section 4.5 for trend analysis evaluation.

Methylene Chloride in Wilcox Formation

The plumes and footprints of MC in the Wilcox formation as depicted in December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 57 through Plot 62. There are two plumes of MC in the Wilcox formation:

- Centered at 18CPTMW01SW located near MW-2, where contamination may have originated from the former UEP operations. MC concentrations in the Wilcox formation around the UEP decreased from > 10,000 µg/L in 2014 to ~ 1500 µg/L in 2014.
- Near the ACD in the western corner of the site, where concentration in 2017 was ~ 12 µg/L.

Overall, the footprint of MC appears stable in the Wilcox formation

Perchlorate in Shallow Formation

The plumes and footprints of perchlorate in the Shallow formation as depicted in December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 63 through Plot 68.

Overall the perchlorate footprint in the shallow formation appears stable with numerous well showing overall declining trend in concentration and few with increasing trends (Plot 66, Plot 67, Plot 68), which is likely due to redistribution of the plume by the operation of the extraction system.

Perchlorate in Wilcox Formation

The plumes and footprints of perchlorate in the Wilcox formation as depicted in December 2014, June 2015, December 2015, June 2016, December 2016, and December 2017 are shown in Plot 69 through Plot 75.

Significant perchlorate contamination in the Wilcox aquifer was identified near 18CPTMW08SW and MW5 north of the UEP, in MW-14 located near the ACD, and outside of the containment on the south corner of the site at 18CPTMW22SW. Overall, the footprint of perchlorate in the Wilcox formation appears stable.

Elevated perchlorate concentrations extending to the northeast outside the boundaries of LHAAP18/24 toward extraction well 18WW17 were observed, the trend analysis showed a decline and a low recovery rate at 18WW17. Although the overall trend at 18WW08, located downgradient of the lined ICT13# and upgradient/adjacent to surface water body, is declining, the concentrations have been fluctuating since the last Five-Year Review between 0.2 and 2400 µg/L (Plot 75 and Appendix F). This fluctuation is likely due to plume redistribution in response to meteorological conditions and changes in operation of the extraction system. The elevated perchlorate concentrations downgradient of ICT13# were observed. They are located upgradient/adjacent to surface water body monitored by HBW-1 and HBW7 (Plot 25). Results of surface water monitoring are discussed in section 4.7.

3.4.2 Discharge of Treated Groundwater – 2012-2017

Extracted groundwater collected at the GWTP is treated to the levels established in the 1995 IRA ROD. Treatment plant effluent is discharged according the following protocol in decreasing order of preference as of May 2017:

- Discharge to Harrison Bayou if surface water quality parameters are suitable and if there is minimum natural flow in Harrison Bayou to provide dilution of GWTP effluent. Discharge to the creek is dependent on having some flow in the creek, and meeting sulfate and chloride water quality criteria.
- If Harrison Bayou is not flowing, discharge to Intermediate-Range Nuclear Forces (INF, Plot 76) Pond for temporary storage until Harrison Bayou flow resumes. The INF Pond has a flexible membrane liner protected by soil cover with a gravity discharge pipe (and valve) to Harrison Bayou. The INF Pond has a nominal capacity of 3 million gallons.
- Discharge as irrigation water (Plot 77) within LHAAP-18 as a last resort. Concerns have been expressed that irrigation may facilitate downward migration of COCs into the deeper Wilcox Formation.

Review of available quarterly reports indicates that discharge as irrigation water took place mainly in 2015 and 2016, however, in 2017 effluent was discharged either directly to the Bayou or to the INF Pond and subsequently to the Bayou.

3.5 Capture Zone Analysis

The Fourth Five-Year Review delineated capture zones to independently review the performance of the ICT and EW groundwater extraction system to eliminate or minimize the potential for exposure to human and ecological receptors by reducing or preventing further migration of contaminants from source material and shallow groundwater into deeper groundwater zones, and possibly surface water bodies.

Groundwater levels are measured monthly at LHAAP-18/24. Two groundwater potentiometric contour maps are prepared for each monthly round of water level readings: Shallow Groundwater Zone and Wilcox Formation. The ICTs are installed in the Shallow Groundwater Zone, and are generally interpreted to extract shallow groundwater (e.g., < 40 ft bgs).

Groundwater levels are also measured in the Wilcox Formation wells (typically > 40 ft bgs). Wilcox Formation wells correspond generally to those previously identified as “Intermediate” and “Deep” wells. “Intermediate” wells are designated currently as Upper Wilcox Formation (correct terminology is middle Wilcox Formation) wells and “Deep” wells are designated as Lower Wilcox Formation wells, but the regional clay layers separating the middle and lower Wilcox Formation units have not been confirmed under LHAAP (see report section 2.2.2). The middle and lower Wilcox Formation wells are assumed to be in hydraulic communication and are treated as a single hydrogeologic unit. Therefore, the groundwater elevations in middle Wilcox wells were used to construct the potentiometric surface maps for the Wilcox Formation included in the GWTP quarterly reports (AECOM, 2017f, and g).

Regional precipitation (Plot 19) and surface water gage (Figure 3) data were utilized to select wet and dry months to delineate the capture zones in the Shallow Groundwater Zone and Wilcox Formation of the overburden underlying the LHAAP-18/24 site. Based on monthly precipitation data compiled by NOAA for the Shreveport Area, which was considered representative for the LHAAP site, the spring 2016 and spring 2017 were considered “wet” periods, and the fall 2016 and fall 2017 were considered “dry” periods that would provide contrasting groundwater elevation data to compare the delineation of system plume capture.

Additionally, from 2007 to as recently as 2016, the discharge of GWTP treated effluent to the LHAAP-18/24 site via spray irrigation had been employed when discharge to surface water at Harrison Bayou was not allowed due to low stream flows. An additional O&M criterion of irrigation discharge vs. no irrigation discharge was also utilized to select the months of potentiometric surface contour data to analyze in the capture zone analysis.
The GWTP has also experienced extended periods of reduced extraction flows or total system inactivity due to major equipment malfunctions. Months of zero to low extraction volumes were avoided for the delineation of a capture zone since this condition would not create potentiometric contours that represent the active system condition.

Three primary criteria were applied to select the monthly synoptic round of ground and surface water elevation data that was reviewed to delineate capture zones, evaluate the LHAAP-18/24 groundwater extraction system performance, and plume capture:

- System extraction ICTs and EWs were active to produce the highest monthly extraction volumes and drawdowns, based on tables of extraction data included in the quarterly reports.
- Select months of water level data during periods of wet vs dry months preceding or during the monthly water level readings to provide contrasting natural aquifer recharge conditions that may influence the extent of the capture zone.
- Select quarters when irrigation is active vs irrigation inactive for disposal of GWTP effluent, to contrast the influence of irrigation on potentiometric contours and capture zone extent.

Based on the above three criteria, the following four months were selected to review the potentiometric surface maps prepared by the Army's contractor and utilize them for delineation of the capture zones for the Shallow Groundwater Zone and Wilcox Formation:

- May 2016 – Wet Period, Irrigation Active, No Discharge Harrison Bayou
- Nov 2016 – Dry Period, Irrigation Active, No Discharge Harrison Bayou
- May 2017- Wet Period, Irrigation Inactive, Discharge to Harrison Bayou
- Nov 2017 – Dry Period, Irrigation Inactive, Discharge to Harrison Bayou

The eight capture or groundwater flow zone maps are presented on Plot 29 through Plot 36.

Successful plume capture was interpreted to be when the potentiometric contours in the Shallow Groundwater Zone indicated a relatively clear presence of groundwater divides and groundwater flow directions, and prevalence of upward vertical gradients. This suggested the capture of contaminated groundwater that is depicted on isoconcentration contour maps for the three main COCs at LHAAP-18/24: perchlorate, TCE, and methylene chloride.

High Density polyethylene (HDPE) liners were installed on the downgradient vertical wall of ICTs 12, 13, and two vertical extraction wells are also part of this pump and treat groundwater extraction system, EW-1 and 18WW17. The layout of the ICTs and EWs are shown Plot 16 (Figure A-1, Bhate, 2018b).

The capture zone for May 2016 for the Shallow Groundwater Zone, representing a wet precipitation condition with GWTP effluent being discharged to the LHAAP-18 site via the sprinkler irrigation system with no discharge to Harrison Bayou, is depicted on Plot 29. Total monthly extraction volume based on individual ICT meter readings was about 1.09 million gallons (average daily flow of 24 gpm) in May 2016, which was considered a high monthly extraction volume.

Comparison of the footprint of the inferred capture zone in the Shallow Groundwater Zone for May 2016 to the isoconcentration contours for June 2016 indicates that the entire perchlorate and TCE plumes are not captured in the Shallow Groundwater Zone on the northeast and northwest (Harrison Bayou) sides of the site.

The single surface water measurement for a location designated 1824HBSW7, which is reported to be the same as surface water sampling station HBW-7 located cross-gradient from 18WW19, indicated a slight upward vertical when comparing the surface water elevation to 18WW08 and 18CPTMW16.

Calculation of change in head for nested wells with at least one screen in the Shallow Groundwater Zone and one screen in the Wilcox Formation was performed as a semi-quantitative indicator of vertical gradients direction for nine well groups. The water levels measured in May 2016 indicate that 5 out of 9 well groups evaluated exhibited a downward vertical gradient. Change in head calculations that showed minimal differences in head between Upper Wilcox wells and Shallow Groundwater Zone wells at some locations suggest that the hydraulic communication is more connected with less head loss, either due to the Wilcox clay layer being relatively thin and/or higher hydraulic conductivity in that area.

The May 2016 potentiometric contours in the Wilcox Formation did not indicate the presence of a capture zone around the entire perimeter of the site, as illustrated in Plot 30. The potential to capture groundwater from the upper Wilcox Formation is suggested by the upward vertical gradient calculated between shallow well 120 and deeper Wilcox well MW-14. A relative groundwater low in the Wilcox Formations located near the intersection of ICT-12E and ICT-13A, suggests that these lined ICTs are withdrawing sufficiently high volumes of groundwater to possibly pull contaminated groundwater from the upper Wilcox Formation with drawdown in the Wilcox highest near the lateral intakes for the ICTs between the ICTs and MW-14. The clay layer is interpreted to be absent in this part of the LHAAP-18/24 site.

The capture zone for November 2016 for the Shallow Groundwater Zone, representing a dry precipitation condition with GWTP effluent being discharged to the LHAAP-18 site via the sprinkler irrigation system with no discharge to Harrison Bayou, is depicted on Plot 31. Total monthly extraction volume based on individual ICT meter readings was about 679,000 gallons (average daily flow of 15.7 gpm). The highest producing ICTs were ICT-11 (unlined) at the southwest corner of the site near well 102, and ICT-4 at the interior of the site between ICT-12 and AWD-3.

The November 2016 potentiometric contours in the Wilcox Formation did not indicate the presence of a capture zone (Plot 32), but exhibited an east-west trending groundwater high similar in general to that seen in the May 2016 water level data of the Wilcox Formation. With the clay layer less continuous in this area, the Upper Wilcox Formation may be exhibiting a response to extraction resulting in an upward vertical gradient for wells 120 (Shallow Groundwater Zone) and MW-14 (Wilcox Formation) due to capture of groundwater from the upper Wilcox Formation where the clay layer is missing.

Comparison of the capture zone in the Shallow Groundwater Zone to the extent of perchlorate and TCE contamination based on the December 2016 biannual well sampling event indicates that the ICTs are not capturing all contamination in the Shallow Groundwater Zone. The concentration of perchlorate outside and downgradient of the containment area near Harrison Bayou in Shallow Groundwater Zone well 18WW18 was reported to be 2,390 µg/L and TCE was reported outside of the containment area to be 2,400 µg/L in Shallow Groundwater Zone well 18CPTMW23 between ICT-13B and Harrison Bayou.

The May 2017 potentiometric contours in the Shallow Groundwater Zone, representing a wet precipitation condition with no irrigation but with GWTP effluent discharged to Harrison Bayou, is shown on Plot 33. The highest producing ICTs were ICT-4, ICT-8, and ICT-13A. The general shape and extent of the inferred capture zone in the Shallow Groundwater Zone of groundwater was approximately the same as in the May 2016 and November 2016 water level events.

Comparison of the footprint of the inferred capture zone in the Shallow Groundwater Zone for May 2017 to the isoconcentration contours for June 2017 indicates that the capture zone in the Shallow Groundwater Zone of groundwater does not appear to capture the extent of the perchlorate and TCE plumes in the Shallow Groundwater Zone. This may reflect system downtime from the HCl acid spill (Dec 2016 through most of 2017), and not all ICTs being operational as of 21 April 2018.

The November 2017 potentiometric contours in the Shallow Groundwater Zone, representing dry precipitation conditions with no irrigation but with GWTP effluent discharged to Harrison

Bayou, is shown on Plot 36. Total monthly extraction volume based on individual ICT meter readings was 485,000 gallons (average daily flow of 11.2 gpm). The highest producing ICTs were ICT-2, ICT-8, and ICT-11.

Comparison of the extent of the inferred capture zone in the Shallow Groundwater Zone for November 2017 to the isoconcentration contours for December 2017 indicates that the capture zone of in the Shallow Groundwater Zone does not capture the extent of high concentration perchlorate, and possibly TCE. For example, concentrations of perchlorate near Harrison Bayou downgradient of the UEP and ICT-13E/ICT-13F were measured to be 2,400 µg/L at shallow well 18WW08. TCE was reported at a concentration of 2,000 µg/L at Shallow Groundwater Zone well 18CPTMW23 between Harrison Bayou and ICT-13A at the northwest corner of the site.

Based on the capture zone analysis performed on the four monthly groundwater level data sets (May 2016, November 2016, May 2017, November 2017), the vertical hydraulic gradient within the containment (inside the ICTs), between the upper Wilcox Formation and the Shallow Groundwater Zone, is often a vertical downward gradient. This is observed in areas where elevated concentrations of COCs are measured in monitoring wells, including: MW-5, MW-22, 18CPTMW04, and previously at well 120.

3.6 Surface Water Sampling

Harrison Bayou flows within about 200 ft of the western corner of LHAAP-18/24. There are no surface water bodies or watercourses running through the LHAAP-18/24 site, however, minor drainage swales are present in the northwestern part of the site, associated with intermittent ponding in low areas after heavy rainfall events. Surface drainage occurs in all directions, but flow is generally directed toward Harrison Bayou to the west and by both natural and manmade ditches and drainage swales to the north. Harrison Bayou flows approximately northeast to discharge into Caddo Lake, which is located about one mile northeast of LHAAP-18/24 (Figure 3). The extreme western corner of the site is located within the 100-year floodplain of Harrison Bayou.

The Army collects quarterly surface water samples from three locations on Harrison Bayou (HBW-1, HBW-7, HBW-10), and two locations on Goose Prairie Creek (GPW-1, GPW-2), shown on Plot 25. Surface water samples are analyzed for perchlorate, and results are reported to the State and USEPA, and distributed to the public at the quarterly Restoration Advisory Board (RAB) meetings. Surface water sampling is performed on grab samples on months that do not necessarily coincide with biannual monitoring well sampling events (Plot 25). The trend of perchlorate concentrations has been a decline since the start of the period of record for quarterly sampling began at the three locations on Harrison Bayou in September 1999. The three sampling locations depicted in Plot 25 are generally situated with respect to LHAAP-16 and LHAAP-18/24 as follows:

- HBW-10: upstream of LHAAP-16 and LHAAP-18/24
- HBW-1: downstream of LHAAP-16, upstream of LHAAP-18/24
- HBW-7: downstream of LHAAP-16 and LHAAP-18/24

Concentrations reported for upstream location HBW-10 have been ND during the fourth five-year review period.

Concentrations at the midstream location HBW-1, located downstream of LHAAP-16 but upstream of LHAAP-24 has been ND during the fourth five-year review period, with the exception of the last quarterly sample that had 1.1-J µg/L perchlorate.

Perchlorate concentrations in the downstream location HBW-7, which is the location assumed to reflect any impacts to surface water quality from discharge of contaminated groundwater as base flow into the stream, has been ND or trace J-values during the fourth five-year review period.

Groundwater concentrations in Shallow Groundwater Zone monitoring wells have indicated elevated concentrations of perchlorate up to 2,400 µg/L (December 2017) in 18WW08 located about 160 feet southeast of Harrison Bayou. Perchlorate's trend analysis in 18WW08 show that concentrations in this well have been declining, fluctuating between levels that are lower than the PCL (17 µg/L) and 2400 µg/L. Shallow Groundwater Zone well 18CPTMW23, located between the northwest corner of the containment area and the Harrison Bayou (about 150 feet east of the Bayou), has had fluctuating perchlorate concentrations ranging between levels that are lower than the PCL to level as high as 3,220 µg/L (June 2017).

The surface water sampling program includes analysis only for perchlorate. Trend analysis of TCE in MW-16, located 77 feet hydraulically upgradient of Harrison Bayou, indicates an increasing trend (Plot 81). A graph of concentrations versus time show that TCE concentrations started increasing around 2010 (Plot 81) peaking at ~ 1000 µg/L in June 2015. In 2017, TCE concentrations fluctuated between 224 and 695 µg/L.

3.7 Data Analysis Summary

Mass removal rate's analyses from each recovery point conducted by Fourth Five-Year Review using monthly extraction flow data available for February/March 2015 and concentrations of COCs sampled at ICT and recovery wells at the end of February (Plot 82), 2016 indicate that:

- Relatively high groundwater extraction and high mass removal rates are encountered at ICT 4, 8, 11, 13A, 14D, 14E.
- Relatively high extraction rates and low mass removal rate are encountered at ICT 2, 13B, 13C.
- Relatively low extraction rates and high mass removal rates are encountered 18WW17, ICT 12B, 12C, 12D, 12E.

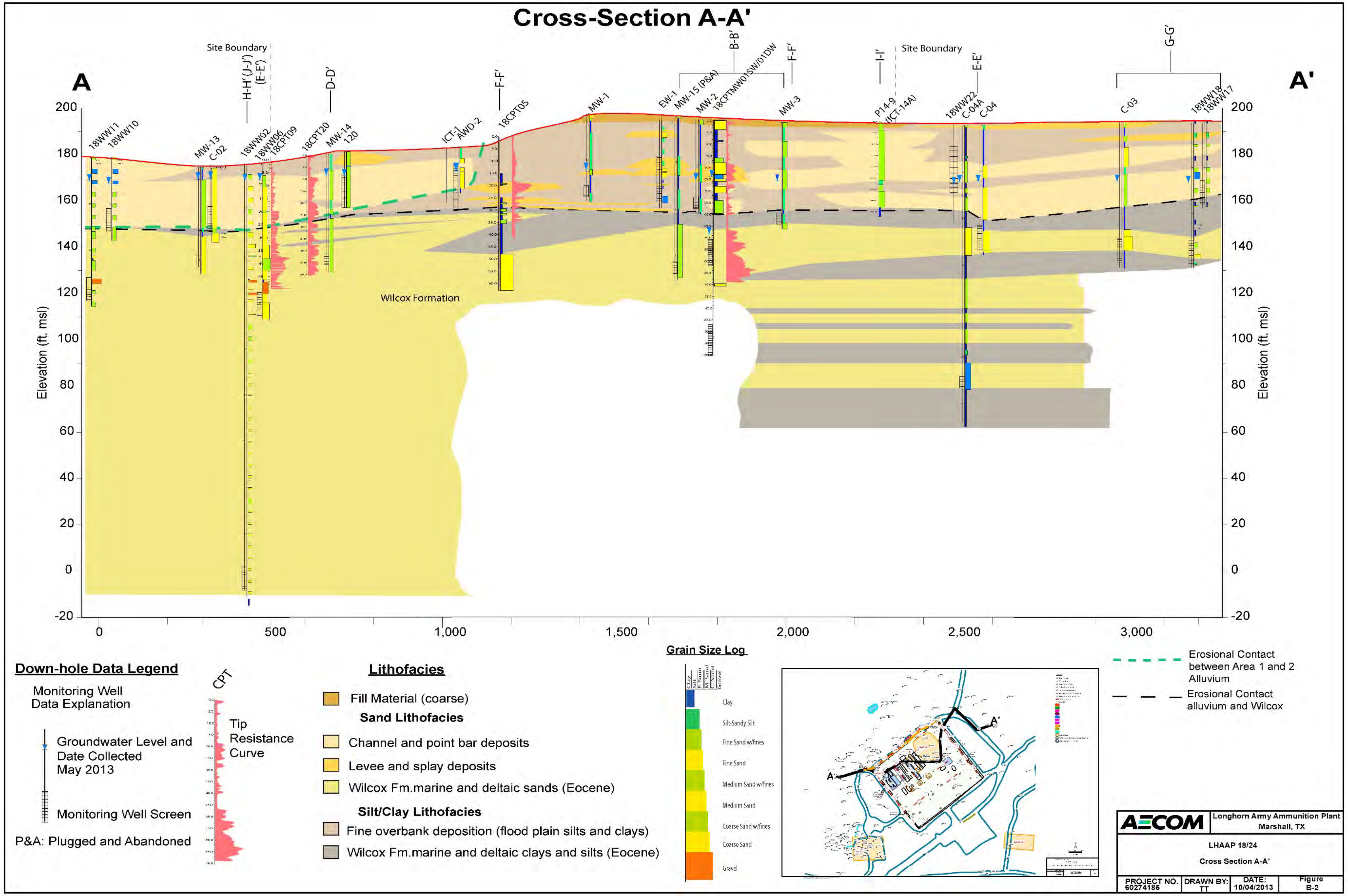
The GWTP removed COCs mass from groundwater and stabilized the COCs footprints. The extraction system appears to provide lateral capture of groundwater in the Shallow Groundwater Zone located within the boundaries of LHAAP18/24, though it does not provide vertical capture of groundwater within these boundaries. Although the system does not provide complete lateral and vertical capture of the footprints of the widespread COCs, it meets the IRA RAOs remedial action objectives in that it reduces the mass loading leaving the perimeters of LHAAP18/24.

Plot 24 depicts the monthly volume treated between 2008 and 2013, included in the 2013 Five-Year Review (AECOM, 2014a), and the monthly volume treated between 2012 and 2017. The maximum monthly volume treated in between 2012 and 2017 is higher than the maximum volume treated between 2008 and 2013, and overall there is no monotonic decline in the trend of monthly flow rate. Precluding the period of key maintenance events, the trend in volume of groundwater treated is predominantly influenced by meteorological conditions with higher flow treated after a prolonged period of precipitation recharge. The volume of water treated is predominantly a function of the meteorological system and the capacity of the treatment system (e.g., the flow rate that the ion exchange system can handle due to the residence time required).

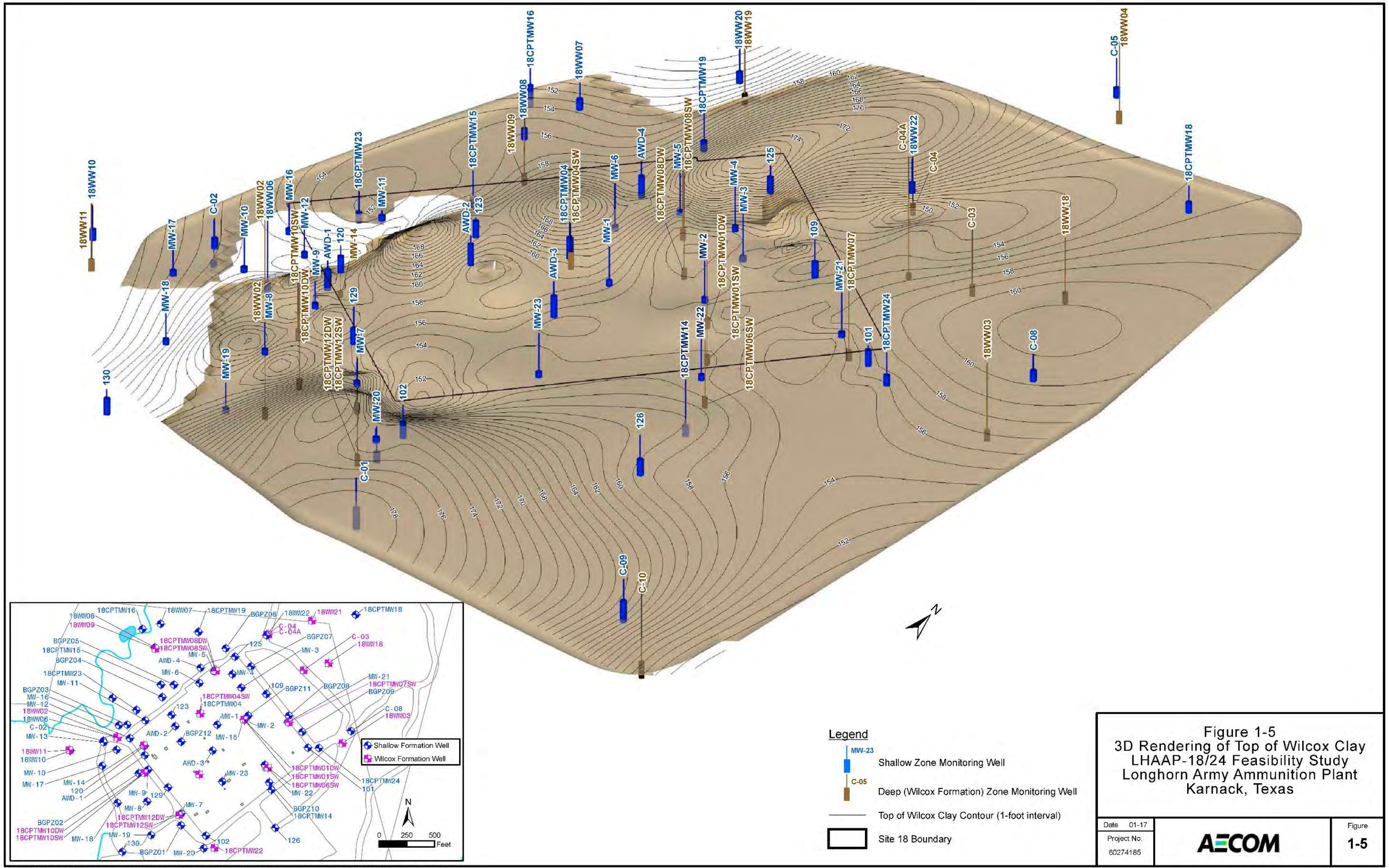
Summary of the analysis leading to the conclusion that the IRA is meeting the remedial action objectives is provided below:

- TCE concentrations (Plot 37) in the Shallow Groundwater Zone along the southeast corner of the UEP declined from levels that were within the solubility limit (as high as 10,550,000 ppb) in 1994, to levels that are less than the 1% solubility limit (i.e. ~ 10,000 ppb, Plot 41) in June 2016. The large areal extent of the Shallow Groundwater Zone's footprint of TCE with concentration above the 1% solubility limits which covered the UEP, burn pits area, and the ACD has decreased significantly between 1994 and June 2016, and in 2017 was limited to one well (Plot 43) located at the ACD (along the northwest corner of LHAAP18/24 property's boundary). Analysis of the 2014 through 2017 COCs contours indicates the presence of two primary source areas (possibly DNAPL in the ACD area) one at MW-2 located near the former UEP, and the second at 120 located near the former ACD operations. The O&M trend analysis results, depicted in Plot 41, and results of trend analysis performed by the Fourth Five-Year Review, depicted in Figure 17, are described in details in Appendix C Section 3.5.2. Overall TCE attenuation outside the capture/containment area is taking place east, north, and west of the capture zone/containment boundary. However the available data for MW16 (Plot 81) indicate an increasing TCE trend in this well. MW16 is located adjacent to the stream. There are two wells with increasing TCE trends within the capture zone/ containment area. Both wells are located in the proximity of the UEP. Wells with decreasing TCE trends are present between the two wells with the increasing TCE trends. This pattern provides the line of evidence that the increase in TCE within the capture zone/containment boundary is likely due to plume redistribution in response to the operation of the recovery system.
- There are two TCE plumes in the middle Wilcox Formation (Plot 61 through Plot 63). The centers of these plumes coincide with the centers of the shallow TCE plumes. TCE's trend analysis conducted by O&M indicates increasing concentration in the plume's center well MW-14, located in the ACD area along the northwest property boundary (Plot 47). The Fourth Five-Year Review trend analysis indicates that the available data did not meet the criteria to conduct a trend analysis.
- Time series of MC concentrations contours in the Shallow Groundwater Zone indicate that MC concentrations along the southeast corner of the UEP declined from levels as high as 10,550,000 ppb (Plot 50) in 1994, to around 100,000 ppb (Plot 54 through Plot 56) in 2017. The 1994 large areal extent of the Shallow Groundwater Zone's footprint of MC with concentration 100,000 ppb covering the UEP, burn pits area, and the ACD decreased significantly, and in 2017 was limited to one well located at the south east corner of the UEP (Plot 56). Analysis of the 2014 through 2017 MC contours indicates the presence of two primary source areas (possibly DNAPL in the southeast corner of the UEP area) one at MW-2 located near the former UEP, and the second at 120 located near the former ACD operations. Results of a trend analysis performed by O&M, depicted in Plot 54, and results of trend analysis performed by the Fourth Five-Year Review, depicted in Figure 18, are described in details in Appendix C Section 3.5.2.

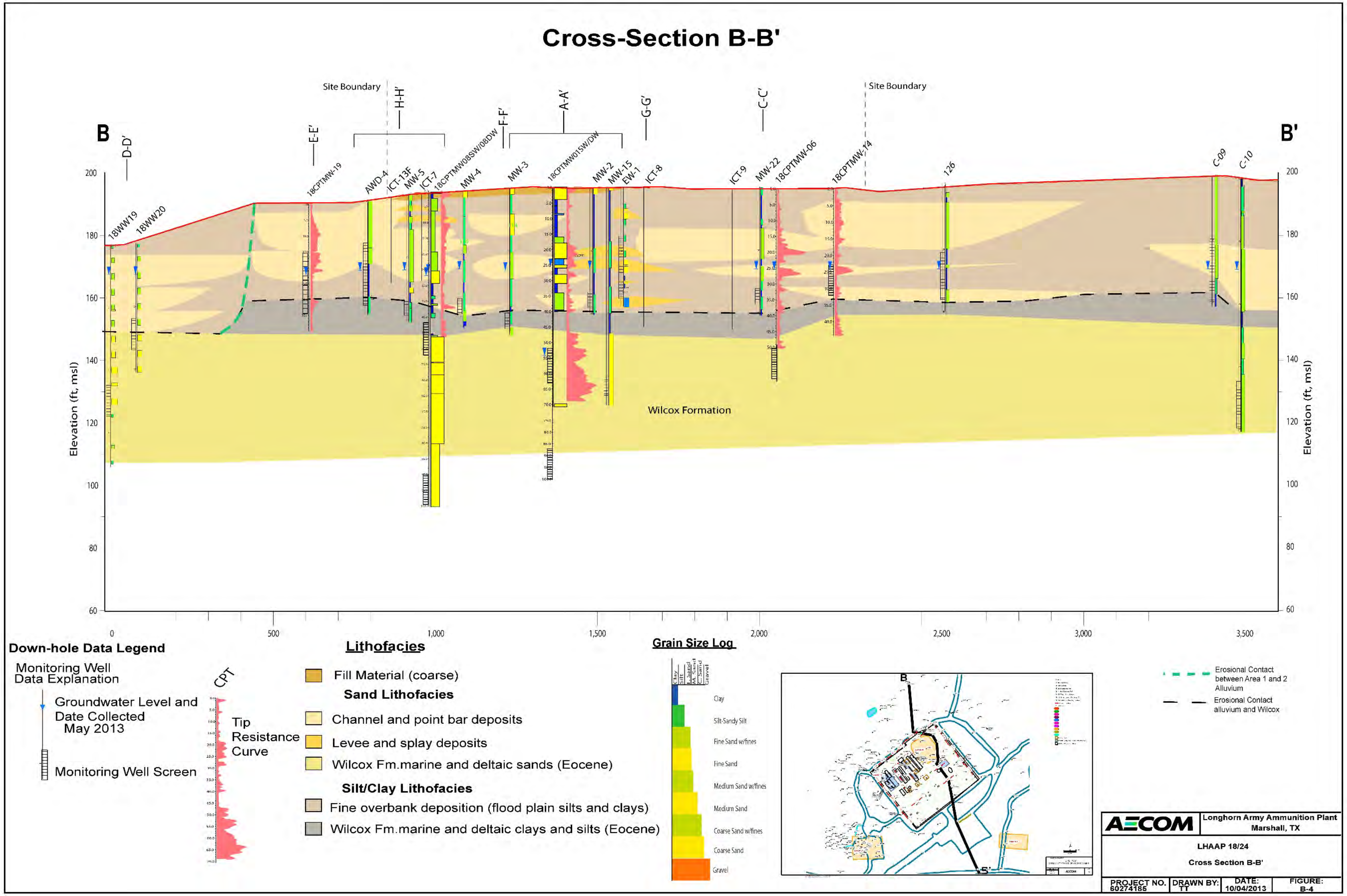
- Perchlorate concentrations in the Shallow Groundwater Zone indicate that increasing trends of perchlorate concentrations are only noted within the containment area (Plot 72 and Figure 18). Perchlorate trends in wells located outside the containment are either declining or indeterminate. Although perchlorate concentration in 18WW08 located ~ 150 feet upgradient of Harrison Bayou and downgradient of the northwest perimeter of the site is declining, recently the fluctuation in concentration ranged between ND and 2400 µg/L.
- Perchlorate in the middle Wilcox Formation include three high perchlorate concentration areas (north of the UEP, near the ACD, and outside of the containment on the south corner of the site, (Plot 86)), and the footprints appear stable.



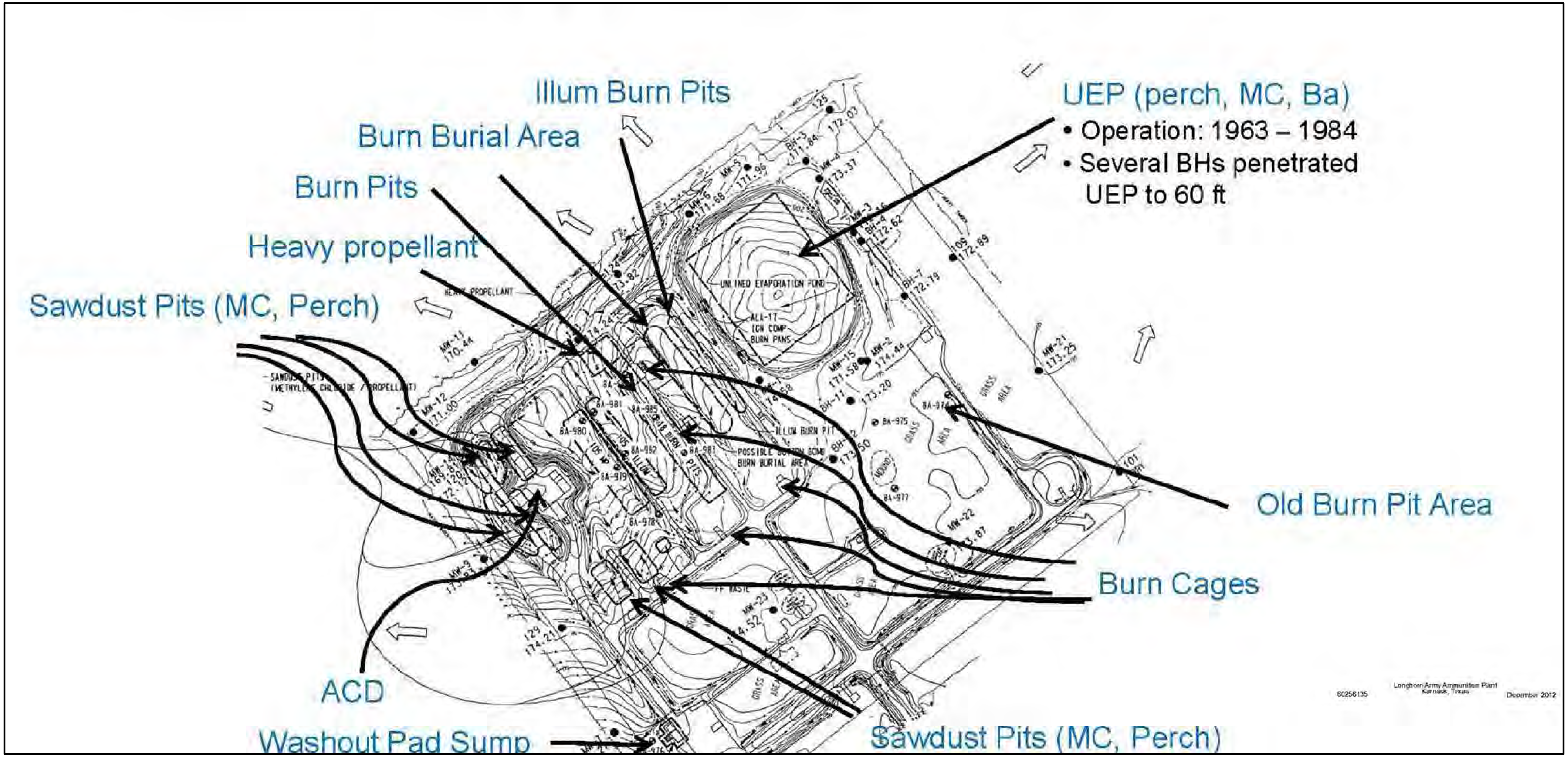
Plot 12. LHAAP-18/24 Cross-Section Line A-A' (AECOM, 2013g).



Plot 13. Modeled clay layer (Yoakum Shale) surface separating the overlying Pleistocene terrace deposits from the underlying middle Wilcox Formation at LHAAP-18/24 (AECOM, 2017a)



Plot 14. LHAAP-18/24 Cross-Section Line B-B' (AECOM, 2013g).



Illum Burn Pits

Burn Burial Area

Burn Pits

Heavy propellant

Sawdust Pits (MC, Perch)

UEP (perch, MC, Ba)

- Operation: 1963 – 1984
- Several BHs penetrated UEP to 60 ft

Old Burn Pit Area

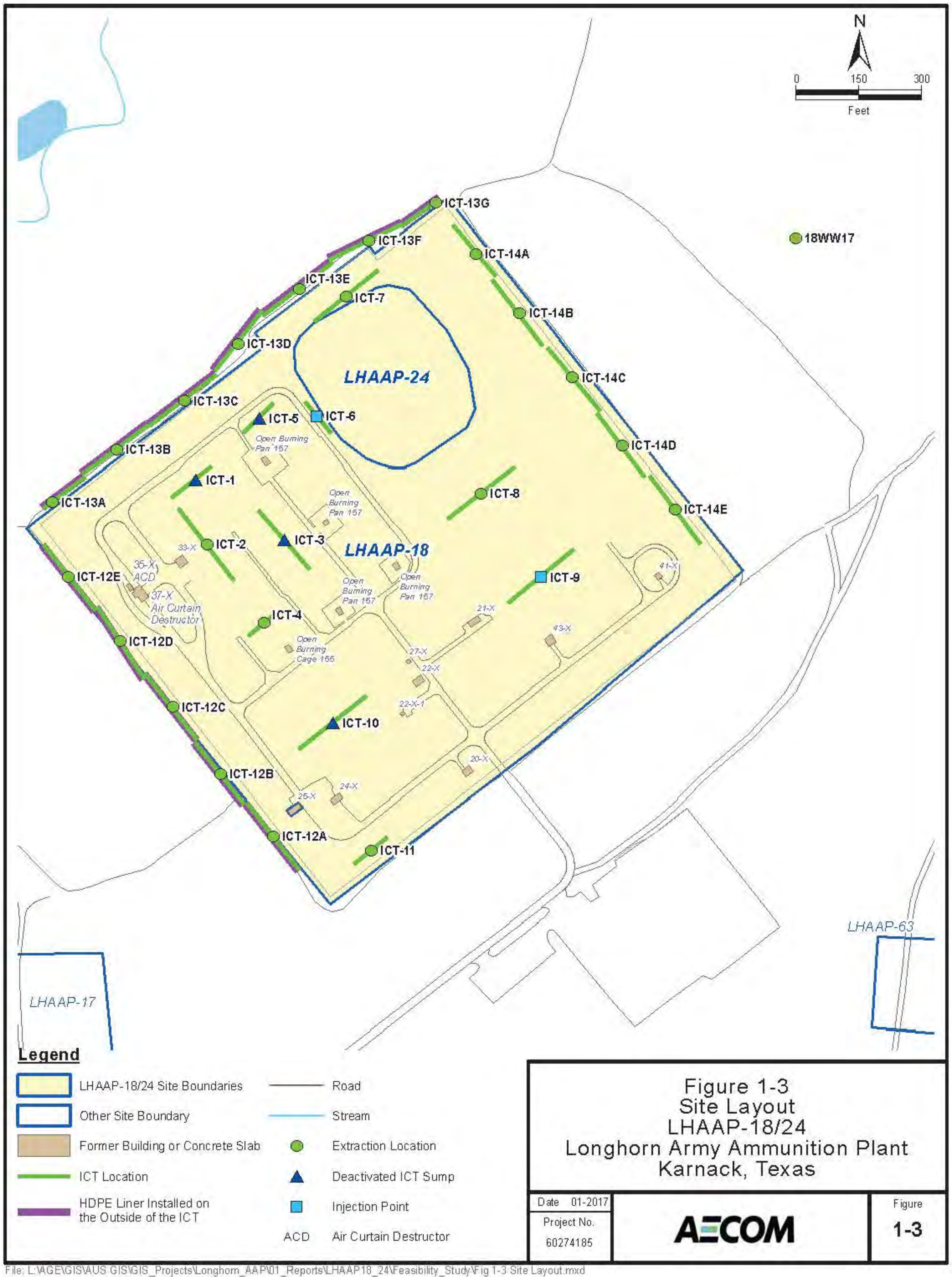
Burn Cages

ACD

Washout Pad Sump

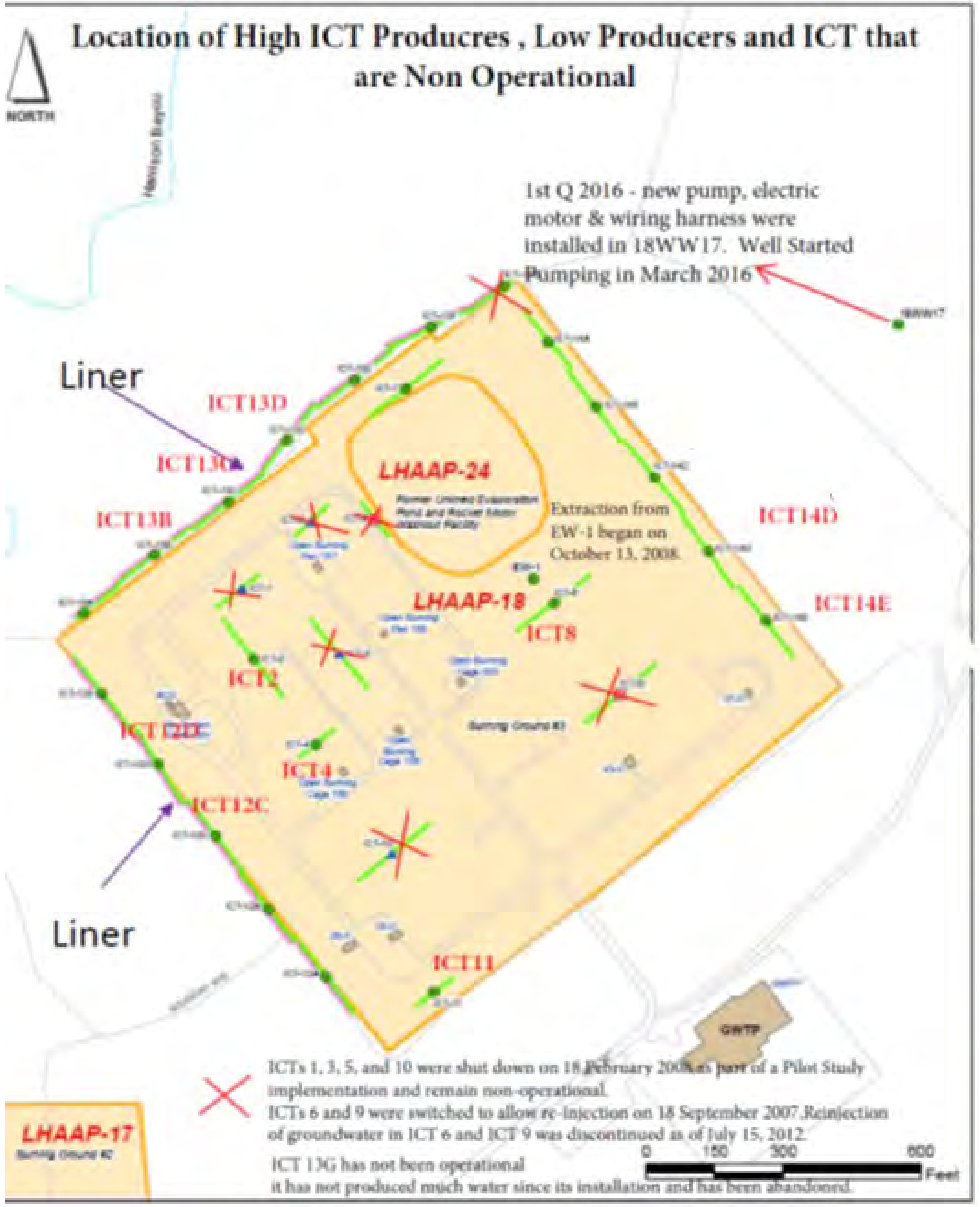
Sawdust Pits (MC, Perch)

Plot 15. Site Features and Historical Contaminant Sources – LHAAP – 18/24 (AECOM, 2014a).



File: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP18_24\Feasibility_Study\Fig 1-3 Site Layout.mxd
Date: Monday, January 23, 2017 2:25:04 PM

Plot 16. LHAAP-18/24 interception collection trenches (ICTs) and vertical extraction wells (EW-1, 18WW17) (AECOM, 2017a)



1st Q 2016 - new pump, electric motor & wiring harness were installed in 18WW17. Well Started Pumping in March 2016

Extraction from EW-1 began on October 13, 2008.

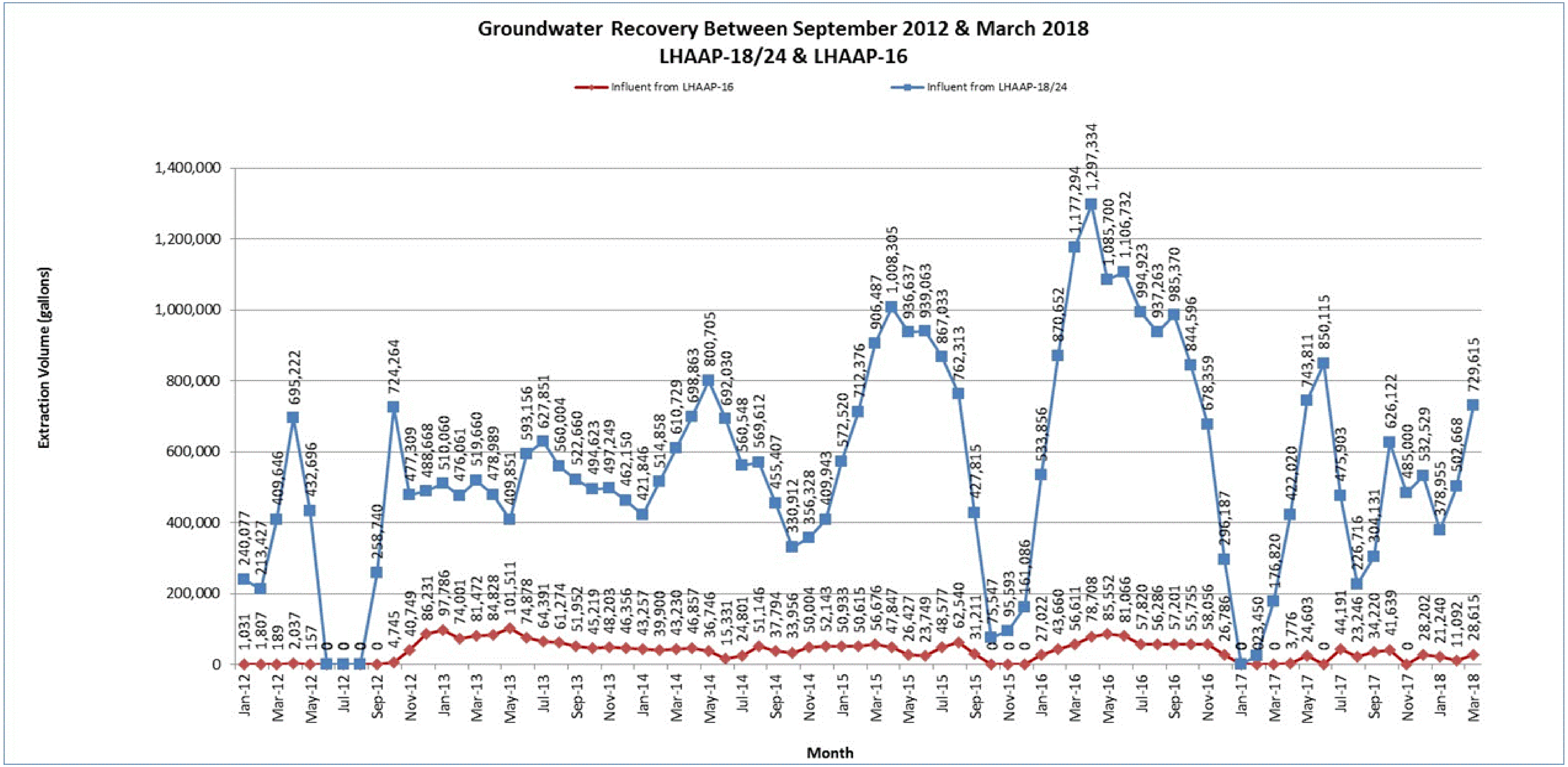
ICTs 1, 3, 5, and 10 were shut down on 18 February 2008 as part of a Pilot Study implementation and remain non-operational.
ICTs 6 and 9 were switched to allow re-injection on 18 September 2007.Reinjection of groundwater in ICT 6 and ICT 9 was discontinued as of July 15, 2012.

ICT 13G has not been operational
it has not produced much water since its installation and has been abandoned.

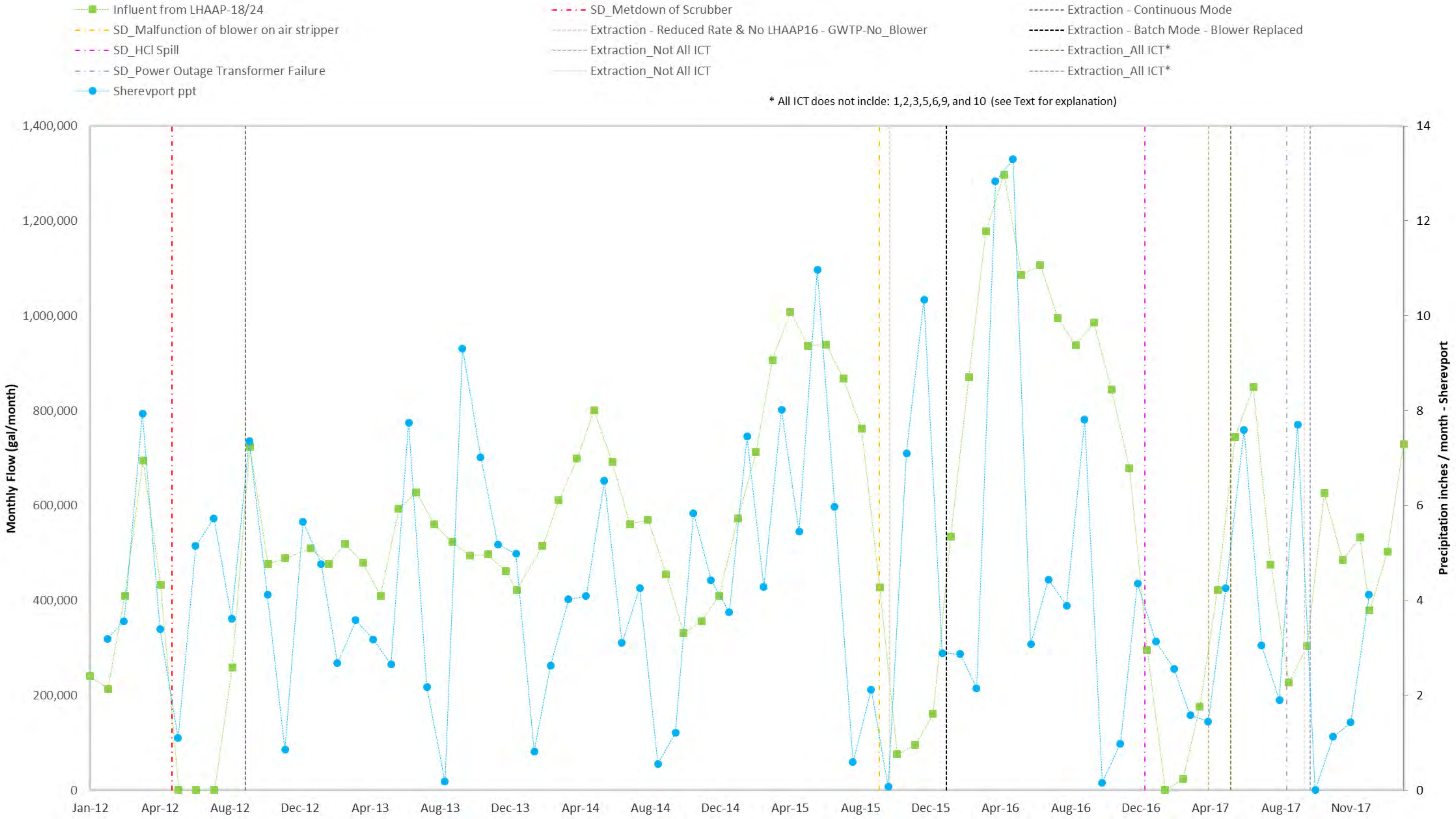
Minimum and Maximum Flow Rates in Extraction System - 2012 through the end 2016.

ICT	Min	Max
	gpm	gpm
ICT-2	0.114	6.00
ICT-4	0.121	5.14
EW-01	0.00023	0.18
ICT-7	0.00028	0.51
ICT-8	0.00005	3.88
18WW17	0.117	0.22
ICT-11	0.048	3.96
ICT-12A	0.003	0.32
ICT-12B	0.001	0.75
ICT-12C	0.001	2.20
ICT-12D	0.054	1.97
ICT-12E	0.0003	0.93
ICT-13A	0.0001	2.60
ICT-13B	0.069	7.54
ICT-13C	0.002	6.79
ICT-13D	0.001	1.93
ICT-13E	0.010	0.47
ICT-13F	0.00002	0.46
ICT-14A	0.056	0.08
ICT-14B	0.006	1.76
ICT-14C	0.001	1.43
ICT-14D	0.033	1.97
ICT-14E	0.037	1.67
Site 16	1.091	25.63

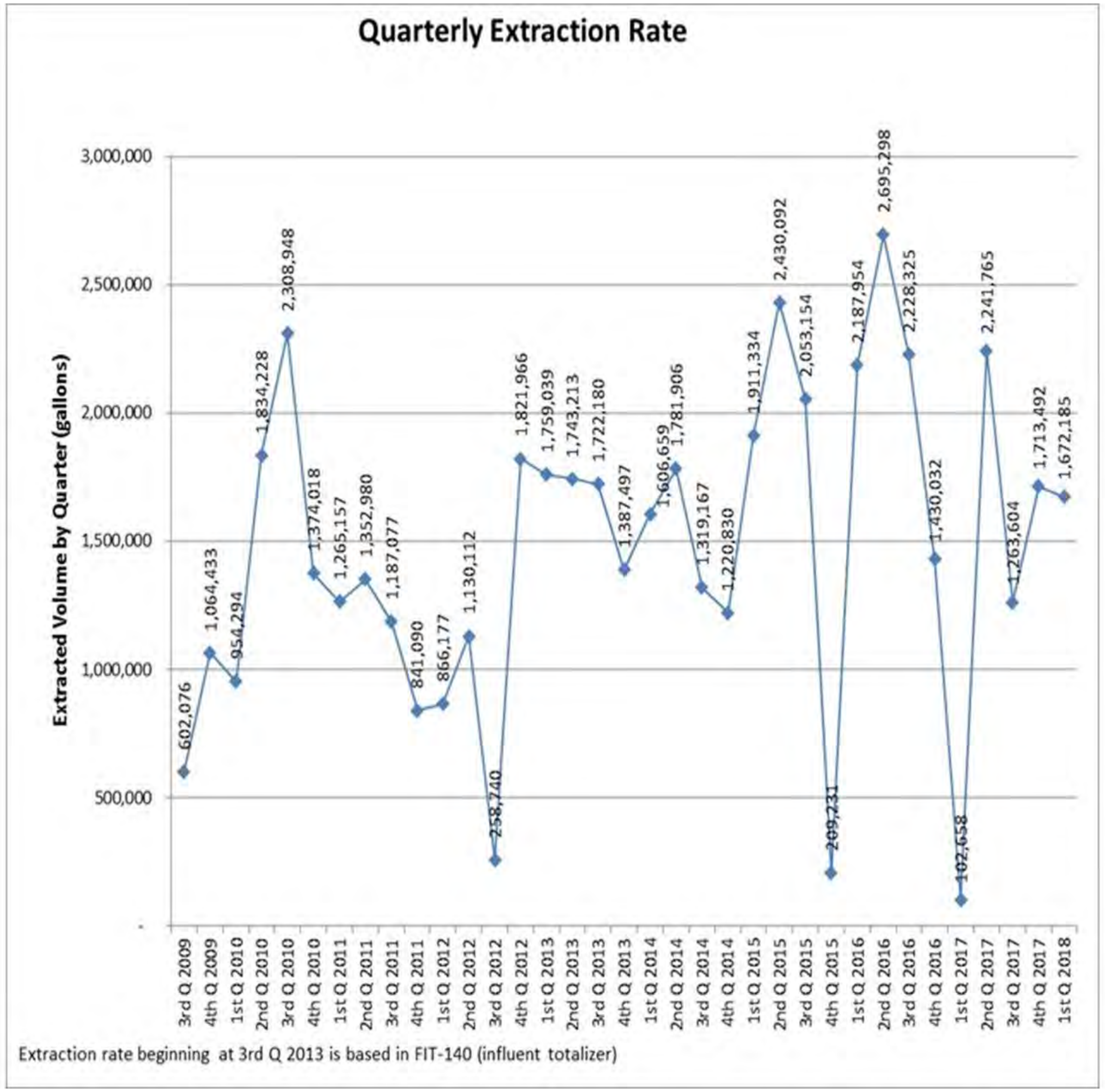
Plot 17. LHAAP-18/24 Groundwater extraction system operational and ranges in groundwater flow rates – 2012-2018.



Plot 18. LHAAP-18/24 + LHAAP-16 monthly groundwater recovery rate – September 2012 to March 2018.

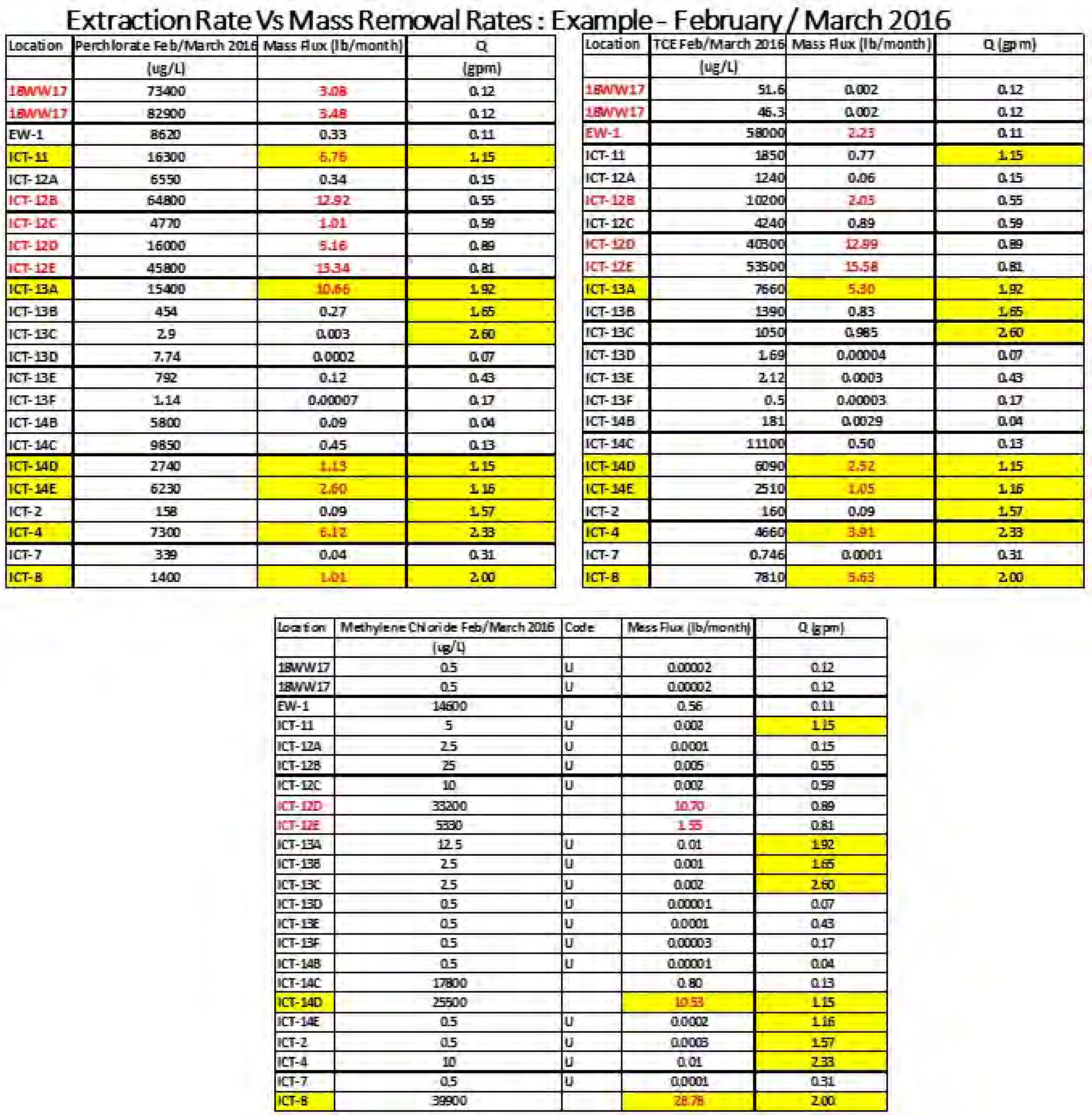


Plot 19. LHAAP-18/24 monthly total extraction rates from LHAAP-18/24, monthly precipitation, and maintenance events (LHAAP, 2018b, NOAA, 2018).



Extraction rate beginning at 3rd Q 2013 is based in FIT-140 (influent totalizer)

Plot 20 Total GWTP quarterly extraction rates, 3rd Q 2009 through 1st Q 2018.



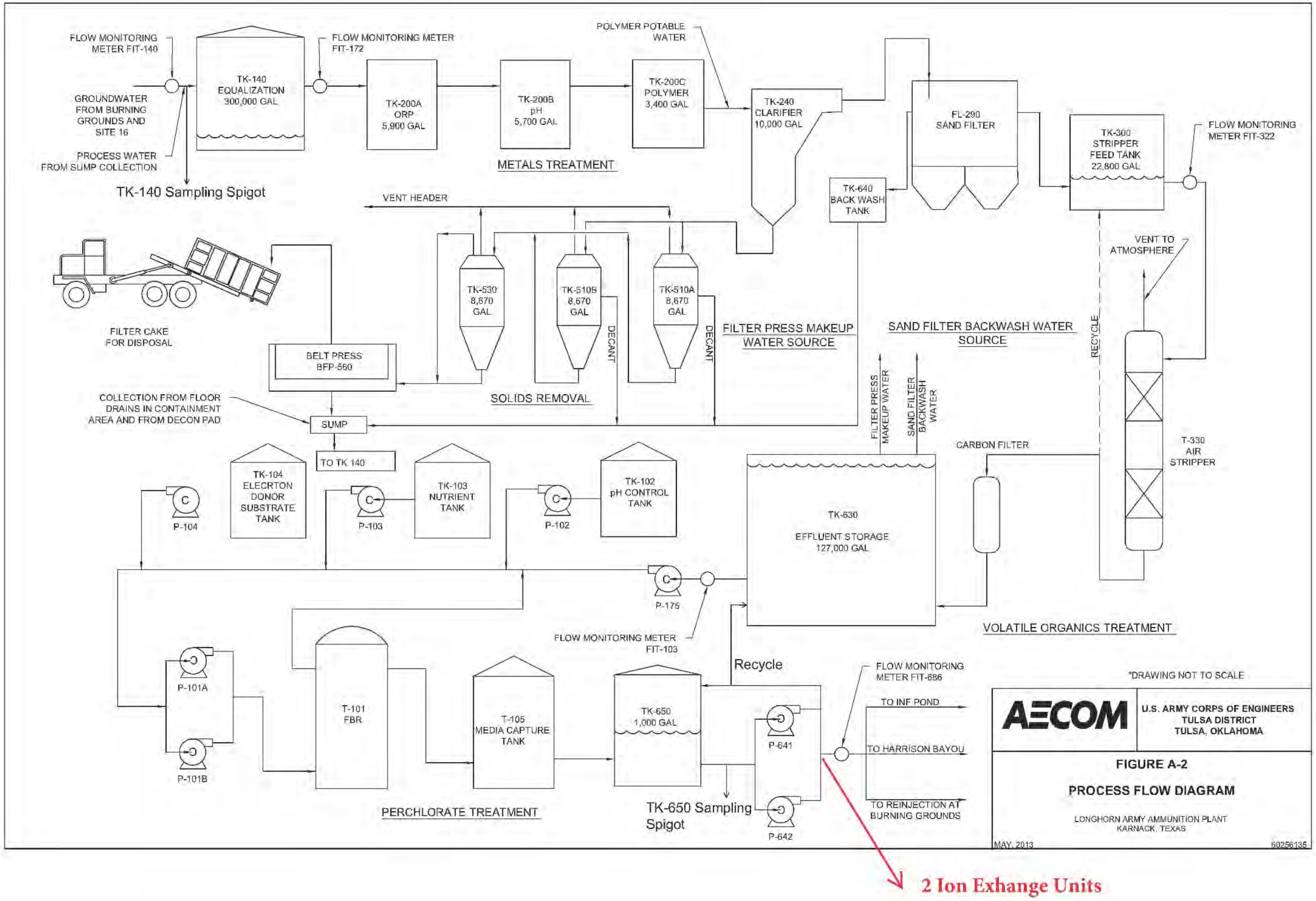
Extraction Rate Vs Mass Removal Rates : Example - February / March 2016

Location	Perchlorate Feb/March 2016	Mass Flux (lb/month)	Q
	(ug/L)		(gpm)
18WW17	73400	3.08	0.12
18WW17	82900	3.48	0.12
EW-1	8620	0.33	0.11
ICT-11	16300	6.76	1.15
ICT-12A	6550	0.34	0.15
ICT-12B	64800	12.92	0.55
ICT-12C	4770	1.01	0.59
ICT-12D	16000	5.16	0.89
ICT-12E	45800	13.34	0.81
ICT-13A	15400	10.66	1.92
ICT-13B	454	0.27	1.65
ICT-13C	2.9	0.003	2.60
ICT-13D	7.74	0.0002	0.07
ICT-13E	792	0.12	0.43
ICT-13F	1.14	0.00007	0.17
ICT-14B	5800	0.09	0.04
ICT-14C	9850	0.45	0.13
ICT-14D	2740	1.13	1.15
ICT-14E	6230	2.60	1.16
ICT-2	158	0.09	1.57
ICT-4	7300	6.12	2.33
ICT-7	339	0.04	0.31
ICT-8	1400	1.01	2.00

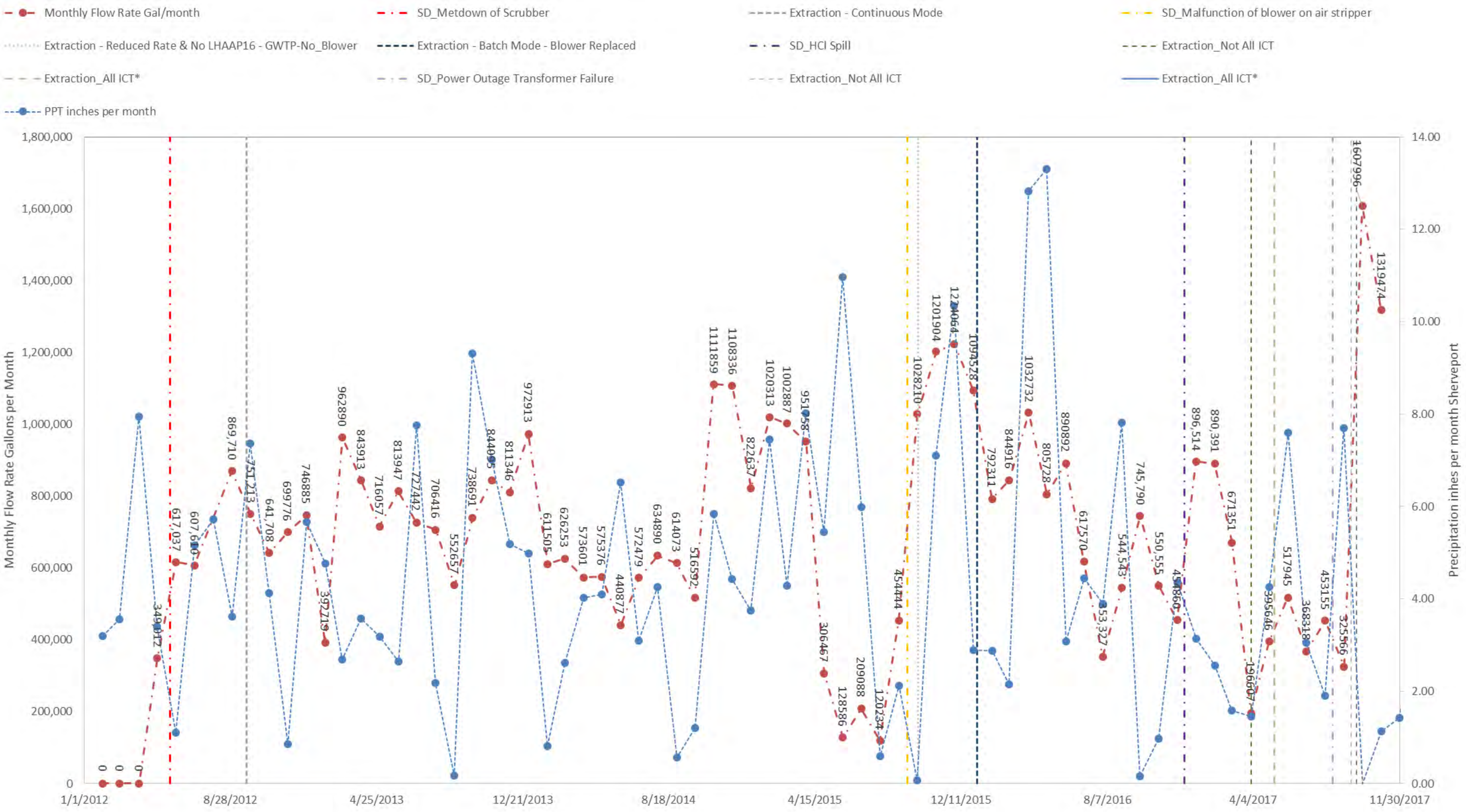
Location	TCE Feb/March 2016	Mass Flux (lb/month)	Q (gpm)
	(ug/L)		
18WW17	51.6	0.002	0.12
18WW17	46.3	0.002	0.12
EW-1	58000	2.23	0.11
ICT-11	1850	0.77	1.15
ICT-12A	1240	0.06	0.15
ICT-12B	10200	2.03	0.55
ICT-12C	4240	0.89	0.59
ICT-12D	40300	12.99	0.89
ICT-12E	53500	15.58	0.81
ICT-13A	7660	5.30	1.92
ICT-13B	1390	0.83	1.65
ICT-13C	1050	0.985	2.60
ICT-13D	1.69	0.00004	0.07
ICT-13E	2.12	0.0003	0.43
ICT-13F	0.5	0.00003	0.17
ICT-14B	181	0.0029	0.04
ICT-14C	11100	0.50	0.13
ICT-14D	6090	2.52	1.15
ICT-14E	2510	1.05	1.16
ICT-2	160	0.09	1.57
ICT-4	4660	3.91	2.33
ICT-7	0.746	0.0001	0.31
ICT-8	7810	5.63	2.00

Location	Methylene Chloride Feb/March 2016	Code	Mass Flux (lb/month)	Q (gpm)
	(ug/L)			
18WW17	0.5	U	0.00002	0.12
18WW17	0.5	U	0.00002	0.12
EW-1	14600		0.56	0.11
ICT-11	5	U	0.002	1.15
ICT-12A	2.5	U	0.0001	0.15
ICT-12B	25	U	0.005	0.55
ICT-12C	10	U	0.002	0.59
ICT-12D	33200		10.70	0.89
ICT-12E	5330		1.55	0.81
ICT-13A	12.5	U	0.01	1.92
ICT-13B	2.5	U	0.001	1.65
ICT-13C	2.5	U	0.002	2.60
ICT-13D	0.5	U	0.00001	0.07
ICT-13E	0.5	U	0.0001	0.43
ICT-13F	0.5	U	0.00003	0.17
ICT-14B	0.5	U	0.00001	0.04
ICT-14C	17800		0.80	0.13
ICT-14D	25500		10.53	1.15
ICT-14E	0.5	U	0.0002	1.16
ICT-2	0.5	U	0.0003	1.57
ICT-4	10	U	0.01	2.33
ICT-7	0.5	U	0.0001	0.31
ICT-8	39900		28.78	2.00

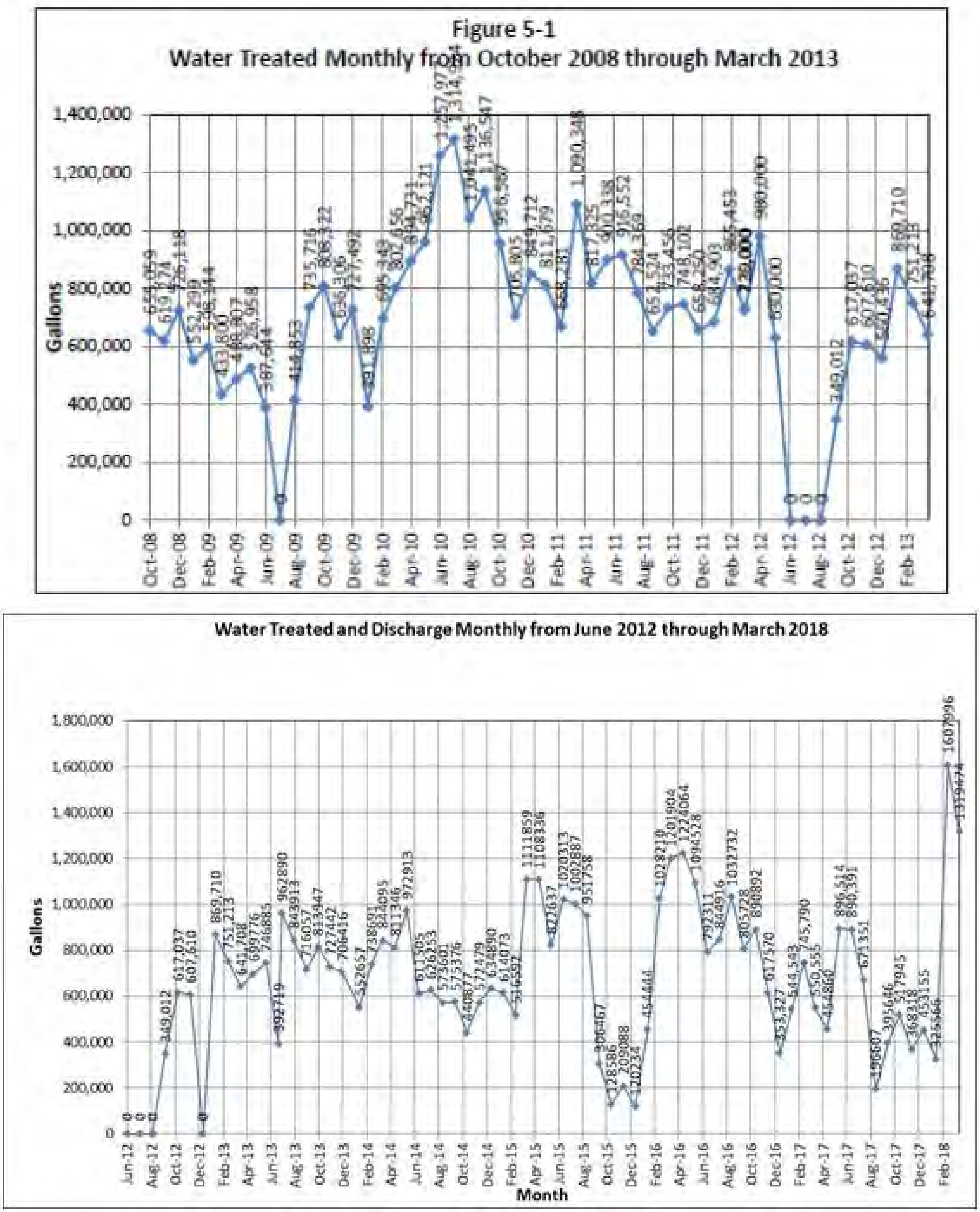
Plot 21. LHAAP 18-24 and LHAAP-16 groundwater extraction and mass removal rates – February/March 2016 (LHAAP, 2018b).



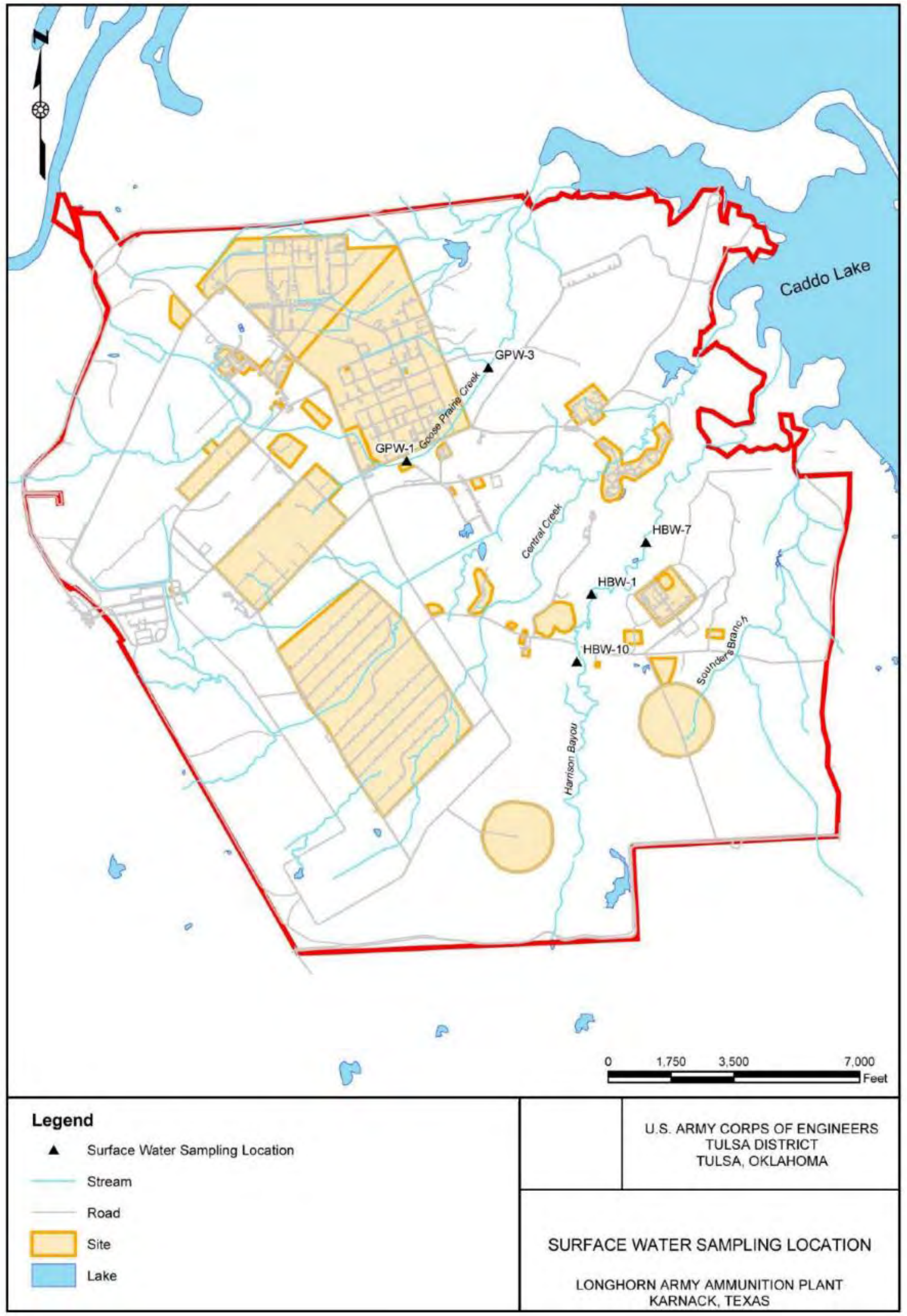
Plot 22. Updated LHAAP-16 and 18/24 GWTP process flow diagram (AECOM, 2017a annotated by the Fourth Five-Year Review [red]).



Plot 23. Monthly GWTP flow rate of water treated, monthly precipitation, and key maintenance events, 2012 through 2018 (LHAAP, 2018b, NOAA, 2018).



Plot 24. Monthly GWTP water volume treated - 2008 through 2013 vs 2012 through 2017.



Plot 25. Harrison Bayou and Goose Prairie Creek surface water sampling locations.

Harrison Bayou and Goose Prairie Creek – Perchlorate Data

Surface water samples are collected quarterly from each location in Harrison Bayou and Goose Prairie Creek, unless the sampling location is dry.

Surface Water Sample Data (in micrograms per liter)

Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st
Creek Sample ID	Jul 1999	Sep 1999	Feb 2000	Apr 2000	Aug 2000	Dec 2000	Feb 2001	Apr 2001	July 2001	Oct 2001	Jan 2002
GPW-1	<1.0U	-	4	<4.0 U	<4.0 U	<4.0 U	-	2.65	<4.0 U	<4.0 U	<4.0 U
GPW-3	<1.0U	<4.0 U	17	8	<4.0 U	<4.0 U	-	2.28	<4.0 U	<4.0 U	<4.0 U
HBW-1	-	<80.0 U	310	23	-	-	<4.0 U	-	<4.0 U	<4.0 U	<4.0 U
HBW-7	-	<8.0 U	370	110	-	-	<4.0 U	-	<4.0 U	<4.0 U	<4.0 U
HBW-10	-	<8.0 U	905	650	<4.0 U	-	<4.0 U	-	<4.0 U	-	-

Quarter	2nd	3rd	4th	1st	2nd	3rd	3rd	4th	2nd	3rd	4th
Creek Sample ID	June 2002	Sept 2002	Dec 2002	Feb 2003	June 2003	Aug 2003	July 2004	Dec 2006	May 2007	Aug 2007	Dec 2007
GPW-1	<4.0 U	<4.0 U	18.3	18.6	59.9	-	2.25	-	<1.0 U	<1.0 U	10.7
GPW-3	<4.0 U	<4.0 U	5.49	12.6	14.7	-	2.2	-	<1.0 U	<1.0 U	7.48
HBW-1	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	99.3	<0.2U	<1.0 U	<1.0 U	122	<1.0 U
HBW-7	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	<4.0 U	<0.2U	<1.0 U	<1.0 U	1.02	<1.0 U
HBW-10	<4.0 U	<4.0 U	<4.0 U	-	<4.0 U	-	<0.2U	<1.0 U	<1.0 U	<1.0 U	<1.0 U

Quarter	1st	2nd	3rd	4th	2nd	3rd	3rd	3rd	4th	1st	2nd
Creek Sample ID	Mar 2008	Jun 2008	Sep 2008	Dec 2008	May 2009	Jul 2009	Aug 2009	Sep 2009	Dec 2009	Mar 2010	Jun 2010
GPW-1	27	<0.5U	<0.5U	<0.22U	16	<4U	NS	<1.2U	3.7	1.3J	<0.6U
GPW-3	21.9	9.42	1.1	<0.22U	8.9	<4U	NS	<0.6U	2.8	1.8J	<0.6U
HBW-1	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	NS	<1.5U	<0.275U	1.5U	<0.6U
HBW-7	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	24	<1.2U	<0.275U	1.5U	<0.6U
HBW-10	<0.5U	<0.5U	<0.5U	<0.22U	<0.55U	<4U	NS	<1.5U	<0.275U	1.2U	<0.6U

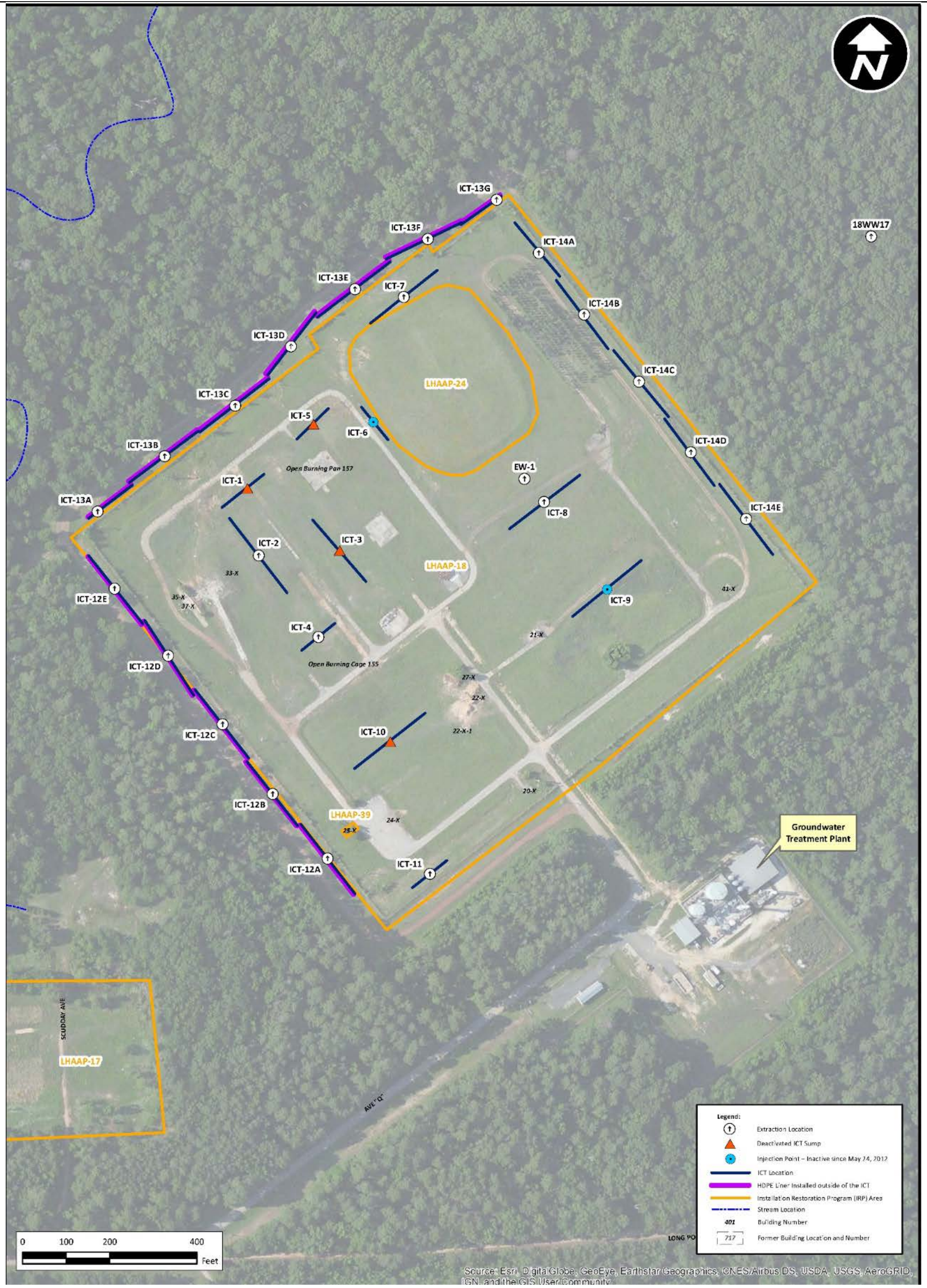
Quarter	3rd	4th	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st
Creek Sample ID	Sep 2010	Dec 2010	Mar 2011	Jun 2011	Sep 2011	Dec 2011	Mar 2012	Jun 2012	Not Applicabl e	Jan & Feb 2013	Mar 2013
GPW-1	dry	<0.1U	8.7	dry	dry	1.76	0.163J	dry	NS	1.65	0.735
GPW-3	dry	0.199J	0.673	dry	dry	1.31	0.261	dry	NS	1.74	0.754
HBW-1	dry	<0.1U	<0.2U	dry	dry	<0.1U	0.1U	dry	NS	<0.2U	<0.2U
HBW-7	dry	<0.1U	<0.2U	dry	dry	0.171J	0.1U	dry	NS	<0.2U	<0.2U
HBW-10	dry	<0.1U	<0.2U	dry	dry	<0.1U	0.1U	dry	NS	<0.2U	<0.2U

Quarter	2nd	3rd	4th	1st	2nd	3nd	4th	1st	2nd	3rd	4th
Creek Sample ID	Jun 2013	Sept 2013	Dec 2013	Feb 2014	May 2014	Aug 2014	Nov 2014	Feb 2015	May 2015	Aug 2015	Nov 2015
GPW-1	dry	<0.2 U	dry	0.766	dry	dry	0.244 J	0.311 J	0.156J	dry	0.142 J
GPW-3	dry	<0.2 U	dry	1.15	dry	dry	0.276 J	0.344 J	dry	dry	0.311 J
HBW-1	<0.2U	<0.2 U	dry	<0.2 U	dry	dry	<0.2 U	<0.2 U	dry	dry	<0.2 U
HBW-7	<0.2U	<0.2 U	dry	0.201 J	dry	dry	<0.2 U	0.124 J	dry	dry	<0.2 U
HBW-10	<0.2U	<0.2 U	dry	<0.2 U	dry	dry	<0.2 U	<0.2 U	dry	dry	<0.2 U

Quarter	1st	2nd	3rd	4th	1st	2nd	3rd	4th	1st	2nd
Creek Sample ID	Feb 2016	May 2016	Aug 2016	Nov 2016	Feb 2017	May 2017	Aug 2017	Dec 2017	Mar 2018	Jun 2018
GPW-1	0.447	6.59	<0.2 U	0.301 J	<1 U	0.263	dry	<4.0 U	<4.0 U	dry
GPW-3	0.474	0.457	0.141	0.563	<1 U	0.274	dry	<4.0 U	<4.0 U	dry
HBW-1	<0.2 U	<0.2 U	<0.2 U	<0.2 U	<1 U	<0.2 U	<0.2 U	1.1 J	<4.0 U	dry
HBW-7	<0.2 U	<0.2 U	<0.2 U	0.318 J	<1 U	0.155	<0.2 U	<4.0 U	<4.0 U	dry
HBW-10	<0.2 U	<0.2 U	<0.2 U	<0.2 U	<1 U	<0.2 U	0.111J	<4.0 U	<4.0 U	dry

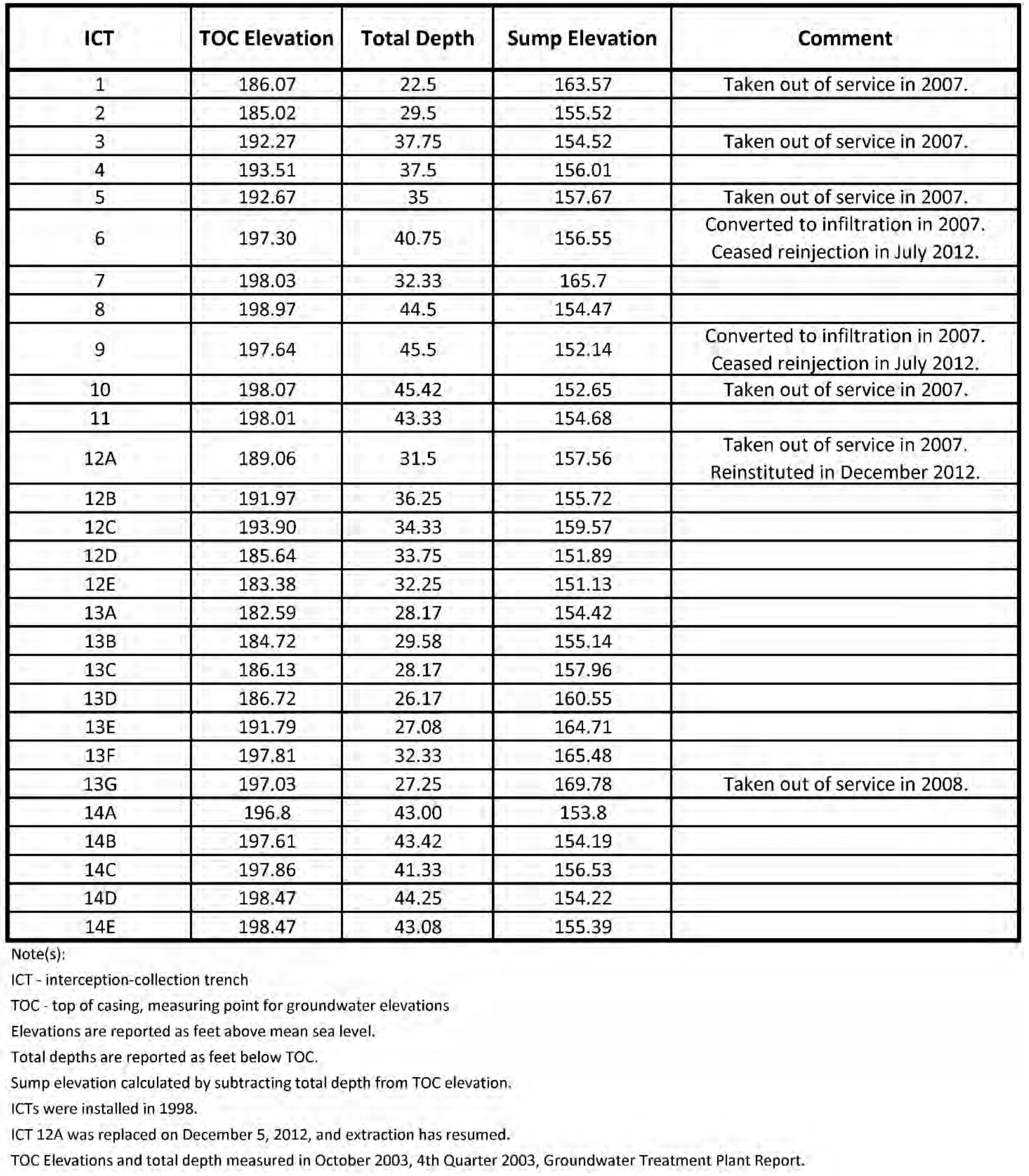
NS – not sampled U – non-detect J – Estimated Dry – no surface water

Plot 26. Harrison Bayou and Goose Prairie Creek perchlorate data.



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Plot 27. LHAAP-18/24 interception-collection trench and vertical extraction well locations (Bhate, 2018b)



ICT	TOC Elevation	Total Depth	Sump Elevation	Comment
1	186.07	22.5	163.57	Taken out of service in 2007.
2	185.02	29.5	155.52	
3	192.27	37.75	154.52	Taken out of service in 2007.
4	193.51	37.5	156.01	
5	192.67	35	157.67	Taken out of service in 2007.
6	197.30	40.75	156.55	Converted to infiltration in 2007. Ceased reinjection in July 2012.
7	198.03	32.33	165.7	
8	198.97	44.5	154.47	
9	197.64	45.5	152.14	Converted to infiltration in 2007. Ceased reinjection in July 2012.
10	198.07	45.42	152.65	Taken out of service in 2007.
11	198.01	43.33	154.68	
12A	189.06	31.5	157.56	Taken out of service in 2007. Reinstituted in December 2012.
12B	191.97	36.25	155.72	
12C	193.90	34.33	159.57	
12D	185.64	33.75	151.89	
12E	183.38	32.25	151.13	
13A	182.59	28.17	154.42	
13B	184.72	29.58	155.14	
13C	186.13	28.17	157.96	
13D	186.72	26.17	160.55	
13E	191.79	27.08	164.71	
13F	197.81	32.33	165.48	
13G	197.03	27.25	169.78	Taken out of service in 2008.
14A	196.8	43.00	153.8	
14B	197.61	43.42	154.19	
14C	197.86	41.33	156.53	
14D	198.47	44.25	154.22	
14E	198.47	43.08	155.39	

Note(s):

ICT - interception-collection trench

TOC - top of casing, measuring point for groundwater elevations

Elevations are reported as feet above mean sea level.

Total depths are reported as feet below TOC.

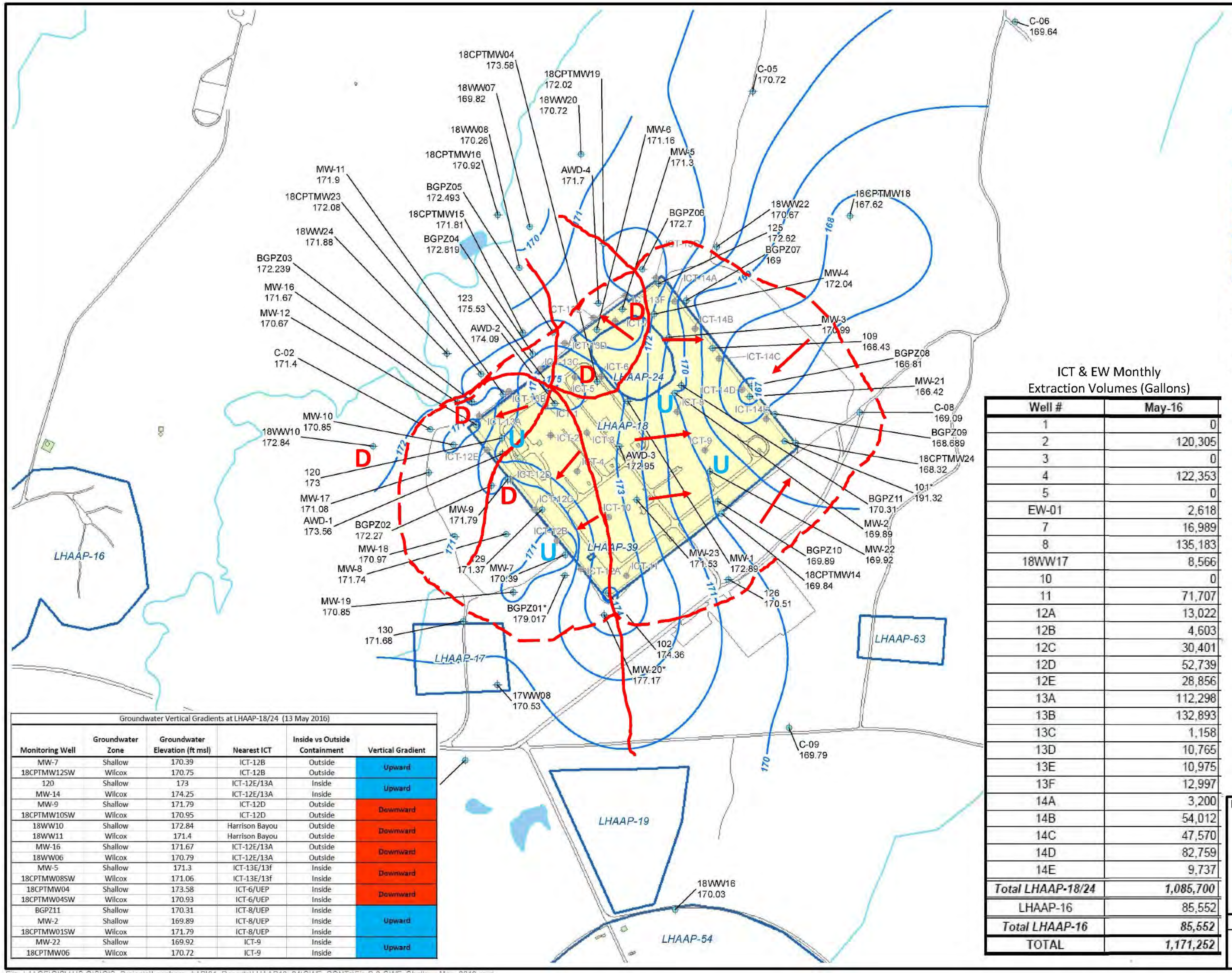
Sump elevation calculated by subtracting total depth from TOC elevation.

ICTs were installed in 1998.

ICT 12A was replaced on December 5, 2012, and extraction has resumed.

TOC Elevations and total depth measured in October 2003, 4th Quarter 2003, Groundwater Treatment Plant Report.

Plot 28. LHAAP-18/24 ICT completion depths and operational status (Bhate, 2018b)



Groundwater Vertical Gradients at LHAAP-18/24 (13 May 2016)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	170.39	ICT-12B	Outside	Upward
18CPTMW12SW	Wilcox	170.75	ICT-12B	Outside	
120	Shallow	173	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	174.25	ICT-12E/13A	Inside	
MW-9	Shallow	171.79	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	170.95	ICT-12D	Outside	
18WW10	Shallow	172.84	Harrison Bayou	Outside	Downward
18WW11	Wilcox	171.4	Harrison Bayou	Outside	
MW-16	Shallow	171.67	ICT-12E/13A	Outside	Downward
18WW06	Wilcox	170.79	ICT-12E/13A	Outside	
MW-5	Shallow	171.3	ICT-13E/13f	Inside	Downward
18CPTMW08SW	Wilcox	171.06	ICT-13E/13f	Inside	
18CPTMW04	Shallow	173.58	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	170.93	ICT-6/UEP	Inside	
BGPZ11	Shallow	170.31	ICT-8/UEP	Inside	Upward
MW-2	Shallow	169.89	ICT-8/UEP	Inside	
18CPTMW01SW	Wilcox	171.79	ICT-8/UEP	Inside	
MW-22	Shallow	169.92	ICT-9	Inside	Upward
18CPTMW06	Wilcox	170.72	ICT-9	Inside	

ICT & EW Monthly Extraction Volumes (Gallons)

Well #	May-16
1	0
2	120,305
3	0
4	122,353
5	0
EW-01	2,618
7	16,989
8	135,183
18WW17	8,566
10	0
11	71,707
12A	13,022
12B	4,603
12C	30,401
12D	52,739
12E	28,856
13A	112,298
13B	132,893
13C	1,158
13D	10,765
13E	10,975
13F	12,997
14A	3,200
14B	54,012
14C	47,570
14D	82,759
14E	9,737
Total LHAAP-18/24	*1,085,700*
LHAAP-16	85,552
Total LHAAP-16	*85,552*
TOTAL	*1,171,252*

Notes
* Data not used to contour. MW-20 and 101 are screened in a perched sand channel. BGPZ01 not included in contour, value considered anomalous.
1) Elevations in Feet Above Mean Sea Level (MSL)
2) Groundwater Extraction System partially in Operation During Gauging Event

During April to June 2016 Quarter all Treated Effluent Returned Via Irrigation to LHAAP-18/24. There was no discharge to Harrison Bayou or the INF Pond.

Longhorn Army Base

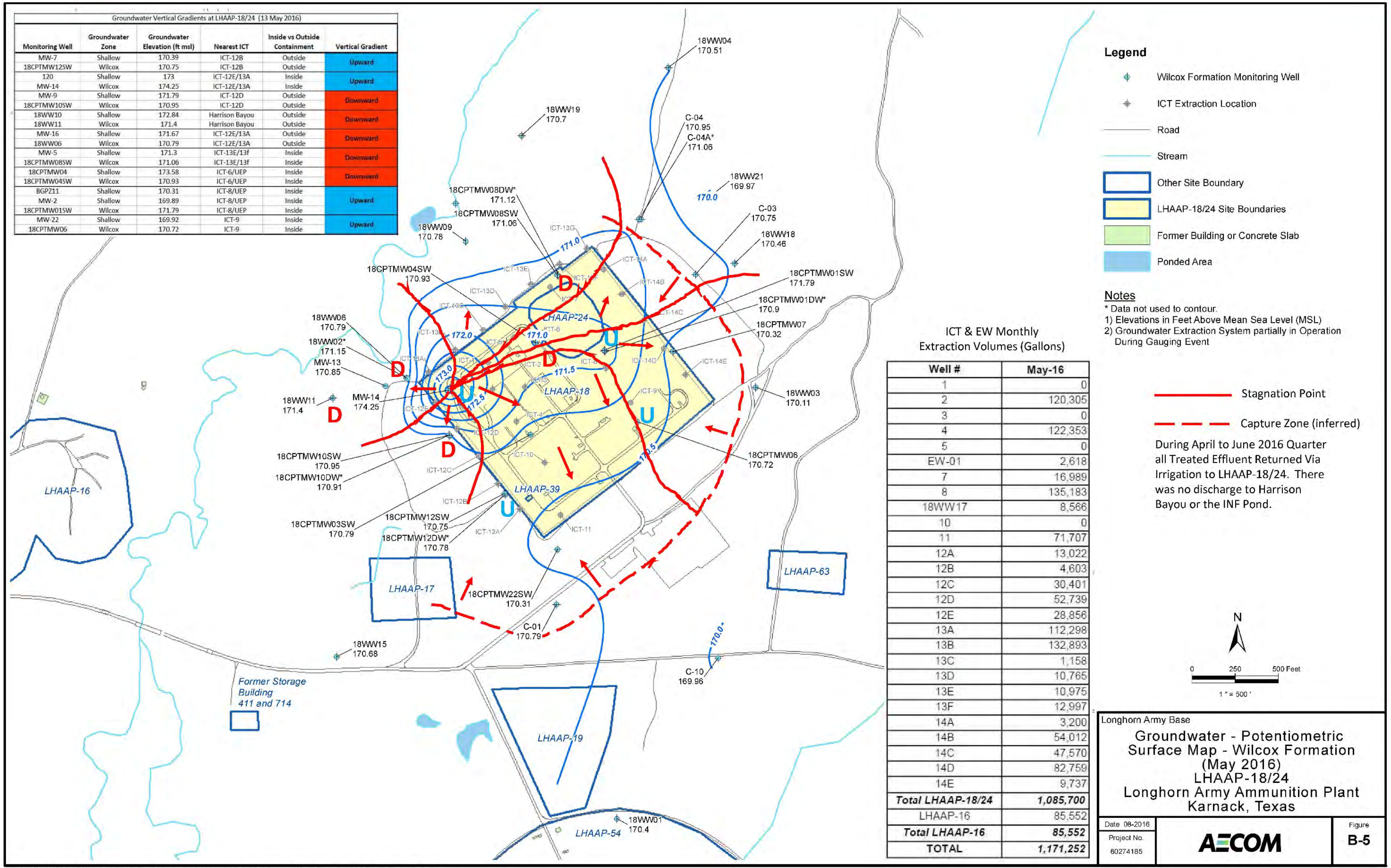
Groundwater Potentiometric
Surface Map - Shallow Zone
(May 2016)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 09-2016
Project No.
60274185

AECOM

Figure
B-2

Plot 29. LHAAP-18/24 May 2016 Shallow Groundwater Zone capture zone by THE Fourth Five-Year Review, and GWTP effluent discharged on-site via irrigation.



Groundwater Vertical Gradients at LHAAP-18/24 (13 May 2016)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	170.39	ICT-12B	Outside	Upward
18CPTMW12SW	Wilcox	170.75	ICT-12B	Outside	
120	Shallow	173	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	174.25	ICT-12E/13A	Inside	
MW-9	Shallow	171.79	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	170.95	ICT-12D	Outside	
18WW10	Shallow	172.84	Harrison Bayou	Outside	Downward
18WW11	Wilcox	171.4	Harrison Bayou	Outside	
MW-16	Shallow	171.67	ICT-12E/13A	Outside	Downward
18WW06	Wilcox	170.79	ICT-12E/13A	Outside	
MW-5	Shallow	171.3	ICT-13E/13f	Inside	Downward
18CPTMW08SW	Wilcox	171.06	ICT-13E/13f	Inside	
18CPTMW04	Shallow	173.58	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	170.93	ICT-6/UEP	Inside	
BGPZ11	Shallow	170.31	ICT-8/UEP	Inside	Upward
MW-2	Shallow	169.89	ICT-8/UEP	Inside	
18CPTMW01SW	Wilcox	171.79	ICT-8/UEP	Inside	
MW-22	Shallow	169.92	ICT-9	Inside	Upward
18CPTMW06	Wilcox	170.72	ICT-9	Inside	

ICT & EW Monthly Extraction Volumes (Gallons)

Well #	May-16
1	0
2	120,305
3	0
4	122,353
5	0
EW-01	2,618
7	16,989
8	135,183
18WW17	8,566
10	0
11	71,707
12A	13,022
12B	4,603
12C	30,401
12D	52,739
12E	28,856
13A	112,298
13B	132,893
13C	1,158
13D	10,765
13E	10,975
13F	12,997
14A	3,200
14B	54,012
14C	47,570
14D	82,759
14E	9,737
Total LHAAP-18/24	***1,085,700***
LHAAP-16	85,552
Total LHAAP-16	***85,552***
TOTAL	***1,171,252***

Legend

⌖	Wilcox Formation Monitoring Well
✛	ICT Extraction Location
—	Road
—	Stream
▭	Other Site Boundary
🟨	LHAAP-18/24 Site Boundaries
🟩	Former Building or Concrete Slab
🟦	Ponded Area

Notes
* Data not used to contour.
1) Elevations in Feet Above Mean Sea Level (MSL)
2) Groundwater Extraction System partially in Operation During Gauging Event

—	Stagnation Point
– – –	Capture Zone (inferred)

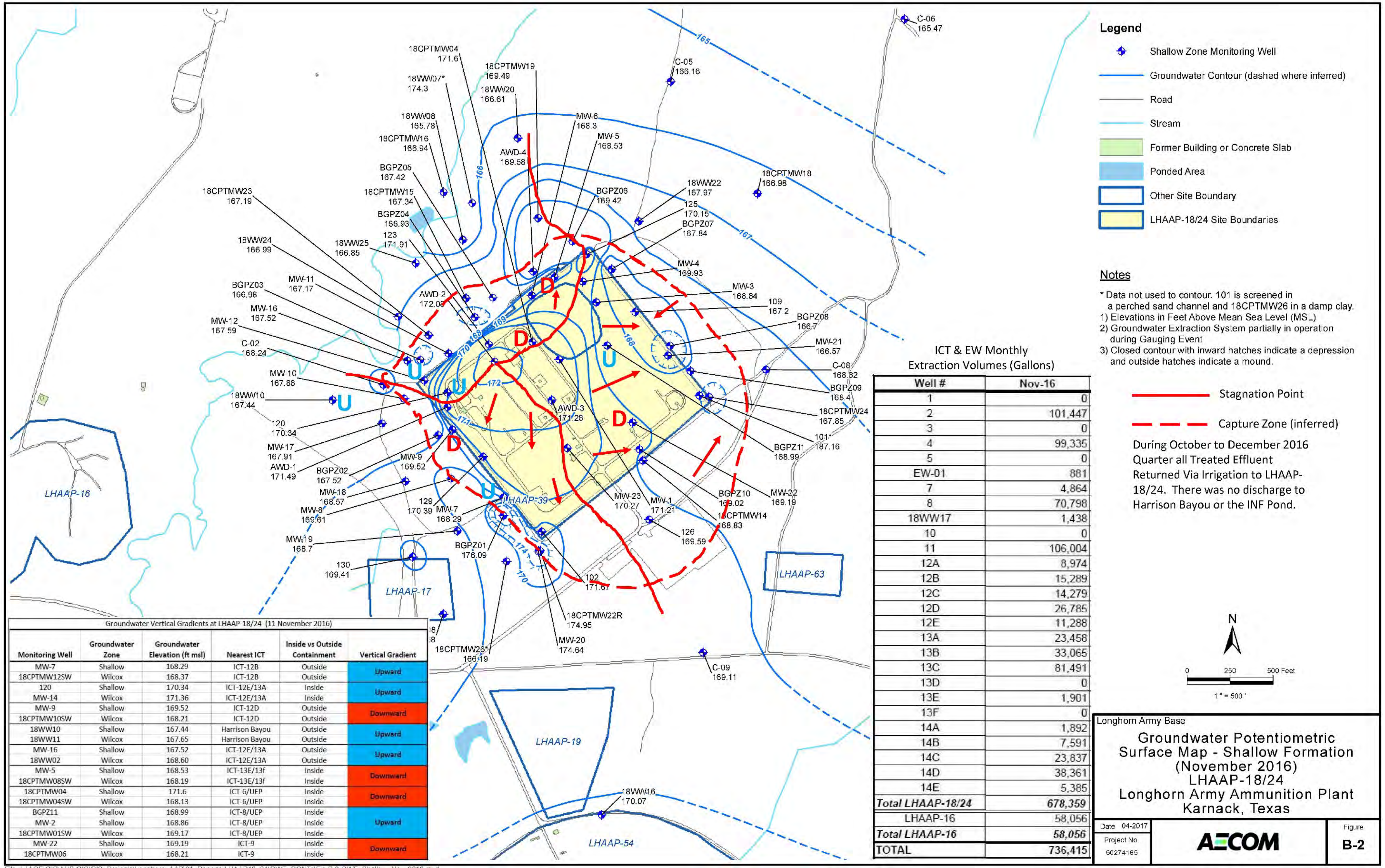
During April to June 2016 Quarter all Treated Effluent Returned Via Irrigation to LHAAP-18/24. There was no discharge to Harrison Bayou or the INF Pond.

Longhorn Army Base

Groundwater - Potentiometric
Surface Map - Wilcox Formation
(May 2016)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 08-2016
Project No. 60274185
AECOM
Figure
B-5

Plot 30. LHAAP-18/24 May 2016 middle Wilcox Formation, THE Fourth Five-Year Review-derived capture zone, and GWTP effluent discharged on-site via irrigation.



Legend

- Shallow Zone Monitoring Well
- Groundwater Contour (dashed where inferred)
- Road
- Stream
- 🟩 Former Building or Concrete Slab
- 🟦 Ponded Area
- Other Site Boundary
- 🟨 LHAAP-18/24 Site Boundaries

Notes

* Data not used to contour. 101 is screened in a perched sand channel and 18CPTMW26 in a damp clay.
1) Elevations in Feet Above Mean Sea Level (MSL)
2) Groundwater Extraction System partially in operation during Gauging Event
3) Closed contour with inward hatches indicate a depression and outside hatches indicate a mound.

- Stagnation Point
- Capture Zone (inferred)

During October to December 2016 Quarter all Treated Effluent Returned Via Irrigation to LHAAP-18/24. There was no discharge to Harrison Bayou or the INF Pond.

Groundwater Vertical Gradients at LHAAP-18/24 (11 November 2016)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	168.29	ICT-12B	Outside	Upward
18CPTMW12SW	Wilcox	168.37	ICT-12B	Outside	
120	Shallow	170.34	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	171.36	ICT-12E/13A	Inside	
MW-9	Shallow	169.52	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	168.21	ICT-12D	Outside	
18WW10	Shallow	167.44	Harrison Bayou	Outside	Upward
18WW11	Wilcox	167.65	Harrison Bayou	Outside	
MW-16	Shallow	167.52	ICT-12E/13A	Outside	Upward
18WW02	Wilcox	168.60	ICT-12E/13A	Outside	
MW-5	Shallow	168.53	ICT-13E/13f	Inside	Downward
18CPTMW08SW	Wilcox	168.19	ICT-13E/13f	Inside	
18CPTMW04	Shallow	171.6	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	168.13	ICT-6/UEP	Inside	
BGPZ11	Shallow	168.99	ICT-8/UEP	Inside	Upward
MW-2	Shallow	168.86	ICT-8/UEP	Inside	
18CPTMW01SW	Wilcox	169.17	ICT-8/UEP	Inside	
MW-22	Shallow	169.19	ICT-9	Inside	Downward
18CPTMW06	Wilcox	168.21	ICT-9	Inside	

ICT & EW Monthly Extraction Volumes (Gallons)

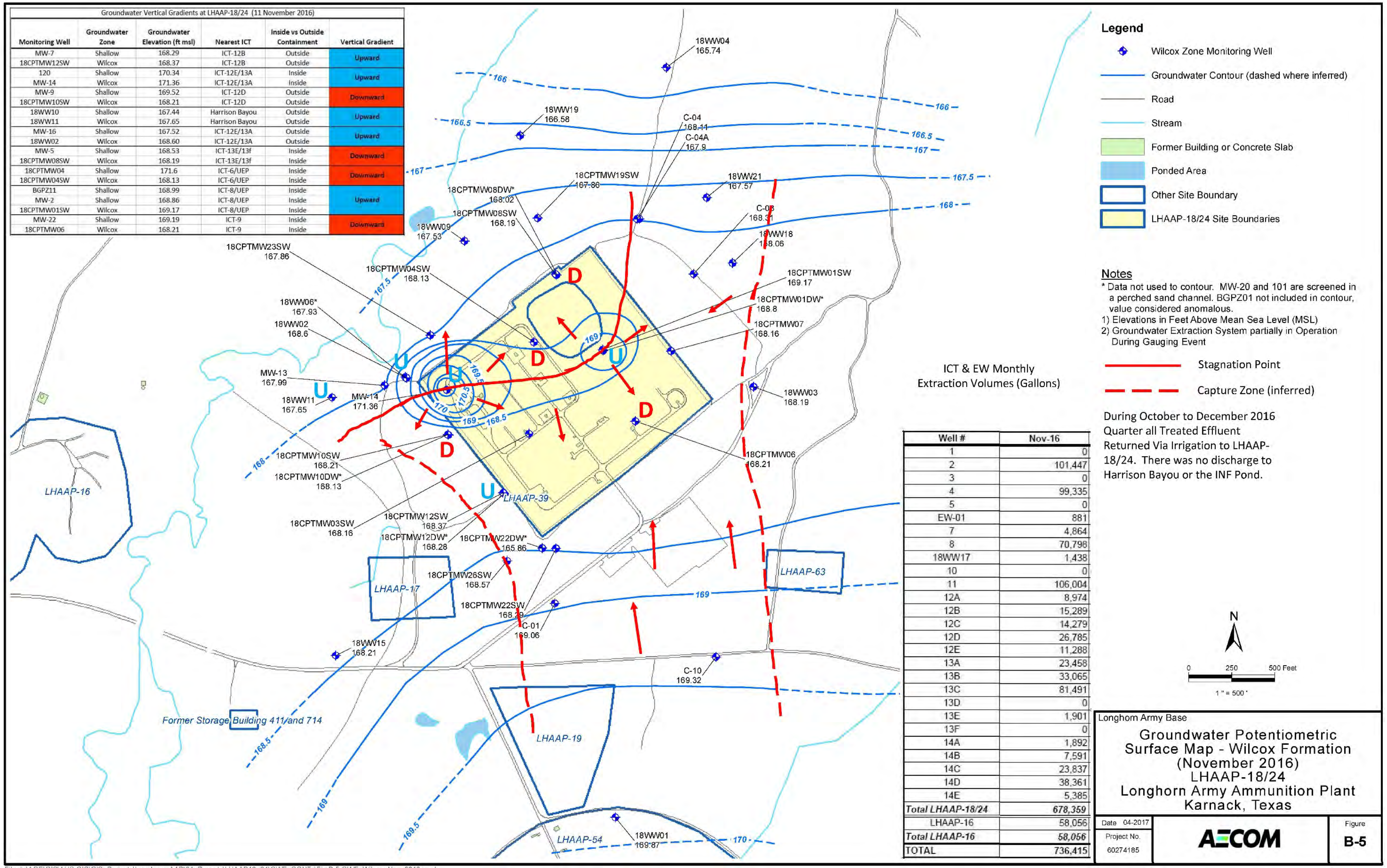
Well #	Nov-16
1	0
2	101,447
3	0
4	99,335
5	0
EW-01	881
7	4,864
8	70,798
18WW17	1,438
10	0
11	106,004
12A	8,974
12B	15,289
12C	14,279
12D	26,785
12E	11,288
13A	23,458
13B	33,065
13C	81,491
13D	0
13E	1,901
13F	0
14A	1,892
14B	7,591
14C	23,837
14D	38,361
14E	5,385
Total LHAAP-18/24	***678,359***
LHAAP-16	58,056
Total LHAAP-16	***58,056***
TOTAL	736,415

Longhorn Army Base

Groundwater Potentiometric
Surface Map - Shallow Formation
(November 2016)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 04-2017
Project No. 60274185
AECOM
Figure B-2

Plot 31. LHAAP-18/24 November 2016 Shallow Groundwater Zone, THE Fourth Five-Year Review-derived capture zone, and GWTP effluent discharged on-site via irrigation.



Groundwater Vertical Gradients at LHAAP-18/24 (11 November 2016)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	168.29	ICT-12B	Outside	Upward
18CPTMW12SW	Wilcox	168.37	ICT-12B	Outside	
120	Shallow	170.34	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	171.36	ICT-12E/13A	Inside	
MW-9	Shallow	169.52	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	168.21	ICT-12D	Outside	
18WW10	Shallow	167.44	Harrison Bayou	Outside	Upward
18WW11	Wilcox	167.65	Harrison Bayou	Outside	
MW-16	Shallow	167.52	ICT-12E/13A	Outside	Upward
18WW02	Wilcox	168.60	ICT-12E/13A	Outside	
MW-5	Shallow	168.53	ICT-13E/13f	Inside	Downward
18CPTMW08SW	Wilcox	168.19	ICT-13E/13f	Inside	
18CPTMW04	Shallow	171.6	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	168.13	ICT-6/UEP	Inside	
BGPZ11	Shallow	168.99	ICT-8/UEP	Inside	Upward
MW-2	Shallow	168.86	ICT-8/UEP	Inside	
18CPTMW01SW	Wilcox	169.17	ICT-8/UEP	Inside	
MW-22	Shallow	169.19	ICT-9	Inside	Downward
18CPTMW06	Wilcox	168.21	ICT-9	Inside	

ICT & EW Monthly
Extraction Volumes (Gallons)

Well #	Nov-16
1	0
2	101,447
3	0
4	99,335
5	0
EW-01	881
7	4,864
8	70,798
18WW17	1,438
10	0
11	106,004
12A	8,974
12B	15,289
12C	14,279
12D	26,785
12E	11,288
13A	23,458
13B	33,065
13C	81,491
13D	0
13E	1,901
13F	0
14A	1,892
14B	7,591
14C	23,837
14D	38,361
14E	5,385
Total LHAAP-18/24	*678,359*
LHAAP-16	58,056
Total LHAAP-16	*58,056*
TOTAL	736,415

Legend

⯐	Wilcox Zone Monitoring Well
—	Groundwater Contour (dashed where inferred)
—	Road
—	Stream
🟩	Former Building or Concrete Slab
🟦	Ponded Area
☐	Other Site Boundary
🟨	LHAAP-18/24 Site Boundaries
—	Stagnation Point
– –	Capture Zone (inferred)

Notes
* Data not used to contour. MW-20 and 101 are screened in a perched sand channel. BGPZ01 not included in contour, value considered anomalous.
1) Elevations in Feet Above Mean Sea Level (MSL)
2) Groundwater Extraction System partially in Operation During Gauging Event

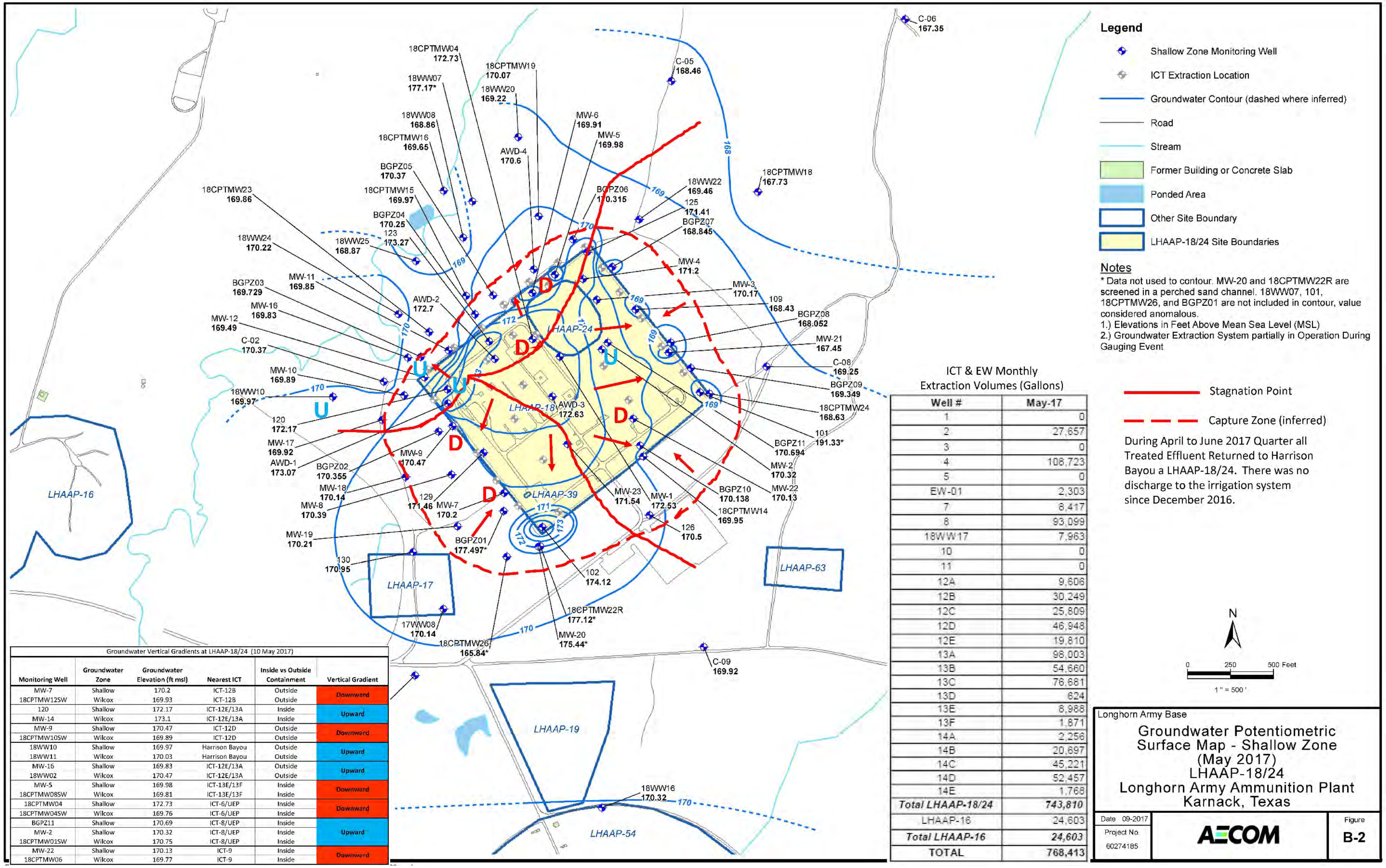
During October to December 2016 Quarter all Treated Effluent Returned Via Irrigation to LHAAP-18/24. There was no discharge to Harrison Bayou or the INF Pond.

Longhorn Army Base

Groundwater Potentiometric
Surface Map - Wilcox Formation
(November 2016)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 04-2017
Project No.
60274185
AECOM
Figure
B-5

Plot 32. LHAAP-18/24 November 2016 middle Wilcox Formation, THE Fourth Five-Year Review-derived capture zone, and GWTP effluent discharged on-site via irrigation.



Legend
- Shallow Zone Monitoring Well
- ICT Extraction Location
- Groundwater Contour (dashed where inferred)
- Road
- Stream
- Former Building or Concrete Slab
- Ponded Area
- Other Site Boundary
- LHAAP-18/24 Site Boundaries
- Stagnation Point
- Capture Zone (inferred)

Notes
* Data not used to contour. MW-20 and 18CPTMW22R are screened in a perched sand channel. 18WW07, 101, 18CPTMW26, and BGPZ01 are not included in contour, value considered anomalous.
1.) Elevations in Feet Above Mean Sea Level (MSL)
2.) Groundwater Extraction System partially in Operation During Gauging Event

During April to June 2017 Quarter all Treated Effluent Returned to Harrison Bayou a LHAAP-18/24. There was no discharge to the irrigation system since December 2016.

Groundwater Vertical Gradients at LHAAP-18/24 (10 May 2017)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	170.2	ICT-12B	Outside	Downward
18CPTMW12SW	Wilcox	169.93	ICT-12B	Outside	
120	Shallow	172.17	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	173.1	ICT-12E/13A	Inside	
MW-9	Shallow	170.47	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	169.89	ICT-12D	Outside	
18WW10	Shallow	169.97	Harrison Bayou	Outside	Upward
18WW11	Wilcox	170.03	Harrison Bayou	Outside	
MW-16	Shallow	169.83	ICT-12E/13A	Outside	Upward
18WW02	Wilcox	170.47	ICT-12E/13A	Outside	
MW-5	Shallow	169.98	ICT-13E/13F	Inside	Downward
18CPTMW08SW	Wilcox	169.81	ICT-13E/13F	Inside	
18CPTMW04	Shallow	172.73	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	169.76	ICT-6/UEP	Inside	
BGPZ11	Shallow	170.69	ICT-8/UEP	Inside	Upward
MW-2	Shallow	170.32	ICT-8/UEP	Inside	
18CPTMW01SW	Wilcox	170.75	ICT-8/UEP	Inside	
MW-22	Shallow	170.13	ICT-9	Inside	Downward
18CPTMW06	Wilcox	169.77	ICT-9	Inside	

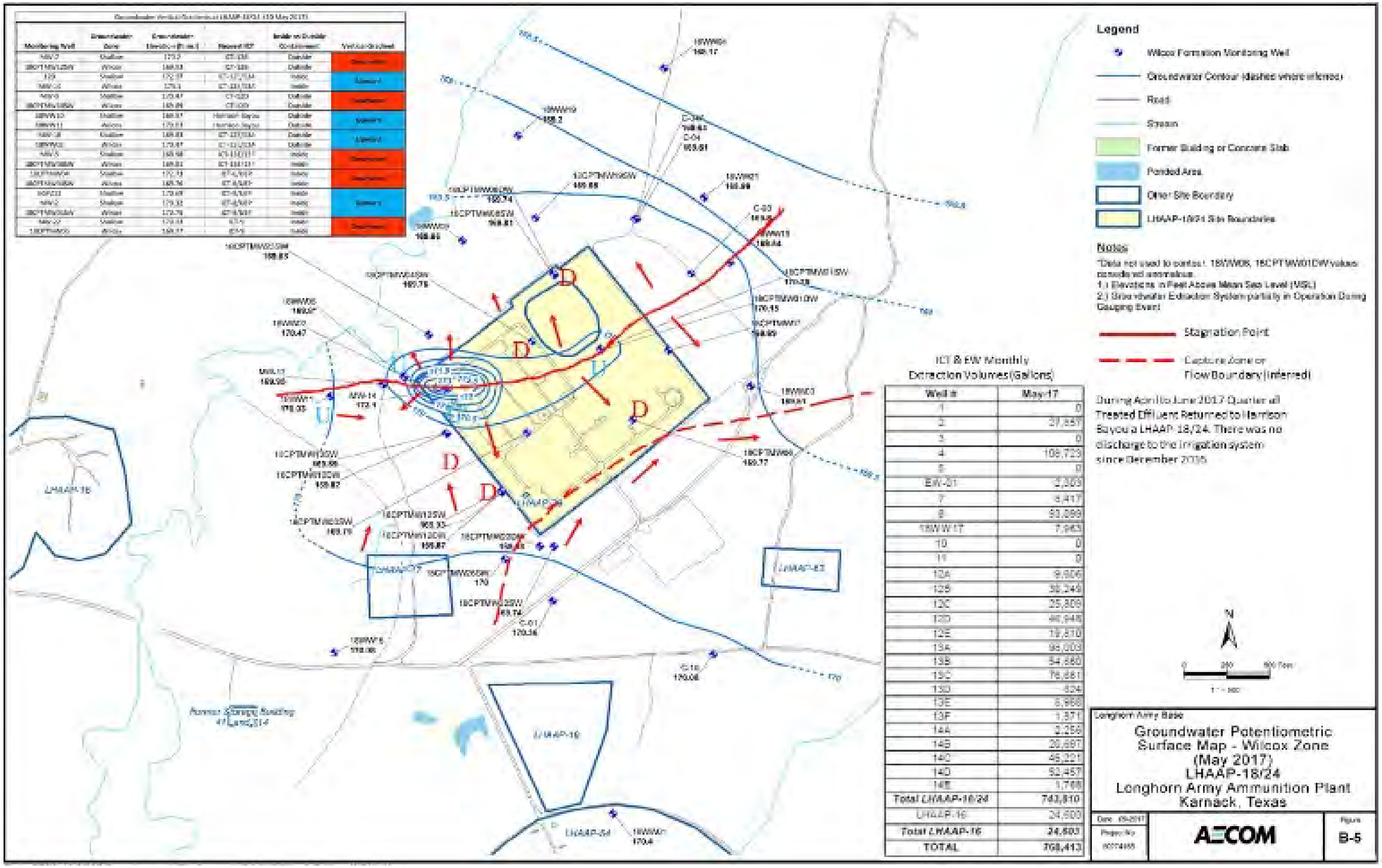
ICT & EW Monthly Extraction Volumes (Gallons)

Well #	May-17
1	0
2	27,657
3	0
4	108,723
5	0
EW-01	2,303
7	8,417
8	93,099
18WW17	7,963
10	0
11	0
12A	9,606
12B	30,249
12C	25,809
12D	46,948
12E	19,810
13A	98,003
13B	54,660
13C	76,681
13D	624
13E	6,988
13F	1,871
14A	2,256
14B	20,697
14C	45,221
14D	52,457
14E	1,768
Total LHAAP-18/24	*743,810*
LHAAP-16	24,603
Total LHAAP-16	*24,603*
TOTAL	768,413

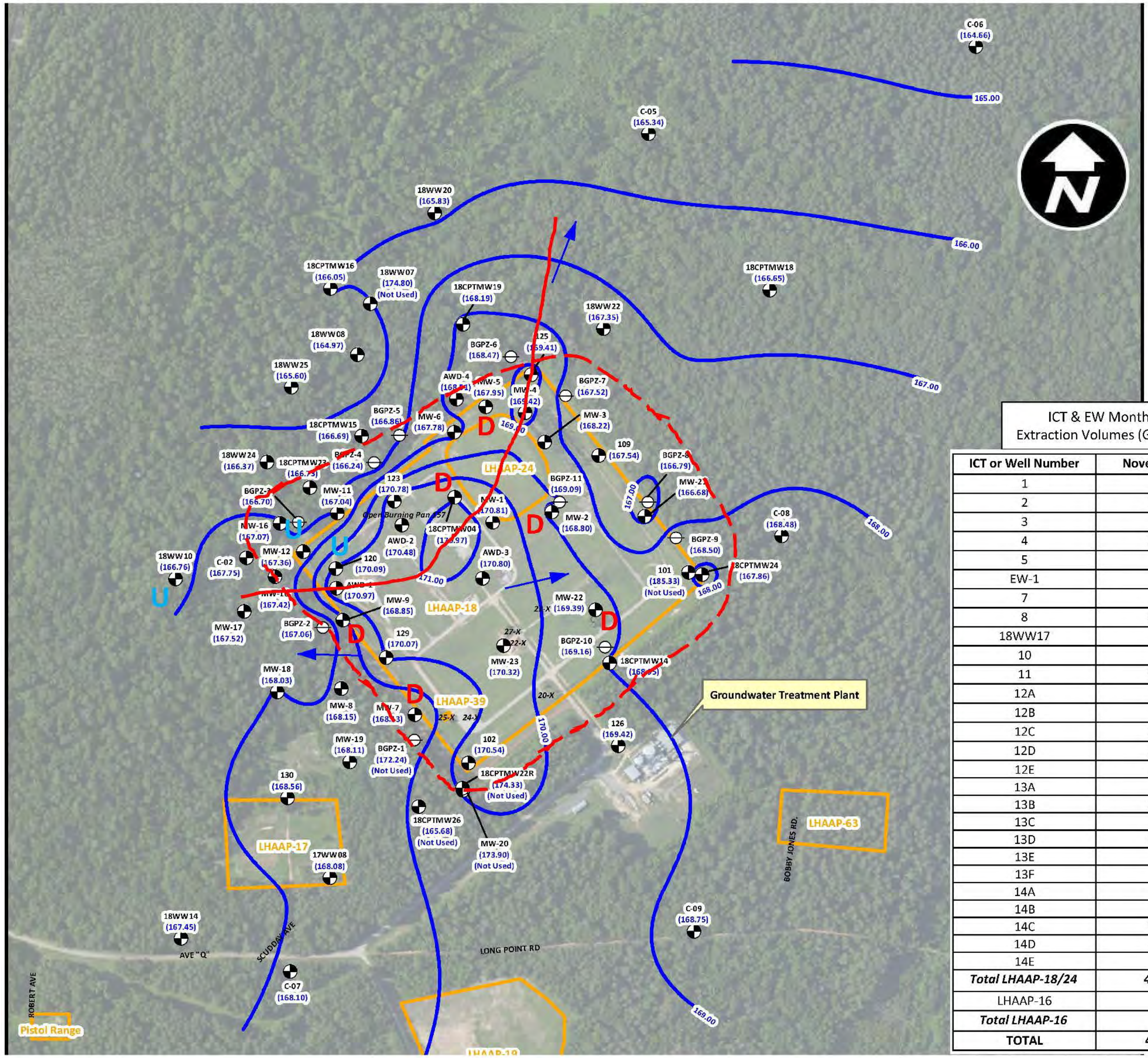
Longhorn Army Base
Groundwater Potentiometric
Surface Map - Shallow Zone
(May 2017)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 09-2017
Project No.
60274185
AECOM
Figure
B-2

Plot 33. LHAAP-18/24 May 2017 Shallow Groundwater Zone, THE Fourth Five-Year Review-derived capture zone, and GWTP effluent discharge to Harrison Bayou, no on-site via irrigation.



Plot 34. LHAAP-18/24 May 2017 middle Wilcox Formation, THE Fourth Five-Year Review-derived capture zone, and GWTP effluent discharge to Harrison Bayou, no on-site via irrigation.



Legend:

●	Shallow Monitoring Well Location
⊖	Shallow Piezometer Location
(168.75)	Potentiometric Surface Elevation in Feet Above Mean Sea Level
▬	Potentiometric Surface Contour
→	Direction of Groundwater Flow
▬	Installation Restoration Program (IRP) Area
401	Building Number
717	Former Building Location and Number
▬	Stagnation Point
– – –	Capture Zone or Flow Boundary (inferred)

During October to December 2017 Quarter all Treated Effluent Returned to Harrison Bayou at LHAAP-18/24. There was no discharge to the irrigation system since December 2016.

ICT & EW Monthly Extraction Volumes (Gallons)

ICT or Well Number	November 2017
1	0
2	72,989
3	0
4	51,244
5	0
EW-1	51
7	2,549
8	85,862
18WW17	1,962
10	0
11	98,022
12A	7,287
12B	23
12C	11,037
12D	23,806
12E	9,959
13A	89
13B	27,484
13C	133
13D	10,013
13E	503
13F	0
14A	1,998
14B	7,139
14C	28,484
14D	44,366
14E	0
Total LHAAP-18/24	***485,000***
LHAAP-16	0
Total LHAAP-16	***0***
TOTAL	**485,000**

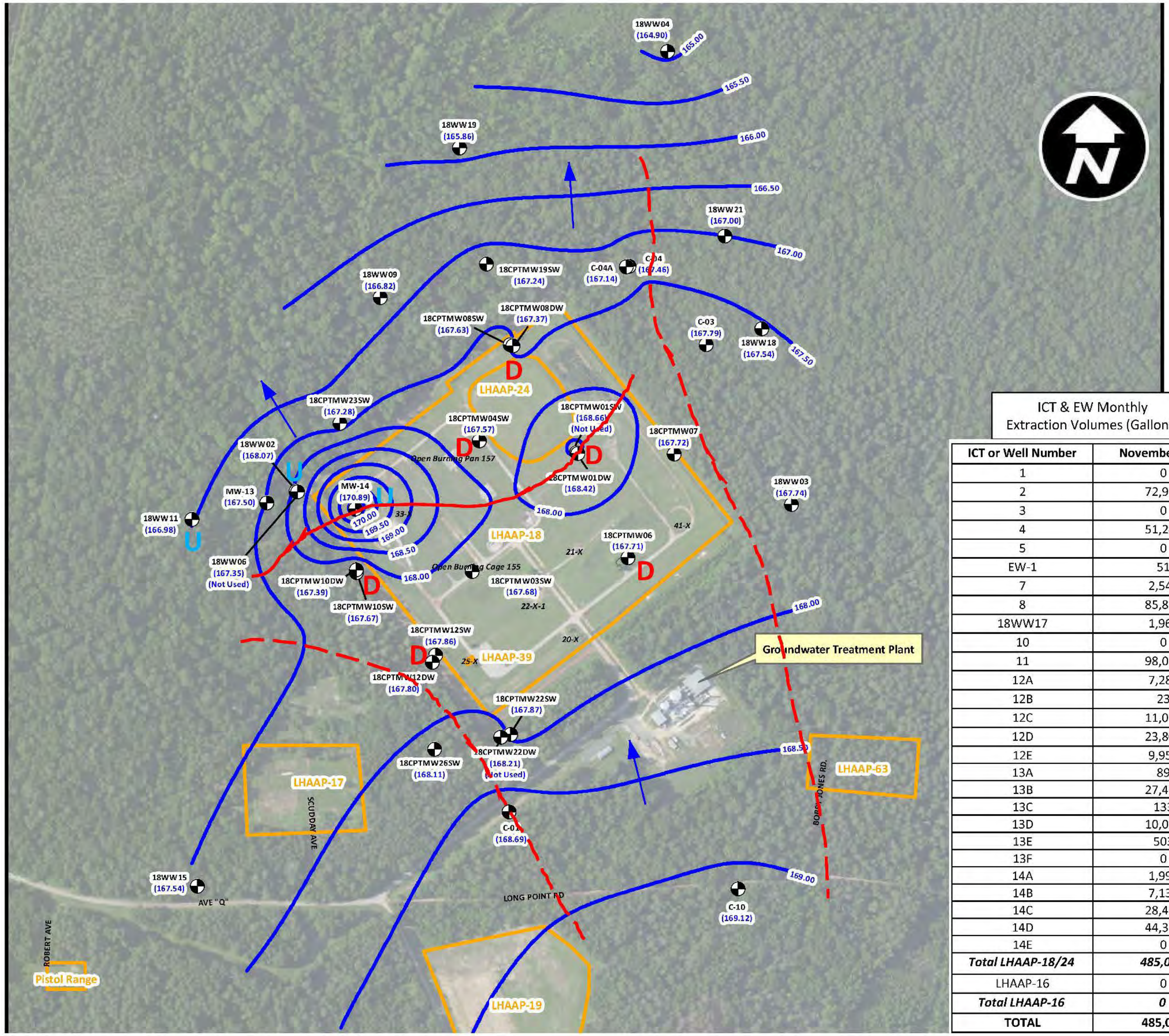
Groundwater Vertical Gradients at LHAAP-18/24 (30 Nov 2017)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	168.13	ICT-12B	Outside	Downward
18CPTMW12SW	Wilcox	167.86	ICT-12B	Outside	
120	Shallow	170.09	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	170.89	ICT-12E/13A	Inside	
MW-9	Shallow	168.85	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	167.67	ICT-12D	Outside	
18WW10	Shallow	166.76	Harrison Bayou	Outside	Upward
18WW11	Wilcox	166.98	Harrison Bayou	Outside	
MW-16	Shallow	167.07	ICT-12E/13A	Outside	Upward
18WW02	Wilcox	168.07	ICT-12E/13A	Outside	
MW-5	Shallow	167.95	ICT-13E/13F	Inside	Downward
18CPTMW08SW	Wilcox	167.63	ICT-13E/13F	Inside	
18CPTMW04	Shallow	170.97	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	167.57	ICT-6/UEP	Inside	
BGPZ11	Shallow	169.09	ICT-8/UEP	Inside	Downward
MW-2	Shallow	168.8	ICT-8/UEP	Inside	
18CPTMW01DW	Wilcox	168.42	ICT-8/UEP	Inside	
MW-22	Shallow	169.39	ICT-9	Inside	Downward
18CPTMW06	Wilcox	167.71	ICT-9	Inside	

Groundwater Potentiometric Surface Map
Shallow Zone (November 2017) LHAAP-18/24

Figure B-2

Plot 35. LHAAP-18/24 November 2017 Shallow Groundwater Zone, THE Fourth Five-Year Review-derived capture zone, GWTP effluent discharge to Harrison Bayou via INF Pond, no on-site irrigation.



Legend:

⊕	Wilcox Zone Monitoring Well Location
(169.12)	Potentiometric Surface Elevation in Feet Above Mean Sea Level
▬	Potentiometric Surface Contour
→	Direction of Groundwater Flow
▬	Installation Restoration Program (IRP) Area
401	Building Number
717	Former Building Location and Number
▬	Stagnation Point
– – –	Capture Zone or Flow Boundary (inferred)

During October to December 2017 Quarter all Treated Effluent Returned to Harrison Bayou at LHAAP-18/24. There was no discharge to the irrigation system since December 2016.

ICT & EW Monthly Extraction Volumes (Gallons)

ICT or Well Number	November 2017
1	0
2	72,989
3	0
4	51,244
5	0
EW-1	51
7	2,549
8	85,862
18WW17	1,962
10	0
11	98,022
12A	7,287
12B	23
12C	11,037
12D	23,806
12E	9,959
13A	89
13B	27,484
13C	133
13D	10,013
13E	503
13F	0
14A	1,998
14B	7,139
14C	28,484
14D	44,366
14E	0
Total LHAAP-18/24	***485,000***
LHAAP-16	0
Total LHAAP-16	***0***
TOTAL	**485,000**

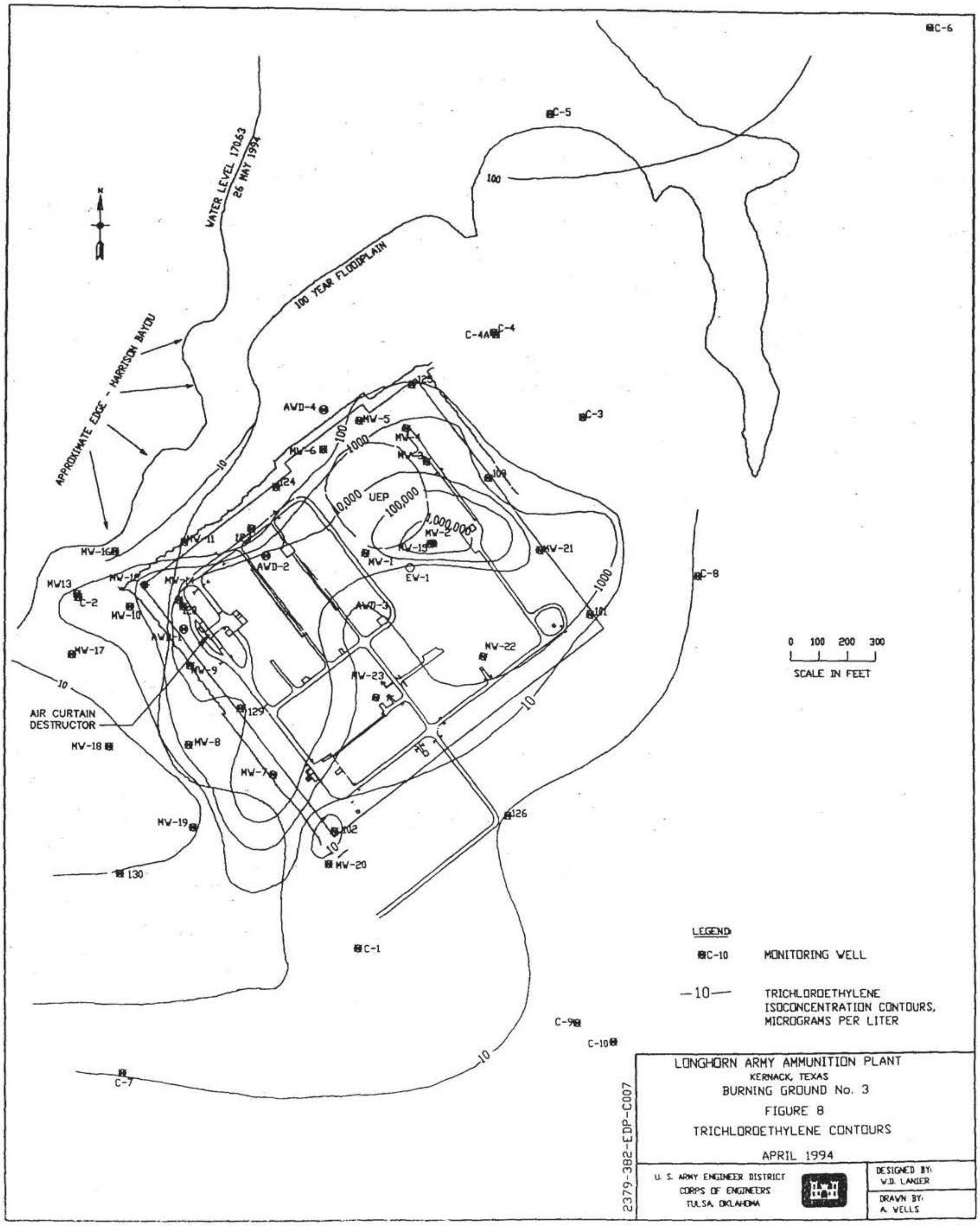
Groundwater Vertical Gradients at LHAAP-18/24 (30 Nov 2017)

Monitoring Well	Groundwater Zone	Groundwater Elevation (ft msl)	Nearest ICT	Inside vs Outside Containment	Vertical Gradient
MW-7	Shallow	168.13	ICT-12B	Outside	Downward
18CPTMW12SW	Wilcox	167.86	ICT-12B	Outside	
120	Shallow	170.09	ICT-12E/13A	Inside	Upward
MW-14	Wilcox	170.89	ICT-12E/13A	Inside	
MW-9	Shallow	168.85	ICT-12D	Outside	Downward
18CPTMW10SW	Wilcox	167.67	ICT-12D	Outside	
18WW10	Shallow	166.76	Harrison Bayou	Outside	Upward
18WW11	Wilcox	166.98	Harrison Bayou	Outside	
MW-16	Shallow	167.07	ICT-12E/13A	Outside	Upward
18WW02	Wilcox	168.07	ICT-12E/13A	Outside	
MW-5	Shallow	167.95	ICT-13E/13F	Inside	Downward
18CPTMW08SW	Wilcox	167.63	ICT-13E/13F	Inside	
18CPTMW04	Shallow	170.97	ICT-6/UEP	Inside	Downward
18CPTMW04SW	Wilcox	167.57	ICT-6/UEP	Inside	
BGPZ11	Shallow	169.09	ICT-8/UEP	Inside	Downward
MW-2	Shallow	168.8	ICT-8/UEP	Inside	
18CPTMW01DW	Wilcox	168.42	ICT-8/UEP	Inside	
MW-22	Shallow	169.39	ICT-9	Inside	Downward
18CPTMW06	Wilcox	167.71	ICT-9	Inside	

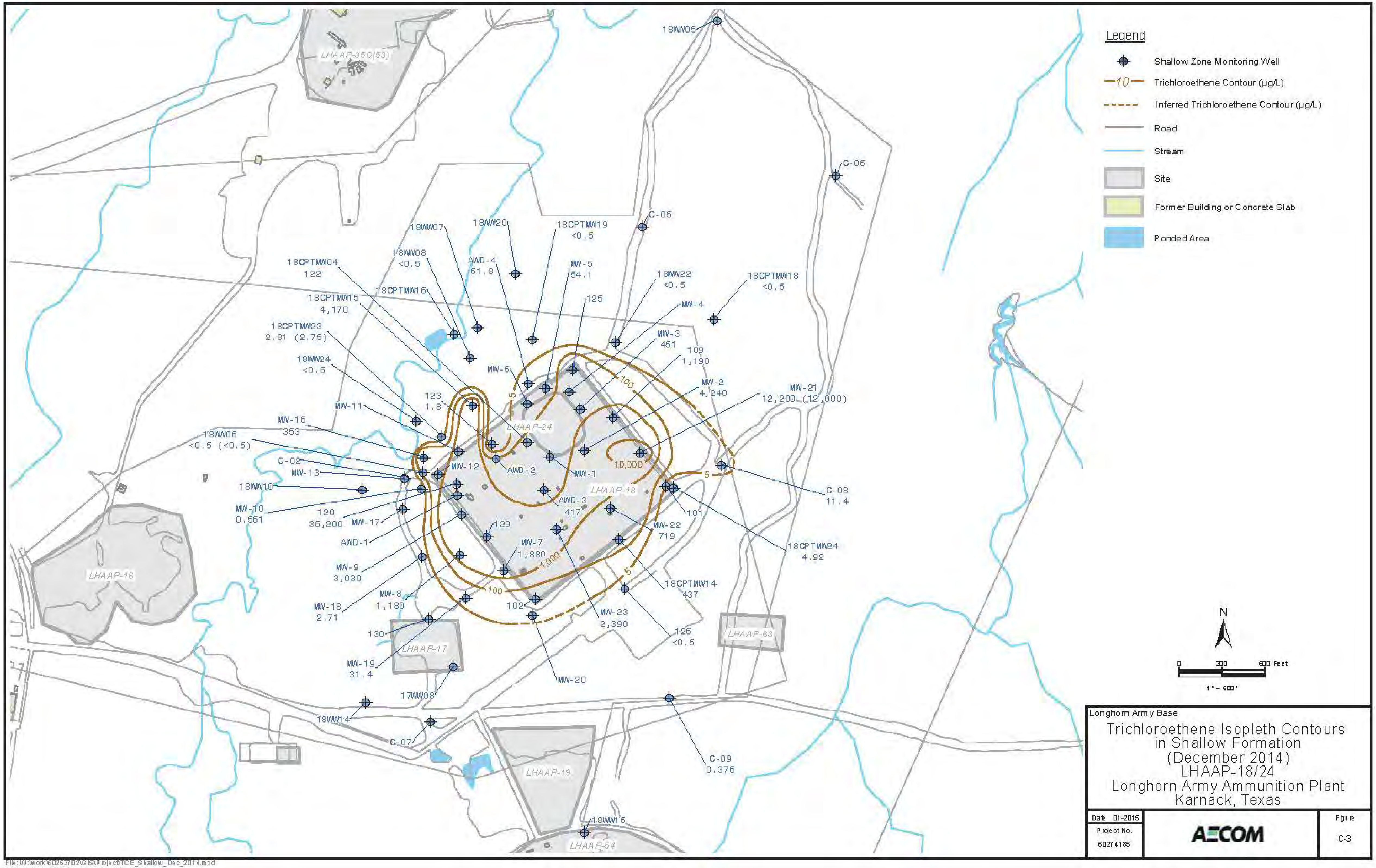
Groundwater Potentiometric Surface Map
Wilcox Zone (November 2017) LHAAP-18/24

Figure B-5

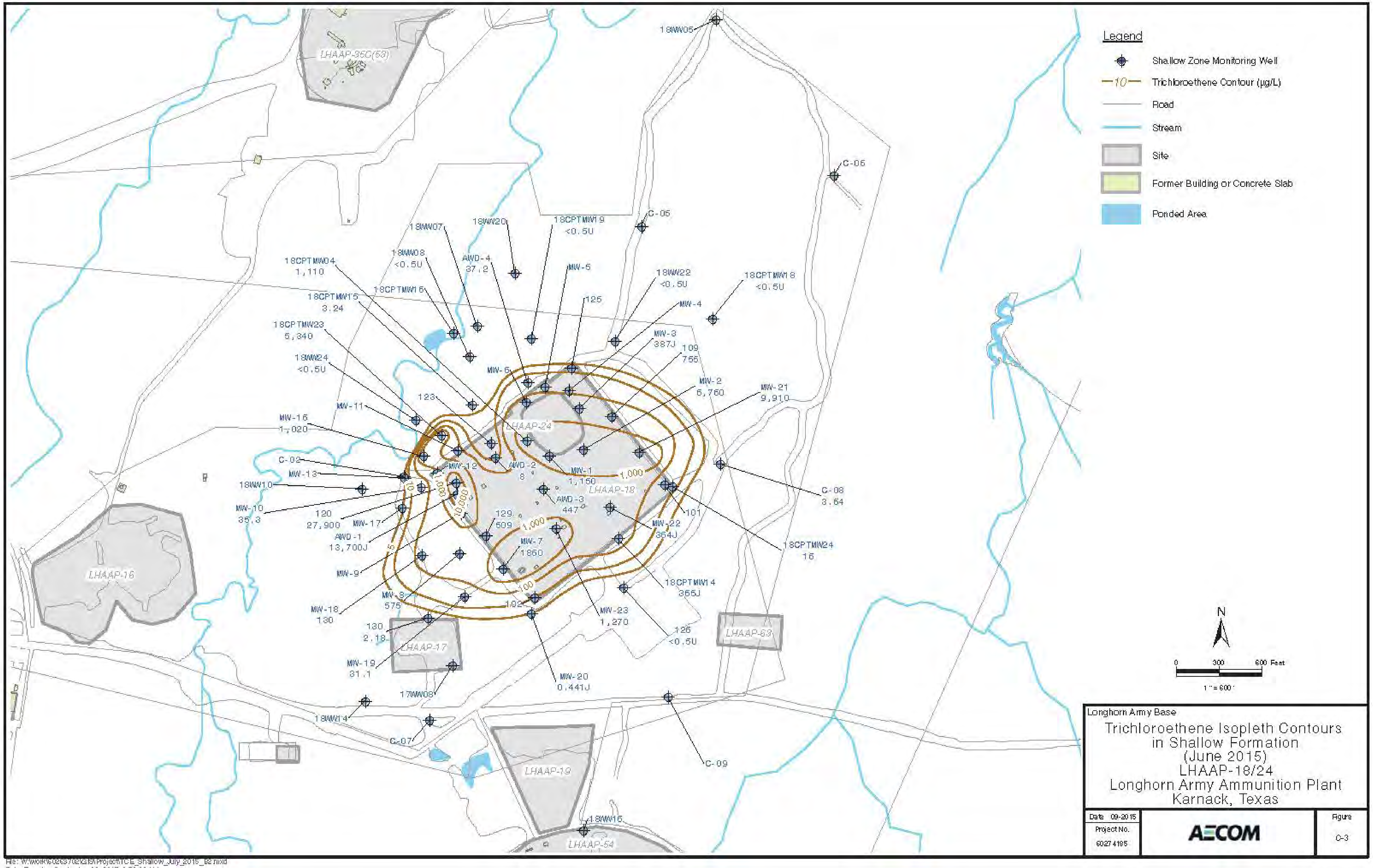
Plot 36. LHAAP-18/24 November 2017 middle Wilcox Formation, THE Fourth Five-Year Review-derived capture zone, GWTP effluent discharge to Harrison Bayou via INF Pond, no on-site irrigation.



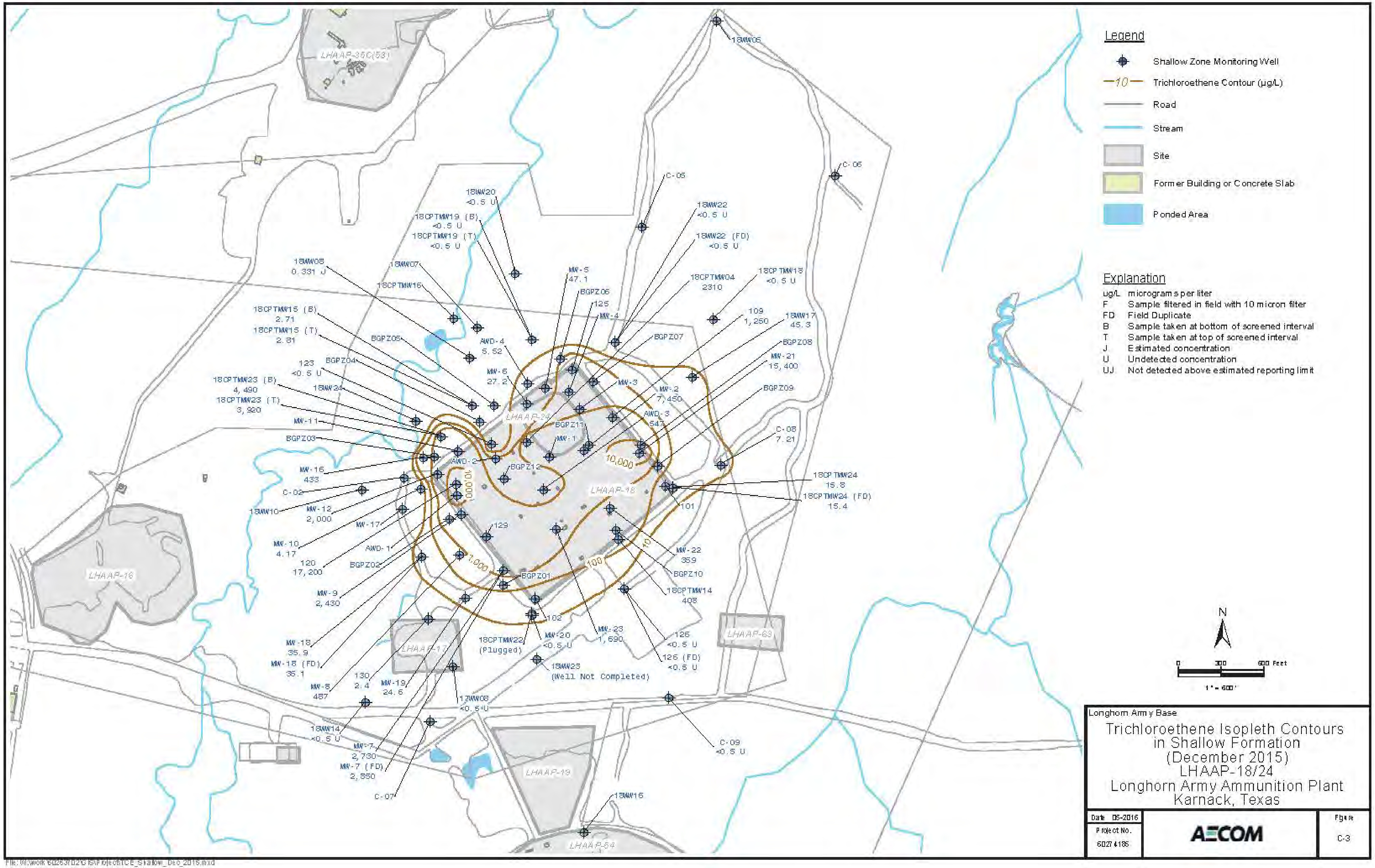
Plot 37. LHAAP-18/24 TCE Contours – April 1994 (EPA, May 1995).



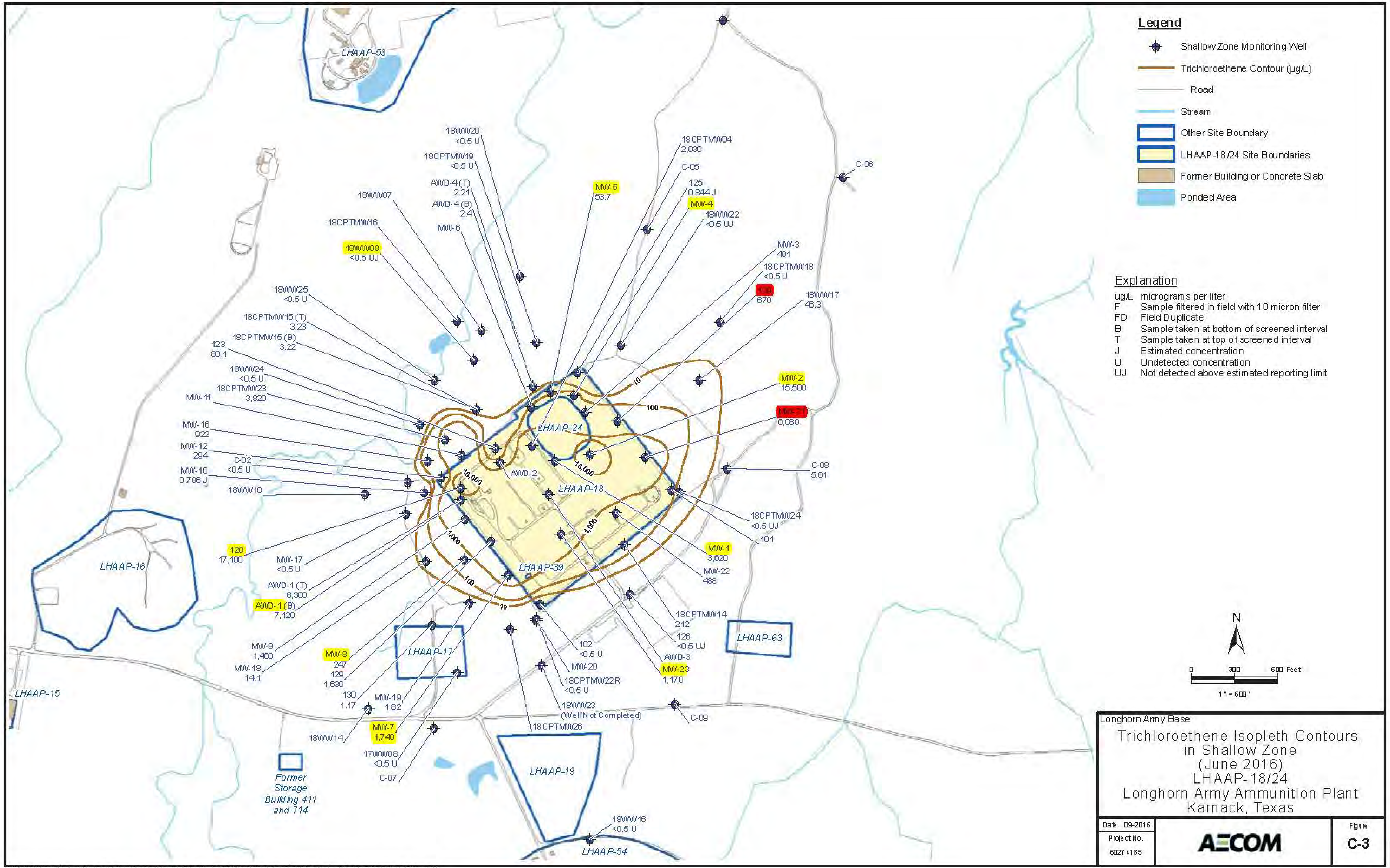
Plot 38. LHAAP-18/24 TCE Shallow Groundwater Zone – December 2014 (AECOM, 2015c).



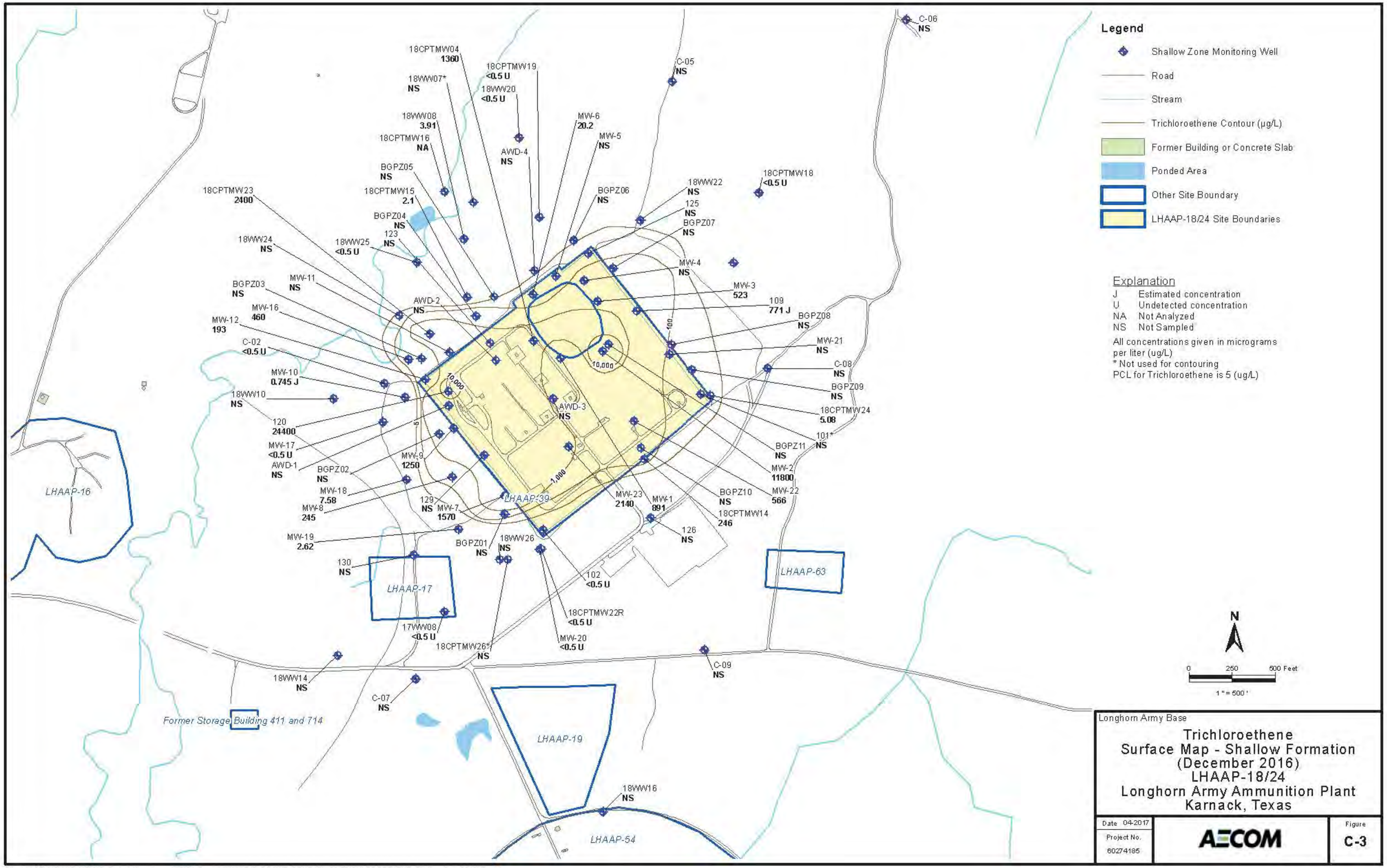
Plot 39. LHAAP-18/24 TCE Shallow Groundwater Zone – June 2015 (AECOM, 2015b).



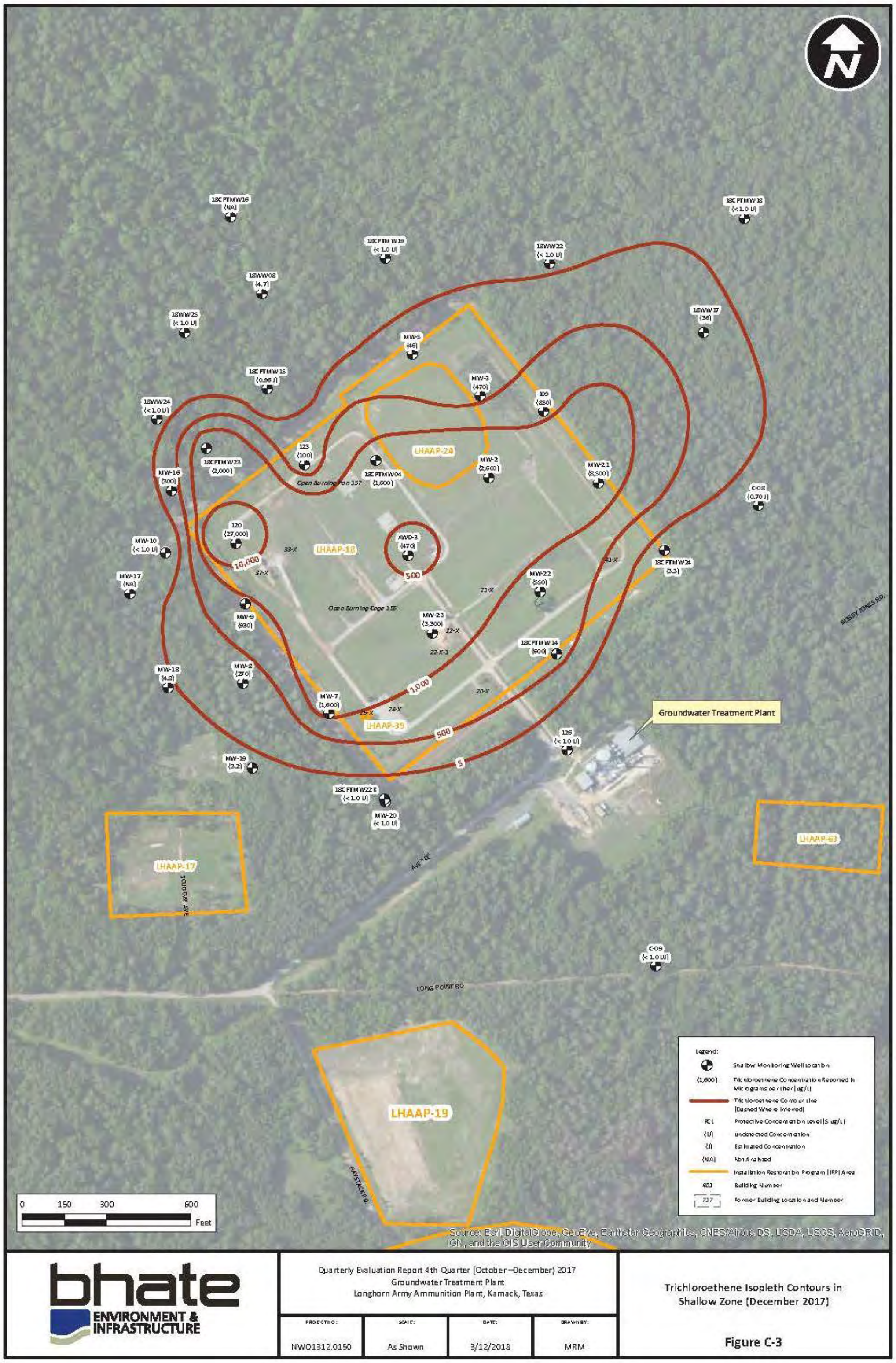
Plot 40. LHAAP-18/24 TCE Shallow Groundwater Zone – December 2015 (AECOM, 2016d).



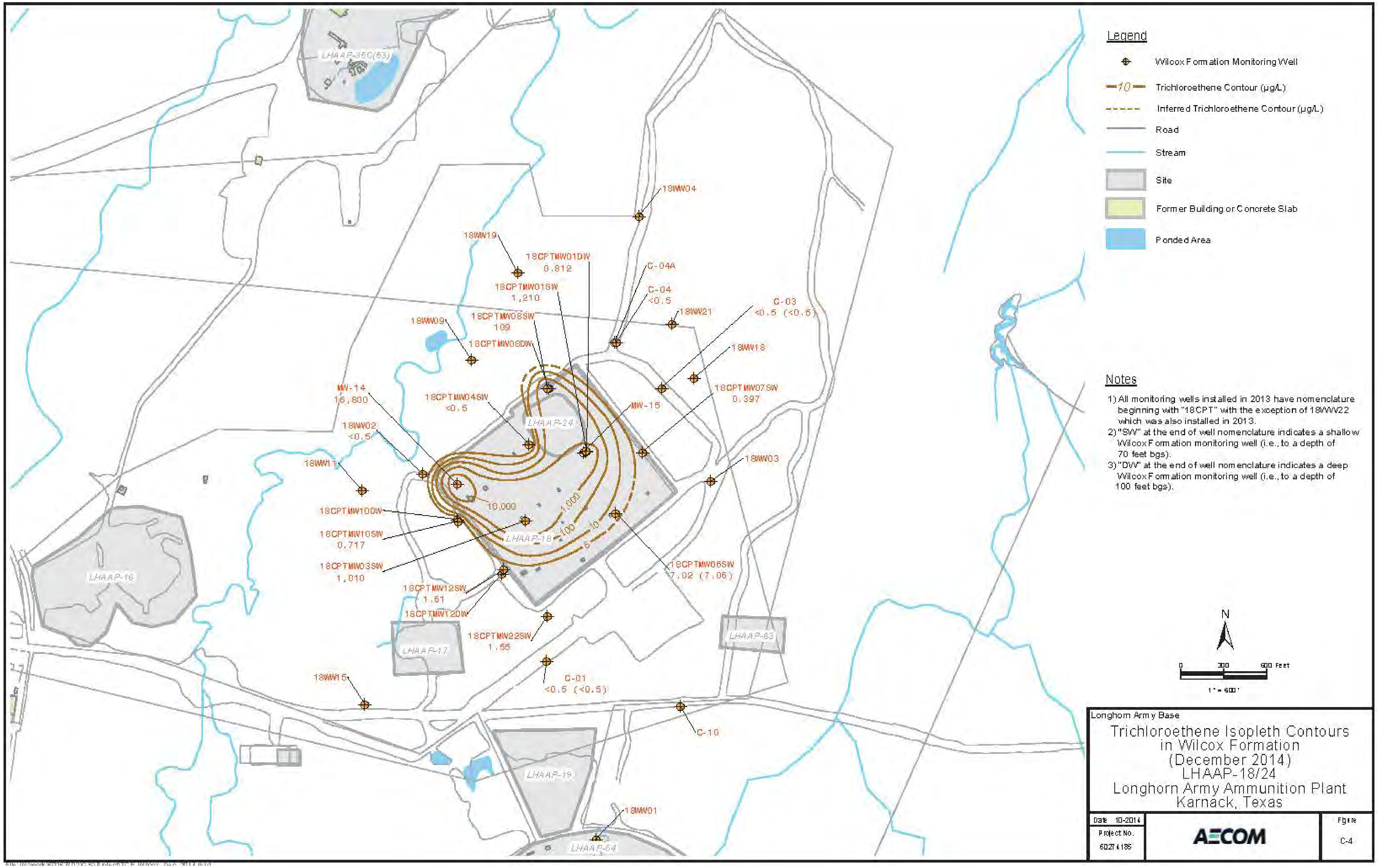
Plot 41. LHAAP-18/24 TCE and Fourth Five-Year Review spatial distribution of trends in the Shallow Groundwater Zone (Yellow Highlight = Decreasing Trend, Red Highlight = Increasing Trend), June 2016 (AECOM, 2017g).



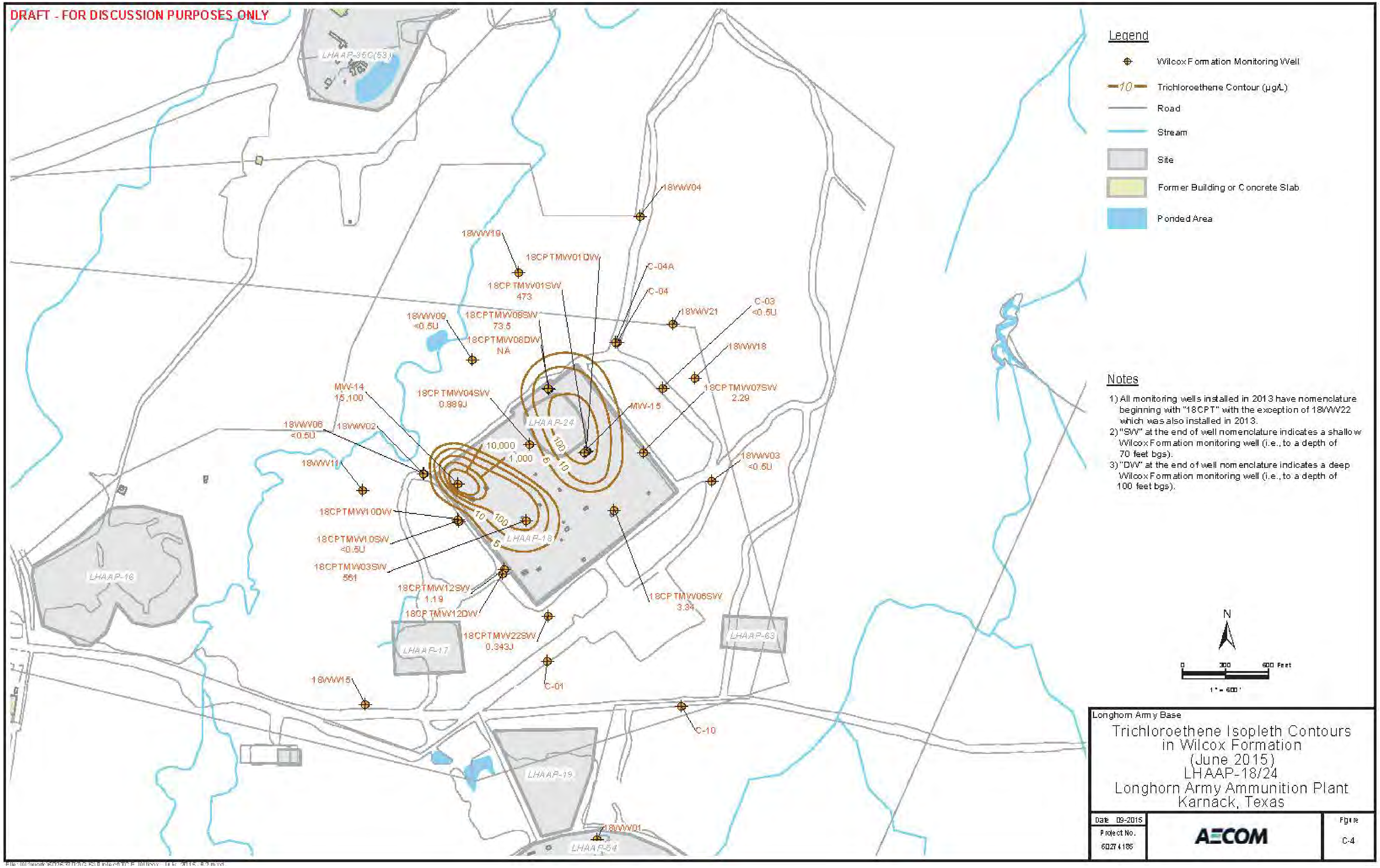
Plot 42. LHAAP-18/24 TCE Shallow Groundwater Zone – December 2016 (AECOM, 2017f).



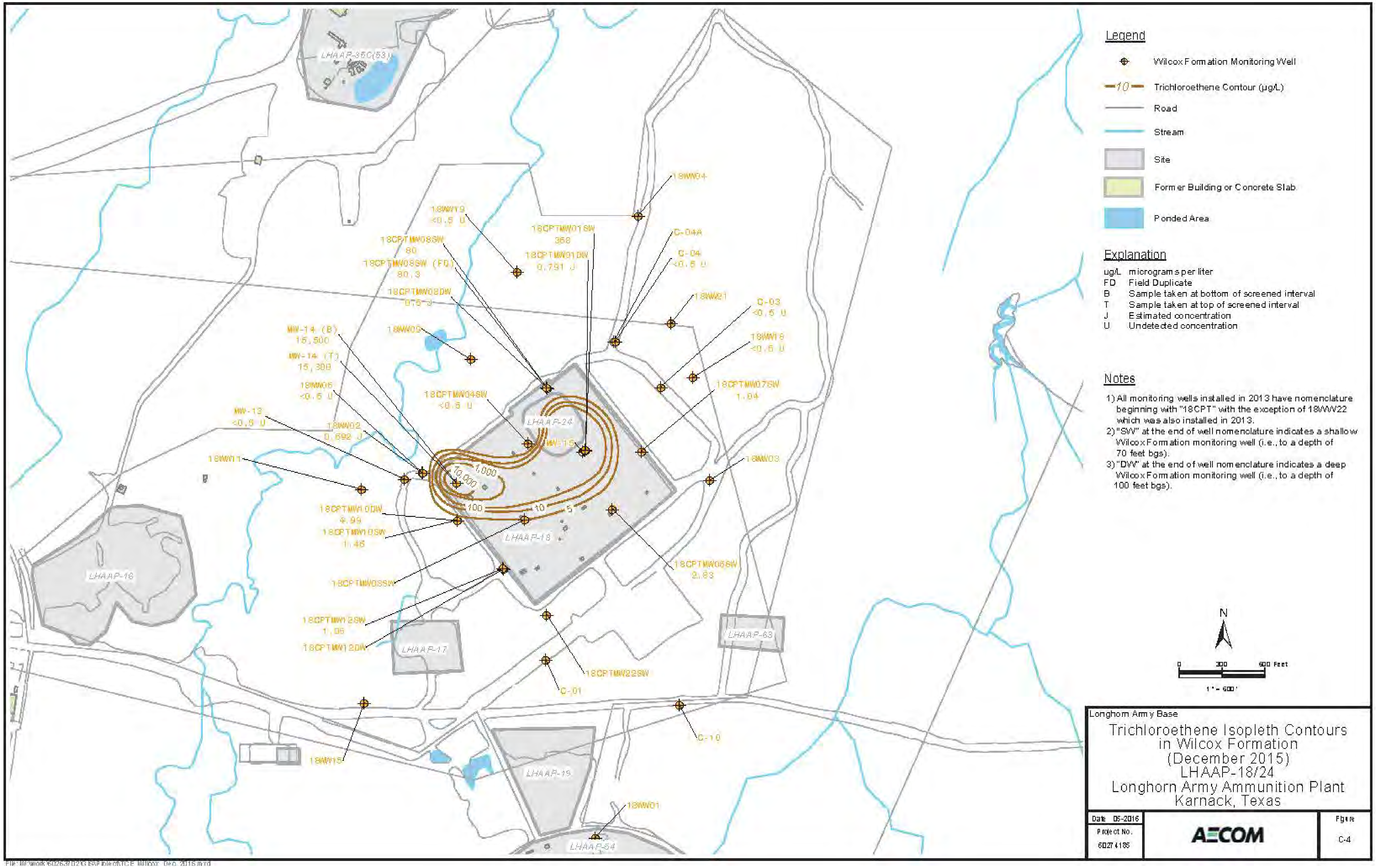
Plot 43. LHAAP-18/24 TCE Shallow Groundwater Zone – December 2017 (Bhate, 2018b).



Plot 44. LHAAP-18/24 TCE middle Wilcox Formation – December 2014 (AECOM, 2015c).



Plot 45. LHAAP-18/24 TCE middle Wilcox Formation – June 2015 (AECOM, 2015b).



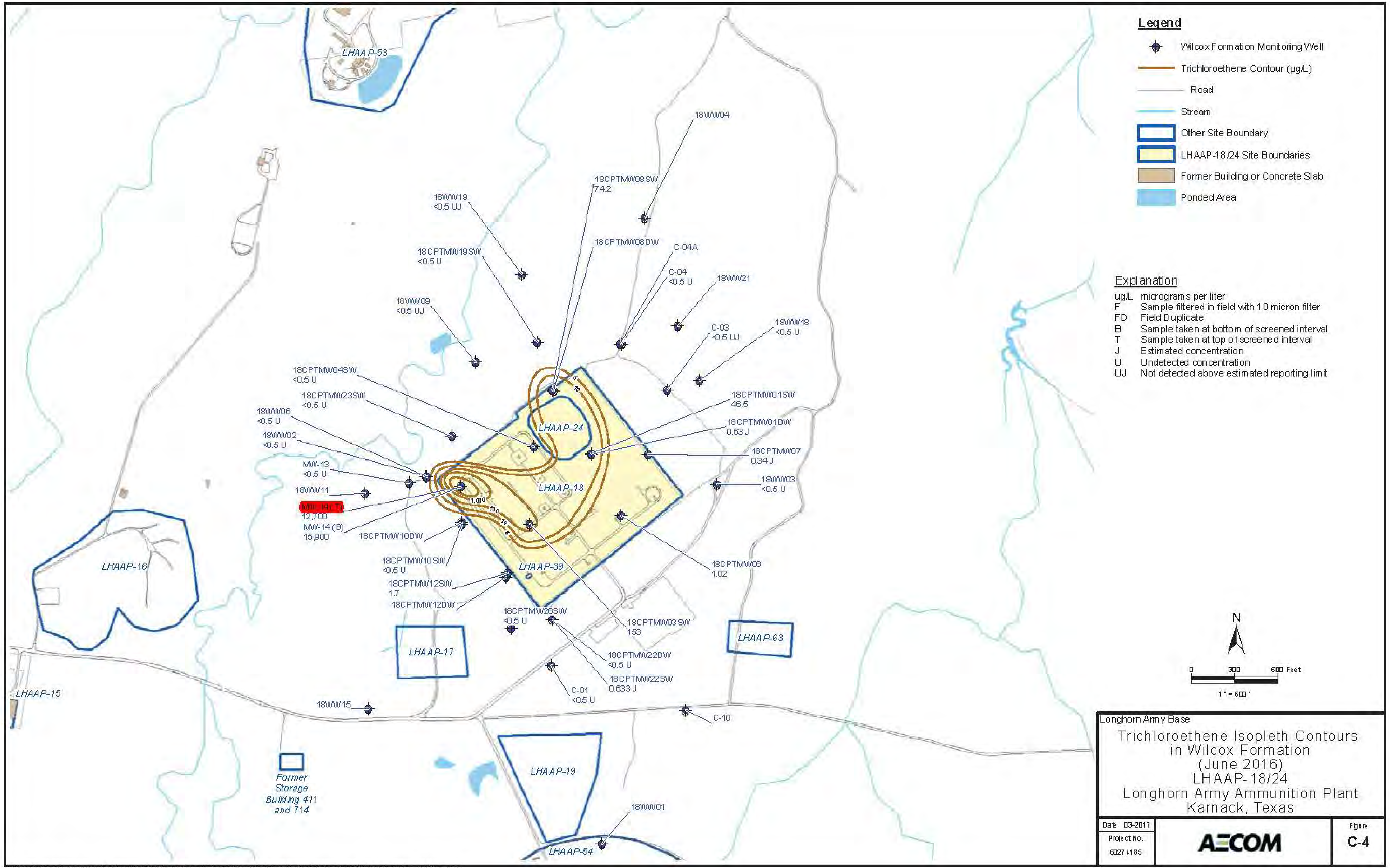
Explanation

ug/L	micrograms per liter
FD	Field Duplicate
B	Sample taken at bottom of screened interval
T	Sample taken at top of screened interval
J	Estimated concentration
U	Undetected concentration

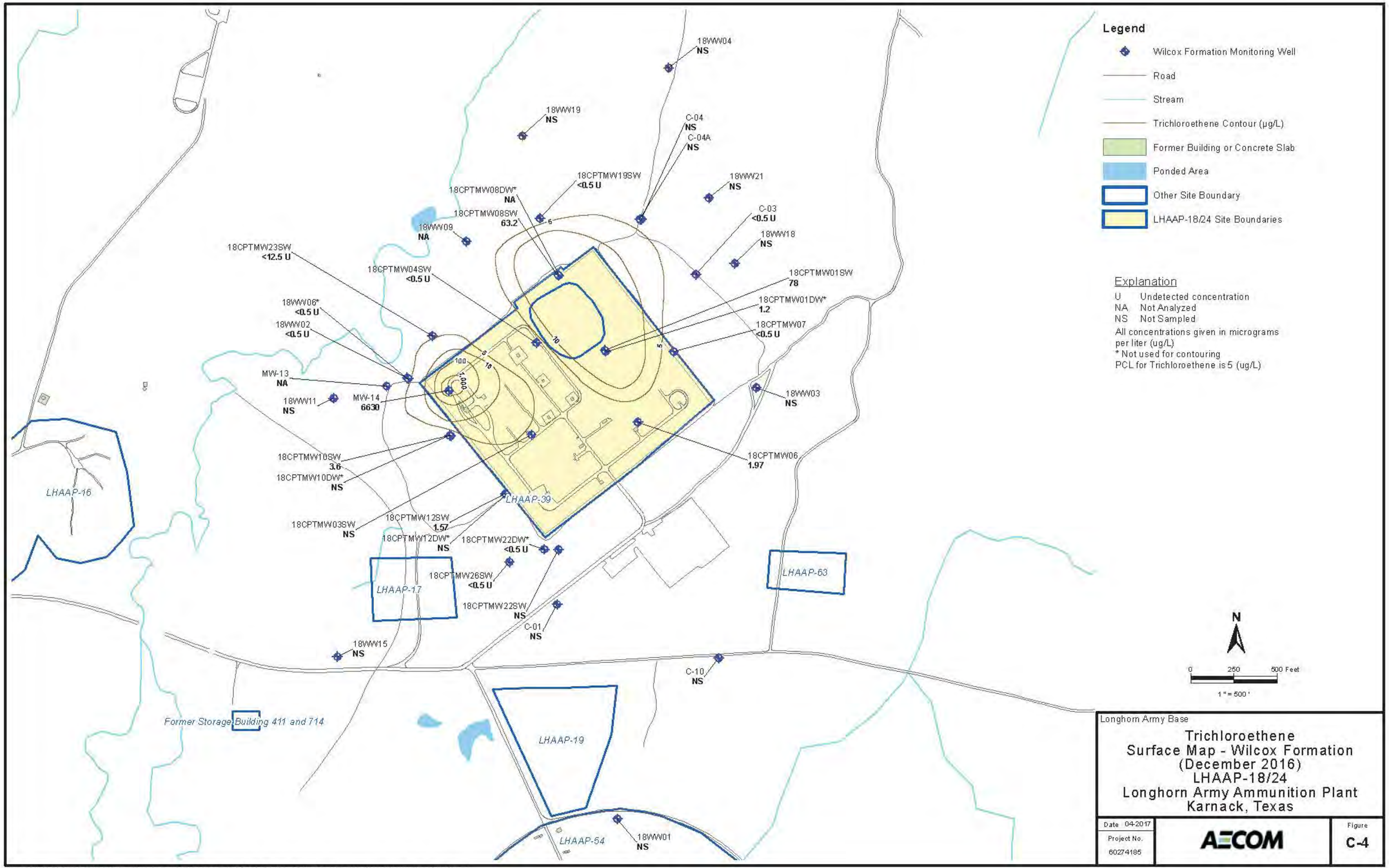
Notes

1) All monitoring wells installed in 2013 have nomenclature beginning with "18CPT" with the exception of 18WW22 which was also installed in 2013.
2) "SW" at the end of well nomenclature indicates a shallow Wilcox Formation monitoring well (i.e., to a depth of 70 feet bgs).
3) "DW" at the end of well nomenclature indicates a deep Wilcox Formation monitoring well (i.e., to a depth of 100 feet bgs).

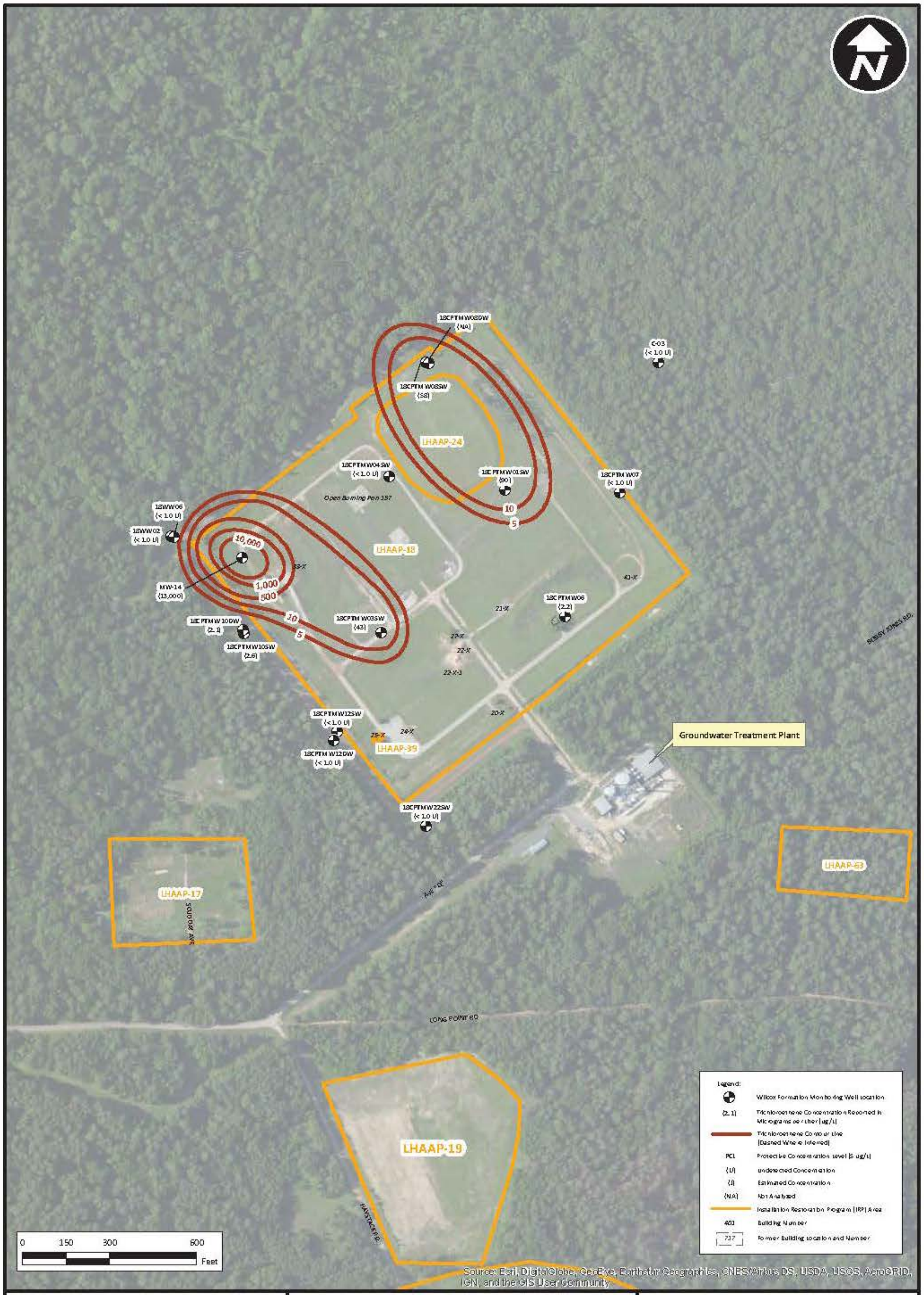
Plot 46. LHAAP-18/24 TCE middle Wilcox Formation – December 2015 (AECOM, 2016d).



Plot 47. LHAAP-18/24 TCE and Fourth Five-Year Review spatial distribution of trends in the middle Wilcox Formation (Yellow Highlight = Decreasing Trend, Red Highlight = Increasing Trend), June 2016 (AECOM, 2017g).

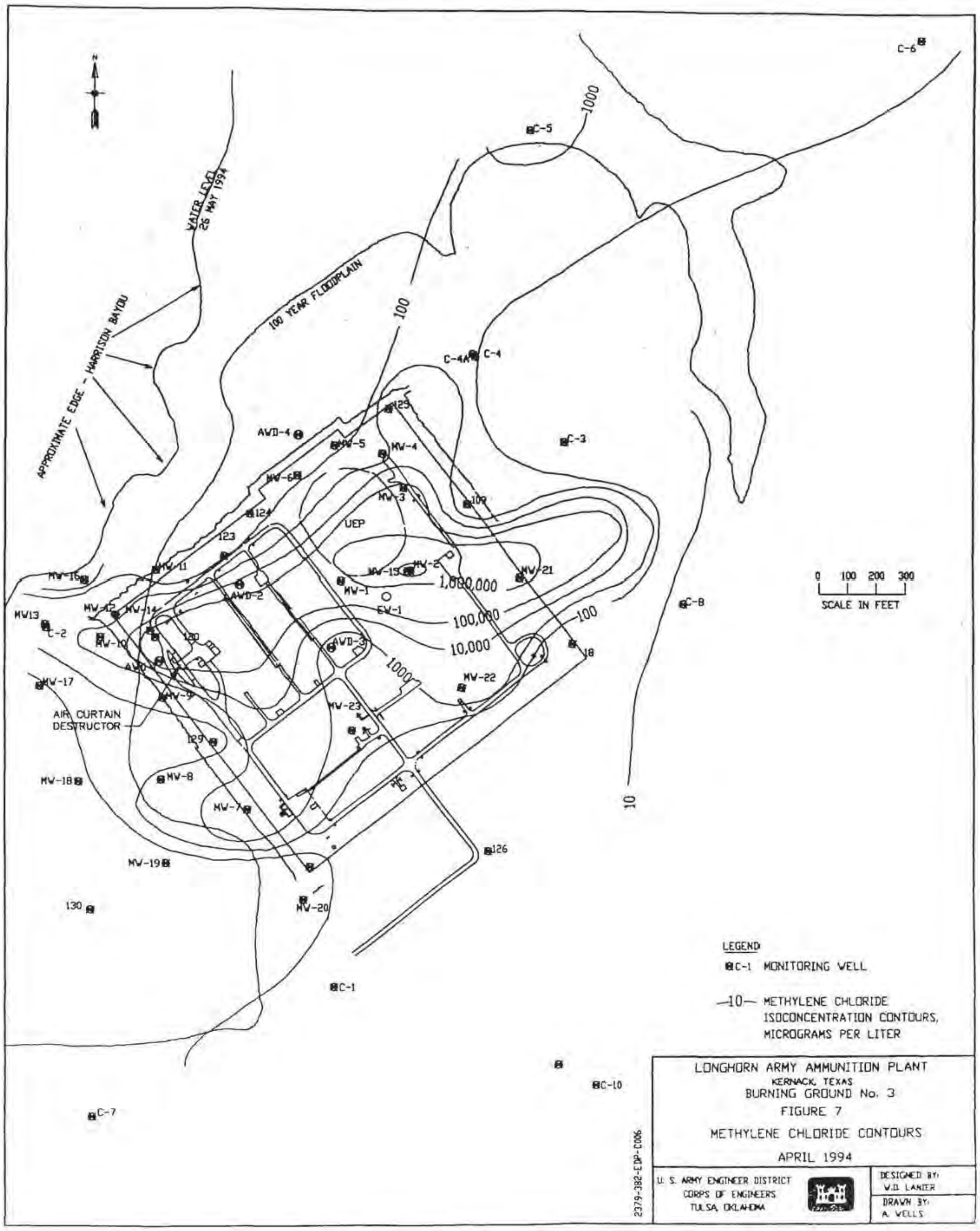


Plot 48. LHAAP-18/24 TCE middle Wilcox Formation – December 2016 (AECOM, 2017f).

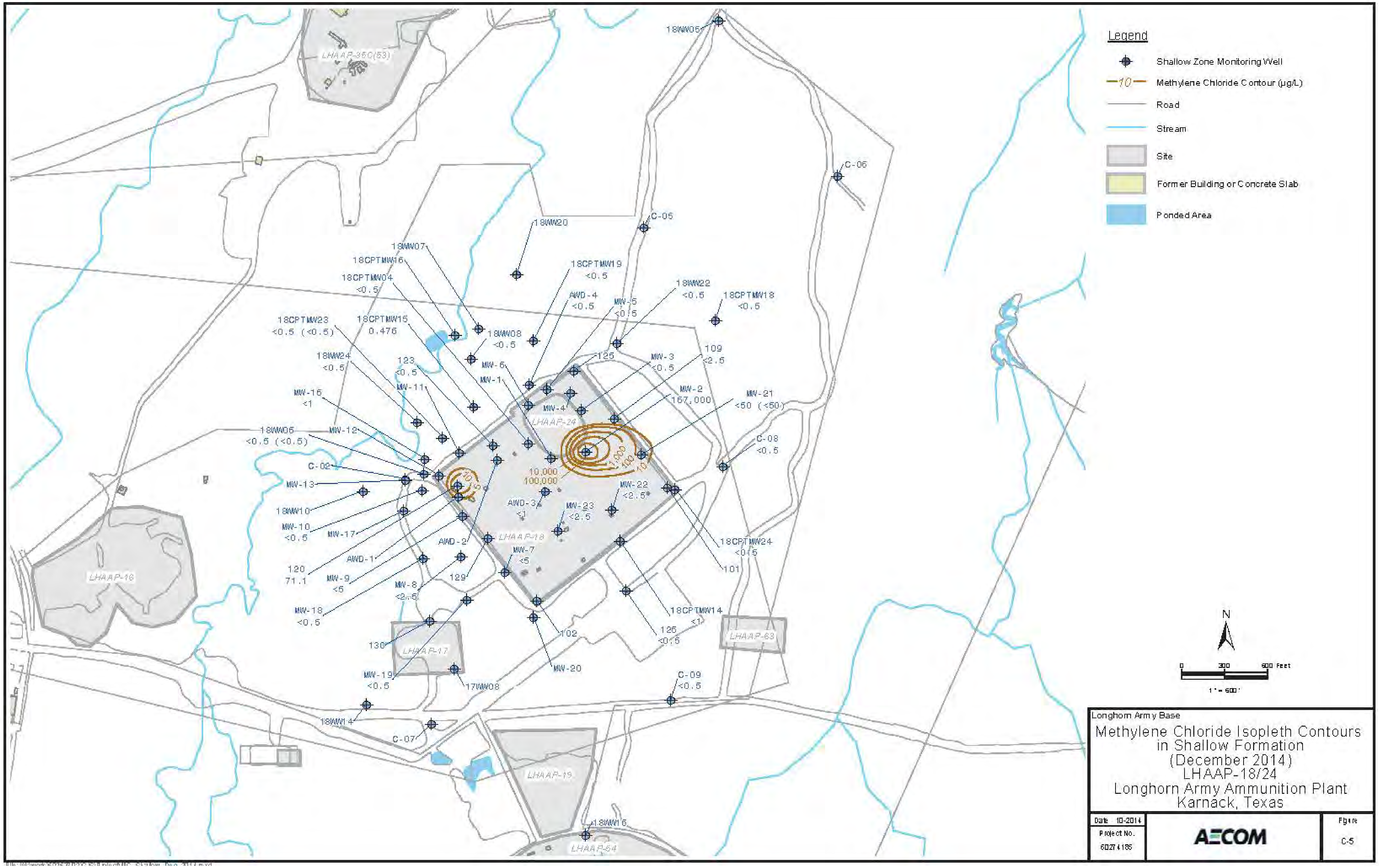


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

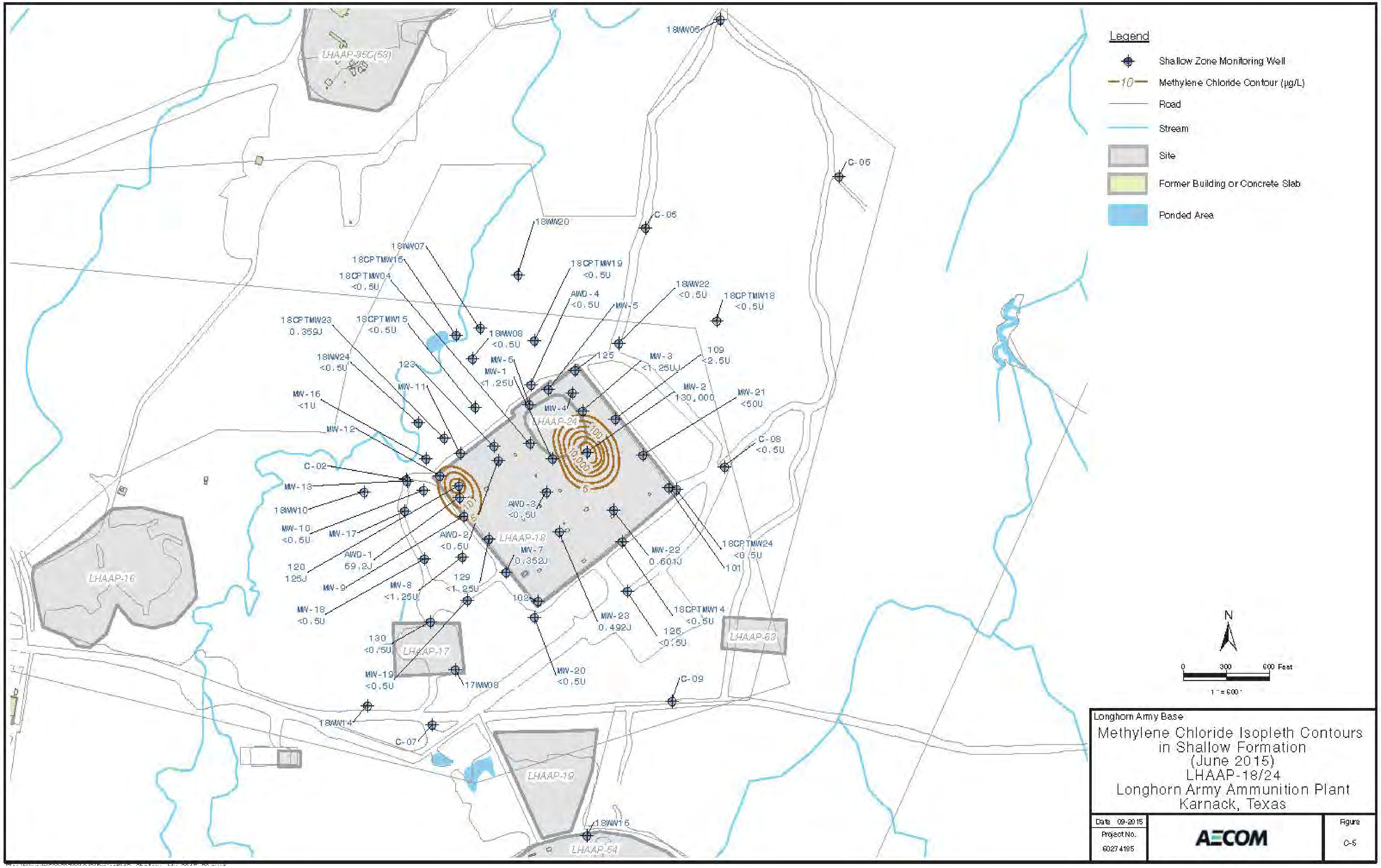
Plot 49. LHAAP-18/24 TCE middle Wilcox Formation – December 2017 (Bhate, 2018b).



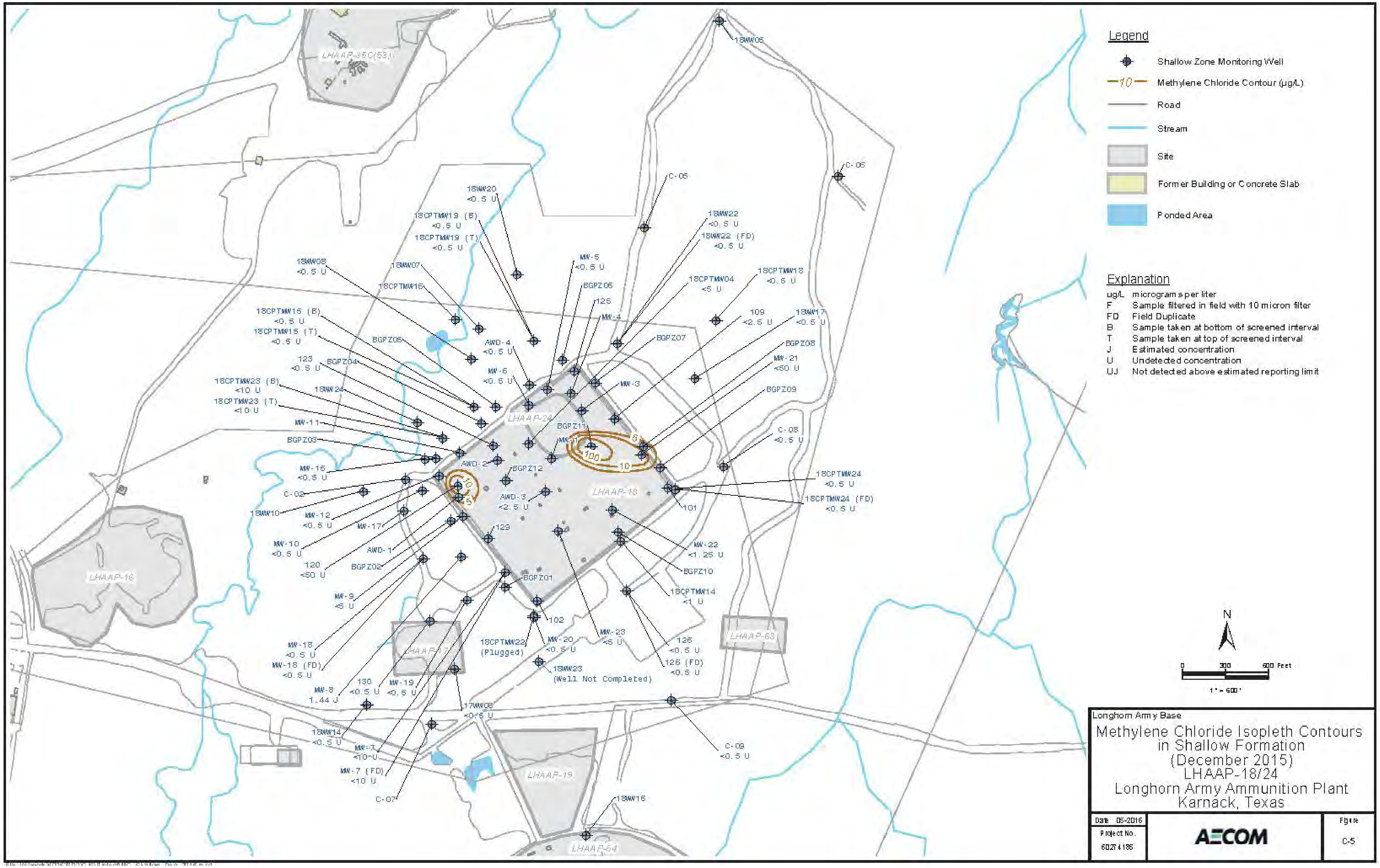
Plot 50. LHAAP-18/24 Methylene Chloride – April 1994 (US Army, 1995b).



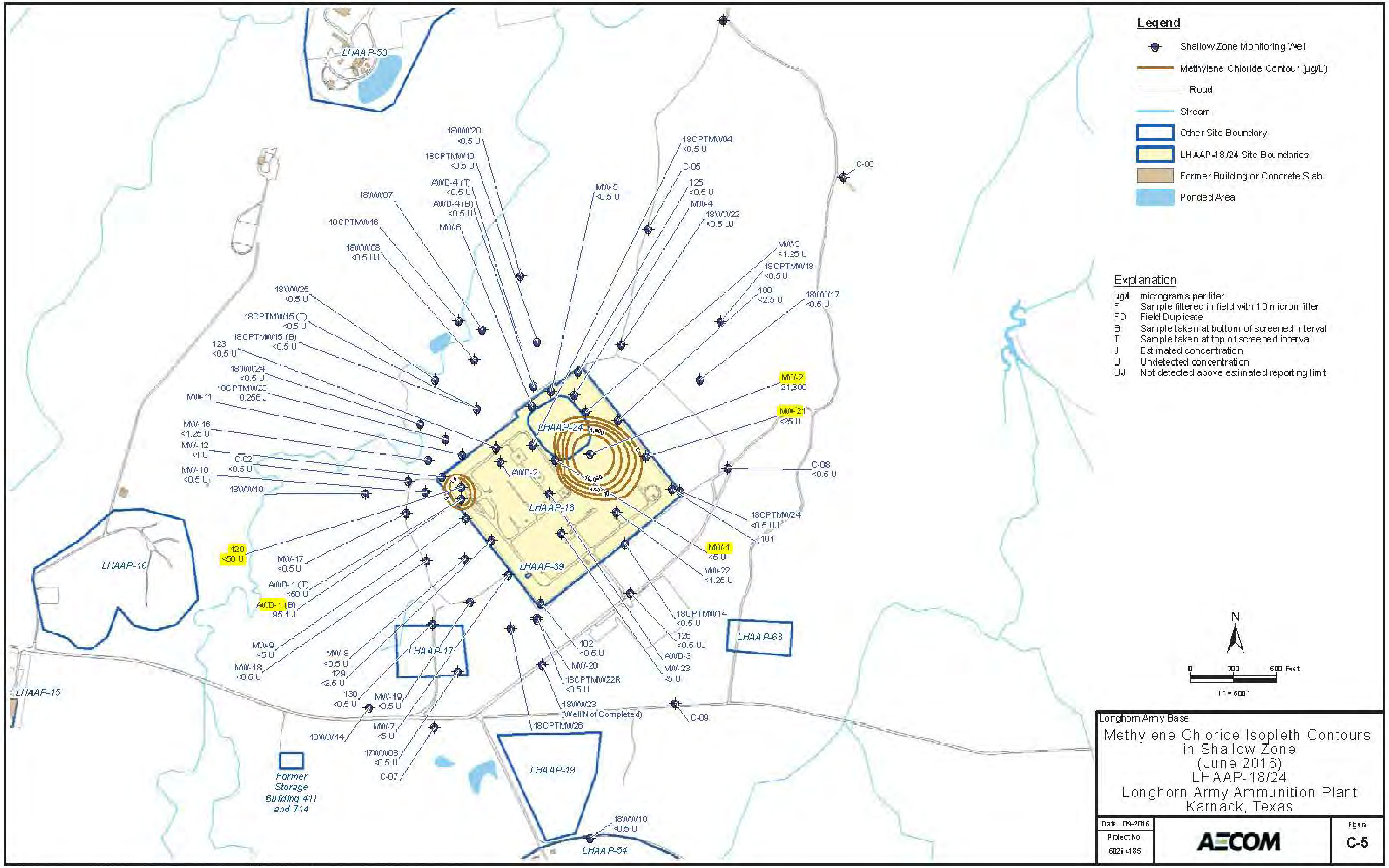
Plot 51. LHAAP-18/24 Methylene Chloride, Shallow Groundwater Zone – December 2014 (AECOM, 2015c).



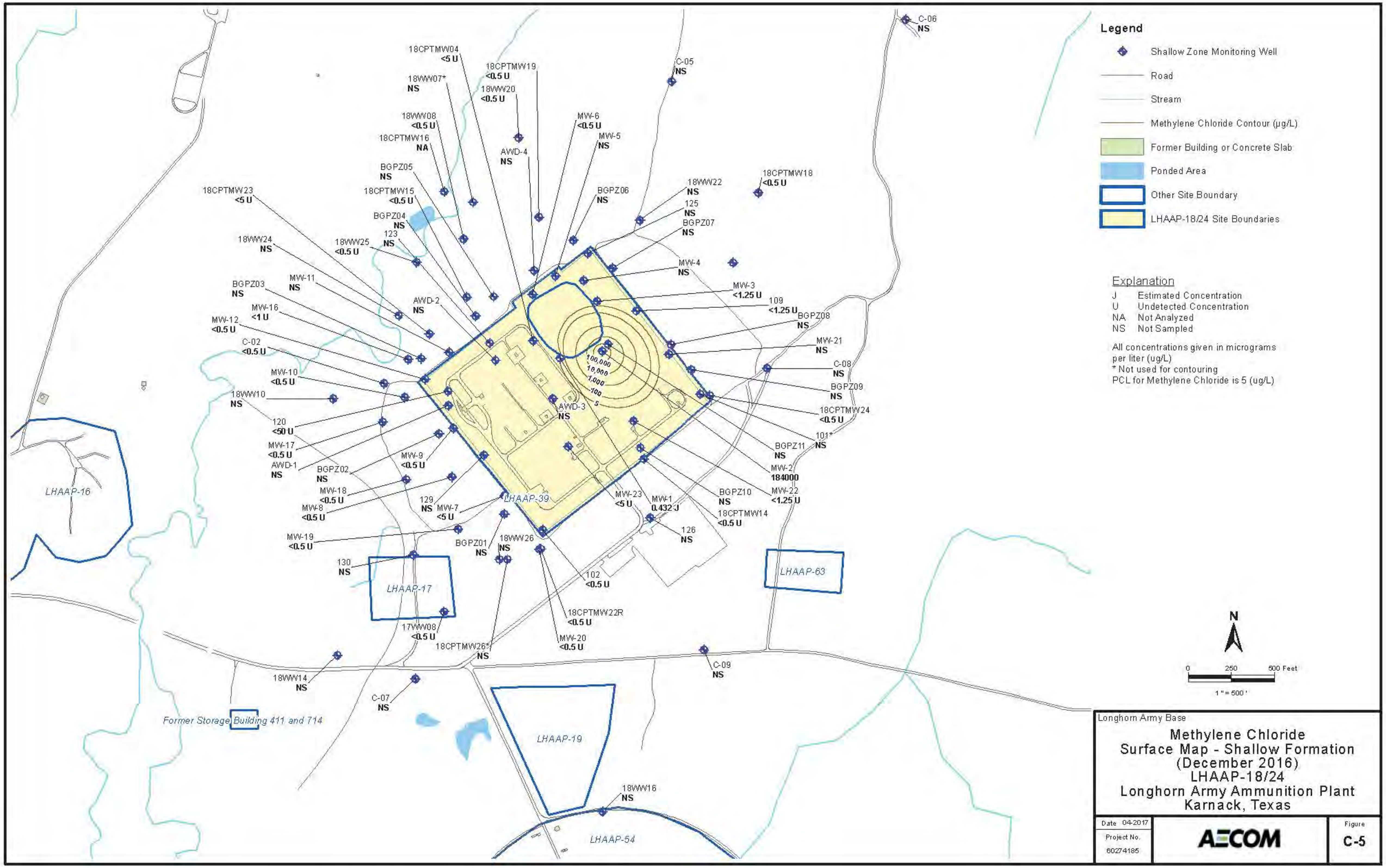
Plot 52. LHAAP-18/24 Methylene Chloride, Shallow Groundwater Zone – June 2015 (AECOM, 2015b).



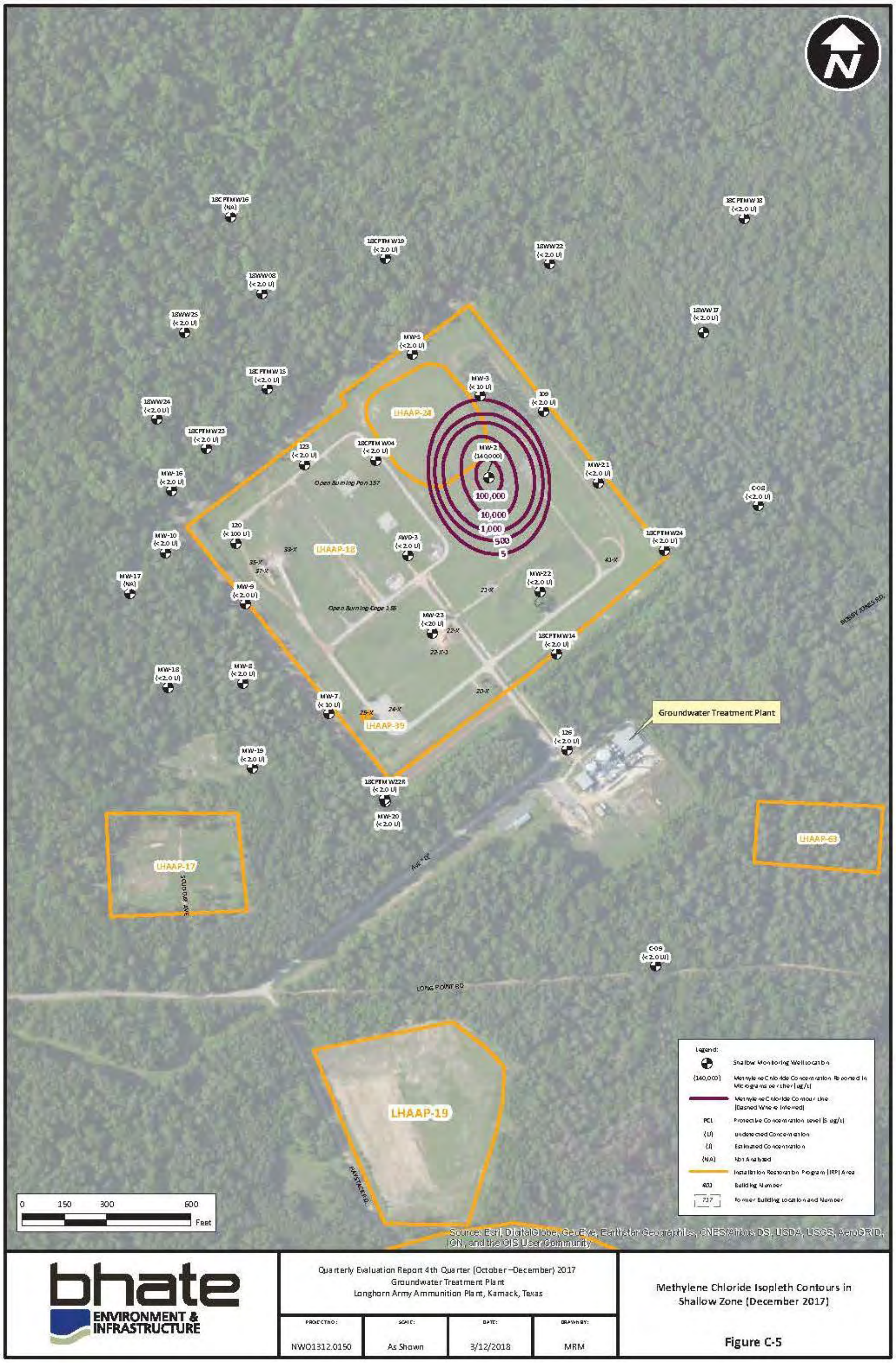
Plot 53. LHAAP-18/24 Methylene Chloride, Shallow Groundwater Zone – December 2015 (AECOM, 2016d).



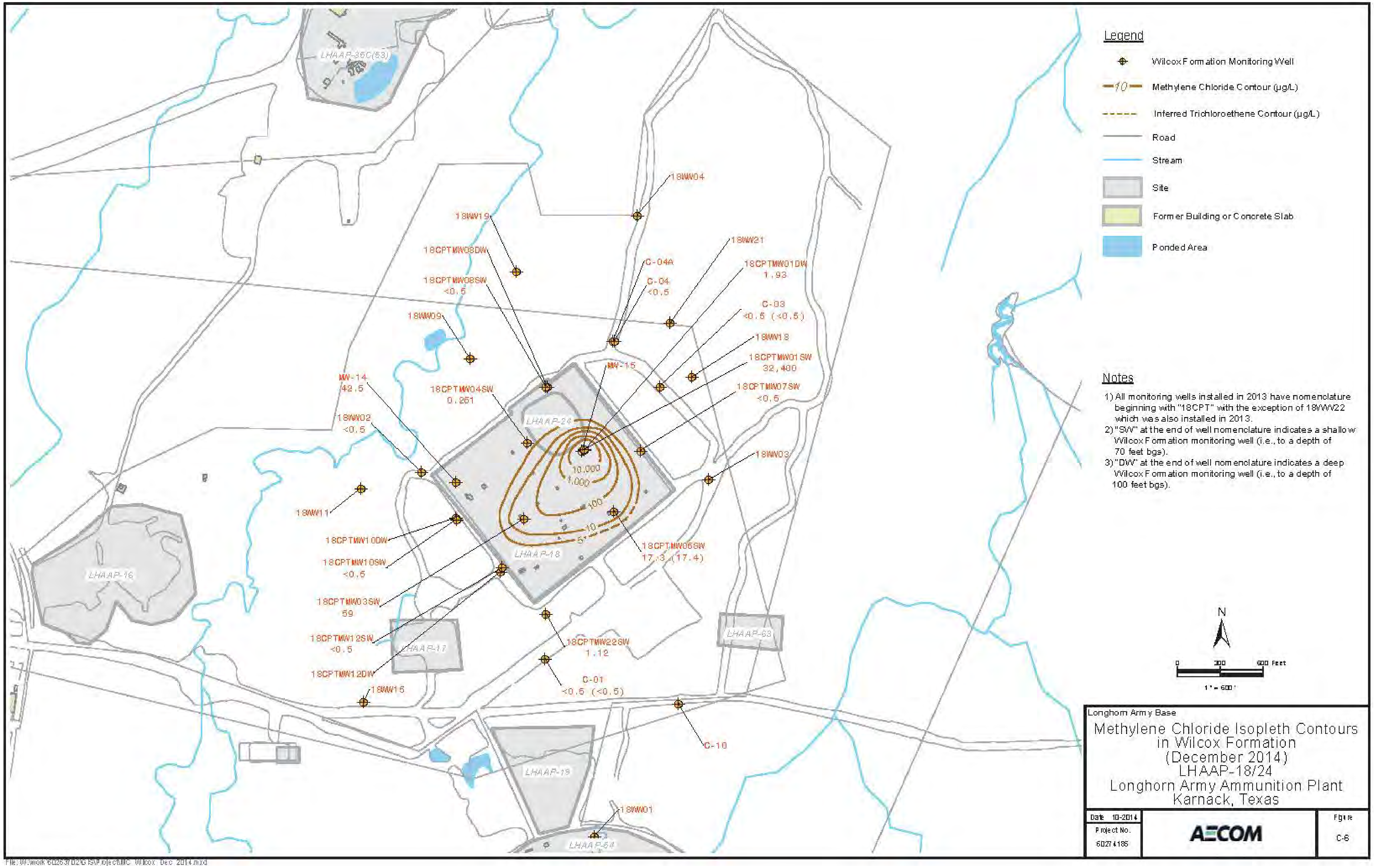
Plot 54. LHAAP-18/24 Methylene Chloride and Fourth Five-Year Review spatial distribution of trends (Yellow Highlight = Decreasing Trend, Red Highlight = Increasing Trend), Shallow Groundwater Zone – June 2016 (AECOM, 2017g).



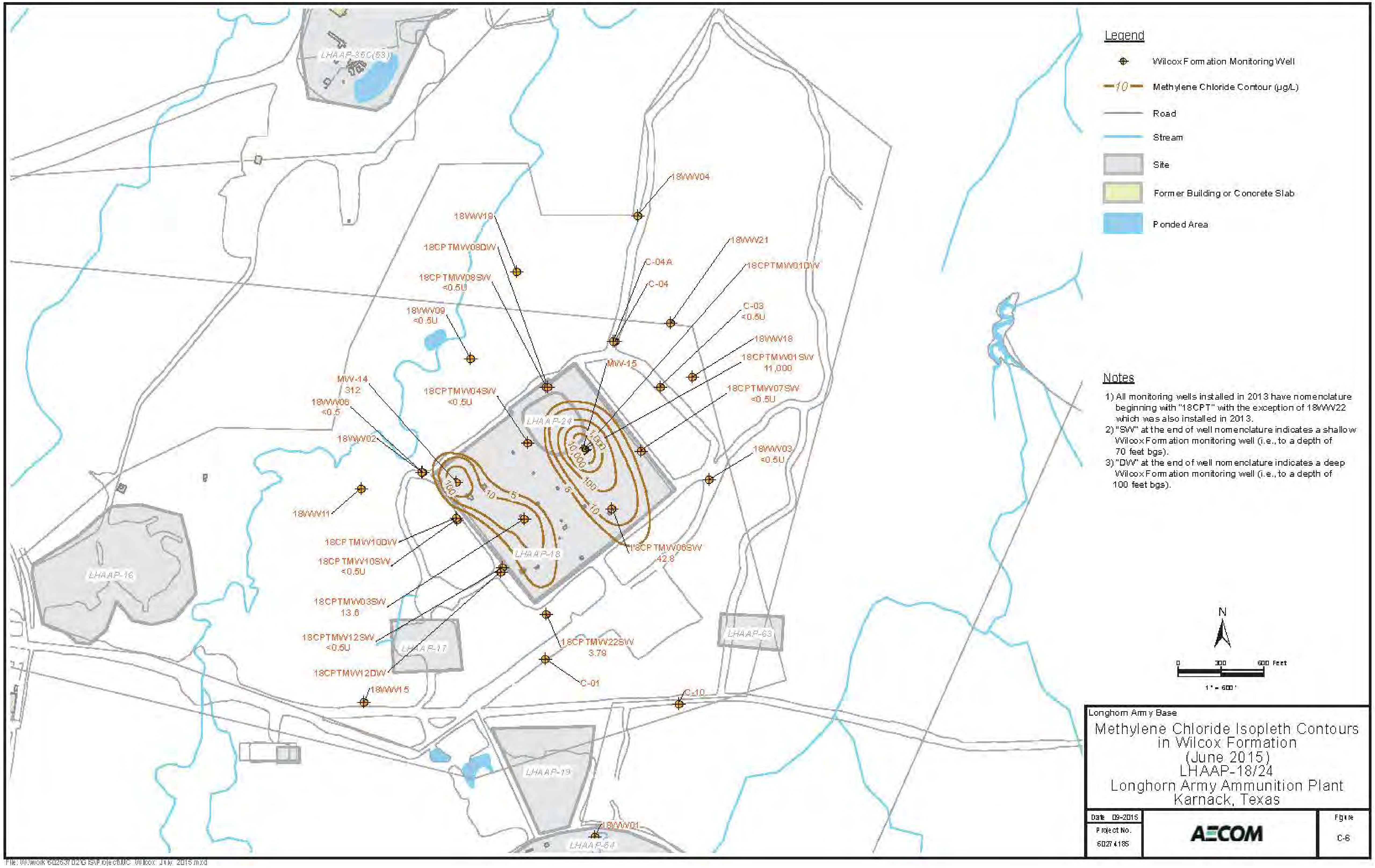
Plot 55. LHAAP-18/24 Methylene Chloride, Shallow Groundwater Zone – December 2016 (AECOM, 2017f).



Plot 56. LHAAP-18/24 Methylene Chloride, Shallow Groundwater Zone – December 2017 (Bhate, 2018b).



Plot 57 LHAAP-18/24 Methylene Chloride, middle Wilcox Formation – December 2014 (AECOM, 2015c).



Notes

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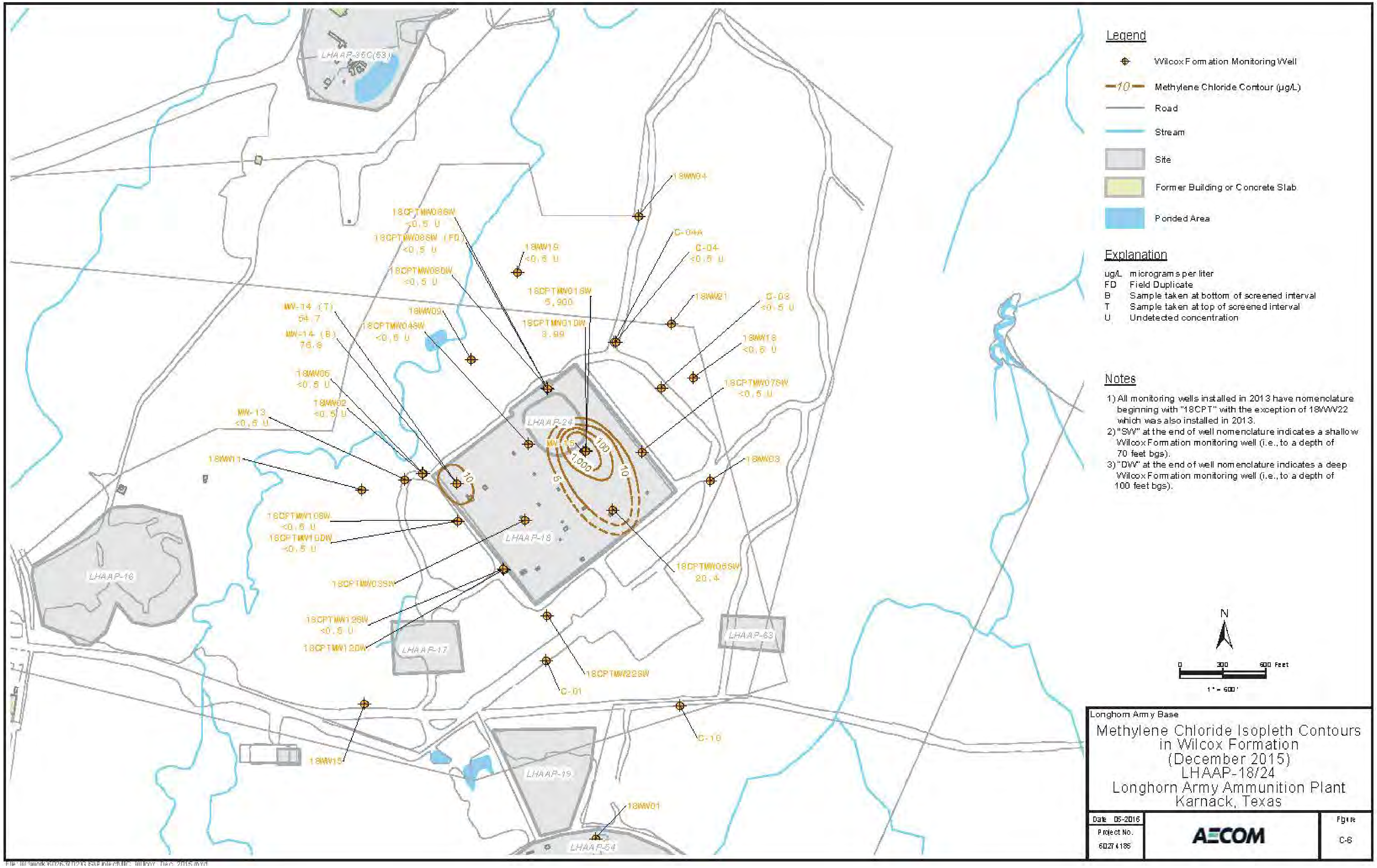
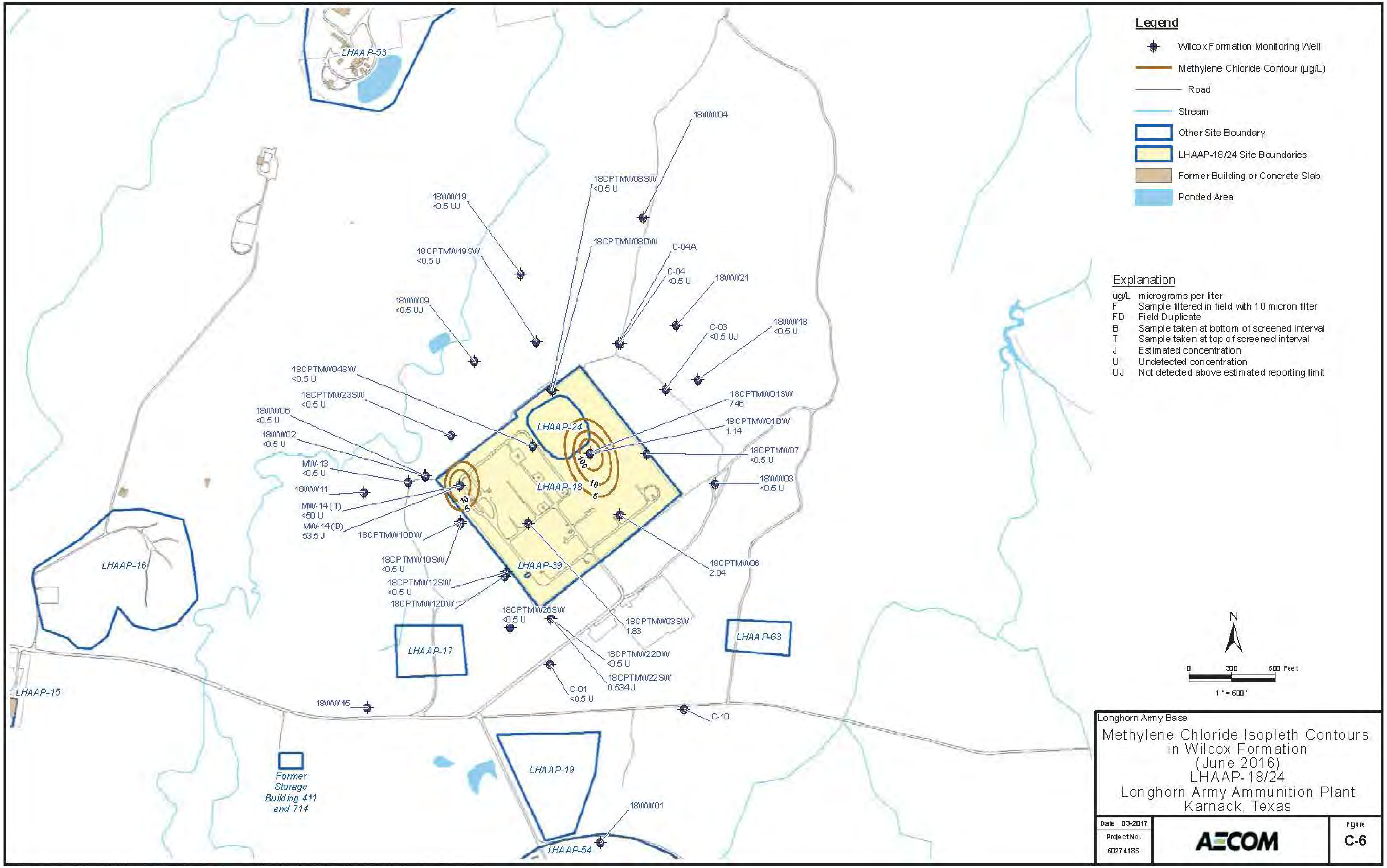
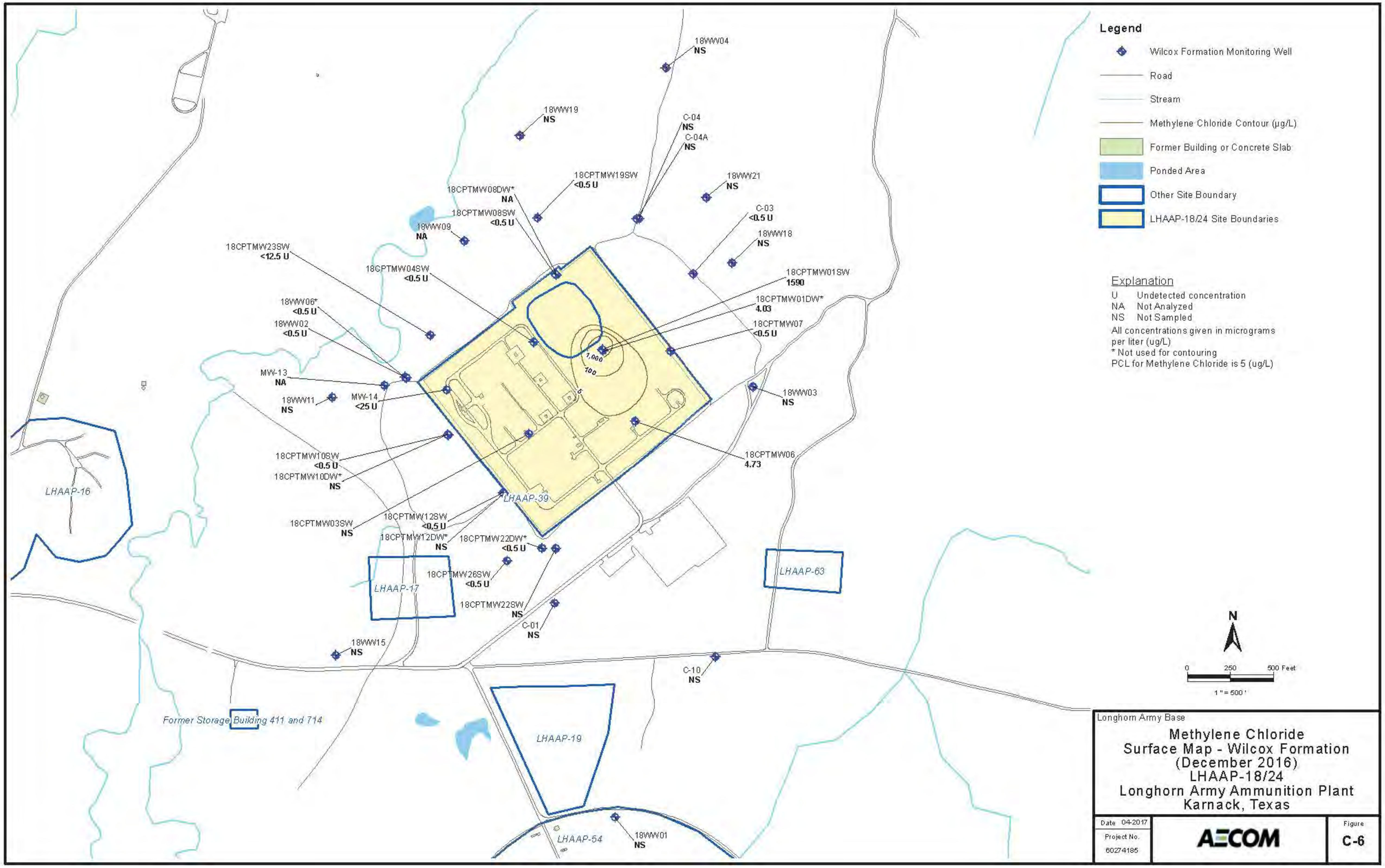
Plot 58 LHAAP-18/24 Methylene Chloride, middle Wilcox Formation – June 2015 (AECOM, 2015b).



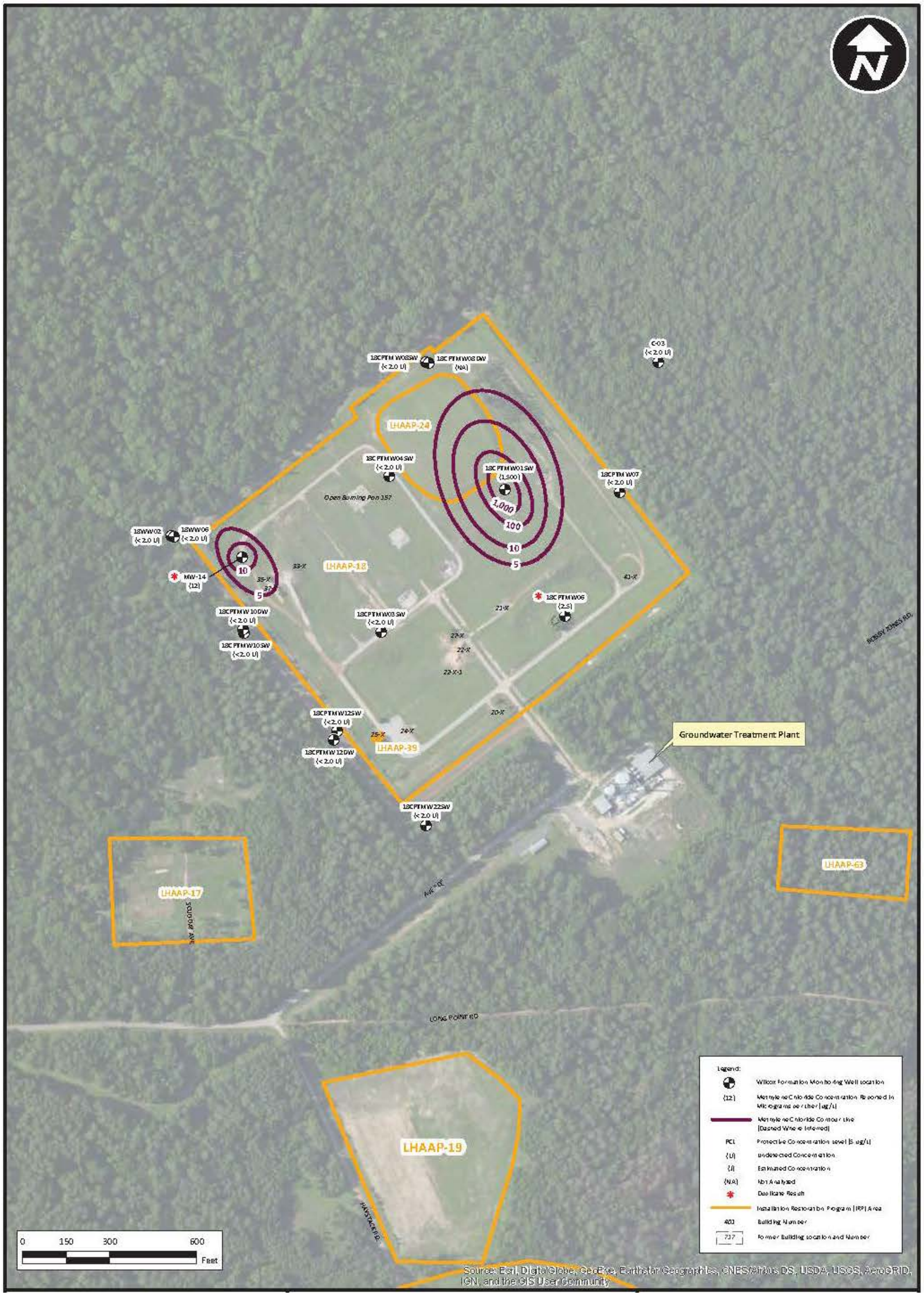
Plot 59 LHAAP-18/24 Methylene Chloride, middle Wilcox Formation – December 2015 (AECOM, 2016d).



Plot 60 LHAAP-18/24 Methylene Chloride, middle Wilcox Formation – June 2016 (AECOM, 2017g).

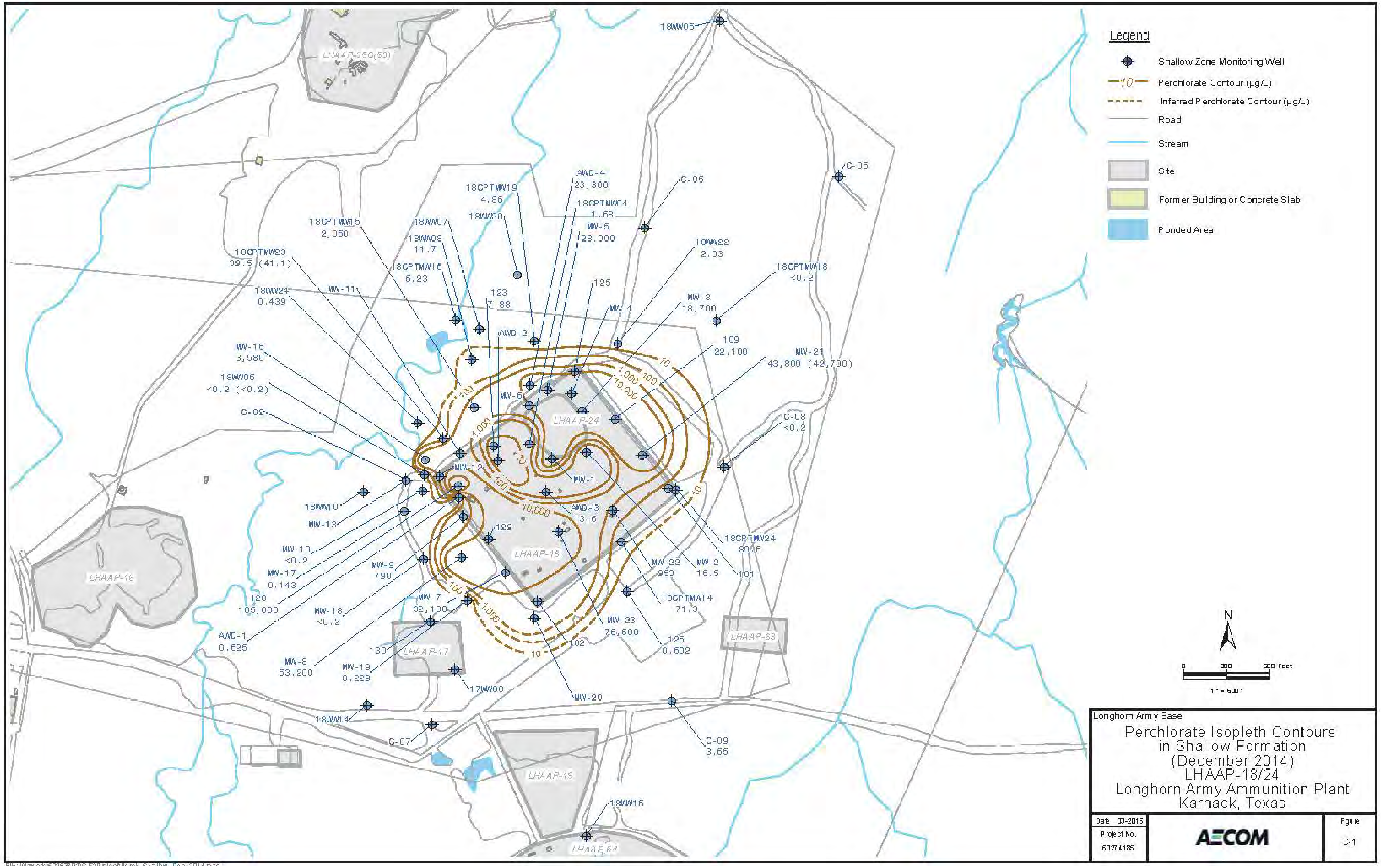


Plot 61 LHAAP-18/24 Methylene Chloride, middle Wilcox Formation – December 2016 (AECOM, 2017f).

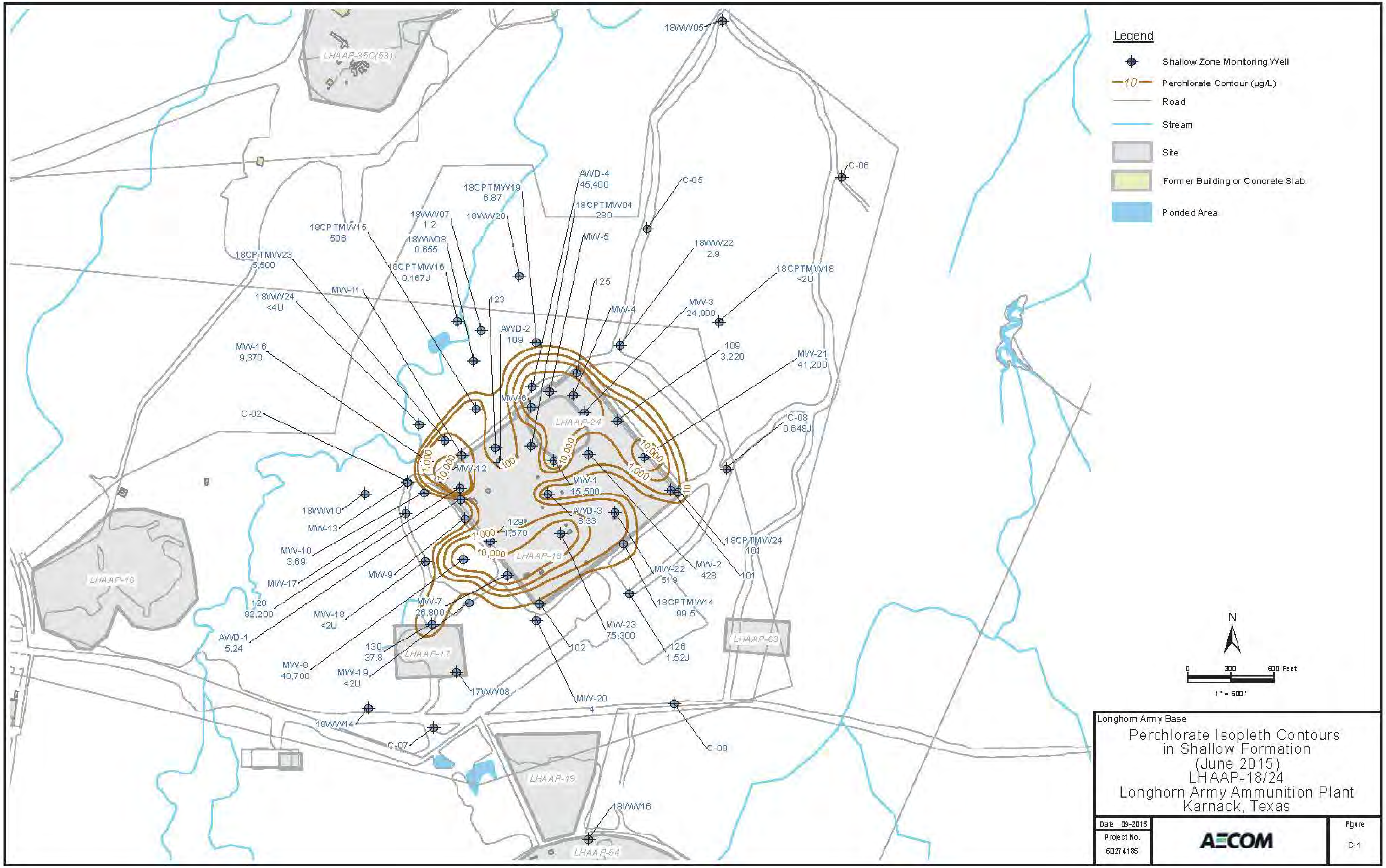


Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

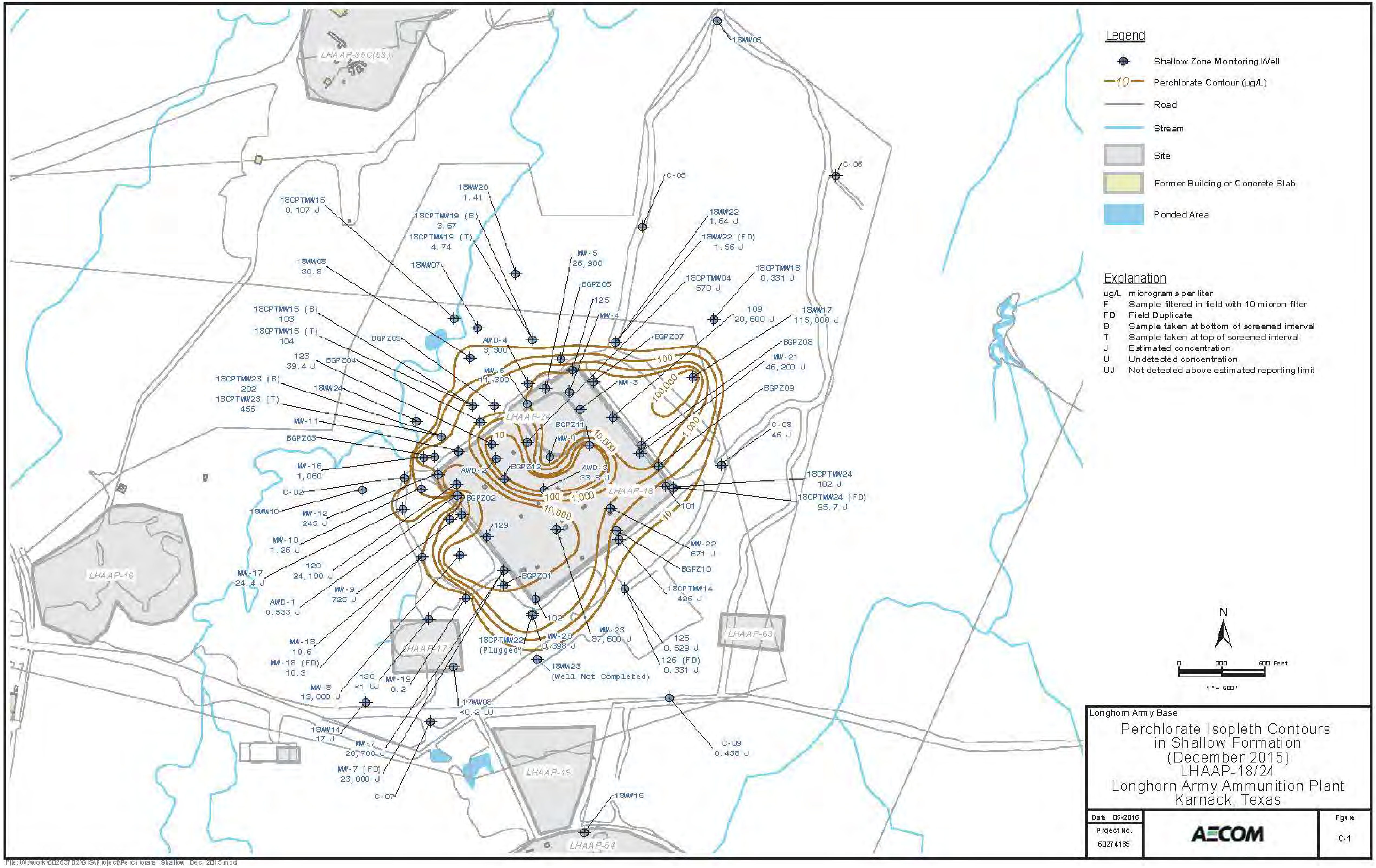
Plot 62 LHAAP-18/24 Methylene Chloride in the middle Wilcox Formation – December 2017 (Bhate, 2018b).



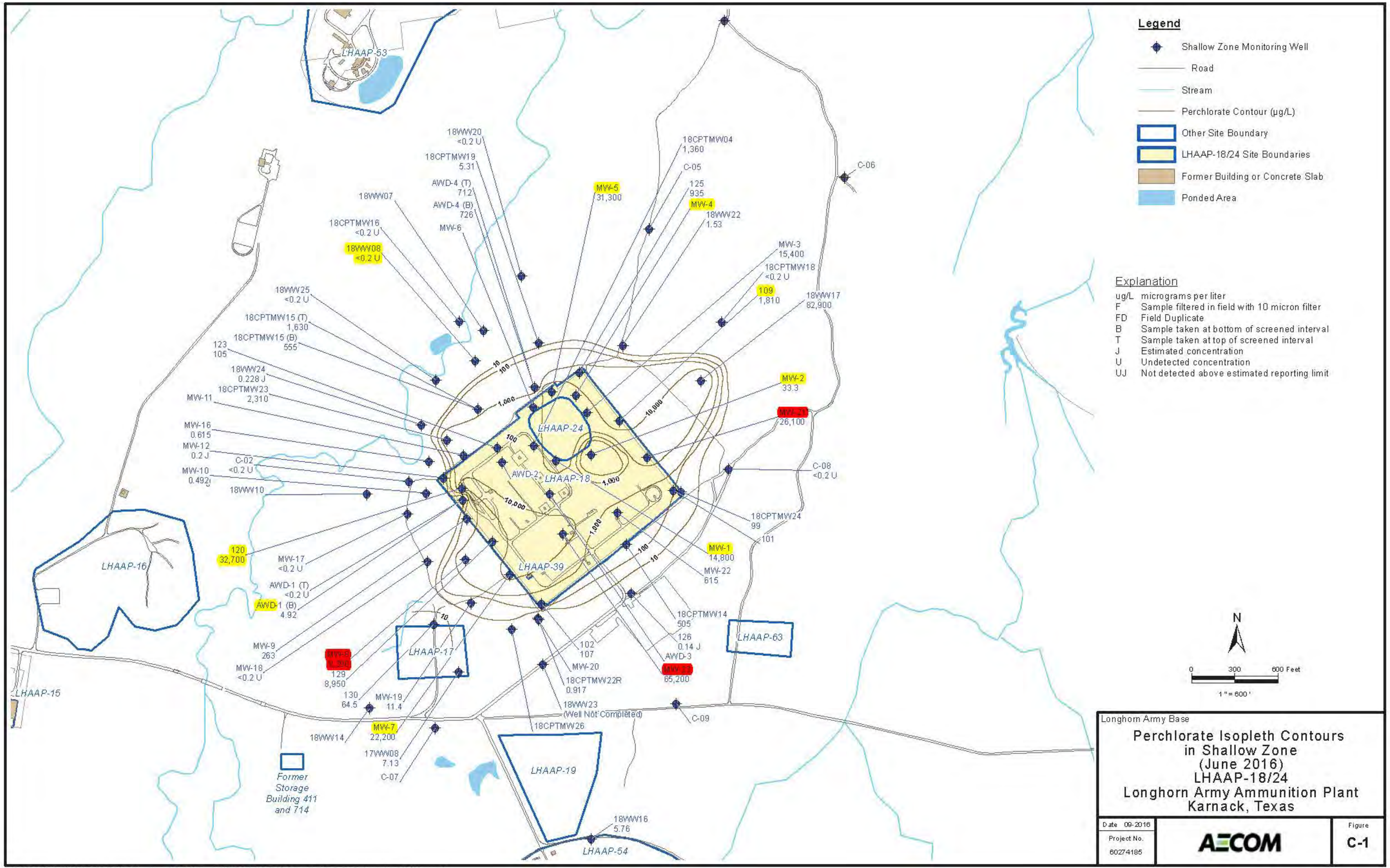
Plot 63. LHAAP-18/24 Perchlorate in the Shallow Groundwater Zone – December 2014 (AECOM, 2015c).



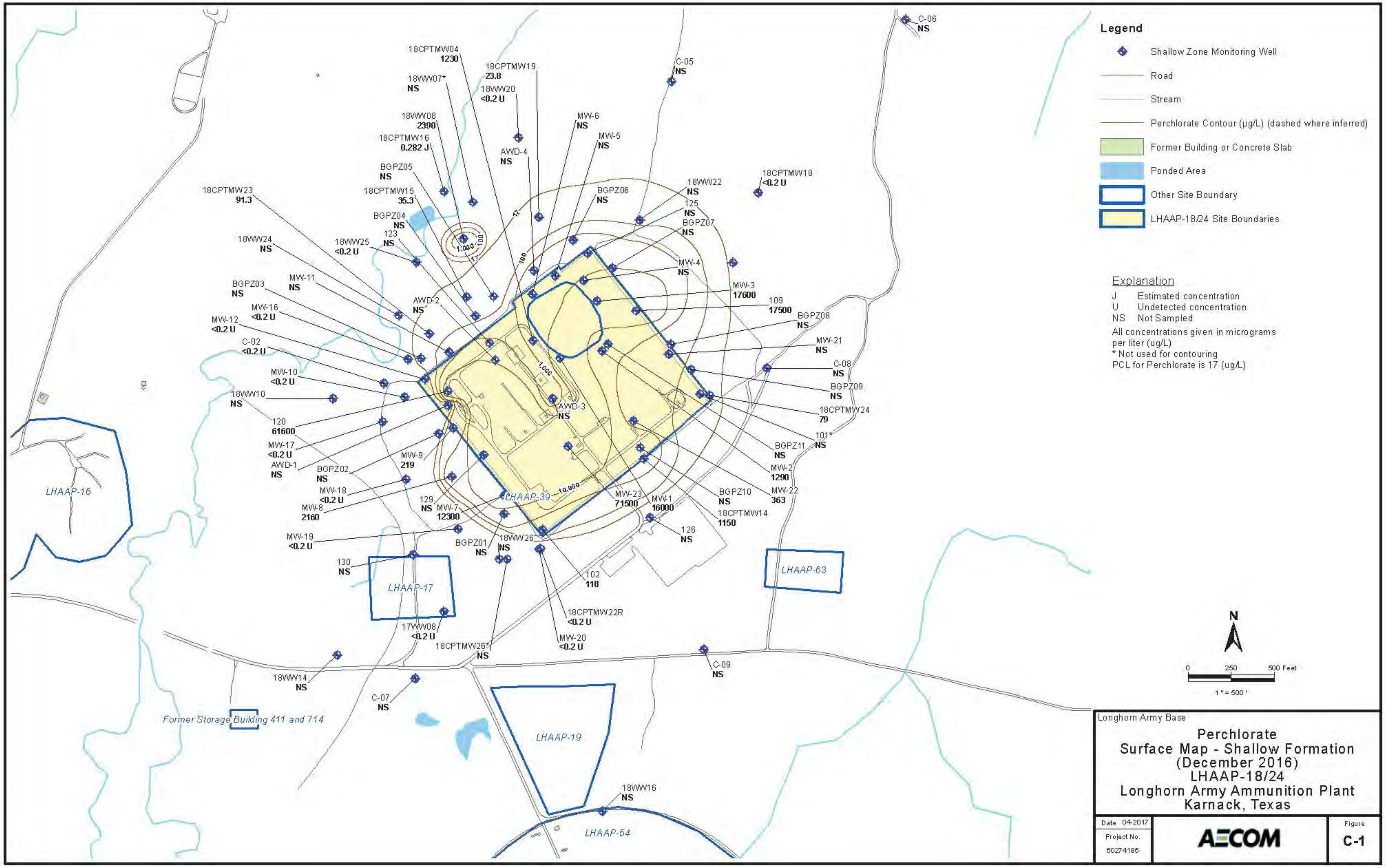
Plot 64. LHAAP-18/24 Perchlorate in the Shallow Groundwater Zone – June 2015 (AECOM, 2015b).



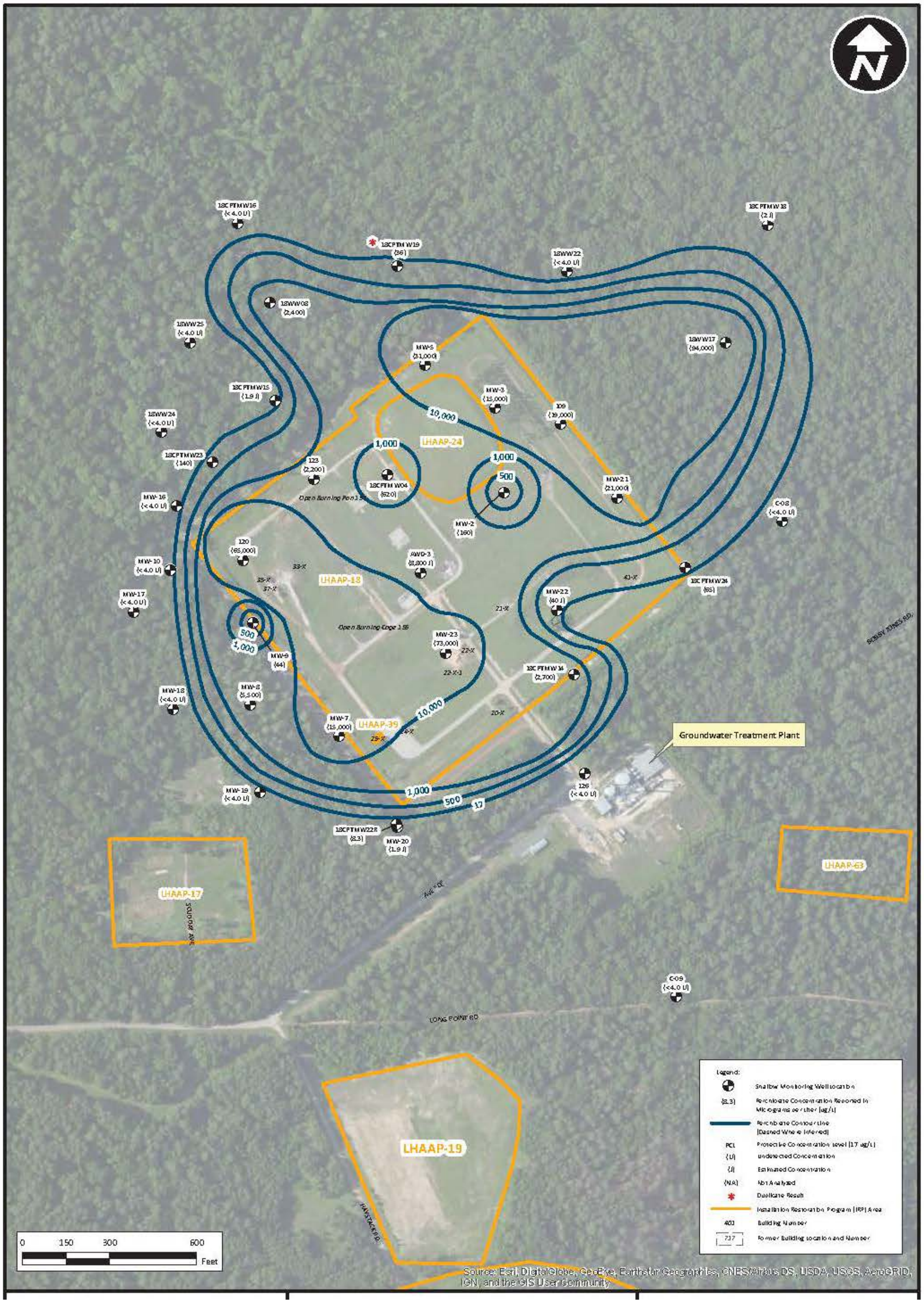
Plot 65. LHAAP-18/24 Perchlorate in the Shallow Groundwater Zone – December 2015 (AECOM, 2016d).



Plot 66. LHAAP-18/24 Perchlorate and Fourth Five-Year Review spatial distribution of trends (Yellow Highlight = Decreasing Trend, Red Highlight = Increasing Trend), Shallow Groundwater Zone – June 2016 (AECOM, 2017g).

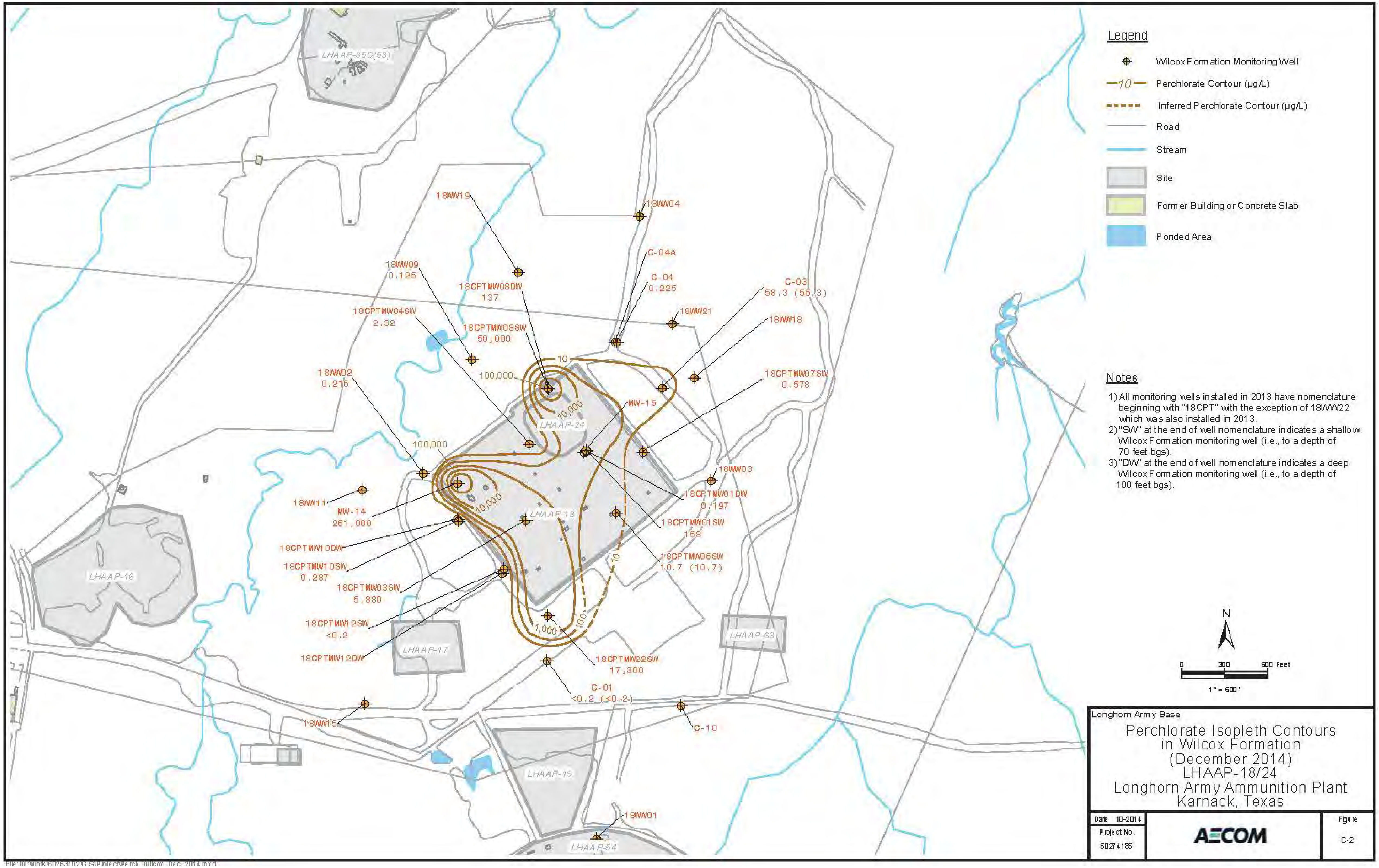


Plot 67. LHAAP-18/24 Perchlorate in the Shallow Groundwater Zone – December 2016 (AECOM, 2017f).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Plot 68. LHAAP-18/24 Perchlorate in the Shallow Groundwater Zone – December 2017 (Bhate, 2018b).



Notes
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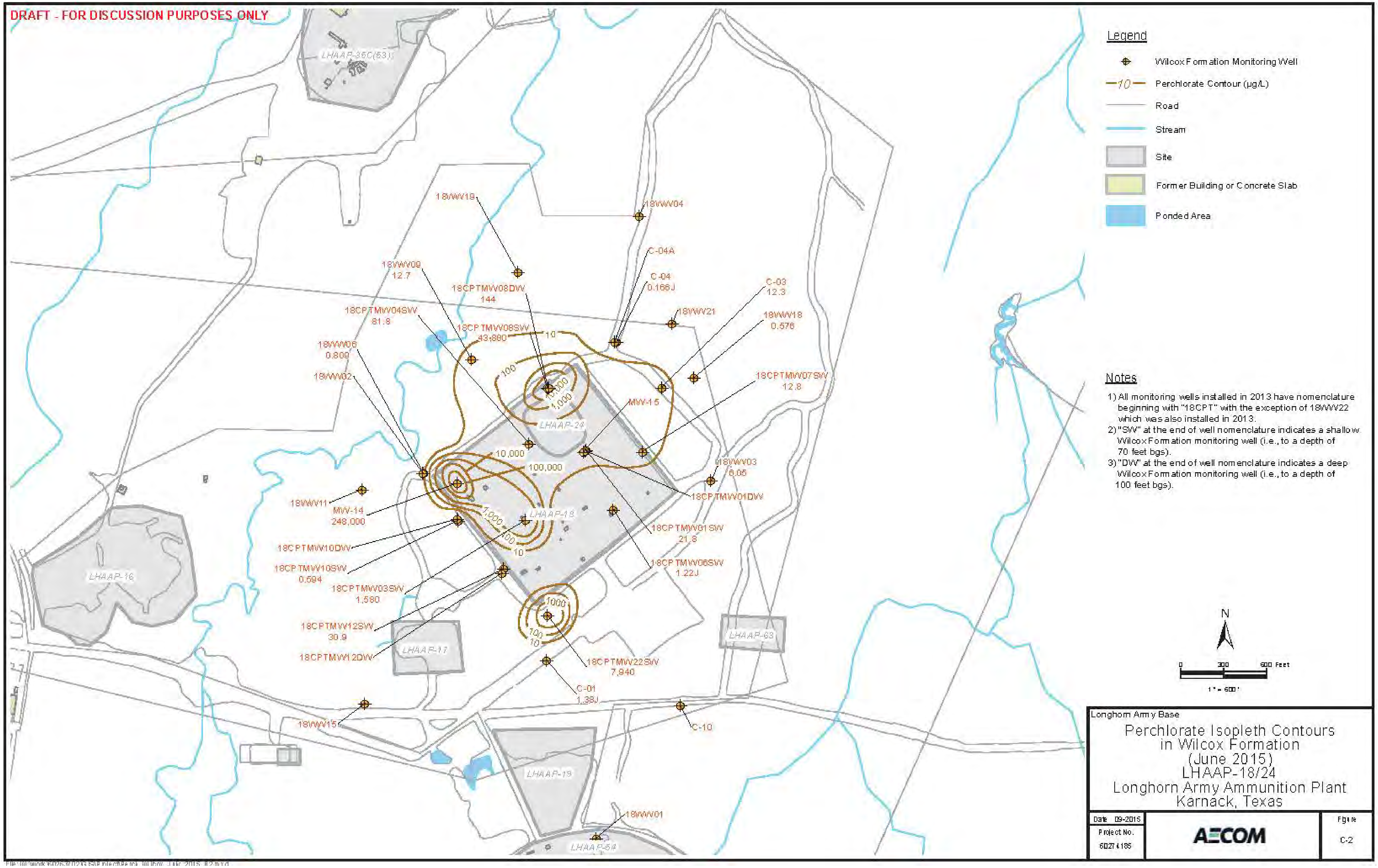
Plot 69. Perchlorate in the middle Wilcox Formation under LHAAP-18-24 – December 2014 (AECOM, 2015c).

DRAFT - FOR DISCUSSION PURPOSES ONLY



Notes

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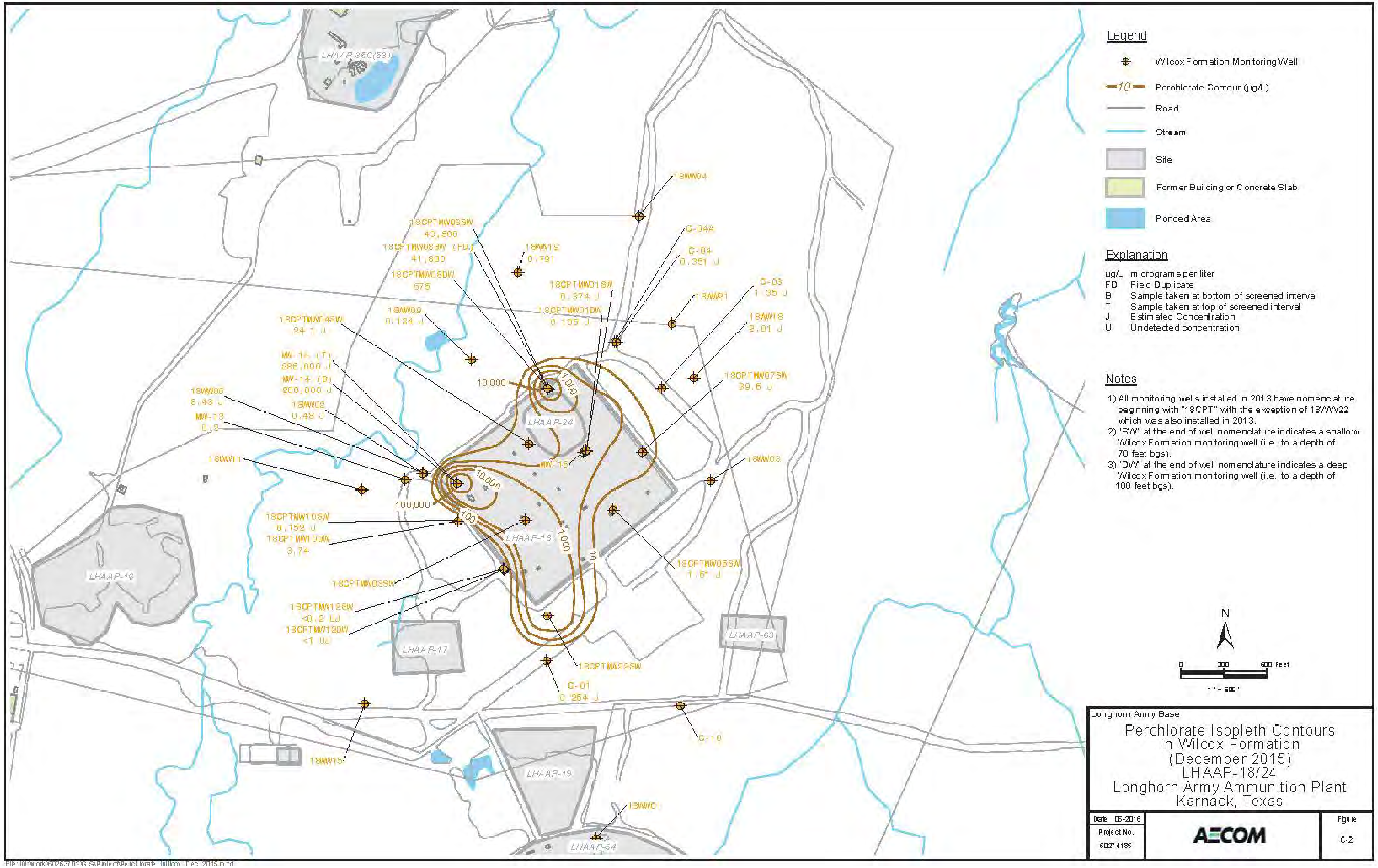
Longhorn Army Base

Perchlorate Isopleth Contours
in Wilcox Formation
(June 2015)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

Date 09-2015
Project No.
60274185
Figure
C-2

Plot 70. Perchlorate in the middle Wilcox Formation under LHAAP-18-24 – June 2015 (AECOM, 2015b).



Legend

⊕ Wilcox Formation Monitoring Well

—10— Perchlorate Contour (µg/L)

— Road

— Stream

▨ Site

▨ Former Building or Concrete Slab

▨ Ponded Area

Explanation

ug/L	micrograms per liter
FD	Field Duplicate
B	Sample taken at bottom of screened interval
T	Sample taken at top of screened interval
J	Estimated Concentration
U	Undetected concentration

Notes

1) All monitoring wells installed in 2013 have nomenclature beginning with "18CPT" with the exception of 18WW22 which was also installed in 2013.
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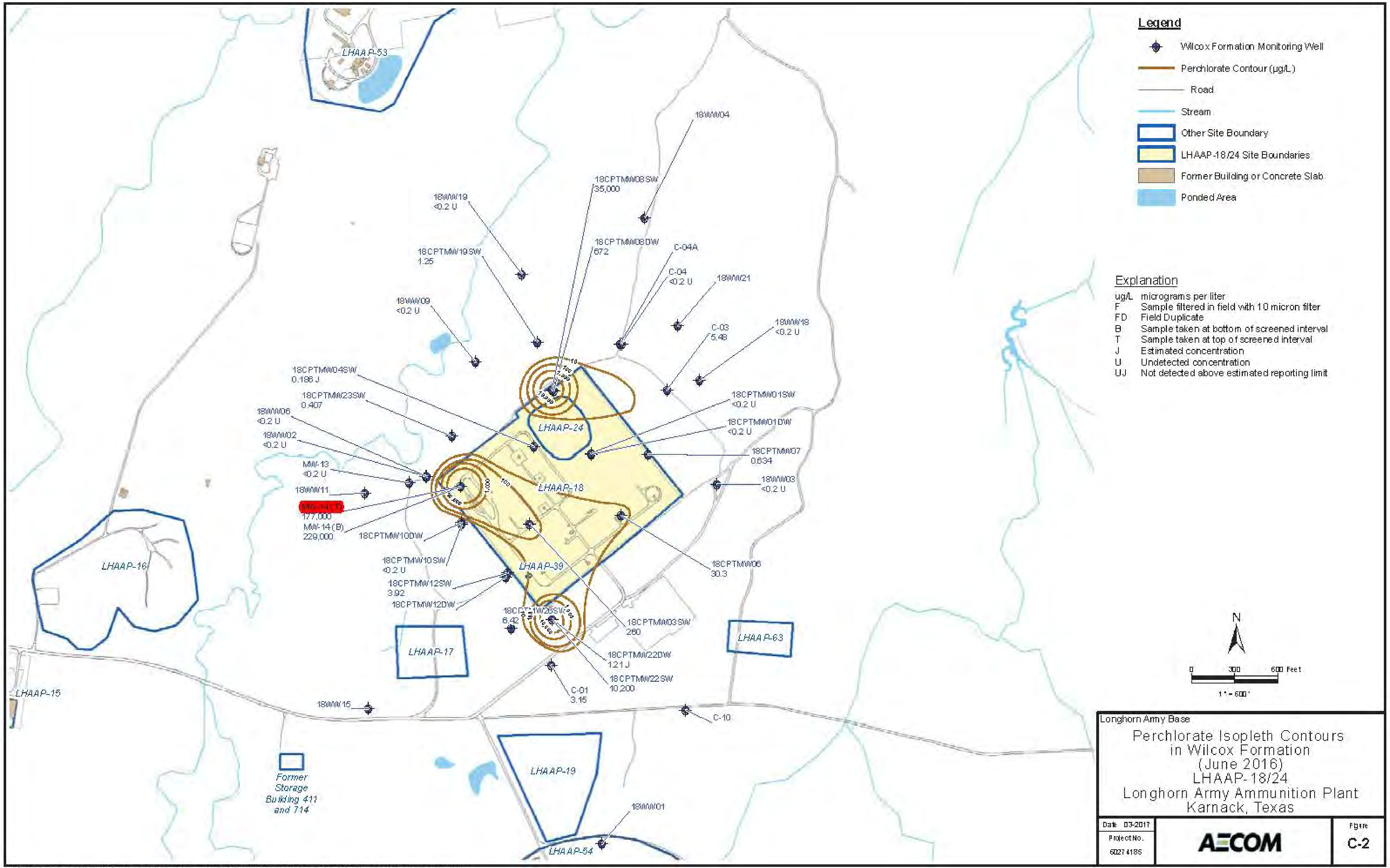
Longhorn Army Base

Perchlorate Isopleth Contours
in Wilcox Formation
(December 2015)
LHAAP-18/24
Longhorn Army Ammunition Plant
Karnack, Texas

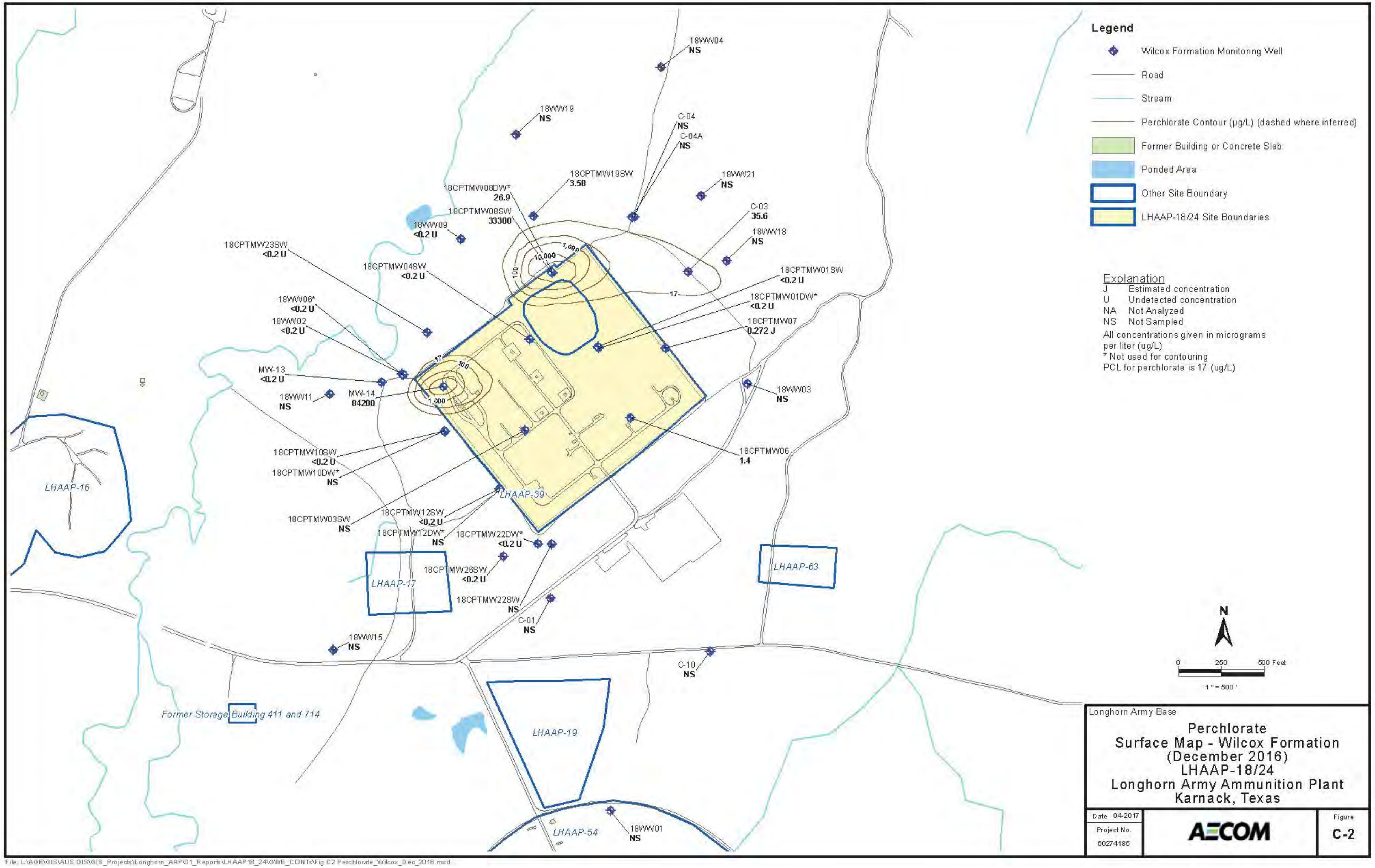
Date 05-2016
Project No.
60274185
Figure
C-2

Plot 71. Perchlorate in the middle Wilcox Formation under LHAAP-18-24 – December 2015 (AECOM, 2016d).

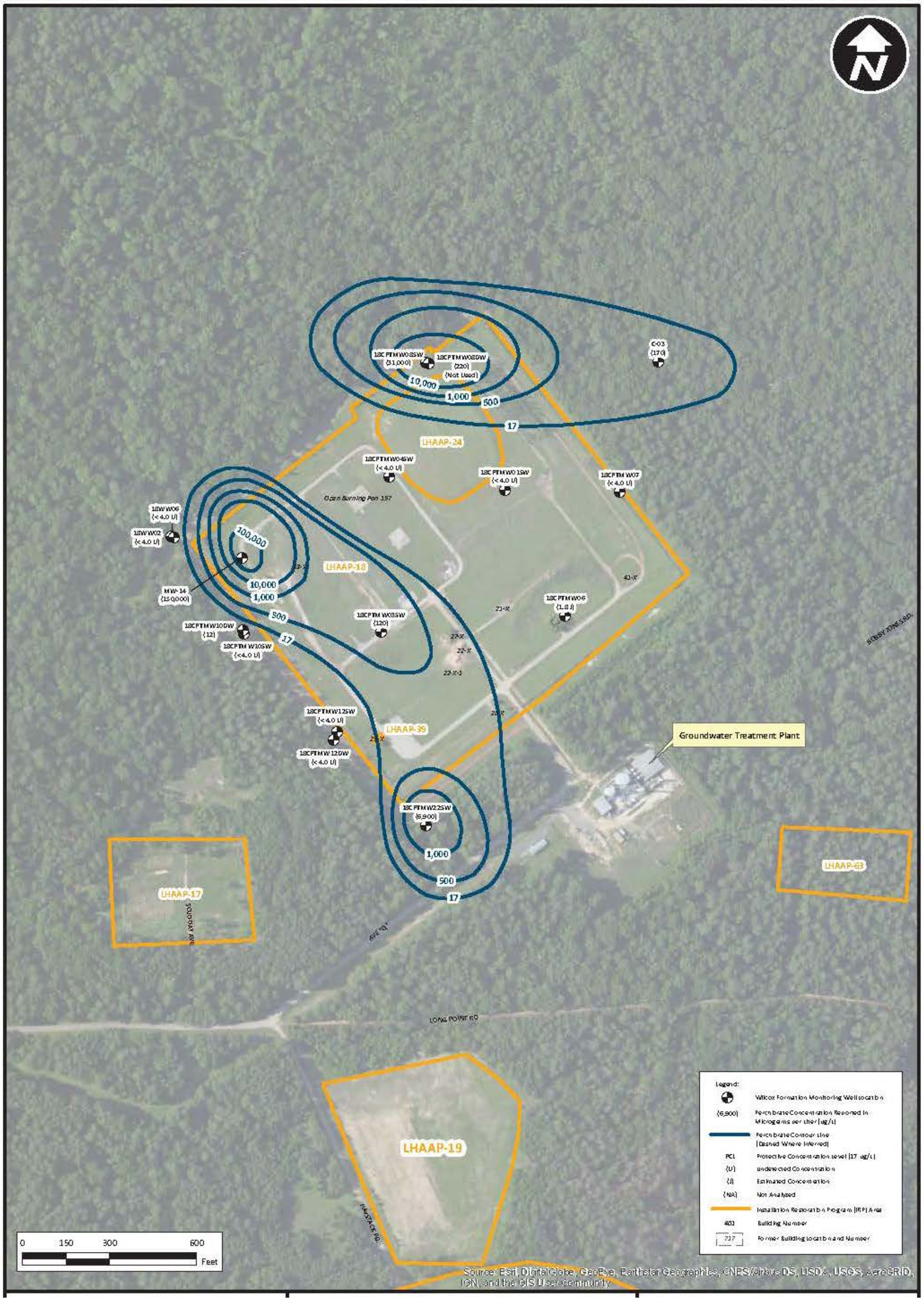


File: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP18_24\QuarterlyGroundReport\Fig C-2 Perch_Wilcox_2016Jun.mxd

Plot 72. Perchlorate and Fourth Five-Year Review spatial distribution of trends (Yellow Highlight = Decreasing Trend, Red Highlight = Increasing Trend), middle Wilcox Formation – June 2016 (AECOM, 2017g).



Plot 73. Perchlorate in the middle Wilcox Formation under LHAAP-18-24 – December 2016 (AECOM, 2017f).



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Plot 74. Perchlorate in the middle Wilcox Formation under LHAAP-18-24 – December 2017 (Bhate, 2018b).

Figure A-12: First-Order Decay Rate Calculation for Attenuation Determination
LHAAP-18/24 Feasibility Study
Longhorn Army Ammunition Plant
Karnack, Texas

18WW08

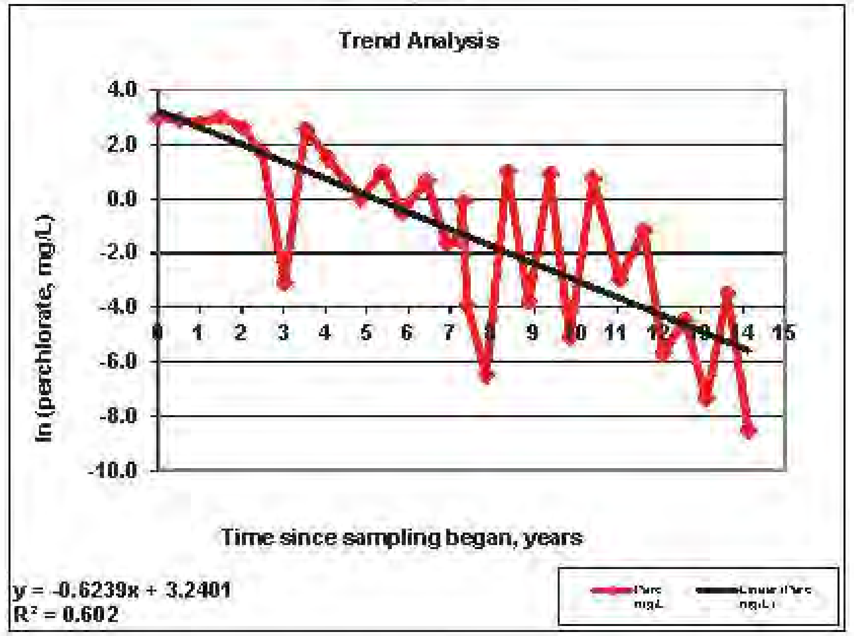
Facility Name: LHAAP 18/24 Feasibility Study - Appendix A Evaluation of Perchlorate Attenuation

Facility Location and Address: ________ Longhorn Army Ammunition Plant, Karnack Texas

COC: Perchlorate

Date: Oct-16

Sampling Date	Perc mg/L	Perc ug/L	ln Perc mg/L	Elapsed time since 10/1/00 years
01-May-02	19.800	19800	2.986	0.00
01-Nov-02	18.400	18400	2.912	0.50
01-May-03	16.400	16400	2.797	1.00
01-Nov-03	20.300	20300	3.011	1.50
01-May-04	14.000	14000	2.639	2.00
01-Nov-04	5.200	5200	1.649	2.51
11-May-05	0.046	45.7	-3.086	3.03
11-Nov-05	13.200	13200	2.580	3.53
18-May-06	4.500	4500	1.504	4.05
06-Mar-07	1.000	1000	0.000	4.85
15-Sep-07	2.750	2750	1.012	5.38
12-Mar-08	0.610	610	-0.494	5.87
01-Oct-08	1.920	1920	0.652	6.42
03-Apr-09	0.190	190	-1.661	6.93
16-Jul-09	0.220	220	-1.514	7.21
14-Aug-09	0.883	883	-0.124	7.29
23-Sep-09	0.020	20	-3.912	7.40
09-Mar-10	0.002	2	-6.502	7.86
07-Sep-10	2.700	2700	0.993	8.36
17-Mar-11	0.023	22.6	-3.790	8.88
15-Sep-11	2.500	2500	0.916	9.38
08-Mar-12	0.006	6.19	-5.085	9.86
26-Sep-12	2.080	2080	0.732	10.42
15-May-13	0.051	51.2	-2.972	11.05
19-Dec-13	0.304	304	-1.191	11.64
03-Jun-14	0.003	3.4	-5.696	12.10
10-Dec-14	0.012	12	-4.448	12.62
16-Jun-15	0.001	0.66	-7.331	13.13
17-Dec-15	0.031	31	-3.480	13.64
20-Jun-16	0.000	0.20	-8.517	14.15
TRRP PCL	*0.017*	*17*		



Solutions

Enter C_{CL}	⇨	17	
Enter C_o	⇨	0.2	
Enter k_{point}	⇨	0.6239	
Time to reach cleanup level		NA	years

Formula $t = -[\ln(CCL/Co)] / kpoint$

where:

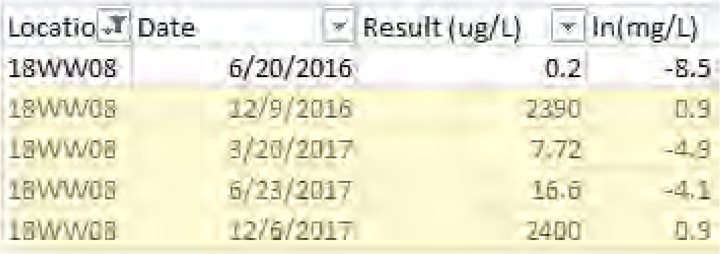
t = Time to achieve cleanup levels, years

C_{CL} = Cleanup level for contaminant of concern, µg/L

C_o = Initial concentration of contaminant of concern, µg/L

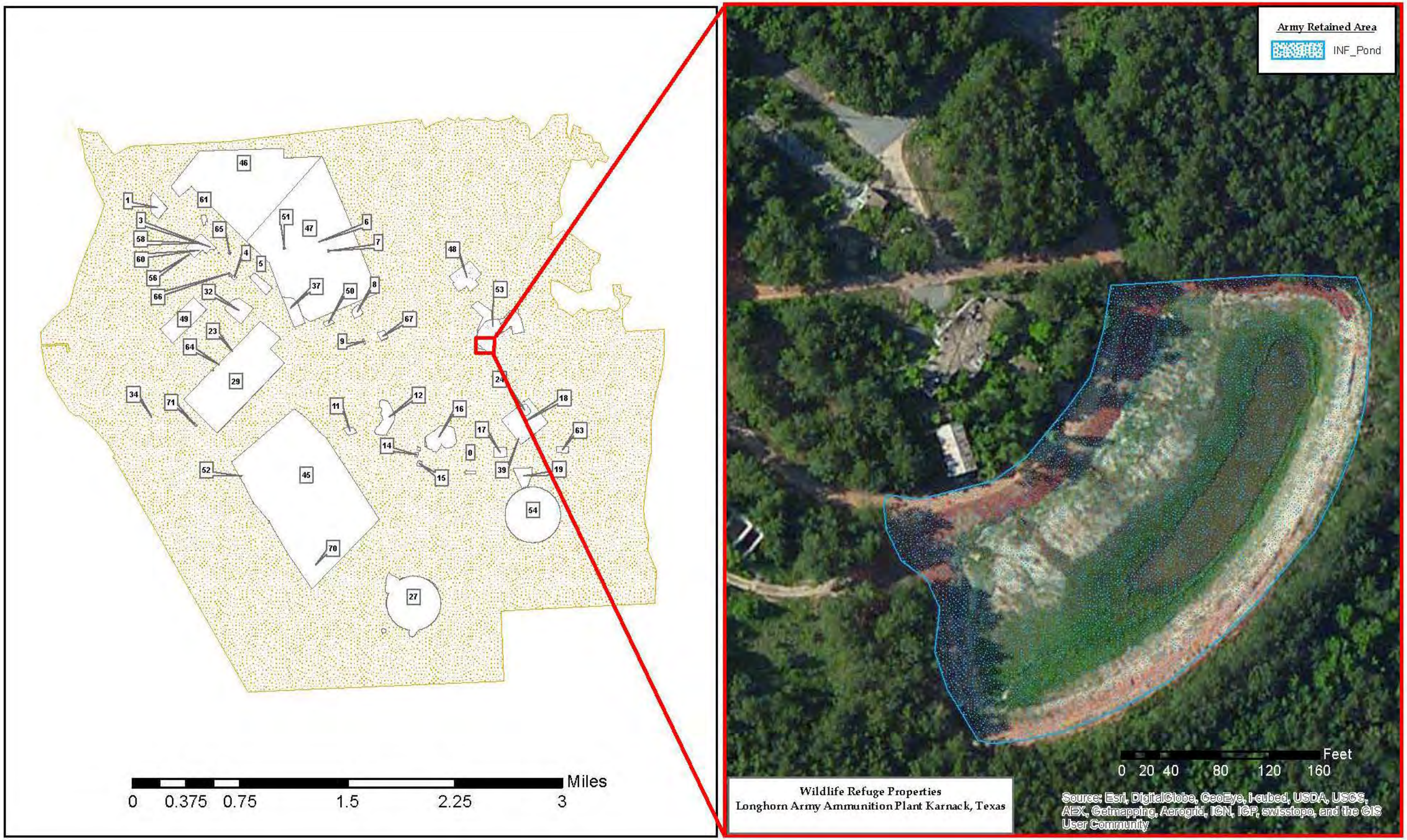
k_{point} = First-order decay rate constant at one monitoring point, years^{-1}

= slope of the line, y

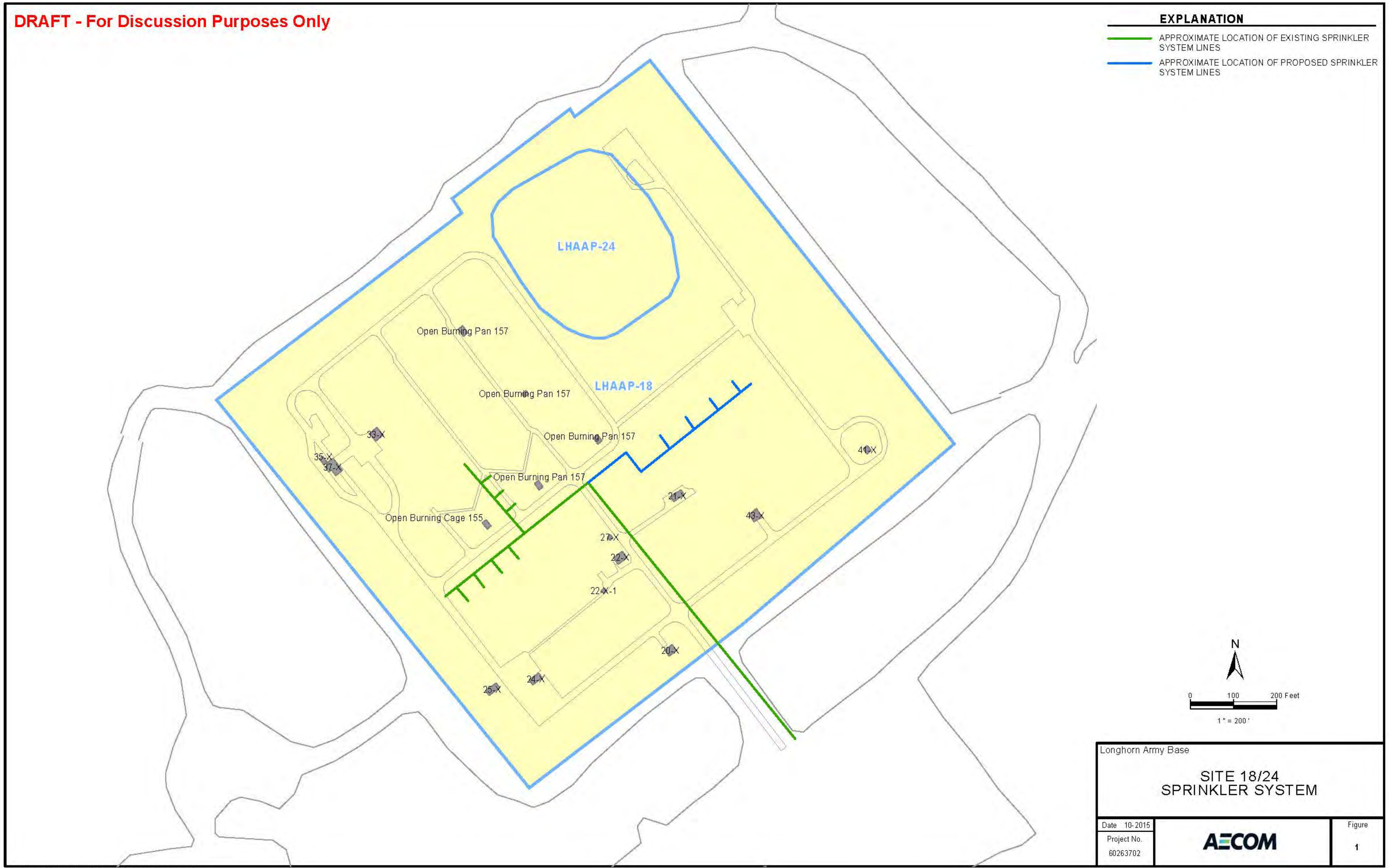


Locatio	Date	Result (ug/L)	ln(mg/L)
18WW08	6/20/2016	0.2	-8.5
18WW08	12/9/2016	2390	0.9
18WW08	3/20/2017	7.72	-4.9
18WW08	6/23/2017	16.6	-4.1
18WW08	12/6/2017	2400	0.9

Plot 75. LHAAP-18-24 Perchlorate Trend Analysis – 18WW08 (AECOM, 2017a and Fourth Five-Year Review's posting of recent data)

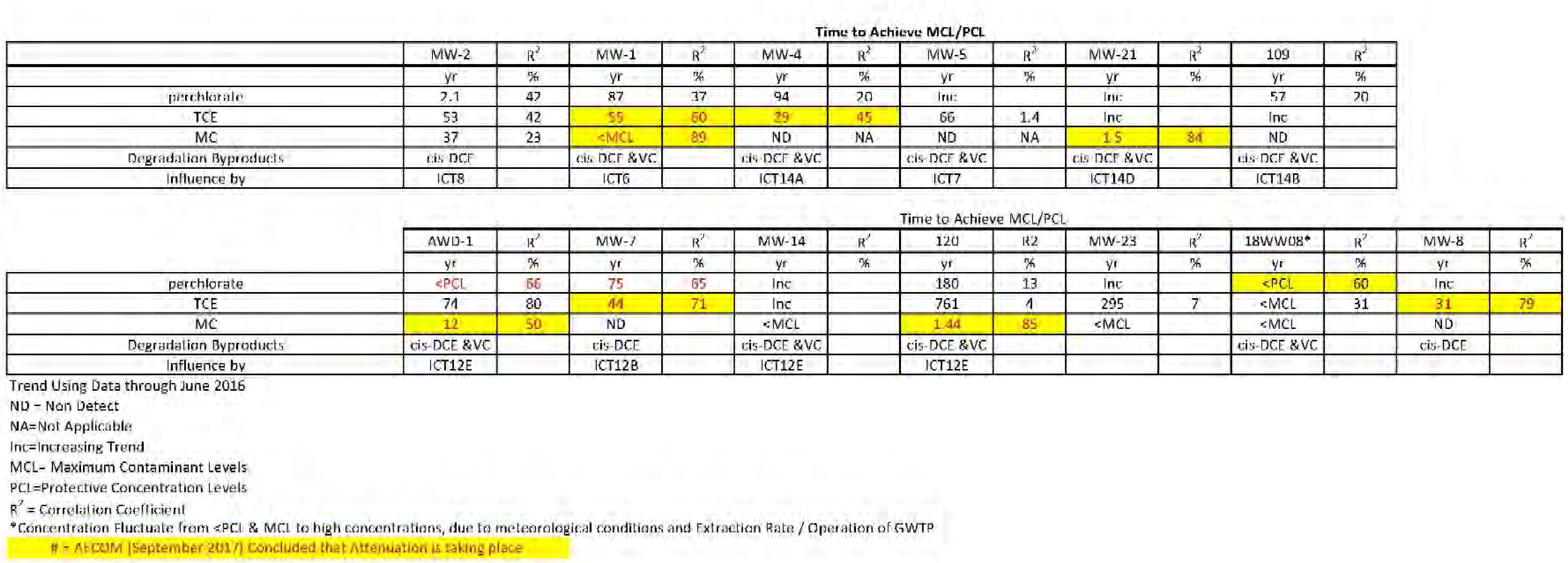


Plot 76 Location of INF Pond that receives GWTP treated effluent.



File: W:\work\60263702\GIS\Project\Sprinkler_System.mxd

Plot 77 Lo cation and configuration of LHAAP-18/24 sprinkler system.



Time to Achieve MCL/PCL

	MW-2	R^2	MW-1	R^2	MW-4	R^2	MW-5	R^2	MW-21	R^2	109	R^2
	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%
perchlorate	2.1	42	87	37	94	20	Inc		Inc		57	20
TCE	53	42	55	60	29	45	66	1.4	Inc		Inc	
MC	37	23	<MCL	89	ND	NA	ND	NA	1.5	84	ND	
Degradation Byproducts	cis-DCE		cis-DCE &VC		cis-DCE &VC		cis-DCE &VC		cis-DCE &VC		cis-DCE &VC	
Influence by	ICT8		ICT6		ICT14A		ICT7		ICT14D		ICT14B	

Time to Achieve MCL/PCL

	AWD-1	R^2	MW-7	R^2	MW-14	R^2	120	R2	MW-23	R^2	18WW08*	R^2	MW-8	R^2
	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%	yr	%
perchlorate	<PCL	66	75	65	Inc		180	13	Inc		<PCL	60	Inc	
TCE	74	80	44	71	Inc		761	4	295	7	<MCL	31	31	79
MC	12	50	ND		<MCL		1.44	85	<MCL		<MCL		ND	
Degradation Byproducts	cis-DCE &VC		cis-DCE		cis-DCE &VC		cis-DCE &VC				cis-DCE &VC		cis-DCE	
Influence by	ICT12E		ICT12B		ICT12E		ICT12E							

Trend Using Data through June 2016

ND – Non Detect

NA=Not Applicable

Inc=Increasing Trend

MCL– Maximum Contaminant Levels

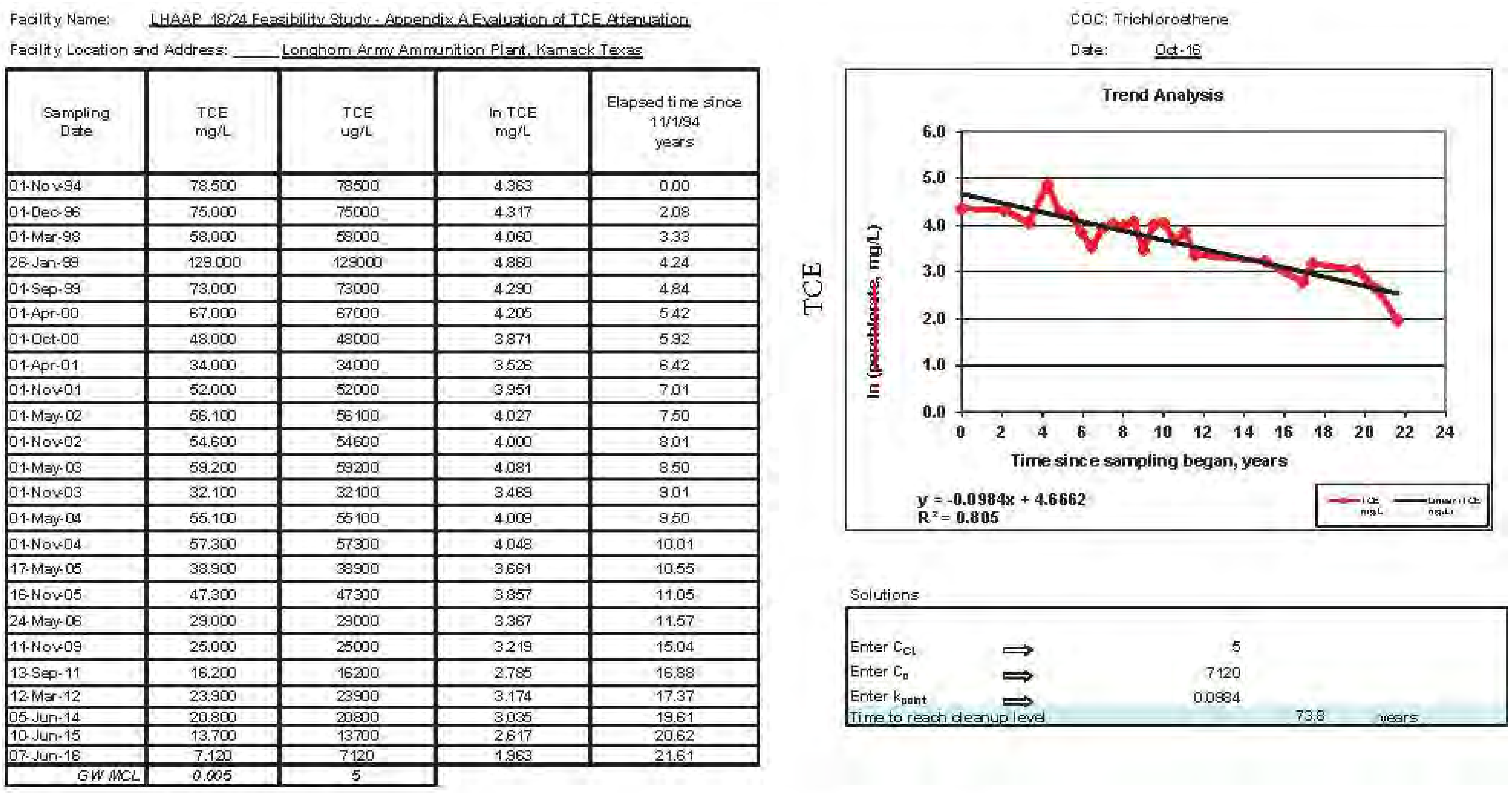
PCL=Protective Concentration Levels

R^2 = Correlation Coefficient

*Concentration Fluctuate from <PCL & MCL to high concentrations, due to meteorological conditions and Extraction Rate / Operation of GWTP

– AECOM (September 2017) Concluded that Attenuation is taking place

Plot 78. Estimated time to achieve LHAAP-18/24 MCL/PCL (AECOM, 2017a. Trend Analysis Using Data through June 2016) (MC is methylene chloride).



Facility Name: LHAAP 18/24 Feasibility Study - Appendix A Evaluation of TCE Attenuation

COC: Trichloroethene

Facility Location and Address: Longhorn Army Ammunition Plant, Karnack Texas

Date: Oct-16

Sampling Date	TCE mg/L	TCE ug/L	ln TCE mg/L	Elapsed time since 11/1/94 years
01-Nov-94	78.500	78500	4.363	0.00
01-Dec-96	75.000	75000	4.317	2.08
01-Mar-98	58.000	58000	4.060	3.33
26-Jan-99	129.000	129000	4.860	4.24
01-Sep-99	73.000	73000	4.290	4.84
01-Apr-00	67.000	67000	4.205	5.42
01-Oct-00	48.000	48000	3.871	5.92
01-Apr-01	34.000	34000	3.526	6.42
01-Nov-01	52.000	52000	3.951	7.01
01-May-02	56.100	56100	4.027	7.50
01-Nov-02	54.600	54600	4.000	8.01
01-May-03	59.200	59200	4.081	8.50
01-Nov-03	32.100	32100	3.469	9.01
01-May-04	55.100	55100	4.009	9.50
01-Nov-04	57.300	57300	4.048	10.01
17-May-05	38.900	38900	3.661	10.55
16-Nov-05	47.300	47300	3.857	11.05
24-May-06	29.000	29000	3.367	11.57
11-Nov-09	25.000	25000	3.219	15.04
13-Sep-11	16.200	16200	2.785	16.88
12-Mar-12	23.900	23900	3.174	17.37
05-Jun-14	20.800	20800	3.035	19.61
10-Jun-15	13.700	13700	2.617	20.62
07-Jun-16	7.120	7120	1.963	21.61
GW MCL	*0.005*	5		

Solutions

Enter C_{CL} ⇨ 5

Enter C_o ⇨ 7120

Enter k_{point} ⇨ 0.0984

Time to reach cleanup level 73.8 years

Formula $t = -[ln(CCL/Co)] / kpoint$

where:

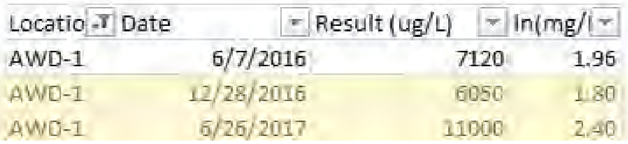
t = Time to achieve cleanup levels, years

C_{CL} = Cleanup level for contaminant of concern, µg/L

C_o = Initial concentration of contaminant of concern, µg/L

k_{point} = First-order decay rate constant at one monitoring point, years^{-1}

= slope of the line, y



Locatio	Date	Result (ug/L)	ln(mg/l
AWD-1	6/7/2016	7120	1.96
AWD-1	12/28/2016	6050	1.80
AWD-1	6/26/2017	11000	2.40

Plot 79. LHAAP-18/24 TCE Trend Analysis – AWD-1 (AECOM, 2017a and Fourth Five-Year Review's posting of recent data).

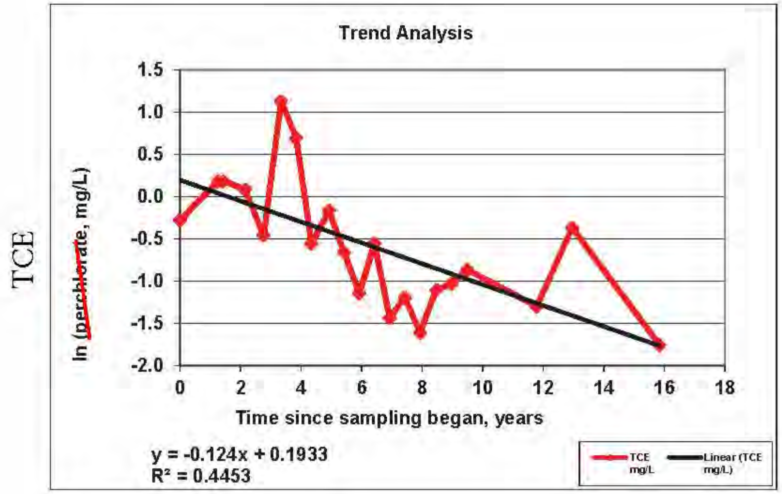
Facility Name: LHAAP 18/24 Feasibility Study - Appendix A Evaluation of TCE Attenuation

COC: Trichloroethene

Facility Location and Address: Longhorn Army Ammunition Plant, Karnack Texas

Date: Oct-16

Sampling Date	TCE mg/L	TCE ug/L	ln TCE mg/L	Elapsed time since 12/1/96 years
01-Dec-96	0.757	757	-0.278	0.00
01-Mar-98	1.200	1200	0.182	1.25
01-May-98	1.200	1200	0.182	1.41
21-Jan-99	1.090	1090	0.086	2.14
01-Sep-99	0.630	630	-0.462	2.75
01-Apr-00	3.100	3100	1.131	3.33
01-Oct-00	2.000	2000	0.693	3.84
01-Apr-01	0.570	570	-0.562	4.33
01-Nov-01	0.850	850	-0.163	4.92
01-May-02	0.517	517	-0.660	5.42
01-Nov-02	0.318	318	-1.146	5.92
01-May-03	0.572	572	-0.559	6.42
01-Nov-03	0.237	237	-1.440	6.92
01-May-04	0.302	302	-1.197	7.42
01-Nov-04	0.199	199	-1.614	7.92
17-May-05	0.331	331	-1.106	8.46
16-Nov-05	0.355	355	-1.036	8.96
24-May-06	0.419	419	-0.870	9.48
10-Sep-08	0.272	272	-1.302	11.78
10-Nov-09	0.690	690	-0.371	12.95
29-Sep-12	0.173	173	-1.757	15.84
GW MCL	*0.005*	5		



Solutions

Enter C_{CL}	⟹	5	
Enter C_o	⟹	173	
Enter k_{point}	⟹	0.1240	
Time to reach cleanup level		28.6	years

Formula $t = -[\ln(CCL/Co)] / kpoint$

where:

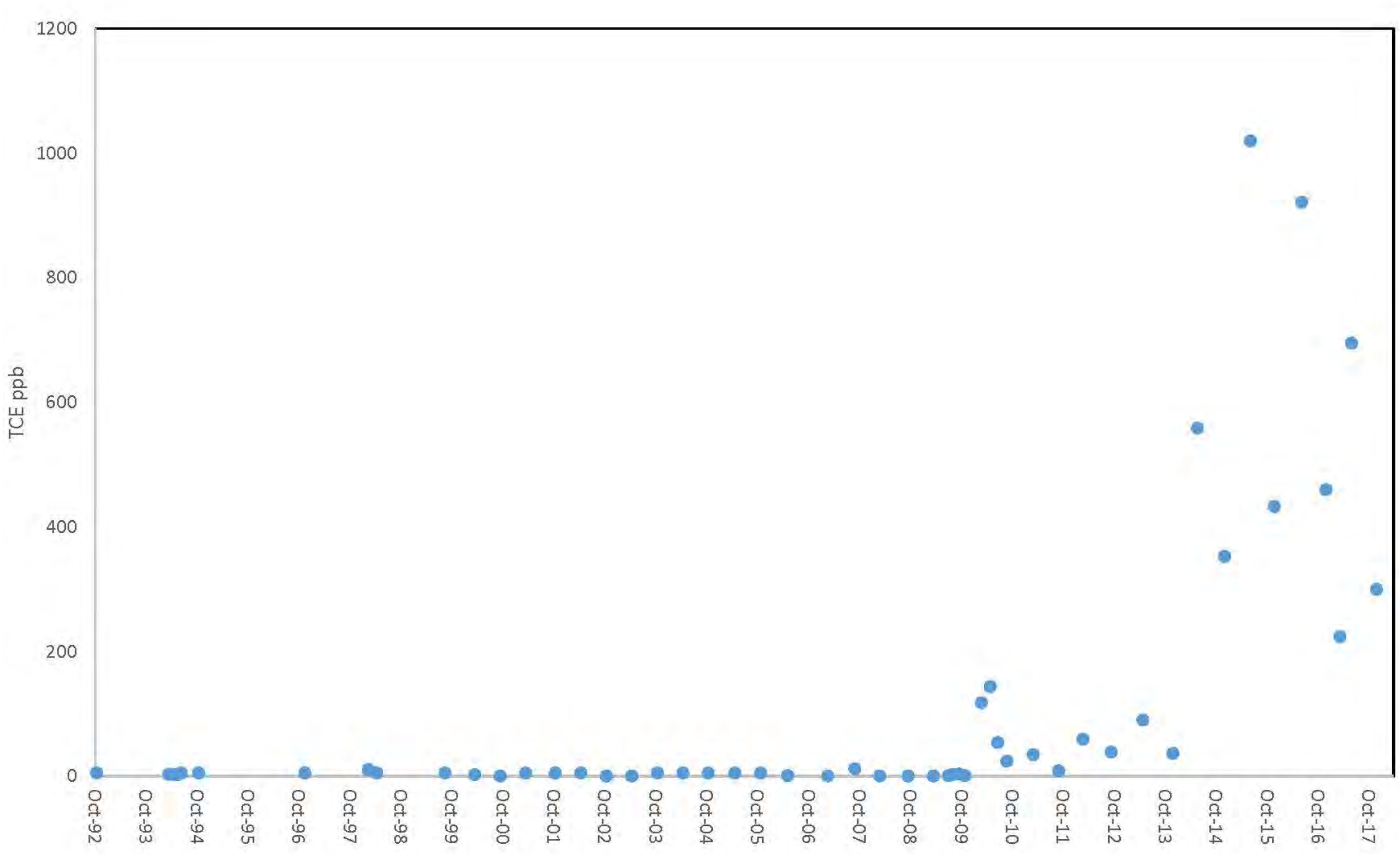
t = Time to achieve cleanup levels, years

C_{CL} = Cleanup level for contaminant of concern, µg/L

C_o = Initial concentration of contaminant of concern, µg/L

k_{point} = First-order decay rate constant at one monitoring point, years^{-1}
= slope of the line, y

Plot 80. LHAAP-18/24 TCE Trend Analysis – MW-4 (AECOM, 2017a and Fourth Five-Year Review's posting of recent data).



Plot 81. MW-16 TCE Concentrations, LHAAP 18/24 (USAEC, 2018)

4.0 LHAAP-46

4.1 MNA Monitoring Network

4.1.1 Groundwater

Groundwater flow direction in the Shallow Groundwater Zone has been consistently east toward Goose Prairie Creek, 1,500 feet down slope from the site (e.g., Plot 82, see also Figure 3) (AECOM, 2017k, 2016j, 2015e, g). The groundwater flow direction in the intermediate groundwater zone is northwest to northeast (e.g., Plot 83). Greater than 3 foot difference in groundwater elevations seen in the Shallow and Intermediate Groundwater Zone wells suggests some degree of hydraulic separation between these zones, but COCs in the Shallow Groundwater Zone are also present in the Intermediate Groundwater Zone (Plot 84 and Plot 85) so the clay separating the two zones acts as a leaky aquitard.

Only one groundwater monitoring well (46WW03, Plot 86) is completed in the Deep Groundwater Zone. Communication between the intermediate groundwater zone and the Deep Groundwater Zone is limited because the difference in groundwater elevations in co-located wells 46WW02 (intermediate well, Plot) and 46WW03 (deep well, Plot 86) have stayed near 3.5 ft during the 2nd and 3rd year RA(O) periods. COCs were not detected in the deep well 46WW03 located within the COCs plume centers of the Intermediate Groundwater Zone (Plot 85 and Plot 86).

4.1.2 Surface Water Sampling

In 2013 and 2014, surface water samples were taken from 46SW09 (Plot 86) located in Goose Prairie Creek adjacent to LHAAP-46. In response to USEPA comments on the LHAAP-46 draft RACR report (AECOM, 2015e), the surface water sample location was subsequently relocated from 46SW09 to 46SW10. Surface water sample 46SW10 is located in the tributary to Goose Prairie Creek (Plot 86). Sample location 46SW10 is downgradient of the Intermediate Groundwater Zone’s groundwater plume but is cross gradient from the Shallow Groundwater Zone’s groundwater plume. No VOCs were detected in the surface water sample.

The source pathway is currently incomplete because the footprints of COCs do not extend to surface water bodies and because the COC plumes at LHAAP-46 appears to be stable or decreasing and are not migrating under the current meteorological conditions.

4.2 MNA Performance

4.2.1 Spatial and Temporal Variation in COCs

Plume delineation activities were performed subsequent to issuance of the ROD (US Army, 2010c), during the period of February through May 2013 and May through July 2014. Therefore, the TCE footprints of the Shallow and Intermediate Groundwater Zones delineated in the ROD (Plot 84 and Plot 85) cannot be used in the stability analysis.

4.2.1.1 Shallow Groundwater Zone

The Shallow Groundwater Zone TCE footprint delineated in the ROD (Plot 84) which included only one well LHSMW19 was revised to include wells 46WW11 and 46WW13 (AECOM, 2015e) where TCE exceeded the MCL (Plot 87). The revised TCE footprint in the Shallow Groundwater Zone utilized the historical data collected through May 2013 including the old and new Shallow Groundwater Zone monitoring wells. The difference between the ROD's footprint and the revised footprint is due to the addition of new monitoring wells rather than increase in the areal extent of the footprint. Although, TCE concentrations in monitoring well LHSMW18 exceeded MCL between 1994 and 1998 it is not included in the TCE footprint because TCE and its biodegradation byproduct were non-detect in subsequent sampling events (Plot 87). The COC data over the monitoring period indicate that the Shallow Groundwater Zone plume is stable with decreasing concentrations observed over the last two years.

Based on the direction of Shallow Groundwater Zone flow (towards the east, Plot 82, the following wells are considered to be along the groundwater flow paths (Plot 87):

- 46WW10, LHSMW19, 46WW11, 46WW12, and LHSMW24; and
- 46WW04, LHSMW18, 46WW13, and 46WW15.

Monitoring well 46WW10 is considered a background well for the Shallow Groundwater Zone. The COCs in upgradient well 46WW10 have remained below the MCLs throughout its monitoring history. The in-plume wells (LHSMW19 and 46WW11) exhibit the highest levels of COCs along this plume path, which have generally remained stable, with a recent decreasing trend (Plot 87). The downgradient well 46WW12 was never sampled because it was dry. Monitoring well LHSMW24 was dry in recent sampling events and is no longer included in the monitoring program; however, historical results for the period between 1994 and 1998 for LHSMW24 were below the detection limits for TCE, cis-1,2-DCE, and VC, with the reporting limits below the MCLs.

The Mann-Kendall trend analysis (AECOM, 2017k) indicates TCE concentrations decreasing in plume center Shallow Groundwater Zones monitoring wells LHSMW19 and 46WW11 (Plot 87, Plot 88, and Plot 89), with TCE concentrations at 4LHSMW19 lower than MCL in the most recent sampling event of 2018. The trend analysis results performed for Fourth Five-Year Review are in line with the O&M results showing decreasing trend in TCE concentrations in LHSMW19 and 46WW11 (Figure 24). Limited data is available for well 46WW13, where concentrations of TCE, cis-1,2DCE, and VC were elevated above the MCL in 2013 (Plot 87), because the well was dry in all sampling events subsequent to 2013 (Plot 86). Cis-1,2-DCE and VC exceeded the MCL in the Shallow Groundwater Zone only in 46WW13. Well 46WW15, located hydraulically downgradient of LHSMW13, was not sampled because it was dry in all sampling events. COCs in Wells LHSMW27 and LHSMW24 (Plot 87), located further side/down gradient, sampled in 1996 and 1998, and in 2016 were ND. .

Along the flow path of 46WW04, LHSMW18, 46WW13, and 46WW15, well 46WW04 is an upgradient, clean well. Historically, TCE was detected above the MCL in LHSMW18 (in-plume well, Plot 90), but concentrations decreased below the MCL in February 2007 and remained below the MCL in March 2016. Samples from monitoring well 46WW13 exceeded the MCL for TCE and VC (Plot 90) in May 2013 and September 2013, but the well was dry in 2014, 2015, and 2016 (Plot 86). Monitoring well 46WW15 was installed approximately 150 ft east (downgradient) of well 46WW13 to bound the plume to the east in a downgradient direction, but well 46WW15 was dry and could not be sampled for the entire 3-year RA(O) period. Monitoring wells east (downgradient) of the Shallow Groundwater Zone plume are dry. Monitoring wells 46WW15, LHSMW22, and 46WW12, located east of 46WW13, 46WW01, and 46WW11, respectively, have been dry since May 2013 and have not been sampled (Plot 86).

Although direction of groundwater flow is toward the east, the potential exposure point, the ditch upstream of Goose Prairie Creek (Plot 86), is along the northern perimeter of the plume. Wells 46WW12, LHSMW20 and LHSMW21 bound the plume to the north. Historically COCs concentrations in LHSMW20 were ND and COCs concentrations in LHSMW21 were below the MCL. The last sampling event in LHSMW20 was in 2008 and the last sampling events in LHSMW21 was in 2013. Wells LHSMW20 and 46WW12 were not sampled subsequently because they were dry. Well LHSMW21, located immediately adjacent to the ditch was not sampled even though this well was not dry.

4.2.1.2 Intermediate Groundwater Zone

The Intermediate Groundwater Zone TCE footprint delineated in the ROD (Plot 85) includes two wells 46WW02 and 46WW05. Subsequent to the installation of the new monitoring wells the footprint was refined (AECOM, 2015e) to include two separate footprints one centered around 46WW02 and one centered around 46WW05 (Plot 87). In well 46WW05 concentrations of 1,1-DCE and VC also exceeded their MCLs of 7 and 2 µg/L, respectively. Trend plots of TCE and biodegradation byproducts in these wells are shown in Plot 91.

Intermediate Groundwater Zone flow is northwest and northeast toward the installation boundary and offsite water supply wells (Plot 83, Plot 84, and Figure 2). The following wells are considered to be along the groundwater flow path: 46WW02, 46WW09, 46WW05, and 46WW16 (Plot 87). Additionally, well LHSMW23 is considered a background well for the Intermediate Groundwater Zone, although it was not sampled during the monitoring period. Contaminated groundwater near wells 46WW02 and 46WW05 occurs in two separate, isolated plumes (Plot 87). COCs have not been detected above MCLs at well 46WW09, which is located between impacted wells 46WW02 and 46WW05. In addition, no COCs above the MCL have been detected in downgradient well 46WW16. Therefore, based on the inferred flow path (using the groundwater flow direction), COC levels are not increasing with distance from the source area, as evidenced by non-detection of COCs in downgradient wells (46WW09 downgradient of 46WW02, and 46WW16 downgradient of 46WW05).

Concentrations of COCs in wells surrounding the most impacted wells (46WW02 and 46WW05) have not increased and no new COCs have been detected at boundary area wells, indicating no plume migration.

A Mann-Kendall trend analysis conducted by O&M (AECOM, 2017k) included TCE in wells 46WW02 (Plot 92), and TCE, VC, and 1,1-DCE in well 46WW05 (Plot 93 through Plot 95). Results of the trend analysis for TCE, VC, and 1,1-DCE indicate a decrease in COCs with 95 % confidence at 46WW05. The Fourth Five-Year Review trend analysis for TCE in well 46WW05 (Figure 28) are in line with the declining trend results reported by the O&M. The Fourth Five-Year Review trend analysis results for VC and 1,1-DCE in well 46WW05 show insufficient data, a designation that is assigned when a trend analysis is not performed, when there is insufficient data and/or concentrations are less than 10xMCL (see Appendix C section 1.3). In this case VC and 1,1-DCE concentrations in 46WW05 were less than 10XMCL (Plot 94 and Plot 95). The Army's 3rd quarter GWTP evaluation report for April through June 2017 indicates there was insufficient statistical evidence for trend at the 95% confidence level for TCE at 46WW02 (AECOM, 2017k).

4.2.1.3 Deep Groundwater Zone

The deep zone well at LHAAP-46, 46WW03 (Plot 87) was installed during the investigation phase. No COCs were detected in this well.

4.2.2 Geochemical Indicators

The qualitative assessment of geochemical indicators in the groundwater at LHAAP-46 indicates current geochemical conditions are less than optimal for MNA, and that the conditions within the plume currently do not support complete reductive dechlorination. The last sampling event for geochemical parameters took place in 2014. The entire data is provided in Table 2-2 of the 2nd year RA(O) (AECOM, 2016j) and key findings are summarized below:

- DO levels in the Shallow and Intermediate Groundwater Zones wells in most wells and most of the time were low, in general < 1 mg/L. These conditions are favorable conditions for MNA through reductive dechlorination of chlorinated ethenes and ethanes.
- Field Oxidation-Reduction Potential (ORP) levels in Shallow and Intermediate Groundwater Zones in most wells, including the COC impacted wells, are elevated greater than 50 mV most of the time, indicating that the water bearing zones are not reaching anaerobic conditions favorable for the biological reductive dechlorination of chlorinated ethenes and ethanes.
- Ferrous iron and methane levels were low while sulfate levels were elevated confirming that methanogenesis, and iron or sulfate reducing conditions which indicate that the aquifer is anaerobic are not present.
- Total Organic Carbon (TOC) levels were relatively low (<20 mg/L) indicating insufficient concentrations of organic carbon required to sustain microbial activity.
- Ethane and ethene, the two end products of the reductive dechlorination pathways were below the laboratory reporting limits, indicating that complete reductive dechlorination is not taking place.
- Dechlorinating bacteria such as dehalococcoides ethenogenes and associated functional genes have not been measured at this site.

Although the geochemical indicators conditions are less than optimal for MNA, degradation products (cis-1,2-DCE and VC) have been detected in the plume monitoring wells. Furthermore, the computed values of site-specific first order decay rates for TCE estimated from temporal trends of TCE are identical for the Shallow and Intermediate Groundwater Zones and are within the range of the literature values reported for reductive dechlorination.

4.2.3 Time to Restoration

The decline in TCE concentrations noted since 2013 and the presence of cis-1,2-DCE and VC in the Shallow Groundwater Zone provide lines of evidence that attenuation is occurring. A first order decay rate of 1E-03 1/day (Plot 97) is estimated for TCE at 46WW11. This first order decay rate is within the literature range of 8.2E-04 to 8.7 E-03 1/day for reductive de-chlorination (Biochlor, March 2002). A restoration time for TCE of approximately 8 years is calculated using the declining trend at 46WW11 (Plot 97) and TCE concentrations reported in 2013, below the lower range of 23 years estimated for MNA in 2010's ROD (US Army, 2010c). The ROD's the estimated restoration time of 23 years could vary by one order of magnitude due to heterogeneity (i.e., restoration time could be up to 230 years). Restoration time for LHSMW19 was not calculated because the TCE concentration in this well was below the MCL in 2018. However, it is not clear whether TCE concentrations in this well will remain below MCL, because the historical increasing trend (Plot 90) noted between 1994 and 2007 cannot be explained. In addition, numerous wells have been dry through all monitoring events that took place since 2013 (Plot 86). Attempts to correlate the historical and recent trends in TCE concentrations at LHSMW19 to precipitation records (NOAA, 2018) were not successful.

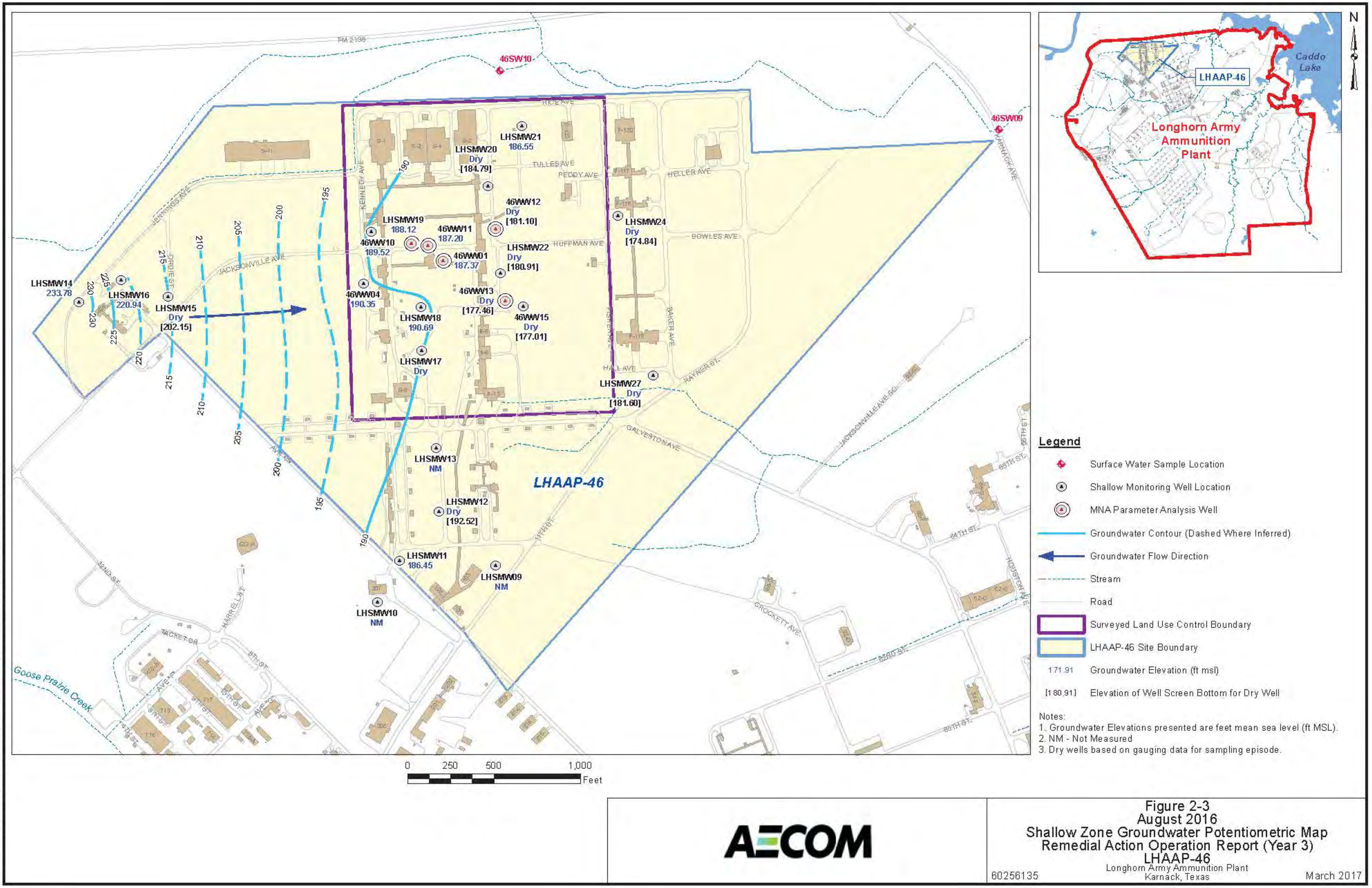
The decline in TCE concentrations noted since 2013 and the presence of cis-1,2 DCE and VC in the Intermediate Groundwater Zone provide the line of evidence that attenuation is occurring. A first order decay rate of 1E-03 1/day (Plot 96) is estimated for TCE at 46WW05. This first order decay rate is the same as that computed for TCE in the Shallow Groundwater Zone at well 46WW11. This first order decay rate is within the literature range of 8.2E-04 to 8.7 E-03 1/day for reductive de-chlorination (Biochlor, March 2002). Restoration time for TCE of approximately 8 years was calculated using the declining trend at 46WW05 (Plot 96) and maximum TCE concentrations reported in July 2014, below the lower range of 23 years estimated for MNA in 2010's ROD (US Army, 2010c). A restoration time for 46WW02 was not calculated because the Mann-Kendall indicates insufficient statistical evidence for a significant trend at the 95% confidence.

4.3 Data Analysis Summary

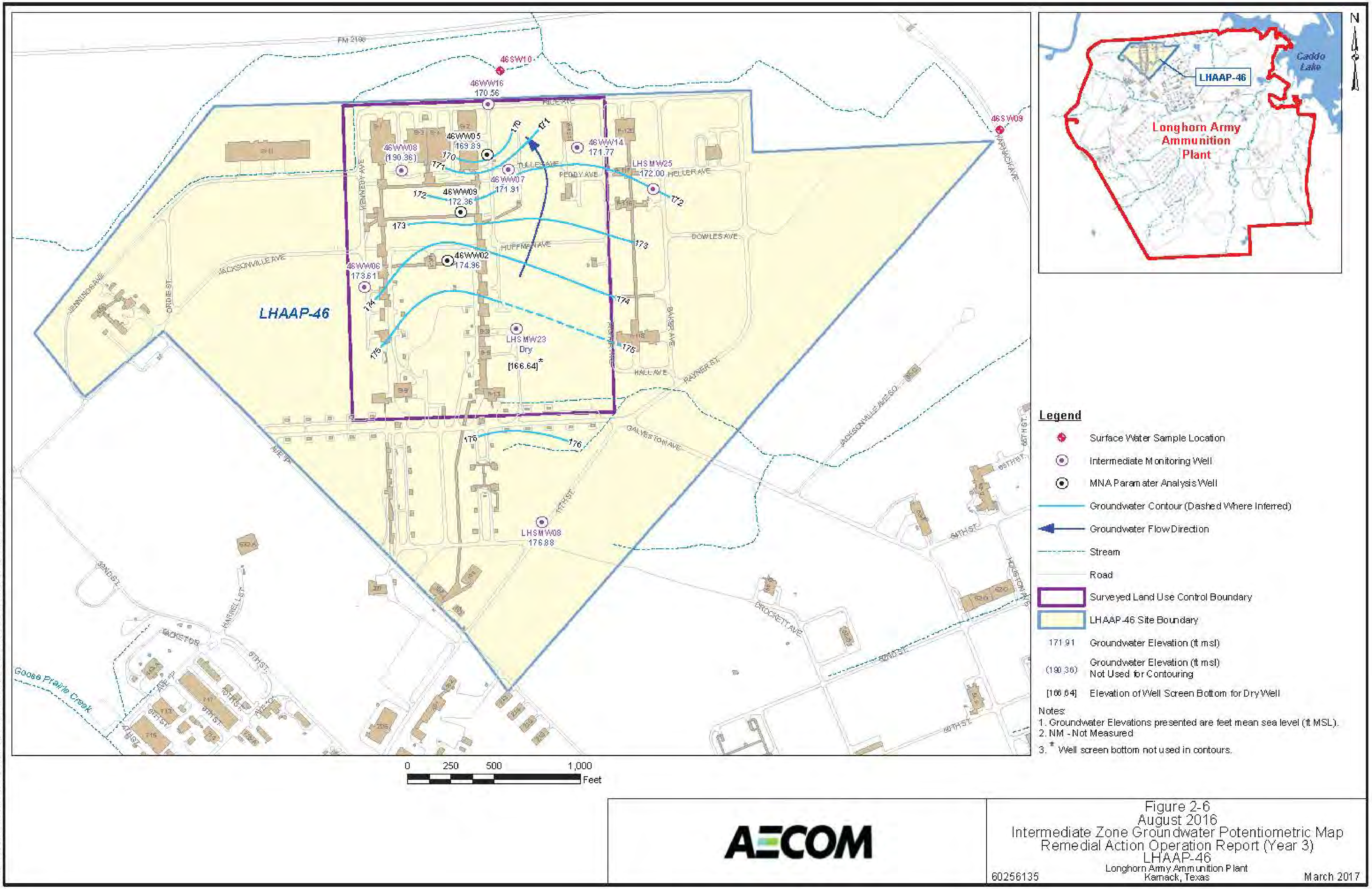
MNA appears to have stabilized the COCs' plumes. TCE and its initial breakdown products are the only site wide COCs in the Shallow Groundwater Zone. TCE concentrations in wells LHSMW18 (in-plume well, Plot 90) and 46WW19 (in-plume well, Plot 89) decreased below the MCL, while TCE concentration at 46WW11 (in-plume well, Plot 87) may drop below the MCL in 8 years (well below the range of 23 to 230 years estimated in the ROD), if the declining trend in concentrations is maintained. Neither the trend in well 46WW13, located east of the plume center (Plot 87), nor the extent of the plume downgradient of this well, could be determined because this well, located immediately east of the TCE plume center (Plot 82 and Plot 86) and other wells located east of the TCE plume center were dry since 2013 (Plot 86). Although direction of groundwater flow is toward the east, the unnamed tributary to Goose Prairie Creek (Plot 86), is along the northern perimeter of the plume, and has not been routinely monitored due to it being dry, or the wells next to the tributary not being sampled (LHSMW20, 46WW12, and LHSMW21).

TCE and its initial breakdown products are the only wide spread COCs in the Intermediate Groundwater Zone. Two separate footprints of TCE have been delineated in the Intermediate Groundwater Zone, one centered around 46WW02, and one centered on 46WW05 (Plot 87). Concentrations of TCE have not increased with distance from the most impacted wells, 46WW02 and 46WW05, and no new detections of COCs at boundary area wells have been reported, indicating no plume migration. First order decay rates, for TCE estimated for the intermediate wells with declining TCE concentrations are identical to that estimated for the Shallow Groundwater Zone, providing the line of evidence that attenuation is occurring in part through reductive dechlorination, even though geochemical conditions are not optimal for complete reductive dechlorination. In addition, the presence of degradation byproduct cis-1,2-DCE and VC provide additional line of evidence that reductive dechlorination is taking place. Restoration time in one plume, defined by the well showing a declining TCE trend in 46WW05, is 8 years, well below the range of 23 to 230 years assumed for the MNA remedial action in the ROD. However, the restoration time in the plume centered on 46WW02 cannot be calculated until the Mann-Kendall analyses show statistically declining trend at 95% confidence.

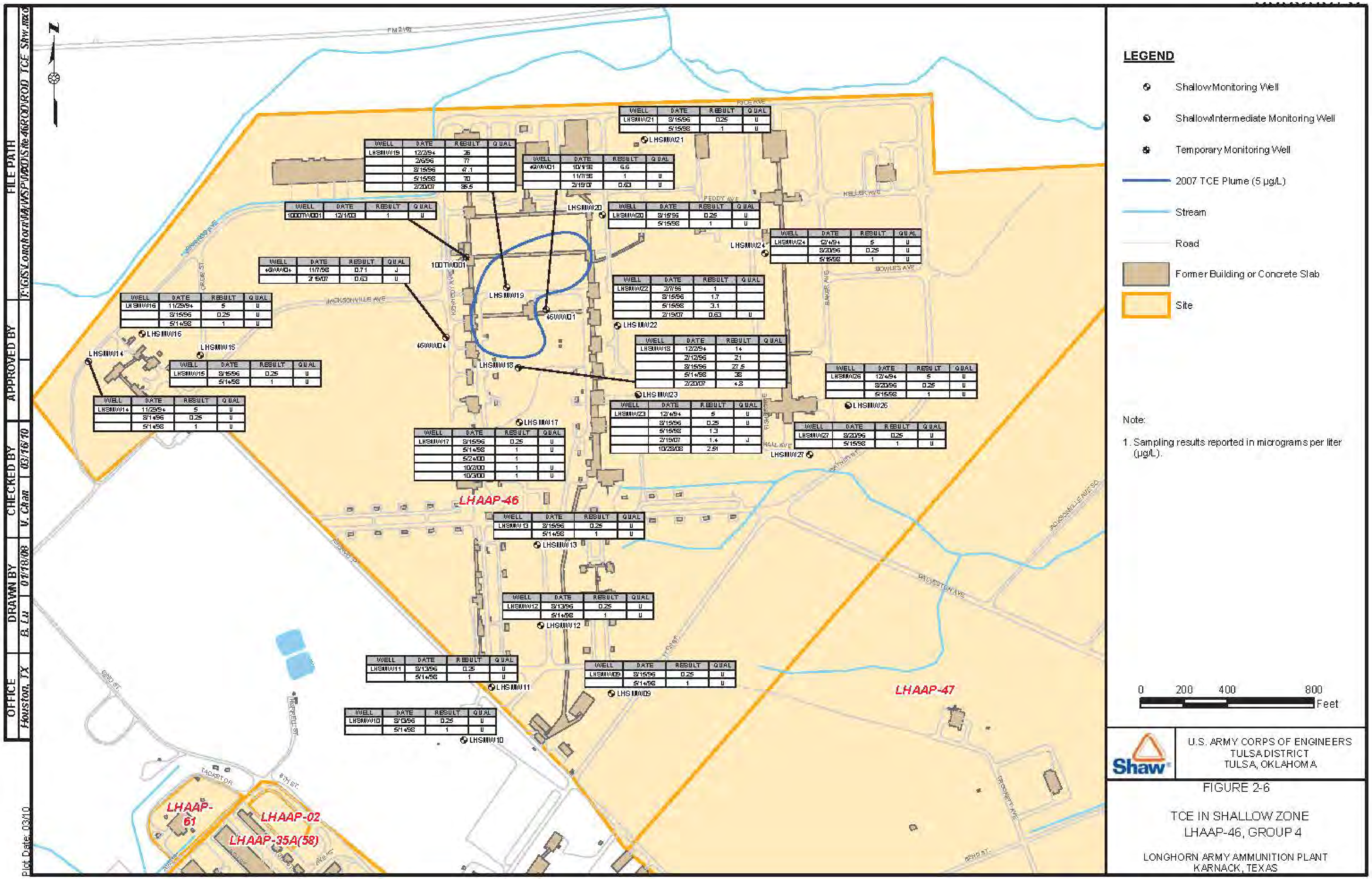
Although the current results indicate that the TCE plume in the Shallow Groundwater Zone is stable and concentrations throughout most of the delineated TCE footprint are declining, there is a need to continue monitoring to ensure that the trends are maintained when groundwater elevations are recovered during high recharge periods.



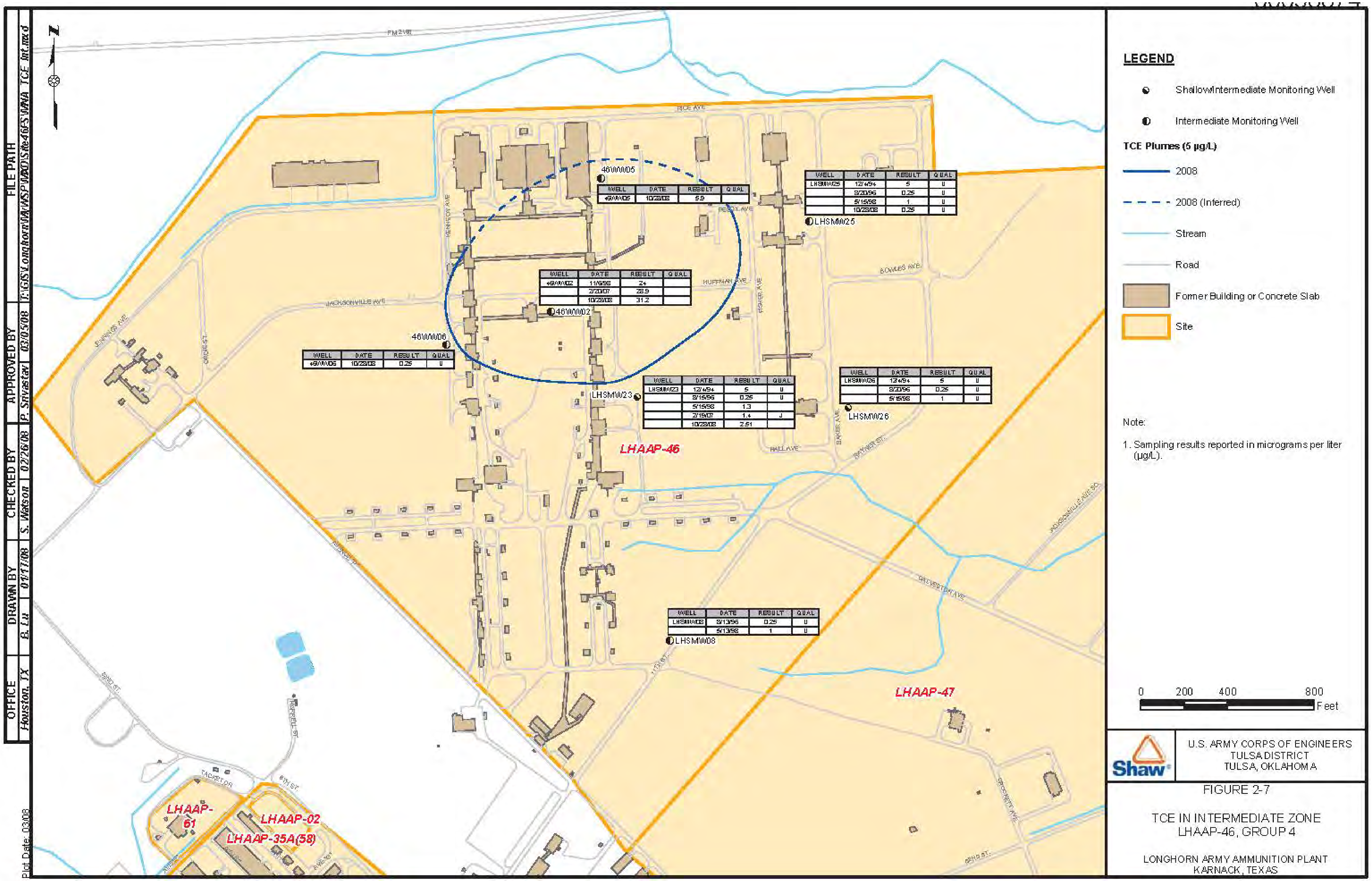
Plot 82. LHAAP-46 groundwater contours, Shallow Groundwater Zone – August 2016 (AECOM, 2017k).



Plot 83. LHAAP-46 groundwater contours, Intermediate Groundwater Zone – August 2016 (AECOM, 2017k).



Plot 84. LHAAP-46 TCE Footprint in Shallow Groundwater Zone Depicted in the ROD (US Army, 2010c).



WELL	DATE	RESULT	QUAL
46WW05	10/23/08	5.9	

WELL	DATE	RESULT	QUAL
LHSMW25	12/4/94	5	U
	8/20/96	0.25	U
	5/15/98	1	U
	10/23/08	0.25	U

WELL	DATE	RESULT	QUAL
46WW02	11/6/98	24	
	2/20/07	28.9	
	10/23/08	31.2	

WELL	DATE	RESULT	QUAL
46WW06	10/23/08	0.25	U

WELL	DATE	RESULT	QUAL
LHSMW23	12/4/94	5	U
	8/15/96	0.25	U
	5/15/98	1.3	
	2/19/07	1.4	J
	10/23/08	2.51	

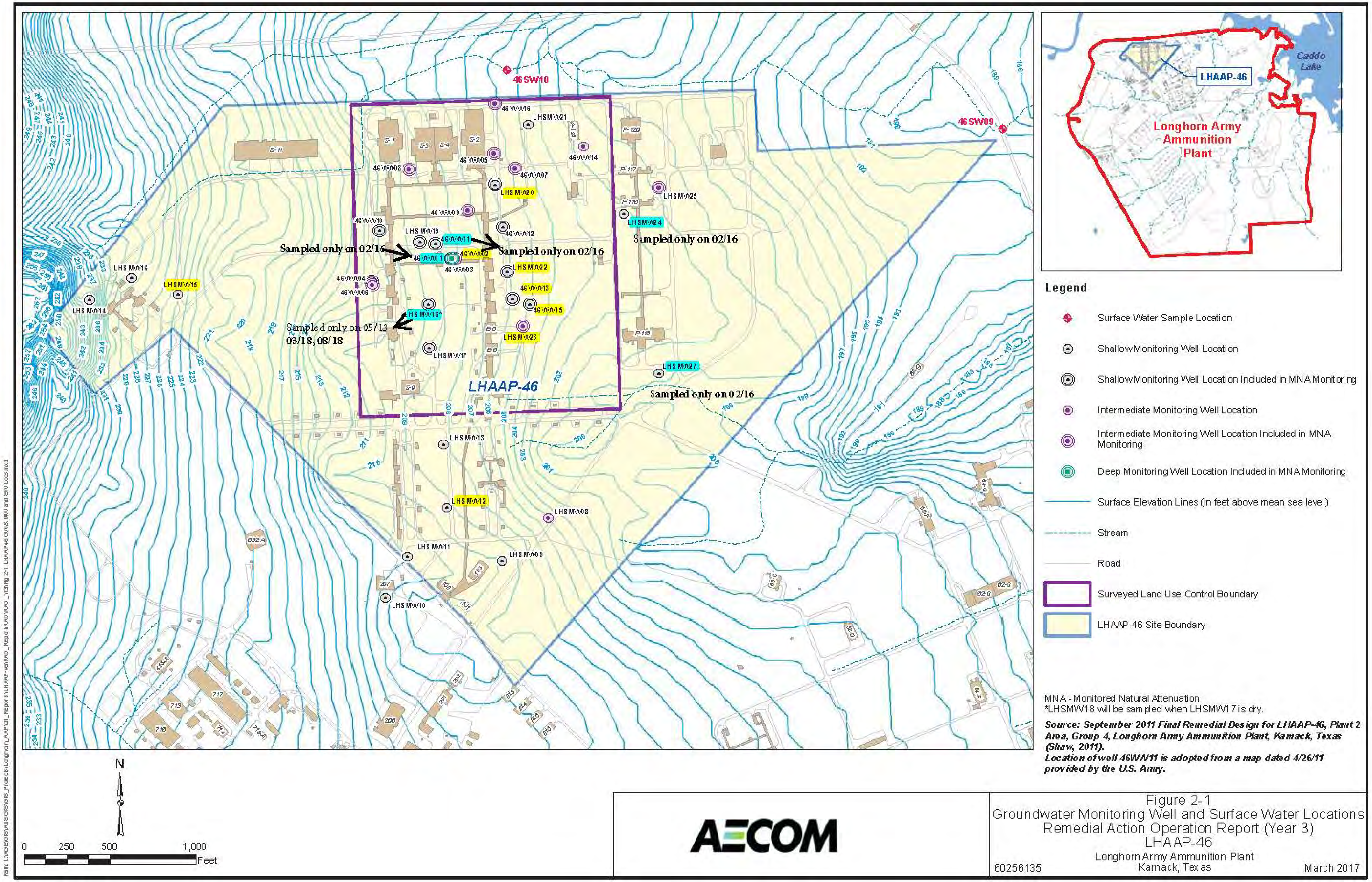
WELL	DATE	RESULT	QUAL
LHSMW26	12/4/94	5	U
	8/20/96	0.25	U
	5/15/98	1	U

WELL	DATE	RESULT	QUAL
LHSMW08	8/13/96	0.25	U
	5/13/98	1	U

Plot 85. LHAAP-46 TCE footprint in Intermediate Groundwater Zone depicted in the ROD (US Army, 2010c).

Monitoring Well that were not sampled in all sampling events since they were dried

Monitoring Well that were only samped once or twice. Dates of sampling posted next to Wells.



Plot 86. LHAAP-46 groundwater monitoring well and surface water locations & wells that were not sampled because they were dry– LHAAP-46 (AECOM, 2017k & Fourth Five-Year Review).

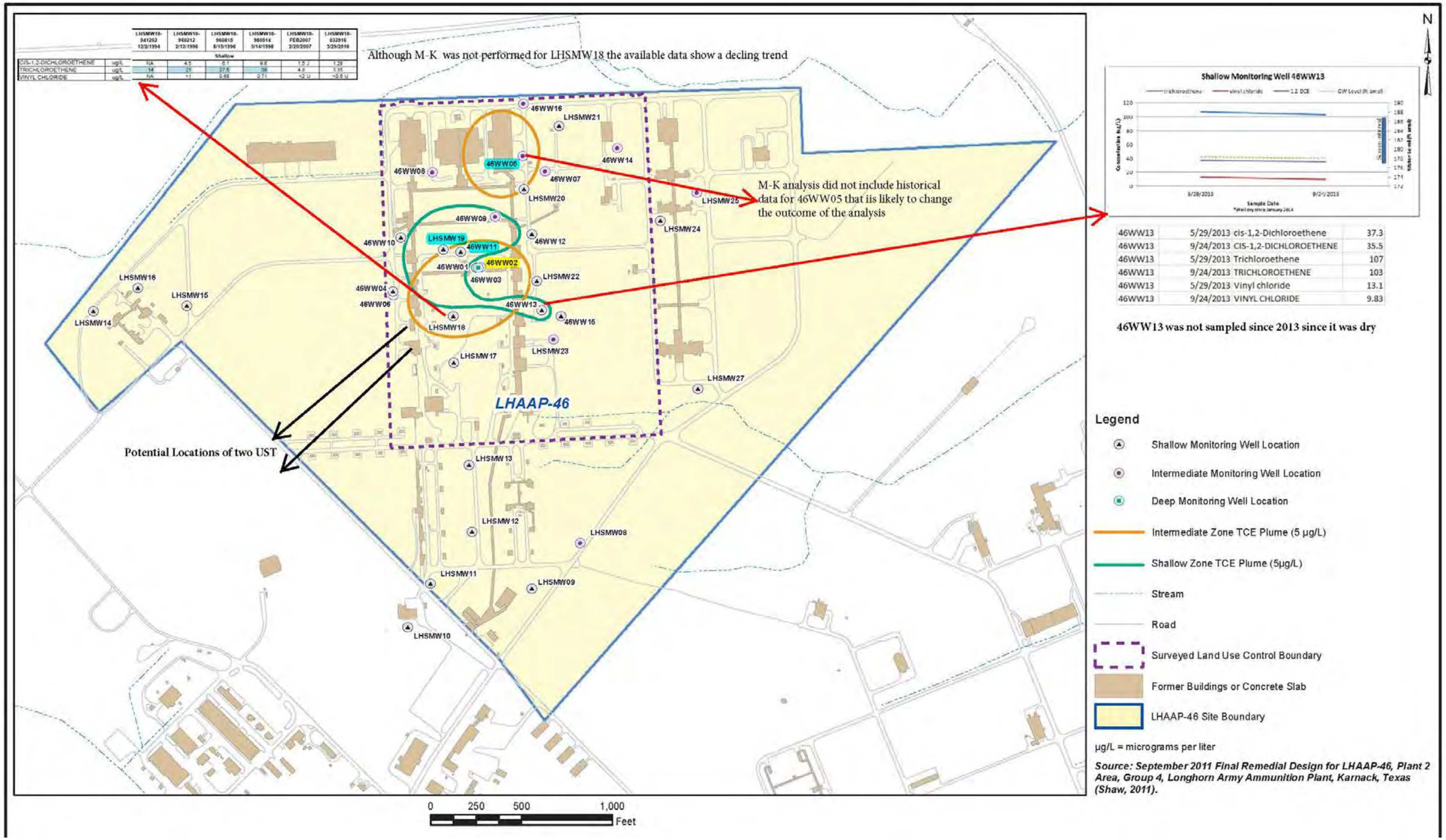
Mann-Kendall: Significant Decreasing Trend at 95% Confidence

Mann-Kendall: Significant Increasing Trend at 95% Confidence

Mann-Kendall: No Trend Data is Stable at 95% Confidence

Mann-Kendall: No Trend Data is not Stable at 95% Confidence

Mann_Kendall Analysis Performed for Data Collected between 2013 and 2016



		LHSMW18-941202 12/2/1994	LHSMW18-960212 2/12/1996	LHSMW18-960815 8/15/1996	LHSMW18-980514 5/14/1998	LHSMW18-FEB2007 2/20/2007	LHSMW18-032916 3/29/2016
		Shallow					
CIS-1,2-DICHLOROETHENE	ug/L	NA	4.5	6.1	9.8	1.5 J	1.29
TRICHLOROETHENE	ug/L	14	21	27.5	38	4.8	3.35
VINYL CHLORIDE	ug/L	NA	<1	0.68	0.71	<2 U	<0.5 U

Although M-K was not performed for LHSMW18 the available data show a decling trend

M-K analysis did not include historical data for 46WW05 that iis likely to change the outcome of the analysis

Potential Locations of two UST

46WW13	5/29/2013	cis-1,2-Dichloroethene	37.3
46WW13	9/24/2013	CIS-1,2-DICHLOROETHENE	35.5
46WW13	5/29/2013	Trichloroethene	107
46WW13	9/24/2013	TRICHLOROETHENE	103
46WW13	5/29/2013	Vinyl chloride	13.1
46WW13	9/24/2013	VINYL CHLORIDE	9.83

46WW13 was not sampled since 2013 since it was dry

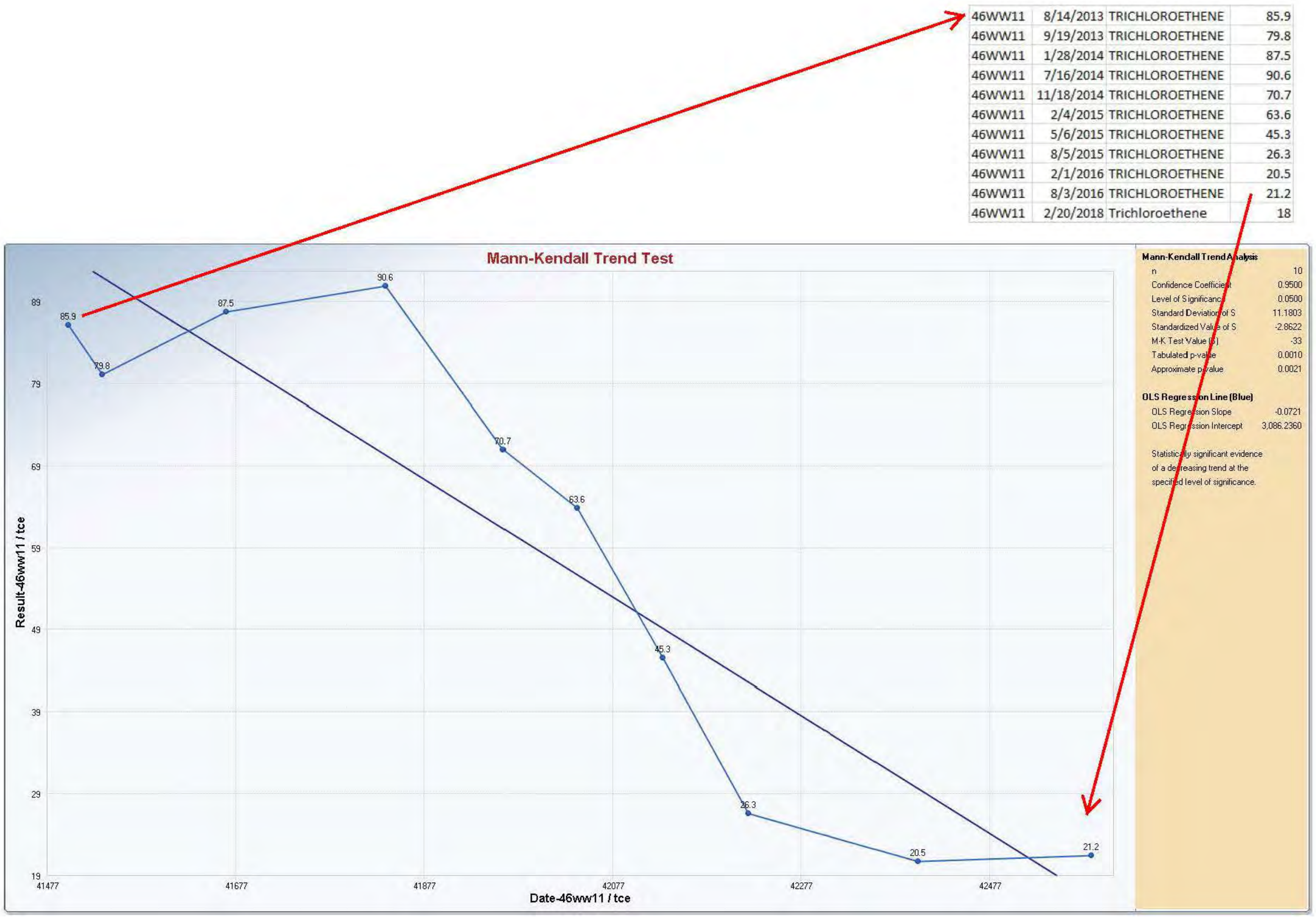
Legend

⦿	Shallow Monitoring Well Location
⦿	Intermediate Monitoring Well Location
⦿	Deep Monitoring Well Location
━	Intermediate Zone TCE Plume (5 µg/L)
━	Shallow Zone TCE Plume (5µg/L)
┄	Stream
─	Road
▭	Surveyed Land Use Control Boundary
■	Former Buildings or Concrete Slab
▭	LHAAP-46 Site Boundary

µg/L = micrograms per liter

Source: September 2011 Final Remedial Design for LHAAP-46, Plant 2 Area, Group 4, Longhorn Army Ammunition Plant, Karnack, Texas (Shaw, 2011).

Plot 87. LHAAP-46 Shallow and Intermediate Groundwater Zone's TCE footprint, revised by Fourth Five-Year Review based on wells installed subsequent to ROD (AECOM, 2015e & Fourth Five-Year Review).



46WW11	8/14/2013	TRICHLOROETHENE	85.9
46WW11	9/19/2013	TRICHLOROETHENE	79.8
46WW11	1/28/2014	TRICHLOROETHENE	87.5
46WW11	7/16/2014	TRICHLOROETHENE	90.6
46WW11	11/18/2014	TRICHLOROETHENE	70.7
46WW11	2/4/2015	TRICHLOROETHENE	63.6
46WW11	5/6/2015	TRICHLOROETHENE	45.3
46WW11	8/5/2015	TRICHLOROETHENE	26.3
46WW11	2/1/2016	TRICHLOROETHENE	20.5
46WW11	8/3/2016	TRICHLOROETHENE	21.2
46WW11	2/20/2018	Trichloroethene	18

Mann-Kendall Trend Analysis

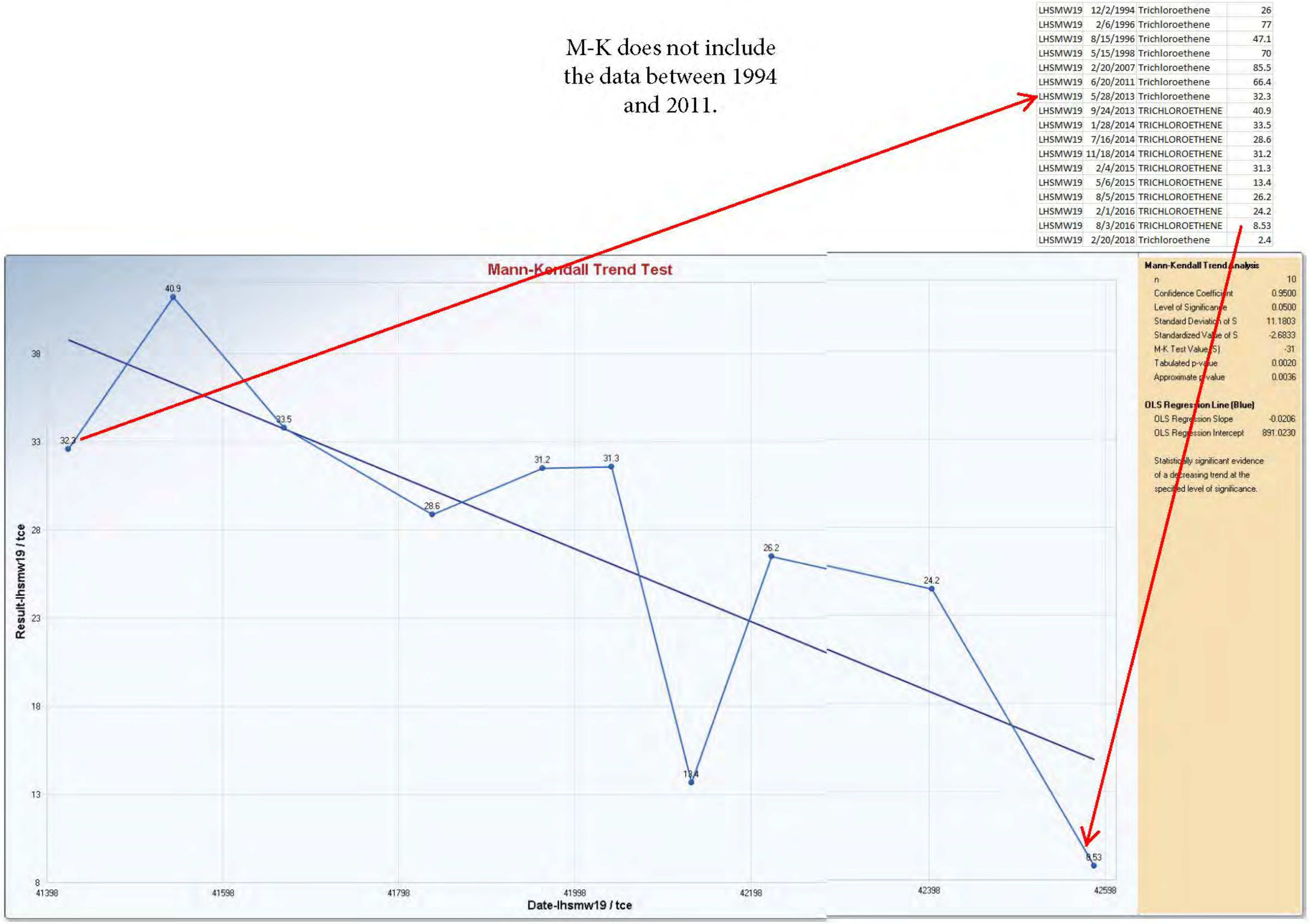
n	10
Confidence Coefficient	0.9500
Level of Significance	0.0500
Standard Deviation of S	11.1803
Standardized Value of S	-2.8622
M-K Test Value (S)	-33
Tabulated p-value	0.0010
Approximate p-value	0.0021

OLS Regression Line (Blue)

OLS Regression Slope	-0.0721
OLS Regression Intercept	3,086.2360

Statistically significant evidence of a decreasing trend at the specified level of significance.

Plot 88. LHAAP-46 Mann-Kendall Analysis – TCE, 46WW11 (AECOM, 2017k).



M-K does not include the data between 1994 and 2011.

LHSMW19	12/2/1994	Trichloroethene	26
LHSMW19	2/6/1996	Trichloroethene	77
LHSMW19	8/15/1996	Trichloroethene	47.1
LHSMW19	5/15/1998	Trichloroethene	70
LHSMW19	2/20/2007	Trichloroethene	85.5
LHSMW19	6/20/2011	Trichloroethene	66.4
LHSMW19	5/28/2013	Trichloroethene	32.3
LHSMW19	9/24/2013	TRICHLOROETHENE	40.9
LHSMW19	1/28/2014	TRICHLOROETHENE	33.5
LHSMW19	7/16/2014	TRICHLOROETHENE	28.6
LHSMW19	11/18/2014	TRICHLOROETHENE	31.2
LHSMW19	2/4/2015	TRICHLOROETHENE	31.3
LHSMW19	5/6/2015	TRICHLOROETHENE	13.4
LHSMW19	8/5/2015	TRICHLOROETHENE	26.2
LHSMW19	2/1/2016	TRICHLOROETHENE	24.2
LHSMW19	8/3/2016	TRICHLOROETHENE	8.53
LHSMW19	2/20/2018	Trichloroethene	2.4

Mann-Kendall Trend Analysis

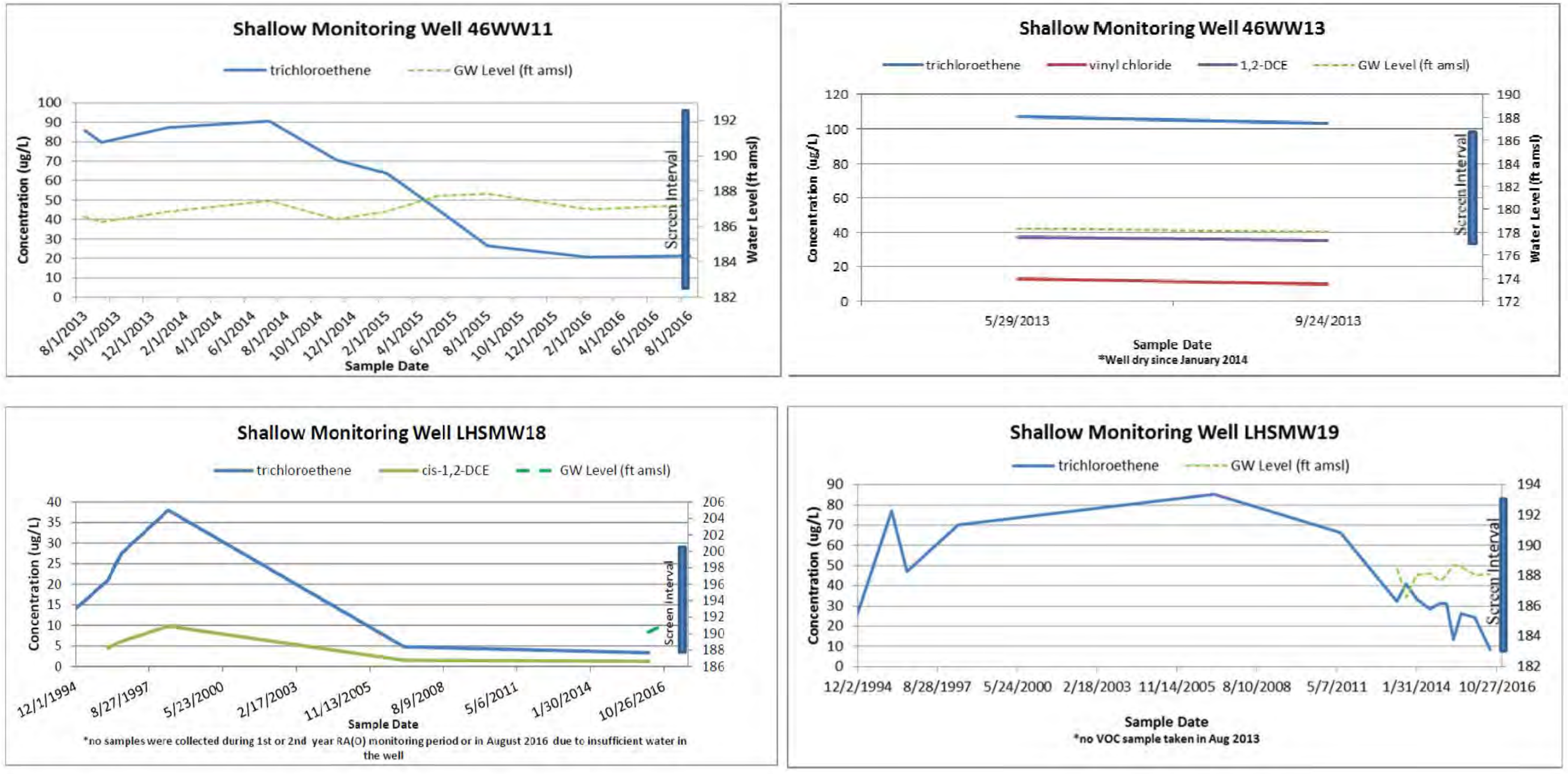
n	10
Confidence Coefficient	0.9500
Level of Significance	0.0500
Standard Deviation of S	11.1803
Standardized Value of S	-2.6833
M-K Test Value (S)	-31
Tabulated p-value	0.0020
Approximate p-value	0.0036

OLS Regression Line (Blue)

OLS Regression Slope	-0.0206
OLS Regression Intercept	891.0230

Statistically significant evidence of a decreasing trend at the specified level of significance.

Plot 89. LHAAP-46 Mann-Kendall Analysis – TCE, 46WW19 (AECOM, 2017k).



MCLs: TCE = 5 µg/L cis-1,2-DCE = 70 µg/L VC = 2 µg/L

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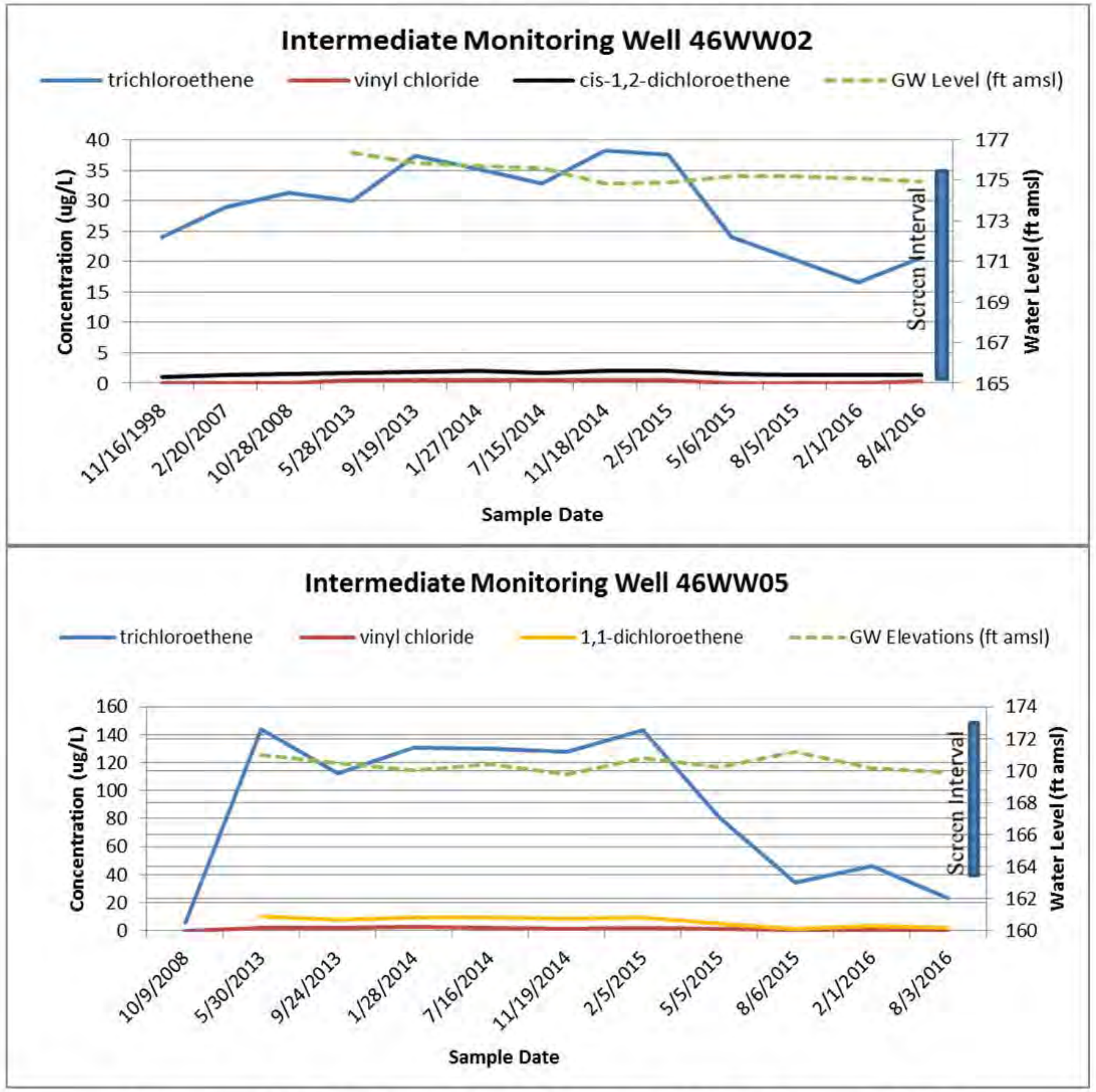
Figure 2-12
Shallow Zone COC Concentrations
Remedial Action Operation (Year 3)
LHAAP-46
Longhorn Army Ammunition Plant
Karnack, Texas

60256135

March 2017

Plot 90. LHAAP-46 temporal variation of TCE and biodegradation byproduct – Shallow Groundwater Zone (AECOM, 2017k).



MCLs: TCE = 5 ug/L VC = 2 ug/L cis-1,2-DCE = 70 1,1-DCE = 7

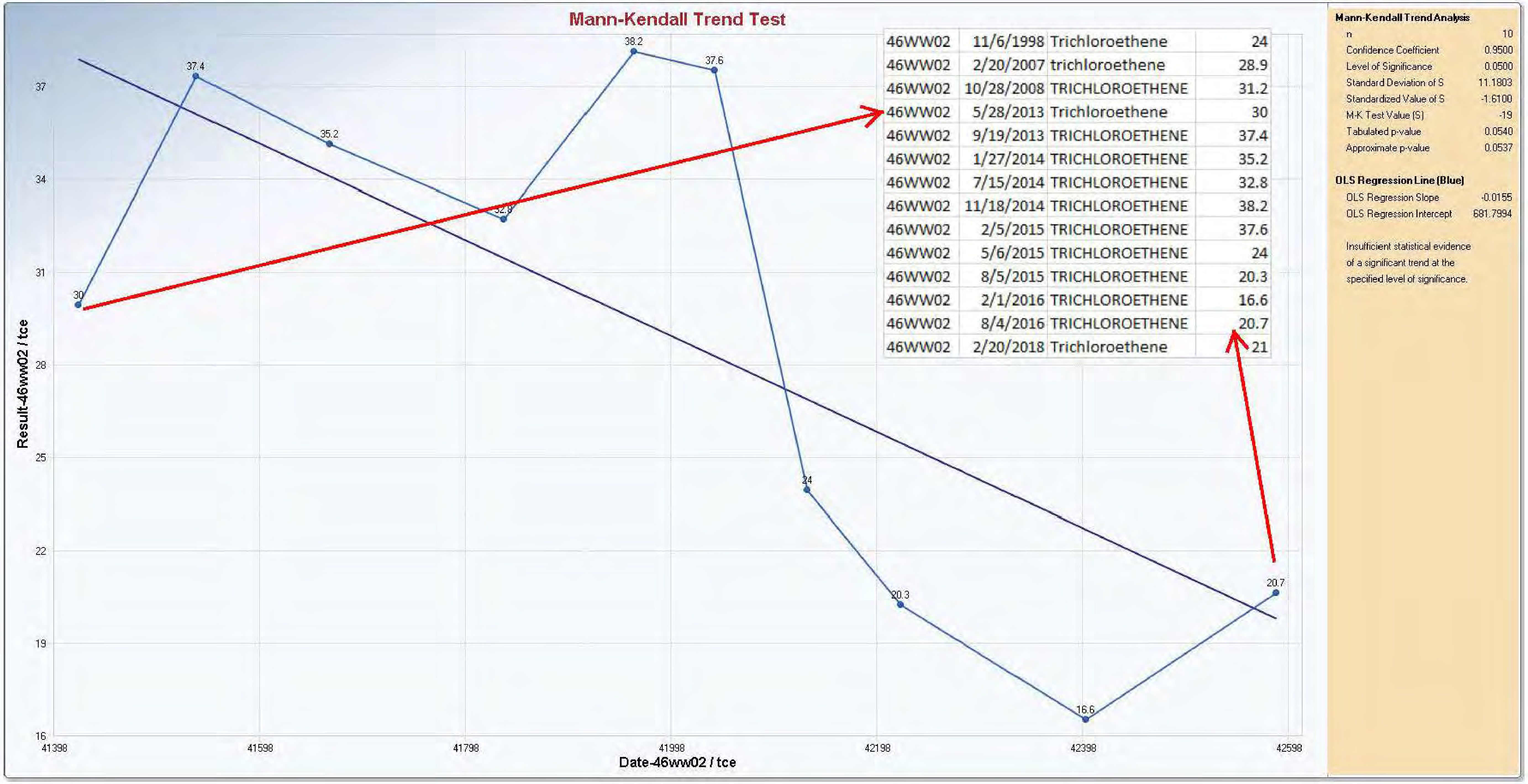
AECOM

Figure 2-13
Intermediate Zone COC Concentrations
Remedial Action Operation (Year 3)
LHAAP-46
Longhorn Army Ammunition Plant
Karnack, Texas

60256135

March 2017

Plot 91. LHAAP-46 temporal variation of TCE and biodegradation byproducts – Shallow Groundwater Zone (AECOM, 2017k).



46WW02	11/6/1998	Trichloroethene	24
46WW02	2/20/2007	trichloroethene	28.9
46WW02	10/28/2008	TRICHLOROETHENE	31.2
46WW02	5/28/2013	Trichloroethene	30
46WW02	9/19/2013	TRICHLOROETHENE	37.4
46WW02	1/27/2014	TRICHLOROETHENE	35.2
46WW02	7/15/2014	TRICHLOROETHENE	32.8
46WW02	11/18/2014	TRICHLOROETHENE	38.2
46WW02	2/5/2015	TRICHLOROETHENE	37.6
46WW02	5/6/2015	TRICHLOROETHENE	24
46WW02	8/5/2015	TRICHLOROETHENE	20.3
46WW02	2/1/2016	TRICHLOROETHENE	16.6
46WW02	8/4/2016	TRICHLOROETHENE	20.7
46WW02	2/20/2018	Trichloroethene	21

Mann-Kendall Trend Analysis

n	10
Confidence Coefficient	0.9500
Level of Significance	0.0500
Standard Deviation of S	11.1803
Standardized Value of S	-1.6100
M-K Test Value (S)	-19
Tabulated p-value	0.0540
Approximate p-value	0.0537

OLS Regression Line (Blue)

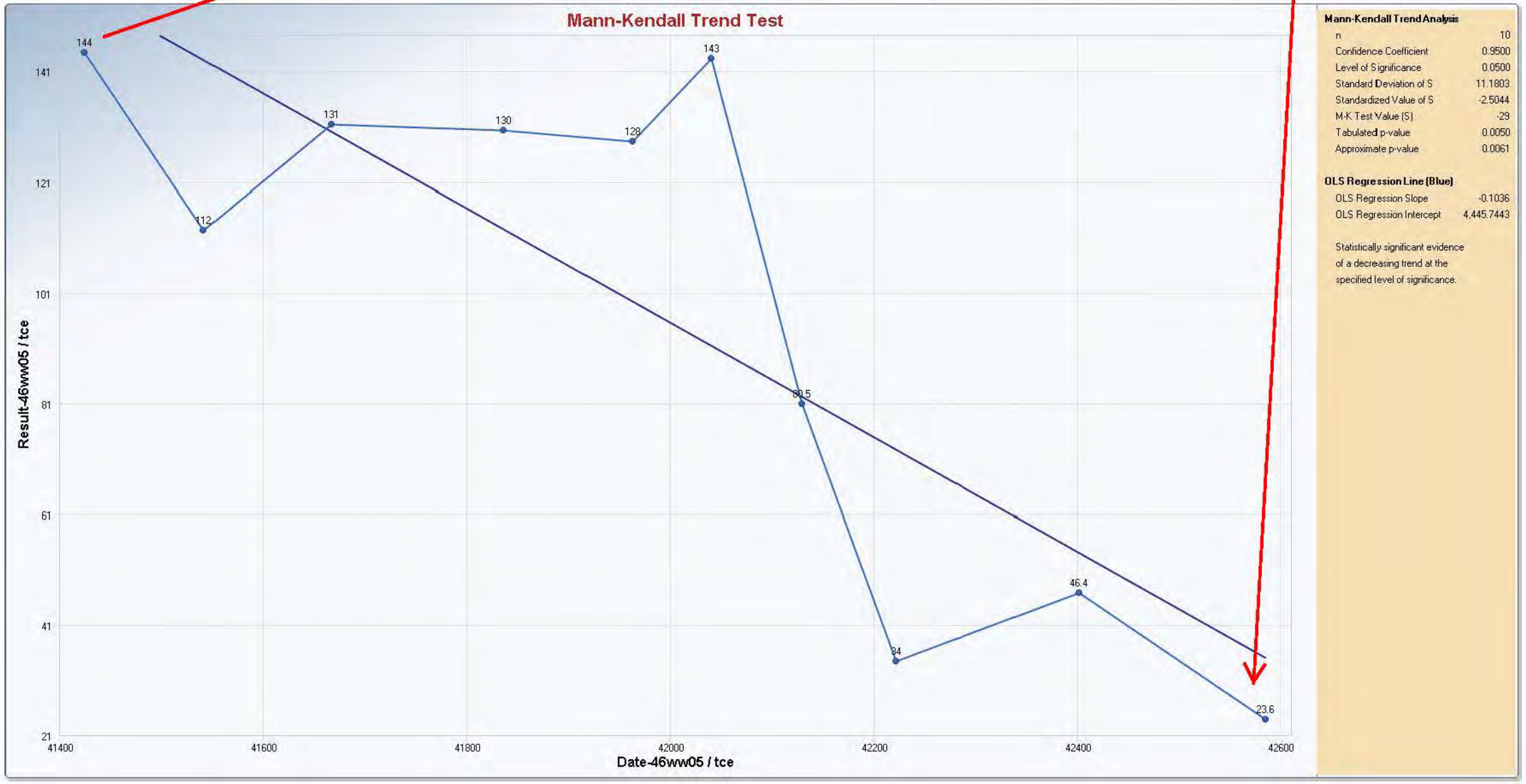
OLS Regression Slope	-0.0155
OLS Regression Intercept	681.7994

Insufficient statistical evidence of a significant trend at the specified level of significance.

Plot 92. LHAAP-46 Mann-Kendall Analysis – TCE, 46WW02 (AECOM, 2017k).

In 1998 TCE concentration was the lowest. M-K did not include that data in the analysis. it seem that between 2013 and Feb 2015 concentrations remained stable, decrasing after May 2015.

46WW05	10/9/2008	TRICHLOROETHENE	5.9
46WW05	5/30/2013	Trichloroethene	144
46WW05	9/24/2013	TRICHLOROETHENE	112
46WW05	1/28/2014	TRICHLOROETHENE	131
46WW05	7/16/2014	TRICHLOROETHENE	130
46WW05	11/19/2014	TRICHLOROETHENE	128
46WW05	2/5/2015	TRICHLOROETHENE	143
46WW05	5/5/2015	TRICHLOROETHENE	80.5
46WW05	8/6/2015	TRICHLOROETHENE	34
46WW05	2/1/2016	TRICHLOROETHENE	46.4
46WW05	8/3/2016	TRICHLOROETHENE	23.6
46WW05	2/26/2018	Trichloroethene	14



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Mann-Kendall Trend Analysis
  n                                  10
  Confidence Coefficient         0.9500
  Level of Significance          0.0500
  Standard Deviation of S       11.1803
  Standardized Value of S       -2.5044
  M-K Test Value (S)                -29
  Tabulated p-value              0.0050
  Approximate p-value            0.0061

OLS Regression Line (Blue)
  OLS Regression Slope          -0.1036
  OLS Regression Intercept   4,445.7443

  Statistically significant evidence
  of a decreasing trend at the
  specified level of significance.
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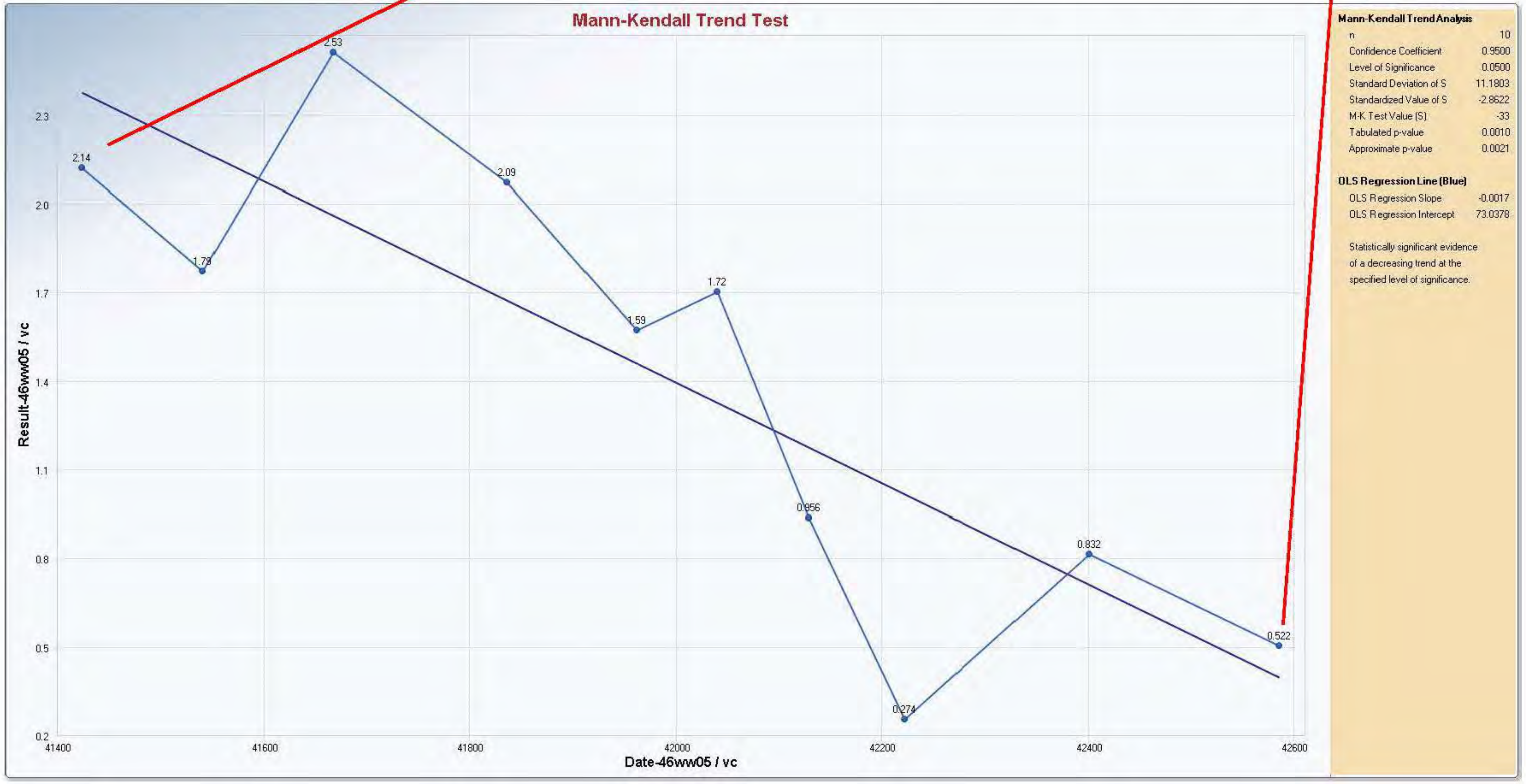
Plot 93. LHAAP-46 Mann-Kendall Analysis – TCE, Intermediate Groundwater Zone monitoring well 46WW05 (AECOM, 2017k).

46WW05	10/9/2008	VINYL CHLORIDE	0.25	U
46WW05	5/30/2013	Vinyl chloride	2.14	
46WW05	9/24/2013	VINYL CHLORIDE	1.79	
46WW05	1/28/2014	VINYL CHLORIDE	2.53	
46WW05	7/16/2014	VINYL CHLORIDE	2.09	
46WW05	11/19/2014	VINYL CHLORIDE	1.59	
46WW05	2/5/2015	VINYL CHLORIDE	1.72	
46WW05	5/5/2015	VINYL CHLORIDE	0.956	J
46WW05	8/6/2015	VINYL CHLORIDE	0.274	J
46WW05	2/1/2016	VINYL CHLORIDE	0.832	J
46WW05	8/3/2016	VINYL CHLORIDE	0.522	J
46WW05	2/26/2018	Vinyl chloride	0.5	U



Mann-Kendall Trend Analysis

n	10
Confidence Coefficient	0.9500
Level of Significance	0.0500
Standard Deviation of S	11.1803
Standardized Value of S	-2.8622
M-K Test Value (S)	-33
Tabulated p-value	0.0010
Approximate p-value	0.0021

OLS Regression Line (Blue)

OLS Regression Slope	-0.0017
OLS Regression Intercept	73.0378

Statistically significant evidence of a decreasing trend at the specified level of significance.

Plot 94. LHAAP-46 Mann-Kendall Analysis – VC, Intermediate Groundwater Zone monitoring well 46WW05 (AECOM, 2017k).