DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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

January 18, 2017

DAIM-ODB-LO

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

Re: Draft Final Remedial Design for LHAAP-16 Landfill at Longhorn Army Ammunition Plant, Karnack, Texas

Dear Mr. Mayer,

The above-referenced document is being transmitted to you for your records and includes revisions based upon your comments on the Draft. In accordance with the FFA, the Draft Final will be considered Final after 30 days without further comment.

The document was prepared by AECOM on behalf of the Army as part of AECOM's Performance Based Remediation contract for the facility. I ask that Debra Richmann, AECOM'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
P. Bruckwicki, Caddo Lake NWR, TX
R. Smith, USACE, Tulsa District, OK
A. Williams, USACE, Tulsa District, OK
N. Smith, USAEC, San Antonio, TX
D. Richmann, AECOM – San Antonio, TX (for project files)

DEPARTMENT OF DEFENSE
UNITED STATES OF AMERICA

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

January 18, 2017

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 for LHAAP-16 Landfill at Longhorn Army Ammunition Plant, Karnack, Texas

Dear Ms. Palmie,

The above-referenced document is being transmitted to you for your records and includes revisions based upon your comments on the Draft. In accordance with the FFA, the Draft Final will be considered Final after 30 days without further comment.

The document was prepared by AECOM on behalf of the Army as part of AECOM's Performance Based Remediation contract for the facility. I ask that Debra Richmann, AECOM'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:
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
N. Smith, USAEC, San Antonio, TX
D. Richmann, AECOM, San Antonio, TX (for project files)

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
1		General Comment	Will the 2009 shallow zone pilot wells need to be redeveloped/maintained?	C	Due to the nature of pilot test conducted that used the recirculation method of distributing the electron donor, it is not anticipated that the wells will need redevelopment. However, slug tests will be performed to determine their acceptability for use as injection wells. If necessary, they will be redeveloped. The following sentence has been inserted after the first sentence in 4.2.2.1: “Before any of the pilot test wells are used for injection, slug tests will be performed to confirm they are in acceptable condition. If the results show they are not, they will be re-developed prior to use as injection wells for Landfill Biobarrier #2”.	
2		General Comment, Figure 4-7	Why is the well spacing (injection points) for the Mid Plume wells in the intermediate zone aquifer less dense than the shallow zone aquifer?	C	The perchlorate and VOCs concentrations in the intermediate zone are much lower than in the shallow zone. The details for the Mid Plume injection are based on the ROD document which states that the carbon source and bioaugmentation culture would be injected into the shallow zone using 40 DPT injection points and into the intermediate zone by injection through existing wells. However, according to the ESTCP demonstration, travel time between recirculation wells 35 feet apart was approximately one to two months. Therefore two injection wells will be installed between existing extraction wells 16EW05 and 16EW06, 16EW06 and 16EW07, and 16EW07 and 16EW08 for a total of six new injection wells at approximately 35 ft apart in the mid plume area intermediate groundwater zone. Figures 4-1 and 4-7, Table 4-9, and Table 4-10 and associated text have been revised to reflect the additional intermediate zone injection wells.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
3		General Comment	What are the criteria for determining when MNA will be implemented at the site?		Please refer to Section 4.5 – Performance Monitoring. Subsection 4.5.3.2 – MNA Performance Monitoring, provides the criteria for determining when MNA will be implemented in the active remedy areas, based on eight quarters of monitoring results and historical data, as required by the ROD. In the following subsection, (4.5.3.3) it is stated that in accordance with the ROD, these same criteria are applicable to passive MNA areas, and if not met, would trigger implementation of a contingency remedy.	
4		General Comment	Is the surface water monitoring/sampling plan similar to the other sites (such as sites 50, 47, 37, etc.) being monitored for surface water? Please include a reference for the surface water sampling plan.		The ROD requires that the surface water sampling plan be included in the RD and it is presented in Section 4.5.3.5, with locations depicted on Figure 4-8. The second to the last paragraph in Section 4.5.3.5 has been revised to indicate that the surface water samples will be collected following the protocols in Section 3.7 of the Final Installation-wide Work Plan, and to state that the surface water cleanup levels for the COCs are provided in Table 1-1. The phrase "Surface water samples are collected for the purpose of evaluating impact from groundwater, therefore, " has been inserted at the beginning of the last paragraph in the section. The last sentence in Section 4.5.5 has been revised to insert "and surface water locations" after "by the data, the wells".	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
5		Figure 4-1, ISB Locations	Also, should Landfill Barrier # 3 be connected to Landfill Barrier # 2 on the figure, otherwise there is a small gap?	C	Yes, Landfill biobarrier #3 shown in Figure 4-1 consists of DPT injection points and Landfill biobarrier #2 consists of recirculation wells to distribute the electron donor. The southernmost DPT injection point and the northernmost recirculation well in Landfill biobarriers #3 and #2, respectively will distribute the electron donor in the gap mentioned in the comment. Figure 4-1 has been revised to connect the lines for Landfill biobarriers #3 and #2.	
6		Figure 4-4	It appears that proposed well 16IW10 is not evenly spaced between DPTs 22 and 23? It seems closer to DPT-22.	C	The location of 16IW10 in Figure 4-4 will be revised so it is equally spaced between DPT 22 and DPT 23, approximately 2.5 ft south of its currently shown location.	
7		Figure 4-8	Should the surface water location HBW-1 in Harrison Bayou be moved equal to or slightly NW of monitoring well 16WW40 to capture the higher plume concentrations of the groundwater (potential) to surface water releases?	D	HBW-1 is an established surface water sampling location and captures flow of groundwater from site LHAAP-16. Perchlorate was most recently detected above the TRRP Tier 1 groundwater residential PCL (17µg/L) in a sample from HBW-1 collected in August 2007 at a concentration of 122 µg/L, and prior to that, at a concentration of 99.3 µg/L in a sample collected in August 2003.	
8	Page 4-3	Section 4.1.2.2	The ESTCP ISB study mentions a distance of 30 feet between the injection and extraction wells: however, the Figure 4-7 only shows four wells (injection wells) approximately 100 feet apart. Please clarify.	C	Based on the ESTCP study that recommended approximately 35 feet between the recirculation wells, two new injection wells will be installed between existing extraction wells 16EW05 and 16EW06, 16EW06 and 16EW07, and 16EW07 and 16EW08 for a total of six new injection wells in the Intermediate Zone ISB area to recirculate the groundwater between the injection and extraction wells. Figure 4-7, Table 4-9, and Section 4.4.1.2 have been revised to reflect installation of the additional injection wells.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
9	Page 4-11	Sections 4.4.2.1 & 4.4.2.2	It appears that the injection numbers mentioned in this section are different that those shown in Table 4-10.	C	The tables had not been revised to reflect edits made to the text when the draft was submitted for review. Now Sections 4.4.2 and 4.4.3, Table 4-9, 4-10, and Appendix D have been made consistent to reflect correct quantities and locations as shown in Figures 4-6 and 4-7. A calculation sheet is included to show how the correct quantities were derived, based on the treatment areas shown in Figure 4-6 and 4-7 and using the model presented in Appendix D.	
10		Table 4-11, ISB Area Column	Please correct the following: Well 16WW12 is upgradient; Well 16WW14 is upgradient to Landfill Biobarrier #3; Well 16WW26 is downgradient to Landfill Barrier #2; and, Well 16WW42 is downgradient of Landfill Barrier #1.	C	Table 4-11 has been revised for consistency with the figures, and corrected to reflect the following: 16WW26: Downgradient to landfill biobarrier #1 16WW42: Downgradient to landfill biobarrier #1 16WW12: Upgradient to Bayou Biobarrier 16WW14: Upgradient to Landfill Biobarrier #3	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
11		Table 4-12, ISB Area Column	Please correct the following: Well 16WW37 is upgradient of proposed Landfill Barrier #2; Well 16WW35 is downgradient of proposed Landfill Barrier #2; Well 16WW25 is downgradient of proposed Landfill Barrier #1; Wells 16WW41 and 29 need to be designated as proposed (please identify them on a figure); Well 16WW43 is not an intermediate well; Well 16WW21is not downgradient of the Mid-Plume ISB Area, it is downgradient of the Bayou Biobarrier. Also, revised Figure 4-1 (a Rose and April collaboration from Nov. 3 email from Rose) indicates it is a shallow well.	C	Table 4-12 has been revised for consistency with the figures, and corrected to reflect the following: 16WW37: Downgradient of Landfill/Upgradient of Landfill Biobarrier #2 16WW25: Upgradient of Mid-Plume ISB Area/ Downgradient of Landfill Barrier #1 16WW35: Upgradient of Mid-Plume ISB Area/ Downgradient of Landfill Barrier #2 16WW43 has been deleted.	
				D	16WW21 (shown as blue diamond in Figure 4-1) is downgradient of the mid plume ISB area and is an existing upper-deep monitoring well. 16WW41 and 16WW29 are existing intermediate zone wells.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
12		Table 4-16, Rationale Column	Please correct the following: Well 16RW12 is downgradient of the Biobarrier; Well 16RW11 is within the Biobarrier; and, Wells 16RW13 and 16WW22 do not show up on Figure 4-5.	C	Table 4-16 has been revised for consistency with the figures, and corrected to reflect the following in Primary Rationale for Well Selection: 16RW12: Performance data downgradient of the biobarrier 16RW11: Performance data within the biobarrier 16RW13: Not included in Figure 4-5 and deleted from Table 4-16 because no record of this well could be found. 16WW22 is shown in Figure 4-5, however, it is an upgradient well to monitor effluent concentrations and biobarrier effectiveness 16WW12: Upgradient well to monitor effluent concentrations and biobarrier effectiveness	
13		Table 4-18, MNA and LTM Performance Monitoring Plan	Please provide a separate figure that identifies the wells found in the table. It is difficult to discern which figure all these wells are found on.	C	A separate figure (4-8) has been included that identifies the wells shown in Table 4-18	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
14		Table 4-17, Rationale Column	Please correct the following: Well 16EW01 appears questionable (as compared to wells 16EW03 & 16EW02) for monitoring within the Mid-Plume ISB as it is farther in distance from the DPT points than 16EW04;	D	Since 16EW01 is an existing well, it will be sampled to determine the outside influence of injection within the ISB Area. The monitoring data will also show if any contamination has been pushed outside of the treatment area shown in Figure 4-6.	
			Well 16WW30 is not shown on figure 4-6;		16WW30 is shown on Figure 4-6 near injection point DPT-70.	
			Well 16WW30 appears questionable for the downgradient monitoring of the Mid-Plume (it depends on the flow direction). If the groundwater flow direction is consistently east, then it would be acceptable. If the groundwater flow direction is consistently to the northeast, then probably it is not.		Well 16WW30 along with 16WW39 and 16WW48 will be used to determine the downgradient influence of the ISB injection. These three monitoring wells approximately cover the path perpendicular to the groundwater flow and should capture the downgradient influence of ISB injection even if there is a slight change in groundwater flow direction.	
			Also, well 16WW21 is not found on Figure 4-7.	C	16WW21 is not included on Figure 4-7, because this figure depicts the Mid Plume Design for the intermediate Groundwater Zone. Therefore it only shows the locations and proposed locations of Intermediate Zone monitoring wells.	
15		Appendix A, RAO Inspection and Maintenance Checklist, Groundwater Monitoring Wells	EPA recommends adding a row requiring the inspection of the concrete aprons and bollards.	C	A row has been added for inspection of the concrete aprons and bollards.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
16		General Comment	Was there an evaluation performed on all the injection materials to ensure that there will not be deleterious effects to the wells or to the groundwater aquifers? In other words, are all these materials compatible? Also, another potential concern is when injection is conducted, are there detrimental effects on pushing contaminants downward (or outward in certain instances).		The proposed materials are compatible. ABC is an oil based product but is formulated with lactic acid and a buffer solution. ABC+ adds ZVI. The fatty acids used in the formulation are essentially the same as produced from hydrolysis of vegetable oil when introduced in the environment. Hence, it is the same as vegetable oil but it is completely soluble. Hence it is not emulsified. The fatty acids are the long term releasing carbon source. No need for site testing because the material behaves similar to EVO. The buffer in ABC provides an added benefit and testing is not required because there is no downside for the presence of the buffer. ZVI is micro-scale and therefore, it does not have a tendency to clog the aquifer. Manufacturer's information is appended. The presence of ZVI requires the material to be mixed in specialized mixers before injecting. Redox Tech provides the equipment and field crew to conduct the work. Details of the substrate selection and evaluation for each biobarrier are presented in corresponding subsections in Section 4.1.3.The SDS for these products are included in Appendix B. The potential to push the contaminants downward or outside the treatment zone will be avoided by using low pressures for injection, as stated in Section 4.1.1.1 for direct push and for injection wells in Section 4.1.1.2. It is anticipated that the substrate will be injected at low pressures (< 200 psi) to minimize spreading of the contaminants	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: Richard Mayer, EPA

Respondents: Purshotam Juriasingani, Glenn Hilton, Cheri Walker and Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
17		General Comment	EPA agrees with the additional shallow wells proposed by TCEQ shown on revised Figure 4-1. Also, EPA recognizes there may be a need for additional Intermediate groundwater monitoring wells in the future, especially in the outer eastern reaches of the plume.		Noted.	
18		General Comment	When is the last time that the Upper Deep and Lower Deep groundwater monitoring wells have been sampled at the site?		May 2013.	
19		Overall Note	There seems to be an error on Figure 4-1. Shallow Groundwater ISB Treatment Area detail is referred to 4-5; however, figure 4-5 is the Bayou Biobarrier; Bayou Biobarrier detail is referred to fig 4-6; however, figure 4-6 is Mid Plume Design Shallow Groundwater Zone; Mid Plume Design Intermediate Groundwater Zone (figure 4-7) is not depicted on Figure 4-1.	C	Figure 4-1 has been revised to reflect correct treatment area call-out figures.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
1	1-1	Section 1.2	Last paragraph - Why CVOCs here but VOCs elsewhere?	C	cVOCs has been replaced with VOCs throughout the document.	
2	2-2 & 2-3	Section 2.4	This section should reference LHAAP-16 (not 18/24) throughout.	C	The incorrect references to LHAAP-18/24 have been replaced with LHAAP-16 throughout this section.	
3		Figure 2-3	Add note to reference date collected well location data	C	The well location information is from the Banks Environmental Data, June 17, 2015 Water Well Report for LHAAP. A note identifying this source has been added to Figure 2-3.	
4		Figures	General notes: Change orange and brown fonts to black or other more readable color. Isocontour maps should not be based on two data sets (such as in Figure 2-4, 2-6 and 2-7). Interpretation should be based on one clear data set.	 C C	 The orange and brown color have been replaced with a more readable dark color (black or dark blue). The isocontour maps have been redrawn using COC concentrations from the most recent comprehensive monitoring event, which was performed in May 2013.	
5		Figure 2-5	Contours by Harrison Bayou (100 and 17) are based on nothing since we have no downgradient data points. They should be removed.	C	The inner perchlorate contours (dashed 17ug/L and solid100 ug/L) have been deleted.	
6		Figure 2-7	Remove the closed (dashed) loop for 1,000 isocontour by Harrison Bayou. We don't have data to support this inference.	C	The closed 1,000 µg/L isoconcentration contour in Figure 2-7 has been re-drawn as an inferred contour line that truncates at Harrison Bayou.	
7	3-1	Section 3	O&M components in 2nd sentence should not have each word capitalized.	C	The names of the O&M components in the 2nd sentence have been changed to all lower case letters.	
8		Section 3.1.2	First sentence, Typo "majorevents"	C	The typo has been corrected by inserting a space between "major" and "events".	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
9	4-11 & 4-12	Section 4.4.2 & 4.4.3	The narrative and tables are not consistent regarding injection locations and quantities. Here are the specific inconsistencies I noticed:		Section 4.4.2 and 4.4.3, Table 4-9, 4-10, and Appendix D have been made consistent to reflect correct quantities and locations as shown in Figures 4-6 and 4-7. A calculation sheet is included to show how the correct quantities were derived, based on the treatment areas shown in Figure 4-6 and 4-7 and using the model presented in Appendix D.	
			4.4.2.1 – 2nd paragraph 6,533 and 10,018 lbs. don't seem to match table 4-10. Shouldn't points be DPT-40-70?	C	Shallow Zone DPT ID numbers in both Tables 4-9 and 4-10 have been corrected to DPT-40 through DPT-79. In Table 4-10, substrate weight and volumes have been re-calculated.	
			4.4.2.2 – Add total lbs. for consistency	C	The weight of substrate for the Intermediate Zone wells in Table 4-10 has been verified and included in Section 4.4.2.2 for consistency.	
			4.4.3 – 1st paragraph 2nd sentence, regarding shallow is not correct. Probably should be 30 points at 1 liter each. 16IW12, 14, 16, and 18 are only in this sentence – nowhere else in the document.	E	The sentence, and the following sentence, have been changed to reflect the correct number of injection points and wells with correct quantities of KB-1. The correct locations are DPT-40 through DPT-79 for the shallow zone, and wells 16EW05, 16EW06, 16EW07, and 16EW08 for the intermediate zone. The correct quantities of KB-1 are 40 L for the shallow zone and 12 L for the intermediate zone.	
			Last paragraph, can we stick with the term "anaerobic" rather than "anoxic"?	C	The term "anoxic" in the last paragraph will be replaced with "anaerobic".	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
10		Figure 4-1	I received a revised Figure 4-1 on 11/3 which addressed many of my concerns:			
			Additional delineation wells are needed on other side of Harrison Bayou, between Landfill Biobarrrier #3 and Mid-Plume shallow in-situ, and down gradient of Bayou biobarrier. Four additional wells were proposed and I accept those locations. If the plume is not delineated across Harrison Bayou additional wells will be necessary.	C	The need for additional wells across Harrison Bayou, beyond the two already proposed, will be addressed, if needed, during the RD implementation phase.	
			Furthermore, the LUC boundary will most likely need to be adjusted based on these new wells.	C	Agree that the final LUC boundary may need to be adjusted, however, the Army will continue to use the boundary that was presented in the ROD until additional data are in hand, in order to avoid having two boundaries in the record.	
			The proposed wells from Figures 4-2 through 4-7 were added to the figure. Please add the proposed well numbers.	C	The proposed well numbers have been added to Figure 4-1.	
			Orange replaced with black. Thank you.		You are welcome.	
			Additional edit - Please rename yellow box to add "Mid-Plume" (pop-out and legend)	C	"Mid-Plume" has been inserted between "Shallow" and "Groundwater" in the pop-out box on the figure and the symbol in the legend has been re-named for consistency.	
11		Figure 4-8	The LUC boundary will most likely need to be adjusted based on the new wells across Harrison Bayou. It would be preferable to go ahead and estimate extent on this figure.	E	The Army will use the boundary that was presented in the ROD until additional data is in hand to avoid having more than two boundaries in the record.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
12		Table 4-9	DPT points should be DPT-40 through 70	E	As shown in Figure 4-6, there are 40 injection points (DPT 40-79). Table 4-9 has been corrected to reflect the correct DPT points.	
			16WW39 & 30 should be Existing (not Proposed)	C	For 16WW39 and 30, the entry in the second column has been changed to ”Existing”.	
13		Table 4-10	DPT point should be DPT-40 -70, volume of KB-1 in shallow should probably be 30(1)	E	Please see response to comment to comment 9, fourth part. Table 4-10 has been revised accordingly and thetotal volume of KB-1 that will be injected in the Mid-Plume ISB shallow zone is 40L.	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
14		Table 4-11	ISB Area description edits needed for:		Table 4-11 has been edited as indicated in the comment and in the responses below:	
			16WW26 & 16WW42– Downgradient to landfill biobarrier #1	C	16WW26 and 16WW42: Changed from Downgradient to Landfill Biobarrier #3 to #1	
			Add new point for Downgradient to landfill biobarrier #3	C	The proposed well located Downgradient to Landfill Biobarrier #3 is identified as 16WW55 in Figure 4-1and has been added to Table 4-11	
			16WW39 – existing, not proposed	C	16 WW39 has been changed from Proposed to Existing	
			16WW12 & 16WW22– Upgradient to Bayou Biobarrier	C	16WW12 and 16WW22 have been changed from Downgradient to Bayou Biobarrier to Updgradient	
			Add new point for Downgradient to Bayou Biobarrier	C	The proposed well located Downgradient to Bayou Biobarrier is identified as 16WW56 in Figure 4-1and has been added to Table 4-11	
			No crossgradient to south of plume – need 16WW24 & 16WW43	C	Existing wells 16WW24 and 16WW43 have been added to Table 4-11 as Cross-gradient to South of Plume	
			Add new wells across Harrison Bayou		The two proposed wells across Harrison Bayou are identified as 16WW57 and 16W58 in Figure 4-1 and have been added to Table 4-11	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
15		Table 4-12	ISB Area description edits needed for:		Table 4-12 have been edited as indicated in the comment and in the responses below:	
			16WW37 & 16WW13 – Downgradient of Landfill	C	16WW37 and 16WW13 have been changed from Upgradient and Downgradient of Mid-Plume ISB Area, respectively, to Downgradient of Landfill	
			16WW 35 & 16WW25 – Upgradient of Mid-Plume ISB Area	C	16WW25 and 16WW35 have been changed from Downgradient of Mid-Plume ISB Area to Upgradient of Mid-Plume ISB Area	
			16WW43 – Is a shallow well. Do mean 16WW27 or 28?	C	16WW43 has been deleted; Intermediate Zone well 16WW27 is co-located with 16WW43 and is already included in Table 4-12.	
16		Table 4-18	16WW50 – This well is not in the document anywhere else.	C	16WW50 has been deleted from Table 4-18.	
			Please add the four new locations on Figure 4-1 (include MNA) - new well downgradient of Bayou Biobarrier, new well between landfill biobarrier #3/Mid-Plume ISB, and two new wells across Harrison Bayou	C	The following proposed four new monitoring wells (identified as 16WW55, 16WW56, 16WW57, and 16WW58 in Figure 4-1have been added to Table 4-18 as suggested: -New well 16WW55 between landfill biobarrier #3/Mid-Plume ISB -New well 16WW56 downgradient of Bayou Biobarrier, and -New wells 16WW57 and 16WW58 across Harrison Bayou	

Responses to Comments on
Draft Remedial Design for LHAAP-16 Landfill
Longhorn Army Ammunition Plant, Karnack, Texas

October 2016

Reviewer: April Palmie, TCEQ

Respondent: Debra Richmann, AECOM

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

Comment #	Page	Section/ Paragraph	Comment	C, D, E or X[1]	Response	A or D[2]
17	5-3	Section 5.2	First bullet on page – Note that LUC boundary may (will) change following plume delineation on other side of Harrison Bayou.	E	Finalizing the LUC boundaries is addressed in Section 5.1 – LUC Implementation on page 5-2. After the first sentence of the second sub-bullet, the following sentence has been added: “The LUC boundary presented in this RD is subject to change, based on COC results from the two proposed wells to be installed on the east side of Harrison Bayou”.	
18		Section 5.3.1	End of paragraph, unnecessary “	C	The extraneous ” will be deleted.	
19		Section 5.3.5	Sentence beginning with “The decision to terminate” revise “potentially including an explanation”	C	The “and” after “potentially including” has been changed to “an”.	
20		Figure 5-1	The LUC boundary will extend across Harrison Bayou. It would be preferable to go ahead and estimate extent on this figure.	E	Please see responses to comment numbers 10, second part; and 11.	
21		General	For future work (such as Section 6) – Suggest a change from AECOM to Contractor.	C	AECOM has been replaced with “Contractor” wherever future work is discussed in the RD.	
22	6-2	Section 6.4	First paragraph, sentence beginning with “The two biobarriers” Please revise since there are more than two. Suggest “The biobarriers”	C	The word “two” has been deleted from the sentence.	
23		Table 6-1	2. Coordinate with TCEQ. Permit not required but must meet substantive requirements. We will have to provide detailed information to Underground Injection Control.	C	Under “Notes”, the entry has been changed to “Permit not required, but must meet substantive requirements.”	

From: Mayer, Richard <mayer.richard@epa.gov>
Sent: Thursday, January 26, 2017 2:31 PM
To: Snow, JoLynn; Zeiler, Rose M CIV USARMY HQDA ACSIM (US)
Cc: Aaron.K.Williams@usace.army.mil; Smith, Nicholas B CIV USARMY IMCOM (US; 'Becher, Kent'; Tzhone, Stephen; Richmann, Debra; Richard.P.Smith@usace.army.mil; April Palmie; Forsythe, Barry; Harrison, Dorelle; Sharp, Elspeth; paul_bruckwicki@fws.gov
Subject: FW: EPA Approval of the Longhorn Site 16 (Landfill) Draft Final Remedial Design

Good Afternoon JoLynn/Rose, I've reviewed the Draft Final Remedial Design for Longhorn Site 16 (Landfill) and accept all edits and comment responses. Thanks.

From: April Palmie <april.palmie@tceq.texas.gov>
Sent: Tuesday, January 31, 2017 2:40 PM
To: Snow, JoLynn
Cc: Williams, Aaron K CIV USARMY CESWT (US); Zeiler, Rose M CIV USARMY HQDA ACSIM (US); Smith, Nicholas B CIV USARMY IMCOM (US); Smith, Richard P CIV USARMY CESWF (US); Richmann, Debra; Sharp, Elspeth; Juriasingani, Purshotam; April Palmie; Holloway, Craig; mayer.richard@epa.gov
Subject: RE: FOR AGENCY REVIEW - LHAAP-16 Draft Final RD

Thank you. With these edits, I accept the LHAAP-16 Draft Final RD and RTCs.

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

From: Snow, JoLynn [mailto:JoLynn.Snow@aecom.com]
Sent: Tuesday, January 31, 2017 2:15 PM
To: April Palmie <april.palmie@tceq.texas.gov>
Cc: Williams, Aaron K CIV USARMY CESWT (US) <Aaron.K.Williams@usace.army.mil>; Zeiler, Rose M CIV USARMY HQDA ACSIM (US) <rose.m.zeiler.civ@mail.mil>; Smith, Nicholas B CIV USARMY IMCOM (US) <nicholas.b.smith56.civ@mail.mil>; Smith, Richard P CIV USARMY CESWF (US) <Richard.P.Smith@usace.army.mil>; Richmann, Debra <debra.richmann@aecom.com>; Sharp, Elspeth <elspeth.sharp@aecom.com>; Juriasingani, Purshotam <purshotam.juriasingani@aecom.com>; Holloway, Craig <craig.holloway@aecom.com>; mayer.richard@epa.gov
Subject: RE: FOR AGENCY REVIEW - LHAAP-16 Draft Final RD

Good afternoon April,

Please see the attached redline RTC table and revised figure based on your additional comment to Aaron. Please let us know if you need anything else.

Thank you,
JoLynn

JoLynn Snow
Project Administrator, AECOM Environment
Direct: 1-210-823-6710
jolynn.snow@aecom.com

AECOM
4921 Shed Road, Suite 400
Bossier City, LA, 71111
318- 742-3191
aecom.com

From: Snow, JoLynn
Sent: Wednesday, January 18, 2017 11:52 AM
To: 'April Palmie'; 'mayer.richard@epa.gov'
Cc: Williams, Aaron K CIV USARMY CESWT (US); 'Zeiler, Rose M CIV USARMY HQDA ACSIM (US)'; Smith, Nicholas B CIV USARMY IMCOM (US); Smith, Richard P CIV USARMY CESWF (US); Richmann, Debra; Sharp, Elspeth; Juriasingani, Purshotam; Holloway, Craig
Subject: FOR AGENCY REVIEW - LHAAP-16 Draft Final RD

Good afternoon,

Please see the attached Draft Final RD for LHAAP-16. I have also attached the redline Draft Word document to assist in review. Please let me know if you need anything else.

Thank you,
JoLynn

JoLynn Snow
Project Administrator, AECOM Environment
Direct: 1-210-823-6710
jolynn.snow@aecom.com

AECOM
4921 Shed Road, Suite 400
Bossier City, LA, 71111
318- 742-3191
aecom.com

DRAFT FINAL
REMEDIAL DESIGN
LHAAP-16 LANDFILL
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Prepared For:

U.S. Army Corps of Engineers
Tulsa District

Prepared By:

AECOM Technical Services

January 2017

DRAFT FINAL
REMEDIAL DESIGN LHAAP-16 LANDFILL
LONGHORN ARMY AMMUNITION PLANT
KARNACK, TEXAS

Prepared For:

U.S. Army Corps of Engineers

Tulsa District

Prepared By:

AECOM Technical Services

Contract No. W912DY-09-D-0059

Task Order No. DS01

January 2017

Table of Contents

List of Figures

List of Tables

List of Appendixes

Acronyms and Abbreviations

µg/L	microgram per liter
ABC+	Anaerobic Biochem Plus
API	American Petroleum Institute
ARAR	applicable or relevant and appropriate requirements
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
cm/sec	centimeters per second
COC	contaminant of concern
DCA	Dichloroethane
DCE	Dichloroethene
DO	dissolved oxygen
DPT	direct push technology
ECP	Environmental Condition of Property
EDS-ER	Electron Donor Solution - Extended Release
ESD	Explanation of Significant Difference
ESTCP	Environmental Security Technology Certification Program
EVO	emulsified vegetable oil
FFA	Federal Facilities Agreement
FS	Feasibility Study
HDPE	high-density polyethyelene
HFCS	high-fructose corn syrup
HSA	hollow stem auger
IRA	Interim Remedial Action
ISB	in-situ bioremediation
IWWP	Installation-Wide Work Plan
lbs	pounds
LHAAP	Longhorn Army Ammunition Plant
LTM	long-term monitoring
LUC	land use control
mg/L	milligrams per liter

MNA	monitored natural attenuation
MOA	Memorandum of Agreement
msl	mean sea level
mV	millivolt
NPL	National Priorities List
O&M	operation and maintenance
ORP	Oxidation-Reduction Potential
RACR	Remedial Action Completion Report
RAO	Remedial Action Objectives
RD	Remedial Design
RI	Remedial Investigation
ROD	Record of Decision
ROI	Radius of Influence
SARA	Superfund Amendment and Reauthorization Act
TAC	Texas Administrative Code
TCA	Trichloroethane
TCE	Trichloroethene
TCEQ	Texas Commission on Environmental Quality
U.S.	United States
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
VOC	volatile organic compound
VC	Vinyl chloride
ZVI	zero valent iron

1 INTRODUCTION

This document presents the remedial design (RD), inspection and maintenance requirements, and land use control (LUC) requirements associated with the remedy set forth in the Final Longhorn Army Ammunition Plant (LHAAP)-16 Record of Decision (ROD) (U.S. Army 2016), generated in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986.

This RD document was prepared for the United States (U.S.) Army under the Worldwide Environmental Remediation Services Contract No. W912DY-09-D-0059 managed by the U.S. Army Corps of Engineers, Tulsa District.

1.1 LHAAP Background

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 1,200 of its former 8,416 acres located between State Highway 43 in Karnack, Texas, and the western shore of Caddo Lake as shown in **Figure 1-1**. LHAAP was listed as a National Priorities List (NPL) site on August 9, 1990 due to threatened releases of hazardous substances, pollutants, or contaminants. The United States Environmental Protection Agency (USEPA), the Texas Water Commission (now the Texas Commission on Environmental Quality [TCEQ]), and the U.S. Army signed a Federal Facility Agreement (FFA) on December 30, 1991.

1.2 LHAAP-16 Site Description

LHAAP-16 is a capped landfill covering approximately 20 acres in the south-central portion of the former LHAAP (**Figures 1-2 and 1-3**). Harrison Bayou is located along the northeastern edge of the site and flows into Caddo Lake, northeast of the site (**Figure 1-2**). The landfill, which covered approximately 13 acres prior to cap construction, was established in the 1940s for the disposal of solid and industrial wastes, until the 1980s, when disposal activities were terminated.

The U.S. Army and the USEPA signed a ROD and the Texas Water Commission concurred in 1995 approving an interim remedial action for LHAAP-16 to mitigate potential risks posed by buried source material at the site. The interim remedial action included the construction of a landfill cap, which is considered a component of the final remedy for the site. Construction of the multilayer cap was completed in 1998. The ROD also specified that the U.S. Army would be required to “perform long-term maintenance of the cap.” LUCs, such as future use restrictions, would also be required.

Previous investigations identified groundwater impacted with chlorinated volatile organic compounds (VOCs), perchlorate, and five metals (arsenic, chromium, manganese, nickel, and thallium) at LHAAP-16 (U.S. Army 2016). Figure 1-3 shows the existing groundwater monitoring system and the approximate lateral extent of perchlorate and TCE in the Shallow Zone and Intermediate Zone groundwater, based on the last comprehensive groundwater sampling event performed in May 2013 (AECOM, 2013). The source of this impacted groundwater is the landfill, although the metals were only detected at elevated concentrations sporadically, and do not appear to reflect widespread contamination from the landfill. A groundwater extraction system was voluntarily installed by the U.S. Army in 1996 and 1997 as a treatability study to prevent the groundwater plume from migrating to Harrison Bayou. The extraction system was shut down in August 2012 due to operational issues including damage to the power feed to the system, but operation was restored in November 2012 and the extraction system has been operational since that time.

The Final ROD for LHAAP-16 was issued in September 2016 and documents the final selected remedy for the site, including impacted groundwater (U.S. Army 2016). A summary of remedial action objectives (RAOs), cleanup levels, and the selected remedy for LHAAP-16 presented in the Final ROD is presented in the following sections.

1.3 Remedial Action Objectives

The RAOs developed for LHAAP-16 and outlined in the LHAAP-16 ROD (US Army 2016) are:

- 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 contaminants of concern (COCs) and COC by-products from migrating into Harrison Bayou at levels that cause surface water in Harrison Bayou to exceed surface water criteria; and
- Return of groundwater to its potential beneficial uses as drinking water, wherever practicable.

1.4 Planned Remedial Action

The planned remedial action at LHAAP-16 is comprised of several elements:

- Maintenance of the existing landfill cap to preserve its integrity and minimize or prevent infiltration through the landfill.
- Installation of two (2) biobarriers in the shallow groundwater, one located adjacent to the landfill and the other located near Harrison Bayou.
- In situ bioremediation (ISB) in the most contaminated portion of the shallow and intermediate groundwater zones in conjunction with phased shut down of the existing groundwater extraction system.
- Monitored natural attenuation (MNA) of both the shallow and intermediate groundwater zones to ensure continued degradation of COCs and daughter products and that surface water in Harrison Bayou is not adversely affected by groundwater such that it fails to meet surface water standards for COCs and daughter products. MNA includes**:**
    - Evaluation of MNA based on performance objectives after 2 years quarterly monitoring;
    - Reapplication of bio-amendments if MNA is found to be ineffective; and

  - Long-term monitoring (LTM) semiannually for 3 years, then annually thereafter until recommended otherwise by the five-year review. LTM will not be initiated until MNA performance monitoring establishes the effectiveness of MNA.

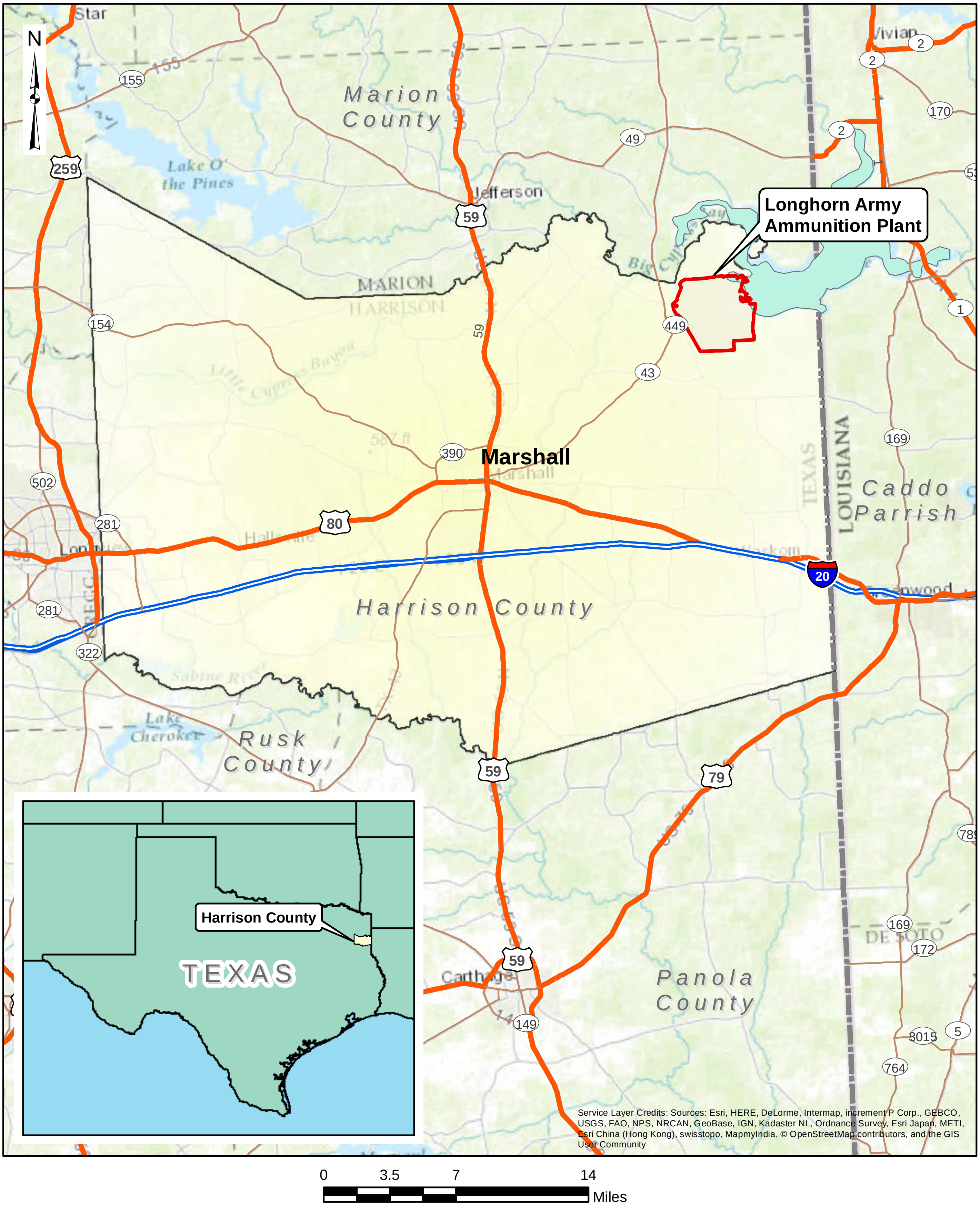
- LUCs to prohibit access to the contaminated groundwater except for environmental monitoring and testing only;
- LUCs to preserve the integrity of the landfill cap, and to restrict intrusive activities (e.g., digging) that would degrade or alter the cap;
- LUCs to restrict land use to nonresidential; and
- LUCs to maintain the integrity of any current or future remedial or monitoring systems.

1.5 Cleanup Levels

Groundwater and surface water cleanup levels were established in the ROD (U.S. Army 2016) to meet the RAOs and are presented in **Table 1-1** (adapted from Table 2-7 of the ROD).

1.6 Applicable or Relevant and Appropriate Requirements

The applicable or relevant and appropriate requirements (ARARs) for the planned remedial action at LHAAP-16 documented in the ROD are summarized in **Table 1-2**.



Service Layer Credits: Sources: Esri, HERE, DeLorme, 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

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 1-1 LHAAP Location.mxd

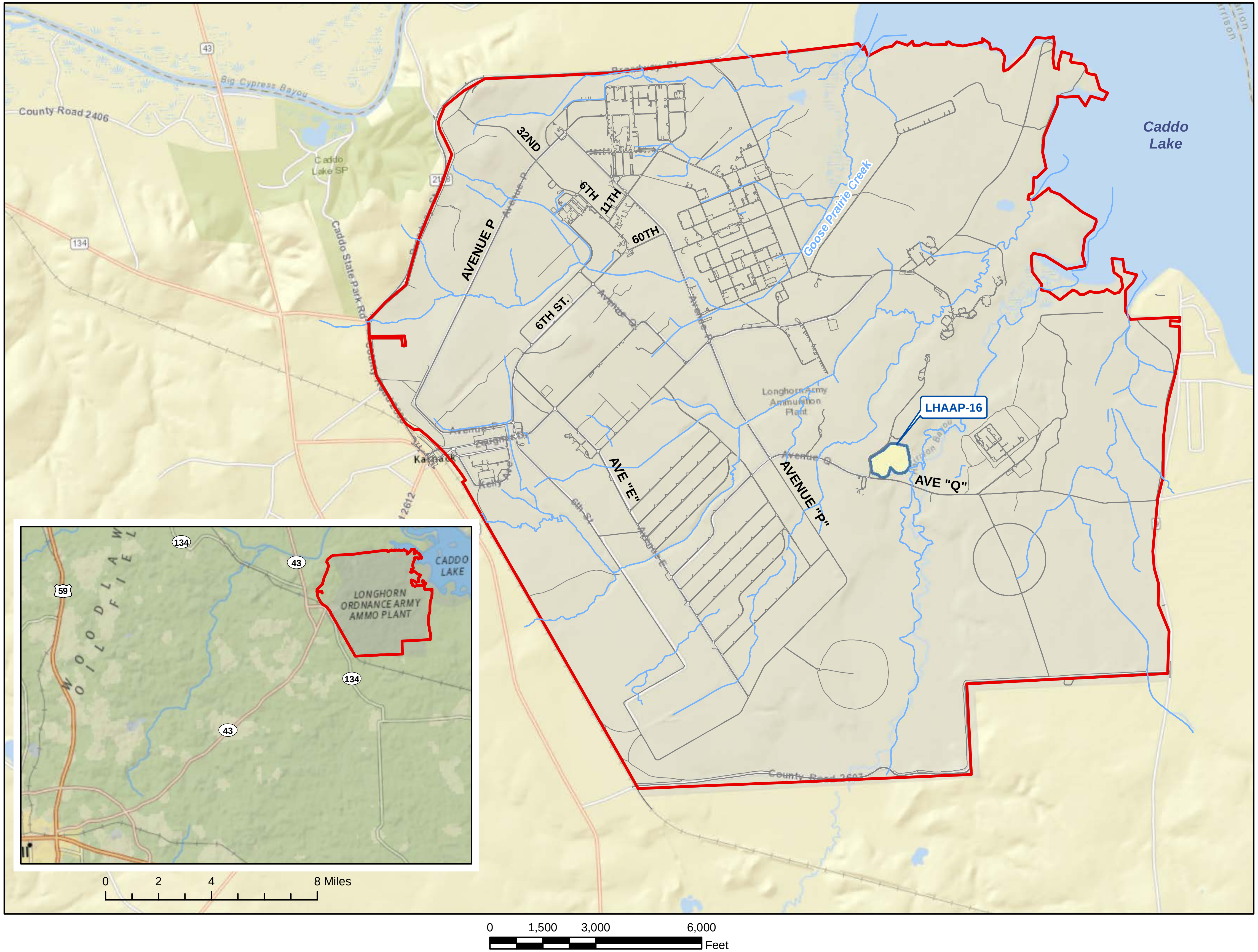
AECOM

Figure 1-1
LHAAP Location
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017



Legend

Streams

Roads

🟥 LHAAP Boundary

🟨 LHAAP-16 Site Boundary

🟦 Lake/Pond

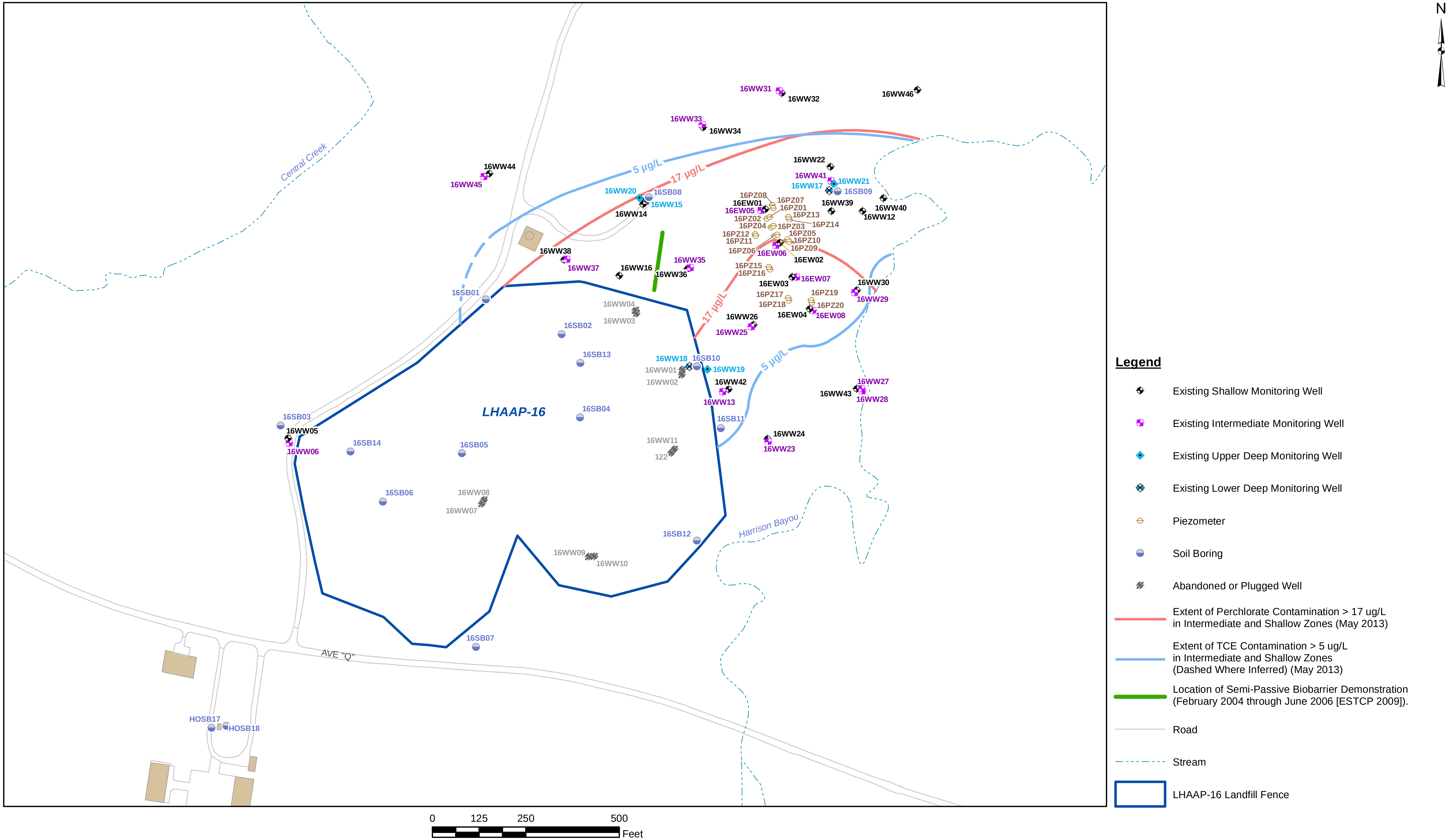
Figure 1-2
Site Location Map
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Document Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 1-2 LHAAP-16 Site Location Map.mxd



AECOM

Figure 1-3
LHAAP-16 Site Plan
LHAAP-16 Remedial Design
Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 1-3 LHAAP-16 Site Plan.mxd

Table 1-1: Groundwater and Surface Water Cleanup Levels

Chemical of Concern	Cleanup Level (µg/L)
	MCL
Trichloroethene	5
cis-1,2-Dichloroethene	70
1,1-Dichloroethene	7
1,2-Dichloroethane	5
Vinyl Chloride	2
1,1,2-Trichloroethane	5
Methylene Chloride	5
Chromium	100
Arsenic	10
Thallium	2
	TRRP Tier 1 Groundwater Residential PCLs
Nickel	490
Perchlorate	17
Manganese	1,100*

Notes and Abbreviations:

All values are in micrograms per liter (µg/L).

MCL maximum contaminant level

PCL – Texas Risk Reduction Program (TRRP) Tier 1 Groundwater Residential Protective Concentration Level

* 95% UTL value from Final Evaluation of Perimeter Well Data for Use as Groundwater Background (Shaw, 2007) for Manganese is 7,820 µg/L, which is above the TRRP Tier 1 Groundwater Residential PCL thus the background value will be considered the Cleanup Level for Manganese

Table 1-2: Federal and State ARARs – LHAAP-16 Remedial Action*

Description of ARARs for Final Selected Remedy

Citation	Activity or Prerequisite/Status	Requirement
Groundwater		
Federal Safe Drinking Water Act Maximum Contaminant Levels (MCLs) 40 CFR 141	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 MCLs/non-zero MCLGs for water designated as a current or potential source of drinking water. See Table 2-7 for specific numeric criteria
Surface Water		
State of Texas Surface Water Quality Standards: General Criteria and Toxic Materials Criteria 30 TAC 307.4 30 TAC 307.6	Applicable to surface waters of the state - **applicable** if water is discharged to a surface water body or surface waters are remediated as part of the remedial action.	Discharges to waters of the state must not cause in-stream exceedance of numeric and narrative water quality standards. Remediation of contaminated surface waters must ensure that numeric and narrative water quality standards are achieved, as determined by 307.8 (Application of the Standards) and Section 307.9 (Determination of Standards Attainment). See Table 2-7 for specific numeric criteria.
State of Texas Surface Water Quality Standards: Antidegradation 30TAC 307.5	Applicable to surface waters of the state – **applicable** if water is discharged directly to a surface water body or surface waters are remediated as part of the remedial action.	No activity subject to regulatory action that would cause degradation of waters that exceed fishable/swimmable quality will be allowed. Degradation is defined as a lowering of water quality by more than a de minimis extent but not to the extent than an existing use is impaired. Water quality sufficient to protect existing uses will be maintained. The highest water quality sustained since November 28, 1975, defines baseline conditions for determination of degradation.
General Site Preparation, Construction, and Excavation Activities		
Air Contaminants – General Nuisance Rules 30 TAC 101.4	Emissions of air contaminants—**applicable**.	No person shall discharge from any source whatsoever one or more air contaminants or combinations thereof, to exceed an opacity of 30 percent for any 6-minute period as are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation, or property, or as to interfere with the normal use and enjoyment of animal life, vegetation, or property.
Storm Water Runoff Controls 40 CFR 122.26; 30 TAC 205, Subchapter A; 30 TAC 308.121	Storm water discharges associated with construction activities—**applicable** to disturbances of equal to or greater than 1 acre of land.	Good construction management techniques, phasing of construction projects, minimal clearing, and sediment, erosion, structural, and vegetative controls shall be implemented to mitigate storm water run-on/runoff in areas of active remediation.
Waste Management		
Characterization of Solid Waste 40 CFR 262.11 30 TAC 335.62 30 TAC 335.504 30 TAC 335.503(a)(4)	Generation of solid waste, as defined in 30 TAC 335.1—**applicable**.	Must determine whether the generated solid waste is RCRA hazardous waste by using prescribed testing methods or applying generator knowledge based on information regarding material or process used. If the waste is determined to be hazardous, it must be managed in accordance with 40 CFR 262–268. After making the hazardous waste determination as required, if the waste is determined to be nonhazardous, the generator shall then classify the waste as Class 1, Class 2, or Class 3 (as defined in Section 335.505 through Section 335.507) using one or more of the methods listed in Section 335.503(a)(4) and Section 335.508 and manage the waste in accordance with the requirements of Chapter 335 of the TAC for industrial solid waste.

Table 1-2: Federal and State ARARs – LHAAP-16 Remedial Action*

Citation	Activity or Prerequisite/Status	Requirement
Characterization of Hazardous Waste 40 CFR 268.7 30 TAC 335.504(3) 30 TAC 335.509 30 TAC 335.511	Generation of a RCRA hazardous waste for treatment, storage, or disposal—**applicable** if hazardous waste is generated (e.g., personal protective equipment [PPE]).	Must obtain a detailed chemical and physical analysis of a representative sample of the waste(s) that at a minimum contains all the information that must be known to treat, store, or dispose of the waste in accordance with 40 CFR 264 and 268. Must also determine whether the waste is restricted from land disposal under 40 CFR 268 et seq. by testing in accordance with prescribed methods or use of generator knowledge of waste.
Requirements for Temporary Storage of Hazardous Waste in Accumulation Areas 40 CFR 262.34(a) and (c)(1) 30 TAC 335.69(a) and (d)	On-site accumulation of 55 gallons or less of RCRA hazardous waste for 90 days or less at or near the point of generation—**applicable** if hazardous waste is generated (e.g., PPE) and stored in an accumulation area.	Remedial activities derived waste (from monitoring, intercepting and treating contaminated groundwater) is expected for this facility. A generator may accumulate hazardous waste at the facility provided that • Waste is placed in containers that comply with 40 CFR 264.171 to 264.173 (Subpart I); and • Container is marked with the words “hazardous waste”; or • Container may be marked with other words that identify the contents.
Well Construction		
Well Construction Standards—Monitoring or Injection Wells 16 TAC 76.1000	Construction of water wells—**applicable** to construction of new monitoring or injection wells, if needed.	Injection wells shall be completed in accordance with the technical requirements of Section 76.1000, as appropriate. Substantive requirements applicable to the injection wells will be adhered to.
Class V Injection Wells 30 TAC 331, Subchapters A,C and H	Installation, operation, and closure of injection wells fall in the category of Class V Injection Wells – **relevant and appropriate**.	Injection wells shall be constructed to the required specifications for isolation casing, surface completion, prevention of commingling, and confinement of undesirable groundwater to its zone of origin. Closure shall be accomplished by removing all of the removable casing and the entire well shall be pressure filled via a tremie pipe with cement from bottom to the land surface, or closure shall be performed by the alternative method for Class V Wells completed in zones of undesirable groundwater. Groundwater concentrations at time of well closure will determine the appropriate method of abandonment. Substantive requirements applicable to the injection wells will be adhered to.
Treatment/Disposal		
Disposal of Wastewater (e.g., contaminated groundwater, dewatering fluids, decontamination liquids) 40 CFR 268.1(c)(4)(i) 30 TAC 335.431(c)	RCRA-restricted characteristically hazardous waste intended for disposal—**applicable** if extracted groundwater or rinsate from incinerator is determined to be RCRA characteristically hazardous.	Disposal is not prohibited if such wastes are managed in a treatment system subject to regulation under Section 402 of the CWA that subsequently discharges to waters of the United States.

Table 1-2: Federal and State ARARs – LHAAP-16 Remedial Action*

Citation	Activity or Prerequisite/Status	Requirement
Closure		
Standards for Plugging Wells that Penetrate Undesirable Water or Constituent Zones 16 TAC 76.1004(a) through (c)	Plugging and abandonment of wells—**applicable** to plugging and closure of monitoring and/or extraction wells.	If a well is abandoned, all removable casing shall be removed and the entire well pressure filled via a tremie pipe with cement from bottom up to the land surface. In lieu of this procedure, the well shall be pressure-filled via a tremie tube with bentonite grout of a minimum 9.1 lb/gal weight followed by a cement plug extending from land surface to a depth of not less than 2 feet. Undesirable water or constituents or the freshwater zone(s) shall be isolated with cement plugs.
Post Closure Care		
Post Closure Care Requirements for Hazardous Waste Landfills 40 CFR 264.310(b)(1)(4)(5)(6) 40 CFR 264.228(b)(1)(3)(4) 30 TAC 335.174(b) 40 CFR 264.117 - 264.120	Closure of a RCRA landfill – **relevant and appropriate** to closure or post closure under CERCLA of landfills containing RCRA hazardous waste	Owner or operator must • Maintain the effectiveness and integrity of the final cover including making repairs to the cap as necessary to correct effects of settling, erosion, etc.; • Prevent run-on and runoff from eroding or otherwise damaging final cover; and • Maintain and monitor a groundwater monitoring system.

Abbreviations:

CFR	Code of Federal Regulations
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act of 1976
TAC	Texas Administrative Code

* Source: Final Record of Decision, LHAAP-16 Landfill, Longhorn Army Ammunition Plant, Karnack, TX (U.S. Army 2016).

2 SITE CHARACTERISTICS

This section presents a summary of site characteristics for LHAAP-16 primarily based on the following historical documents: (1) Final ROD (U.S. Army 2016), (2) Addendum to Final Feasibility Study (Shaw 2010), (3) Feasibility Study Report (Jacobs 2002), and (4) Remedial Investigation Report (Jacobs 2000).

LHAAP-16 encompasses an area of approximately 20 acres. Harrison Bayou runs along the northeastern edge of LHAAP-16. Most of LHAAP-16 is relatively flat. The outer edges of the site are forested, and the land becomes steeper near Harrison Bayou. The capped landfill is vegetated.

Surface drainage from LHAAP-16 flows mostly through small gullies and ditches to Harrison Bayou. Harrison Bayou flows into Caddo Lake, to the northeast of the site. The eastern and southeastern edges of LHAAP-16 are located within the 100-year floodplain of Harrison Bayou. LHAAP-16 has no known areas of archeological or historical importance.

2.1 Geology and Hydrogeology

The surface soil at LHAAP-16 consists of fine sandy loam. The subsurface is composed of medium plastic sandy silt, fine sands, and clay. The clay layers tend to separate the groundwater into shallow, intermediate, upper deep and deep zones.

The shallow groundwater zone varies in thickness from 9 to 18 feet and extends 33 feet below ground surface (bgs). **Figure 2-1** presents shallow groundwater elevation contours based on the last comprehensive groundwater elevations measured at the Site in June 2016. Depth to groundwater in the shallow zone is approximately 4 feet to 25 feet bgs. In general, the shallower groundwater depths (approximately 4 feet bgs) are encountered near the locations of monitoring wells 16WW42 and 16WW24; and the deeper groundwater depths (approximately 25 feet bgs) are encountered near the locations of piezometers 16PZ02 and 16PZ08 (see **Figure 2-1**).

An intermediate groundwater zone containing fewer fines than the shallow zone extends from 35 to 62 feet bgs. **Figure 2-2** presents intermediate groundwater elevation contours based on the last comprehensive groundwater elevations measured at the Site in June 2016. The upper deep groundwater zone extends from approximately 80 to 151 feet bgs. The lower deep groundwater zone extends below 220 feet bgs. While flow is primarily horizontal in these zones, vertical interaction between the shallow and intermediate zones is evidenced by pumping test results as well as the presence of contamination in both zones. Such interconnection is consistent with soil layers formed in fluvial depositional environments.

The groundwater flow direction is northeast toward Harrison Bayou in the shallow, intermediate and deep zones, while flow direction is southeast toward Harrison Bayou in the upper deep groundwater zone. Overall, the groundwater flow is toward Caddo Lake. The mean hydraulic conductivity value varies from 1.5×10^{-3} centimeters per second (cm/sec) in the Shallow Zone to 4.2×10^{-4} cm/sec in the Deep Zone (Jacobs 2002). Groundwater flow between the landfill and Harrison Bayou is also influenced by the presence of an extraction well system consisting of four wells in the shallow groundwater zone and four wells in the intermediate groundwater zone. The wells were installed in 1996 and 1997 as part of a treatability study.

2.2 Current and Future Land Use

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), and current access measures at the LHAAP preclude unlimited public access to areas within the fence. The fence now represents the National Wildlife Refuge boundary. Approved access for hunters is limited.

The reasonably anticipated future use of LHAAP-16 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 United States 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-16. Presently the Caddo Lake National Wildlife Refuge occupies approximately 7,200 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.

2.3 Current and Future Surface Water Uses

Harrison Bayou, which is located on and adjacent to LHAAP, currently supports wildlife and aquatic life. Humans may have limited access to parts of Harrison Bayou during animal hunts, but there is no routine use of Harrison Bayou located at LHAAP. Harrison Bayou does not carry adequate numbers and size of fish to support either sport or subsistence fishing. During the summer months, Harrison Bayou ceases flowing and/or dries up. The eastern portion of the LHAAP-16 is located within Harrison Bayou's 100-year flood-plain. When flowing, Harrison Bayou discharges 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. The lake is also a source of drinking water for several neighboring communities in Louisiana including Vivian, Oil City, Mooringsport, South Shore, Blanchard, Shreveport, and Bossier City. The anticipated future uses of surface water are the same as the current uses (U.S. Army 2016).

2.4 Current and Future Groundwater Uses

Groundwater in the drinking water aquifer (250-430 feet bgs) is currently used as a drinking water source in areas outside the former installation boundary. The drinking water aquifer should not be confused with the deep zone groundwater. The deep zone groundwater, a term used in LHAAP environmental documents, and the drinking water aquifer are distinct from each other and there is no connectivity between the contaminated zone and the drinking water aquifer (U.S. Army 2016).

As of May 2015, six active water supply wells near the LHAAP were identified (**Figure 2-3**). All of the six wells are located greater than 2 miles from LHAAP-16. Karnack Water Supply Corporation operates two groundwater supply wells servicing the town of Karnack that are greater than two miles from the LHAAP-16 site. These wells were completed in 1905 to depths of 287 and 285 feet 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 groundwater supply 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 feet below ground surface. These wells are also greater than two miles from the LHAAP-16 site. Caddo Lake State Park operates one groundwater supply 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 250 ft (**Figure 2-3**). There are three water supply wells located within LHAAP (see **Figure 2-3**) upgradient of LHAAP-16. These water wells supply water to buildings currently in use on the installation. Their approximate locations and depths are as follows:

- 150 ft south-southeast of the fire station approximately 1.7 miles from LHAAP-16; 128 ft deep
- ½ mile southwest of the fire station approximately 1.6 miles from LHAAP-16; 195 ft deep
- At the U.S. Fish and Wildlife Service facility approximately 2.1 miles from LHAAP-16; 220 ft deep

None of these wells are close to LHAAP-16, and none of these wells are used for drinking water. Two additional wells that had previously supplied water to the installation have been plugged and abandoned. None of the water supply wells are associated with or are in imminent danger from the localized contaminated groundwater at LHAAP-16. The water well search report (Banks Environmental Data, 2015).is presented in the Final Updated PSI for LHAAP-18/24 (AECOM, 2016).

Although the anticipated future use of the facility as a national wildlife refuge does not include the use of the groundwater at LHAAP-16 as a drinking water source, the State of Texas designates all groundwater as potential drinking water, unless otherwise classified, and consistent with 30 TAC 335.563(h)(1). To be conservative, a hypothetical industrial use scenario was evaluated for risk assessment summarized in the Final ROD (U. S. Army 2016). The future industrial scenario for LHAAP assumes limited use of groundwater as a drinking water source. At the current time, the wild life refuge uses public water supply for their drinking purposes.

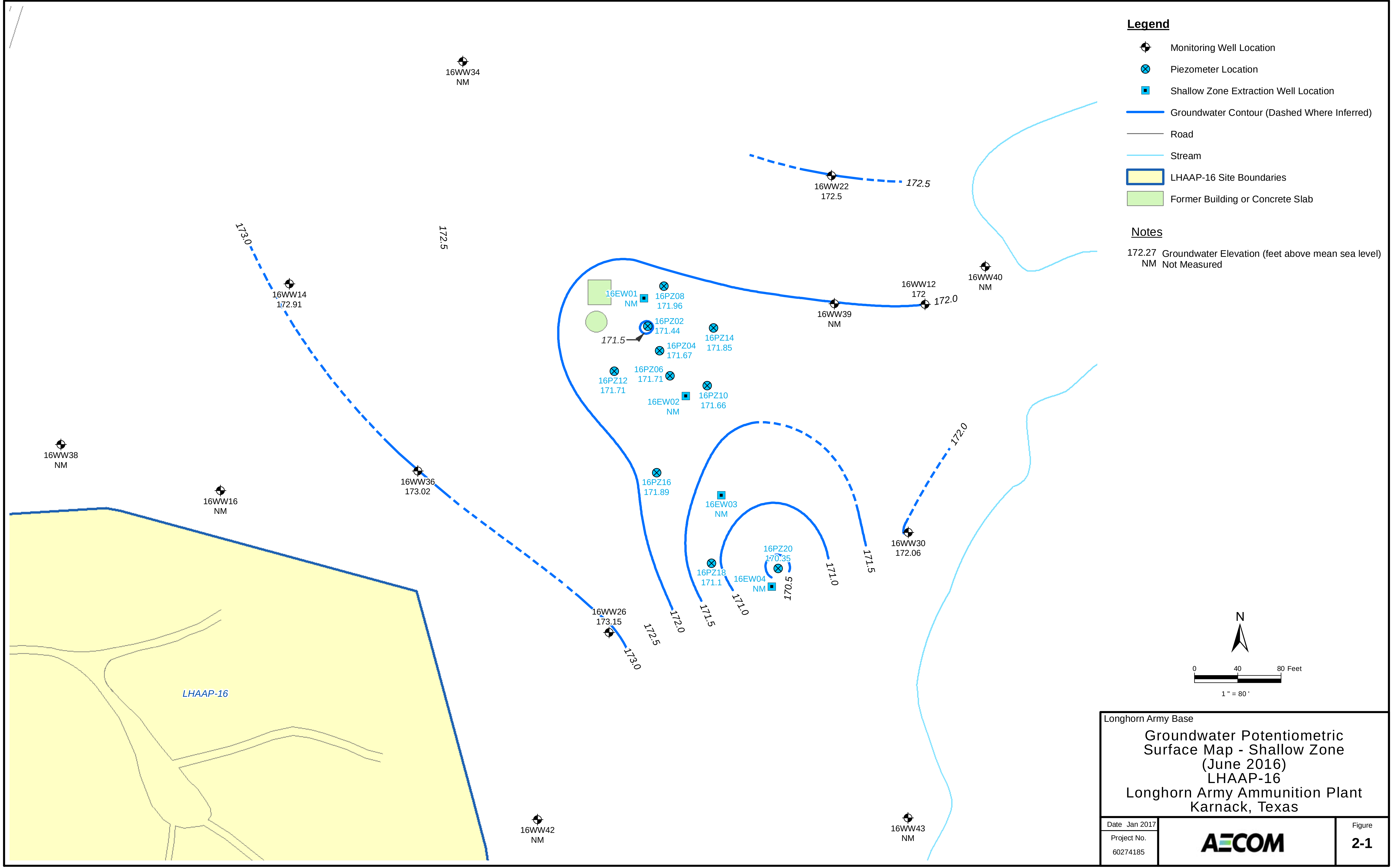
2.5 Nature and Extent of Contamination

The contaminated media at LHAAP-16 include buried source material (landfill waste under the cap) and the shallow and intermediate groundwater beneath and downgradient of the landfill. A presumptive remedy (interim remedial action [IRA]) was implemented in 1996 through 1998, which included placement of a multilayer cap at LHAAP-16 mitigating potential risks posed by buried landfill waste. The cap prevents rainfall from infiltrating and leaching contaminants from principal threat wastes within the landfill. However, groundwater in contact with the buried waste material still provides a mechanism for transportation of COCs away from the landfill (Jacobs 2000). A groundwater extraction system was installed as a treatability study to prevent the groundwater plume from migrating to Harrison Bayou.

The groundwater COCs for LHAAP-16 identified in the Final ROD (U.S. Army 2016) include chlorinated volatile organic compounds (VOCs) (trichloroethene [TCE]; cis-1,2-dichloroethene [DCE]; 1,1-DCE; 1,2-dichloroethane [DCA]; vinyl chloride [VC]; 1,1,2-trichloroethane [TCA]; methylene chloride), perchlorate, and metals (arsenic, chromium, manganese, nickel and thallium) in the shallow and/or intermediate groundwater. **Figures 2-4 through 2-7** present the isoconcentration contours for major VOCs, and perchlorate, in Shallow Zone and Intermediate Zone groundwater based on the last comprehensive round of groundwater sampling conducted in May 2013.

Five metals (arsenic, chromium, manganese, nickel and thallium) had sporadic elevated detections and were retained as COCs in the Final ROD. The detected metals do not appear to be associated with widespread contamination from the landfill.

Data collected from the upper deep groundwater zone from 1998 until 2008 indicate that no COCs were reported at concentrations exceeding their respective cleanup levels (**Table 1-1**). In addition, the data collected from deep groundwater from 1997 until 2004 indicate that no COCs were reported at concentrations exceeding their respective cleanup levels (Shaw 2010).



Longhorn Army Base

Groundwater Potentiometric Surface Map - Shallow Zone (June 2016)
LHAAP-16
Longhorn Army Ammunition Plant
Karnack, Texas

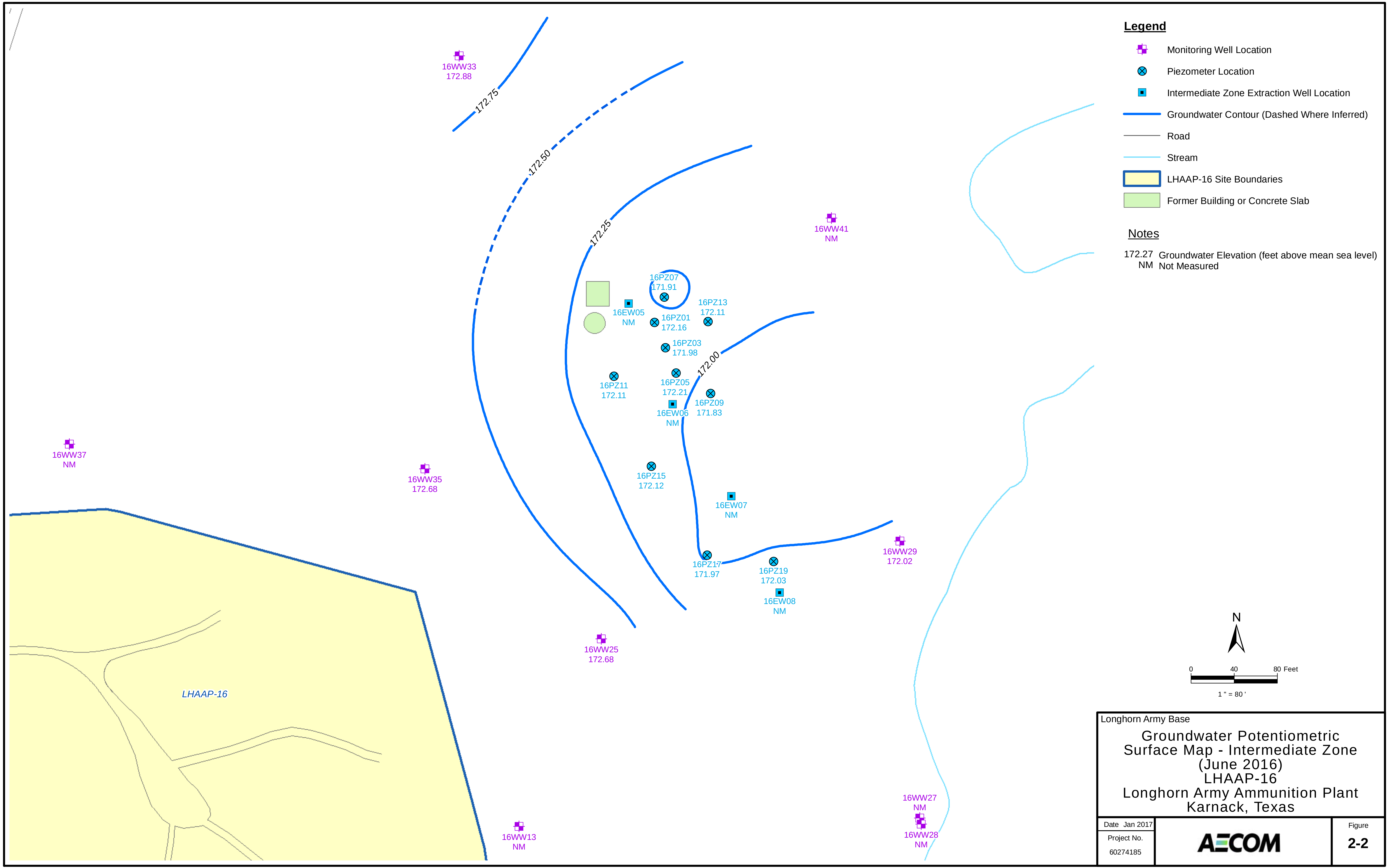
Date Jan 2017

Project No.
60274185

AECOM

Figure
2-1

File: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-1 GWE_Shallow_Jun_2016.mxd
Date: Wednesday, January 18, 2017 8:06:45 AM



Longhorn Army Base

Groundwater Potentiometric Surface Map - Intermediate Zone (June 2016)
LHAAP-16
Longhorn Army Ammunition Plant
Karnack, Texas

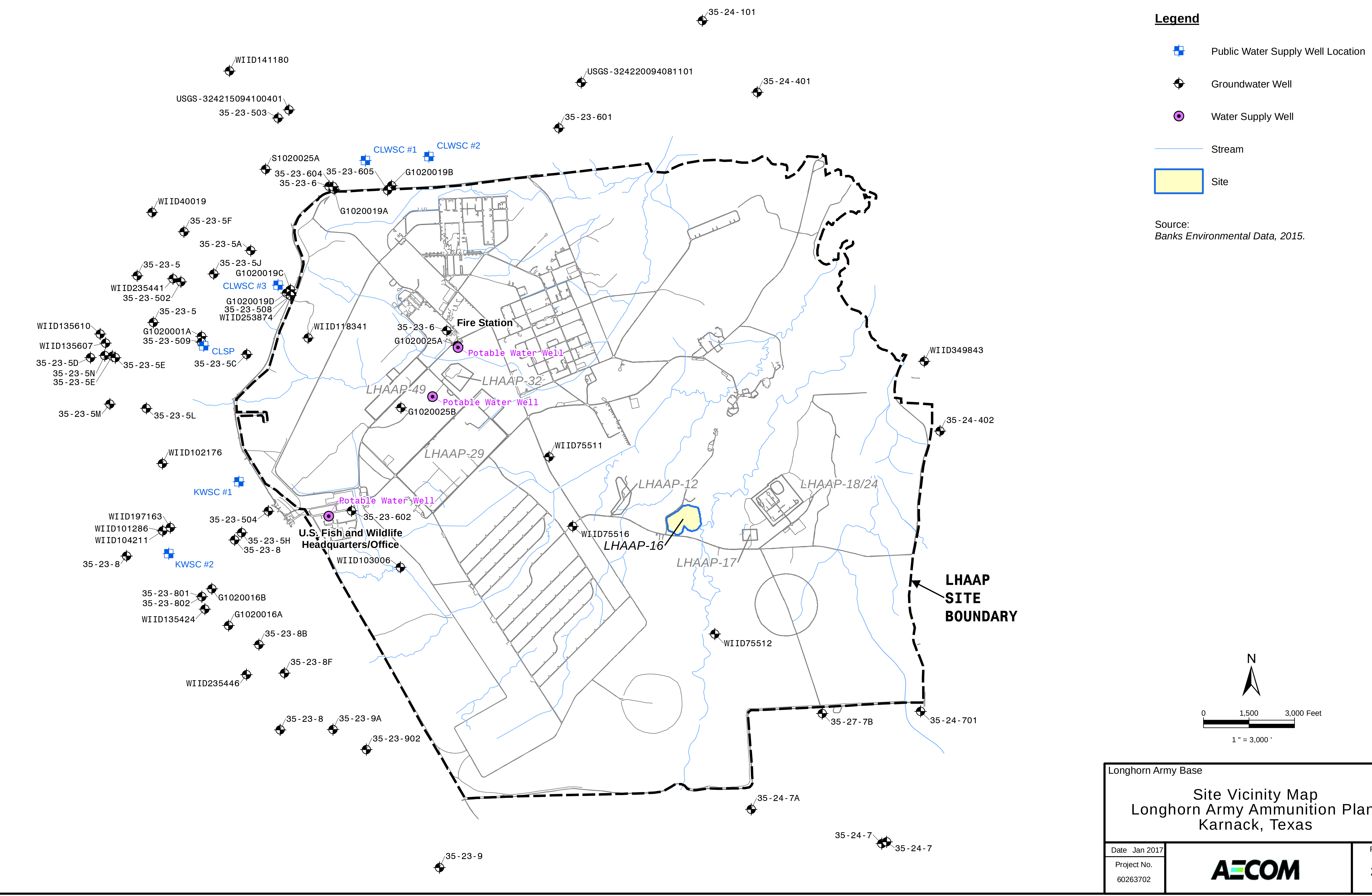
Date Jan 2017

Project No.
60274185

AECOM

Figure
2-2

File: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-2 GWE_Int_Jun_2016.mxd
Date: Wednesday, January 18, 2017 8:07:58 AM



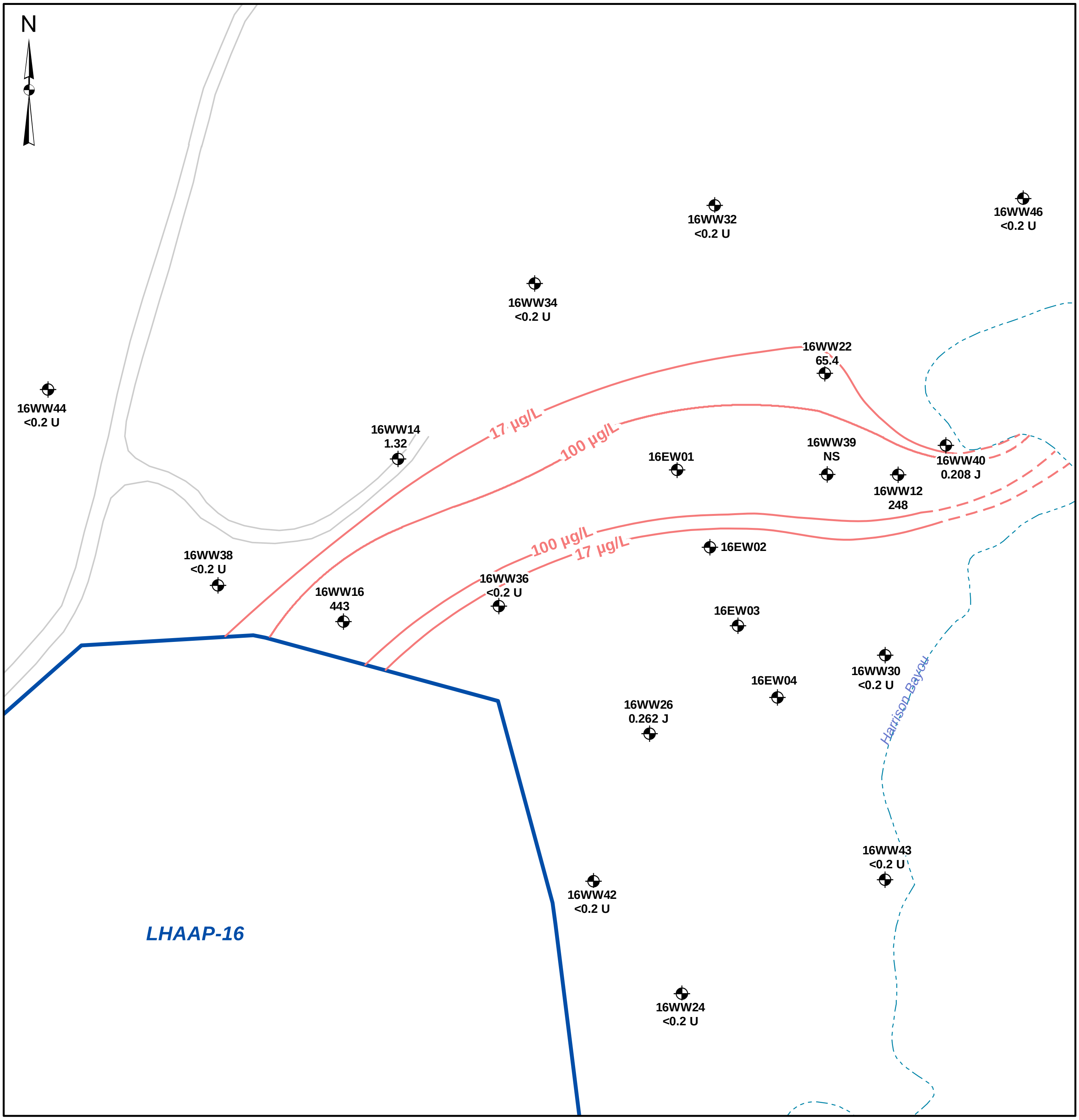
Source:
Banks Environmental Data, 2015.

Longhorn Army Base

Site Vicinity Map
Longhorn Army Ammunition Plant
Karnack, Texas

Date Jan 2017	AECOM	Figure
Project No. 60263702		2-3

File: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-3 GW_Wells_Site_Vicinity.mxd
Date: Wednesday, January 18, 2017 8:24:00 AM



Legend

⊕	Shallow Monitoring Well
—	Perchlorate Concentration Contour (Dashed Where Inferred)
- - -	Stream
—	Road
▭	LHAAP-16 Landfill Fence

Notes:
Results are in micrograms per liter (µg/L)
TRRP Residential PCL for Perchlorate = 17 µg/L.
J - Estimated: The analyte was positively identified, the quantitation is an estimation due to discrepancies in meeting certain analyte-specific quality control criteria.
U - Undetected: The analyte was analyzed for, but not detected.
NS - Not Sampled

0 85 170 340
Feet

AECOM

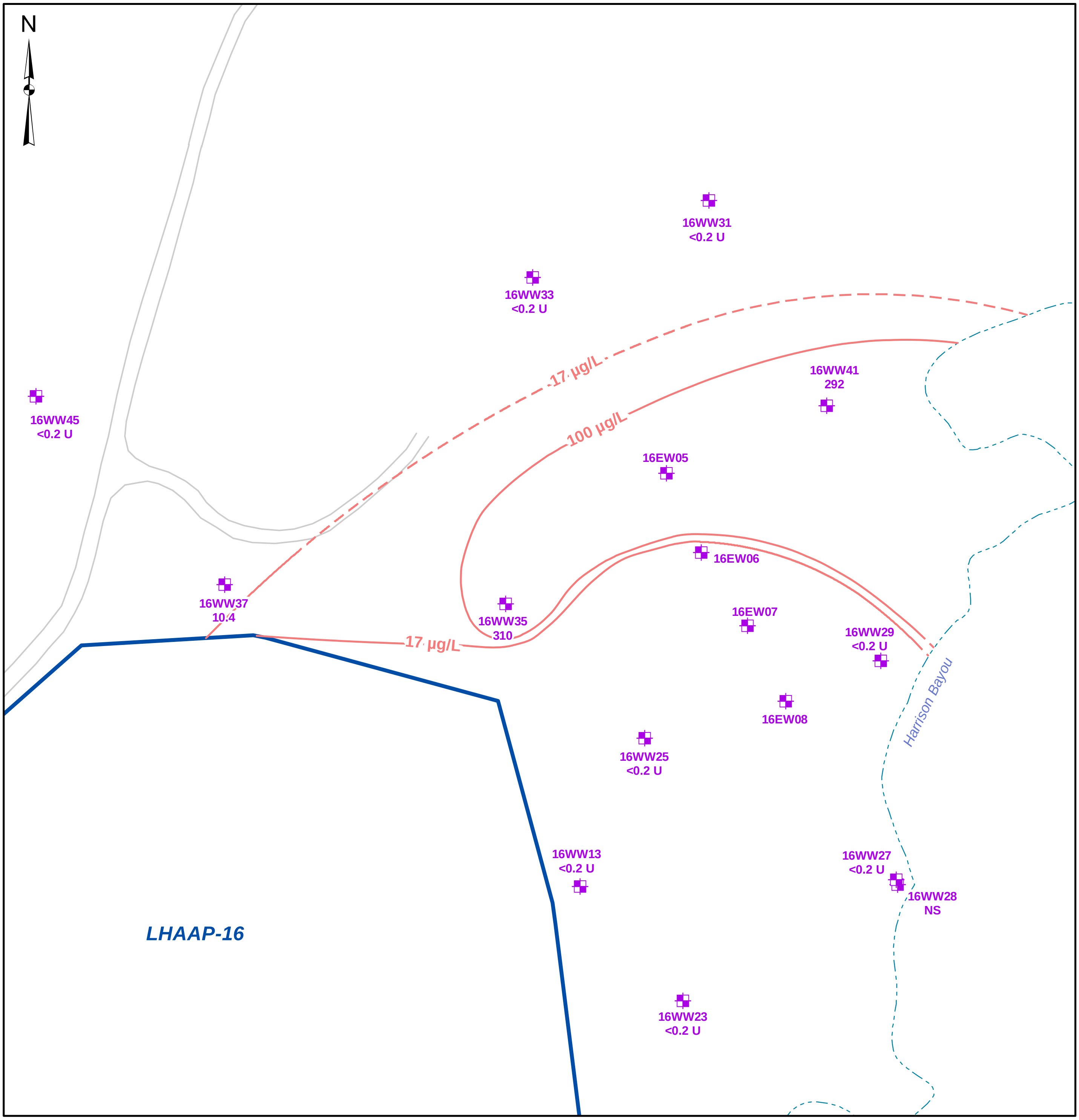
Figure 2-4
Perchlorate Concentrations in Groundwater Shallow Zone - May 2013 LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGEIGIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-4 LHAAP-16 Perchlorate in Shallow Zone May 2013.mxd



Legend

✚	Intermediate Monitoring Well
―	Perchlorate Concentration Contour (Dashed Where Inferred)
-·-·-	Stream
―	Road
▭	LHAAP-16 Landfill Fence

Notes:
Results are in micrograms per liter (µg/L)
TRRP Residential PCL for Perchlorate = 17 µg/L.
J - Estimated: The analyte was positively identified, the quantitation is an estimation due to discrepancies in meeting certain analyte-specific quality control criteria.
U - Undetected: The analyte was analyzed for, but not detected.
NS - Not Sampled

0 85 170 340
Feet

AECOM

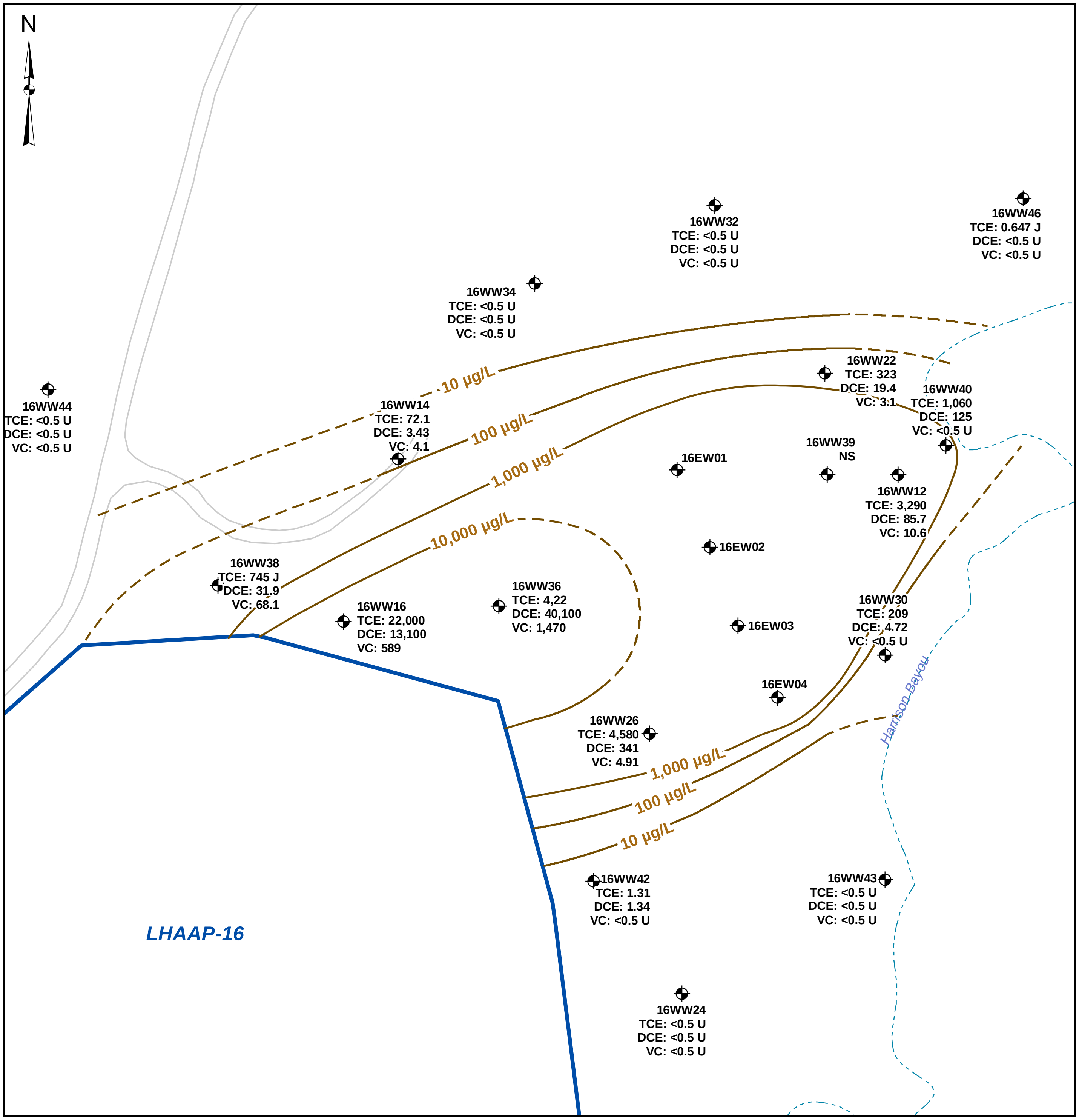
Figure 2-5
Perchlorate Concentrations in Groundwater Intermediate Zone - May 2013
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-5 LHAAP-16 Perchlorate in Intermediate Zone May 2013.mxd



Legend

⌖	Shallow Monitoring Well
—	TCE Concentration Contour (Dashed Where Inferred)
- · -	Stream
—	Road
▭	LHAAP-16 Landfill Fence

Notes:
Results are in micrograms per liter (µg/L)
DCE - cis-1,2-Dichloroethene
U - Undetected: The analyte was analyzed for, but not detected.
J - Estimated Value
NS - Not Sampled
TCE - Trichloroethene
VC - Vinyl Chloride
VOC - Volatile Organic Compound

0 85 170 340
Feet

AECOM

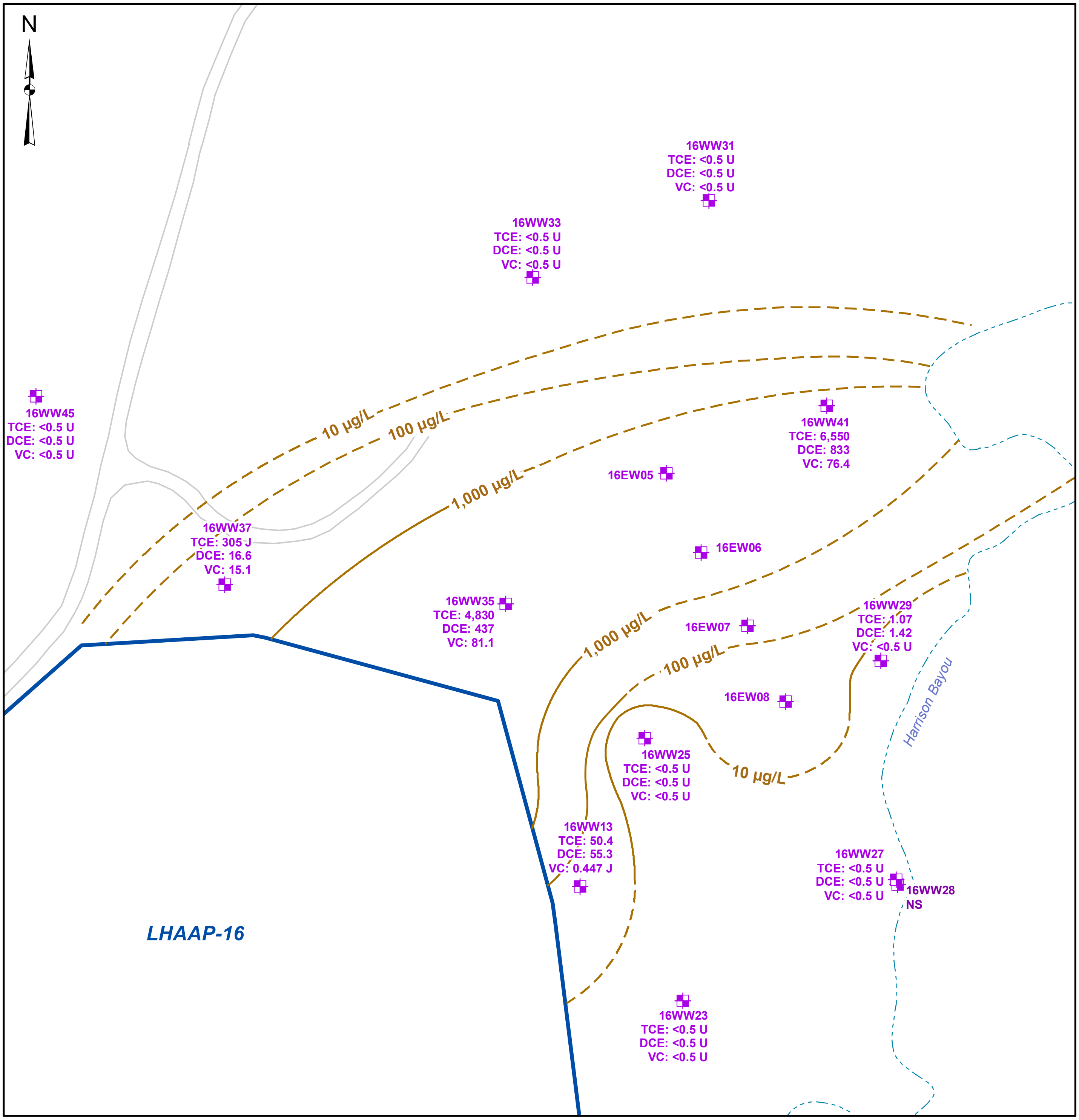
Figure 2-6
VOCs in Groundwater Shallow Zone - May 2013 LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-6 LHAAP-16 VOCs in Shallow Zone May 2013.mxd



Legend

⊞ Intermediate Monitoring Well

— TCE Concentration Contour (Dashed Where Inferred)

- - - Stream

— Road

▭ LHAAP-16 Landfill Fence

Notes:
Results are in micrograms per liter (µg/L)
DCE - cis-1,2-Dichloroethene
U - Undetected: The analyte was analyzed for, but not detected.
J - Estimated Value
NS - Not Sampled
TCE - Trichloroethene
VC - Vinyl Chloride
VOC - Volatile Organic Compound

0 85 170 340
Feet

AECOM

Figure 2-7
VOCs in Groundwater Intermediate Zone - May 2013 LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 2-7 LHAAP-16 VOCs in Intermediate Zone May 2013.mxd

3 OPERATION AND MAINTENANCE PROCEDURES

Some components of the final remedy at LHAAP-16 require operation and maintenance (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 existing landfill cap, which includes signage; and maintenance of the current or future groundwater monitoring system (this would include all wells that serve some purpose, including bioremediation, MNA, background, water levels, and cap performance). Other routine maintenance activities include maintenance and repair of site access features, such as roads, gates, and fencing, as needed. These activities will be conducted annually unless recommended otherwise during a five-year review.

3.1 Maintenance of the Existing Landfill Cap

As discussed previously, a multilayer cap was constructed at LHAAP-16 landfill from 1996 through 1998 as part of an early IRA (under CERCLA) in accordance with the interim ROD signed in 1995. Per the 1995 IRA ROD and 2016 Final ROD, this cap includes the following layers: foundation soil layer, sodium bentonite geocomposite liner, geomembrane, 18-inch fill soil layer, 6-inch top soil, and perimeter berms and drainage swales (see **Figure 3-1**).

Per the selected remedy documented in the 2016 Final ROD, the existing cap will continue to be monitored, maintained, and repaired, as necessary, to preserve its long-term effectiveness. This includes inspection of the landfill cap to check for erosion, settlement, and deep-rooted vegetation, and implementation of necessary repairs. Per the 1995 IRA ROD and 2016 Final ROD, the substantive post-closure requirements at 40 CFR Sections 264.228 (b)(1), (3), and (4); 264.310 (b); and 30 TAC 335.174 are ARARs for landfill cap maintenance and monitoring. The substantive requirements of these post-closure ARARs relevant to LHAAP-16 include the following:

- Maintain the integrity and effectiveness of the final cover, including making repairs to the cap as necessary to correct the effects of settling, subsidence, erosion, or other events (e.g. deep-rooted vegetation and burrowing animals).
- Maintain and monitor the ground-water monitoring system.
- Prevent run-on and run-off from eroding or otherwise damaging the final cover.

In order to comply with above requirements, annual inspections will be conducted for the different components of the landfill cap. Inspections will include examining each component of the cap to determine maintenance needs. **Table 3-1** summarizes the landfill cap inspection schedule. Inspection and maintenance of the signs will be conducted as part of the landfill cap inspection and maintenance activities. The area will be checked for proper signage to ensure that required signs are posted and are legible. If missing or no longer legible, the signs will be replaced.

An RAO Inspection and Maintenance Checklist is presented in **Appendix A**.

3.1.1 Vegetative Cover Maintenance

Vegetative cover is intended to reduce erosion caused by wind or water. Vegetation will be visually inspected annually, or as needed, following major events including a seismic event greater than a magnitude of 4 on the Richter scale, wildfires, or floods that may affect the integrity of the cover system, for overall health and continuous coverage. Bare spots where the topsoil is exposed, and/or areas of the cap where vegetation is dead or stressed to the point it no longer adequately inhibit erosion will be re-seeded, as appropriate Unwanted vegetation (e.g. plants with potentially deep root systems such as trees) that have the potential to compromise the integrity of the cap will be removed.

3.1.2 Erosion and Settlement Inspection and Maintenance

The landfill cap will be inspected annually, for erosion and settlement, or as needed following major events including a seismic event greater than a magnitude of 4 on the Richter scale, wildfires, or floods that may affect the integrity of the cover system. If evidence of significant erosion, settlement, or deterioration, such as gullies, linear crevasses, washouts, rills, or settlement depressions, are observed, the need for cap repair will be evaluated. Settlement can cause cracks, differential displacement, or zones of depression that disrupt the intended flow of storm water over the cover. If repairs are determined to be needed, they will be performed to preserve the integrity of the cap and may include filling and covering the erosion and settlement features with material of similar composition to the existing topsoil. Replacement topsoil will be compacted to restore the cap to the specified grade.

3.1.3 Drainage System Inspection and Maintenance

The drainage system consisting of graded drainage swales will be visually inspected annually, or as needed, following major events including a seismic event greater than a magnitude of 4 on the Richter scale, wildfires, or floods that may affect the integrity of the cover system, for overgrown vegetation, debris and silt, and erosion of banks and slopes. Areas of the drainage system where vegetation is overgrown to the point that it interferes with drainage off the cover, or where silt and/or debris have accumulated, will be maintained by removing the overgrowth and/or accumulated sediment/debris from the drainage swale. Also, areas with bank and slope erosion will be restored by removing eroded soil, adding new soil, compacting in 6 inch lifts, and adding vegetation for slope stability. If further stabilization is required, riprap can be placed along the bank slope.

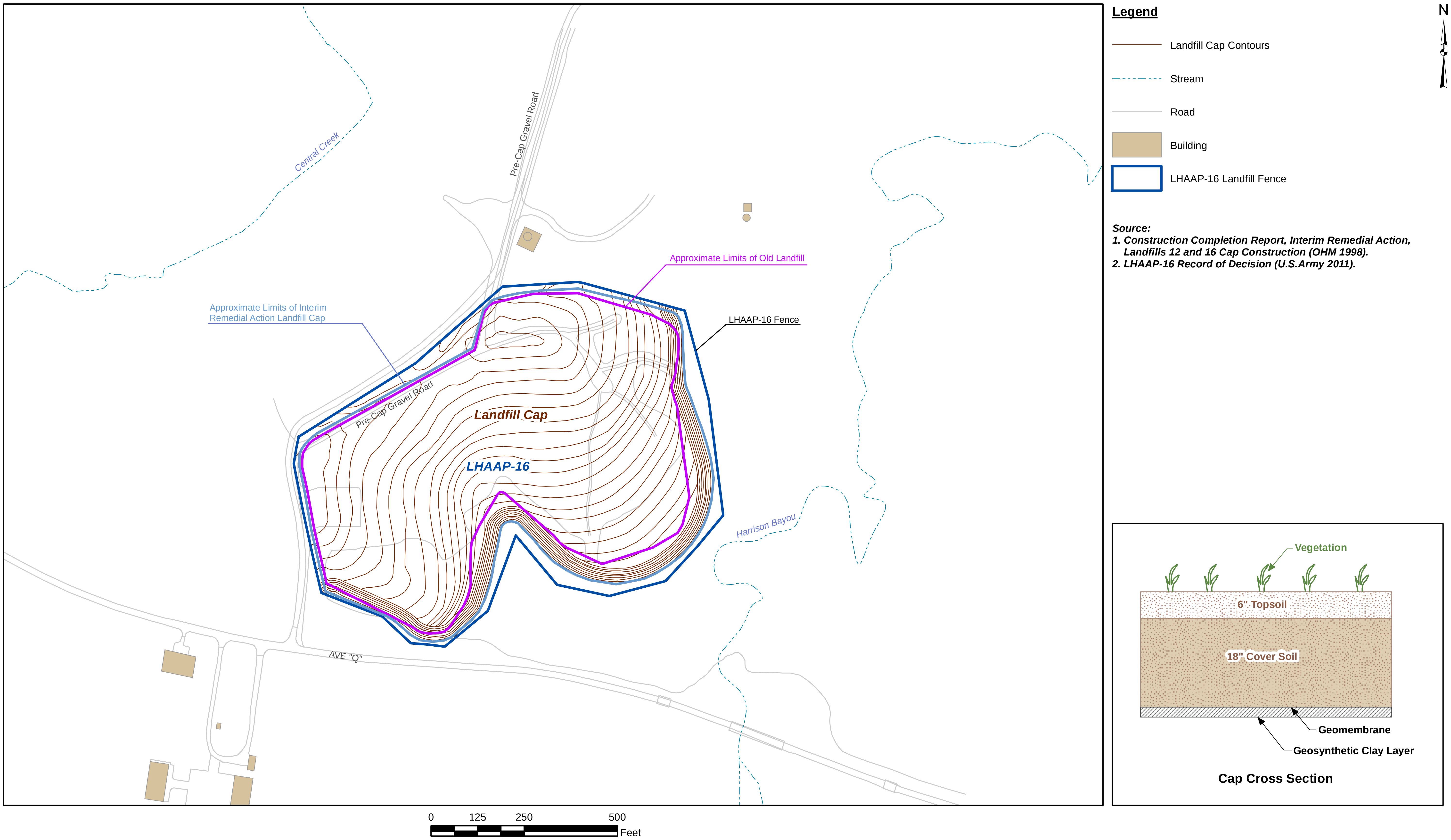
3.2 Maintenance of the Current or Future Groundwater Monitoring System

The groundwater monitoring system is comprised of a network of monitoring wells used to implement enhanced in-situ bioremediation (discussed later), monitor progress of the remedial activities, evaluate the performance of the cap, 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 discussed for the landfill cap. 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, 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.

3.3 Maintenance of Site Access Features

LHAAP-16 is accessed by roads and through gates in a perimeter fence. The roads, perimeter fence and gates will be visually inspected annually, or as needed, to ensure that the roads remain accessible and the perimeter fence and gates are intact and undamaged. Maintenance will be conducted as needed.

Any fence posts that are not securely anchored in the ground and/or metallic parts that are excessively corroded, will be repaired or replaced. If evidence of unauthorized entry through, over, or under the fence is observed, these sections of the fence will be reinforced.



Source:
1. Construction Completion Report, Interim Remedial Action, Landfills 12 and 16 Cap Construction (OHM 1998).
2. LHAAP-16 Record of Decision (U.S.Army 2011).

AECOM

Figure 3-1
Landfill Cap
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 3-1 LHAAP-16 Landfill Figure.mxd

Table 3-1: Landfill Inspection Schedule

Landfill Feature	Frequency of Inspection
Existing Landfill Cap	Annually, or as needed, and after a major event[a]
- Vegetative Cover	
- Erosion and Settlement	
- Drainage System	
Current and Future Groundwater Monitoring Systems	Annually, or as needed, and after a major event[a]
Site Access Features*	Annually, or as needed

Notes:

[a] A major event is defined as a storm event that causes major local flooding, a seismic event greater than a magnitude of 4, or other events such as wildfires that may affect the cover.

* This is not a ROD requirement

4 IN-SITU BIOREMEDIATION DESIGN

ISB will be implemented at LHAAP-16 to remediate groundwater impacted with COCs. Per the Final ROD (U.S. Army 2016), the following ISB systems will be designed and implemented to remediate COC-impacted groundwater at LHAAP-16:

- Biobarriers in the Shallow Zone groundwater adjacent to the landfill (hereinafter referred to as Landfill Biobarriers)
- Biobarrier in the Shallow Zone groundwater near Harrison Bayou (hereinafter referred to as Bayou Biobarrier)
- ISB in the most contaminated portion of the Shallow Zone and Intermediate Zone groundwater (hereinafter referred to as Mid-Plume ISB)

The proposed locations of these ISB systems are presented on **Figure 4-1**. The Final ROD provides preliminary design concepts, but states that the details of the ISB implementation would be established during the remedial design phase. The design and implementation details of the ISB systems are summarized in the subsections below.

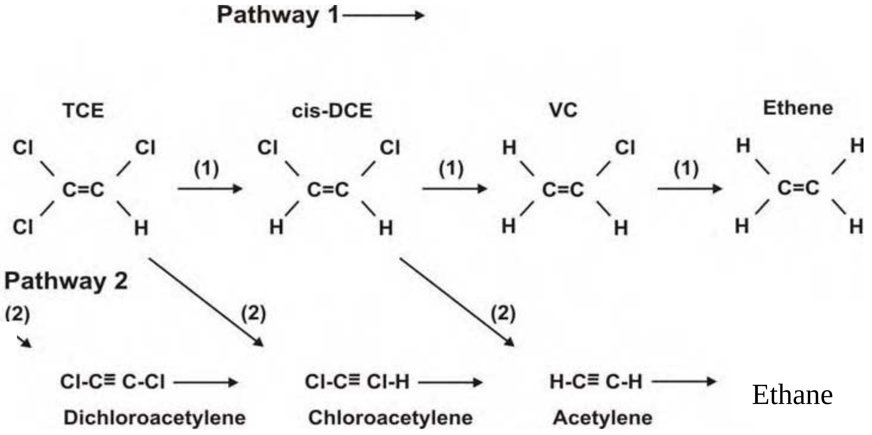
In general, implementation of biobarriers and ISB will include injection of an electron donor/ substrate, and a microbial consortium capable of biodegrading primary chlorinated COCs (perchlorate, TCE, cis-1,2-DCE; and VC) in the subsurface. The indigenous and augmented microorganisms will grow and multiply using injected substrate as a carbon and energy source, thereby degrading perchlorate, TCE, cis-1,2-DCE, and VC. The schematics showing degradation pathways for perchlorate and chlorinated VOCs are provided below. For chlorinated VOCs, if zero valent iron (ZVI) is mixed with substrate, abiotic degradation to ethene (Pathway 2 shown on the schematic) may occur in addition to biotic degradation (Pathway 1). While the ROD does not prescribe the use of ZVI for ISB, ZVI supplements the use of electron donor/substrate and accelerates degradation of site COCs in groundwater to the same end product, ethene, although through a different degradation pathway.

Perchlorate Degradation Pathway

$$ClO_4^- \longrightarrow ClO_3^- \longrightarrow ClO_2^- \longrightarrow Cl^- + O_2$$

Perchlorate Chlorate Chlorite Chloride + Oxygen

Biotic and Abiotic Degradation Pathways – Chlorinated VOCs



A groundwater extraction system was voluntarily installed by the U.S. Army in 1996 and 1997 as a treatability study to prevent the groundwater plume from migrating to Harrison Bayou. The groundwater extraction system is comprised of four wells in the Shallow Zone and four wells in the Intermediate Zone. The existing Shallow Zone extraction system will be shut down prior to implementation of the remedy. The existing Intermediate Zone extraction wells will continue to be pumped during implementation of ISB and will be shut down immediately after injection is complete to prevent extraction of the injected substrate. The downhole equipment in the extraction wells will be removed after power shut down and the extraction wells will be used as injection points in the Intermediate Zone. The extraction conveyance conduits will be evaluated for conveying substrate to the subsurface and the existing above ground tank will be evaluated for mixing injectate. The conveyance pipes and above ground storage tanks will be decommissioned when there is no longer a need for their use. This will occur when the criteria for MNA are met (i.e., MNA is demonstrated to be an effective remedy).

4.1 ISB Design Parameters

This section presents the general ISB design parameters common to the three ISB systems summarized above (Landfill Biobarriers, Bayou Biobarrier, and Mid-Plume ISB). The specific design details for each ISB system are discussed in subsequent sections. The details of the field implementation procedures are presented in Section 6.

4.1.1 General Substrate Injection Strategies

The substrate for the Shallow Zone Mid-Plume ISB and the biobarriers will be injected using direct push technology (DPT), except for Landfill Biobarrier #2, where existing wells will be used for injection. The substrate for the Intermediate Zone Mid-Plume ISB will be emplaced using injection wells, as summarized below. The type of substrate and specific injection quantities are discussed in the detailed design of each ISB system in **Sections 4.2 through 4.4**.

4.1.1.1 Direct Push Technology

Substrate for the Landfill Biobarriers, Bayou Biobarrier, and Shallow Zone Mid-Plume ISB will be injected using DPT, except for Shallow Zone Landfill Biobarrier #2, which will use existing wells installed in this area for the Environmental Security Technology Certification Program (ESTCP) study (Geosyntec 2009) for injection of the substrate.

DPT will be used to inject substrate at 2- to 3-foot intervals to cover the entire Shallow Zone groundwater treatment interval using a “top-down” approach at each proposed injection point. Using this approach, the injection tool string is advanced to the top of the injection interval and the substrate is pumped through the probe rods. The tools are then advanced to the next injection depth and the substrate is again pumped through the rods. This cycle is repeated to provide coverage across the entire injection interval. The top-down injection approach is expected to be effective since it will prevent backflow of injected material up through the tool string and reduces preferential flow of substrate.

Several direct push injection points may be manifolded for simultaneous injection to maximize delivery efficiency. The substrate will be injected at relatively low pressures (e.g., up to 200 psi) to avoid development of preferential flow pathways within the formation. The injection pressure at each DPT location will be dictated by the formation back pressure on the pumping system, but will be controlled by use of pressure relief valves.

4.1.1.2 Injection Wells

Injection wells will be used to emplace Landfill Biobarrier #2 and the Intermediate Zone Mid-Plume ISB. The substrate will be gravity fed or injected into wells using pumps operated at relatively low pressures to avoid development of preferential flow pathways within the formation. The injection and distribution of substrate within the subsurface will be hydraulically controlled by extracting groundwater from nearby wells during injection to enhance distribution of substrate away from the injection well.

Groundwater will be extracted from wells located adjacent to or near the injection wells using submersible pumps. The extracted groundwater will be used as dilution water for substrate at a central dosing unit. Diluted substrate will be injected into wells through a multi-channel manifold with simultaneous groundwater extraction from nearby wells. Following injection of substrate, chase water may be injected, if required, to enhance substrate distribution and flush the wells to limit biological growth and/or plugging of injection wells screens.

4.1.2 Radius of Influence and Injection Point Spacing

4.1.2.1 Direct Push Technology

An ISB pilot study was conducted at LHAAP-16 from 2004 through 2006 as part of ESTCP demonstration (Geosyntec 2009). As part of this pilot study, substrate solution, including a conservative tracer, was gravity fed into injection wells and its distribution was enhanced by extracting groundwater from nearby wells. The pilot study generally achieved good distribution of the electron donor with extraction wells 35 feet apart except in one area. The biobarrier achieved perchlorate reduction from 450 micrograms per liter (μg/L) to 13 μg/L on average. No biofouling was observed and minimal impact on sulfate and metals concentrations was observed. These results indicate use of biobarriers would be effective at LHAAP-16.

In general, the substrate was distributed (i.e. travel time for peak tracer concentration injected with substrate) to a distance of 14 feet in one to two weeks and to a distance of 35 feet in one to two months. The injection radius of influence (ROI) for low pressure injection using DPT is unknown at the Site. However, it is estimated that substrate can be pushed under pressure to approximately half the tracer travel distance (7.5 feet) in one to two week time-frame. Therefore, the ROI for each DPT injection point for the biobarriers was conservatively estimated to be 7.5 feet. Groundwater monitoring will be conducted as proposed in Section 4.5 to evaluate if adequate zone of influence has been attained to create an effective biobarrier.

4.1.2.2 Injection Wells

Based on the ESTCP ISB study, a distance between injection and extraction wells of approximately 35 feet was selected to distribute substrate for the Intermediate Zone Mid-Plume area.

4.1.3 Substrate Selection

4.1.3.1 Landfill Biobarrier

Emulsified vegetable oil (EVO) was selected as the substrate for the installation of Landfill Biobarrier per the Final ROD (June 2016). Sufficient EVO mass will be injected such that replenishment would not be required for 3 years to 5 years; therefore, the use of EVO is expected to be cost-effective since it would eliminate the need for continuous or more frequent injection of substrate into the subsurface. There are various formulations of EVO commercially-available in the market for groundwater remediation. Most of these EVOs are vegetable oil based products and are expected to have similar long-term performance for bioremediation. The specific formulation of EVO proposed for this project is Electron Donor Solution - Extended Release (EDS-ER™) available from Tersus Environmental (**Appendix B**). EDS-ER is a water-mixable oil formulated with at least 92 percent natural seed oils. EDS-ER is a food-grade carbon and is made from renewable crop-based oils. 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. This 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 biobarrier 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 same procedure will be followed for the other injection locations. The manufacturer’s product information sheet is provided in **Appendix B**

4.1.3.2 Bayou Biobarrier

Anaerobic Biochem Plus (ABC+), an oil-based product, was selected as the substrate for the installation of Bayou Biobarrier. ABC is an oil based product but is formulated with lactic acid and a buffer solution. ABC+ includes ZVI also. The fatty acids used in the formulation are essentially the same as produced from hydrolysis of vegetable oil when introduced in the environment. Hence, it is the same as vegetable oil but it is completely soluble and not emulsified. The fatty acids are the long term releasing carbon source. There is no need for site testing because the material behaves similar to EVO. The buffer in ABC provides an added benefit because the buffer helps to maintain the pH in a range that is best suited for microbial growth.

ZVI is micro-scale and therefore, it does not have a tendency to clog the aquifer. Manufacturer's information is presented in Appendix B. The presence of ZVI requires the material to be mixed in specialized mixers before injecting. Redox Tech provides the equipment and field crew to conduct the work.

Micro-scale ZVI will be added to ABC at 50 percent by weight. The ZVI will result in abiotic degradation of chlorinated hydrocarbons and may limit the generation of byproducts (cis-1,2-DCE and VC) of incomplete reductive dechlorination of TCE. Studies have shown that once injected, ZVI will remain active for years in the subsurface (ITRC 2011).

Following establishment of Bayou Barrier using ABC+, any subsequent replenishment of substrate (if required) will be conducted using EVO (EDS-ER) similar to the Landfill Biobarrier.

4.1.3.3 Mid-Plume ISB

EDS-ER was selected as the substrate for the Mid-Plume ISB for the Shallow Zone and Intermediate Zone groundwater. Sufficient EVO mass will be injected such that replenishment would not be required for 3 years to 5 years; therefore, the use of EVO is expected to be cost-effective since it will eliminate the need for continuous or more frequent injection of substrate into the subsurface.

EDS-ER will be mixed with water in the field and does not require high energy mixers. It formulates a completely miscible product with water, preventing clogging effects when injected in groundwater. A mixing tank located adjacent to the location of the injection points 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.

4.2 Landfill Biobarrier Design

The purpose of the Landfill Biobarriers is to control migration of COCs in shallow groundwater immediately downgradient of the landfill. In order to take advantage of existing infrastructure installed as part of the ESTCP study at LHAAP-16 (Geosyntec 2009), and based on the review of groundwater flow conditions, the Landfill Biobarrier will contain the following three segments (see **Figure 4-1**):

- Landfill Biobarrier #1: This segment will be approximately 270 feet long and will be installed upgradient of existing wells 16WW26 and 16WW42.
- Landfill Biobarrier #2: This segment will be approximately 140 feet long and was installed as part of ESTCP study at the Site (Geosyntec 2009). This biobarrier is located upgradient of monitoring well 16WW36.
- Landfill Biobarrier #3: This segment will be approximately 100 feet long and will be installed to the north of Landfill Biobarrier #2 and downgradient from monitoring well 16WW14.

The locations of Landfill Biobarriers #1, #2, and #3 are designed to fully intercept the plume of VOCs and perchlorate from the landfill in the Shallow Zone above their respective cleanup goals (see **Figures 2-4 through 2-7, and 4-1**).

4.2.1 Landfill Biobarrier #1

4.2.1.1 Injection Point and Monitoring Well Placement and Design

Eighteen DPT locations (DPT01 through DPT18) and one injection well (16IW09) will be used to inject EVO transverse to the direction of groundwater flow to establish Landfill Biobarrier #1 (see **Figure 4-2**). The injection well is proposed to also serve as a groundwater monitoring location within the biobarrier (see **Section 4.5** for details).

The rationale for selection of EVO for the Landfill Biobarriers is presented in **Section 4.1.3**. The spacing of 15 feet between injection locations was selected based on the rationale and injection ROI presented in **Section 4.1.2**.

Table 4-1 presents the injection intervals for DPT borings and screen intervals for monitoring wells for Landfill Biobarrier #1. Existing well logs for monitoring wells 16WW26 and 16WW42, located downgradient of the biobarrier, are presented in **Appendix C**. These injection/screen intervals are intended to target the treatment of Shallow Zone groundwater. The injection depths and monitoring well screen intervals and lengths may be modified, based on initial field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

4.2.1.2 Substrate Loading and Injection

The mass of EVO required for the establishment of Landfill Biobarrier #1 was calculated based on the stochiometric demand exerted by the native (e.g., dissolved oxygen [DO], nitrate, and sulfate) and anthropogenic (COCs) electron acceptors. These calculations were performed using the ESTCP spreadsheet-based Substrate Estimating Tool (ESTCP 2010). **Appendix D** provides the input and output calculations spreadsheets.

The specific formulation of EVO proposed for the establishment of Landfill Biobarrier #1 is EDS-ER. Based on the stochiometric demand, the total estimated weight of concentrated EDS-ER (at least 92 percent natural seed oils) proposed for injection is 5,041 pounds (see **Table 4-2**). This is the same as 7,729 pounds (lbs) determined using the ESTCP spreadsheet for 60% EVO formulation – **Appendix D**. The concentrated solution of EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of water. During mixing, sodium bromide (a conservative tracer) will be added to the solution at a target concentration of 500 milligrams per liter (mg/L) to evaluate distribution of substrate as part of performance monitoring (see **Section 4.5**). The diluted EDS-ER solution will be injected into injection points, DPT-01 through DPT-18, and well 16IW09. The details of the substrate injection using DPT and wells are discussed in **Section 4.1.1**.

4.2.1.3 Bioaugmentation Culture Injection

Based on vendor recommendations, one liter of dechlorinating culture KB-1 will be injected at each of the nineteen injection points (DPT-01 through DPT-18, and 16IW09) of Landfill Biobarrier #1 to facilitate a more rapid onset of complete reductive dechlorination of TCE to ethene. The injection of KB-1 will be conducted in conjunction with the injection of EDS-ER at each direct push point and injection well. Fifty percent of the target volume of EDS-ER will be injected into each injection location before the introduction of KB-1. To provide conducive conditions for KB-1 in situ, 200 to 300 gallon of anaerobic water will be injected before and after the KB-1 injection. After the addition of the anaerobic water, one liter of KB-1 will be delivered to the middle of the injection interval. Following KB-1 injection, an additional 200 to 300 gallons of anaerobic water will be injected into each injection point before proceeding with the injection of the remaining EDS-ER solution.

The anaerobic water used during the KB-1 injection will be generated on-site in bladder tanks or equivalent, using potable water. The potable water will be mixed with soluble electron donor such as high fructose corn syrup (HFCS) and seeded with groundwater containing indigenous bacteria and/or KB-1. The water will be ready for injection once the anaerobic condition in the tank is confirmed (DO less than 0.5 mg/L and oxidation-reduction potential [ORP] less than -75 millivolts [mV]). Multiple tanks will be used to generate anaerobic water to ensure a constant supply of anaerobic water needed during the KB-1 injections.

4.2.2 Landfill Biobarrier #2

4.2.2.1 Injection and Monitoring Well Placement and Design

Existing wells installed during the ESTCP study (Geosyntec 2009) will be used to inject EVO to establish Landfill Biobarrier #2 transverse to the direction of groundwater flow (see **Figure 4-3**). Before any of the pilot test wells are used for injection, slug tests will be performed to confirm they are in acceptable condition. If the results show they are not, they will be re-developed prior to use as injection wells for Landfill Biobarrier #2. The rationale for selection of EVO for the Landfill Biobarriers is presented in **Section 4.1.3**.

Table 4-3 presents the screen intervals and depths of existing injection/monitoring wells for the Landfill Biobarrier #2. Existing well log for monitoring well 16WW35, located downgradient of the biobarrier, is presented in **Appendix C**. No new monitoring wells or injection wells are proposed for Landfill Biobarrier #2, because based on the ESTCP Study (Geosyntec 2009), existing injection/monitoring wells can be used to create/monitor an effective biobarrier.

4.2.2.2 Substrate Loading and Injection

The mass of EVO required for the establishment of Landfill Biobarrier #2 was calculated based on the stochiometric demand exerted by the native (e.g., DO, nitrate, and sulfate) and anthropogenic (COCs) electron acceptors. These calculations were performed using the ESTCP spreadsheet-based Substrate Estimating Tool (ESTCP 2010). **Appendix D** provides the input and output calculations spreadsheets.

The specific formulation of EVO proposed for the establishment of Landfill Biobarrier #2 is EDS-ER. Based on the stochiometric demand, the total estimated weight of concentrated EDS-ER (at least 92 percent natural seed oils) proposed for injection is 3,594 pounds (see **Table 4-4**). This is the same as 5,510 lbs determined using the ESTCP spreadsheet for 60% EVO formulation – **Appendix D**. As discussed in **Sections 4.1.1.2**, the EDS-ER will be injected into the subsurface using hydraulically-enhanced injection strategy as summarized in **Table 4-4** and described below:

- ***Phase I:*** The concentrated solution of EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of water. During mixing, sodium bromide (a conservative tracer) will be added to the solution at a target concentration of 500 mg/L to evaluate distribution of substrate as part of performance monitoring (see **Section 4.5**). The diluted EDS-ER will be injected into wells 16IW01, 16IW03, 16IW05, and 16IW07. During the entire duration of injection, which is expected to last approximately 2-3 days, groundwater extraction will be conducted from wells 16EW11, 16EW12B, 16EW13, 16EW14B, and 16EW15 to enhance distribution of substrate cross-gradient. The specific injection volumes for EDS-ER are presented in **Table 4-4**. Just before extraction ends (i.e., concurrently with the end of the injection period), a sample of the extracted groundwater from each extraction well will be collected and tested for the presence of bromide. If bromide is detected, the hydraulically-enhanced injection strategy would be considered successful. If bromide is not detected, additional extraction of groundwater would take place until bromide is detected in the extraction wells. The extracted groundwater will be used to prepare the solution for Phase II described below.

- ***Phase II:*** The concentrated solution of EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of extracted groundwater. During mixing, sodium bromide (a conservative tracer) will be added to the solution at a target concentration of 500 mg/L to evaluate distribution of substrate as part of performance monitoring (see **Section 4.5**). The diluted EDS-ER will be injected into wells 16EW11, 16EW12B, 16EW13, 16EW14B, and 16EW15 over a 2-3 day period. The specific injection volumes for EDS-ER are presented in **Table 4-4**.

4.2.2.3 Bioaugmentation Culture Injection

Injection of dechlorinating culture KB-1 will be conducted during Phase I and Phase II of the EDS-ER injection. During Phase I of EDS-ER injection, based on the vendor recommendations, two liters of dechlorinating culture KB-1 will be injected at each of the four injection locations (16IW01, 16IW03, 16IW05, and 16IW07). During Phase II of EDS-ER injection, two liters of dechlorinating culture KB-1 will be injected into each of the five injection locations (16EW11, 16EW12B, 16EW13, 16EW14B, and 16EW15).

During both phases, fifty percent of the target volume of EDS-ER will be injected into each injection location before the introduction of KB-1. To provide conducive conditions for KB-1 in situ, 200 to 300 gallon of anaerobic water will be injected before and after the KB-1 injection. After the addition of the anaerobic water, two liters of KB-1 will be delivered to the middle of the injection interval. Following KB-1 injection, an additional 200 to 300 gallons of anaerobic water will be injected into each injection well before proceeding with the injection of remaining EDS-ER Solution. The procedure for generating anaerobic water used during the KB-1 injection is presented in **Section 4.2.1.3**; however, Extraction groundwater could be used to make up the anaerobic water.

4.2.3 Landfill Biobarrier #3

4.2.3.1 Injection Point and Monitoring Well Placement and Design

Seven DPT locations (DPT19 through DPT25) and one injection well (16IW10) will be used to inject EVO transverse to the direction of groundwater flow to establish Landfill Biobarrier #3 (see **Figure 4-4**). The injection well is proposed to also serve as a groundwater monitoring location within the biobarrier along with 16RW08 (see **Section 4.5** for details).

The rationale for selection of EVO for the Landfill Biobarriers is presented in **Section 4.1.3**. The spacing of 15 feet between injection locations was selected based on the rationale and injection ROI presented in **Section 4.1.2**.

Table 4-5 presents the injection intervals for direct push points and screen intervals for monitoring wells for the Landfill Biobarrier #3. Existing well log for monitoring well 16WW14, located upgradient of the biobarrier is presented in **Appendix C**. These injection/screen intervals are intended to target the treatment of Shallow Zone groundwater. The injection depths and monitoring well screen intervals and lengths may be modified based on initial field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

4.2.3.2 Substrate Loading and Injection

The mass of EVO required for the establishment of Landfill Biobarrier #3 was calculated based on the stochiometric demand exerted by the native (e.g., DO, nitrate, and sulfate) and anthropogenic (COCs) electron acceptors. These calculations were performed using the ESTCP spreadsheet-based Substrate Estimating Tool (ESTCP 2010). **Appendix D** provides the input and output calculations spreadsheets.

The specific formulation of EVO proposed for the Landfill Biobarrier #3 establishment is EDS-ER. Based on the stochiometric demand, the total estimated weight of concentrated EDS-ER (at least 92 percent natural seed oils) proposed for injection is 2,333 pounds (see **Table 4-6**). This is the same as 3,578 lbs determined using the ESTCP spreadsheet for 60% EVO formulation – **Appendix D**. The concentrated solution of EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of water. During mixing, sodium bromide (a conservative tracer) will be added to the solution at a target concentration of 500 mg/L to evaluate distribution of substrate as part of performance monitoring (see **Section 4.5**). The diluted EDS-ER solution will be injected into at injection points, DPT-19 through DPT-25, and well 16IW10. The details of the substrate injection using DPT and wells are discussed in **Section 4.1.1**.

4.2.3.3 Bioaugmentation Culture Injection

Based on vendor recommendations, one liter of dechlorinating culture KB-1 will be injected at each of the eight injection points (DPT-19 through DPT-25, and 16IW10) of Landfill Biobarrier #3 to facilitate a more rapid onset of complete reductive dechlorination of TCE to ethene. The injection of KB-1 will be conducted in conjunction with the injection of EDS-ER at each direct push point and injection well. Fifty percent of the target volume of EDS-ER will be injected into each injection location before the introduction of KB-1. To provide conducive conditions for KB-1 in situ, 200 to 300 gallon of anaerobic water will be injected before and after the KB-1 injection. After the addition of the anaerobic water, one liter of KB-1 will be delivered to the middle of the injection interval. Following KB-1 injection, an additional 200 to 300 gallons of anaerobic water will be injected into each injection wells before proceeding with the injection of remaining EVO. The procedure for generating anaerobic water used during the KB-1 injection is presented in **Section 4.2.1.3**.

4.3 Bayou Biobarrier

4.3.1 Injection Point and Monitoring Well Placement and Design

Thirteen direct push locations (DPT-26 through DPT-39) and one injection well (16IW20) will be used to inject ABC+ transverse to the direction of groundwater flow to establish the Bayou biobarrier (see **Figure 4-5**). One injection well is proposed to also serve as a groundwater monitoring location within the biobarrier along with 16RW11 (see **Section 4.5** for details). The biobarrier is planned to be positioned downgradient of monitoring well 16WW12, as specified in the ROD and shown on **Figure 4-5**. However if the slope of the ground surface near Harrison

Bayou is too steep for safe injection in this area of the site, the biobarrier location will be moved just upgradient of monitoring well 16WW12.

The rationale for selection of ABC+ for the Bayou Biobarrier is presented in **Section 4.1.3**. The spacing of 15 feet between injection locations is selected based on the rationale and injection ROI presented in **Section 5.1.2**.

Table 4-7 presents the injection intervals for the DPT borings and the screen intervals for monitoring wells for the Bayou Biobarrier. Existing well logs for monitoring wells 16WW22 and 16WW12, located upgradient of the biobarrier are presented in **Appendix C**. These injection/screen intervals are intended to target the treatment of shallow groundwater zone. The injection depths and monitoring well screen intervals and lengths may be modified based on initial field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

4.3.2 Substrate Loading and Injection

The mass of ABC+ for establishment of Bayou Biobarrier is based on the recommendation of the vendor and is presented in **Table 4-8**. ABC+ will contain 3,500 pounds of ABC and 3,500 pounds of ZVI. The ABC will be diluted with water to form a solution of approximately 10 percent by weight before injection. During mixing, sodium bromide (a conservative tracer) will be added to the solution at a target concentration of 500 mg/L to evaluate distribution of substrate as part of performance monitoring (see **Section 4.5**). The injection of ABC+ will be conducted using DPT at 2 to 3-foot intervals.

4.3.3 Bioaugmentation Culture Injection

Based on vendor recommendations, one liter of dechlorinating culture KB-1 will be injected at each of the fourteen injection points (DPT-26 through DPT-39, and 16IW20) of Bayou Biobarrier to facilitate a more rapid onset of complete reductive dechlorination of TCE to ethene. The injection of KB-1 will be conducted in conjunction with the injection of ABC+ at each direct push point and injection well. Fifty percent of the target volume of ABC+ will be injected into each injection location before the introduction of KB-1. To provide conducive conditions for KB-1 in situ, 200 to 300 gallon of anaerobic water will be injected before and after the KB-1 injection. After the addition of the anaerobic water, one liter of KB-1 will be delivered to the middle of the injection interval. Following KB-1 injection, an additional 200 to 300 gallons of anaerobic water will be injected into each injection wells before proceeding with the injection of remaining EVO. The procedure for generating anaerobic water used during the KB-1 injection is presented in **Section 4.2.1.3**.

4.4 Mid-Plume ISB

4.4.1 Well Placement and Design

4.4.1.1 Shallow Groundwater Zone

The Mid-Plume ISB will be approximately 280 feet long. Forty DPT locations (DPT40 through DPT79) will be used to inject EVO transverse to the direction of groundwater flow (see **Figure 4-6**). The injection will occur in a wide area in the vicinity of existing extraction wells 16EW01, 16EW02, 16EW03, and 16EW04. The DPT injection points will be staggered to provide good distribution of injected chemicals. The extraction wells, two existing monitoring wells, 16WW30 and 16WW39, and

one new well that will be installed in the Shallow Zone approximately 40 to 50 feet downgradient from the Shallow Zone ISB area (16WW48), will be used to monitor ISB performance. The proposed DPTs for substrate emplacement within Shallow Zone groundwater are listed in **Table 4-9** and the locations are shown on **Figure 4-6**. The injection depths may be modified during field implementation activities based on field observations including depth to groundwater.

4.4.1.2 Intermediate Groundwater Zone

Per the Final ROD (U.S. Army 2016), the existing wells screened in the Intermediate Zone listed in **Table 4-9** and shown on **Figure 4-7** will be used for implementing ISB. These wells will be redeveloped after extraction is shut down and downhole equipment has been removed. Based on the ESTCP study that recommended approximately 35 feet between the recirculation wells, two new injection wells will be installed between the existing extraction wells 16EW05 and 16EW06, 16EW06 and 16EW07, and 16EW07 and 16EW08 for a total of six new injection wells in the Intermediate Zone ISB area to recirculate the groundwater between the injection and extraction wells. The existing extraction wells will be used as injection wells once the recirculation of groundwater between the injection and extraction wells is terminated, as required by the ROD. Two new Intermediate Zone wells (16WW49 and 16WW51) will also be installed approximately 40 feet downgradient from the Intermediate Zone ISB area and will be used to monitor ISB performance.

4.4.2 Substrate Loading and Injection

4.4.2.1 Shallow Groundwater Zone

The mass of EVO required for Mid-Plume ISB in the Shallow Zone groundwater was estimated based on the stochiometric demand exerted by the native (e.g. DO, nitrate, and sulfate) and anthropogenic electron acceptors. These calculations were performed using the ESTCP spreadsheet-based Substrate Estimating Tool (ESTCP 2010). **Appendix D** provides the input and output calculations spreadsheets.

The specific formulation of EVO proposed is EDS-ER. Based on the stochiometric demand, the total estimated weight of concentrated EDS-ER (at least 92 percent natural seed oils) proposed for injection is 28,414 pounds (see **Table 4-10**). This is the same as 43,568 lbs determined using the ESTCP spreadsheet for 60% EVO formulation – **Appendix D**. The concentrated solution of EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of water. Approximately 41,070 gallons of dilute EDS-ER solution will be injected into 40 injection points listed in **Table 4-10**. During mixing, sodium bromide (at target concentration of 500 mg/L) and fluorescein dye will be added to the solution to evaluate distribution of substrate during performance monitoring (see **Section 4.5**). The diluted EDS-ER solution will be injected at injection points DPT-40 through DPT-79. The details of the substrate injection using DPT and injection wells are discussed in **Section 4.1.1**.

4.4.2.2 Intermediate Groundwater Zone

Similar to the electron donor estimation for the shallow plume, the mass of EDS-ER required for Mid-Plume ISB in Intermediate Zone groundwater was estimated based on stochiometric demand. The total estimated weight of concentrated EDS-ER (at least 92 percent natural seed oils) proposed for injection is 16,565 pounds (see **Table 4-10**). This is the same as 25,399 lbs determined using the ESTCP spreadsheet for 60% EVO formulation – **Appendix D**. The EDS-ER will be diluted by mixing 1 part of EDS-ER with 10 parts of water. Approximately 23,940 gallons of dilute EDS-ER solution will be injected into six injection wells listed in **Table 4-10**.

4.4.3 Bioaugmentation Culture Injection

Injection of dechlorinating culture KB-1 will be conducted during the EDS-ER injections in the ISB area. For the shallow groundwater zone, based on the vendor recommendation, one liter of dechlorinating culture KB-1 will be injected at each of the 40 injection locations (DPT-40 through DPT-79) for a total of forty liters. For intermediate groundwater, two liters of dechlorinating culture KB-1 will be injected at each of the six injection locations (16IW25 through 16IW30) and four previously used extraction wells (16EW05, 16EW06, 16EW07, and 16EW08) for a total of twenty liters.

Fifty percent of the target volume of EDS-ER will be injected into each injection location before the introduction of KB-1. To provide conducive conditions for KB-1 in situ, 200 to 300 gallons of anaerobic water will be injected before and after the KB-1 injection. After the addition of the anaerobic water, one liter (two liters in case of injection wells) of KB-1 will be delivered to the middle of the injection interval. Following KB-1 injection, an additional 200 to 300 gallons of anaerobic water will be injected into each injection points/wells before proceeding with the injection of remaining EDS-ER. The procedure for generating anaerobic water used during the KB-1 injection is presented in Section 4.2.1.3.

4.5 Performance Monitoring

Performance monitoring conducted as part of the selected remedy for LHAAP-16 will include the following:

- Groundwater monitoring in the areas of active ISB to evaluate its effectiveness, and to assess changes in groundwater geochemistry, concentrations of COCs and their degradation products.
- Groundwater monitoring to evaluate changes in concentrations of COCs and their degradation products in the areas outside the influence of active ISB.
- Surface water monitoring

In the short-term (1-3 months), monitoring of groundwater conditions will be conducted to evaluate design effectiveness associated with the distribution of the injectate in the formation.

Per the ROD, the performance evaluation for MNA will be conducted after the collection of eight quarters of ISB performance data (see MNA criteria in **Section 4.5.3**). If MNA is determined to be effective, a baseline will be established from the data to this point in time. Monitoring will be conducted to evaluate the remedy performance and determine if the plume conditions remain constant, improve, or worsen after the baseline is established. This LTM will be implemented at a semiannual frequency for three years, then annually until the next five-year review. If after eight quarters of ISB performance data collection, MNA is determined to be ineffective according to **Section 4.5.3.1** criteria, a contingency action would be initiated as described in **Section 4.5.3.2**.

4.5.1 Pre-Remedy Implementation Groundwater Sampling

The pre-remedy implementation groundwater sampling will be performed as a single-event to characterize the COC concentrations and geochemical conditions in the Shallow Zone and Intermediate Zone prior to emplacement of bioremediation substrate. The wells selected for the pre-remedy groundwater sampling include wells inside and outside of the contaminant plumes, and wells located upgradient, within, and downgradient of ISB areas. The pre-remedy groundwater sampling results will be used to optimize the locations of biobarriers. In addition, the baseline groundwater sampling results will be compared with monitoring results following substrate emplacement to assess the performance of ISB systems. The baseline sampling plan is summarized in **Table 4-11** for the Shallow Zone groundwater and **Table 4-12** for the Intermediate Zone groundwater.

4.5.2 Evaluation of Design Effectiveness

Within the first two months after remedy implementation, groundwater data will be collected from the various monitoring points in the treatment areas to evaluate effectiveness of injectate distribution and the occurrence of geochemical changes. Up to two sets of groundwater samples will be collected before the 1st quarterly sampling is implemented. The ISB performance monitoring plans for Landfill Biobarrier #1, Landfill Biobarrier #2, Landfill Biobarrier #3, Bayou Biobarrier, and Mid-Plume ISB, are presented in **Tables 4-13, 4-14, 4-15, 4-16,** and **4-17**, respectively. These tables present the proposed monitoring locations along with the rationale for the selection of each monitoring location.

4.5.3 Performance Monitoring – Years 1 and 2

Performance monitoring will be conducted at LHAAP-16 during Years 1 and 2 in accordance with the monitoring plans summarized in the subsections below. After each monitoring round, the data will be reviewed to evaluate progress towards attainment of remedial action objectives/cleanup levels. Optimization/changes of the monitoring plans presented below will be conducted as warranted by the results of the data reviews. The optimizations/changes will be presented to the regulatory agencies prior to implementation.

4.5.3.1 ISB Performance Monitoring

When a bioremediation substrate such as EVO and ABC+ is injected into the subsurface, the naturally-occurring bacteria are stimulated and degrade the injected organic substrate. Biodegradation of substrate depletes the DO and other terminal electron acceptors (e.g., nitrate or sulfate), and lowers the ORP of groundwater, thereby creating conditions conducive to the anaerobic COC degradation processes. The ISB performance monitoring will be conducted to assess changes in geochemical conditions and perchlorate concentrations due to biodegradation reactions.

The performance monitoring plans for Landfill Biobarrier #1, Landfill Biobarrier #2, Landfill Biobarrier #3, Bayou Biobarrier, and Mid-Plume ISB, are presented in **Tables 4-13, 4-14, 4-15, 4-16,** and **4-17**, respectively. These tables present the proposed monitoring locations along with the rationale for the selection of each monitoring location.

4.5.3.2 MNA Performance Monitoring

MNA is the component of the selected remedy for LHAAP-16 to reduce COC concentrations and to return groundwater to its potential beneficial use, wherever practical. No new groundwater monitoring wells are proposed to implement MNA at LHAAP-16. Monitoring of existing wells is expected to provide sufficient data to evaluate the performance of MNA. The performance monitoring plan for MNA for shallow and intermediate groundwater zones is presented in **Table 4-18** and shown in **Figure 4-8**.

Per the Final ROD (U.S. Army 2016), the performance evaluation for MNA will be based on data from eight quarters of monitoring combined with historical data to evaluate the effectiveness of various natural physical, chemical, and biological processes in reducing contaminant concentrations. Per the Final ROD, the following performance objectives will be used to evaluate MNA performance after two years:

- Plume stability (i.e., the plume concentrations are decreasing in the majority of performance wells, and the plume is not expanding in area as demonstrated with compliance wells).
- MNA potential based on evaluation of biodegradation screening scores using USEPA guidance
- MNA process evaluation, based on an attenuation rate calculated with empirical performance monitoring data, and MNA process demonstration based on the presence of daughter products and bacterial culture counts.

4.5.3.3 Contingency Action for MNA Areas

Per the ROD, a contingency remedy would be implemented if the above criteria (**Section 4.5.3.2**) are not met for the passive MNA areas (i.e., MNA areas outside the active remediation areas). The contingency remedy includes application of bioamendments (i.e., additional in-situ bioremediation) to address the ineffective aspects of MNA. The area and the elements of the contingency remedy would be determined based on the magnitude of deviation from the MNA performance criteria and the remedy area(s) with observed deviations. Therefore, the contingency remedy will evaluate any deficiencies in MNA performance and will attempt to address those deficiencies. If the contingency remedy is required, it will be documented in an Explanation of Significant Difference (ESD).

4.5.3.4 Follow-up Injections in Biobarriers

As specified in the ROD, follow-up injections for the biobarriers will be implemented based on groundwater monitoring results. The emulsified oil for the biobarriers is specified to last between 3 and 5 years. Nonetheless, the decision for reapplication of organic carbon will be made based on groundwater monitoring results. Three criteria for determining the need to reinject are:

- Depletion of the organic carbon to below 20 mg/L;

- ORP increases above -50 mV; and
- Contaminant concentrations in groundwater for the Landfill Biobarriers and in surface water for the Bayou Biobarrier remain above the cleanup standards.

If these conditions occur, then reinjection of organic carbon would be conducted, but only in those specific areas that meet the above criteria.

4.5.3.5 Surface Water Monitoring

Surface water monitoring will be conducted to confirm that surface water standards for the contaminants and by-product contaminants are not exceeded in Harrison Bayou, which flows into Caddo Lake. The surface water sampling events will be conducted concurrently with the groundwater sampling events for performance monitoring. Harrison Bayou is classified as an intermittent stream with perennial pools. Therefore, it is not expected that Harrison Bayou would be dry. However, as a contingency, if surface water samples could not be collected from Harrison Bayou during the quarterly sampling events, samples from Harrison Bayou would be collected outside the routine quarterly sampling events following significant rain events. The goal is to collect four surface water samples every monitoring year.

During each monitoring round, surface water samples will be collected at three locations in Harrison Bayou; upgradient, downgradient and immediately adjacent to LHAAP-16 (**Figure 4-9**). Surface water samples will be collected following the protocols included in Section 3.7 of the Final Installation-wide Work Plan (IWWP) for LHAAP (AECOM, 2014). These surface water samples will be analyzed for the COCs and the sample concentrations will be compared to the surface water cleanup levels listed in **Table 1-1**.

Surface water samples are collected for the purpose of evaluating impact from groundwater. Therefore, at these locations and during surface water sampling, the groundwater elevation in wells 16WW46, 16WW40, and 16WW43 will be gauged and compared to the bottom elevation of the creek to determine whether there is groundwater contribution to surface water.

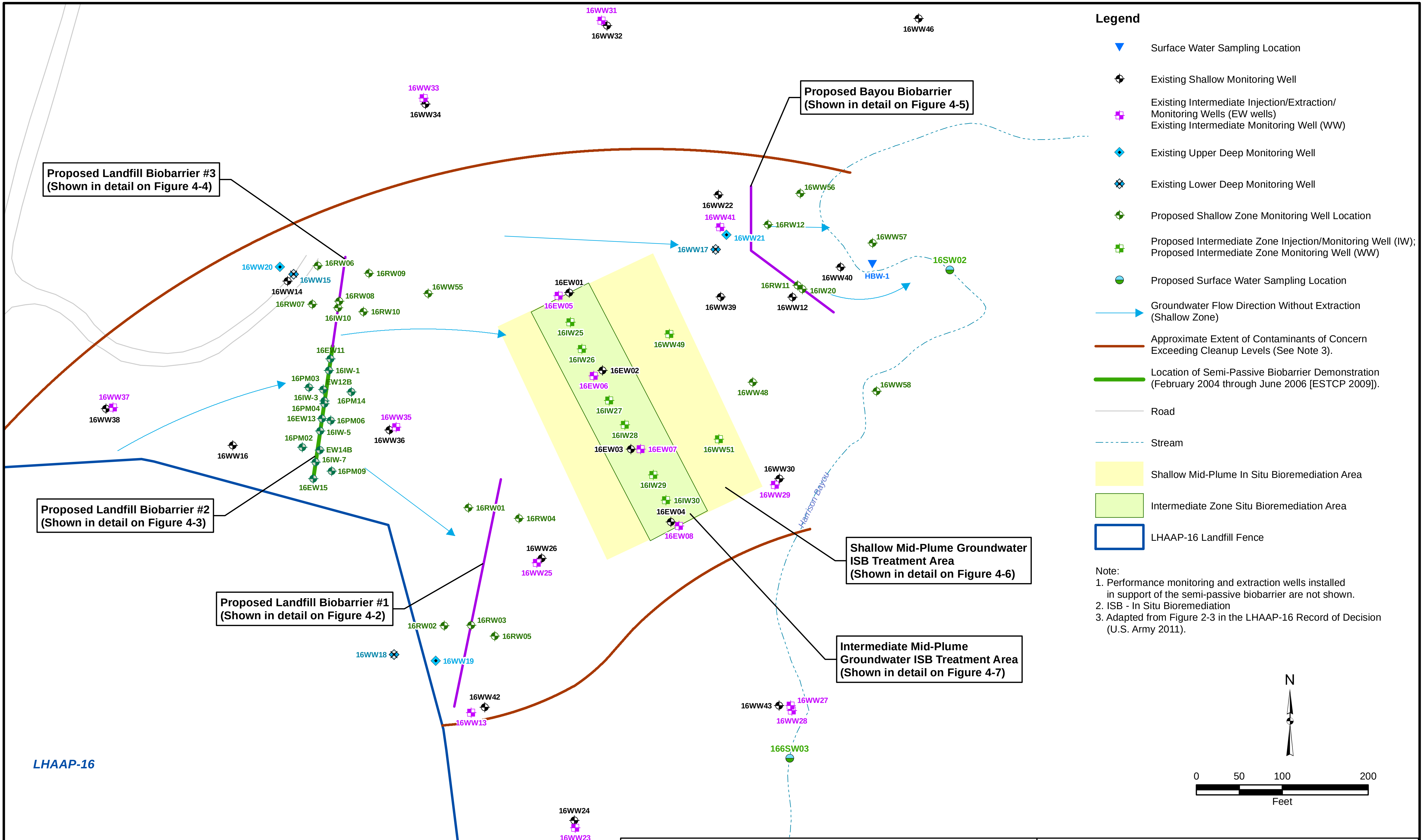
4.5.4 Performance Monitoring – Year 3 through Five-Year Review

If MNA is determined to be effective based on the first two years of performance monitoring data, LTM will be initiated. Per the Final ROD, LTM will be implemented at a semiannual frequency for three years, then annually until the next five-year review. For LTM, the performance monitoring plan presented in **Table 4-18** will be modified as appropriate based on the review of first two years of data.

If MNA is found to be ineffective, a contingency remedy will be implemented to include application of bioamendments to address the ineffective aspects of MNA. If the bioamendments are reapplied, the ISB and MNA performance monitoring plans presented in **Tables 4-12 through 4-17** and the frequency of monitoring will be modified as appropriate based on the review of first two years of data.

4.5.5 Performance Monitoring Following Five-Year Review

Per the ROD, the results from performance monitoring will be reviewed during the five-year review. Unless otherwise indicated by the data, the wells and surface water locations will then be sampled during each five-year review.



Note:
1. Performance monitoring and extraction wells installed in support of the semi-passive biobarrier are not shown.
2. ISB - In Situ Bioremediation
3. Adapted from Figure 2-3 in the LHAAP-16 Record of Decision (U.S. Army 2011).

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-1 LHAAP-16 Remedial Design Site Plan.mxd

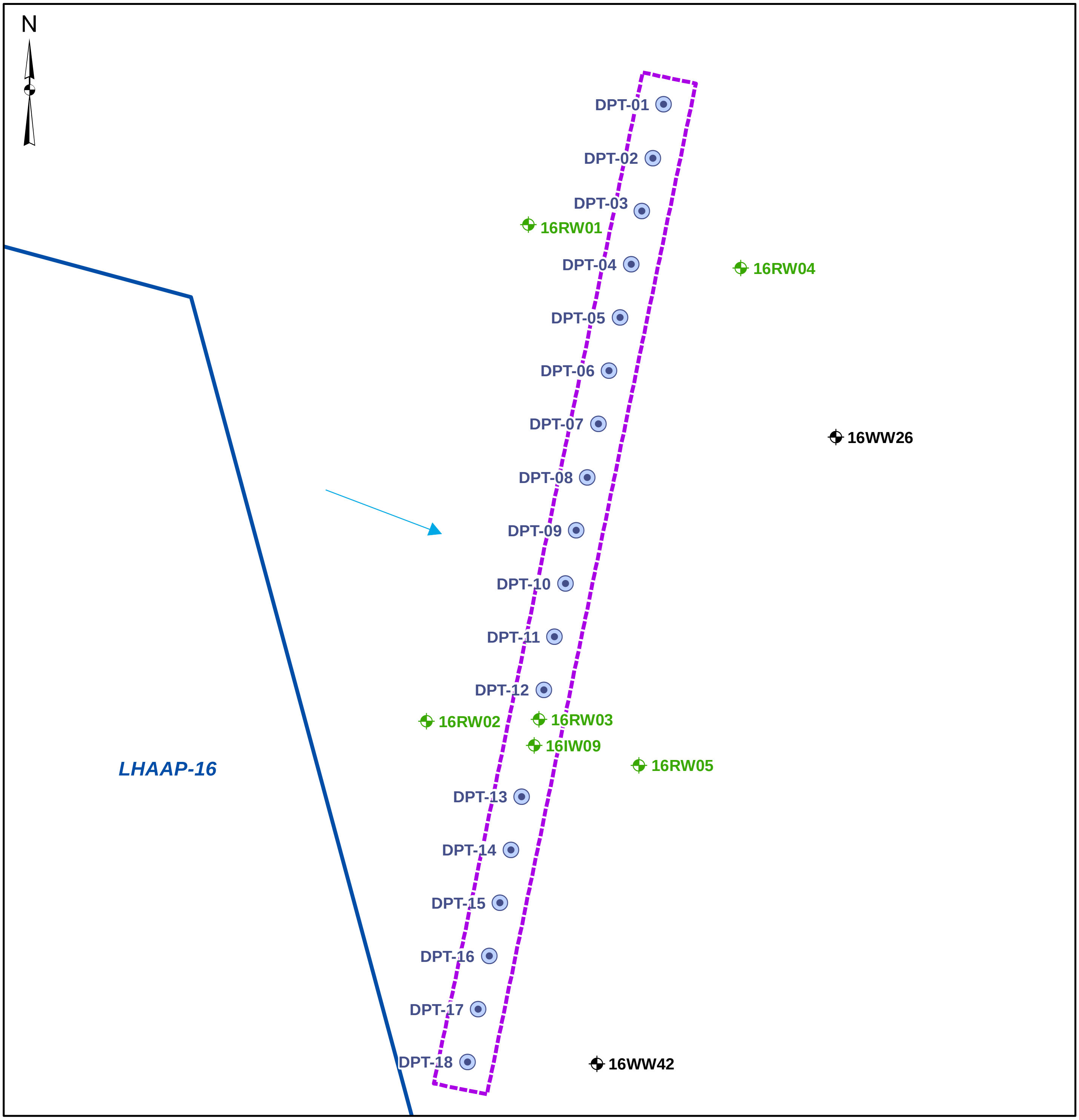
AECOM

Figure 4-1
Existing and Proposed Monitoring Well Locations
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017



Legend

✥	Proposed Well Location
✥	Existing Well Location
◉	Proposed Direct Push Injection Point
→	Groundwater Flow Direction Without Extraction (Shallow Zone)
▭	Target In-Situ Reaction Zone Based on Design Radius of Influence
▭	LHAAP-16 Landfill Fence

0 20 40 80
Feet

AECOM

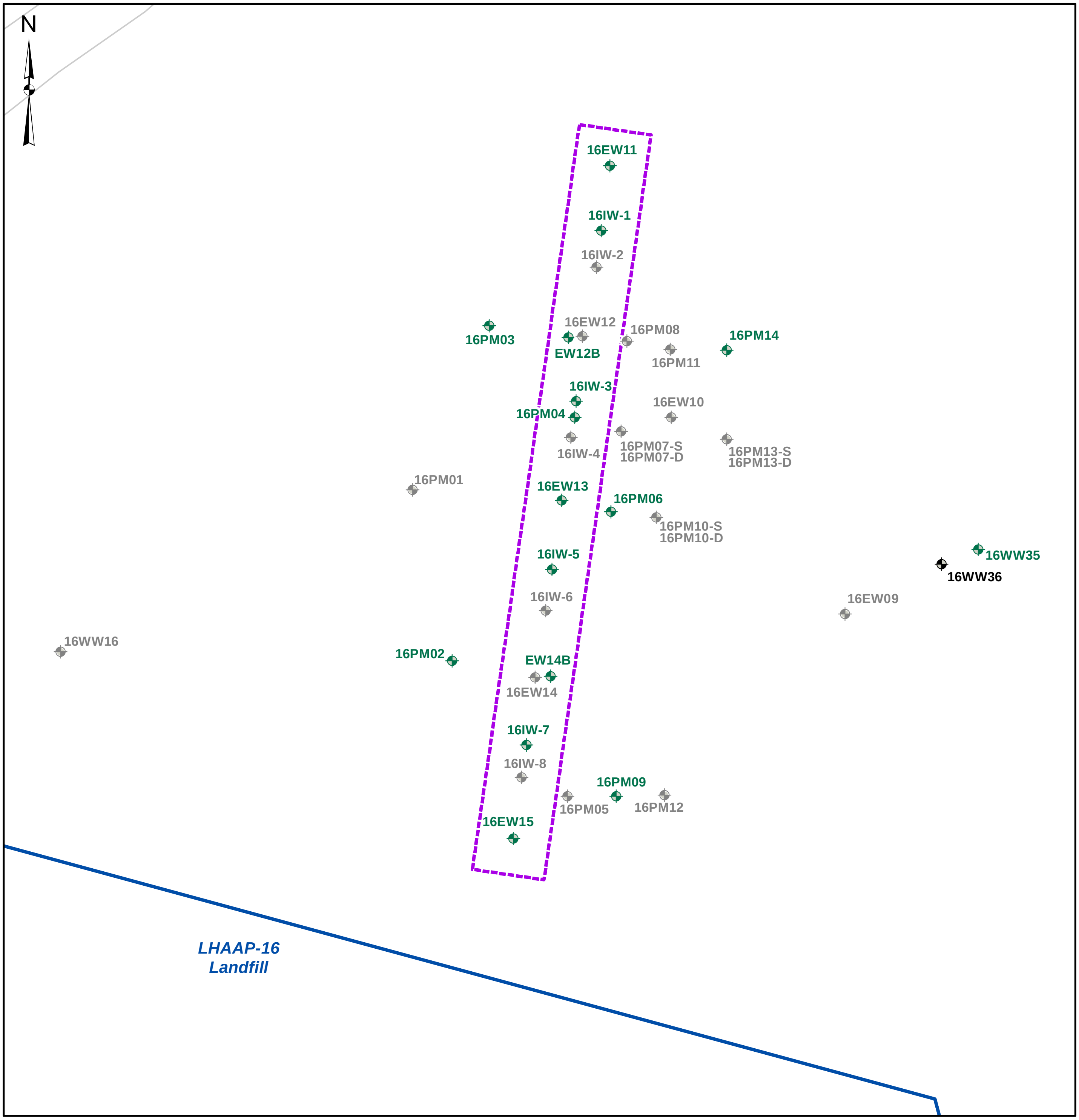
Figure 4-2
Landfill Biobarrier #1 Design
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-2 LHAAP-16 Landfill Biobarrier 1.mxd



Legend

- 🟢 Existing In-Situ Bioremediation Injection/ Extraction/Performance Monitoring Well
- ● Existing Monitored Natural Attenuation Performance Monitoring Well
- ○ Other Existing Monitoring Well
- ▭ Target In-Situ Reaction Zone Based on Design Radius of Influence
- ▭ LHAAP Landfill Fence

0 15 30 60
Feet

Note:
1. Adapted from Figure 5-1 (ESTCP 2009).

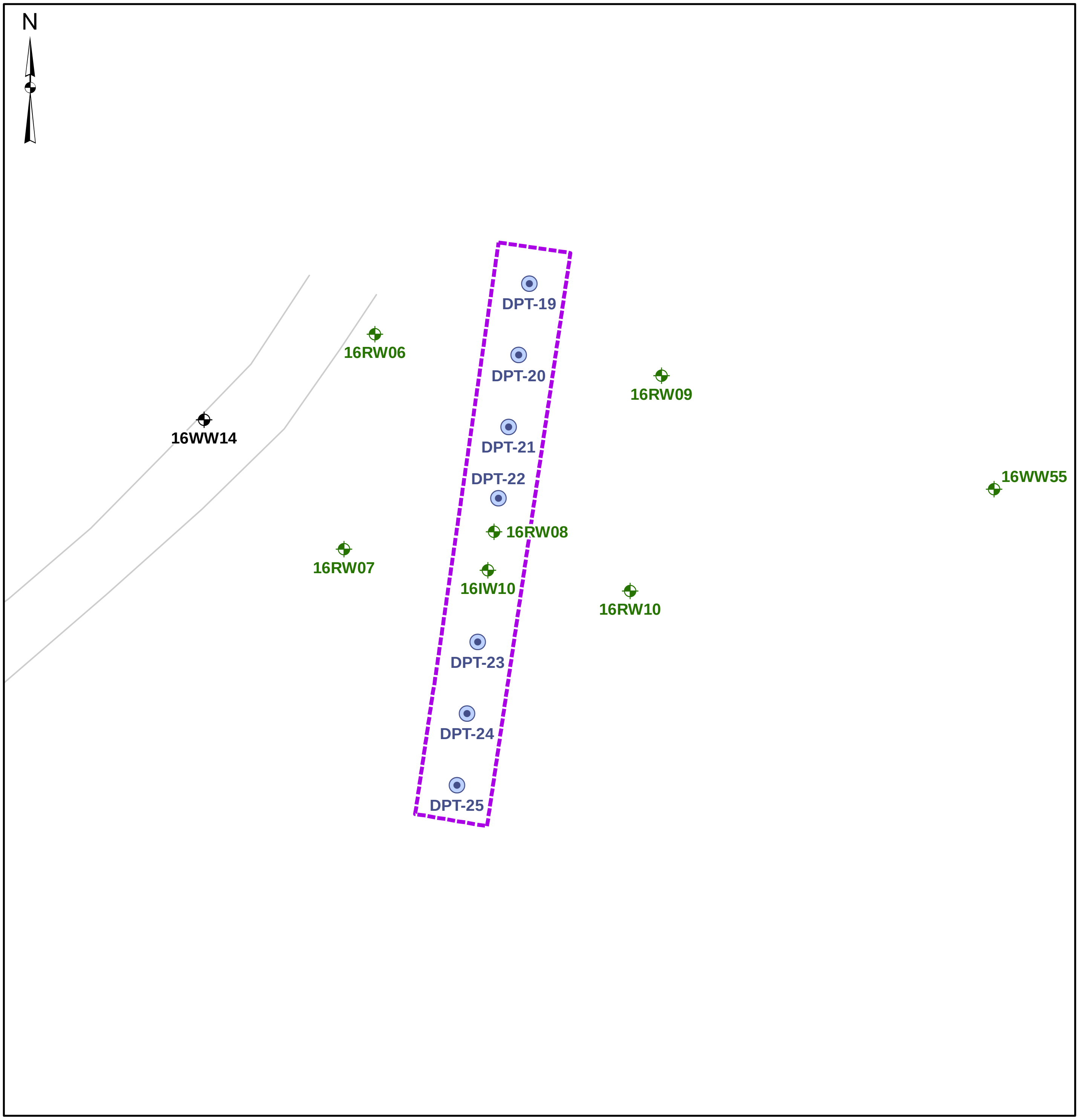
Figure 4-3
Landfill Biobarrier #2 Design
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-3 LHAAP-16 Landfill Biobarrier 2.mxd



Legend

⊕ Existing Shallow Monitoring Well

⊕ Proposed Shallow Well Location
IW -- Injection Well Location
RW - Recovery Well Location

◉ Proposed Direct Push Injection Point

▭ Target In-Situ Reaction Zone Based
on Design Radius of Influence

0 10 20 40
Feet

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-4 LHAAP-16 Landfill Biobarrier 3.mxd

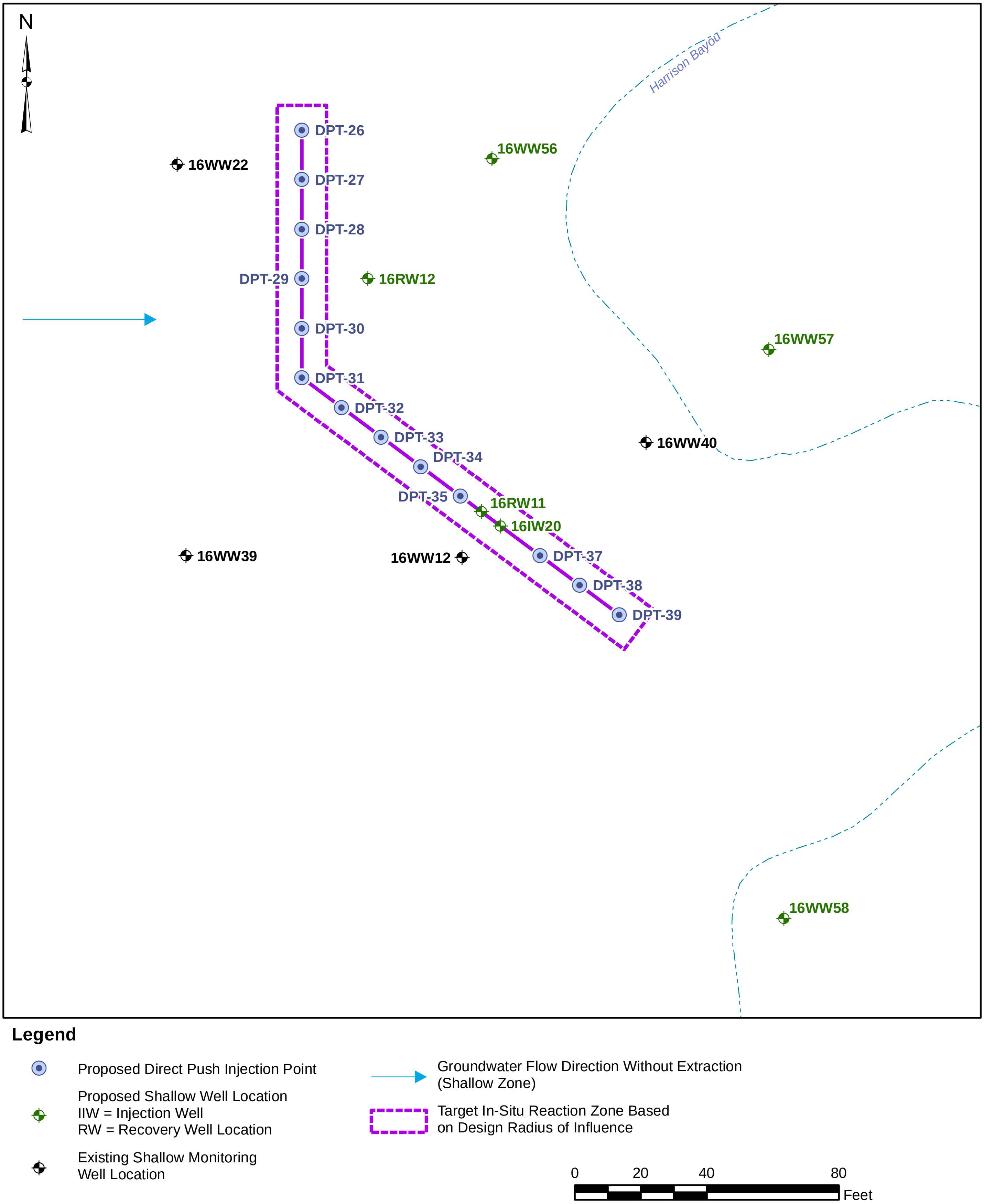
AECOM

Figure 4-4
Landfill Biobarrier #3 Design
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017



AECOM

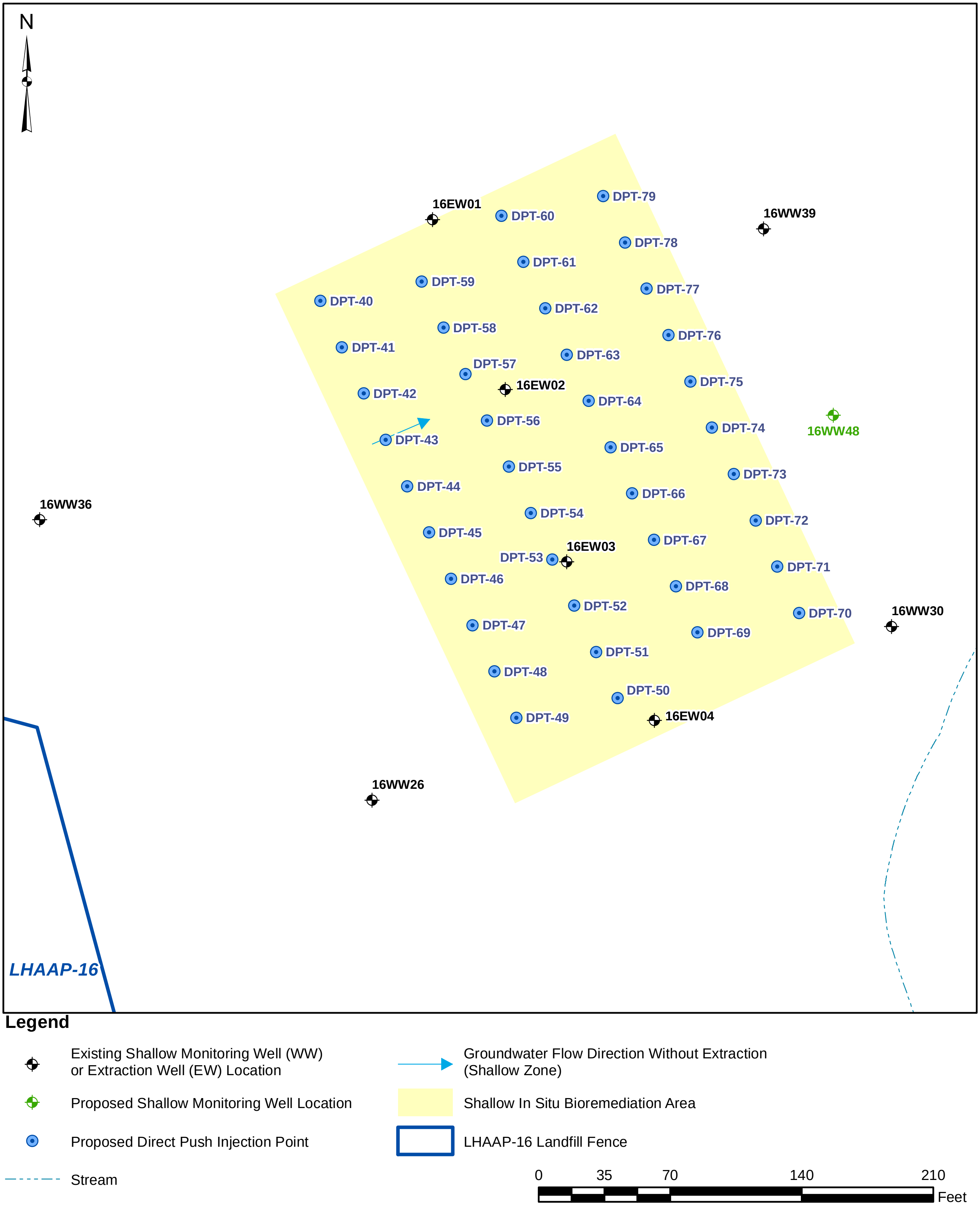
Figure 4-5
Bayou Biobarrier Design
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-5 LHAAP-16 Bayou Biobarrier.mxd



AECOM

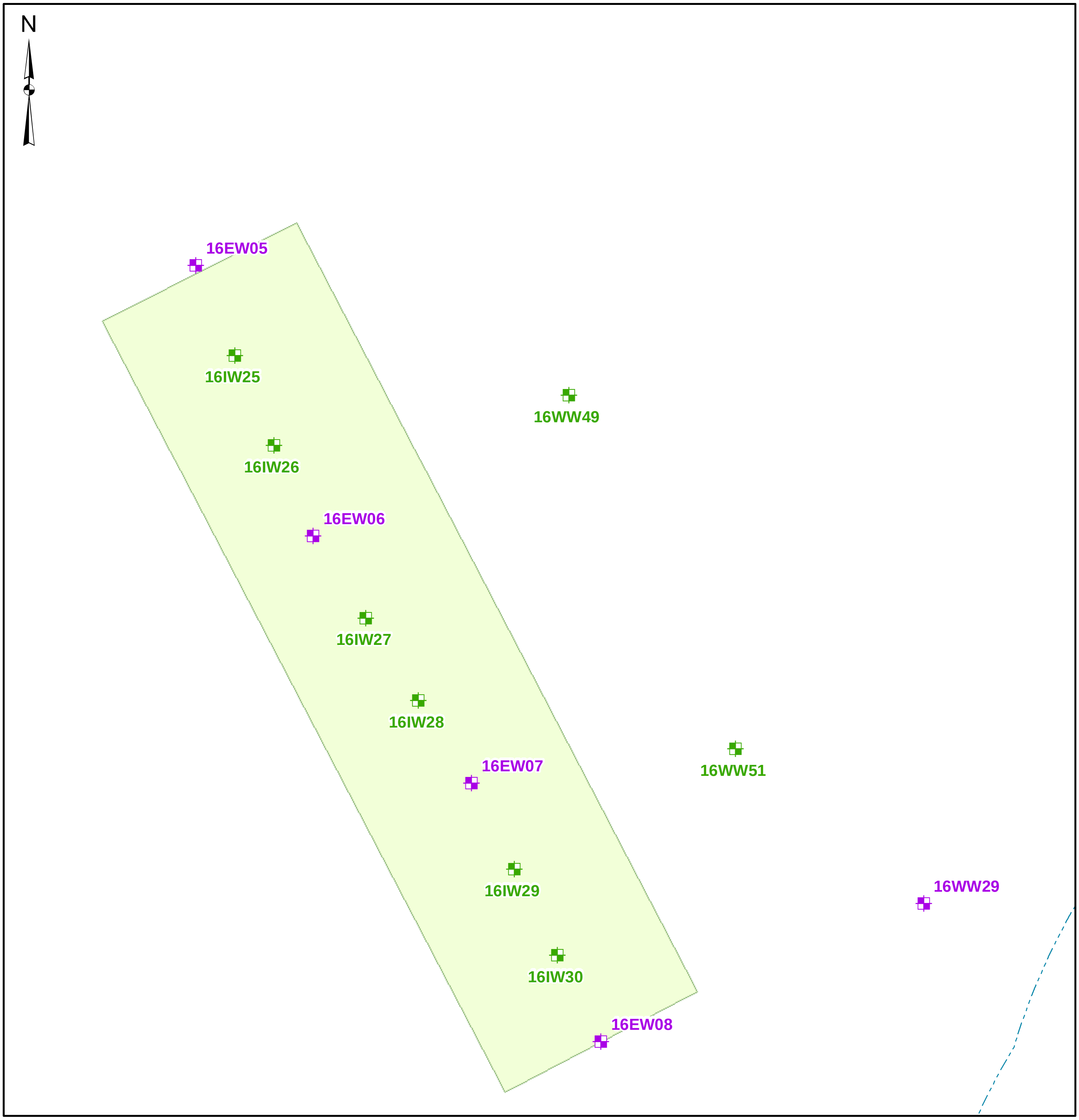
Figure 4-6
Mid Plume Design Shallow Groundwater Zone
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-6 LHAAP-16 Shallow Groundwater In Situ Bio Area.mxd



Legend

- 🟪 Existing Intermediate Injection/Extraction/Monitoring Well (EW well)
  Existing Intermediate Monitoring Well (WW)
- 🟩 Proposed Intermediate Zone Injection/Monitoring Well (IW);
  Proposed Intermediate Zone Monitoring Well (WW)
- 🟩 Intermediate Zone Situ Bioremediation Area

0 25 50 100
Feet

AECOM

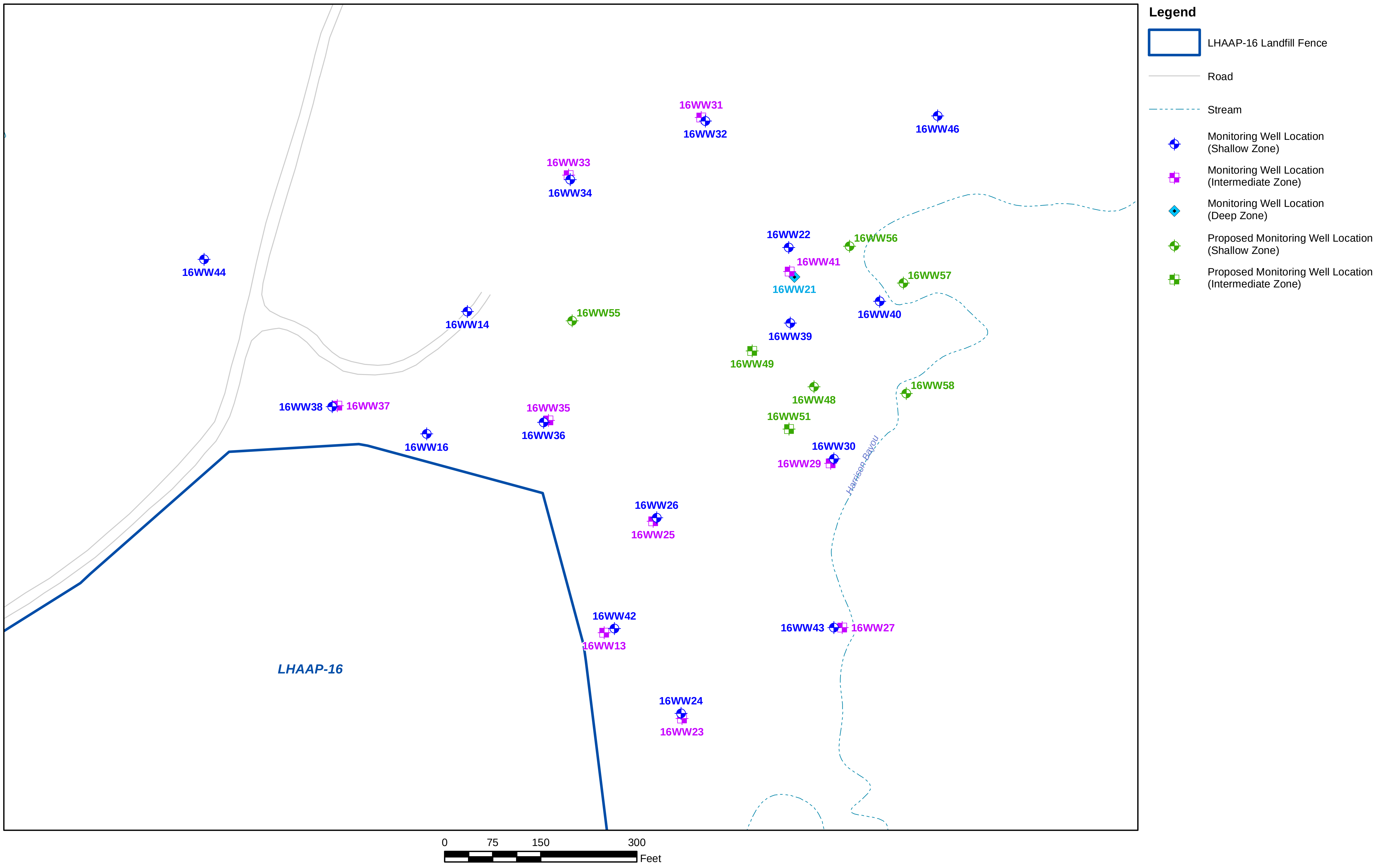
Figure 4-7
Mid Plume Design Intermediate Groundwater Zone
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-7 LHAAP-16 Int Groundwater In Situ Bio Area1.mxd



N

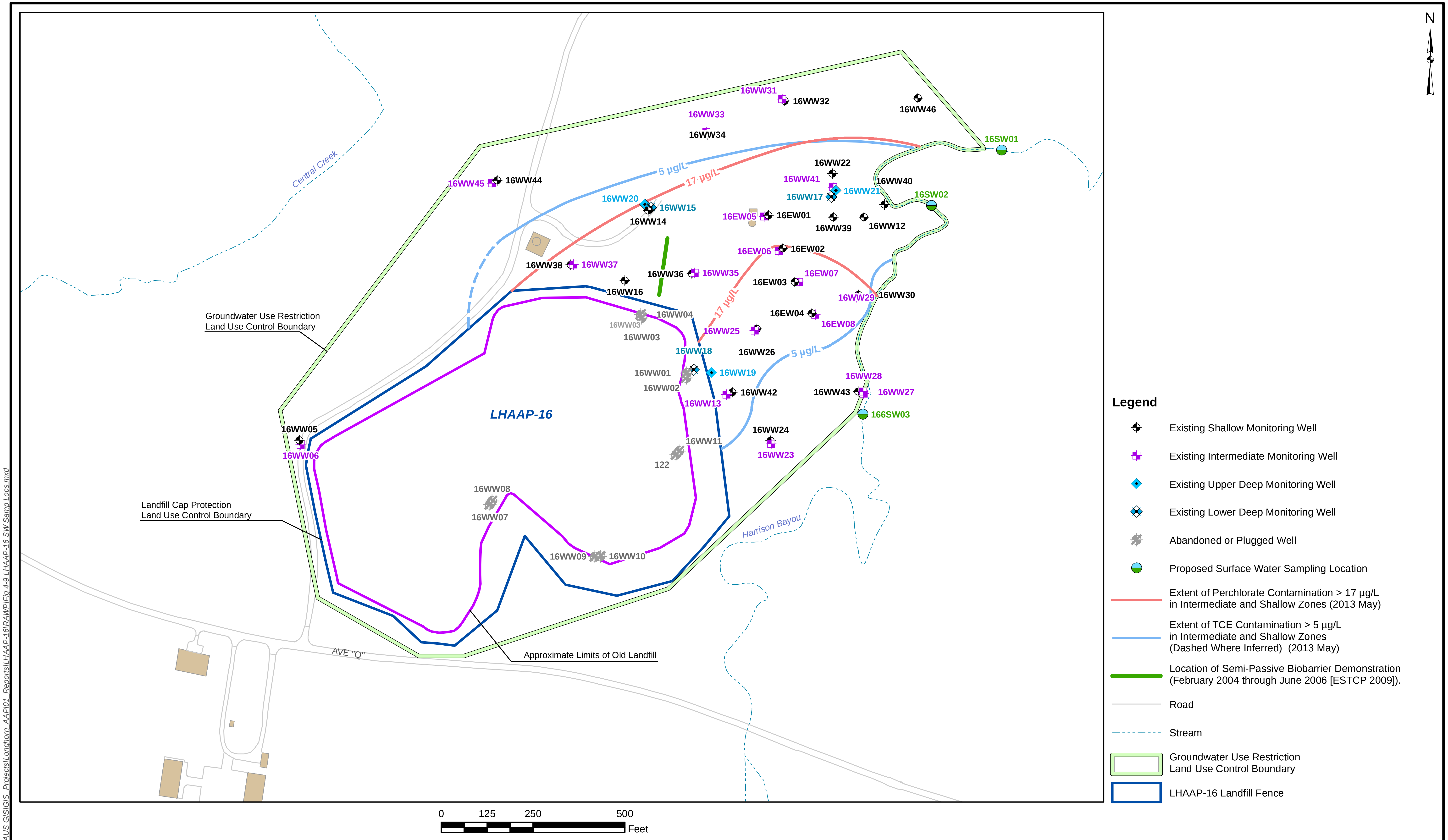
Figure 4-8
MNA and LTM Performance Monitoring Plan
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

L:\AGE\GIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 4-8 LHAAP-16 MNA&LTM PerfMonPlan.mxd



AECOM

Figure 4-9
Surface Water Sampling Locations
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Table 4-1: Injection Depths and Monitoring Well Screen Intervals – Landfill Biobarrier #1

Well or DPT ID	Existing/ Proposed	Primary Purpose		DPT Injection Depths/ Screen Intervals (feet bgs)*
		Substrate Injection	Performance Monitoring	
DPT-01 — DPT-07	Proposed	✓		15 - 21
DPT-08 — DPT-12	Proposed	✓		13 – 18
DPT-13 — DPT-18	Proposed	✓		5 – 18
16IW09	Proposed	✓		13 – 18
16RW01	Proposed		✓	15 – 21
16RW02	Proposed		✓	13 – 18
16RW03	Proposed		✓	13 – 18
16RW04	Proposed		✓	15 – 21
16RW05	Proposed		✓	13 – 18
16WW26	Existing		✓	13 – 18
16WW42	Existing		✓	2 – 12

Note:

* DPT Injection depths and monitoring well screen intervals may be modified based on field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

Existing wells boring and well logs are included in **Appendix B**. Wells 16WW26 and 16WW42 used to estimate injection depths.

bgs - below ground surface

ID - identification

Table 4-2: Summary of Substrate Loading/Injection – Landfill Biobarrier #1

Injection Points	Total Weight of Concentrated Substrate (pounds)	Total Volume of Concentrated Substrate (gallons)	Dilution Ratio of Substrate with Water (by volume)	Volume of Diluted EDS-ER (with water) (gallons)	Volume of KB-1 Culture (liters)
DPT-01 through DPT-18, and 16IW09	5,041	729	10:1	7,290 (383.7)[a]	19 (1) [a]

Notes:

[a] Total volume in all injection points (Volume in each injection point).

EDS-ER - Electron Donor Substrate – Extended Release

ESTCP	EVO @ 60%	7729	lbs
	EDS-ER @ 92%	5041	lbs
	Volume of Conc. Sub.	729	gallons
	Specific gravity of EDS-ER	0.925	s.g of EDS-ER

Table 4-3: Screen Intervals of Injection/Monitoring Wells – Landfill Biobarrier #2

Well ID	Existing/Proposed	Primary Purpose		Injection/ Screen Intervals (feet bgs)*
		Substrate Injection	Performance Monitoring	
16EW11	Existing	✓		15.2 – 24.8
16EW12B	Existing	✓		13 – 28
16EW13	Existing	✓		15 – 24.6
16EW14B	Existing	✓		14 – 29
16EW15	Existing	✓		13.9 – 23.5
16IW01	Existing	✓		15 – 25
16IW03	Existing	✓		15 – 25
16IW05	Existing	✓		15 – 25
16IW07	Existing	✓		14 – 24
16PM02	Existing		✓	15.1 – 24.8
16PM03	Existing		✓	15 – 24.5
16PM04	Existing		✓	15.1 – 24.8
16PM14	Existing		✓	15.2 – 24.8
16PM06	Existing		✓	14.9 – 24.6
16PM09	Existing		✓	14.1 – 23.8

Note:

* Injection / monitoring well screen intervals may be modified during field implementation activities based on field observations including depth clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

Existing wells boring and well logs are included in **Appendix B**. Wells 16EW11 through 16EW15 used to estimate injection depths.

bgs - below ground surface

ID - identification

Table 4-4: Summary of Substrate Loading/Injection – Landfill Biobarrier #2

Injection Wells	Extraction Wells	Total Weight of Concentrated Substrate (pounds)	Total Volume of Concentrated Substrate (gallons)	Dilution Ratio of Substrate with Water (by volume)	Volume of Dilute EDS-ER + Water (gallons)	Volume of KB-1 Culture (liters)
Phase I						
16IW01 16IW03 16IW05 16IW07	16EW11 16EW12B 16EW13 16EW14B 16EW15	1797	260	10:1	2,600 (1,475.5)[a]	8 (2)[a]
Phase II						
16EW11 16EW12B 16EW13 16EW14B 16EW15	No extraction will take place during Phase II	1797	260	10:1	2,600 (1,180)[a]	10 (2)[a]

Notes:

[a] Total volume in all injection wells during subject injection phase (Volume in each injection well during subject injection phase).

EDS-ER - Electron Donor Substrate – Extended Release

ESTCP	EVO @ 60%	5510	lbs
	EDS-ER @ 92%	3593	lbs
	EDS-ER @ 92% per Phase	1797	lbs
	Volume of Conc. Sub.	260	gallons
	Specific gracity of EDS-ER	0.925	s.g of EDS-ER

Table 4-5: Injection Depths and Monitoring Well Screen Intervals – Landfill Biobarrier #3

Well or DPT ID	Existing/Proposed	Primary Purpose		DPT Injection Depths/Screen Intervals (feet bgs)*
		Substrate Injection	Performance Monitoring	
DPT-19 — DPT-22	Proposed	✓		17 - 27
DPT-23 — DPT-25	Proposed	✓		15 – 25
16IW10	Proposed	✓		15 – 25
16RW06	Proposed		✓	17 – 27
16RW07	Proposed		✓	15 – 25
16RW08	Proposed		✓	15 – 25
16RW09	Proposed		✓	17 - 27
16RW10	Proposed		✓	15 – 25

Note:

* DPT Injection depths and monitoring well screen intervals may be modified based on field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

Existing wells boring and well logs are included in Appendix B. Wells 16WW14 used to estimate injection depths.

bgs - below ground surface

ID - identification

Table 4-6: Summary of Substrate Loading/Injection – Landfill Biobarrier #3

Injection Points	Total Weight of Concentrated Substrate (pounds)	Total Volume of Concentrated Substrate (gallons)	Dilution Ratio of Substrate with Water (by volume)	Volume of Diluted EDS-ER (with water) (gallons)	Volume of KB-1 Culture (liters)
DPT-19 through DPT-25, and 16IW10	2,333	337	10:1	3,370 (374.5)[a]	8 (1) [a]

Notes:

[a] Total volume in all injection points (Volume in each injection point).

EDS-ER - Electron Donor Substrate – Extended Release

ESTCP	EVO @ 60%	3578	lbs
	EDS-ER @ 92%	2333	lbs
	Volume of Conc. Sub.	337	gallons
	Specific gracity of EDS-ER	0.925	s.g of EDS-ER

Table 4-7: Injection Depths and Monitoring Well Screening Intervals – Bayou Biobarrier

Well or DPT ID	Existing/Proposed	Primary Purpose		DPT Injection Depths/Screen Intervals (feet bgs)*
		Substrate Injection	Performance Monitoring	
DPT-26 — DPT-31	Proposed	✓		22 – 32
DPT-32 — DPT-35	Proposed	✓		18 – 28
DPT-37 — DPT-39	Proposed	✓		14 – 24
16IW20	Proposed	✓		14 – 24
16WW22	Existing		✓	21 – 31
16RW11	Proposed		✓	14 – 24
16RW12	Proposed		✓	22 – 32
16WW39	Existing		✓	N/A
16WW12	Existing		✓	14 – 24

Note:

* DPT Injection depths and monitoring well screen intervals may be modified based on field observations including depth of clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

Existing wells boring and well logs are included in **Appendix B**. Wells 16WW12 and 16WW22 used to estimate injection depths.

bgs - below ground surface

ID - identification

N/A - not available

Table 4-8: Summary of Substrate Loading/Injection – Bayou Biobarrier

Injection Points	Total Weight of Concentrated Substrate (pounds)	Dilution Ratio of Substrate (ABC) with Water (by weight)	Volume of Diluted ABC[b] (with water) (gallons)	Volume of KB-1 Culture (liters)
DPT-26 through DPT-39, and 16IW20	7,000[a]	10:01	3,800 (271)[c]	14 (1) [c]

Notes:

[a] Includes 3,500 pounds of ABC and 3,500 pounds of ZVI.

[b] Includes ABC volume only (ZVI volume not included).

[c] Total volume in all injection points (Volume in each injection point).

Table 4-9: Screen Intervals of Injection/Extraction Wells – Mid-Plume ISB

Well ID	Existing/ Proposed	Purpose		Screen Intervals (feet bgs)^{b}
		Substrate Emplacement^{a}	Performance Monitoring	
Shallow Groundwater Zone				
DPT-40 — DPT-79	Proposed	✓		14-36
16EW01	Existing		✓	31.2 – 36.2
16EW02	Existing		✓	21.5 – 26.5
16EW03	Existing		✓	13 – 18
16EW04	Existing		✓	14 – 19
16WW48	Proposed		✓	25-35
16WW39	Existing		✓	N/A
16WW30	Existing		✓	25-35
Intermediate Groundwater Zone				
16EW05	Existing	✓	✓	47 – 52
16EW06	Existing	✓	✓	50 – 55
16EW07	Existing	✓	✓	41 – 46
16EW08	Existing	✓	✓	34 – 39
16IW25	Proposed	✓		40 - 55
16IW26	Proposed	✓		40 - 55
16IW27	Proposed	✓		40 - 55
16IW28	Proposed	✓		35 - 50
16IW29	Proposed	✓		35 - 50
16IW30	Proposed	✓		35 - 50
16WW49	Proposed		✓	45-55
16WW51	Proposed		✓	35-45

Note:

[a] See Table 4-10 for details.

[b] Injection / monitoring well screen intervals may be modified during field implementation activities based on field observations including depth clay layer separating shallow and intermediate groundwater zones and depth to groundwater.

Existing wells boring and well logs are included in **Appendix B**. Wells 16EW01 through 16EW04 in the Shallow Zone and wells 16EW05 through 16EW08 in the Intermediate Zone used to estimate injection depths.

N/A - not available

Table 4-10: Summary of Substrate Loading/Injection – Mid-Plume ISB

Injection Wells	Total Weight of Substrate (pounds)	Total Volume of Concentrated Substrate (gallons)	Dilution Ratio of Substrate with Water (by volume)	Volume of Diluted EDS-ER (with water) (gallons)	Volume of KB-1 Culture (liters)
Shallow Zone					
DPT-40 through DPT-79	28,414	4,107	10:1	41,070 (1,027)[a]	40 (1) [a]
Intermediate Zone					
Injection Wells 16IW25 16IW26 16IW27 16IW28 16IW29 16IW30 Injection/Extraction Wells 16EW05 16EW06 16EW07 16EW08	16,565	2,394	10:1	23,940 (3,990)[a]	20 (2)[a]

Notes:

[a] Total volume in all injection points/wells (Volume in each injection point/wells)
EDS-ER - Electron Donor Substrate – Extended Release

Shallow Zone

ESTCP	EVO @ 60% (ESTCP)	43568	lbs
	EDS-ER @ 92%	28414	lbs
	Volume of Conc. Sub.	4107	gallons
	Specific gracity of EDS-ER	0.925	

Intermeidate Zone

ESTCP	EVO @ 60% (ESTCP)	25399	lbs
	EDS-ER @ 92%	16565	lbs
	Volume of Conc. Sub.	2394	gallons
	Specific gracity of EDS-ER	0.925	

Table 4-11: Pre-Remedy Groundwater Sampling Plan in the Shallow Zone - LHAAP-16

Monitoring Locations	ISB Area	Proposed Analyses								
		VOCs[a] (SW8260B)	Perchlorate (314.0)	Anions[b] (E300.0)	Dissolved Gases[c] (RSK-175)	Alkalinity (2320B)	TOC (SW9060)	DHC (qPCR)	Bromide (E300.0)	Field Parameters[d]
16WW44	Background	✓	✓							✓
16WW38	Upgradient to Landfill Biobarrier #2	✓	✓							✓
16WW16	Upgradient to Landfill Biobarrier #2	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW14	Upgradient to Landfill Biobarrier #3	✓	✓							✓
16WW55	Downgradient to Landfill Biobarrier #3	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW36	Downgradient to Landfill Biobarrier #2	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW26	Downgradient to Landfill Biobarrier #1	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW42	Downgradient to Landfill Biobarrier #1	✓	✓						✓	✓
16WW30	Downgradient of Mid-Plume ISB Area	✓	✓						✓	✓
16WW48	Downgradient of Mid-Plume ISB Area (proposed)	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW39	Downgradient of Mid-Plume ISB Area (Existing)	✓	✓						✓	✓
16WW12	Upgradient to Bayou Biobarrier	✓	✓						✓	✓
16WW40	Downgradient to Bayou Biobarrier	✓	✓						✓	✓
16WW22	Upgradient to Bayou Biobarrier	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW56	Downgradient to Bayou Biobarrier	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW57	Across Bayou Biobarrier	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW58	Across Bayou Biobarrier	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW46	Downgradient Outside of Contaminated Area	✓	✓							✓
16WW32	Cross-graident Outside of Containment Area	✓	✓							✓
16WW34	Cross-graident Outside of Containment Area	✓	✓							✓
16WW24	Cross-gradient to South of Plume	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW43	Cross-gradient to South of Plume	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW21	Downgradient of Mid-Plume ISB Area	✓	✓						✓	✓
16EW02	Inside Mid-Plume ISB Area	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 4-11: Pre-Remedy Groundwater Sampling Plan in the Shallow Zone - LHAAP-16

Notes:

This schedule assumes sampling of the extraction wells will be continued annualy until the remedy is implemented; therefore, only 16EW02 will be sampled during pre-remedy monitoring.

[a] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

[b] Anions include nitrate and sulfate.

[c] Dissolved gasses include ethene, ethane, and methane.

[d] Field Parameters include dissolved oxygen, oxidation reduction potential, and pH.

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

DHC - Dehalococcoides (microbial analysis)

TOC - total organic carbon

VOCs - volatile organic compounds

Table 4-12: Pre-Remedy Groundwater Sampling Plan in the Intermediate Zone - LHAAP-16

Monitoring Locations	ISB Area	Proposed Analyses								
		VOCs[a] (SW8260B)	Perchlorate (314.0)	Anions[b] (E300.0)	Dissolved Gases[c] (RSK-175)	Alkalinity (2320B)	TOC (SW9060)	DHC (qPCR)	Bromide (E300.0)	Field Parameters[d]
16WW45	Background	✓	✓							✓
16WW37	Downgradient of Landfill/Upgradient of Landfill Biobarrier #2	✓	✓							✓
16WW35	Upgradient of Mid-Plume ISB Area/Downgradient of Landfill Biobarrier #2	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW25	Upgradient of Mid-Plume ISB Area/Downgradient of Landfill Biobarrier #1	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW13	Downgradient of Landfill	✓	✓						✓	✓
16WW23	Downgradient of Landfill	✓	✓							✓
16WW27	Downgradient Outside of Contaminated Area	✓	✓							✓
16WW29	Downgradient of Mid-Plume ISB Area	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW41	Downgradient of Mid-Plume ISB Area	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW31	Cross-graident Outside of Containment Area	✓	✓							✓
16WW33	Cross-graident Outside of Containment Area	✓	✓							✓
16WW49	Downgradient of Mid-Plume ISB Area (proposed)	✓	✓						✓	✓
16WW51	Downgradient of Mid-Plume ISB Area (proposed)	✓	✓						✓	✓
16WW21[e]	Downgradient of Mid-Plume ISB Area	✓	✓							✓
16EW06	Inside Mid-Plume ISB Area	✓	✓	✓	✓	✓	✓	✓	✓	✓

Notes:

This schedule assumes sampling of the extraction wells will be continued annualy until the remedy is implemented; therefore, only 16EW06 will be sampled during pre-remedymonitoring.

[a] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

[b] Anions include nitrate and sulfate.

[c] Dissolved gasses include ethene, ethane, and methane.

[d] Field Parameters include dissolved oxygen, oxidation reduction potential, and pH.

[e] Upper Deep Monitoring Well

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

DHC - Dehalococcoides (microbial analysis)

TOC - total organic carbon

VOCs - volatile organic compounds

Table 4-13: ISB Performance Monitoring Plan (Years 1 and 2) – Landfill Biobarrier #1

Monitoring Locations	Primary Rationale for Well Selection	Proposed Analyses																																			
		First Two Months (Up to Two Events)[a]												Year 1 (Quarterly)													Year 2 (Quarterly)												
		Perchlorate (314.0)	VOCs^c (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions^b (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs^c (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions^b (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	DHC (qPCR)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs^c (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions^b (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)
16IW09	Performance data within the biobarrier			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16RW03	Performance data within the biobarrier			✓	✓	✓						✓	✓																									
16RW01	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16RW02	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16RW04	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16RW05	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW26	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓
16WW42	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓

Notes:

[a] To be conducted within 15 to 30 days of the completion of substrate injection. A second event will be collected between 45 and 60 days if the results from the first event were inconclusive.

[b] Anions include nitrate and sulfate.

[c] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

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

Table 4-14: ISB Performance Monitoring Plan (Years 1 and 2) – Landfill Biobarrier #2

Monitoring Locations	Primary Rationale for Well Selection	Proposed Analyses																																				
		First Two Months (Up to Two Events)[a]												Year 1 (Quarterly)													Year 2 (Quarterly)											
		Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	DHC (qPCR)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)
16IW03	Performance data within the biobarrier			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16IW04	Performance data within the biobarrier			✓	✓	✓						✓	✓																									
16PM02	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16PM03	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16PM06	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16PM09	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16PM14	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW36	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓

Notes:

[a] To be conducted within 15 to 30 days of the completion of substrate injection. A second event will be collected between 45 and 60 days if the results from the first event were inconclusive.

[b] Anions include nitrate and sulfate.

[c] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

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

Table 4-15: ISB Performance Monitoring Plan (Years 1 and 2) – Landfill Biobarrier #3

Monitoring Locations	Primary Rationale for Well Selection	Proposed Analyses																																				
		First Two Months (Up to Two Events)[a]												Year 1 (Quarterly)													Year 2 (Quarterly)											
		Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	DHC (qPCR)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)
16IW10	Performance data within the biobarrier			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16RW08	Performance data within the biobarrier			✓	✓	✓						✓	✓																									
16RW06	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16RW07	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16RW09	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓
16RW10	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓

Notes:

[a] To be conducted within 15 to 30 days of the completion of substrate injection. A second event will be collected between 45 and 60 days if the results from the first event were inconclusive.

[b] Anions include nitrate and sulfate.

[c] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

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

Table 4-16: ISB Performance Monitoring Plan (Years 1 and 2) – Bayou Biobarrier

Monitoring Locations	Primary Rationale for Well Selection	Proposed Analyses																																		
		First Two Months (Up to Two Events)[a]												Year 1 (Quarterly)													Year 2 (Quarterly)											
		Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	DHC (qPCR)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)
16IW20	Performance data within the biobarrier			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
16RW12	Performance data downgradient of biobarrier			✓	✓	✓						✓	✓																									
16RW11	Performance data within the biobarrier			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16WW39	Upgradient well for monitoring influent concentrations			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16WW12	Upgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW22	Upgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW40	Downgradient well to monitor effluent concentrations and biobarrier effectiveness			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓			✓	✓	✓		✓

Notes:

[a] To be conducted within 15 to 30 days of the completion of substrate injection. A second event will be collected between 45 and 60 days if the results from the first event were inconclusive.

[b] Anions include nitrate and sulfate.

[c] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

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

Table 4-17: ISB Performance Monitoring Plan (Years 1 and 2) – Mid-Plume ISB

Monitoring Locations	Primary Rationale for Well Selection	Proposed Analyses																																				
		First Two Months (Up to Two Events)[a]												Year 1 (Quarterly)													Year 2 (Quarterly)											
		Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	DHC (qPCR)	Bromide (E300.0)	TOC (SW9060)	Perchlorate (314.0)	VOCs[c] (SW8260B)	DO (field reading)	ORP (field reading)	pH (field reading)	Alkalinity (2320B)	Anions[b] (E300.0)	Ethene (RSK-175)	Ethane (RSK-175)	Methane (RSK-175)	Bromide (E300.0)	TOC (SW9060)
16EW01	Performance data for injection ISB area - Shallow Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16EW02	Performance data for injection ISB area - Shallow Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓							
16EW03	Performance data for injection ISB area - Shallow Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16EW04	Performance data for injection ISB area - Shallow Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16EW05	Performance data for injection well - Intermediate Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16EW06	Performance data for injection well - Intermediate Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16EW07	Performance data for injection well - Intermediate Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓									✓	✓	✓	✓	✓							
16EW08	Performance data for injection well - Intermediate Zone			✓	✓	✓						✓	✓	✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW48	Performance data for downgradient - Shallow Zone (proposed)													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW30	Performance data for downgradient - Shallow Zone													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW39	Performance data for downgradient - Shallow Zone													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW29	Performance data for downgradient well - Intermediate Zone													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW49	Performance data for downgradient well - Intermediate Zone (proposed)													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW51	Performance data for downgradient well - Intermediate Zone (proposed)													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							
16WW21	Performance data for downgradient well in Upper Deep Zone													✓	✓	✓	✓	✓							✓	✓	✓	✓	✓	✓	✓							

Notes:

[a] To be conducted within 15 to 30 days of the completion of substrate injection. A second event will be collected between 45 and 60 days if the results from the first event were inconclusive.

[b] Anions include nitrate and sulfate.

[c] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

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

Table 4-18: MNA and LTM Performance Monitoring Plan - LHAAP-16

Monitoring Locations	Groundwater Zone	Proposed Analyses								
		VOCs[a] (SW8260B)	Perchlorate (314.0)	Anions[b] (E300.0)	Dissolved Gases[c] (RSK-175)	Alkalinity (2320B)	TOC (SW9060)	DHC (qPCR)	Bromide (E300.0)	Field Parameters[d]
16WW44	Shallow	✓	✓							✓
16WW38	Shallow	✓	✓							✓
16WW16	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW14	Shallow	✓	✓							✓
16WW36	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW26	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW42	Shallow	✓	✓							✓
16WW43	Shallow	✓	✓							✓
16WW30	Shallow	✓	✓							✓
16WW40	Shallow	✓	✓							✓
16WW22	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW46	Shallow	✓	✓							✓
16WW32	Shallow	✓	✓							✓
16WW34	Shallow	✓	✓							✓
16WW24	Shallow	✓	✓							✓
16WW48	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW39	Shallow	✓	✓							✓
16WW55	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW56	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW57	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW58	Shallow	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW37	Intermediate	✓	✓							✓
16WW35	Intermediate	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW13	Intermediate	✓	✓							✓
16WW23	Intermediate	✓	✓							✓
16WW25	Intermediate	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW27	Intermediate	✓	✓							✓
16WW29	Intermediate	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW41	Intermediate	✓	✓	✓	✓	✓	✓	✓	✓	✓
16WW31	Intermediate	✓	✓							✓
16WW33	Intermediate	✓	✓							✓
16WW49	Intermediate	✓	✓							✓
16WW51	Intermediate	✓	✓							✓
16WW21	Upper Deep	✓	✓							✓

Notes:

This schedule assumes sampling of the extraction wells will be continued annualy until the remedy is implemented; therefore, only 16EW02 will be sampled during baseline monitoring.

[a] VOCs include TCE; cis-1,2-DCE; 1,1-DCE; 1,2-DCA; 1,1,2-TCA; VC; and methylene chloride.

[b] Anions include nitrate and sulfate.

[c] Dissolved gasses include ethene, ethane, and methane.

[d] Field Parameters include dissolved oxygen, oxidation reduction potential, and pH.

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

DHC - Dehalococcoides (microbial analysis)	LTM - Long-Term Monitoring
TOC - total organic carbon	VOCs - volatile organic compounds

5 LAND USE CONTROL REMEDIAL DESIGN

This section describes the LUC RD for LHAAP-16. In accordance with the Final ROD (U.S. Army, 2016), the LUC RD will be finalized as the land use component of the Remedial Design.

Per the Final ROD (U.S. Army, 2016), LUCs' performance objectives are to:

- Prohibit access to the contaminated groundwater except for environmental monitoring and testing only;
- Preserve the integrity of the landfill cap, and to restrict intrusive activities (e.g., digging) that would degrade or alter the cap;
- Restrict land use to nonresidential;
- Maintain the integrity of any current or future remedial or monitoring systems; and

The implementation, maintenance, and inspection requirements associated with each of the performance objectives that comprise this LUC RD are described below. The actions taken to implement the LUC objectives during the RA phase, 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 distributed as part of the Comprehensive LUC Management Plan.

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

5.1 LUC Implementation

The actions required to implement the LUCs for LHAAP-16 are described below. The first of these, the initial notice of LUCs, has been completed. A figure depicting the preliminary LUC boundaries is presented in **Figure 5-1**. The following actions will be undertaken to implement the LUCs for LHAAP-16:

- Provide initial notice of the LUCs before remedial action is implemented.
    - Develop the initial 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 preliminary LUC boundaries presented in **Figure 5-1**.

    - 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 land use controls within 90 days of ROD signature, which is on or before December 12, 2016. The notices will be sent to federal, state and local officials including: U.S. Senator Ted Cruz, U.S. Senator John Cornyn, U.S. Congressman Louie Gohmert, State Senator Kevin Eltiffe, State Representative Chris Paddie, Harrison County

Judge Hugh Taylor, Harrison County Commissioner Precinct 1 William D. Hatfield, City of Uncertain Mayor Sam Canup, and Karnack Water Supply Corporation Board Members. Notice will also be sent to the Caddo Lake National Wildlife Refuge Manager.

- Finalize the Boundaries for the LUCs as a part of the remedial action.
    - Revise the boundaries if necessary. The LUC boundary presented in this RD is subject to change, based on COC results from the two proposed wells to be installed on the east side of Harrison Bayou. The final boundaries 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 landfill LUCs (preserve the integrity of the landfill cap, and to restrict intrusive activities (e.g., digging) that would degrade or alter the cap); 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 remedial action activities after an evaluation of new 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.

5.2 Maintenance and Monitoring Requirements

The LUCs will be maintained in place as follows:

- The landfill LUCs will remain in place as long as the landfill waste remains at the site or until the levels of Contaminants of Concern (i.e., including all hazardous substances, pollutants, and contaminants found at the Site at cleanup levels as listed in **Table 1-1**) allow for unlimited use and unrestricted exposure;
- 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 1-1**) 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 1-1**) are met; and,
- The LUC prohibiting groundwater use (except for environmental monitoring and testing) as a potable source will remain in place until the levels of COCs (i.e., all hazardous substances, pollutants, and contaminants found at the Site at cleanup levels as listed in **Table 1-1**) in soil and groundwater allow for unlimited use and unrestricted exposure.

Landfill and Remedial or Monitoring System LUCs include physical components that require repair and maintenance. These are described in **Section 3.0.** The Inspection and Maintenance Checklist is provided in **Appendix A.**

The administrative maintenance required to ensure the five 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 A).**
- 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-16. 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-16.

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.

5.3 Reporting of LUC Inspection and Monitoring

Beginning with finalization of this RD and approval of the Inspection and Maintenance forms 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.

5.3.1 Notice of Planned Property Conveyances

Upon transfer of Army-owned property, the Army will provide written notice to the transferee of the LHAAP-16 groundwater and soil (surface and subsurface) 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 US 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 US 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 land use controls 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.

5.3.2 Opportunity to Review Text of Intended Land Use Controls

The US 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 US Army will produce an ECP or other environmental document for transfer of LHAAP-16, but before executing transfer, the US 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.

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

Should the US Army discover after conveyance of the site any activity on the property inconsistent with the LUC performance objectives, the US Army shall notify USEPA and TCEQ within 72 hours of such discovery. Consistent with Section 5.2.5 below, the US Army will then work with USEPA, TCEQ and the transferee to correct the problem(s) discovered. This reporting requirement does not preclude the US Army from taking immediate action pursuant to its CERCLA authorities to prevent any perceived risk(s) to human health or the environment.

5.3.4 Land Use Control Enforcement

Should the LUC remedy reflected in this RD fail, the US 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 US Army could choose to exercise its response authorities under CERCLA. Should the US 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 US Army may notify those agencies of such violation(s) and work cooperatively with them to re-achieve owner/user compliance with the LUC.

5.3.5 Modification or Termination of Land Use Controls

The LUCs shall remain in effect until such time as the US Army and USEPA agree that the concentrations of COCs in groundwater have met cleanup levels in groundwater and that surface and subsurface soil concentrations 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 differences or a remedial action complete report. If the property has been transferred and a determination by the US Army and USEPA has been made to terminate the LUC, the US 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.

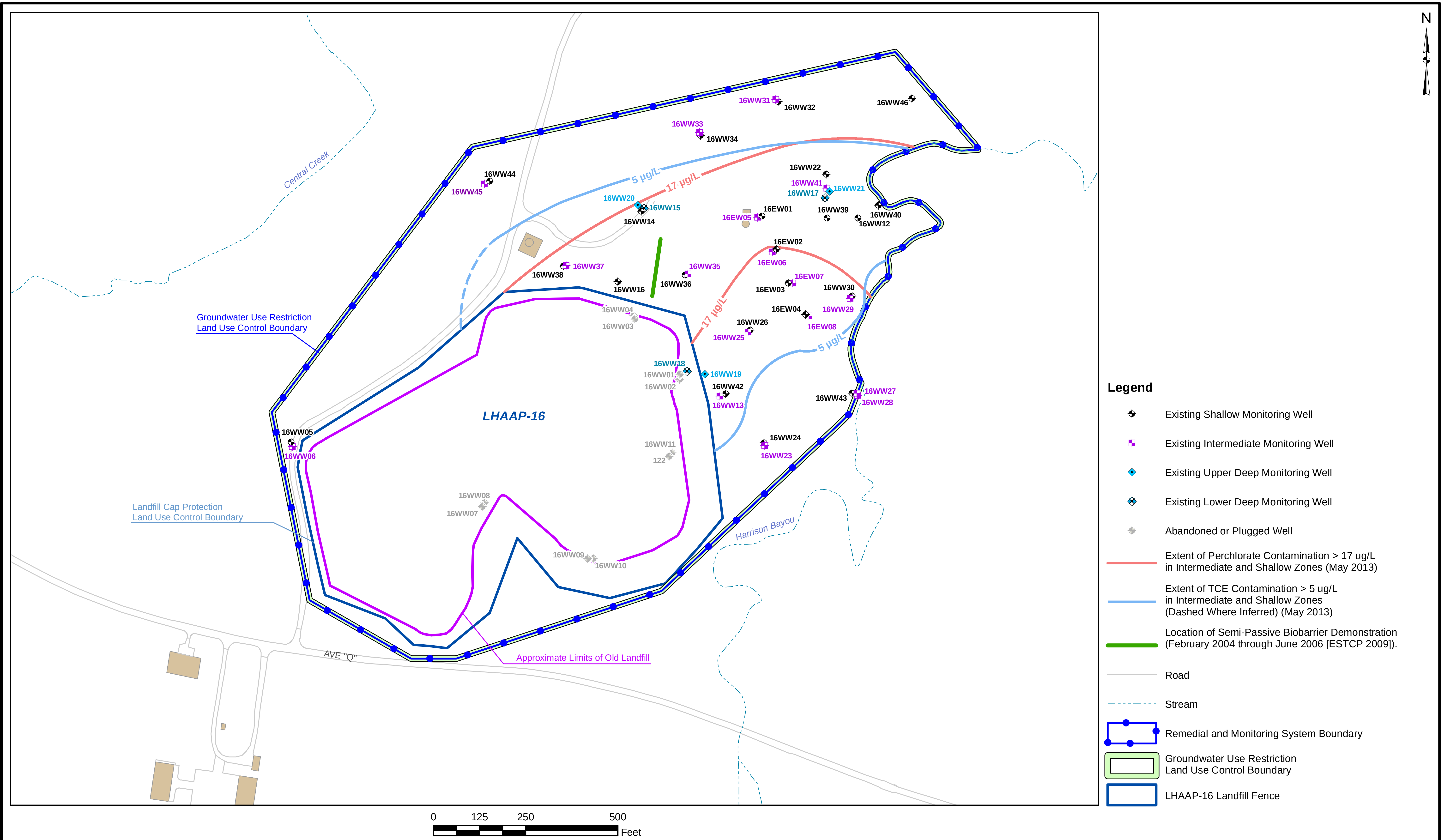


Figure 5-1
Land Use Contol Boundaries
LHAAP-16 Remedial Design

Longhorn Army Ammunition Plant
Karnack, Texas

60256135

January 2017

Path: L:\AGEIGIS\AUS GIS\GIS_Projects\Longhorn_AAP\01_Reports\LHAAP-16\RAWP\Fig 5-1 LHAAP-16 Land Use Control Boundaries.mxd

6 FIELD ACTIVITIES

All field activities proposed as part of implementation of the selected remedy at LHAAP-16 will be performed in accordance with the *Installation-Wide Work Plan* (IWWP) (AECOM 2014). This section generally describes field activities planned at LHAAP-16. Field activities to be conducted as part of this RD are:

- Pre-Mobilization Activities
- Site Preparation
- Utility Clearance
- Drilling and Well Installation
- Amendment Procurement and Storage
- Substrate Injection and Equipment
- Location Survey
- Performance Monitoring and MNA Groundwater Sampling
- Remediation-Derived Wastes Management

The proposed schedule of implementation is presented in **Table 6-1**.

6.1 Pre-Mobilization Activities

Prior to commencing field work, a pre-construction meeting will be held. USEPA, TCEQ and USFWS will be notified of the meeting at least two weeks prior. A survey will be performed by a state-licensed surveyor to determine the metes-and-bounds for the LUC and notification of non-residential use. The Texas State Plane, NAD 1983 coordinate system will be used. **Figure 5-1** shows the proposed LUC boundary that will be surveyed.

Prior to mobilization for any field activities, the Contractor will secure any applicable approvals and notifications, which can include federal, state, and local requirements (i.e. underground injection control, notification of Texas 811). The Contractor will also secure utility clearance, where applicable, for water, sewer, gas, electric, and communication.

Mobilization and site setup will be performed in accordance with the procedures outlined in Section 3.1 of the IWWP. Once onsite, the Contractor will inspect the site to identify any underground or overhead obstructions that may interfere with in situ bioremediation activities or groundwater and landfill cap monitoring. If necessary, injection and biobarrier locations will be modified to avoid any obstructions.

6.2 Site Preparation

Proposed well locations will be staked based on site maps. Areas around these wells will be cleared of vegetation and biohazards (e.g. poison ivy, stinging insects) to the extent practicable to protect field staff while minimizing impact to the environment.

6.3 Utility Clearance

The Contractor will secure utility clearance for water, sewer, gas, electric, and communication. This will include survey of the site to assess the presence of any underground or overhead utilities that may limit groundwater sampling and notify Texas811 prior to any subsurface activities.

6.4 Drilling and Well Installation

All drilling and well installation activities will be supervised by a Texas-registered geologist. Monitoring and injection well installation and development will be performed in accordance with **Section 3.3** of the IWWP. The biobarriers will be installed primarily using DPT. Monitoring wells will be installed within and downgradient from the biobarriers for performance monitoring. Mid-plume treatment will include the use of 40 DPT injection points in the shallow zone.

The injection wells for the remedial action will be classified as Class V injection wells. The substantive requirements for Class V injection wells at 30 TAC 331.5(a); 30 TAC 331.6; 30 TAC 331.132(c), (d); and 30 TAC 331.133(a) - (e) will be complied with for installation, operation and closure of injection wells (see Table 1-2). Injection wells will be constructed to the required specifications for isolation casing, surface completion, prevention of commingling, and confinement of undesirable groundwater to its zone of origin. The closure of injection wells following completion of the remedial action will be accomplished by removing all of the removable casing and by pressure filling via tremmie pipe with cement, or other alternative method for Class V wells stipulated in 30 TAC 331.133 (a) – (e).

6.4.1 DPT Drilling

DPT drilling will be used for the biobarriers. A total of 79 injection points will be advanced using DPT techniques in the area of high VOC concentration between the landfill and Harrison Bayou (**Figures 4-2 through 4-6**). DPT drilling will be conducted in accordance with procedures presented in the IWWP (AECOM, 2014).

6.4.2 Drilling

All injection and monitoring wells will be installed using either a hollow stem auger (HSA) or rotary sonic drilling techniques and the borehole lithology will be logged. Proposed well locations are presented on **Figures 4-2 through 4-6**. Eight-inch diameter augers will be used to drill all boreholes. Drilling will be conducted in accordance with **Section 3.2** of the IWWP (AECOM, 2014).

6.4.3 Well Installation

All injection wells will be completed with 2-inch diameter Schedule 80 PVC well screen and blank casing. All monitoring wells will be completed with 4-inch diameter Schedule 40 PVC well screen and blank casing.

All wells will be completed using 0.02-inch slot well screen and Lone Star #3 sand filter pack material. All well casings will be sealed at the bottom with a flush threaded end cap of the same material as the well screen. Screen and blank riser sections will be steam cleaned and wrapped in plastic for transportation to the well locations. The casing will remain wrapped in plastic until it is assembled and lowered down the borehole.

The well casing will be plumb and centered with centralizers placed every 20 feet, if necessary. Once the casing is installed, the filter pack, consisting of acid-resistant, washed and graded silica sand, will be placed by tremie pipe down the annulus between the well casing and the borehole wall. The sand will be furnished in sacks and will be certified clean and free of oil, acids, and organic and other deleterious materials. The filter pack will be placed from the bottom of the borehole to 2 feet above the top of the well screen or between the bentonite seals for the multi-screen wells. The filter pack depth will be periodically sounded to monitor the depth and to locate any points of bridging between the well casing and the borehole wall. Potable water may be poured down the annulus to break bridges if they are encountered. The amount of water introduced into the well will be kept to a minimum and the quantities will be recorded in the field logbook.

The volume of filter pack material used will be recorded in the field logbook during filter pack construction. The volume of sand used will be compared to the volume of annulus filled every 5 feet to 10 feet. If a significant discrepancy arises between the sand volume used versus the filled volume measured, the source of this error will be identified and corrected.

Wells will be predeveloped by bailing and surging to aid in settling the filter pack before placing the bentonite seal. After the filter pack has been placed, a 2-foot to 5-foot sodium bentonite seal (either granular for unsaturated conditions or coated pellet form for saturated conditions) will be introduced into the well above the filter pack. The bentonite will be saturated with potable water and allowed to hydrate for at least 1 hour. After the bentonite seal has hydrated, the remaining annulus will be grouted using a Type I Portland or American Petroleum Institute (API) Class A cement/bentonite slurry.

6.4.4 Well Development

Each newly-installed well will be developed no sooner than 24 hours following well completion in accordance with **Section 3.3.1** of the IWWP. Existing wells that will be used for injection will be redeveloped.

6.5 Location Survey

After well installation and injection operations are complete, a survey of new well locations and DPT injection points (including top of casing elevation in the wells) will be performed by a state-licensed surveyor. Vertical elevations of the casings and elevations of the ground surface will be measured to the nearest 0.01-foot, referenced to mean sea level (msl). The horizontal location will be measured to the nearest 0.1-foot. The Texas State Plane, NAD 1983 coordinate system will be used. All surveying will be performed in accordance with **Section 3.4** of the IWWP (AECOM, 2014). The“as built” blank length of casing will be included on the well construction log.

6.6 Groundwater and Surface Water Sampling

Prior to groundwater sampling, areas around the wells will be cleared of vegetation and biohazards (e.g. poison ivy, stinging insects) to protect field staff. Low-flow groundwater sampling will be performed in accordance with **Section 3.5** of the IWWP. Surface water samples will be collected in accordance with **Section 3.7** of the IWWP.

6.7 Remediation-Derived Waste Management

All remediation-derived waste will be managed appropriately. Remediation-derived waste includes the following:

- Cuttings from injection and monitoring well boreholes
- Groundwater generated from development of new wells
- Groundwater generated from purging of wells prior to sampling
- Decontamination fluids
- Disposable protective clothing and supplies.

Drill cuttings may be placed in 55-gallon drums or high-density polyethylene (HDPE)-lined roll-off containers. Composite samples will be collected and analyzed for waste characterization prior to disposal. All handling of drill cuttings will be performed in accordance with **Section 3.8.1** of the IWWP (AECOM, 2014).

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 groundwater treatment plant at LHAAP-18/24, as specified in **Section 3.8.2** of the IWWP.

Table 6-1: LHAAP-16 Remedial Design Implementation Schedule

Task	Duration (days)	Elapsed Time* (days)	Notes
1. Develop RAWP	90	90	
2. Coordinate with TCEQ	7	35	Permit not required but must meet substantive requirements
2. GW Sampling	4	35	
3. SOW			
Chemical Vendors	7	29	Concurrently
Drilling Contractor	7	29	Concurrently
Surveyor	7	29	Concurrently
4. Subcontracting			
Chemical Vendors	30	35	Concurrently
Drilling Contractor	30	35	Concurrently
Surveyor	30	35	Concurrently
5. Utility clearance	1	105	At least 48 hours before work can begin
6. Clear injection/new well locations	3	98	
7. Install Injection/Monitoring Wells	35	112	
8. Procure Chemicals	5	112	
9. Conduct Injection	30	147	
10. IDW Management	30	112	
Obtain Roll-off	5	101	
Store on Site		108	
Sample/Analyze	20	111	
Profile	7	130	
Manifest	7	136	
Dispose	5	141	
11. Reporting	75	242	

Sampling will occur on a quarterly basis for 2 years. Quarterly sampling will occur a few weeks after injection takes place.
RA(O) report will be generated one year after injection).
* From initiation of work

7 REFERENCES

AECOM, 2013. *Longhorn Army Ammunition Plant Monthly Managers' Meeting Minutes* (LHAAP-16 Pre-Design Sampling Event Validated Data Attachment). November.

AECOM, 2014. *Final Installation-Wide Work Plan, Longhorn Army Ammunition Plant, Karnack, Texas*. July.

AECOM, 2016. *Final Updated Post-Screening Investigation Report for LHAAP-18/24, Burning Ground No. 3 and Unlined Evaporation Pond at Longhorn Army Ammunition Plant, Karnack, Texas*. February.

Banks Environmental Data, 2015. *Water Well Reportk Longhorn army Base (LHAAP), Karnack, TX*. June.

Environmental Security Technology Certification Program (ESTCP). 2009. *Comparative Demonstration of Active and Semi-Passive In Situ Bioremediation Approaches for Perchlorate-Impacted Groundwater (Longhorn Army Ammunition Plan).* Prepared by Geosyntec consultants. ESTCP Project ER-0219. January.

The Interstate Technology & Regulatory Council. 2011. Technical Regulatory Guidance, Permeable Reactive Barrier: Technology Update. June.

Jacobs Engineering Group, Inc. (Jacobs). 2000. *Final Remedial Investigation Report, Volume 1: Report for the Site 16 Landfill Remedial Investigation and Feasibility Study at the Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas.* Final . St. Louis, Missouri. October 2000.

Jacobs Engineering Group, Inc. (Jacobs). 2002. *Feasibility Study for Site 16, Longhorn Army Ammunition Plant, Karnack, Texas.* Final. Oak Ridge, Tennessee. March.

OHM Remediation Services Corporation (OHM). 1998. *Final Construction Complete Report, Interim Remedial Action, Landfills 12 and 16 Cap Construction, Longhorn Army Ammunition Plant (LHAAP), Karnack, Texas.* Prepared for the USACE. Houston, Texas. December.

US Army. 2016. *Record of Decision LHAAP-16 Landfill, Longhorn Army Ammunition Plant, Karnack, Texas.* Prepared by Shaw Environmental Inc. (Shaw), Houston, Texas. Tulsa, Oklahoma. To Be Determined.

United States Environmental Protection Agency (USEPA). 2004. *Performance Monitoring of MNA Remedies for VOCs in Ground Water*. EPA/600/R-04/027. National Risk Management Research Laboratory. April.

APPENDIX A: LHAAP-16 INSPECTION AND MAINTENANCE CHECKLIST

RAO Inspection and Maintenance Checklist

General Information	
Project Name	RAO Inspection and Maintenance, LHAAP-16 Landfill, 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 --------------------------------

Description		**Yes**	**No**	**N/A**	**Comments** (Attach photos/location sketches)	**Corrective Action** (Attach photos)
A. CAP Cover Surface						
A.1	Are there any significant cracks present?					
A.2.	Are there any damaged areas?					
A.3	Is there any ponded water present?					
A.4	Any other relevant observations?					
B. CAP Vegetation and Animal Burrows						
B.1	Are there signs of stressed/ dead vegetation?					
B.2	Are there any significant bare spots?					
B.3	Are deep-rooted plants present?					
B.4	Are there signs of animal burrows?					
B. 5	Any other relevant observations?					

Description		**Yes**	**No**	**N/A**	**Comments** (Attach photos/location sketches)	**Corrective Action** (Attach photos)
C.	**CAP Erosion and Drainage System**					
C.1	Is there any evidence of significant/ clearly visible erosion, settlement, or other deterioration?					
C.2	Are the drainage systems in poor condition?					
C.3	Is there excessive silting or debris clogging?					
C.4	Is there erosion of banks and slopes?					
C.5	Are there areas of choking by overgrown vegetation?					
C.7	Is there pooling of water in or along side a channel or berm?					
C.8	Any other relevant observations?					
D.	**Groundwater Monitoring Wells**					
D.1	Are the installed groundwater monitoring wells in poor condition?					
D.2	Are there any signs of damage, unusual wear, rust and corrosion, vandalism, unauthorized entry/use, or settlement?					
D.3	Is well cap and/or locking mechanism not properly functioning?					
D.4	Are the well heads and protective casings damaged?					
D.5	Is the well cleared of vegetation and accessible?					
D.6	Any other relevant observations?					

Description		**Yes**	**No**	**N/A**	**Comments** (Attach photos/location sketches)	**Corrective Action** (Attach photos)
E. Site Access Features						
E.1	Are the perimeter fence and gates damaged?					
E.2	Gate(s) damaged?					
E.3	Litter encountered within the area?					
E.4	Are the gate locks missing?					
E.4	Are signs to prevent unauthorized entry missing?					
E.5	Are the access roads in unusable or poor condition?					
E.6	Any other relevant observations?					
F. Concrete Aprons and Bollards						
F.1	Are there any significant cracks present?					
F.2	Are there any damaged areas?					
F.3	Any other relevant observations?					

APPENDIX B: CHEMICAL MANUFACURER'S LITERATURE

REDOX TECH, LLC
"Providing Innovative In Situ Soil and Groundwater Treatment"

Anaerobic BioChem (ABC$^{\circledR}$)
The “Green” Substrate

In 2003, Redox Tech introduced its proprietary formulation for anaerobic biodegradation of halogenated solvents in groundwater. The product, Anaerobic Biochem ABC$^{\circledR}$, is a patented mixture of lactates, fatty acids, alcohols and a phosphate buffer. ABC$^{\circledR}$ contains soluble lactic acid as well as slow- and long-term releasing components. Redox Tech was one of the first companies to recognize the importance of maintaining optimum pH, and for that reason, ABC has always had a phosphate buffer and other alkaline materials, when necessary, to maintain the optimal pH. The phosphate buffer provides phosphates, which are a micronutrient for bioremediation. In addition, the buffer helps to maintain the pH in a range that is best suited for microbial growth.

Since ABC’s introduction, millions of pounds of ABC have been used on hundreds of sites throughout the United States and even Europe. Over time, the “essential ingredients” have been slightly modified, but to our knowledge, ABC remains the only carbon substrate on the crowded market that is formulated specifically for each site’s own unique geochemistry, biology, and hydrogeology.

“Green” Before Green was Cool

Redox Tech is a niche environmental remediation contractor. Therefore, we have always felt obligated to be environmentally conscious. Before “green” was all the rave, Redox Tech utilized waste streams from green energy processes, such as ethanol and biodiesel production to formulate ABC. Only a small percentage of the components are “virgin” chemicals. The phosphate buffer provides phosphates, which are a micronutrient for bioremediation. In addition, the buffer helps to maintain the pH in a range that is best suited for microbial growth.

ABC$^{\circledR}$ Advantages

- WATER SOLUBLE - the biggest advantage with ABC is that it is completely soluble in water, even the long-lasting carbon. There is no need to emulsify our product, and thus no worry about an emulsion breaking. Also, because it is a water soluble product, the need for large volumes of “chase” water is eliminated. ABC is typically injected at about 15 to 25 weight percent mixed into about 100 to 200 gallons of water.
- LONG LASTING – ABC has C14 to C18 fatty acids that have been shown in the field to last over two years. Emulsified oils break down into C18 fatty acids through hydrolysis, so we are essentially using the same long-lived components of emulsified oils without having to emulsify or wait for hydrolysis to occur.
- NATURAL CO-SOLVENT – ABC, through a license with Oregon State University, adds ethyl lactate which is a “green” co-solvent. This helps dissolve the fatty acids, and it also serves as a solvent for sites that may have DNAPL, because the ethyl lactate solvates the DNAPL and promotes rapid treatment.
- GREEN – ABC is formulated with byproducts from “green” energy processes, so it is better for the environment.
- COST-COMPETITIVE – carbon substrates are becoming commodities, and ABC is priced accordingly. When all factors are considered, ABC is a great value.

REDOX TECH, LLC

Providing Innovative In Situ Soil & Groundwater Treatment

SITEMAP SEARCH FEEDBACK LOGIN REGISTRATION EMPLOYMENT DOWNLOADS

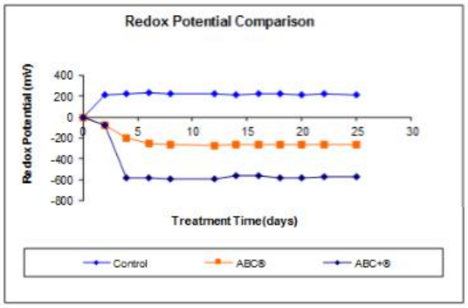
HOME ABOUT PRODUCTS SERVICES LOCATIONS NEWS COST ESTIMATES search...

Home Products ABC+

SATURDAY, 18 JUNE 2016

ABC+

ANAEROBIC BIOCHEM PLUS (ABC$^{®}$+)



ABC+ an enhanced version of our industry proven Anaerobic Biochem (ABC$^{®}$) formula, promoting both anaerobic biodegradation and reductive dechlorination of halogenated solvents in groundwater. This product, Anaerobic Biochem Plus (ABC+), is a mixture of our ABC$^{®}$ formula and Zero Valent Iron (ZVI). Formulated and mixed on a site-by-site basis, up to fifty percent (50%) by weight of ZVI can be added. ZVI has been proven and widely accepted as an effective in situ remediation technology of chlorinated solvents such as TCA, PCE, TCE, and daughter products. The degradation process using ZVI is an abiotic reductive dechlorination process occurring on the surface of the granular iron, with the iron acting as an electron donor.

The addition of ZVI to the ABC$^{®}$ mixture provides a number of advantages for enhanced reductive dechlorination (ERD). The ZVI will provide an immediate reduction. The ABC$^{®}$ will provide short-term and long-term nutrients to anaerobic growth, which also assists to create a reducing environment. ABC$^{®}$ contains soluble lactic acid and a phosphate buffer that provides phosphates, which are a micronutrient for bioremediation, and maintains the pH in a range that is best suited for microbial growth. In addition, the corrosion of iron metal yields ferrous iron and hydrogen, both of which are possible reducing agents. The hydrogen gas produced is also an excellent energy source for a wide variety of anaerobic bacteria.

The ABC$^{®}$ and ZVI are mixed with potable water and emplaced in the subsurface simultaneously. The dilution factor (i.e. water content) can be adjusted to achieve optimal dispersion and distribution based on site-specific parameters such as well spacing, permeability of the formation, and contaminant concentrations. The solution can be emplaced by a variety of techniques, including injection through wells or drill rods (for permeable geologic environments such as sands and fractured rock), hydraulic fracturing (for lower permeable environments such as silt and clay), and through soil blending (for all unconsolidated shallow depth applications less than 20 ft bgs). All of these techniques are part of Redox Tech's service offerings.

Benefits of ABC+ include:

- The presence of ZVI allows for the rapid and complete dechlorination of target compounds. Degradation rates using ZVI are several orders of magnitude greater than under natural conditions. As a consequence, the process does not result in the formation of daughter products other than ethane, ethane, and methane.
- ABC$^{®}$ will last up to 12-24 months in the subsurface environment due to slow releasing compounds, allowing for long-term anaerobic biodegradation
- By creating a reducing environment, ABC+ has the ability to provide long term immobilization of heavy metals (e.g. Ni, Zn, Hg, As)
- Does not require direct contact to act on target constituents.
- Does not divert groundwater flow. ABC is typically mixed at a 15% by weight solution with water. The viscosity of the solution is similar to sugar water and therefore does not measurably influence groundwater flow paths. Due to the relatively low volume of ZVI used, it does not measurably lower the bulk permeability of the formation
- Does not divert groundwater flow. ABC is typically mixed at a 15% by weight solution with water. The viscosity of the solution is similar to sugar water and therefore does not measurably influence groundwater flow paths. Due to the relatively low volume of ZVI used, it does not measurably lower the bulk permeability of the formation
- Patent protection: Redox Tech is licensed under Envirometal Technologies, Inc. (an Adventus Company) who is the current holder of patents pertaining to remediation using ZVI. Therefore, Redox Tech is able to market, sell, and emplace our ABC+ product. There is no patent infringement risk to the client in selecting the ABC+ approach.
- Price advantage. The cost of the ABC+ formula is an extremely competitive approach in relation to other ERD products on the market.

SUB MENU

ABC®

ABC+

ABC-OLÉ

OBC™

OBC+

NUBUFF

ZVI

ANAEROBIC BIOCHEM

Anaerobic Biochem (ABC$^{®}$), is a patented mixture of lactates, fatty acids, and a phosphate buffer that promotes anaerobic biodegradation of halogenated solvents in groundwater.

ABC$^{®}$ BROCHURE
Adobe PDF File
Click here

LATEST NEWS

Redox Tech Introduces NuBuff

Redox Tech, LLC Renews Comarketing Relationship with Carus Corporation

New Soil Blender Debuts in Cambridge, Mass

ABC® and ABC+ Applied at Over 350 Sites

Anaerobic BioChem (ABC®), The "Green" Substrate

- ABC+ produces a significantly lower redox potential of approximately –600 mV

Let Redox Tech help formulate an enhanced anaerobic program for your site today. For more information contact our Main Office.

ADDITIONAL INFO

BROCHURES & PRESENTATIONS	ABC+ Presentation (713.91 kB) ABC+ Presentation (58.6 kB)
CASE STUDIES	ABC+ TCA Case Study (101.76 kB)
OTHER DOCUMENTS	ABC versus Emulsified Oils (55.99 kB) Site Profile for Cost Estimate (27.11 kB) Florida Remediation Conference (2.23 MB) Lactate (webpage)

[1] ABC® is protected by US Patent 6,001,252.

SITEMAP SEARCH FEEDBACK LOGIN REGISTRATION EMPLOYMENT DOWNLOADS

SAFETY DATA SHEET
Anaerobic BioChem (ABC)

1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: **Anaerobic BioChem**
GENERAL USE: **Bioremediation of halogenated organics and metals**

MANUFACTURER:

Redox Tech, LLC
200 Quade Drive
Cary, NC 27513
919-678-0140

EMERGENCY TELEPHONE:

Within USA and Canada: 1-800-424-9300
+1 703-527-3887 (collect calls accepted)

2. HAZARDS IDENTIFICATION

EMERGENCY OVERVIEW: Product is generally recognized as safe. May cause irritation exposure to eyes. Long term contact to skin may cause some drying and minor irritation.

3. COMPOSITION INFORMATION ON INGREDIENTS

Proprietary mixture of fatty acids, glycerol, lactates and dipotassium phosphate.

4. FIRST AID MEASURES

EYES: Immediately flush with water for up to 15 minutes. If irritation persists, seek medical attention.

SKIN: Rinse with water. Irritation is unlikely, but if irritation occurs or persists, seek medical attention.

INGESTION: Generally safe to ingest but not recommended.

INHALATION: No first aid required.

5. FIRE FIGHTING MEASURES

EXTINGUISHING MEDIA: Deluge with water

FIRE/EXPLOSION HAZARDS: Product is combustible only at temperatures above 600C

FIRE FIGHTING PROCEDURES: Use flooding with plenty of water, carbon dioxide or other inert gasses. Wear full protective clothing and self-contained breathing apparatus. Deluging with water is the best method to control combustion of the product.

FLAMMABILITY LIMITS: non-combustible

SENSITIVITY TO IMPACT: non-sensitive

SENSITIVITY TO STATIC DISCHARGE: non-senstive

6. ACCIDENTAL RELEASE MEASURES

Confine and collect spill. Transfer to an approved DOT container and properly dispose. Do not dispose of or rinse material into sewer, stormwater or surface water. Discharge of product to surface water could result in depressed dissolved oxygen levels and subsequent biological impacts.

7. HANDLING AND STORAGE

HANDLING: Protective gloves and safety glasses are recommended.

STORAGE: Keep dry. Use first in, first out storage system. Keep container tightly closed when not in use. Avoid contamination of opened product. Avoid contact with reducing agents.

8. EXPOSURE CONTROLS – PERSONAL PROTECTION

EXPOSURE LIMITS

Chemical Name	ACGIH	OSHA	Supplier
ABC	**NA**	**NA**	**NA**

ENGINEERING CONTROLS: None are required

PERSONAL PROTECTIVE EQUIPMENT
EYES and FACE: Safety glasses recommended
RESPIRATOR: none necessary
PROTECTIVE CLOTHING: None necessary
GLOVES: rubber, latex or neoprene recommended but not required

9. PHYSICAL AND CHEMICAL PROPERTIES

Odor:	none to mild pleasant organic odor
Appearance:	clear to light amber
Auto-ignition Temperature	Non-combustible
Boiling Point	>600 C
Melting Point	NA
Density	1.15 gram/cc
Solubility	infinite
pH	7-9

10. STABILITY AND REACTIVITY

CONDITIONS TO AVOID: Do not contact with strong oxidizers
STABILITY: product is stable
POLYMERIZATION: will not occur
INCOMPATIBLE MATERIALS: strong oxidizers
HAZARDOUS DECOMPOSITION PRODUCTS:

11. TOXICOLOGICAL INFORMATION

Acute Toxicity
A: General Product Information
Acute exposure may cause mild skin and eye irritation.
B: Component Analysis - LD50/LC50

No information available.

B: Component Analysis - TDLo/LDLo
TDLo (Oral-Man) none

Carcinogenicity
A: General Product Information
No information available.
B: Component Carcinogenicity
Product is not listed by ACGIH, IARC, OSHA, NIOSH, or NTP.

Epidemiology
No information available.

Neurotoxicity
No information available.

12. ECOLOGICAL INFORMATION

Ecotoxicity
Discharge to water may cause depressed dissolved oxygen and subsequent ecological stresses
Environmental Fate
No potential for food chain concentration

13. DISPOSAL CONSIDERATIONS

DISPOSAL METHOD: Material is not considered hazardous, but consult with local, state and federal agencies prior to disposal to ensure all applicable laws are met.

14. TRANSPORT INFORMATION

NOTE: The shipping classification information in this section (Section 14) is meant as a guide to the overall classification of the product. However, transportation classifications may be subjectto change with changes in package size. Consult shipperrequirements under I.M.O., I.C.A.O. (I.A.T.A.) and 49 CFR to assure regulatory compliance.

US DOT Information
Shipping Name: Not Regulated
Hazard Class: Not Classified
UN/NA #: Not Classified
Packing Group:None
Required Label(s):None

50thEdition International Air Transport Association (IATA):
Not hazardous and not regulated

INTERNATIONAL MARITIME DANGEROUS GOODS (IMDG)

Material is not regulated under IMDG

15. REGULATORY INFORMATION

UNITED STATES

SARA TITLE III

SECTION 311 No Hazard for Immediate health Hazard
SECTION 312 No Threshold Quanitity
SECTION 313 Not listed

CERCLA NOT REGULATED UNDER CERCLA

TSCA NOT REGULATED UNDER TSCA

CANADA (WHIMS): NOT REGULATED

16. OTHER INFORMATION

HMIS:

Health	1
Flammability	0
Physical Hazard	0
Personal Protection	E

E: Safety Glasses, gloves

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

Submit Query

Electron Donor

Solutions for

Enhanced

Reductive Dechlorination

Interested in a Site Evaluation?

Let our Experienced Technical Service Team assist you with a no charge evaluation of your site.

Learn More

Nutrimens®

- Enhances Efficiency

- Minimizes Methane Production

Learn More

Tersus hosts Technology Lecture Series on groundwater remediation at multiple cities across the US

iSOC®

Accelerating Natural Attenuation of Petroluem Hydrocarbons

Additive injection and groundwater recirculation trailers available for short or long term lease.

TersOx™ - Inorganic Peroxygen for Enhanced Aerobic Bioremediation

RemBind designed to treat TPH, PAH, PFOS, PCBs, PCPs, and various pesticides

Formulating Surfactant Blends

Learn More

Leaders in Remediation of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

Sulfate Enhanced Bioremediation

Advancing the Science of Enhanced Reductive Dechlorination

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 polysorbate 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.), nitrates, perchlorate, energetics, and select immobilization of oxidized heavy metals.

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.

PackagingOptions

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

Chemical & Physical Properties

Parameter	**Typical Value**
Organic Carbon (% by wt.)	100
Refined and Bleached US Soybean Oil (% by wt.)	93
Slow Release Organics, food grade vegetable oil derived fatty acid esters (% by wt.)	7
Specific Gravity	0.92 to 0.93

1116 Colonial Club Rd

Wake Forest, NC 27587

Phone: +1 919 453 5577

info@tersusenv.com

Home / Tersus Online Store / Contact Us

Seminars / Short Courses / Webinar Schedule

Terms of Use / Privacy Policy / Site Map

Find Us on Social Media

Visit our Blog

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.

SAFETY DATA SHEET

Zero Valent Iron (ZVI)

Section 1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME:	**ZVI**
GENERAL USE:	Chemical reduction of halogenated organics and-or metals

MANUFACTURER:

Redox Tech, LLC
200 Quade Drive
Cary, NC 27513
919-678-0140

EMERGENCY TELEPHONE:

Within USA and Canada: 1-800-424-9300
+1 703-527-3887 (collect calls accepted)

Section 2. HAZARDS IDENTIFICATION

Physical state : Solid (Powder)

Emergency Overview : Potential dust explosion. Avoid contact with oxidizing agents.
USE WITH CARE.
Follow good industrial hygiene practice

Routes of entry : Demal contact. Eye contact. Inhalation. Ingestion.

Potential acute health effects
- Eyes : May cause eye irritation.
- Skin : No known significant effects or critical hazards
- Inhalation : May cause respiratory tract irritation.
- Ingestion : No known significant effects or critical hazards.

Potential Chronic Effects: : Carcinogenic effects: Not classified or listed by IARC, NTP, OSHA, EU AND ACGIH.
Mutagenic effects: Not available
: Teratogenic effects: Not Available

Medical conditions : Repeated exposure of the eyes to a low level of dust can produce eye irritation

Section 3. COMPOSITION INFORMATION ON INGREDIENTS

Greater than 98% Iron CAS# 7439-89-6
Contains carbon, sulfur and other metal impurities.

Section 4. FIRST AID MEASURES

Eye contact : Check for and remove any contact lenses. In case of contact, immediately flush eyes with plenty of water for at least 20 minutes. Get medical attention if irritation occurs

Skin contact : Wash with soap and water. Get medical attention if irritation occurs.

Inhalation : Move person to fresh air. Get medical attention if breathing difficulty persists

Ingestion	:	Do not induce vomiting. Never give anything by mouth to an unconscious person. Get medical attention if symptoms appear.
Notes to physician:		No specific antidote. Material is used as an iron supplement in food and vitamins. Treatment would be the same as for iron overdose.

Section 5. FIRE FIGHTING MEASURES

Flammability of the product	Generally non-flammable but susceptible to dust explosion.
Fire-fighting media	Use a fog nozzle to spray water.
Special protective Equipment for fire-fighters	Fire-fighters should wear appropriate protective equipment.
Special remarks on fire	As with any finely granulated product, a risk of dust explosion is present should the material be dispersed in air and exposed to a source of ignition. Fine powder can form flammable and explosive mixtures in air.

Section 6. ACCIDENTAL RELEASE MEASURES

In case of a significant release, take immediate efforts to minimize discharge to surface water (storm drains, streams, lakes, rivers, etc). If the release occurs in a closed area, take steps to improve ventilation. If improvement of ventilation is not possible, call the fire department. The material can be swept up and placed into approved storage containers. Do not use a vacuum to gather the material because this may result in dispersion of dust particles and increase the risk for a dust explosion.

Section 7. HANDLING AND STORAGE

The material should be stored in a cool, dry, environment. It is not recommended to store the material in the proximity of oxidants. When handling the product, wear a dusk mask, eye protection and gloves. The product should always be handled in a well ventilated environment.

Section 8. EXPOSURE CONTROLS – PERSONAL PROTECTION

Engineering controls	:	Use process enclosures, local exhaust ventilation or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fumes or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.
Personal protection		
Eyes	:	Safety eyewear complying with an approved standard should be used and selected based on the t ask being performed and the risks involved (avoid exposure to liquid splashed, mists, gases or dusts). Where there is a risk of exposure to high velocity particles safety glasses or face shield complying with an approved standard should be used to protect against impact. Where there is a risk of exposure to dusts, goggles should be used. Recommended: Safety glasses.
Respiratory	:	Dusk mask or respirator is recommended.
Hands	:	Gloves are recommended

Skin/Body : Personal protective equipment for the body should be selected based on the task being performed and the risks involved. Risk from dermal contact is minimal.

Section 9. PHYSICAL AND CHEMICAL PROPERTIES

Physical State	:	Solid (Powder)
Color	:	Gray
Melting/freezing point	:	1535ºC (2795ºF)
Specific gravity	:	7.88
Bulk density	:	2.4 to 3.2 g/cm³
Solubility	:	Insoluble in water

Section 10. STABILITY AND REACTIVITY

The product is reactive with oxidizers. Precautions should be taken not to store or contact the product with oxidizers.

Fine particles of this product (not widely found in this grade) have a potential for a dust explosion. The product should be handled in a well ventilated area where dust generation is minimized.

Section 11. TOXICOLOGICAL INFORMATION

Acute Effects	
Eyes	May cause eye irritation.
Skin	No known significant effects or critical hazards.
Inhalation	May cause respiratory tract irritation.
Ingestion	No known significant effects or critical hazards.
Chronic Health Effects:	Carcinogenic effects: Not classified or listed by IARC, NTP, OSHA, EU and ACGIH

Section 12. ECOLOGICAL INFORMATION

Will reduce dissolved oxygen levels in aquatic ecosystems. Direct discharge to surface water should be avoided.

Section 13. DISPOSAL CONSIDERATIONS

The generation of waste should be avoided or minimized to the extent practical. Disposal of this product, solutions and any by-products should be completed in an environmentally responsible manner that complies with all local, state and federal laws.

Section 14. TRANSPORT INFORMATION

Classification:

AND/ADR/TDG/DOT/IMDG/IATA: Not regulated.

Section 15. REGULATORY INFORMATION

This product is not regulated in the United States and Canada. The user should ensure this product is not regulated where used.

Section 16. OTHER INFORMATION

Health	0
Fire Hazard	2
Reactivity	1
Personal Protection	C

APPENDIX C: LHAAP-16 WELL LOGS

00084632

HOLE NO. 16WW41

BORING LOG	DIVISION Federal	INSTALLATION Longhorn AAP	SHEET 1 OF 1 SHEETS

1. PROJECT 117591
2. LOCATION Site 16
3. DRILLING AGENCY ETTL
4. HOLE NO. *(As shown on drawing title and file number)* 16WW41
5. NAME OF DRILLER Jonny Cook
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED 0 DEG. FROM VERT.
7. TOTAL DEPTH OF HOLE 50'
8. SIZE AND TYPE OF BIT 10" hollow stem
9. DATUM FOR ELEVATION SHOWN *(TBM or MSL)* MSL
10. MANUFACTURER'S DESIGNATION OF DRILL HSA 10" / mud Rotary
11. OVERBURDEN SAMPLES DISTURBED — UNDISTURBED —
12. TOTAL NUMBER CORE BOXES —
13. ELEVATION GROUND WATER
14. DATE HOLE STARTED 09/30/08 COMPLETED 11/05/08
15. ELEVATION TOP OF HOLE NA
16. TOTAL CORE RECOVERY FOR BORING 55 %
17. LOGGED BY QC

PID *(ppm)* a	DEPTH b	USCS c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	SAMPLE f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
			(LITHOLOGY SAME AS 16WW22).			
	45		No recovery			
0.0	46	SC	Sand, clay, fine-grained damp	10%		
	47	CL	Clay, sand, ~~[illegible]~~ soft, high plasticity, damp			
0.0	48	SC	Sand, clay, fine-grained, damp	100%		▼
	49					
	50	CL	Clay, sand, soft, high plasticity, moist			
			End of Boring			

RoWW41

WELL CONSTRUCTION DETAILS AND ABANDONMENT FORM

FIELD REPRESENTATIVE: Susan Oller / Shaw

DRILLING CONTRACTOR: ETTL

DRILLING TECHNIQUE: Mud Rotary

AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: LH16WW~~42~~ 41 ak 11/25/08

BOREHOLE DIAMETER: 10"

WELL IDENTIFICATION: LH16WW~~42~~41

WELL CONSTRUCTION START DATE: 11/04/08

WELL CONSTRUCTION COMPLETE DATE: 11/05/08

SCREEN MATERIAL: Sch40 PVC

SCREEN DIAMETER: 4"

STRATUM-SCREENED INTERVAL (FT): 10

CASING MATERIAL: Sch 40 PVC

CASING DIAMETER: 4"

TYPE OF FILTER PACK: Quartz Sand

GRADIATION: 20/40

AMOUNT OF FILTER PACK USED: 15 bgs

TYPE OF BENTONITE: Pellets

AMOUNT BENTONITE USED: 50 pounds

TYPE OF CEMENT: Portland

AMOUNT CEMENT USED: 11

GROUT MATERIALS USED: Bentonite

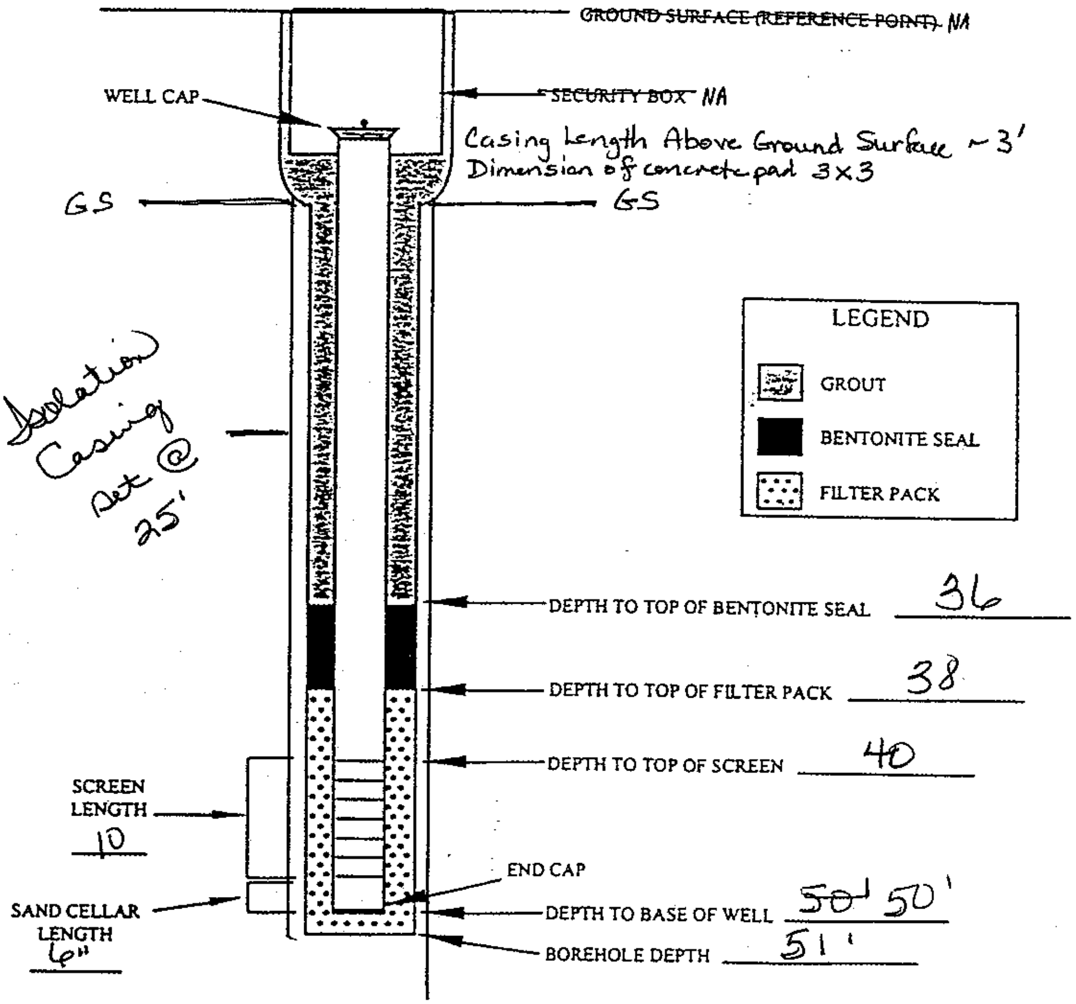
DIMENSIONS OF SECURITY BOX: NA

TYPE OF WELL CAP: Plugging cap

TYPE OF END CAP: Sch 40 PVC

COMMENTS:

SPECIAL CONDITIONS
(describe and draw)



Casing Length Above Ground Surface ~3'
Dimension of concrete pad 3x3

Isolation Casing set @ 25'

DEPTH TO TOP OF BENTONITE SEAL 36

DEPTH TO TOP OF FILTER PACK 38

DEPTH TO TOP OF SCREEN 40

SCREEN LENGTH 10

SAND CELLAR LENGTH 6"

DEPTH TO BASE OF WELL ~~50'~~ 50'

BOREHOLE DEPTH 51'

NOT TO SCALE

INSTALLED BY: ETTL

INSTALLATION OBSERVED BY: Susan Oller

DISCREPANCIES: NONE

HOLE NO. 16WW42

DRILLING LOG

DIVISION: FEDERAL

INSTALLATION: Longhorn

SHEET 1 OF SHEETS

1. PROJECT: LHAAP
2. LOCATION (Coordinates or Station): Karnack, Texas
3. DRILLING AGENCY: ETTL
4. HOLE NO. (As shown on drawing title and file number): 16WW42
5. NAME OF DRILLER: Doug Hinds
6. DIRECTION OF HOLE: ☑ VERTICAL ☐ INCLINED 0° DEG. FROM VERT.
7. THICKNESS OF OVERBURDEN
8. DEPTH DRILLED INTO ROCK: 0'
9. TOTAL DEPTH OF HOLE: 12'
10. SIZE AND TYPE OF BIT: 8" I.D. HSA
11. DATUM FOR ELEVATION SHOWN (TBM or MSL): MSL
12. MANUFACTURER'S DESIGNATION OF DRILL: 5500 CME
13. OVERBURDEN SAMPLES: DISTURBED ☐ UNDISTURBED ✓
14. TOTAL NUMBER CORE BOXES: NR
15. ELEVATION GROUND WATER: NA
16. DATE HOLE: STARTED 11/4/08 COMPLETED 11/4/08
17. ELEVATION TOP OF HOLE: NR
18. TOTAL CORE RECOVERY FOR BORING: NR %

Allen Willmore INSPECTOR

~~ELEVATION~~ PID a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
3.2			SAND CLAYEY, low plasticity, moist, soft, slightly organic, reddish-brown			
		SC				
2.1				100%		
3.6			SAND, SILTY, FINE-GRAINED PALE GRAY, MOIST, LOOSE			
	5	SM				
0.4						
		▼				
4.3			– BECOMES LIGHTER GRAY	100%		
9.1						
	10					
		CL	CLAY, SANDY, moist, soft, fine-grand	10%		
			END OF BORING @ 12'			

16WW42

WELL COMPLETION FORM (Stickup or Above Grade Completion Well)

FIELD REPRESENTATIVE: A. Willmore

DRILLING CONTRACTOR: ETTL

DRILLING TECHNIQUE: HSA

AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: 16WW42

BOREHOLE DIAMETER: (A) ~~16WW42 @~~ 10"

WELL IDENTIFICATION: 16WW42

WELL CONSTRUCTION START DATE: 11/4/08

WELL CONSTRUCTION COMPLETE DATE: 11/4/08

SCREEN MATERIAL: Sch. 40 PVC

SCREEN DIAMETER: 4"

STRATUM-SCREENED INTERVAL (FT): 10'

CASING MATERIAL: Sch. 40 PVC

CASING DIAMETER: 4"

TYPE OF FILTER PACK: Silica Sand

GRADIATION: 20/40

AMOUNT OF FILTER PACK USED:

TYPE OF BENTONITE: bentonite pellets

AMOUNT BENTONITE USED:

TYPE OF CEMENT: Portland

AMOUNT CEMENT USED:

GROUT MATERIALS USED: bentonite

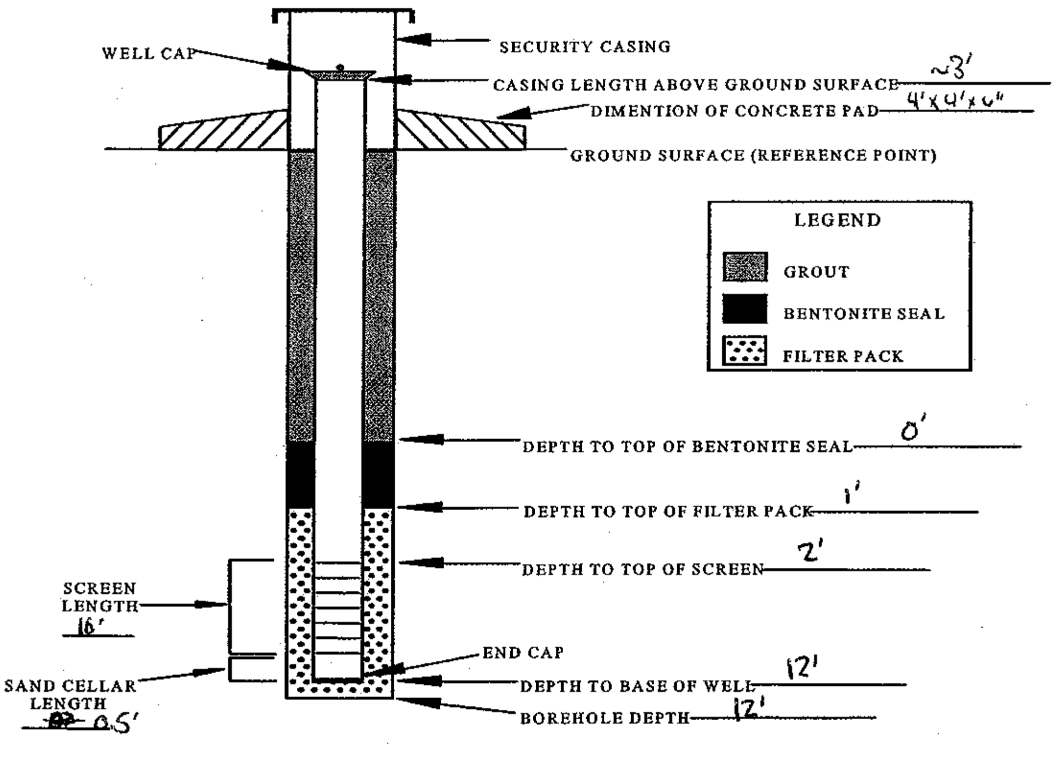
DIMENSIONS OF SECURITY CASING: 8" x 8" x 5'

TYPE OF WELL CAP: plugging cap

TYPE OF END CAP: Sch 40 pvc

COMMENTS:

SPECIAL CONDITIONS
(describe and draw)



CASING LENGTH ABOVE GROUND SURFACE ~3'

DIMENTION OF CONCRETE PAD 4' x 4' x 6"

GROUND SURFACE (REFERENCE POINT)

DEPTH TO TOP OF BENTONITE SEAL 0'

DEPTH TO TOP OF FILTER PACK 1'

DEPTH TO TOP OF SCREEN 2'

SCREEN LENGTH 10'

SAND CELLAR LENGTH ~~[illegible]~~ 0.5'

DEPTH TO BASE OF WELL 12'

BOREHOLE DEPTH 12'

NOT TO SCALE

INSTALLED BY: Billy Ragon

INSTALLATION OBSERVED BY: Allen Willmore

DISCREPANCIES: see log for 16DPT01 for lithology

00084636

HOLE NO. 16WW43

DRILLING LOG	**DIVISION** FEDERAL	**INSTALLATION** Longhorn	**SHEET** 1 **OF** 1 **SHEETS**

1. PROJECT LHAAP	**10. SIZE AND TYPE OF BIT** 8" I.D. HSA
2. LOCATION *(Coordinates or Station)* Karnack, Texas	**11. DATUM FOR ELEVATION SHOWN** *(TBM or MSL)* MSL
3. DRILLING AGENCY ETTL	**12. MANUFACTURER'S DESIGNATION OF DRILL** 5500 CME
4. HOLE NO. *(As shown on drawing title and file number)* WW 16WW43	**13. OVERBURDEN SAMPLES** DISTURBED / UNDISTURBED ✓
5. NAME OF DRILLER Doug Hinds	**14. TOTAL NUMBER CORE BOXES** NR
6. DIRECTION OF HOLE ☑ VERTICAL ☐ INCLINED 0° DEG. FROM VERT.	**15. ELEVATION GROUND WATER**
	16. DATE HOLE STARTED 11/4/08 COMPLETED 11/4/08
7. THICKNESS OF OVERBURDEN 12'	**17. ELEVATION TOP OF HOLE** NR
8. DEPTH DRILLED INTO ROCK 0'	**18. TOTAL CORE RECOVERY FOR BORING** NR %
9. TOTAL DEPTH OF HOLE 12'	Allen Willmore **INSPECTOR**

~~ELEVATION~~ PID a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
0.0			Sand, SILTY, fine-graind, dry, loose organic			
0.0				100%		
0.0						
	5	SM	← Increasing moisture			
0.0				100%		
0.0						
			- Become wet & pale brown			
0.0						
0.0	10			100%		
0.0		CL	CLAY, SOFT, MOIST, Low Plasticity			
			END OF BORING @ 12'			

16WW43

WELL COMPLETION FORM (Stickup or Above Grade Completion Well)

FIELD REPRESENTATIVE: A. Willmore
DRILLING CONTRACTOR: EMC

DRILLING TECHNIQUE: HSA
AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: 16WW43
BOREHOLE DIAMETER: 10"
WELL IDENTIFICATION: 16WW43

WELL CONSTRUCTION START DATE: 11/4/08
WELL CONSTRUCTION COMPLETE DATE: 11/4/08

SCREEN MATERIAL: sch. 40 PVC
SCREEN DIAMETER: 4"
STRATUM-SCREENED INTERVAL (FT): 10'

CASING MATERIAL: sch. 40 pvc
CASING DIAMETER: 4"

TYPE OF FILTER PACK: silica sand
GRADIATION: 20/40
AMOUNT OF FILTER PACK USED:

TYPE OF BENTONITE: bentonite pellets
AMOUNT BENTONITE USED:

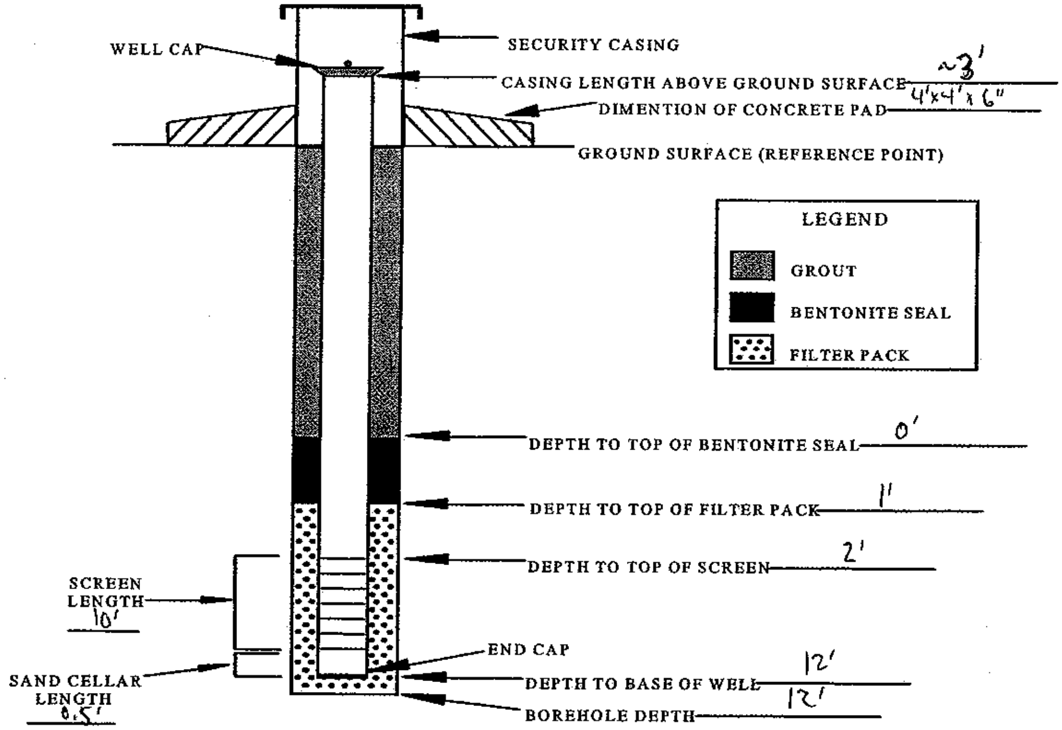
TYPE OF CEMENT: portland - cement
AMOUNT CEMENT USED:
GROUT MATERIALS USED: bentonite

DIMENSIONS OF SECURITY CASING: 8" x 8" x ~5'

TYPE OF WELL CAP: plugging cap
TYPE OF END CAP: sch. 40 PVC

COMMENTS:

SPECIAL CONDITIONS
(describe and draw)



CASING LENGTH ABOVE GROUND SURFACE ~3'
DIMENTION OF CONCRETE PAD 4'x4'x6"
GROUND SURFACE (REFERENCE POINT)
DEPTH TO TOP OF BENTONITE SEAL 0'
DEPTH TO TOP OF FILTER PACK 1'
DEPTH TO TOP OF SCREEN 2'
SCREEN LENGTH 10'
SAND CELLAR LENGTH 0.5'
DEPTH TO BASE OF WELL 12'
BOREHOLE DEPTH 12'

NOT TO SCALE

INSTALLED BY: Billy Ragon
INSTALLATION OBSERVED BY: Allen Willmore
DISCREPANCIES: See log for 16DPT02 for lithology

00084638

HOLE NO. 16WW44

BORING LOG	DIVISION Federal	INSTALLATION Longhorn AAP	SHEET 1 OF 3 SHEETS

1. PROJECT 117591
2. LOCATION Site 19
3. DRILLING AGENCY ETTL
4. HOLE NO. *(As shown on drawing title and file number)* Ola 11/5/08 ~~16W~~ 16WW44
5. NAME OF DRILLER Tommy Cook
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED 0 DEG. FROM VERT.
7. TOTAL DEPTH OF HOLE 30'
8. SIZE AND TYPE OF BIT 10" hollow stem
9. DATUM FOR ELEVATION SHOWN *(TBM or MSL)* MSL
10. MANUFACTURER'S DESIGNATION OF DRILL 10" HSA
11. OVERBURDEN SAMPLES DISTURBED — UNDISTURBED —
12. TOTAL NUMBER CORE BOXES —
13. ELEVATION GROUND WATER
14. DATE HOLE STARTED 11/05/08 COMPLETED 11/06/08
15. ELEVATION TOP OF HOLE
16. TOTAL CORE RECOVERY FOR BORING 100 %
17. LOGGED BY Ola QC KE

PID *(ppm)* a	DEPTH b	USCS c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	SAMPLE f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
	0–3					Top 3ft removed during clearing.
0.0 ~~100~~ Ola 11/5/08	3	CL	Clay, sand, dense, low plasticity, dry, brown			
	5	SC	Sand, clay, fine-grained dry, brown	100%		
	6	CL	Clay, sand, dense, low plasticity, dry, brown			
/ Ola 11/5/08	7	SC	Sand, clay, fine to very fine grained, dry, tan			
	8	CL	Clay, sand, very dense, dry, brown			
0.0	9	SC	Sand, clay, fine to medium-grained, dry brown	100%		
	11.7		- becomes more clayey			
	12					

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE	Hole No. 16WW44
PROJECT 117591	INSTALLATION Longhorn AAP	SHEET 2 OF 3 SHEETS

ELEVATION PID a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
	13					
	14					
	15					
0.0	16			100%		
	17					
	18					
	19	SC	Sand, clay, some silt, mottling dense, course-grained dry, gray			
	20					
0.0	21		Clay, sand, some silt, low plasticity dense, dry, brown	100%		
	22	CL	- becomes moist			
	23					
	24					
	25		- becomes clayey			
	26					
	27	SC	Sand, silt, clay, dense, course-grained wet, iron staining			▼

ENG FORM 1836—A PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT | HOLE NO.

DRILLING LOG (Cont Sheet)

ELEVATION TOP OF HOLE

Hole No. 16WW44

PROJECT 117591

INSTALLATION Longhorn AAP

SHEET 3 OF 3 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
0.0	28			100%		
	29	CL	Clay, sand, dense, no plasticity, dry			
	30		End of Boring			

ENG FORM 1836—A PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT

HOLE NO.

16WW44

WELL CONSTRUCTION DIAGRAM (Stickup or Above Grade Completion Well)

FIELD REPRESENTATIVE: Susan Allen

DRILLING CONTRACTOR: ETTL

DRILLING TECHNIQUE: Hollow Stem

AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: 16WW~~45~~ 44 Al 11/05/08

BOREHOLE DIAMETER: 10"

WELL IDENTIFICATION: 16WW~~45~~ 44

WELL CONSTRUCTION START DATE: 11/05/08

WELL CONSTRUCTION COMPLETE DATE: 11/06/08

SCREEN MATERIAL: Sch 40 PVC

SCREEN DIAMETER: 10"

STRATUM-SCREENED INTERVAL (FT): 10'

CASING MATERIAL: Sch 40 PVC

CASING DIAMETER: 10"

TYPE OF FILTER PACK: #2 Silica Sand

GRADATION: 20/40

AMOUNT OF FILTER PACK USED: 12

AMOUNT BENTONITE USED: 50 pounds

TYPE OF CEMENT: Portland

AMOUNT CEMENT USED: 12

GROUT MATERIALS USED: Bentonite

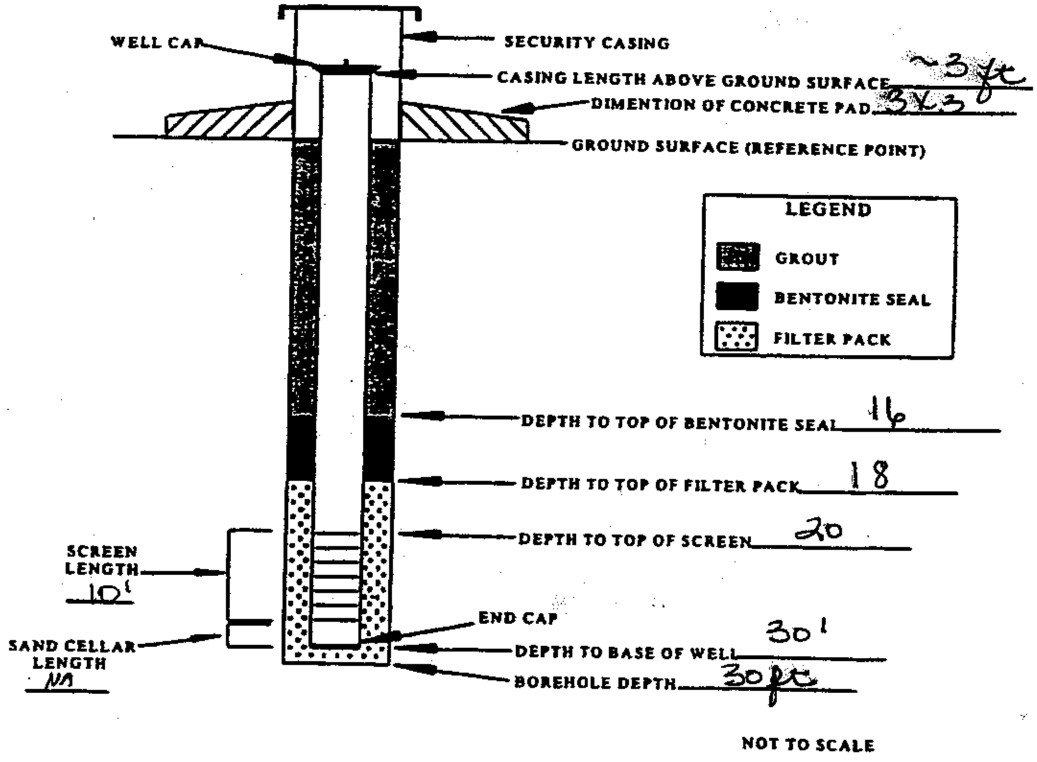
DIMENSIONS OF SECURITY BOX: 8"x8"x~3'

TYPE OF WELL CAP: plugging cap

TYPE OF END CAP: pvc

COMMENTS:

SPECIAL CONDITIONS (describe and draw)



CASING LENGTH ABOVE GROUND SURFACE ~3 ft

DIMENTION OF CONCRETE PAD 3x3

DEPTH TO TOP OF BENTONITE SEAL 16

DEPTH TO TOP OF FILTER PACK 18

DEPTH TO TOP OF SCREEN 20

SCREEN LENGTH 10'

SAND CELLAR LENGTH NA

DEPTH TO BASE OF WELL 30'

BOREHOLE DEPTH 30 ft

INSTALLED BY: Doug Hinds

INSTALLATION OBSERVED BY: Susan Allen

DISCREPANCIES: None

00084642

HOLE NO. 16WW45

BORING LOG	DIVISION Federal	INSTALLATION Longhorn AAP	SHEET 1 OF 4 SHEETS

1. PROJECT 117591
2. LOCATION Site 16
3. DRILLING AGENCY ETTL
4. HOLE NO. (As shown on drawing title and file number) 16WW45
5. NAME OF DRILLER Billy
6. DIRECTION OF HOLE ☒ VERTICAL ☐ INCLINED 0 DEG. FROM VERT.
7. TOTAL DEPTH OF HOLE 51'
8. SIZE AND TYPE OF BIT 10" hollow stem
9. DATUM FOR ELEVATION SHOWN (TBM or MSL) MSl
10. MANUFACTURER'S DESIGNATION OF DRILL HSA 10" / Mud Rotary
11. OVERBURDEN SAMPLES DISTURBED — UNDISTURBED —
12. TOTAL NUMBER CORE BOXES —
13. ELEVATION GROUND WATER —
14. DATE HOLE STARTED 11/5/08 COMPLETED 11/12/08
15. ELEVATION TOP OF HOLE NA
16. TOTAL CORE RECOVERY FOR BORING ≈80 %
17. LOGGED BY D. Oller QC KE

PID (ppm) a	DEPTH b	USCS c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	SAMPLE f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
0.0	3 4	CL	Clay, sand, dense, low plasticity, dry - becomes damp	100%		Top 3' removed during clearing
	5	SC	Sand, clay, fine-grained dry			
	6	CL	Clay, sand, dense, low plasticity, dry			
	7	SC	Sand, clay, fine to very fine, dry			
0.0	8	CL	11/05/08 ~~Sand~~, Clay, sand, very dense, dry, brown	100%		
	9 10 11	SC	Sand, clay, fine to med grained, dry brown - becomes more clayey			
0.0	12 13 14					-Allen Willmore Takes over Log ~~fr~~ from S. Oller

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE NA	Hole No. 16WW45
PROJECT 117591	INSTALLATION Longhorn AAP	SHEET 2 OF 4 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
0.0						
0.0	18	SC	Sand, clayey, mottling (little), dense poorly-sorted slightly, grav			
0.0	20	CL	CLAY, SILTY, LOW PLASTICITY, STIFF brown, dry -becomes damp -becomes harder			
	25		-becomes more clayey			
	27	SP	SAND, SILTY, MODERATELY DENSE, POORLY SORTED, WET, IRON STAINING, GRAY			

PROJECT	HOLE NO.

ENG FORM 1836—A PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE NA	Hole No. 16WW45
PROJECT 117591	INSTALLATION Longhorn AAP	SHEET 3 OF 4 SHEETS

~~ELEVATION~~ PID a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
						- Set isolation casing @ 30' bgs.
0.0	30 31	CL	Clay, sand, dense no plasticity, dry - becomes moist to wet	70%		- Allen takes over from Willmon
0.0	32 33	SC	Sand, clay, dense fine to very fine-grained, moist	80%		
	34		lignite			
0.0	35	SC	Sand, clay, dense course-grained, some iron staining damp	80%		
0.0	36 37	CL	Clay, sand, dense low plasticity	80%		
0.0	38 39	SC	Sand, clay, soft, fine-grained, moist, brownish gray			
0.0	40 41		- becomes clayey	80%		
0.0	42 43		- becomes less clayey			▼
	44					

ENG FORM 1836—A PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT

HOLE NO.

DRILLING LOG (Cont Sheet)

ELEVATION TOP OF HOLE NA

Hole No. 16WW45

PROJECT 117591

INSTALLATION Longhorn AAP

SHEET 4 OF 4 SHEETS

~~ELEVATION~~ P.ID	DEPTH	LEGEND	CLASSIFICATION OF MATERIALS (Description)	% CORE RECOVERY	BOX OR SAMPLE NO.	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant)
0.0	45					
	46		- organics (black)			
0.0	47					
	48					
0.0	49	C1	Clay, sand dense no plasticity dry			Well set @ 50' bgs.
	50					
	51		End of Boring			

ENG FORM 1836—PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT

HOLE NO.

16WW45

WELL CONSTRUCTION DIAGRAM (Stickup or Above Grade Completion Well)

FIELD REPRESENTATIVE: Susan Oller

DRILLING CONTRACTOR: ETTL

DRILLING TECHNIQUE: Mud Rotary

AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: 16WW45

BOREHOLE DIAMETER: 10"

WELL IDENTIFICATION: 16WW45

WELL CONSTRUCTION START DATE: 11/04/08

WELL CONSTRUCTION COMPLETE DATE: ~~11/05/08~~ SO 11/12/08 11/12/08

SCREEN MATERIAL: Sch 40 PVC

SCREEN DIAMETER: 10"

STRATUM-SCREENED INTERVAL (FT): 10'

CASING MATERIAL: Sch 40 PVC

CASING DIAMETER: 10"

TYPE OF FILTER PACK: Silica Sand

GRADATION: 20/40

AMOUNT OF FILTER PACK USED: 11

AMOUNT BENTONITE USED: 50 pounds

TYPE OF CEMENT: Portland

AMOUNT CEMENT USED: 12

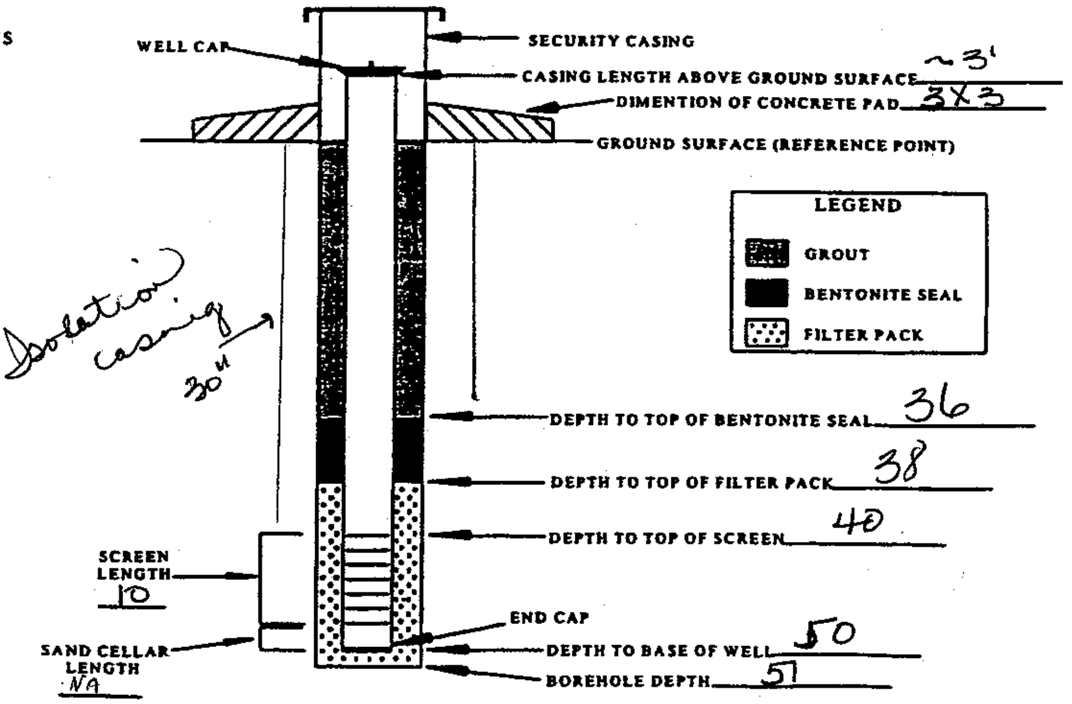
GROUT MATERIALS USED: Bentonite

DIMENSIONS OF SECURITY BOX: ~~3x~~ 8"x8"x3'

TYPE OF WELL CAP: Plugging Cap

TYPE OF END CAP: Sch 40 PVC

COMMENTS:



CASING LENGTH ABOVE GROUND SURFACE ~3'

DIMENTION OF CONCRETE PAD 3X3

DEPTH TO TOP OF BENTONITE SEAL 36

DEPTH TO TOP OF FILTER PACK 38

DEPTH TO TOP OF SCREEN 40

SCREEN LENGTH 10

SAND CELLAR LENGTH NA

DEPTH TO BASE OF WELL 50

BOREHOLE DEPTH 51

NOT TO SCALE

INSTALLED BY: ETTL

INSTALLATION OBSERVED BY: Susan Oller

DISCREPANCIES: None

HOLE NO. 16WW46

BORING LOG

DIVISION: Federal

INSTALLATION: Longhorn AAP

SHEET 1 OF 2 SHEETS

1. PROJECT: 117591
2. LOCATION: LHAAP-16
3. DRILLING AGENCY: ETTL
4. HOLE NO. *(As shown on drawing title and file number)*: 16 WW ~~44~~46 Olen 11/06/08
5. NAME OF DRILLER: Tommy Cook
6. DIRECTION OF HOLE: ☒ VERTICAL ☐ INCLINED 0 DEG. FROM VERT.
7. TOTAL DEPTH OF HOLE: 20'
8. SIZE AND TYPE OF BIT: 10" hollow stem
9. DATUM FOR ELEVATION SHOWN *(TBM or MSL)*: MSL
10. MANUFACTURER'S DESIGNATION OF DRILL: HSA 10"
11. OVERBURDEN SAMPLES: DISTURBED — UNDISTURBED —
12. TOTAL NUMBER CORE BOXES: —
13. ELEVATION GROUND WATER: ~17'
14. DATE HOLE: STARTED 11/06/08 COMPLETED 11/06/08
15. ELEVATION TOP OF HOLE: NA
16. TOTAL CORE RECOVERY FOR BORING: ~100 %
17. LOGGED BY: Olen QC

PID (ppm) a	DEPTH b	USCS c	CLASSIFICATION OF MATERIALS (Description) d	% CORE RECOVERY e	SAMPLE f	REMARKS (Drilling time, water loss, depth of weathering, etc., if significant) g
—	1 2 3 4			0%		
0.0	5 6 7		No Recovery	20%		13:45
	8 9		Clay, sand, dense, no plasticity, dry			
	10		Sand, clay, fine to med-grained, ~~moist~~ moist Olen 11/6/08			
0.0	11 12		— becomes more clayey	100% ~~80%~~ Olen 11/06/08		14:00

DRILLING LOG (Cont Sheet)	ELEVATION TOP OF HOLE NA	Hole No. 16WW46
PROJECT 117591	INSTALLATION Longhorn AAP	SHEET 2 OF 2 SHEETS

ELEVATION a	DEPTH b	LEGEND c	CLASSIFICATION OF MATERIALS *(Description)* d	% CORE RECOVERY e	BOX OR SAMPLE NO. f	REMARKS *(Drilling time, water loss, depth of weathering, etc., if significant)* g
	13 14		Clay, sand, dense, med to high plasticity, damp			
	15		Sand, clay, fine-grained, damp			
	16		Clay, sand, dense high plasticity damp			14:15
0.0	17		Sand, clay, fine-grained, damp	100%	▼	
	18 19		Clay, sand, dense, high plasticity, damp			
	20		End of Boring			

ENG FORM 1836–A PREVIOUS EDITIONS ARE OBSOLETE.
MAR 71

PROJECT

HOLE NO.

16WW46

WELL CONSTRUCTION DIAGRAM (Stickup or Above Grade Completion Well)

FIELD REPRESENTATIVE: Susan Oller

DRILLING CONTRACTOR: ETTL

DRILLING TECHNIQUE: hollow stem

AUGER SIZE AND TYPE: 10"

BOREHOLE IDENTIFICATION: 16WW46

BOREHOLE DIAMETER: 10"

WELL IDENTIFICATION: 16WW46

WELL CONSTRUCTION START DATE: 11/06/08

WELL CONSTRUCTION COMPLETE DATE: 11/06/08

SCREEN MATERIAL: Sch 40 PVC

SCREEN DIAMETER: 10"

STRATUM-SCREENED INTERVAL (FT): 10'

CASING MATERIAL: Sch 40 PVC

CASING DIAMETER: 10"

TYPE OF FILTER PACK: Silica Sand

GRADATION: 20/40

AMOUNT OF FILTER PACK USED: 12

AMOUNT BENTONITE USED: 50 pounds

TYPE OF CEMENT: Portland

AMOUNT CEMENT USED: 12

GROUT MATERIALS USED: Bentonite

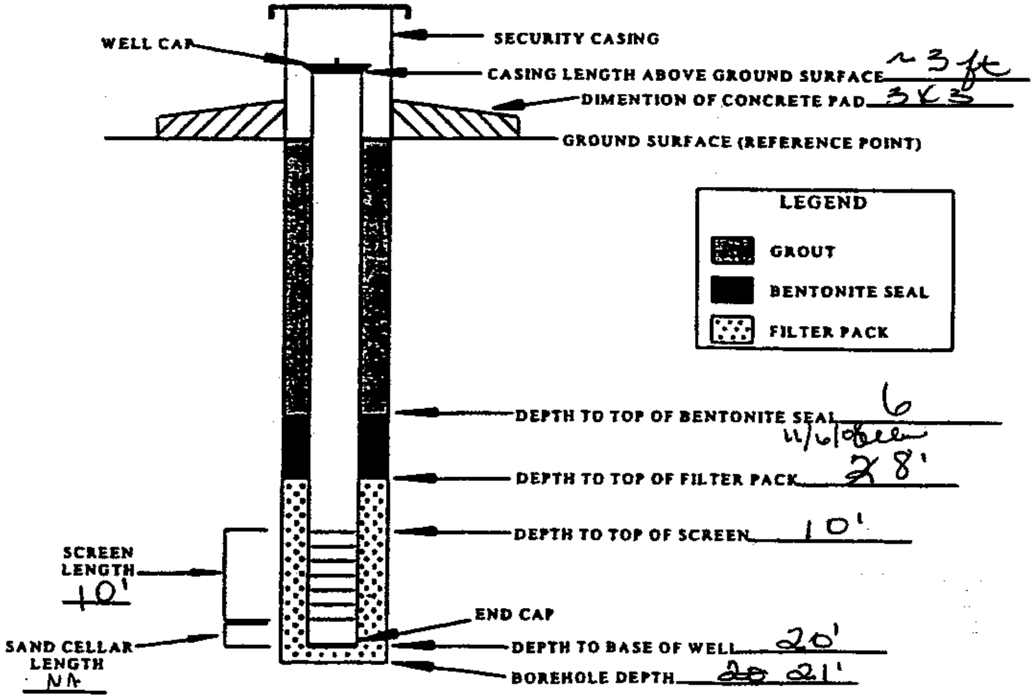
DIMENSIONS OF SECURITY BOX: 8"x8"x~3'

TYPE OF WELL CAP: plugging

TYPE OF END CAP: sch. 40 pvc.

COMMENTS:

SPECIAL CONDITIONS
(describe and draw)



CASING LENGTH ABOVE GROUND SURFACE ~3 ft

DIMENTION OF CONCRETE PAD 3x3

DEPTH TO TOP OF BENTONITE SEAL 6

11/6/08

DEPTH TO TOP OF FILTER PACK ~~2~~ 8'

DEPTH TO TOP OF SCREEN 10'

SCREEN LENGTH 10'

SAND CELLAR LENGTH NA

DEPTH TO BASE OF WELL 20'

BOREHOLE DEPTH ~~20~~ 21'

NOT TO SCALE

INSTALLED BY: Tommy Cook ETTL

INSTALLATION OBSERVED BY: Susan Oller

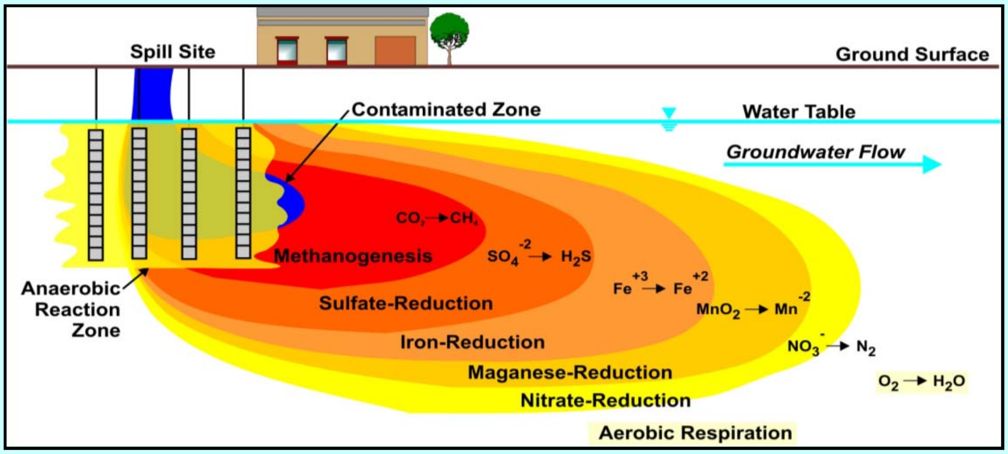
DISCREPANCIES: None

APPENDIX D: ESTCP SUBSTRATE CALCULATION SHEETS

SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table	Calculation Tables	Output Summary Table
TABLE S.1 - INPUT TABLE	Table S.2 - Substrate Calculations in Hydrogen	TABLE S.5 - OUTPUT TABLE
	Table S.3 - Hydrogen Produced by Common Substrates	PRINT SUMMARY TABLE
	Table S.4 - Estimated Substrate Requirements for	



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended soley for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: LHAAP 16

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions	**Values**	**Range**	**Units**	**User Notes**
Width (Perpendicular to predominant groundwater flow direction)	100	1-10,000	feet	Landfill Biobarrier #3
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet	
Saturated Thickness	10	1-100	feet	
Treatment Zone Cross Sectional Area	1000	--	ft^2	
Treatment Zone Volume	15,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	39,281	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	11,223	--	gallons	
Design Period of Performance	5.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	

2. Treatment Zone Hydrogeologic Properties

Total Porosity	35%	.05-50	percent	
Effective Porosity	10%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day	
Average Hydraulic Gradient	0.0025	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	29,016	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	

3. Native Electron Acceptors

A. Aqueous-Phase Native Electron Acceptors

Oxygen	1.6	0.01 to 10	mg/L	
Nitrate	0.10	0.1 to- 20	mg/L	
Sulfate	612	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	20.0	0.1 to 20	mg/L	

B. Solid-Phase Native Electron Acceptors

Manganese (IV) (estimated as the amount of Mn (II) produced)	20	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	5.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	--	mg/L	
Vinyl Chloride (VC)	0.100	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	1.000	--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)	100	-400 to +500	mV	
Temperature	22	5.0 to 30	ºC	
pH	6.0	4.0 to 10.0	su	
Alkalinity	200	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	2500	100 to 10,000	µs/cm	
Chloride	637	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as CaCO$_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions	**Values**	**Range**	**Units**
Width (Perpendicular to predominant groundwater flow direction)	100	1-10,000	feet
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet
Saturated Thickness	10	1-100	feet
Treatment Zone Cross Sectional Area	1000	--	ft^2
Treatment Zone Volume	15,000	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	11,223	--	gallons
Design Period of Performance	5.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties				
Total Porosity		0.35	.05-50	
Effective Porosity		0.10	.05-50	
Average Aquifer Hydraulic Conductivity		4.25	.01-1000	ft/day
Average Hydraulic Gradient		0.0025	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone		0.11	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone		38.8	--	ft/yr
Average Groundwater Flux through the Treatment Zon	0	29,016	--	gallons/year
Soil Bulk Density		1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)		0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.15	7.94	0.02	4
Nitrate (denitrification)	0.1	0.01	12.30	0.00	5
Sulfate	612	57.31	11.91	4.81	8
Carbon Dioxide (estimated as the amount of methane produced)	20.0	1.87	1.99	0.94	8
	Soluble Competing Electron Acceptor Demand (lb.)			**5.77**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	20.0	26.09	27.25	0.96	2
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	26.09	55.41	0.47	1
	Solid-Phase Competing Electron Acceptor Demand (lb.)			**1.43**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	0.47	21.73	0.02	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.05	24.05	0.00	4
Vinyl Chloride (VC)	0.100	0.01	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.09	12.33	0.01	6
	Total Soluble Contaminant Electron Acceptor Demand (lb.)			**0.03**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.27	0.43	21.73	0.02	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.02	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
	Total Sorbed Contaminant Electron Acceptor Demand (lb.)				**0.02**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.39	7.94	0.05	4
Nitrate (denitrification)	0.1	0.02	10.25	0.00	5
Sulfate	612	148.18	11.91	12.44	8
Carbon Dioxide (estimated as the amount of Methane produced)	20	4.84	1.99	2.43	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**14.9**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	1.21	21.73	0.06	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.12	24.05	0.01	4
Vinyl Chloride (VC)	0.100	0.02	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.24	12.33	0.02	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**0.08**	

Initial Hydrogen Requirement First Year (lb)	**22.3**
Total Life-Cycle Hydrogen Requirement (lb)	**82.3**

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**246.9**

6. Acronyns and Abbreviations

^oC =degrees celsius

μs/cm = microsiemens per centimeter

cm/day = centimeters per day

cm/sec = centimeters per second

ft^2 = square feet

ft/day = feet per day

ft/ft = foot per foot

ft/yr = feet per year

gm/cm^3 = grams per cubic centimeter

kg of CaCO3 per mg = kilograms of calcium carbonate per milligram

lb = pounds

meq/100 g = milliequivalents per 100 grams

mg/kg = milligrams per kilogram

mg/L = milligrams per liter

m/m = meters per meters

mV = millivolts

m/yr = meters per year

su = standard pH units

wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

RETURN TO COVER PAGE

Hydrogen Produced by Fermentation Reactions of Common Substrates

Substrate	**Molecular Formula**	**Substrate Molecular Weight (gm/mole)**	**Moles of Hydrogen Produced per Mole of Substrate**	**Ratio of Hydrogen Produced to Substrate (gm/gm)**	**Range of Moles H_2/Mole Substrate**
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4

Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 5

Substrate	**Design Factor**	**Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)**	**Substrate Product Required to Fulfill Hydrogen Demand (pounds)**	**Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)**	**Effective Substrate Concentration (mg/L)**
Lactic Acid	3.0	5,515	5,515	2.50E+09	4,228
Sodium Lactate Product (60 percent solution)	3.0	5,515	11,443	2.50E+09	4,228
Molasses (assuming 6 0	3.0	5,240	8,733	2.38E+09	4,017
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	5,517	6,896	2.50E+09	4,229
Ethanol Product (assuming 80% ethanol by weight)	3.0	2,821	3,526	1.28E+09	2,163
Whey (assuming 100% lactose)	3.0	3,807	5,439	1.73E+09	2,919
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	4,181	4,181	1.90E+09	2,564
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	2,147	2,147	9.74E+08	1,646
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	2,147	3,578	9.74E+08	1,646

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	100	feet	30	meters
Length (parallel to groundwater flow)	15	feet	4.6	meters
Saturated Thickness	10	feet	3.0	meters
Design Period of Performance	5	years	5	years

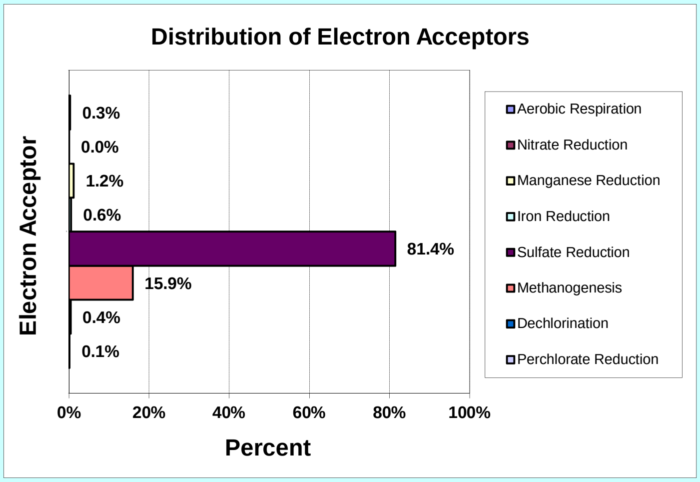
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.1	percent	0.1	percent
Average Aquifer Hydraulic Conductivity	4.25	ft/day	1.5E-03	cm/sec
Average Hydraulic Gradient	0.0025	ft/ft	0.0025	m/m
Average Groundwater Seepage Velocity	0.11	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	39	ft/yr	11.8	m/yr
Effective Treatment Zone Pore Volume	11,223	gallons	42,482	liters
Groundwater Flux (per year)	29,016	gallons/year	109,835	liters/year
Total Groundwater Volume Treated (over entire design period)	156,304	gallons total	591,657	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	0.263
Nitrate Reduction	0.0%	0.013
Sulfate Reduction	81.4%	67.021
Manganese Reduction	1.2%	0.957
Iron Reduction	0.6%	0.471
Methanogenesis	15.9%	13.108
Dechlorination	0.4%	0.352
Perchlorate Reduction	0.1%	0.106
Totals:	**100.00%**	**82.29**

Hydrogen demand in pounds/gallon:	5.26E-04
Hydrogen demand in grams per liter:	6.31E-02



4. Substrate Equivalents: Design Factor = 3.0

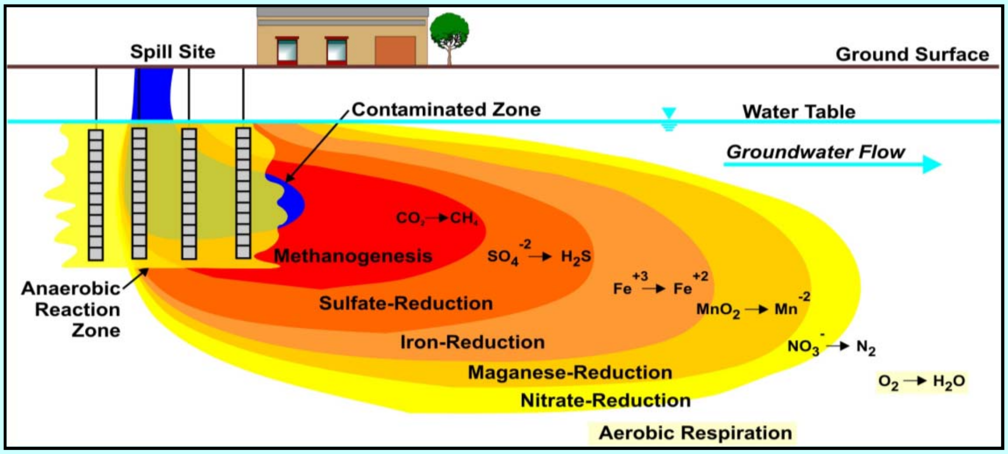
Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	11,443	1,040	4,228	as lactic acid
2. Molasses Product	8,733	728	4,017	as sucrose
3. Fructose Product	6,896	616	4,229	as fructose
4. Ethanol Product	3,526	511	2,163	as ethanol
5. Sweet Dry Whey (lactose)	5,439	sold by pound	2,919	as lactose
6. HRC®	4,181	sold by pound	2,564	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	2,147	275	1,646	as soybean oil
8. Emulsified Vegetable Oil	3,578	459	1,646	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table	**Calculation Tables**	**Output Summary Table**
TABLE S.1 - INPUT TABLE	Table S.2 - Substrate Calculations in Hydrogen	TABLE S.5 - OUTPUT TABLE
	Table S.3 - Hydrogen Produced by Common Substrates	PRINT SUMMARY TABLE
	Table S.4 - Estimated Substrate Requirements for	



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended soley for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: LHAAP 16

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	140	1-10,000	feet	Landfill Biobarrier #2
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet	
Saturated Thickness	11	1-100	feet	
Treatment Zone Cross Sectional Area	1540	--	ft^2	
Treatment Zone Volume	23,100	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	60,492	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	17,283	--	gallons	
Design Period of Performance	5.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	

2. Treatment Zone Hydrogeologic Properties

Total Porosity	35%	.05-50	percent	
Effective Porosity	10%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day	
Average Hydraulic Gradient	0.0025	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	44,685	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	

3. Native Electron Acceptors

A. Aqueous-Phase Native Electron Acceptors

Oxygen	1.6	0.01 to 10	mg/L	
Nitrate	0.10	0.1 to- 20	mg/L	
Sulfate	612	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	20.0	0.1 to 20	mg/L	

B. Solid-Phase Native Electron Acceptors

Manganese (IV) (estimated as the amount of Mn (II) produced)	20	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	5.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	--	mg/L	
Vinyl Chloride (VC)	0.100	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	1.000	--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)	100	-400 to +500	mV	
Temperature	22	5.0 to 30	ºC	
pH	6.0	4.0 to 10.0	su	
Alkalinity	200	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	2500	100 to 10,000	µs/cm	
Chloride	637	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions	Values	Range	Units
Width (Perpendicular to predominant groundwater flow direction)	140	1-10,000	feet
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet
Saturated Thickness	11	1-100	feet
Treatment Zone Cross Sectional Area	1540	--	ft^2
Treatment Zone Volume	23,100	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	17,283	--	gallons
Design Period of Performance	5.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties			
Total Porosity	0.35	.05-50	
Effective Porosity	0.10	.05-50	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day
Average Hydraulic Gradient	0.0025	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr
Average Groundwater Flux through the Treatment Zon 0	44,685	--	gallons/year
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)	0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.23	7.94	0.03	4
Nitrate (denitrification)	0.1	0.01	12.30	0.00	5
Sulfate	612	88.26	11.91	7.41	8
Carbon Dioxide (estimated as the amount of methane produced)	20.0	2.88	1.99	1.45	8
Soluble Competing Electron Acceptor Demand (lb.)				**8.89**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	20.0	40.17	27.25	1.47	2
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	40.17	55.41	0.72	1
Solid-Phase Competing Electron Acceptor Demand (lb.)				**2.20**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	0.72	21.73	0.03	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.07	24.05	0.00	4
Vinyl Chloride (VC)	0.100	0.01	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.14	12.33	0.01	6
Total Soluble Contaminant Electron Acceptor Demand (lb.)				**0.05**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.27	0.66	21.73	0.03	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.03	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)					**0.03**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.60	7.94	0.08	4
Nitrate (denitrification)	0.1	0.04	10.25	0.00	5
Sulfate	612	228.20	11.91	19.16	8
Carbon Dioxide (estimated as the amount of Methane produced)	20	7.46	1.99	3.75	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**23.0**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	1.86	21.73	0.09	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.19	24.05	0.01	4
Vinyl Chloride (VC)	0.100	0.04	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.37	12.33	0.03	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**0.12**	
Initial Hydrogen Requirement First Year (lb)				**34.3**	
Total Life-Cycle Hydrogen Requirement (lb)				**126.7**	

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**380.2**

6. Acronyns and Abbreviations

^{o}C =degrees celsius
μs/cm = microsiemens per centimeter
cm/day = centimeters per day
cm/sec = centimeters per second
ft^{2} = square feet
ft/day = feet per day
ft/ft = foot per foot
ft/yr = feet per year
gm/cm^{3} = grams per cubic centimeter
kg of CaCO3 per mg = kilograms of calcium carbonate per milligram
lb = pounds
meq/100 g = milliequivalents per 100 grams
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
m/m = meters per meters
mV = millivolts
m/yr = meters per year
su = standard pH units
wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

RETURN TO COVER PAGE

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H_2/Mole Substrate
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4
Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 5

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	3.0	8,494	8,494	3.85E+09	4,228
Sodium Lactate Product (60 percent solution)	3.0	8,494	17,622	3.85E+09	4,228
Molasses (assuming 6 0	3.0	8,069	13,448	3.66E+09	4,017
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	8,496	10,620	3.85E+09	4,229
Ethanol Product (assuming 80% ethanol by weight)	3.0	4,344	5,430	1.97E+09	2,163
Whey (assuming 100% lactose)	3.0	5,863	8,376	2.66E+09	2,919
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	6,439	6,439	2.92E+09	2,564
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	3,306	3,306	1.50E+09	1,646
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	3,306	5,510	1.50E+09	1,646

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	140	feet	43	meters
Length (parallel to groundwater flow)	15	feet	4.6	meters
Saturated Thickness	11	feet	3.4	meters
Design Period of Performance	5	years	5	years

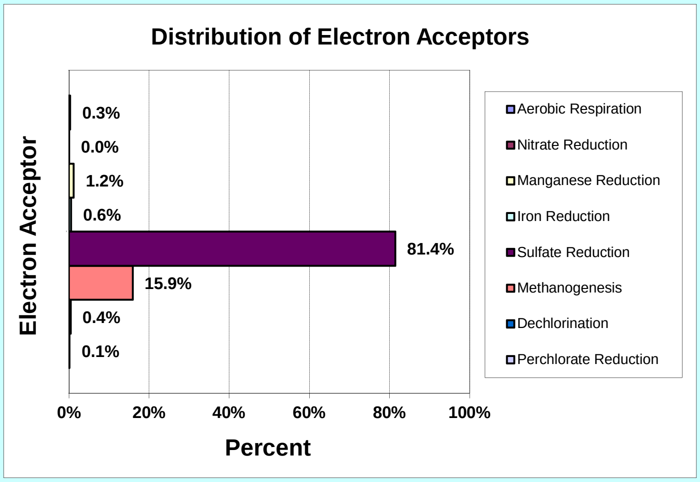
2. Treatment Zone Hydrogeologic Properties

	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.1	percent	0.1	percent
Average Aquifer Hydraulic Conductivity	4.25	ft/day	1.5E-03	cm/sec
Average Hydraulic Gradient	0.0025	ft/ft	0.0025	m/m
Average Groundwater Seepage Velocity	0.11	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	39	ft/yr	11.8	m/yr
Effective Treatment Zone Pore Volume	17,283	gallons	65,423	liters
Groundwater Flux (per year)	44,685	gallons/year	169,146	liters/year
Total Groundwater Volume Treated (over entire design period)	240,708	gallons total	911,152	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	0.405
Nitrate Reduction	0.0%	0.019
Sulfate Reduction	81.4%	103.212
Manganese Reduction	1.2%	1.474
Iron Reduction	0.6%	0.725
Methanogenesis	15.9%	20.187
Dechlorination	0.4%	0.542
Perchlorate Reduction	0.1%	0.163
Totals:	**100.00%**	**126.73**

Hydrogen demand in pounds/gallon:	5.26E-04
Hydrogen demand in grams per liter:	6.31E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	17,622	1,602	4,228	as lactic acid
2. Molasses Product	13,448	1,121	4,017	as sucrose
3. Fructose Product	10,620	948	4,229	as fructose
4. Ethanol Product	5,430	787	2,163	as ethanol
5. Sweet Dry Whey (lactose)	8,376	sold by pound	2,919	as lactose
6. HRC$^{®}$	6,439	sold by pound	2,564	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	3,306	424	1,646	as soybean oil
8. Emulsified Vegetable Oil	5,510	706	1,646	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

SUBSTRATE ESTIMATING TOOL FOR ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table

TABLE S.1 - INPUT TABLE

Calculation Tables

Table S.2 - Substrate Calculations in Hydrogen

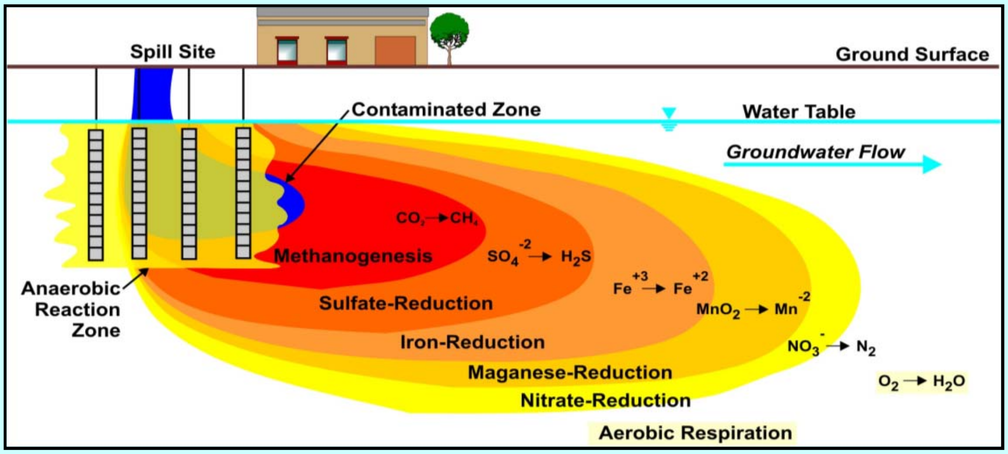
Table S.3 - Hydrogen Produced by Common Substrates

Table S.4 - Estimated Substrate Requirements for

Output Summary Table

TABLE S.5 - OUTPUT TABLE

PRINT SUMMARY TABLE



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended soley for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: LHAAP 16

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	270	1-10,000	feet	Landfill Biobarrier #1
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet	
Saturated Thickness	8	1-100	feet	
Treatment Zone Cross Sectional Area	2160	--	ft^2	
Treatment Zone Volume	32,400	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	84,846	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	24,242	--	gallons	
Design Period of Performance	5.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	

2. Treatment Zone Hydrogeologic Properties

Total Porosity	35%	.05-50	percent	
Effective Porosity	10%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day	
Average Hydraulic Gradient	0.0025	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	62,675	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	

3. Native Electron Acceptors

A. Aqueous-Phase Native Electron Acceptors

Oxygen	1.6	0.01 to 10	mg/L	
Nitrate	0.10	0.1 to- 20	mg/L	
Sulfate	612	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	20.0	0.1 to 20	mg/L	

B. Solid-Phase Native Electron Acceptors

Manganese (IV) (estimated as the amount of Mn (II) produced)	20	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	5.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	--	mg/L	
Vinyl Chloride (VC)	0.100	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	1.000	--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)	100	-400 to +500	mV	
Temperature	22	5.0 to 30	ºC	
pH	6.0	4.0 to 10.0	su	
Alkalinity	200	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	2500	100 to 10,000	µs/cm	
Chloride	637	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units
Width (Perpendicular to predominant groundwater flow direction)	270	1-10,000	feet
Length (Parallel to predominant groundwater flow)	15	1-1,000	feet
Saturated Thickness	8	1-100	feet
Treatment Zone Cross Sectional Area	2160	--	ft^2
Treatment Zone Volume	32,400	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	24,242	--	gallons
Design Period of Performance	5.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties

	Values	Range	Units
Total Porosity	0.35	.05-50	
Effective Porosity	0.10	.05-50	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day
Average Hydraulic Gradient	0.0025	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr
Average Groundwater Flux through the Treatment Zon 0	62,675	--	gallons/year
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)	0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.32	7.94	0.04	4
Nitrate (denitrification)	0.1	0.02	12.30	0.00	5
Sulfate	612	123.80	11.91	10.39	8
Carbon Dioxide (estimated as the amount of methane produced)	20.0	4.05	1.99	2.03	8
Soluble Competing Electron Acceptor Demand (lb.)				**12.47**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	20.0	56.34	27.25	2.07	2
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	56.34	55.41	1.02	1
Solid-Phase Competing Electron Acceptor Demand (lb.)				**3.08**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	1.01	21.73	0.05	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.10	24.05	0.00	4
Vinyl Chloride (VC)	0.100	0.02	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.20	12.33	0.02	6
Total Soluble Contaminant Electron Acceptor Demand (lb.)				**0.07**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.27	0.92	21.73	0.04	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.01	0.04	24.05	0.00	4
Vinyl Chloride (VC)	3.0	0.00	0.00	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)					**0.04**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	0.84	7.94	0.11	4
Nitrate (denitrification)	0.1	0.05	10.25	0.01	5
Sulfate	612	320.07	11.91	26.87	8
Carbon Dioxide (estimated as the amount of Methane produced)	20	10.46	1.99	5.26	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**32.2**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	5.000	2.61	21.73	0.12	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	0.500	0.26	24.05	0.01	4
Vinyl Chloride (VC)	0.100	0.05	31.00	0.00	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	1.000	0.52	12.33	0.04	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**0.18**	

Initial Hydrogen Requirement First Year (lb)	**48.1**
Total Life-Cycle Hydrogen Requirement (lb)	**177.7**

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**533.2**

6. Acronyns and Abbreviations

^{o}C =degrees celsius
μs/cm = microsiemens per centimeter
cm/day = centimeters per day
cm/sec = centimeters per second
ft^2 = square feet
ft/day = feet per day
ft/ft = foot per foot
ft/yr = feet per year
gm/cm^3 = grams per cubic centimeter
kg of CaCO3 per mg = kilograms of calcium carbonate per milligram
lb = pounds

meq/100 g = milliequivalents per 100 grams
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
m/m = meters per meters
mV = millivolts
m/yr = meters per year
su = standard pH units
wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

RETURN TO COVER PAGE

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H_2/Mole Substrate
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4
Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 5

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	3.0	11,913	11,913	5.40E+09	4,228
Sodium Lactate Product (60 percent solution)	3.0	11,913	24,716	5.40E+09	4,228
Molasses (assuming 6 0	3.0	11,318	18,863	5.13E+09	4,017
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	11,916	14,895	5.41E+09	4,229
Ethanol Product (assuming 80% ethanol by weight)	3.0	6,093	7,616	2.76E+09	2,163
Whey (assuming 100% lactose)	3.0	8,224	11,748	3.73E+09	2,919
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	9,031	9,031	4.10E+09	2,564
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	4,637	4,637	2.10E+09	1,646
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	4,637	7,729	2.10E+09	1,646

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	270	feet	82	meters
Length (parallel to groundwater flow)	15	feet	4.6	meters
Saturated Thickness	8	feet	2.4	meters
Design Period of Performance	5	years	5	years

2. Treatment Zone Hydrogeologic Properties

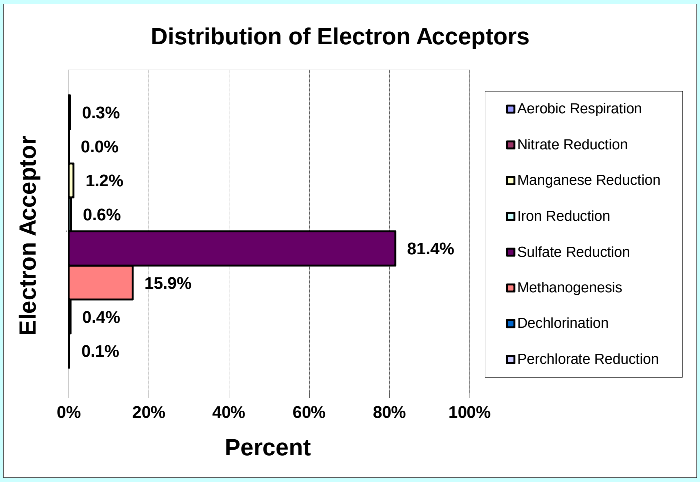
	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.1	percent	0.1	percent
Average Aquifer Hydraulic Conductivity	4.25	ft/day	1.5E-03	cm/sec
Average Hydraulic Gradient	0.0025	ft/ft	0.0025	m/m
Average Groundwater Seepage Velocity	0.11	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	39	ft/yr	11.8	m/yr
Effective Treatment Zone Pore Volume	24,242	gallons	91,762	liters
Groundwater Flux (per year)	62,675	gallons/year	237,243	liters/year
Total Groundwater Volume Treated (over entire design period)	337,616	gallons total	1,277,979	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	0.568
Nitrate Reduction	0.0%	0.027
Sulfate Reduction	81.4%	144.765
Manganese Reduction	1.2%	2.068
Iron Reduction	0.6%	1.017
Methanogenesis	15.9%	28.314
Dechlorination	0.4%	0.760
Perchlorate Reduction	0.1%	0.228
Totals:	**100.00%**	**177.75**

Hydrogen demand in pounds/gallon: 5.26E-04

Hydrogen demand in grams per liter: 6.31E-02



4. Substrate Equivalents: Design Factor = **3.0**

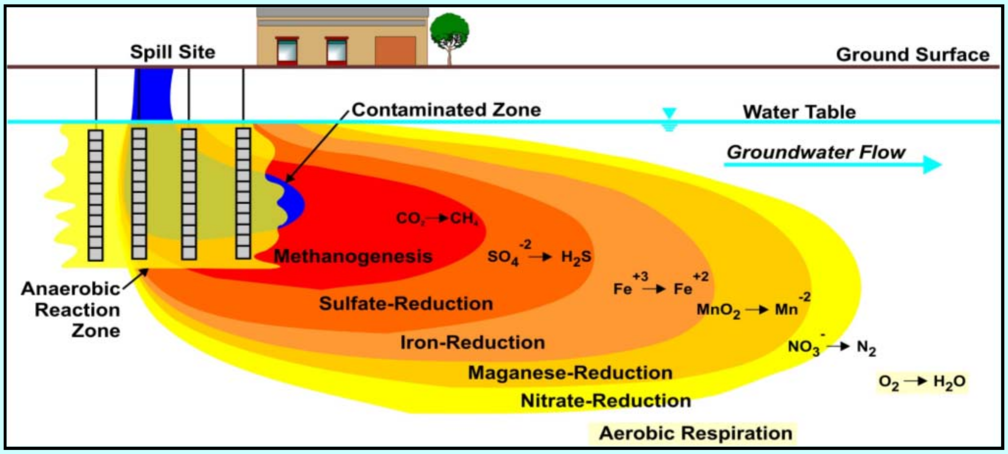
Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	24,716	2,247	4,228	as lactic acid
2. Molasses Product	18,863	1,572	4,017	as sucrose
3. Fructose Product	14,895	1,330	4,229	as fructose
4. Ethanol Product	7,616	1,104	2,163	as ethanol
5. Sweet Dry Whey (lactose)	11,748	sold by pound	2,919	as lactose
6. HRC$^{®}$	9,031	sold by pound	2,564	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	4,637	595	1,646	as soybean oil
8. Emulsified Vegetable Oil	7,729	991	1,646	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

SUBSTRATE ESTIMATING TOOL FOR
ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table	**Calculation Tables**	**Output Summary Table**
TABLE S.1 - INPUT TABLE	Table S.2 - Substrate Calculations in Hydrogen	TABLE S.5 - OUTPUT TABLE
	Table S.3 - Hydrogen Produced by Common Substrates	PRINT SUMMARY TABLE
	Table S.4 - Estimated Substrate Requirements for	



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended soley for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: LHAAP 16

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	280	1-10,000	feet	Mid Plume Intermediate ISB
Length (Parallel to predominant groundwater flow)	70	1-1,000	feet	
Saturated Thickness	20	1-100	feet	
Treatment Zone Cross Sectional Area	5600	--	ft^2	
Treatment Zone Volume	392,000	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	1,026,530	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	293,294	--	gallons	
Design Period of Performance	5.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	

2. Treatment Zone Hydrogeologic Properties

Total Porosity	35%	.05-50	percent	
Effective Porosity	10%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day	
Average Hydraulic Gradient	0.0025	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	162,490	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	

3. Native Electron Acceptors

A. Aqueous-Phase Native Electron Acceptors

Oxygen	1.6	0.01 to 10	mg/L	
Nitrate	0.10	0.1 to- 20	mg/L	
Sulfate	612	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	20.0	0.1 to 20	mg/L	

B. Solid-Phase Native Electron Acceptors

Manganese (IV) (estimated as the amount of Mn (II) produced)	20	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	4.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	6.000	--	mg/L	
Vinyl Chloride (VC)	1.000	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	0.400	--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)	100	-400 to +500	mV	
Temperature	22	5.0 to 30	ºC	
pH	6.0	4.0 to 10.0	su	
Alkalinity	200	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	2500	100 to 10,000	µs/cm	
Chloride	637	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as CaCO$_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions

	Values	Range	Units
Width (Perpendicular to predominant groundwater flow direction)	280	1-10,000	feet
Length (Parallel to predominant groundwater flow)	70	1-1,000	feet
Saturated Thickness	20	1-100	feet
Treatment Zone Cross Sectional Area	5600	--	ft^2
Treatment Zone Volume	392,000	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	293,294	--	gallons
Design Period of Performance	5.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties

	Values	Range	Units
Total Porosity	0.35	.05-50	
Effective Porosity	0.10	.05-50	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day
Average Hydraulic Gradient	0.0025	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr
Average Groundwater Flux through the Treatment Zon 0	162,490	--	gallons/year
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)	0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	3.92	7.94	0.49	4
Nitrate (denitrification)	0.1	0.24	12.30	0.02	5
Sulfate	612	1497.81	11.91	125.76	8
Carbon Dioxide (estimated as the amount of methane produced)	20.0	48.95	1.99	24.60	8
Soluble Competing Electron Acceptor Demand (lb.)				**150.87**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	20.0	184.54	27.25	6.77	2
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	184.54	55.41	3.33	1
Solid-Phase Competing Electron Acceptor Demand (lb.)				**10.10**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	4.000	9.79	21.73	0.45	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	6.000	14.68	24.05	0.61	4
Vinyl Chloride (VC)	1.000	2.45	31.00	0.08	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.400	0.98	12.33	0.08	6
Total Soluble Contaminant Electron Acceptor Demand (lb.)				**1.22**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	0.21	8.90	21.73	0.41	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.14	5.62	24.05	0.23	4
Vinyl Chloride (VC)	3.0	0.00	0.06	31.00	0.00	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)					**0.65**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	2.17	7.94	0.27	4
Nitrate (denitrification)	0.1	0.14	10.25	0.01	5
Sulfate	612	829.82	11.91	69.67	8
Carbon Dioxide (estimated as the amount of Methane produced)	20	27.12	1.99	13.63	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**83.6**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	4.000	5.42	21.73	0.25	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	6.000	8.14	24.05	0.34	4
Vinyl Chloride (VC)	1.000	1.36	31.00	0.04	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.400	0.54	12.33	0.04	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**0.68**	

Initial Hydrogen Requirement First Year (lb)	**247.1**
Total Life-Cycle Hydrogen Requirement (lb)	**584.2**

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**1,752.5**

6. Acronyns and Abbreviations

^{o}C =degrees celsius
μs/cm = microsiemens per centimeter
cm/day = centimeters per day
cm/sec = centimeters per second
ft^2 = square feet
ft/day = feet per day
ft/ft = foot per foot
ft/yr = feet per year
gm/cm^3 = grams per cubic centimeter
kg of CaCO3 per mg = kilograms of calcium carbonate per milligram
lb = pounds

meq/100 g = milliequivalents per 100 grams
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
m/m = meters per meters
mV = millivolts
m/yr = meters per year
su = standard pH units
wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

RETURN TO COVER PAGE

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H_2/Mole Substrate
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4
Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 5

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	3.0	39,152	39,152	1.78E+10	4,243
Sodium Lactate Product (60 percent solution)	3.0	39,152	81,229	1.78E+10	4,243
Molasses (assuming 6 0	3.0	37,194	61,990	1.69E+10	4,031
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	39,161	48,951	1.78E+10	4,244
Ethanol Product (assuming 80% ethanol by weight)	3.0	20,024	25,030	9.08E+09	2,170
Whey (assuming 100% lactose)	3.0	27,027	38,609	1.23E+10	2,929
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	29,680	29,680	1.35E+10	2,573
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	15,240	15,240	6.91E+09	1,652
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	15,240	25,399	6.91E+09	1,652

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	280	feet	85	meters
Length (parallel to groundwater flow)	70	feet	21.3	meters
Saturated Thickness	20	feet	6.1	meters
Design Period of Performance	5	years	5	years

2. Treatment Zone Hydrogeologic Properties

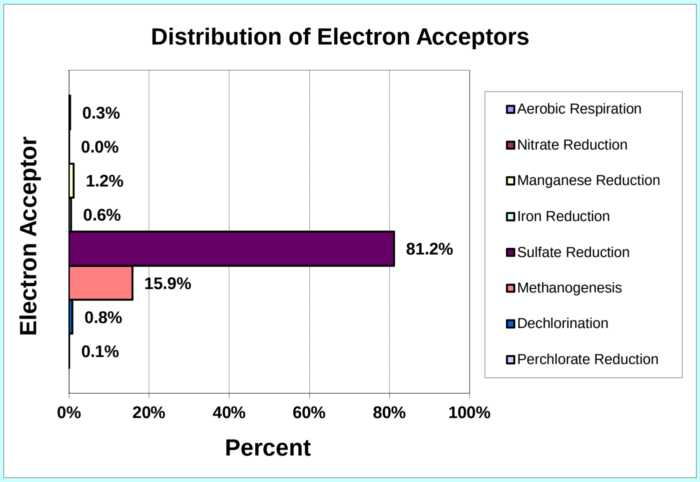
	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.1	percent	0.1	percent
Average Aquifer Hydraulic Conductivity	4.25	ft/day	1.5E-03	cm/sec
Average Hydraulic Gradient	0.0025	ft/ft	0.0025	m/m
Average Groundwater Seepage Velocity	0.11	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	39	ft/yr	11.8	m/yr
Effective Treatment Zone Pore Volume	293,294	gallons	1,110,209	liters
Groundwater Flux (per year)	162,490	gallons/year	615,076	liters/year
Total Groundwater Volume Treated (over entire design period)	1,105,746	gallons total	4,185,587	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	1.859
Nitrate Reduction	0.0%	0.086
Sulfate Reduction	81.2%	474.130
Manganese Reduction	1.2%	6.772
Iron Reduction	0.6%	3.330
Methanogenesis	15.9%	92.733
Dechlorination	0.8%	4.943
Perchlorate Reduction	0.1%	0.299
Totals:	**100.00%**	**584.15**

Hydrogen demand in pounds/gallon: 5.28E-04

Hydrogen demand in grams per liter: 6.33E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	81,229	7,384	4,243	as lactic acid
2. Molasses Product	61,990	5,166	4,031	as sucrose
3. Fructose Product	48,951	4,371	4,244	as fructose
4. Ethanol Product	25,030	3,627	2,170	as ethanol
5. Sweet Dry Whey (lactose)	38,609	sold by pound	2,929	as lactose
6. HRC®	29,680	sold by pound	2,573	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	15,240	1,954	1,652	as soybean oil
8. Emulsified Vegetable Oil	25,399	3,256	1,652	as soybean oil

Notes:
1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

SUBSTRATE ESTIMATING TOOL FOR
ENHANCED ANAEROBIC BIOREMEDIATION OF CHLORINATED SOLVENTS

Version 1.2
November 2010

Site Data Input Table

TABLE S.1 - INPUT TABLE

Calculation Tables

Table S.2 - Substrate Calculations in Hydrogen

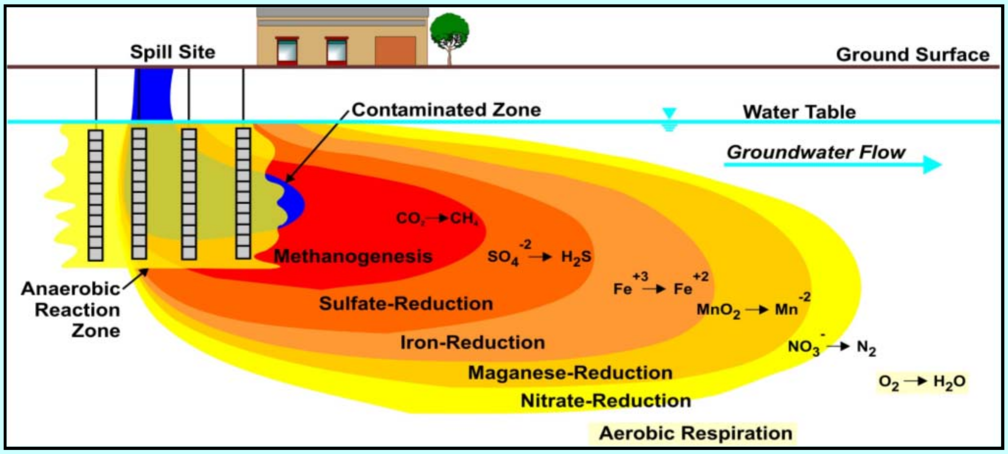
Table S.3 - Hydrogen Produced by Common Substrates

Table S.4 - Estimated Substrate Requirements for

Output Summary Table

TABLE S.5 - OUTPUT TABLE

PRINT SUMMARY TABLE



This Substrate Estimating Tool for Enhanced Anaerobic Bioremediation of Chlorinated Solvents has been developed by Parsons Infrastructure & Technology Group, Inc. (Parsons) for the Environmental Security Technology Certification Program (ESTCP). This substrate estimating tool is made available on an as-is basis without guarantee or warranty of any kind, express or implied. The United States Government, Parsons, the authors, and the reviewers accept no liability resulting from the use of this substrate estimating tool or its documentation; nor does the above warrant or otherwise represent in any way the accuracy, adequacy, efficacy, or applicability of the contents hereof. This substrate estimating tool is intended soley for educational and site screening purposes. Implementation of the substrate estimating tool and interpretation or use of the results provided in the model are the sole responsibility of the user. The substrate estimating tool is provided free of charge for everyone to use, but is not supported in any way by the United States Government or Parsons. Mention of trade names in this report is for information purposes only; no endorsement is implied.

Table S.1 Input for Substrate Requirements in Hydrogen Equivalents

Site Name: LHAAP 16

RETURN TO COVER PAGE

NOTE: Unshaded boxes are user input.

1. Treatment Zone Physical Dimensions

1. Treatment Zone Physical Dimensions	Values	Range	Units	User Notes
Width (Perpendicular to predominant groundwater flow direction)	280	1-10,000	feet	Mid Plume Shallow ISB
Length (Parallel to predominant groundwater flow)	192	1-1,000	feet	
Saturated Thickness	22	1-100	feet	
Treatment Zone Cross Sectional Area	6160	--	ft^2	
Treatment Zone Volume	1,182,720	--	ft^3	
Treatment Zone Total Pore Volume (total volume x total porosity)	3,097,189	--	gallons	
Treatment Zone Effective Pore Volume (total volume x effective porosity)	884,911	--	gallons	
Design Period of Performance	5.0	.5 to 5	year	
Design Factor (times the electron acceptor hydrogen demand)	3.0	2 to 20	unitless	

2. Treatment Zone Hydrogeologic Properties

Total Porosity	35%	.05-50	percent	
Effective Porosity	10%	.05-50	percent	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day	
Average Hydraulic Gradient	0.0025	0.0001-0.1	ft/ft	
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day	
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr	
Average Groundwater Discharge through the Treatment Zone	178,739	--	gallons/year	
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3	
Soil Fraction Organic Carbon (foc)	0.05%	0.01-10	percent	

3. Native Electron Acceptors

A. Aqueous-Phase Native Electron Acceptors

Oxygen	1.6	0.01 to 10	mg/L	
Nitrate	0.10	0.1 to- 20	mg/L	
Sulfate	612	10 to 5,000	mg/L	
Carbon Dioxide (estimated as the amount of Methane produced)	20.0	0.1 to 20	mg/L	

B. Solid-Phase Native Electron Acceptors

Manganese (IV) (estimated as the amount of Mn (II) produced)	20	0.1 to 20	mg/L	
Iron (III) (estimated as the amount of Fe (II) produced)	20	0.1 to 20	mg/L	

4. Contaminant Electron Acceptors

Tetrachloroethene (PCE)	0.000	--	mg/L	
Trichloroethene (TCE)	45.000	--	mg/L	
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	35.000	--	mg/L	
Vinyl Chloride (VC)	1.000	--	mg/L	
Carbon Tetrachloride (CT)	0.000	--	mg/L	
Trichloromethane (or chloroform) (CF)	0.000	--	mg/L	
Dichloromethane (or methylene chloride) (MC)	0.000	--	mg/L	
Chloromethane	0.000	--	mg/L	
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	--	mg/L	
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	--	mg/L	
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	--	mg/L	
Chloroethane	0.000	--	mg/L	
Perchlorate	0.002	--	mg/L	

5. Aquifer Geochemistry (Optional Screening Parameters)

A. Aqueous Geochemistry

Oxidation-Reduction Potential (ORP)	100	-400 to +500	mV	
Temperature	22	5.0 to 30	ºC	
pH	6.0	4.0 to 10.0	su	
Alkalinity	200	10 to 1,000	mg/L	
Total Dissolved Solids (TDS, or salinity)	100	10 to 1,000	mg/L	
Specific Conductivity	2500	100 to 10,000	µs/cm	
Chloride	637	10 to 10,000	mg/L	
Sulfide - Pre injection	0.0	0.1 to 100	mg/L	
Sulfide - Post injection	0.0	0.1 to 100	mg/L	

B. Aquifer Matrix

Total Iron	10000	200 to 20,000	mg/kg	
Cation Exchange Capacity	NA	1.0 to 10	meq/100 g	
Neutralization Potential	10.0%	1.0 to 100	Percent as $CaCO_3$	

NOTES:

Table S.2 Substrate Calculations in Hydrogen Equivalents

Site Name: **LHAAP 16**

RETURN TO COVER PAGE

NOTE: Open cells are user input.

1. Treatment Zone Physical Dimensions	**Values**	**Range**	**Units**
Width (Perpendicular to predominant groundwater flow direction)	280	1-10,000	feet
Length (Parallel to predominant groundwater flow)	192	1-1,000	feet
Saturated Thickness	22	1-100	feet
Treatment Zone Cross Sectional Area	6160	--	ft^2
Treatment Zone Volume	1,182,720	--	ft^3
Treatment Zone Effective Pore Volume (total volume x effective porosity)	884,911	--	gallons
Design Period of Performance	5.0	.5 to 5	year

2. Treatment Zone Hydrogeologic Properties			
Total Porosity	0.35	.05-50	
Effective Porosity	0.10	.05-50	
Average Aquifer Hydraulic Conductivity	4.25	.01-1000	ft/day
Average Hydraulic Gradient	0.0025	0.1-0.0001	ft/ft
Average Groundwater Seepage Velocity through the Treatment Zone	0.11	--	ft/day
Average Groundwater Seepage Velocity through the Treatment Zone	38.8	--	ft/yr
Average Groundwater Flux through the Treatment Zon 0	178,739	--	gallons/year
Soil Bulk Density	1.7	1.4-2.0	gm/cm^3
Soil Fraction Organic Carbon (foc)	0.0005	0.0001-0.1	

3. Initial Treatment Cell Electron-Acceptor Demand (one total pore volume)

A. Aqueous-Phase Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	11.81	7.94	1.49	4
Nitrate (denitrification)	0.1	0.74	12.30	0.06	5
Sulfate	612	4519.12	11.91	379.44	8
Carbon Dioxide (estimated as the amount of methane produced)	20.0	147.68	1.99	74.21	8
Soluble Competing Electron Acceptor Demand (lb.)				**455.20**	

B. Solid-Phase Native Electron Acceptors (Based on manganese and iron produced)	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Manganese (IV) (estimated as the amount of Mn (II) produced)	20.0	296.83	27.25	10.89	2
Iron (III) (estimated as the amount of Fe (II) produced)	20.0	296.83	55.41	5.36	1
Solid-Phase Competing Electron Acceptor Demand (lb.)				**16.25**	

C. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	45.000	332.29	21.73	15.29	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	35.000	258.45	24.05	10.75	4
Vinyl Chloride (VC)	1.000	7.38	31.00	0.24	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.002	0.01	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand (lb.)				**26.28**	

D. Sorbed Contaminant Electron Acceptors (Soil Concentration = Koc x foc x Cgw)	Koc (mL/g)	Soil Conc. (mg/kg)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	263	0.00	0.00	20.57	0.00	8
Trichloroethene (TCE)	107	2.41	302.25	21.73	13.91	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	45	0.79	98.87	24.05	4.11	4
Vinyl Chloride (VC)	3.0	0.00	0.19	31.00	0.01	2
Carbon Tetrachloride (CT)	224	0.00	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	63	0.00	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	28	0.00	0.00	21.06	0.00	4
Chloromethane	25	0.00	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	117	0.00	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	105	0.00	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	30	0.00	0.00	24.55	0.00	4
Chloroethane	3	0.00	0.00	32.00	0.00	2
Perchlorate	0.0	0.00	0.00	12.33	0.00	6
Total Sorbed Contaminant Electron Acceptor Demand (lb.)					**18.03**	

(continued)

Table S.2 Substrate Calculations in Hydrogen Equivalents

4. Treatment Cell Electron-Acceptor Flux (per year)

A. Soluble Native Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Oxygen	1.6	2.39	7.94	0.30	4
Nitrate (denitrification)	0.1	0.15	10.25	0.01	5
Sulfate	612	912.80	11.91	76.64	8
Carbon Dioxide (estimated as the amount of Methane produced)	20	29.83	1.99	14.99	8
Total Competing Electron Acceptor Demand Flux (lb/yr)				**91.9**	

B. Soluble Contaminant Electron Acceptors	Concentration (mg/L)	Mass (lb)	Stoichiometric demand (wt/wt h_2)	Hydrogen Demand (lb)	Electron Equivalents per Mole
Tetrachloroethene (PCE)	0.000	0.00	20.57	0.00	8
Trichloroethene (TCE)	45.000	67.12	21.73	3.09	6
Dichloroethene (cis-DCE, trans-DCE, and 1,1-DCE)	35.000	52.20	24.05	2.17	4
Vinyl Chloride (VC)	1.000	1.49	31.00	0.05	2
Carbon Tetrachloride (CT)	0.000	0.00	19.08	0.00	8
Trichloromethane (or chloroform) (CF)	0.000	0.00	19.74	0.00	6
Dichloromethane (or methylene chloride) (MC)	0.000	0.00	21.06	0.00	4
Chloromethane	0.000	0.00	25.04	0.00	2
Tetrachloroethane (1,1,1,2-PCA and 1,1,2,2-PCA)	0.000	0.00	20.82	0.00	8
Trichloroethane (1,1,1-TCA and 1,1,2-TCA)	0.000	0.00	22.06	0.00	6
Dichloroethane (1,1-DCA and 1,2-DCA)	0.000	0.00	24.55	0.00	4
Chloroethane	0.000	0.00	32.00	0.00	2
Perchlorate	0.002	0.00	12.33	0.00	6
Total Soluble Contaminant Electron Acceptor Demand Flux (lb/yr)				**5.31**	

Initial Hydrogen Requirement First Year (lb)	**613.0**
Total Life-Cycle Hydrogen Requirement (lb)	**1,002.0**

5. Design Factors

Microbial Efficiency Uncertainty Factor	2X - 4X
Methane and Solid-Phase Electron Acceptor Uncertainty	2X - 4X
Remedial Design Factor (e.g., Substrate Leaving Reaction Zone)	1X - 3X
Design Factor	**3.0**
Total Life-Cycle Hydrogen Requirement with Design Factor (lb)	**3,006.1**

6. Acronyns and Abbreviations

^{o}C =degrees celsius
μs/cm = microsiemens per centimeter
cm/day = centimeters per day
cm/sec = centimeters per second
ft^2 = square feet
ft/day = feet per day
ft/ft = foot per foot
ft/yr = feet per year
gm/cm^3 = grams per cubic centimeter
kg of CaCO3 per mg = kilograms of calcium carbonate per milligram
lb = pounds

meq/100 g = milliequivalents per 100 grams
mg/kg = milligrams per kilogram
mg/L = milligrams per liter
m/m = meters per meters
mV = millivolts
m/yr = meters per year
su = standard pH units
wt/wt H2 = concetration molecular hydrogen, weight per weight

Table S.3

Hydrogen Produced by Fermentation Reactions of Common Substrates

RETURN TO COVER PAGE

Substrate	Molecular Formula	Substrate Molecular Weight (gm/mole)	Moles of Hydrogen Produced per Mole of Substrate	Ratio of Hydrogen Produced to Substrate (gm/gm)	Range of Moles H_2/Mole Substrate
Lactic Acid	$C_3H_6O_3$	90.1	2	0.0448	**2 to 3**
Molasses (assuming 100% sucrose)	$C_{12}H_{22}O_{11}$	342	8	0.0471	**8 to 11**
High Fructose Corn Syrup (assuming 50% fructose and 50% glucose)	$C_6H_{12}O_6$	180	4	0.0448	**4 to 6**
Ethanol	C_2H_6O	46.1	2	0.0875	**2 to 6**
Whey (assuming 100% lactose)	$C_{12}H_{22}O_{11}$	342	11	0.0648	**11**
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	$C_{39}H_{56}O_{39}$	956	28	0.0590	**28**
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	$C_{18}H_{32}O_2$	281	16	0.1150	**16**

Table S.4
Estimated Substrate Requirements for Hydrogen Demand in Table S.3

Design Life (years): 5

Substrate	Design Factor	Pure Substrate Mass Required to Fulfill Hydrogen Demand (pounds)	Substrate Product Required to Fulfill Hydrogen Demand (pounds)	Substrate Mass Required to Fulfill Hydrogen Demand (milligrams)	Effective Substrate Concentration (mg/L)
Lactic Acid	3.0	67,159	67,159	3.05E+10	4,525
Sodium Lactate Product (60 percent solution)	3.0	67,159	139,335	3.05E+10	4,525
Molasses (assuming 6 0	3.0	63,801	106,334	2.89E+10	4,299
HFCS (assuming 40% fructose and 40% glucose by weight)	3.0	67,174	83,968	3.05E+10	4,526
Ethanol Product (assuming 80% ethanol by weight)	3.0	34,348	42,934	1.56E+10	2,314
Whey (assuming 100% lactose)	3.0	46,360	66,228	2.10E+10	3,123
HRC® (assumes 40% lactic acid and 40% glycerol by weight)	3.0	50,911	50,911	2.31E+10	2,744
Linoleic Acid (Soybean Oil, Corn Oil, Cotton Oil)	3.0	26,141	26,141	1.19E+10	1,761
Commercial Vegetable Oil Emulsion Product (60% oil by weight)	3.0	26,141	43,568	1.19E+10	1,761

NOTES: Sodium Lactate Product

1. Assumes sodium lactate product is 60 percent sodium lactate by weight.
2. Molecular weight of sodium lactate (CH_3-CHOH-COONa) = 112.06.
3. Molecular weight of lactic Acid ($C_6H_6O_3$) = 90.08 .
4. Therefore, sodium lactate product yields 48.4 (0.60 x (90.08/112.06)) percent by weight lactic acid.
5. Weight of sodium lactate product = 11.0 pounds per gallon.
6. Pounds per gallon of lactic acid in product = 1.323 x 8.33 lb/gal H2O x 0.60 x (90.08/112.06) = 5.31 lb/gal.

NOTES: Standard HRC Product

1. Assumes HRC product is 40 percent lactic acid and 40 percent glycerol by weight.
2. HRC® weighs approximately 9.18 pounds per gallon.

NOTES: Vegetable Oil Emulsion Product

1. Assumes emulsion product is 60 percent soybean oil by weight.
2. Soybean oil is 7.8 pounds per gallon.
3. Assumes specific gravity of emulsion product is 0.96.

Table S.5 Output for Substrate Requirements in Hydrogen Equivalents

RETURN TO COVER PAGE

Site Name: **LHAAP 16**

1. Treatment Zone Physical Dimensions

	Values	Units	Values	Units
Width (perpendicular to groundwater flow)	280	feet	85	meters
Length (parallel to groundwater flow)	192	feet	58.5	meters
Saturated Thickness	22	feet	6.7	meters
Design Period of Performance	5	years	5	years

2. Treatment Zone Hydrogeologic Properties

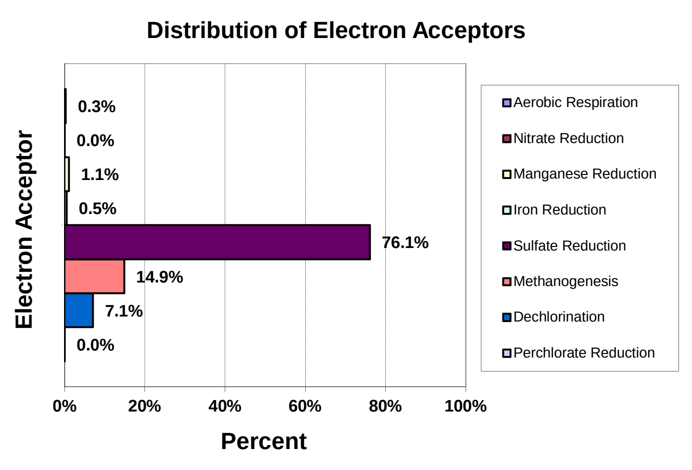
	Values	Units	Values	Units
Total Porosity	0.35	percent	0.35	percent
Effective Porosity	0.1	percent	0.1	percent
Average Aquifer Hydraulic Conductivity	4.25	ft/day	1.5E-03	cm/sec
Average Hydraulic Gradient	0.0025	ft/ft	0.0025	m/m
Average Groundwater Seepage Velocity	0.11	ft/day	3.2E+00	cm/day
Average Groundwater Seepage Velocity	39	ft/yr	11.8	m/yr
Effective Treatment Zone Pore Volume	884,911	gallons	3,349,659	liters
Groundwater Flux (per year)	178,739	gallons/year	676,583	liters/year
Total Groundwater Volume Treated (over entire design period)	1,778,608	gallons total	6,732,575	liters total

3. Distribution of Electron Acceptor Demand

	Percent of Total	Hydrogen Demand (lb)
Aerobic Respiration	0.3%	2.991
Nitrate Reduction	0.0%	0.133
Sulfate Reduction	76.1%	762.645
Manganese Reduction	1.1%	10.893
Iron Reduction	0.5%	5.357
Methanogenesis	14.9%	149.162
Dechlorination	7.1%	70.839
Perchlorate Reduction	0.0%	0.002
Totals:	**100.00%**	**1002.02**

Hydrogen demand in pounds/gallon: 5.63E-04

Hydrogen demand in grams per liter: 6.75E-02



4. Substrate Equivalents: Design Factor = 3.0

Product	Quantity (lb)	Quantity (gallons)	Effective Concentration (mg/L)	Effective concentration is for total volume of groundwater treated.
1. Sodium Lactate Product	139,335	12,667	4,525	as lactic acid
2. Molasses Product	106,334	8,861	4,299	as sucrose
3. Fructose Product	83,968	7,497	4,526	as fructose
4. Ethanol Product	42,934	6,222	2,314	as ethanol
5. Sweet Dry Whey (lactose)	66,228	sold by pound	3,123	as lactose
6. HRC®	50,911	sold by pound	2,744	as 40% lactic acid/40% glycerol
7. Linoleic Acid (Soybean Oil)	26,141	3,351	1,761	as soybean oil
8. Emulsified Vegetable Oil	43,568	5,586	1,761	as soybean oil

Notes:

1. Quantity assumes product is 60% sodium lactate by weight.
2. Quantity assumes product is 60% sucrose by weight and weighs 12 pounds per gallon.
3. Quantity assumes product is 80% fructose by weight and weighs 11.2 pounds per gallon.
4. Quantity assumes product is 80% ethanol by weight and weighs 6.9 pounds per gallon.
5. Quantity assumes product is 70% lactose by weight.
6. Quantity assumes HRC® is 40% lactic acid and 40% glycerol by weight.
7. Quantity of neat soybean oil, corn oil, or canola oil.
8. Quantity assumes commercial product is 60% soybean oil by weight.

APPENDIX E: ANNUAL LUC COMPLIANCE DOCUMENTATION FORM

Annual Land Use Control Compliance Inspection Form

In accordance with the Remedial Design dated ________________ for LHAAP-16 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;
- Landfill integrity - preserve the integrity of the landfill cap and restrict intrusive activities (e.g., digging) that would degrade or alter the cap;
- 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 landfill intrusive activities (e.g., digging) that would degrade or alter the landfill cap; maintenance of vegetative cover and repair of soil subsidence or erosion areas on the cap;
- 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.