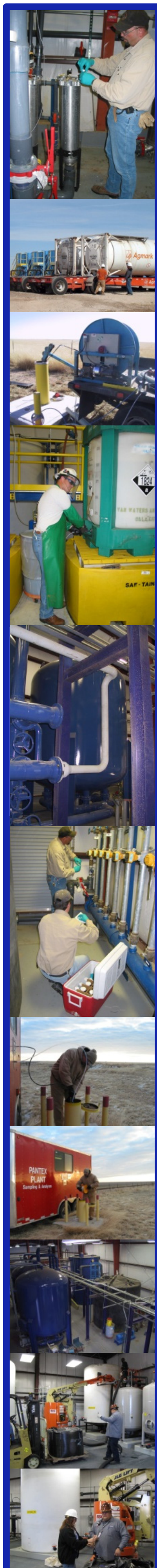

PANTEX QUARTERLY PROGRESS REPORT

Remedial Action Progress

2nd Quarter 2018

In support of Hazardous Waste Permit #50284 and

Pantex Plant Interagency Agreement

September 2018

Pantex Plant

FM 2373 and U.S. Highway 60

P.O. Box 30030

Amarillo, TX 79120

UNCLASSIFIED

CERTIFICATION STATEMENT

2nd Quarter 2018 Remedial Action Progress Report
Pantex Plant, September 2018

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision according to a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

James C. Cantwell — Date: 09/24/2018
Director
Environmental and Safety Programs
Consolidated Nuclear Security, LLC

Quarterly Progress Report
2nd Quarter 2018
in Support of Hazardous Waste Permit #50284
and Pantex Plant Interagency Agreement
for the Pantex Plant, Amarillo, Texas
September 2018

Prepared by
Consolidated Nuclear Security, LLC
Management and Operating Contractor
for the
Pantex Plant and Y-12 National Security Complex
under Contract No. DE-NA0001942
with the
U.S. Department of Energy
National Nuclear Security Administration

In accordance with 30 TAC §335.553 (g), this report has been prepared and sealed by an appropriately qualified licensed professional engineer or licensed professional geoscientist.

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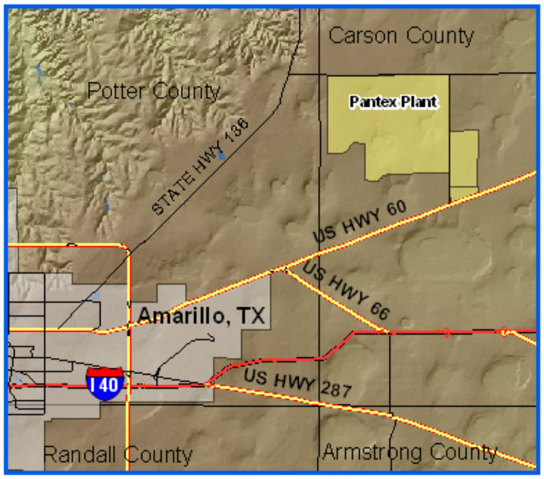
List of Acronyms

µg/L	micrograms per liter
CatOX	catalytic oxidation
COC	contaminant of concern
Cr(VI)	hexavalent chromium
DCE	dichloroethene
DHC	*Dehalococcoides* spp.
DNT4A	4-amino-2,6-dinitrotoluene
DO	dissolved oxygen
FGZ	fine-grained zone
FYR	five-year review
GWPS	groundwater protection standard
HE	high explosive
HW-50284	Hazardous Waste Permit #50284
IAG	Interagency Agreement
ISPM	in situ performance monitoring
ISB	in situ bioremediation
lb	pound
Mgal	million gallons
mV	millivolts
NAPL	non-aqueous phase liquid
ORP	oxidation-reduction potential
P1PTS	Playa 1 Pump and Treat System
PFM	passive flux meter
PID	photoionization detector
PQL	practical quantitation limit
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
SAP	sampling and analysis plan
SEPTS	Southeast Pump and Treat System
SVE	soil vapor extraction
SWMU	Solid Waste Management Units
TCE	trichloroethene
TNT	trinitrotoluene
VOC	volatile organic compound
WWTF	wastewater treatment facility

Introduction



The Pantex Plant, located in the Texas Panhandle 17 miles northeast of Amarillo, has implemented a response action to remediate perched groundwater and soils. Two types of systems have been installed for the groundwater response action: pump and treat systems in two areas and in situ bioremediation (ISB) systems in two areas. A soil vapor extraction (SVE) system has been installed to remediate volatile organic compounds (VOCs) in soils at the Burning Ground area. This quarterly report addresses progress achieved through implementation of the remedial actions for 2nd quarter 2018.

This report provides an intermediate data summary for response action systems throughout the year. More intensive data reporting is included in the annual progress reports. The quarterly progress reports address three of the five evaluations included in the annual progress reports: response action effectiveness, uncertainty management, and early detection. The reports provide required information from Hazardous Waste Permit #50284 (HW-50284) CP Table VII and the Pantex Interagency Agreement (IAG).

Maps of the plumes, remedial action systems, sampling locations, and system wells are provided in Appendix A. Graphs of operation and flow rates for the pump and treat systems are provided in Appendix B. Graphs of important parameters for the ISB treatment zone and downgradient wells are provided in Appendix C.

Response Action Effectiveness

This quarterly progress report focuses on specific criteria for the pump and treat systems, ISB systems, and a small-scale SVE system. System operation, mass removal, and evaluation of effluent in reference to established operational goals are reported for the pump and treat systems. For the ISB systems, this report evaluates geochemical conditions and availability of food source in the treatment zone and reduction of concentrations of contaminants of concern (COCs) in downgradient performance monitoring wells to evaluate whether the treatment zone is working effectively. System operation, mass removal, and effluent photoionization detector (PID) readings are evaluated for the SVE system.

Pump and Treat Systems

The groundwater remedial action at the Pantex Plant includes two pump and treat systems: Southeast Pump and Treat System (SEPTS) and Playa 1 Pump and Treat System (P1PTS). The pump and treat systems are designed to extract water and remove contaminant mass from the water before the effluent is beneficially used by the wastewater treatment facility (WWTF) and irrigation system, for general Plant needs, or for amendment injections at the ISB systems. The systems were also designed to remove water from the perched aquifer to reduce saturated thickness. This reduction in saturated thickness reduces migration of contaminants both vertically and horizontally so that natural breakdown processes can occur over time. Reducing migration provides protection for the underlying High Plains Aquifer (also known as and referred to herein as the Ogallala Aquifer). SEPTS has the capability to inject the treated water back into the perched aquifer when beneficial use is not possible. Operational priorities for the pump and treat systems emphasize beneficial use of water.

Pump and Treat System
2nd Quarter 2018 Operation

Playa 1 Pump and Treat System (P1PTS)	
Days Operated	89
% Operation Time	97%
Volume Water Treated (Mgal)	19.7
HE Mass Removal (lbs)	10.9
Beneficial Use of Water	0
Southeast Pump and Treat System (SEPTS)	
Days Operated	86
% Operation Time	91%
Volume Water Treated (Mgal)	18.9
HE Mass Removal (lbs)	64.1
Chromium Mass Removal (lbs)	22.9
Beneficial Use of Water	<1%

Value below operational goals

SEPTS and P1PTS operation and throughput continued to be impacted in the 2nd quarter by a filter bank break at the irrigation system that occurred in late June 2017. Due to the severity of the break, engineering evaluation, contracting, and major repairs are required, to restore the irrigation system. Repairs are underway with an anticipated completion in early 2019. Meanwhile, Pantex continues to release all WWTF water to Playa 1. The flow to Playa 1 is restricted by permit, so flow from the systems must also be restricted until the irrigation system is repaired. Current and future operations will be impaired by the restricted flow to the WWTF. SEPTS has the capability to reinject, so the system has operated at a lower capacity, with the treated water injected into the two available injection wells for the system and/or released to the WWTF and Playa 1. A small amount of water was beneficially used for rehabilitation of wells at the Zone 11 ISB in preparation for injection.

Consistent with pump and treat goals, the systems operated at a lower capacity during 2nd quarter when release to the WWTF was restricted or injection was required. For this reason, throughput was lower than the usual goal of 90%. Graphs of monthly operation and throughput are included in Appendix B. Over 99% of the treated water was either released to Playa 1 or injected into perched injection wells. Pantex has focused on operating the highest priority wells at SEPTS to continue capture of water along the FM 2373 fence line and along the highest plume concentrations to the south on Texas Tech property. A few of the wells along the FM 2373 fence line were not operating due to problems encountered with pumping. Wells along the northern fence line are demonstrating impact from the reduction in water levels, and continued issues with pumping are expected. Pantex has removed the pumps and is in the process of evaluating both the wells and pumps before returning them to service. Most wells were operating at P1PTS.

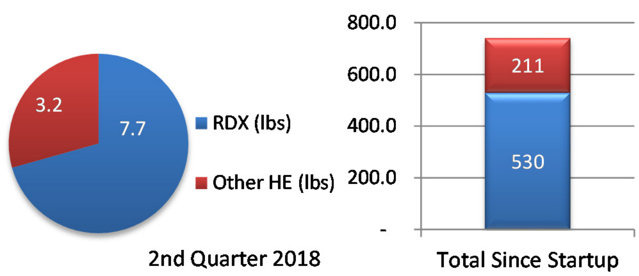


Figure 1. P1PTS Mass Removal

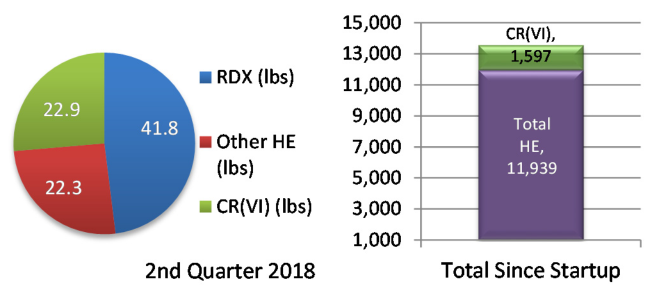


Figure 2. SEPTS Mass Removal

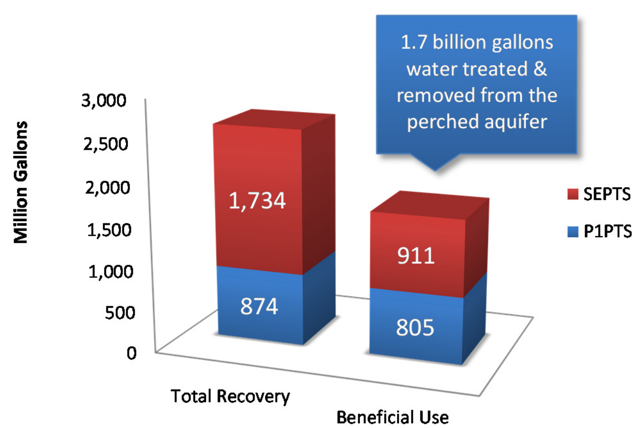


Figure 3. System Recovery and Use

Pantex is currently looking for other irrigation alternatives on the property east of FM 2373 to provide additional long-term use of the treatment system water. Other permit options with the State of Texas are also under evaluation for long-term use or injection of the treated water.

P1PTS removes primarily RDX and SEPTS removes primarily RDX and hexavalent chromium [Cr(VI)]. Figures 1 and 2 provide mass removal information for RDX and other high explosives (HEs) and Cr(VI) for the 2nd quarter, as well as totals since system startup. Concentrations near Playa 1 are much lower due to declining source concentrations; therefore, mass removal is much lower at P1PTS. The primary goal of P1PTS is water removal to decrease saturated thickness and remove the head pressure that pushes groundwater out horizontally, with mass removal as a secondary goal. Overall, the systems have removed about 14,280 lbs of contaminants from perched groundwater since operations began.

The total recovery and treatment from both systems since startup has been calculated at over 2.6 billion gallons. Because SEPTS was originally designed to inject treated water, all of the treated water prior to 2005 was injected. However, a significant volume of treated water has been used beneficially since 2005, with a total of about 1.7 billion gallons of treated water beneficially used since startup of the irrigation system. The recovery and beneficial use totals are presented in Figure 3. Note that the figures have been adjusted to remove the flow to the WWTF, as that water is not currently beneficially used. Water from the WWTF is currently routed to Playa 1, so very little water is used beneficially.

Evaluation of effluent data from both systems indicates that all COCs were treated to levels below the groundwater protection standards (GWPS).

Pantex has not observed any current issues with the movement of plumes due to the continued injection of water from the SEPTS. However, past issues were observed when prolonged injection occurred at a well. Pantex expects to continue injection at SEPTS, as repairs to the irrigation system will be limited to two 100-acre plots. Therefore, Pantex plans to install at least three new injection wells on the east side of Playa 2. This injection will help with two issues:

- Reduction of injection between the Zone 12 source of contamination and the downgradient SEPTS extraction wells. Prolonged injection can cause the plumes to be "pushed" in a different direction and can hinder capture and treatment of the plumes through the SEPTS.
- The Zone 11 plume to the northwest of the current ISB system is not well understood. When PTX06-1181 was installed, the well indicated clean conditions. However, a recent low-level detection of the high explosive HMX, at a level below the practical quantitation limit (PQL), may indicate that the plume is pushing northward due to a dip in the fine-grained zone in that area. Installation of wells to the northwest would help provide a hydraulic barrier to the movement of the plume in that direction and continued treatment of the plume through the Zone 11 ISB.

A treated water line to the Zone 11 area is already in place due to the use of the water for Zone 11 injections. Pantex will have to design and build additional infrastructure to extend the line to the north and west and install new injection wells. This line will allow up to 150 gpm to be released to the injection wells and will help with providing a steady outlet for release of treated water. This injection well expansion will be designed and installed based upon funding availability.

ISB Systems

Three ISB systems (Zone 11 ISB, Southeast ISB, and Southeast ISB Extension) are installed at Pantex. The systems are designed with closely spaced wells to set up a treatment zone in areas of the perched groundwater where pump and treat may not be as effective, or where the area is sensitive to vertical migration of COCs to the Ogallala Aquifer. Amendment is injected into these systems to establish treatment zones where COCs are degraded. Monitoring wells were installed downgradient of the treatment zone to monitor whether the system is effectively degrading the COCs (see maps in Appendix A). The primary COCs at the Zone 11 ISB are trichloroethene (TCE) and perchlorate. The primary COCs at the Southeast ISB are RDX and hexavalent chromium. The primary COC at the Southeast ISB Extension is RDX.

No treatment data are presented in this report for the Southeast ISB Extension, as the system was installed in late 2017 and injection is scheduled to begin in late 2018. Treatment zone data will not be collected until 2019.

For the treatment zone wells, this report evaluates whether the conditions are present to degrade the COCs in each area, and evaluates the presence of a continued food source for the microbial reduction of COCs (see Table 1).

Downgradient monitoring wells are evaluated to determine if the ISB systems are effective in degrading the COCs and any breakdown products of the COCs. Graphs of data from sampled treatment zone wells and downgradient in situ performance monitoring (ISPM) wells are included in Appendix C. Table 1 also summarizes ISB system performance.

Zone 11 ISB

Installation of the Zone 11 ISB remedial action was completed in 2009, and an expansion was completed in early 2015 (see Appendix A maps). Eight injection events have been completed at the current system, with the first injection event occurring in the expansion zone in 2015 and the eighth injection event completed in August 2016 for the original system. As documented in the *2016 Annual Progress Report* (Pantex, 2017), data indicate that moving to a two-year injection frequency in the original portion of the system is appropriate for future injections. The expansion area will continue to be injected yearly until the system is established. Pantex continues to evaluate

Table 1. ISB System Performance

	Treatment Zone Wells		Downgradient Performance Monitoring Wells		
System	**Reducing Conditions**	**Food Source Available**	**Primary COCs Reduced?**	**COCs < GWPS?**	**Degradation Products of COCs Reduced?**
Zone 11 ISB	Very mild to strong	Yes	Yes	Perchlorate in 7 of 9 wells TCE in 8 of 9 wells	No [1]
Southeast ISB	Medium	Yes	Yes	RDX in 2 of 3 wells Cr(VI) in 3 of 3 wells [2]	No [3]

Mild conditions = oxidation-reduction potential (ORP) of 0 to -50 millivolts (mV)
Strong conditions = ORP < -100 mV and sulfate and nitrate reduced, indicating that conditions are present for reductive dechlorination.

[1] cis-1,2-Dichloroethene (DCE) concentrations remain above GWPS in two downgradient wells, while vinyl chloride concentrations (final breakdown compound) remain at low concentrations or not detected. During 2nd quarter, cis-1,2-dichloroethene concentrations were only slightly above the GWPS, indicating that the system is nearing treatment to the GWPS. Pantex bioaugmented the original wells on the west side of the system during the seventh injection event in 2015. Pantex is continuing to monitor the effectiveness of the bioaugmentation.

[2] Pantex formerly sampled four downgradient wells at this system. However, one of the wells (PTX06-1123) continues to demonstrate low water conditions and can no longer be sampled. This well had demonstrated complete treatment of HEs and Cr(VI) from October 2012 to August 2015.

[3] PTX06-1153 is currently demonstrating partial treatment. Therefore, the degradation products of RDX are now observed slightly above the GWPS.

the expansion area to determine the appropriate timing for bioaugmentation with *Dehalococcoides* spp. (DHC) to potentially boost the treatment efficiency for TCE.

The system has a well-established treatment zone in the original portion of the system, where injection has occurred since 2009. The expansion area (see map in Appendix A) has only received two injections, so deeper reducing conditions are just being established at the injection wells. Deep reducing conditions may not be fully demonstrated at all of the wells that are monitored in the expansion area due to their placement between injection wells. Additionally, wells downgradient of the expansion area are not expected to fully demonstrate treatment until up to two years following the second injection, which occurred in 2016. Injection started in the expansion area in July 2018.

Evaluation of data in the treatment zone indicates very mild to strong reducing conditions (ORP > 0 and sulfate rebounding in some wells) across the Zone 11 ISB. Monitored conditions indicate that sulfate was reduced in 8 of 13 wells inside the treatment zone. The five wells that do not have deep reducing conditions are non-injected monitoring wells. Review of data at injection wells versus treatment zone monitoring wells that are located between injection wells indicate that reducing conditions 25 to 50 ft from injection wells are mild and are likely not conducive to reduction of TCE. However, methane concentrations were high in most treatment zone wells this quarter, indicating that strong reducing conditions continue to occur in many areas. TCE continues to be reduced to cis-1,2-dichloroethene (DCE), with TCE concentrations near or below GWPS in all but four wells inside of the treatment zone and cis-1,2-DCE present at concentrations above the GWPS in three of the wells. The presence of TCE and cis-1,2-DCE continues to indicate partial treatment in the non-injected treatment zone wells, as concentrations tend to be higher in the non-injected wells. When greater amounts of TCE and cis-1,2-DCE are being degraded, ethene and vinyl chloride are expected to be detected. Vinyl chloride continues to be detected in one well inside the treatment zone, but is not detected at other wells. Ethene was detected at low concentrations in two wells, indicating that TCE is being completely degraded in limited amounts in some areas of the treatment zone. When TCE concentrations inside the treatment zone are low (< 300 µg/L), these low degradation rates may be enough to treat TCE and its breakdown products to GWPS. Upgradient data still indicate TCE concentrations periodically fluctuating above 300 µg/L.

Pantex evaluates performance at nine downgradient ISPM wells for the Zone 11 ISB, including the wells in the expansion area. Seven of these wells (PTX06-1012, PTX06-1149, PTX06-1150, PTX06-1155, PTX06-1156, PTX06-1173, and PTX06-1174) have perchlorate concentrations below the GWPS. PTX06-1148, which is farther downgradient, has been slower to respond due to expected longer travel times; however, current data indicate a strong decreasing trend nearing the GWPS. One of the new wells downgradient of the expansion area (PTX06-1175) does not yet demonstrate treatment of perchlorate. TCE concentrations are below the GWPS in eight of nine ISPM wells. PTX06-1175, downgradient of the expansion area, continues to demonstrate TCE concentrations above the GWPS, with very low concentrations of the breakdown product cis-1,2-DCE. The first breakdown product of TCE, cis-1,2-DCE continues to be detected above the GWPS in only one downgradient well, PTX06-1155. However, the current concentration is near GWPS, indicating that treatment of TCE and its breakdown products are very close to meeting the

GWPS in treated water from the original portion of the system. The only downgradient well that is not demonstrating strong treatment is PTX06-1175.

Two former ISB injection wells (PTX06-ISB079 and PTX06-ISB082) are now monitored to evaluate conditions on the perchlorate (eastern) side of the ISB, in the second row of injection wells. Pantex will no longer inject into the second row of wells, and will evaluate these wells to ensure that treatment continues on the perchlorate side of the ISB. Additionally, the results for upgradient well PTX06-1127 indicate that TCE is increasing above GWPS on the eastern side of the ISB, so treatment of the TCE will also be evaluated to determine if changes in the system will be required. Currently, perchlorate and the low concentrations of TCE that occur on the eastern side are treated to non-detect. No degradation products of TCE were detected.

Although there are areas in the treatment zone that indicate mild reducing conditions, the downgradient data indicate that treatment is effectively reducing contaminants and risk across the Zone 11 ISB.

Due to a delay in contracting, Pantex began injection in the expansion area in July 2018 after rehabilitation of the wells was completed. Due to very mild conditions that occur in the new treatment zone wells in the expansion area, Pantex will continue to evaluate data to determine the appropriate timing for bioaugmentation and moving to a two-year injection frequency.

Pantex is not currently treating all of the TCE and perchlorate plume at the Zone 11 ISB. When the ISB was expanded, the final ISB well indicated concentrations that exceeded GWPS by more than an order of magnitude. Pantex installed two new upgradient wells to evaluate the plume to the north. PTX06-1180 defined the extent of perchlorate, but TCE was still present. PTX06-1181 defined the extent of TCE contamination. To determine the best path forward for treatment of the plume, Pantex conducted a study in early 2018, using a corrective measure/feasibility study approach, to determine the best path forward for continuing to treat the plume. The evaluation report is included as Appendix D. Pump and treat and in situ bioremediation were considered, with variations of the treatments also evaluated. From a technical and cost perspective, in situ bioremediation with recirculation was considered the most feasible alternative. Pantex plans to extend the current ISB remedial action by installing an additional single line of seven injection wells northwest of the current line of injection wells. Two recirculation (extraction) wells will be drilled downgradient to assist with amendment distribution across the treatment zone. Two downgradient monitoring wells will also be added to evaluate treatment effectiveness. Pantex plans to install the new injection wells in 2019 and will begin injecting early while funding is requested and put in place for the design and construction of recirculation. Pantex also plans to expand the recirculation approach across the western side of the Zone 11 ISB, where treatment of TCE and degradation products to the GWPS has been difficult to achieve. Where needed, Pantex will install new downgradient wells to demonstrate treatment effectiveness.

Southeast ISB

The Southeast ISB was installed in 2007. Six injection events have been completed at this system. The Southeast ISB continues to demonstrate declining water levels at the system; as a result, only

50% of the system was injected during 2016. A discussion of the injection and issues encountered during injection is provided in the 2016 Annual Progress Report. Based on review of system data and ISB Pilot Study data, Pantex recommended waiting three years for the next injection in the Southeast ISB (see 2016 Annual Progress Report).

Due to low water or dry conditions, only four of eight treatment zone monitoring wells were sampled in 2nd quarter. Evaluation of treatment zone data indicates that intermediate reducing conditions are present for treatment of HEs and hexavalent chromium. ORP is between -50 mV and -100 mV and sulfate is reduced to values less than 2 μg/L, indicating that reducing conditions are present for continued reduction of HEs and hexavalent chromium. Total organic carbon results indicate that a continued food source is available to maintain the reducing conditions. All COCs were non-detect in the sampled treatment zone wells.

Four downgradient wells have historically been sampled at this system. Two of the closest downgradient monitoring wells for the Southeast ISB, PTX06-1037 and PTX06-1154, demonstrate reduction of RDX, RDX degradation products, and hexavalent chromium, with all COCs non-detect. PTX06-1123 had demonstrated COC concentrations below the GWPS; however, this well has not been sampled since August 2015 due to insufficient water being present in the well. PTX06-1153 continues to exhibit RDX concentrations above the GWPS, but hexavalent chromium concentrations continue to demonstrate a decreasing trend below the GWPS. During 2nd quarter, this well continued to demonstrate signs of partial treatment. Breakdown products of RDX were detected at concentrations above the GWPS. Upgradient dry wells were injected in 2013 and 2015 in an attempt to affect this well. It is possible that those injections were slow to respond at this location and may only be partially affecting the water that continues to move into PTX06-1153. As with other locations, water levels at this well continue to decline. Pantex will continue to monitor PTX06-1153 for contaminant concentrations and water levels over time.

Many of the injection and performance monitoring wells indicate variable water conditions at the Southeast ISB. Two Southeast ISB performance monitoring wells (one upgradient and one farther downgradient) remain dry and cannot be sampled. PTX06-1123, a downgradient performance monitoring well, has not been sampled since August 2015 due to low water conditions. The remaining three downgradient wells demonstrate declining water levels, with only PTX06-1153 containing more than 4 ft of water above the bottom of screen. PTX06-1037 was sampled only for the highest priority constituents, as this well now goes dry during sampling. Only four of eight monitoring wells in the treatment zone could be sampled in the 2nd quarter due to insufficient water. Injection was completed at only 50% of the injection wells during the 2016 injection event due to dry or low water (< 1 ft) conditions in the wells. The inability to sample or inject into these wells is expected to persist with continued upgradient removal of water by the SEPTS. Evaluation of data indicates that most wells in the Southeast ISB will not contain appreciable water by 2022. Pantex will evaluate the timing and need for further injections after the 2019 injection event.

Southeast ISB Extension

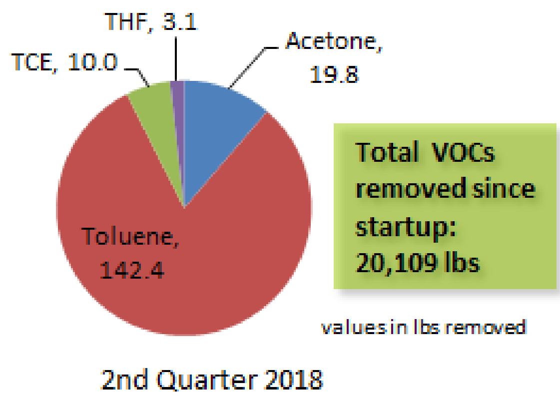
The Southeast ISB Extension was installed in 2017 as an extension of the chosen remedy for the southeast perched groundwater. No injection events have been completed for this system, as the system was completed in December 2017. Pantex is currently installing the roads, pads, and infrastructure to inject. Pantex plans to begin injection at the system in October 2018.

Baseline data were presented in the 1st Quarter 2018 Progress Report and no other data have been collected at the system since that time. Further data will be collected in 2019 after injection is complete.

Burning Ground SVE

The Burning Ground SVE system began operation in 2002 as a large-scale catalytic oxidizer (CatOX) system. Due to a large reduction in VOC concentrations, a small CatOX system has been operating at the Burning Ground SVE system since April 2012. This small-scale system focuses on treating residual non-aqueous phase liquid (NAPL) and soil gas at a single extraction well (SVE-S-20) near the source area.

The system was intermittently operated during 2nd quarter. It was shut down due to low pH levels in April and May, with the system operating about 78% of the quarter (about 1,711 hours of operation). Figure 4 shows mass removal calculated for the 2nd quarter and since startup for VOCs contributing more than 3% of the total VOC concentration.



The system removed about 175 lbs of VOCs during 2nd quarter, and has removed over 20,100 lbs of VOCs since startup. Based on PID data collected at the system effluent port, system destruction efficiency was at least 98%. The system operated at a higher flow due to the modifications to the system, with the flow increased from 32 standard cubic feet per minute (scfm) in early 2017 to the current level of 44.5 scfm. The hourly VOC removal rates increased with the increased flow until 1st quarter of 2018. The removal rate has declined this quarter and is similar to the rate observed before modification of the system. Pantex will continue to evaluate the effectiveness of removal with the increased flow rates to determine when removal appreciably decreases.

Uncertainty Management and Early Detection

Uncertainty management and early detection wells are evaluated to determine if there are unexpected conditions in areas where previous groundwater contamination has not been detected or confirmed (Ogallala and perched aquifers), or in previous plume locations where concentrations have fallen below GWPS, background, and the PQL (e.g., perched wells at the Burning Ground and Old Sewage Treatment Plant areas). Indicator COCs are evaluated at the uncertainty management/early detection wells in the quarterly report. A map depicting the wells evaluated is included in Appendix A.

Summary of Unexpected Ogallala Detections, 2nd Quarter 2018					
Well ID	Sample Date	Analyte	Measured Value (µg/L)	PQL (µg/L)	GWPS (µg/L)
PTX06-1056	4/24/2018	1,2-Dichloroethane	0.81	1	5
PTX06-1056	4/24/2018	4-Amino-2,6-Dinitrotoluene	0.438	0.26	1.2
PTX06-1138	5/17/2018	Chromium, Total	51.7	10	100
PTX06-1138	5/17/2018	Chromium, Hexavalent	45.31	2	100
PTX06-1138	7/12/2018	Chromium, Total	ND	10	100
PTX06-1138	7/12/2018	Chromium, Hexavalent	1.52	0.02	100

Review of the uncertainty management/early detection data collected during the 2nd quarter indicates unexpected conditions at two Ogallala Aquifer wells (PTX06-1056 and PTX06-1138). No detections exceeded the GWPS in the Ogallala Aquifer uncertainty management/early detection wells sampled during the 2nd quarter. There were no unexpected conditions at perched uncertainty management wells in the 2nd quarter.

PTX06-1056 continues to demonstrate detections of 4-amino-2,6-dinitrotoluene (DNT4A), a breakdown product of the HE 2,4,6-trinitrotoluene (TNT), with the initial detection occurring in April 2014. Sample results collected since that time have been variable, with a few values slightly exceeding the PQL. DNT4A concentrations exceeded the PQL during 2nd quarter 2018. 1,2-Dichloroethane (DCA12) has been variably detected since August 2015, with all detections below the PQL. Trends of these analytes were performed using Mann-Kendall statistics; DNT4A continues to demonstrate a slight increasing trend in recent data (last four samples), as well as across all data collected at the well. DCA12 is demonstrating no trend across all data and an increasing trend across recent data.

Pantex has proactively evaluated potential sources for the contamination. A nearby perched well that was drilled deep into the fine-grained zone (FGZ) was plugged to address that potential source. An outside review indicated that, based on fate and transport modeling, the perched well was the most likely source of the contamination. A cement bond log was run on PTX06-1056 in October 2016 to determine the competency of the concrete seal at the FGZ. The log indicates that the seal is competent and that PTX06-1056 is likely not acting as a preferential pathway for contamination to reach the Ogallala Aquifer. As agreed with regulatory agencies, Pantex will continue with quarterly sampling to evaluate trends in these detections. Further actions will be determined based on results of sampling and in accordance with the Pantex Groundwater Contingency Plan.

Detections of total and hexavalent chromium above background were observed in PTX06-1138. Although the values were not above the GWPS, the values were higher than expected. Other corrosion indicators had not elevated, so the well was resampled to evaluate the chromium detections. Pantex resampled PTX06-1138 during 2nd quarter 2018, with results indicating that the chromium detections were not confirmed at a level above background. This well will continue to be monitored in accordance with the approved sampling and analysis plan (SAP).

Other Unexpected Conditions

Pantex routinely evaluates data as they come in from the laboratory to determine if data are off-trend, at an all-time high, or represent a new detection that may require further sampling or evaluation. Through the well maintenance program, Pantex also inspects wells at least every five years to ensure they are not silting in and to evaluate whether the well remains in contact with the formation.

As discussed in the four previous quarterly reports, Pantex drilled PTX06-1182 in 2016 to evaluate water conditions in the southeastern lobe of perched groundwater based on the continued evaluation that indicates that some portions of the southeast perched groundwater are not under the influence of the pump and treat systems. Water containing HEs at concentrations above the GWPS was discovered in PTX06-1182. In response to that information, Pantex installed three new wells (PTX06-1184, PTX06-1185, and PTX06-1186 [subsequently changed to PTX06-ISB107, the first well on the west side of the ISB]) during 2nd quarter 2017 to define the extent of the plume to the southeast (see figure in Attachment A maps for well locations). Water was discovered in PTX06-1184 and PTX06-1186 and data confirmed the presence of the HEs RDX and DNT4A.

As previously recommended, Pantex obtained additional funding to extend the Southeast ISB remedy to the southeast boundary of the site and add new monitoring wells. Pantex completed drilling the ISB wells in December 2017. Pantex also obtained an agreement with the landowner to the south and completed installation of four monitoring wells in January 2018. Water was present in three of the wells; the other (PTX06-1193) was dry. Pantex has completed sampling at the newly completed ISB wells and on the neighboring property. Only one of the new wells on the neighboring property demonstrated detections of COCs above GWPS. In January 2018, Pantex also installed another monitoring well (PTX06-1195) along the eastern fence line, north of the final Southeast ISB extension well, to define extent in that area. Results indicate that the well had no detections of COCs above background concentrations or GWPS.

Pantex installed passive flux meters (PFMs) across the southeast lobe area to evaluate the flux of water moving toward the property boundary. PFMs were installed in eight wells, depicted in Appendix A maps. Values were reported as Darcy velocities, so Pantex applied a range of porosities ($n = 0.25$ and $n = 0.4$) to calculate water seepage velocities. Results of the study indicate that the average water seepage velocities range from 120 to 241 ft/yr. Based on work conducted for the risk assessments and the corrective measures study, perched groundwater seepage velocities were previously estimated to be generally less than 200 ft/yr in the perched groundwater. Using the PFMs, velocities greater than 200 ft/yr were observed in PTX06-1034, PTX06-ISB107, and PTX06-ISB124. These higher velocities would help account for the faster than expected movement of contamination to the property boundary. The calculated Darcy velocities and seepage velocities derived from the PFMs are presented in Appendix E.

Because the contaminants are indicating flow primarily through an old subsurface paleochannel, positioning of wells is important to identify the channel and extent of contamination, as the main RDX plume is only 500 to 700 ft wide at the property boundary. The main paleochannel where the highest concentrations occur is narrower, likely only about 250 ft wide. To identify the boundaries of the paleochannel, Pantex plans to conduct an electromagnetic study using Willowstick Technologies, LLC. The objective of this study will be to attempt to identify the area with faster flow paths in the groundwater so that the extent of contamination can be positively identified. The study is expected to be completed by November 2018. Results are expected to be available for the 4th quarter 2018 and annual reports.

During 2nd quarter, Pantex obtained an agreement with the neighbor to the southeast allowing three monitoring wells (PTX06-1196, PTX06-1197, and PTX06-1199) to be drilled in July 2018. Sample results from these wells are expected to be available in the 3rd quarter 2018 progress report. These wells will also be used in the Willowstick study to attempt to identify the channel that is carrying the high explosive contamination off-site.

Schedule Update

Pantex provided a detailed schedule of upcoming work in the 2017 Annual Progress Report. An update of the activities scheduled to be started or completed by the publication date of this report is provided below.

Pantex completed the following:

- Pantex has obtained an agreement with the neighbor to the southeast and has drilled three new wells to aid in determining contaminant extent in the southeast perched groundwater lobe.
- The RDX natural attenuation study is complete. The study has found evidence of natural attenuation at Pantex; however, a rate of degradation is difficult to obtain due to changes in the plume over time and distance. The full report will be discussed in the 2018 Annual Progress Report.
- Rehabilitation of the Zone 11 ISB wells was completed in July.
- Pantex completed an evaluation of the best methods to treat the plume that extends northwest of the Zone 11 ISB. That evaluation is discussed in the Zone 11 ISB section above.
- Pantex contracted for PFM development for wells in the southeast lobe of contamination, east of FM 2373. The PFMs were used to evaluate water flux in the southeast lobe, east of FM 2373 and south of the Pantex property. The PFMs were deployed and removed by Pantex in April 2018. Results from Enviroflux are included in this report.

Pantex continues progress toward completion of the following items:

- Injection of the Zone 11 ISB Expansion area began in July 2018. The injection is expected to be completed in September 2018.

- Construction of Landfill 3 erosion control began in August 2018. Work is expected to be completed in 2018.

- Pantex is constructing the tie-in of the new wells east of FM 2373 to SEPTS. The construction is expected to be completed in October 2018.

- Construction of the Southeast ISB Extension injection components, electrical, water conveyance, roads, and pad began in 2nd quarter 2018. The design and construction is expected to be completed in November 2018.

- Pantex is in the process of contracting services with Willowstick Technologies, LLC for a specialized geophysical study of the southeast lobe of perched groundwater to attempt to identify preferential flow paths. This study may help identify locations that are conveying most of the contaminants to the southeast. Pantex is planning for this study to be completed in November 2018.

- Pantex is contracting for the 2018 landfill repair work. The work focuses on filling holes/voids, reseeding, and maintenance of the Landfill 1 Closure Turf. This work is expected to be completed by the end of 2018.

- Pantex received comments from the TCEQ and EPA for the second five-year review (FYR). The FYR is expected to be finalized by the end of August, with EPA providing approval by the end of September 2018.

Upcoming work includes the following:

- The Southeast ISB Extension injection is expected to begin in October 2018. Work will begin using generators to expedite the injection while the electrical infrastructure continues to be constructed.

Conclusions and Recommendations for Change

The remedial actions continue to operate and meet short-term expectations for cleanup of the perched groundwater in areas under the influence of the remediation systems. Perched water levels are declining, mass is being removed or reduced, and institutional controls provide protection for use of impacted groundwater, while the remedial actions continue to operate to meet long-term goals. Pantex is working to extend treatment systems to areas that are not currently under the influence of the existing remediation systems.

The pump and treat systems continue to remove COC mass and water from critical areas in the perched aquifer, thus decreasing head that is driving vertical and lateral movement of perched groundwater. The systems have been impacted by the shutdown of the irrigation system and

Pantex is continuing to evaluate other options for release or use of the treated water. Pantex will continue to inject and release water to Playa 1 until the irrigation system is repaired or other uses can be identified and constructed. Pantex is recommending the installation of perched injection wells east of the Playa 2 area. These wells will help provide a consistent outlet for release of treated water from SEPTS. These wells will help reduce reliance on injection wells near the extraction system that may deflect source area plumes away from the downgradient remediation system and is also expected to help deter the movement of the Zone 11 ISB plume to the northwest. Pantex expects to inject up to 150 gpm of treated perched groundwater once construction is complete.

Monitoring results for areas downgradient of the ISB systems continue to demonstrate that system treatment has been generally effective. COC concentrations meet the GWPS at the Southeast ISB at three downgradient wells. One downgradient well (PTX06-1153) for the Southeast ISB is not responding as well as the others. Pantex continues to evaluate conditions in that area to determine if the well is impacted by water from the western end of the Southeast ISB or if it is not hydraulically connected to that system. Data collected this quarter continue to indicate that partially treated water has entered the well. The well may be responding to injections at upgradient dry wells in 2013 and 2015. Monitoring will continue at PTX06-1153 as described in the SAP, as the quarterly samples will provide adequate information for this well. Further recommendations will be made based on evaluation of data over time.

Downgradient wells at the Zone 11 ISB are generally demonstrating treatment. Seven of the nine downgradient ISPM wells exhibit perchlorate concentrations below the GWPS, with perchlorate concentrations near GWPS in one of the remaining two wells. A long-term declining trend has been observed in the other well. Since the start of the remedial action, TCE concentrations continue to indicate a decreasing trend, with current concentrations below the GWPS in eight of nine downgradient wells. Detected concentrations of the TCE breakdown product cis-1,2-DCE persist, although the latest results indicate that it is being treated to concentrations below the GWPS in the seven of nine ISPM wells. Sampling results indicated some presence of vinyl chloride and ethene this quarter, indicating that complete reduction of TCE is occurring on a limited basis. Pantex will collect samples again in 4th quarter 2018 to further evaluate the effectiveness of the bioaugmentation. Rehabilitation and injection began in the expanded area in 2nd quarter 2018.

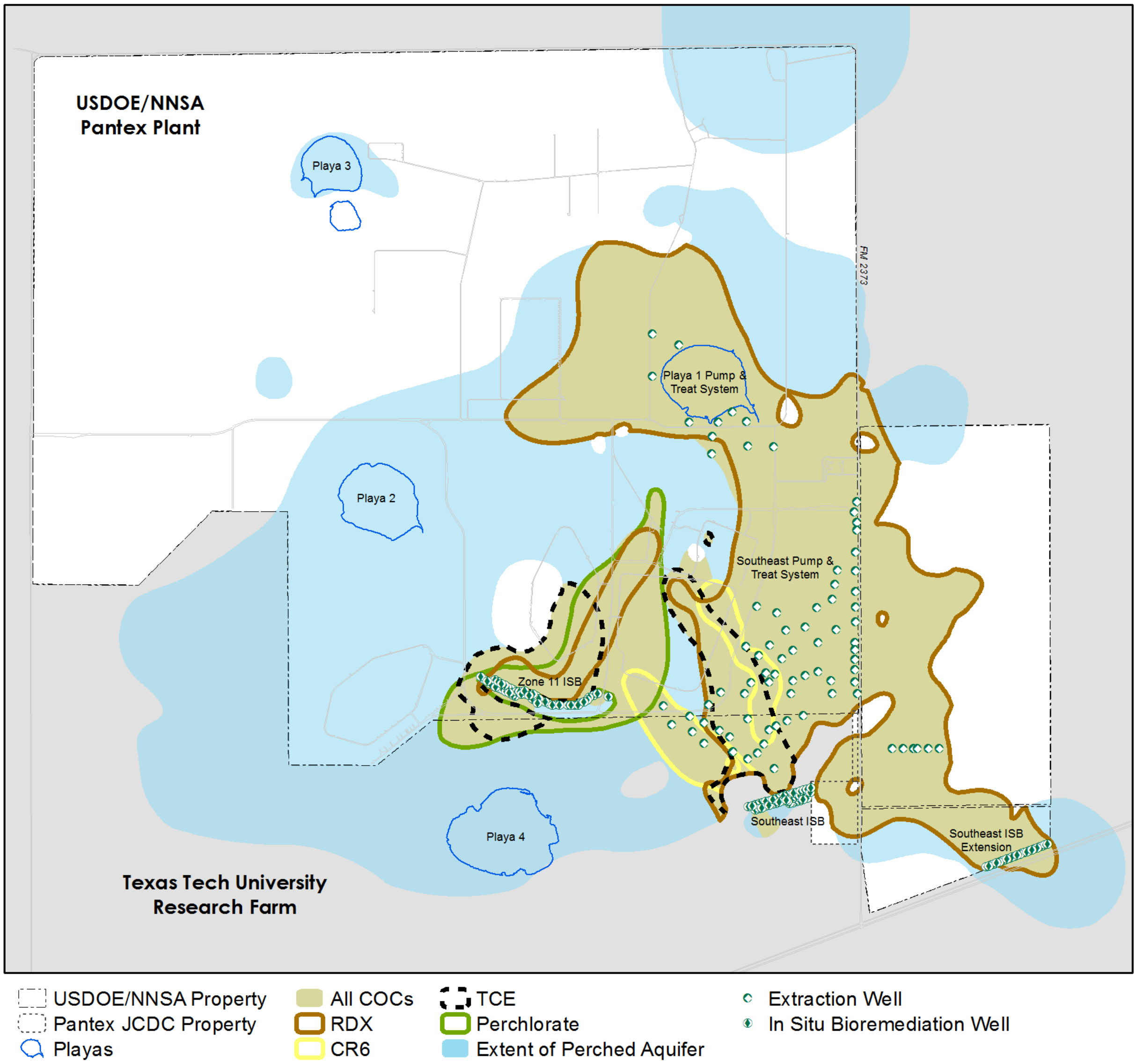
Pantex is not currently treating all of the TCE and perchlorate plume to the northwest of the Zone 11 ISB. Since the last expansion of the ISB, Pantex has installed new upgradient wells and has delineated the extent of the plume. Based on an evaluation of technical and cost factors, Pantex is recommending to expand the current ISB remedy to the northwest. The ISB will be coupled with downgradient recirculation wells to improve amendment distribution. Pantex plans to install a single row of seven injection wells, two downgradient extraction wells, and two downgradient ISPM wells in the expanded system. Injection well installation will begin in 2019 so that injections could begin early. Design and construction of recirculation infrastructure will begin when funding is available.

The SVE system continues to treat soil gas and residual NAPL in the solvent evaporation pit/ chemical burn pit area of the Burning Ground, thereby mitigating vertical movement of VOCs to groundwater. Pantex has continued to have problems with completing rebound tests, and has been unable to prepare a path to closure as recommended in the first FYR. Therefore, Pantex has evaluated other paths to closure for this system. In May 2017, Pantex completed a modification to six inactive SVE extraction wells surrounding the active extraction well SVE-S-20 to open the wells to ambient air. This modification enhances air flow through the formation while the system is operating. The air flow was increased from 32 scfm to about 45 scfm over time. Evaluation of hourly VOC removal indicates that the mass removal rate initially increased with the increase in influent air flow. Current data indicate a decline in the mass removal rate. Pantex will continue to evaluate the VOC removal to determine when the removal rates appreciably decrease. Pantex will provide further recommendations based on review of influent SVE data over time.

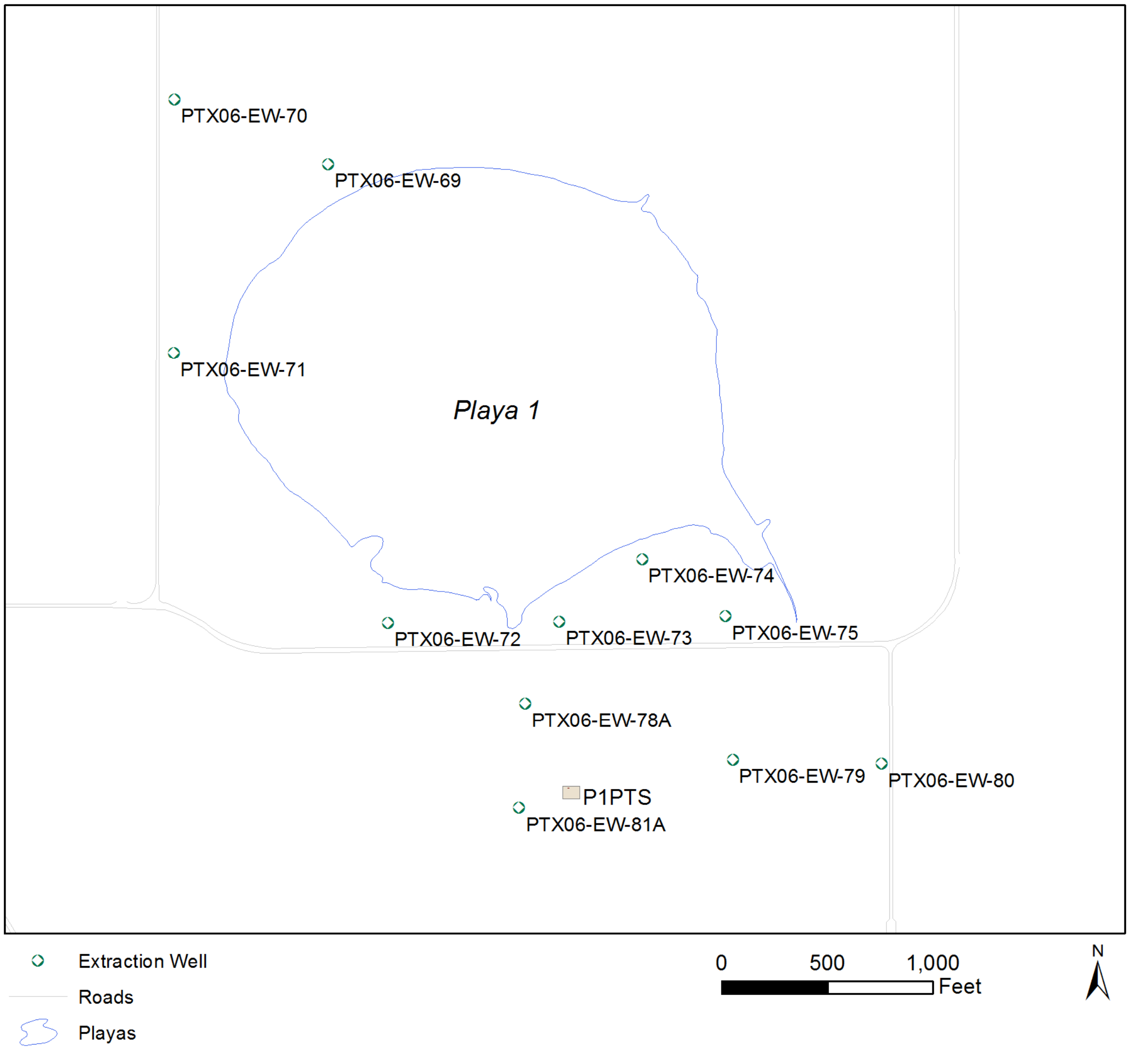
The groundwater remedies are considered to be protective for the short-term, as untreated perched groundwater use is controlled to prevent human contact and monitoring data continue to indicate that the remedial actions remain protective of the Ogallala Aquifer. Detections of DNT4A and 1,2-dichloroethane at concentrations below the GWPS continue to occur in one Ogallala well (PTX06-1056), and Pantex is actively following the Groundwater Contingency Plan to guide the response. Pantex proactively conducted work to determine possible causes of the detections; those results indicate that the most likely cause is the nearby perched well that was drilled deep into the FGZ. Pantex plugged the nearby perched well in November 2014. Pantex will continue to monitor this Ogallala well quarterly to determine if a trend emerges, and will determine if further steps are necessary for the protection of the Ogallala Aquifer. Another Ogallala well (PTX06-1138) demonstrated an unexpected elevated detection of hexavalent chromium above background and the PQL during 2nd quarter. The well was resampled, and results indicated that hexavalent chromium was not confirmed above background.

Pantex continues to evaluate options for the southeast lobe of perched groundwater east of FM 2373. As recommended in the 2016 Annual Progress Report, Pantex is actively working toward extending the SEPTS operation to that area to address the continued plume movement to the south. Pantex obtained additional funding to extend the Southeast ISB to the southeast boundary of the site, and drilling of the ISB wells was completed in December 2017. After gaining an access agreement, Pantex also installed four monitoring wells south of the Pantex property in January 2018. Water is present in three wells; the other well is dry. Results indicate one well with concentrations that exceed the GWPS for RDX and DNT4A. Pantex also obtained an agreement with the landowner to the southeast and three new wells were drilled there in July 2018. Sampling will be conducted during 3rd quarter 2018. The new SEPTS extraction wells are scheduled to be tied in and operating in October 2018, and injection into the Southeast ISB Extension beginning in the same month.

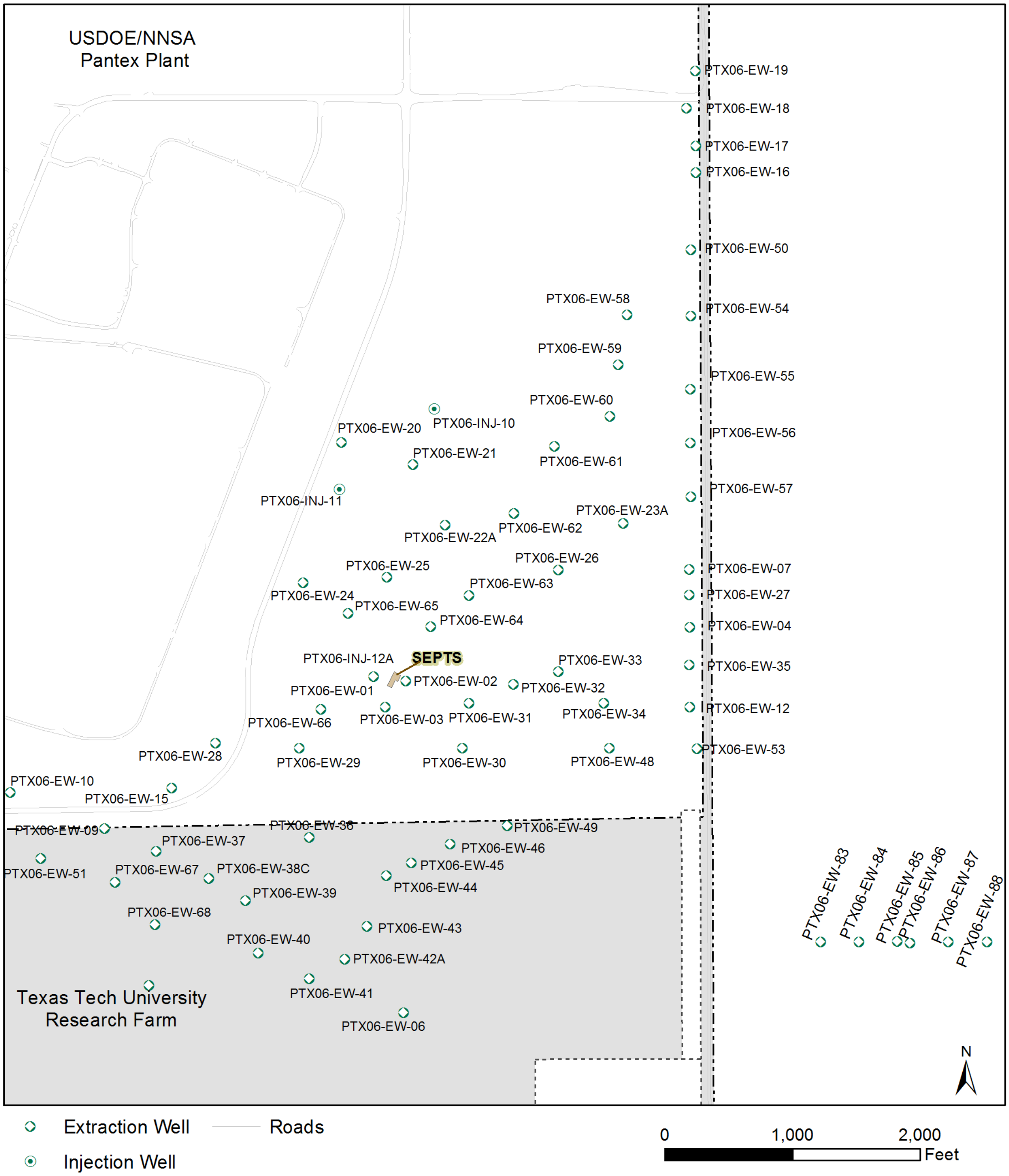
Appendix A
Maps



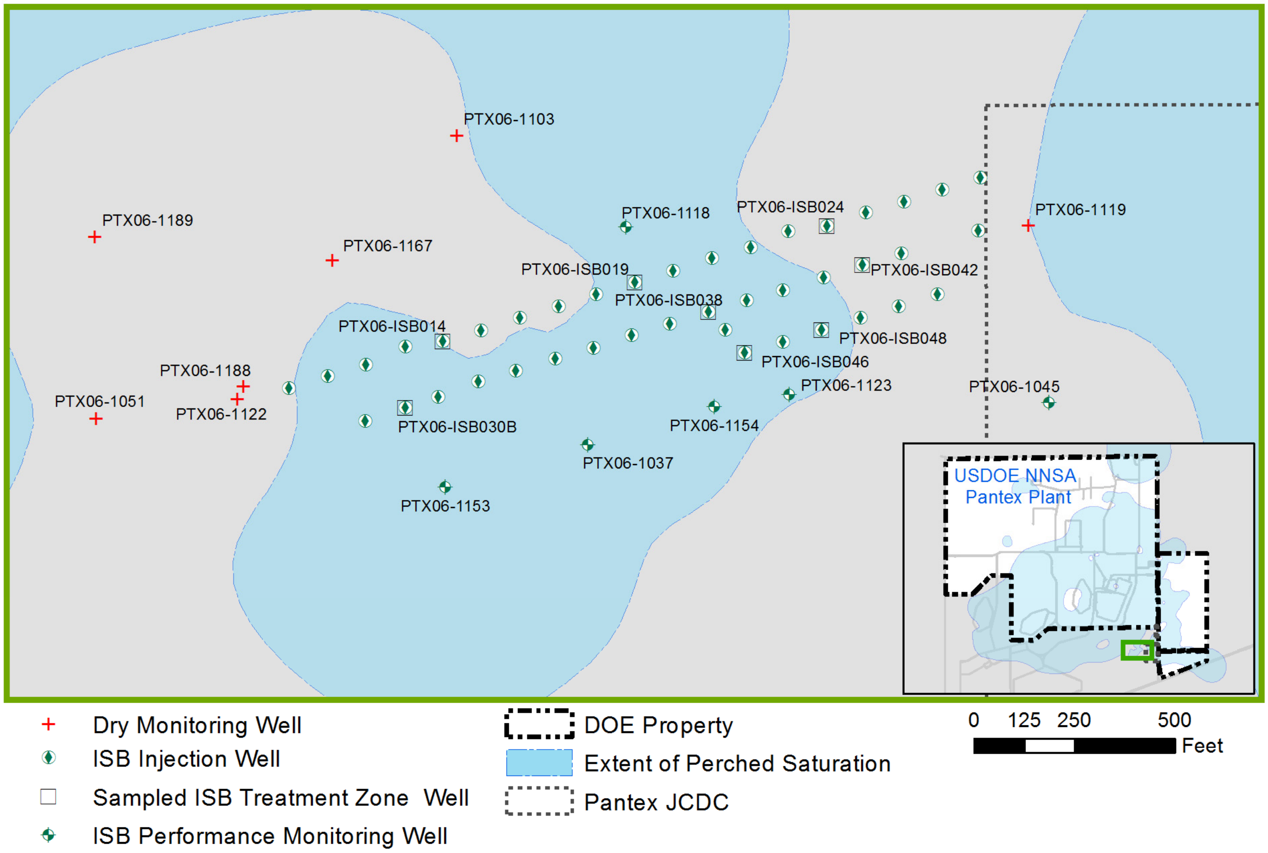
Extent of Perched Groundwater and Contaminant Plumes



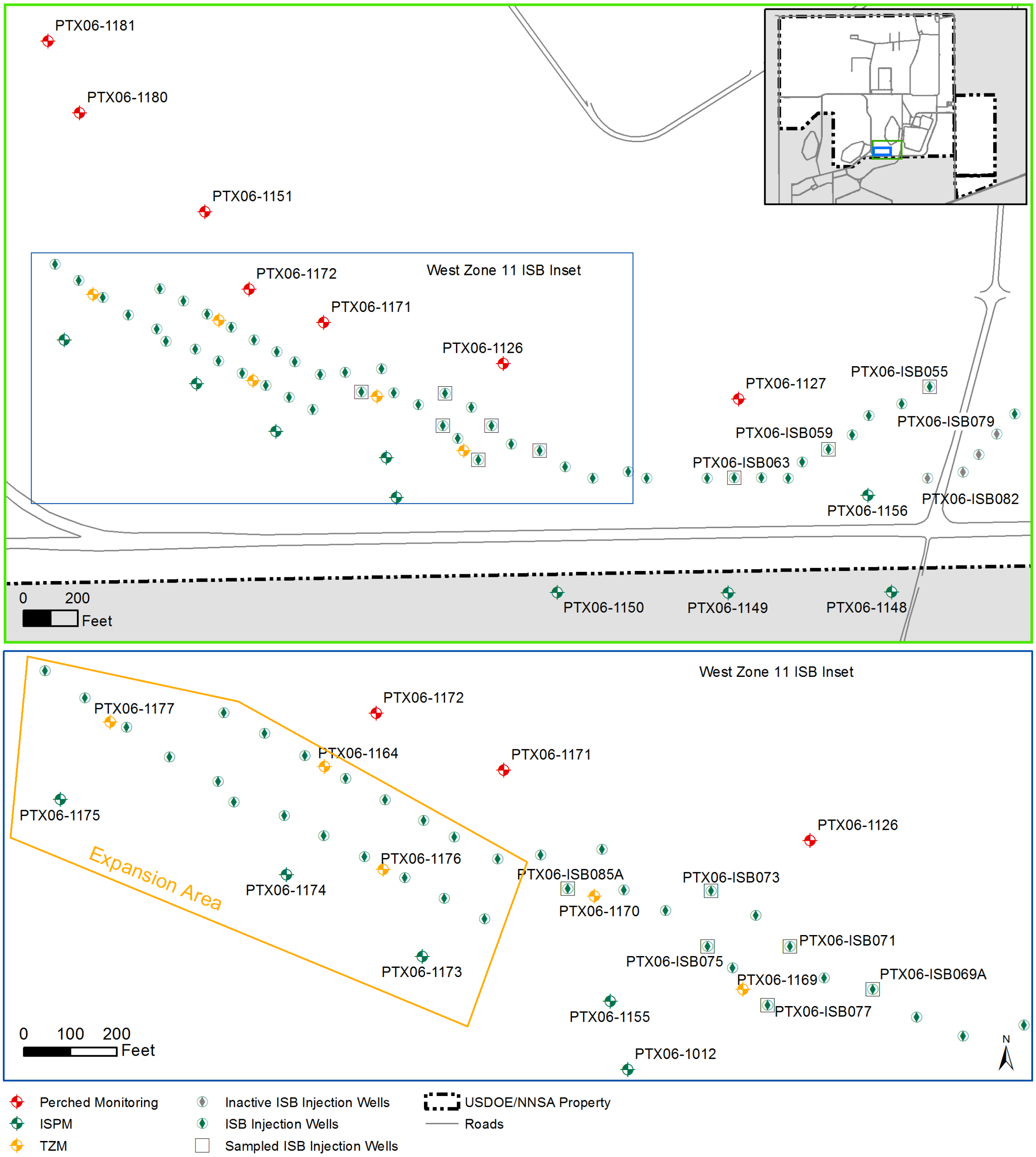
Playa 1 Pump and Treat System Wells



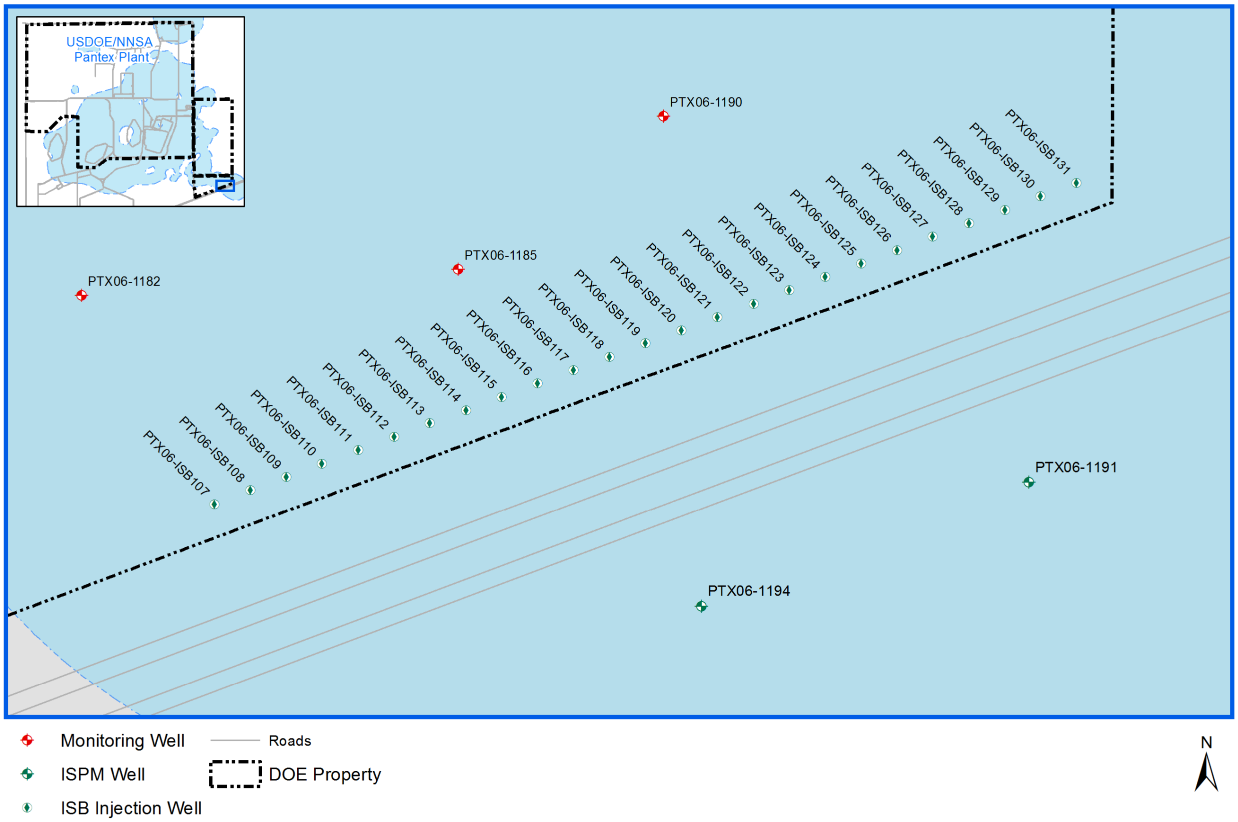
Southeast Pump and Treat System Wells



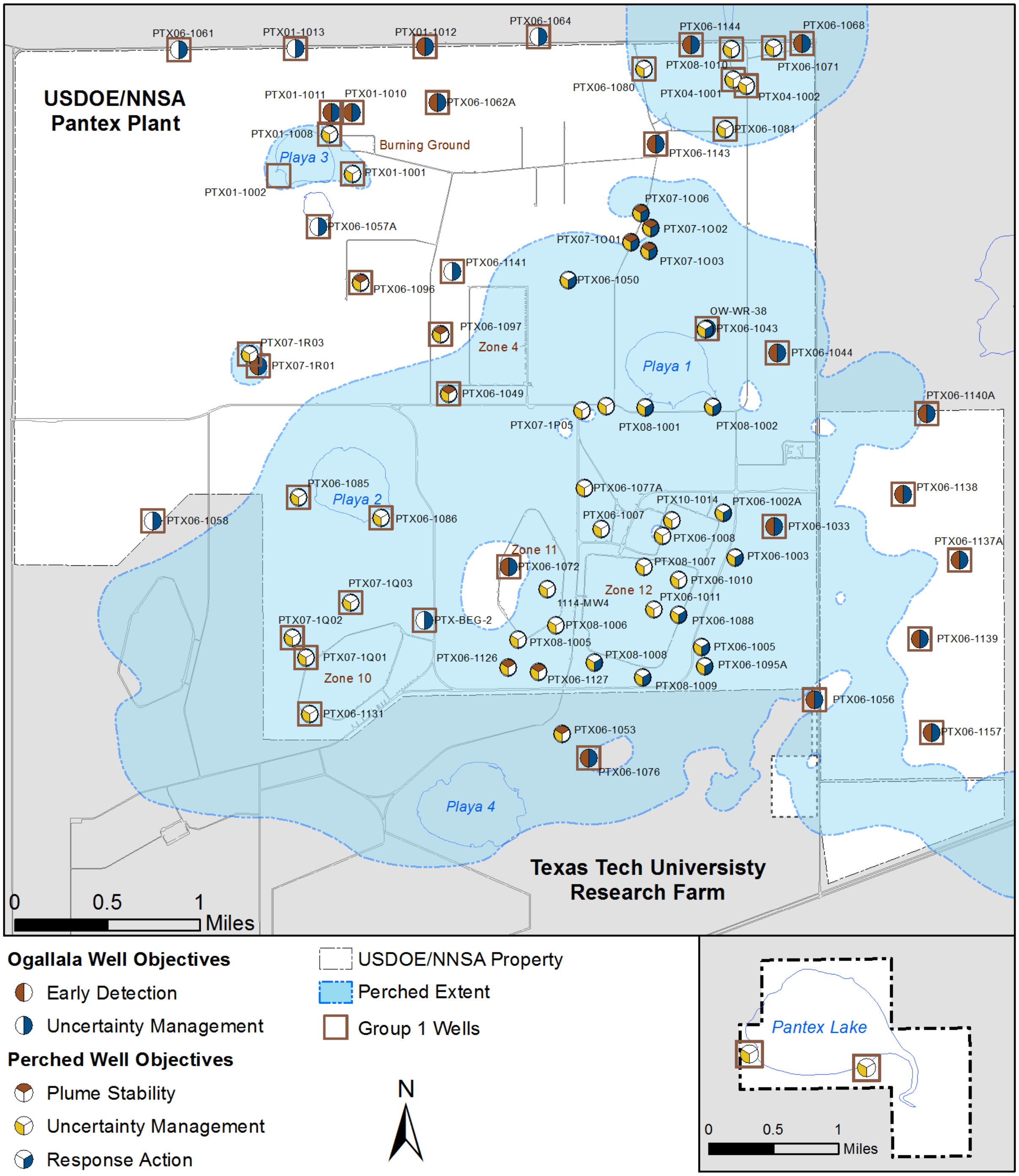
Southeast ISB Wells and Sampling Locations



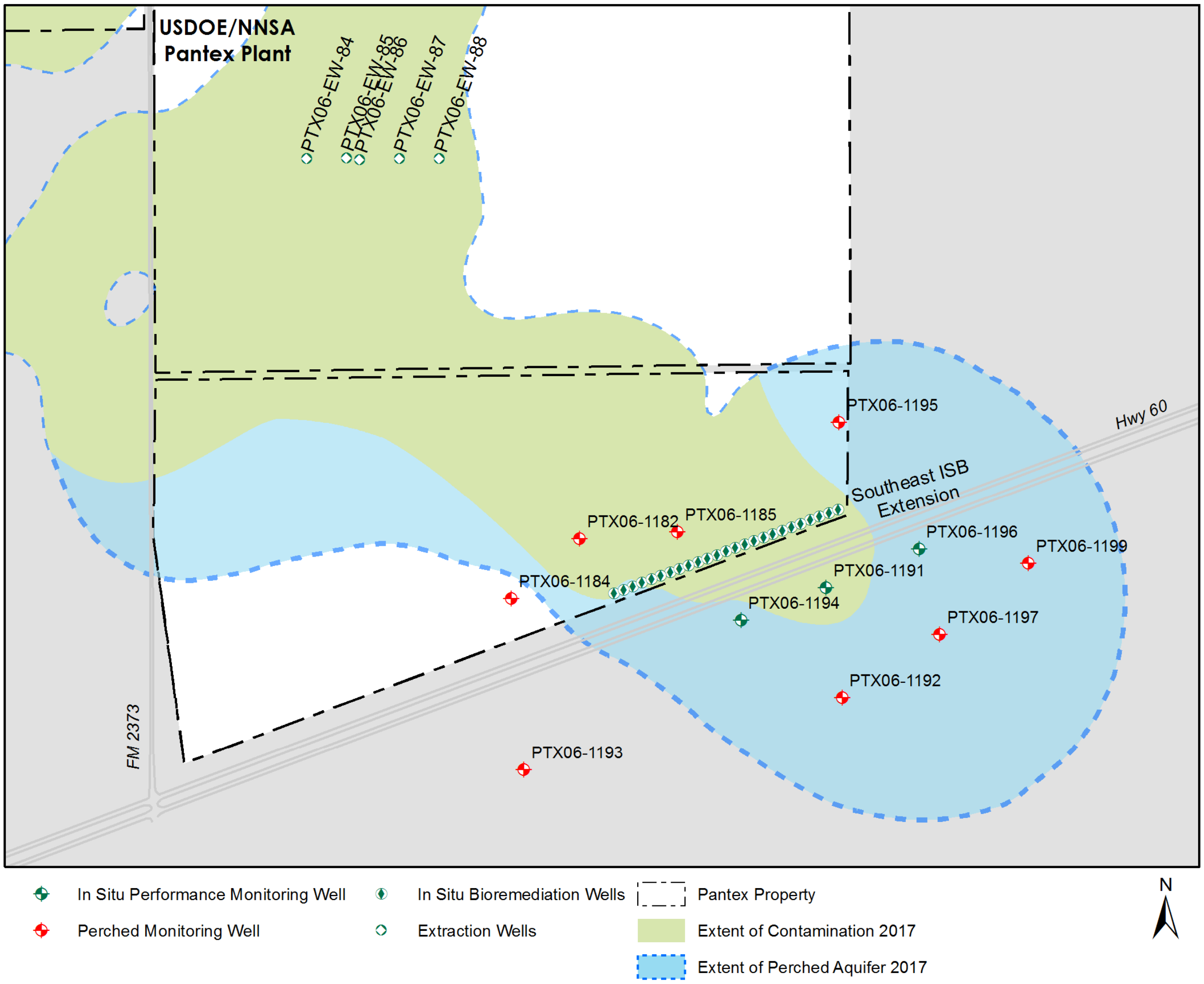
Zone 11 ISB Wells and Sampling Locations



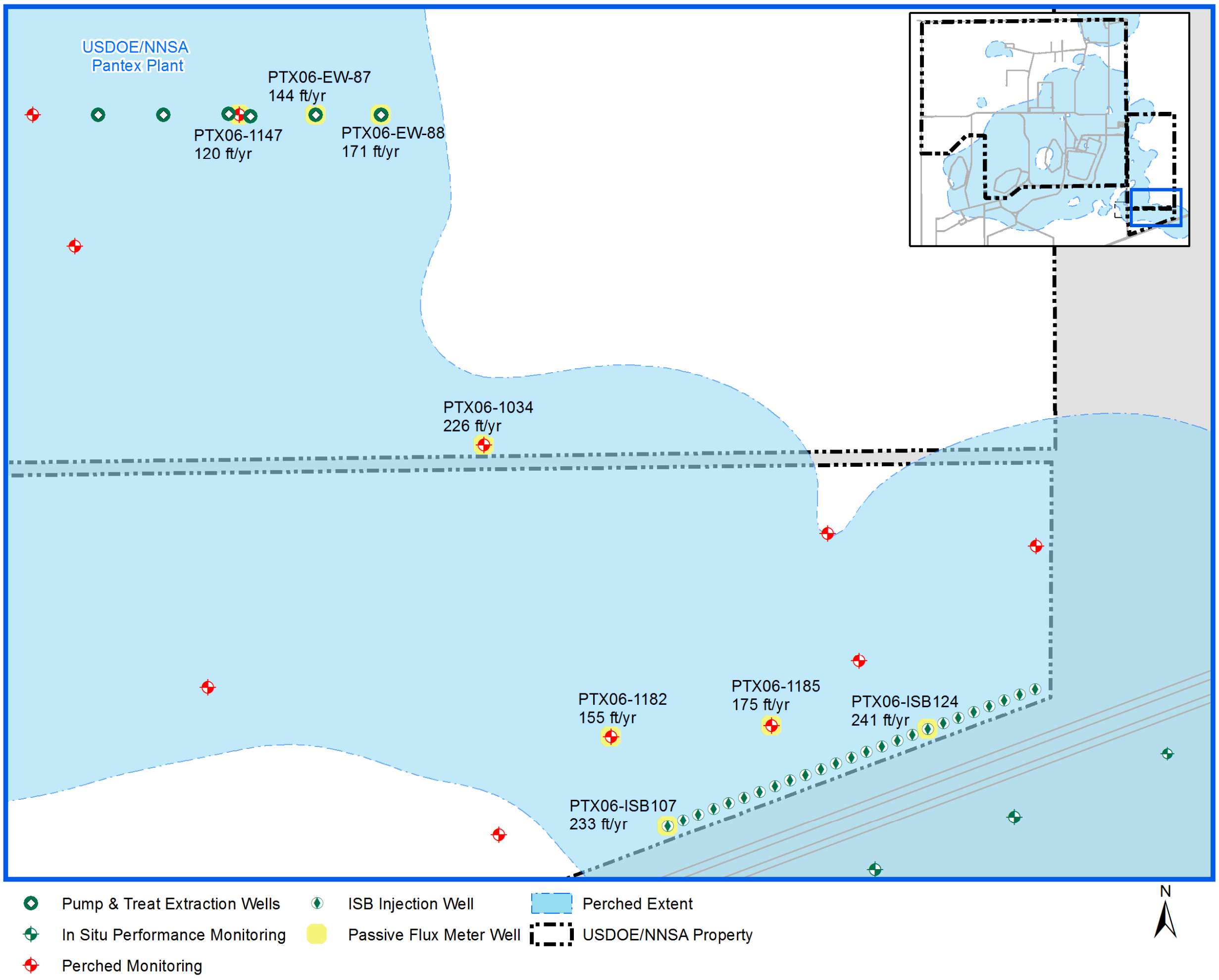
Southeast ISB Extension Wells



Uncertainty Management and Early Detection Wells
Evaluated in the Quarterly Progress Report



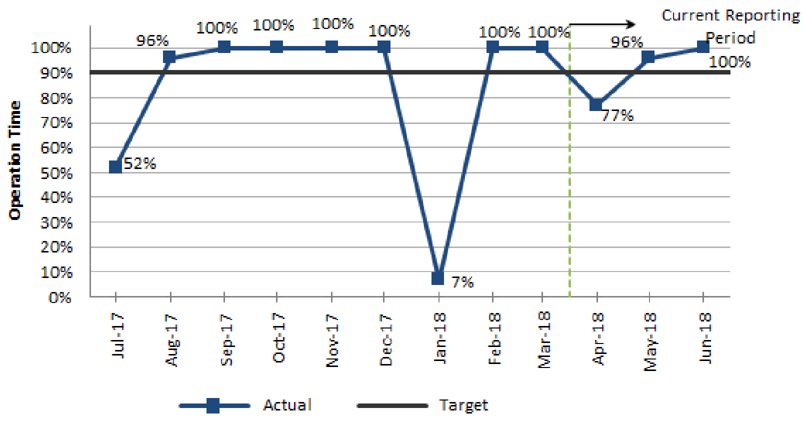
Other Unexpected Conditions Wells



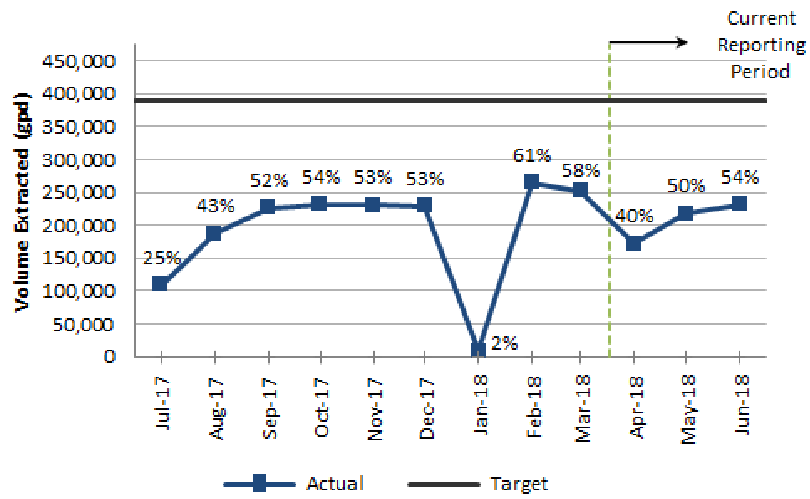
Passive Flux Meter Wells and Average Groundwater Seepage Velocities

Appendix B
Pump and Treat System Graphs

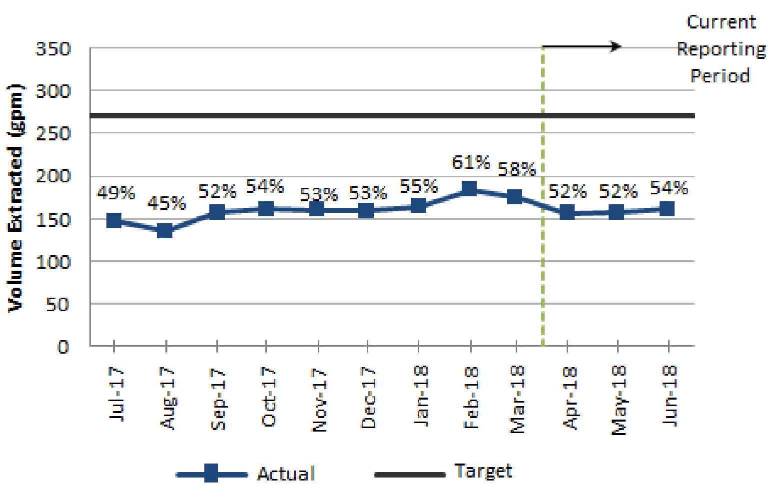
Southeast Pump and Treat System Graphs



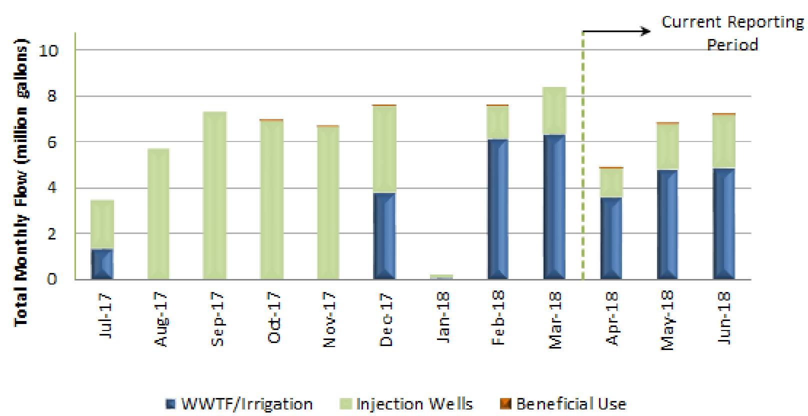
SEPTS Operation Time vs Target



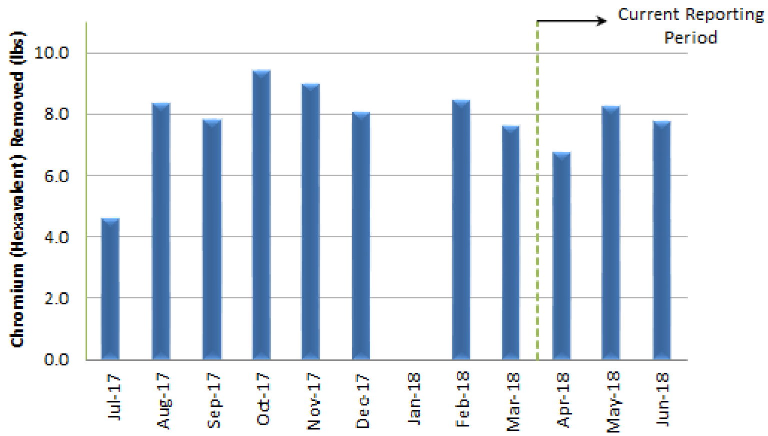
SEPTS GPD and % Capacity



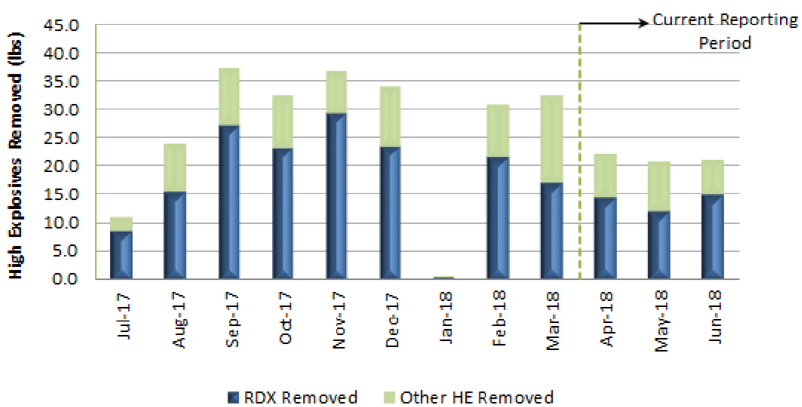
SEPTS Average GPM and % Capacity



SEPTS Monthly Total Flow

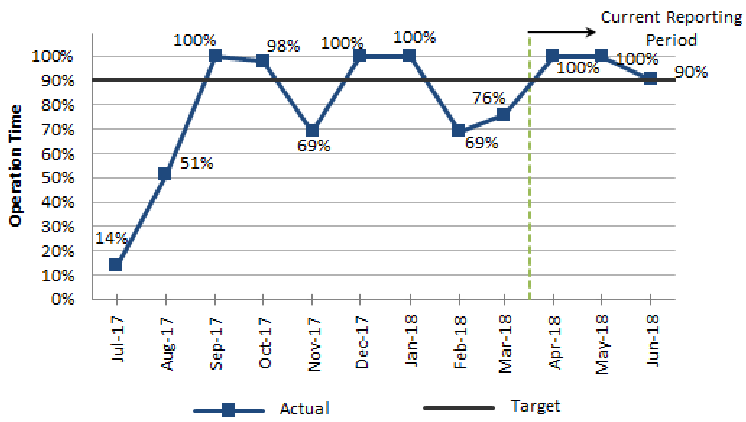


SEPTS Chromium Mass Removal by Month

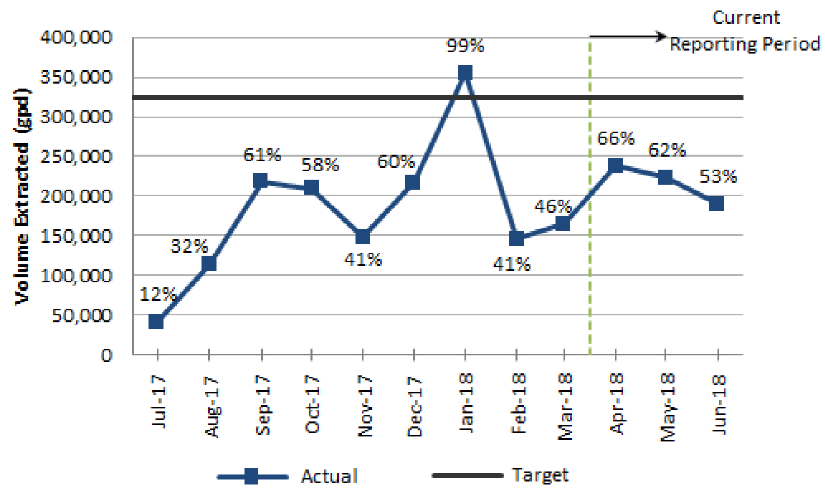


SEPTS HE Mass Removal by Month

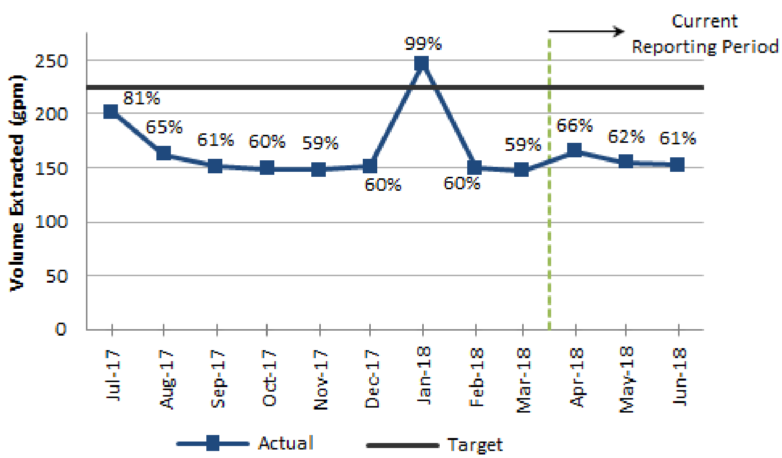
Playa 1 Pump and Treat System Graphs



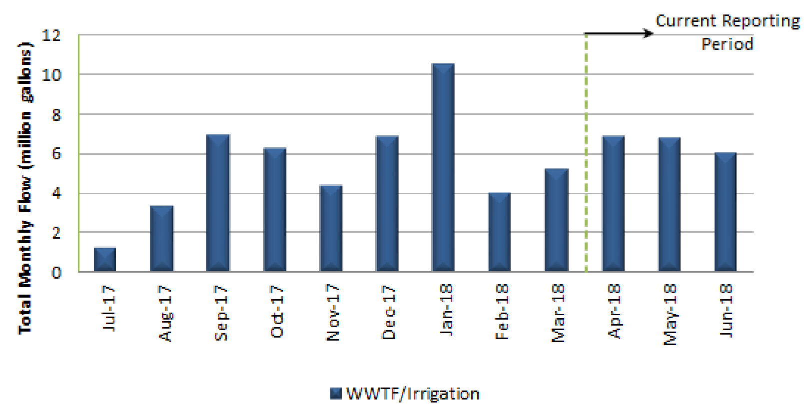
P1PTS Operational Time Vs Target



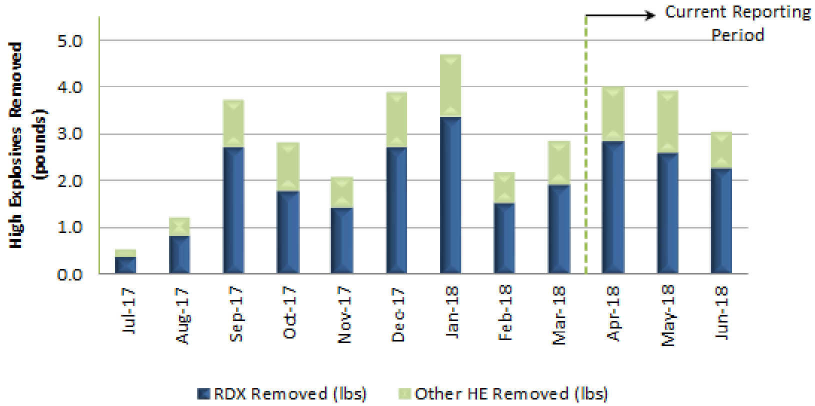
P1PTS Average GPD and % Capacity



P1PTS Average GPM and % Capacity



P1PTS Monthly System Total Flow



P1PTS HE Mass Removal by Month

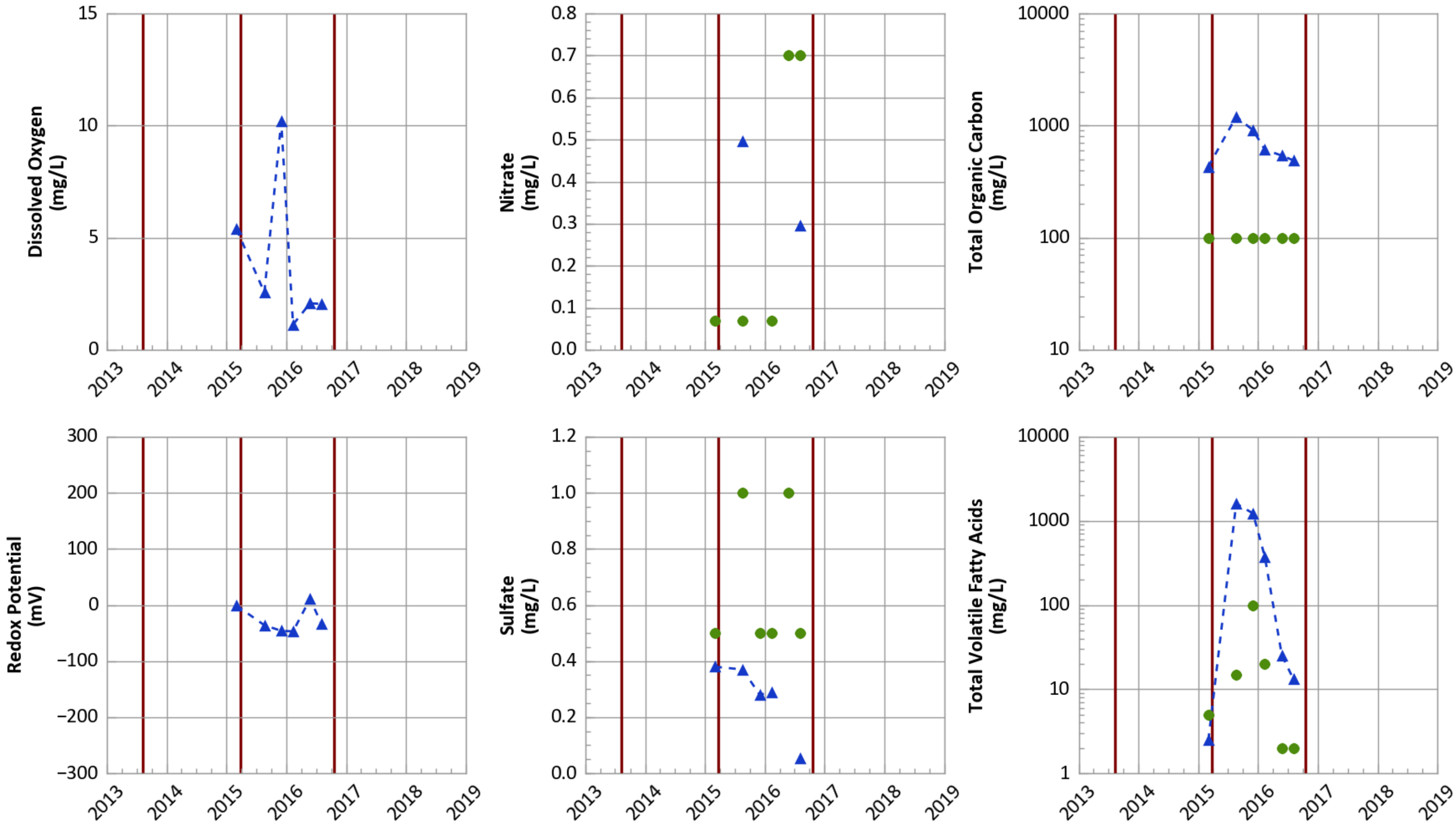
Appendix B Glossary

Operation Time	Operation time represents the percentage of the total number of hours the system was actually operated vs. the total possible hours the system could have operated on a monthly basis.
GPM Extraction	The gallons per minute (GPM) extraction rate represents the extraction rate from the well field while the system was operating. This is a measurement of the well field's capability to support the overall system throughput goals. Low well field rates can occur due to inoperable wells or decline in saturated thickness that makes extraction difficult.
GPD Extraction	The gallons per day (GPD) extraction rate represents the system's ability to meet overall throughput goals, considering the well field extraction rate and the system's operational rate. This rate is affected by the ability to extract water from the well field and the system downtime.
Total Monthly Flow	Total monthly flow is the total volume of extracted water measured at the influent point of the pump and treat system. Individual well measurements and flow rates are provided in the annual progress report.

Appendix C
ISB Graphs

Southeast ISB Graphs

PTX06-ISB014 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

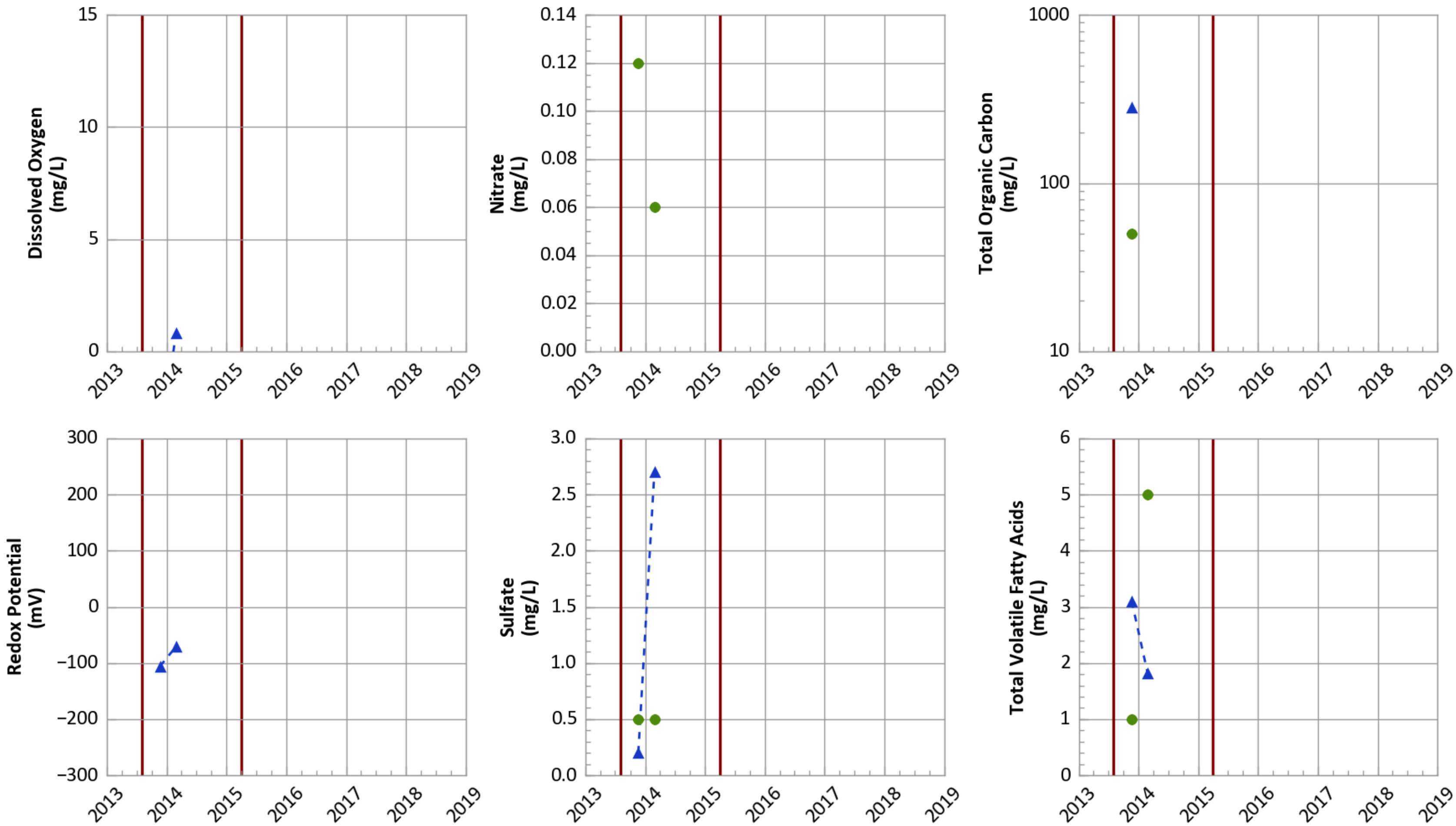


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Injection Dates

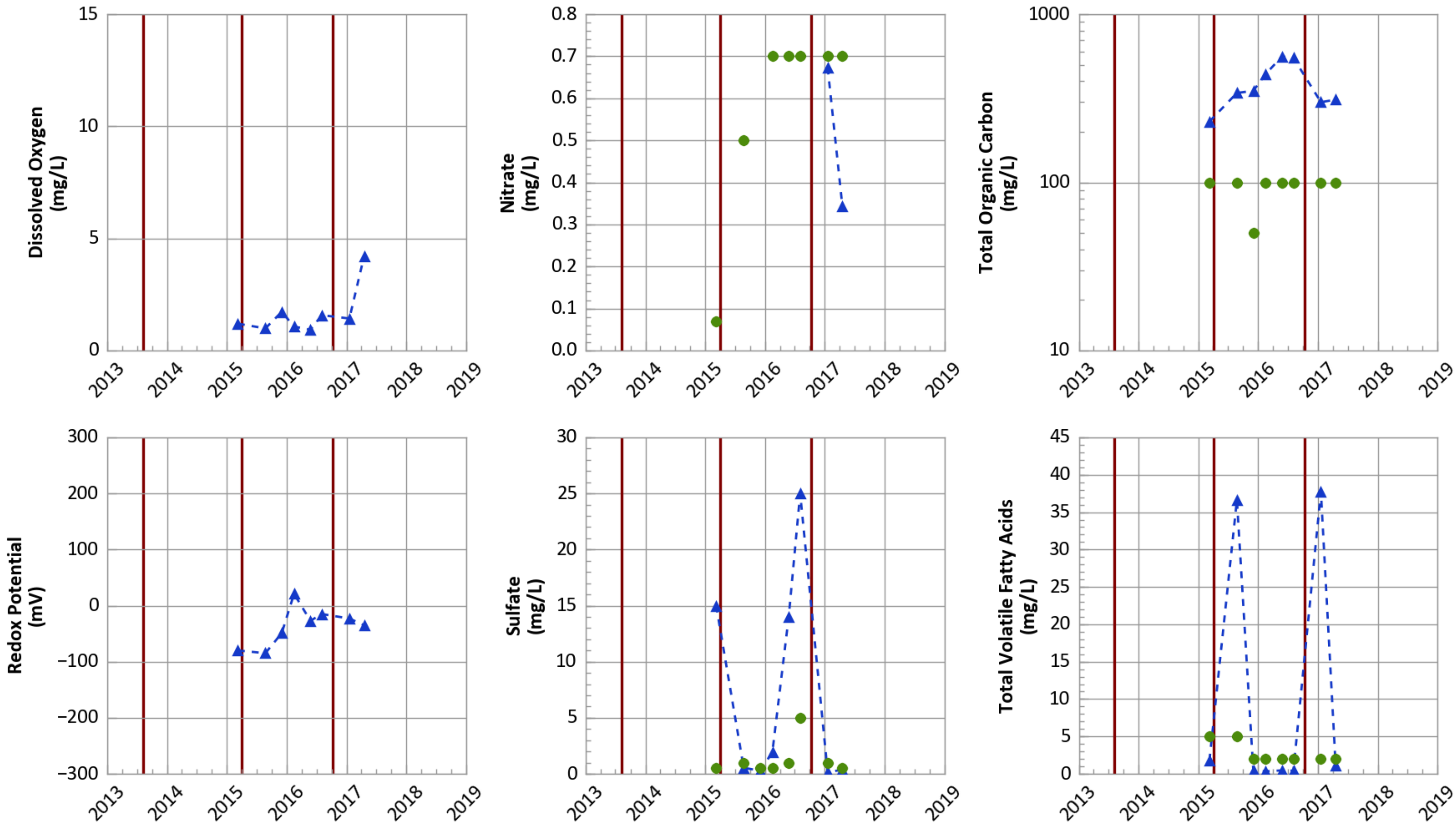
Well Location

PTX06-ISB019 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

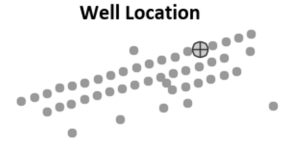
PTX06-ISB024 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



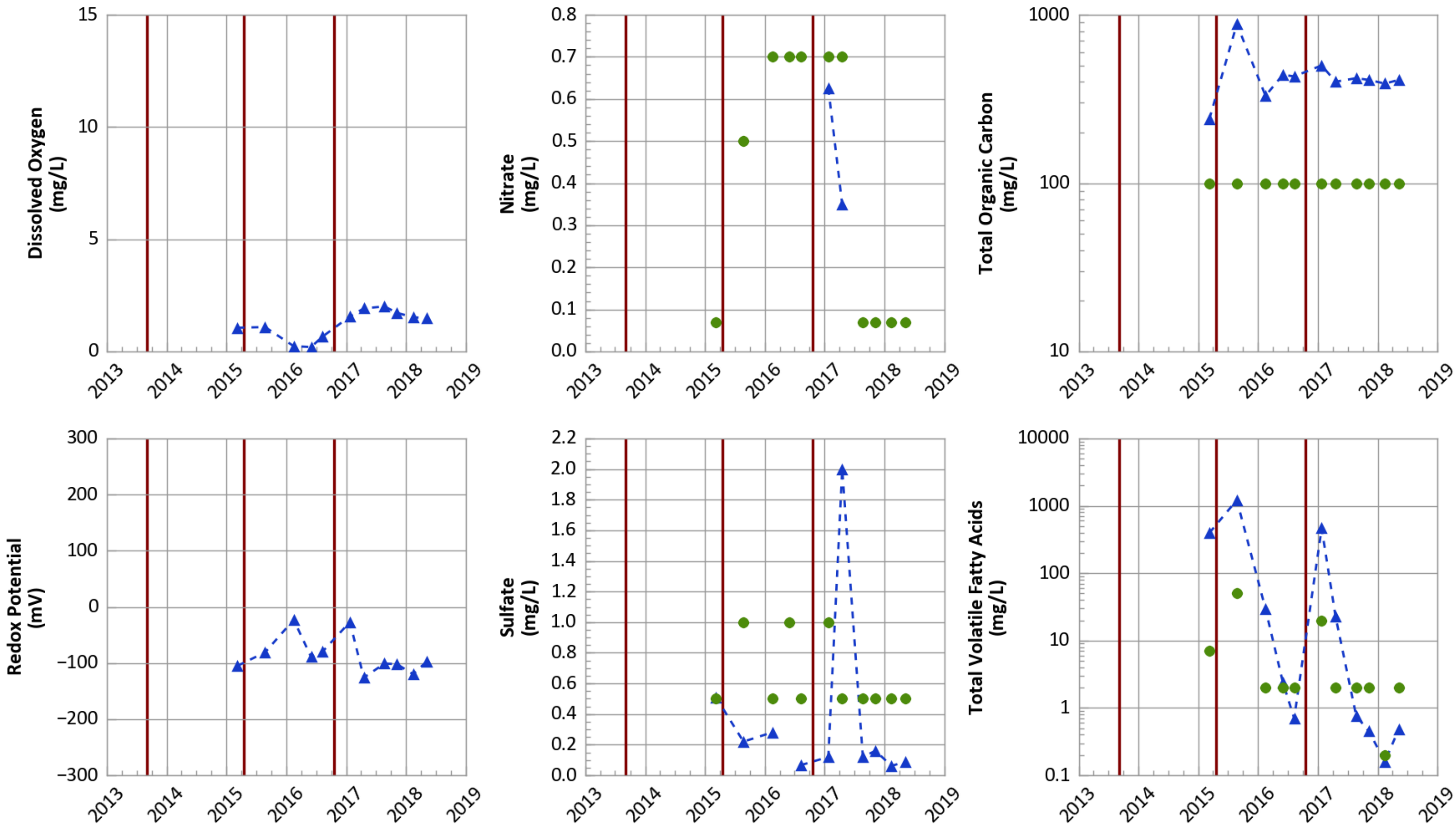
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Injection Dates

Well Location



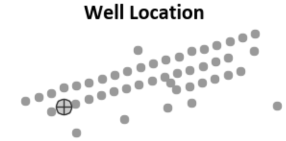
PTX06-ISB030B Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



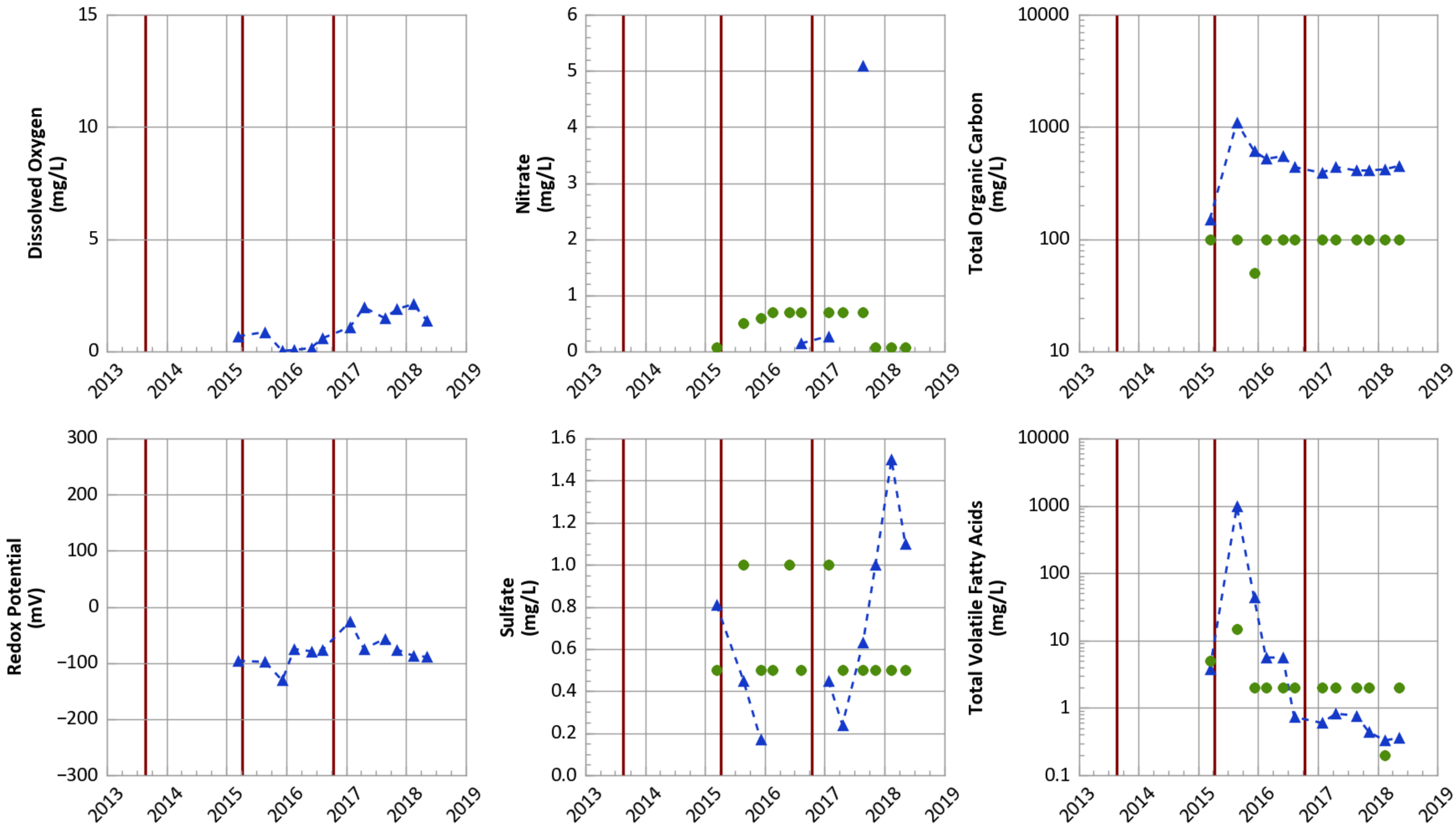
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

Measured Value
Sample Detection Limit
Concentration Trend
Injection Dates

Well Location



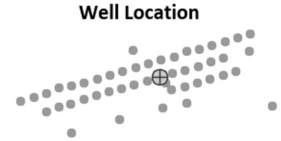
PTX06-ISB038 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



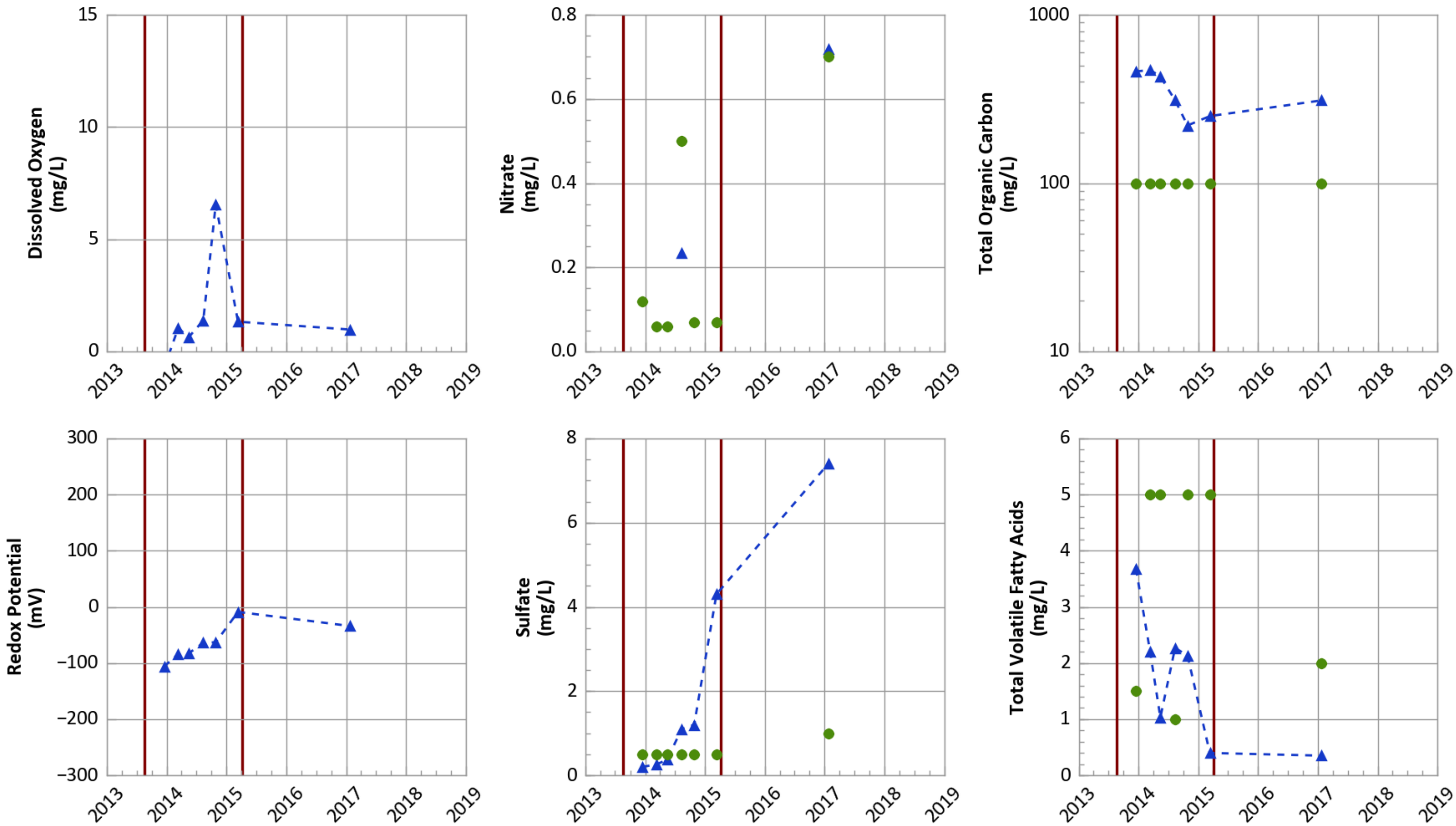
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

▲ Measured Value
● Sample Detection Limit
Concentration Trend
Injection Dates

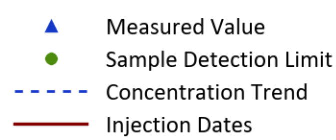
Well Location

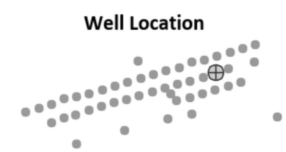


PTX06-ISB042 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

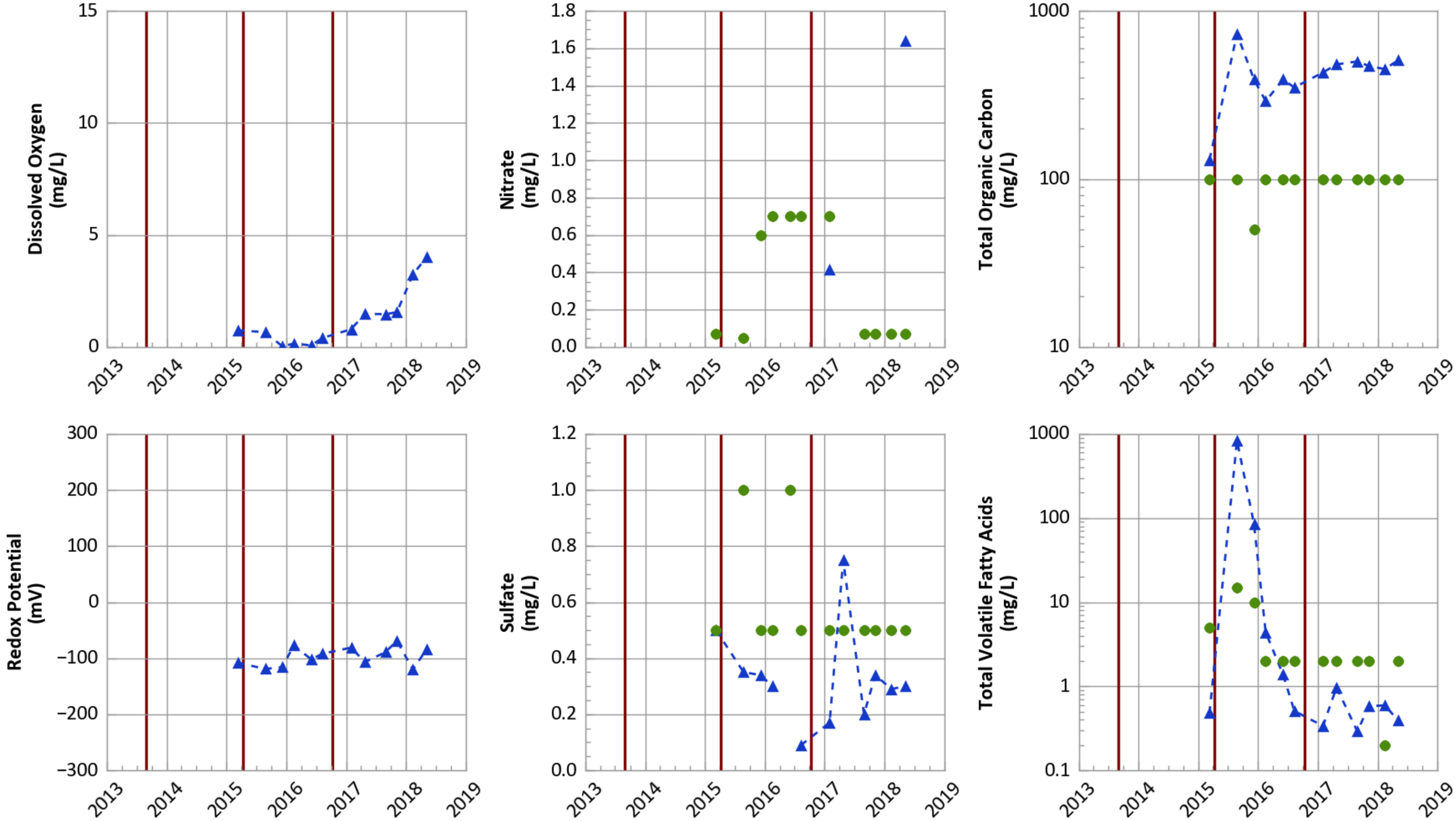


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected





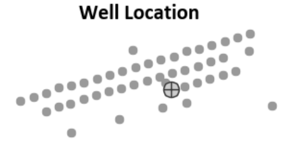
PTX06-ISB046 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



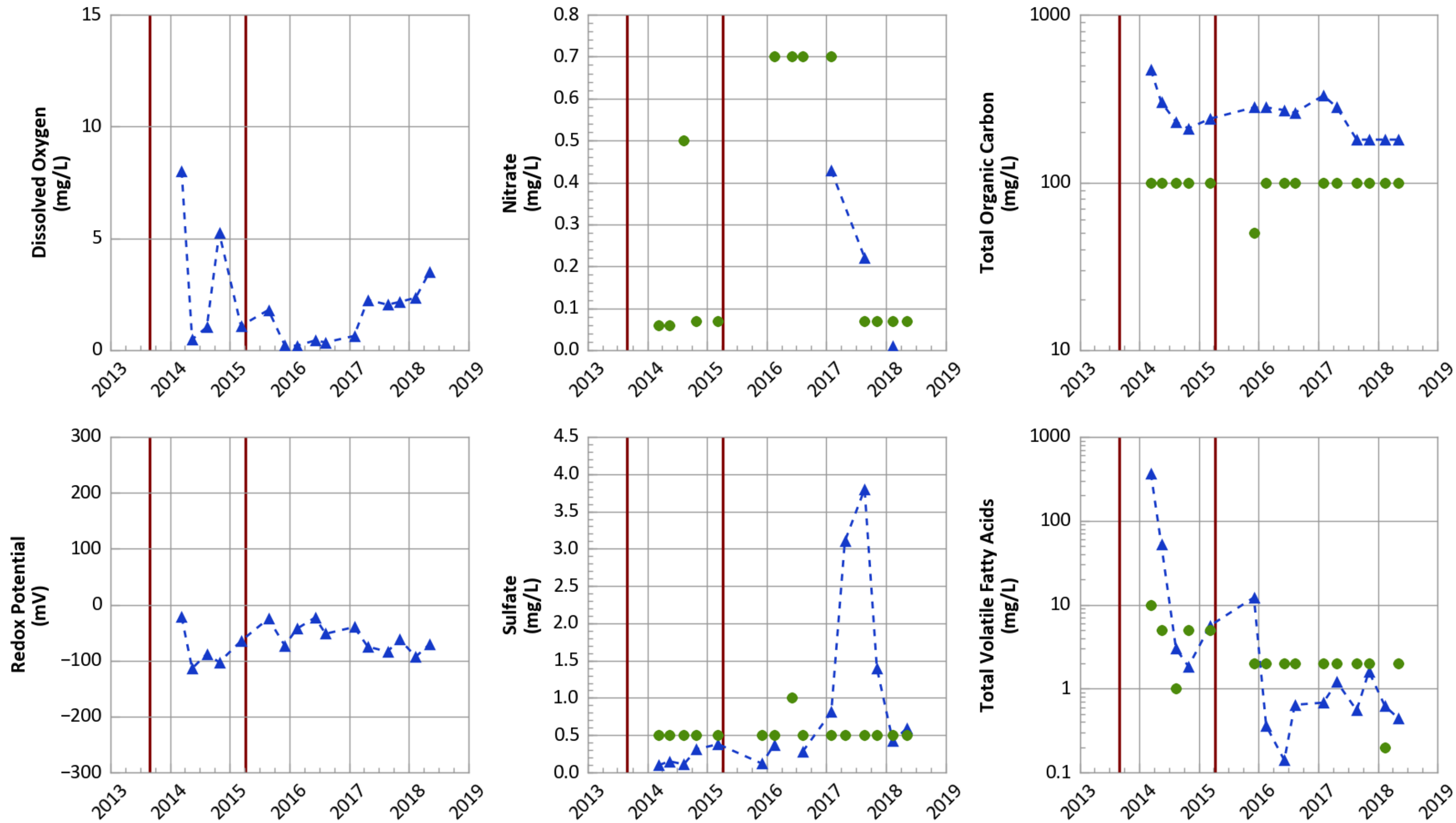
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

- ▲ Measured Value
- ● Sample Detection Limit
- - - - Concentration Trend
- —— Injection Dates

Well Location

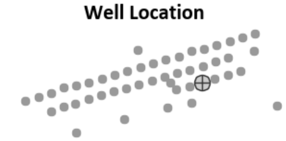


PTX06-ISB048 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

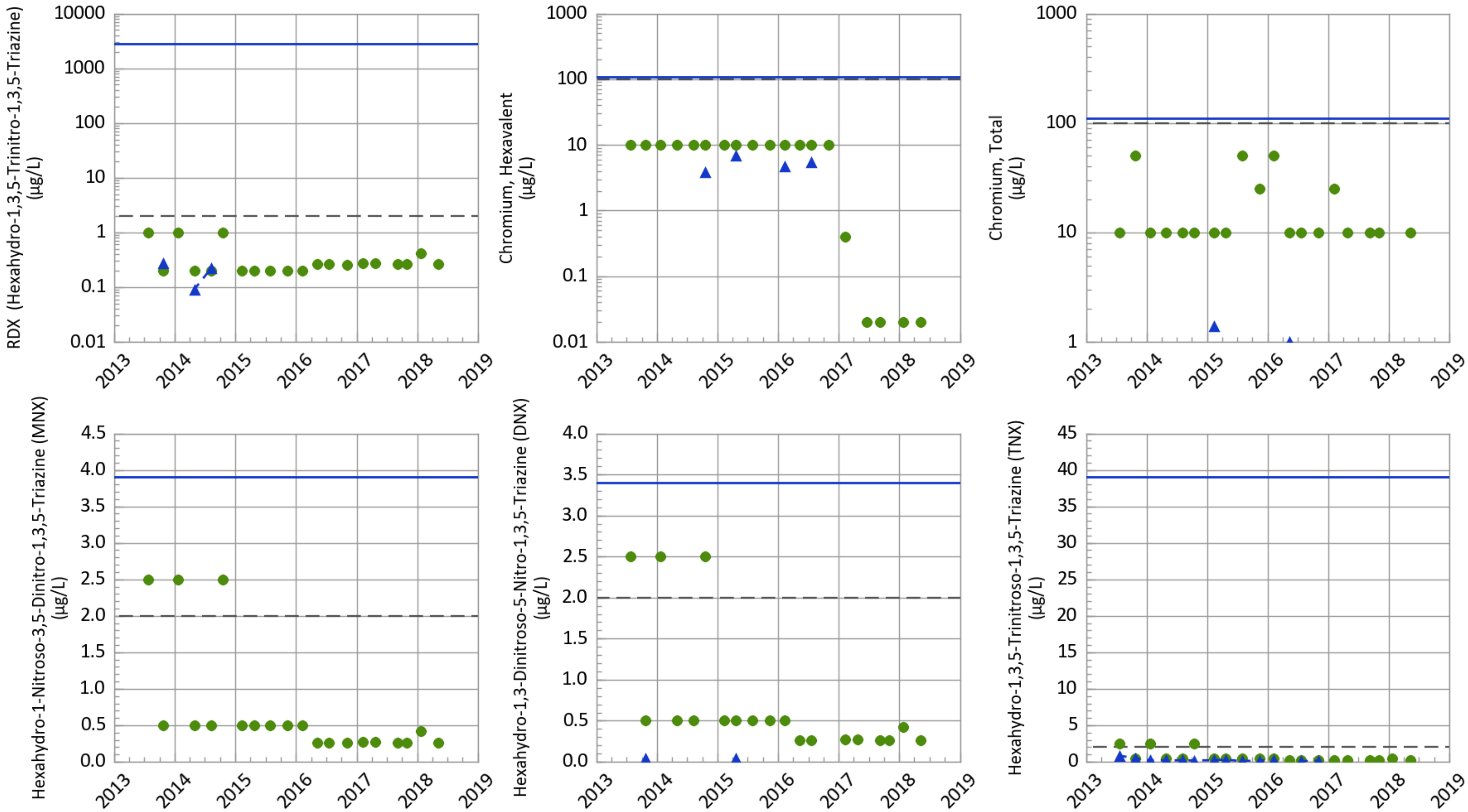


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

Well Location



PTX06-1037 Downgradient Performance Indicators
Southeast In Situ Bioremediation System
USDOE/NNSA Pantex Plant

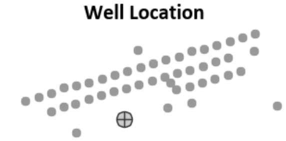


Most Recent Measured COC Concentrations (Nov 02, 2016)

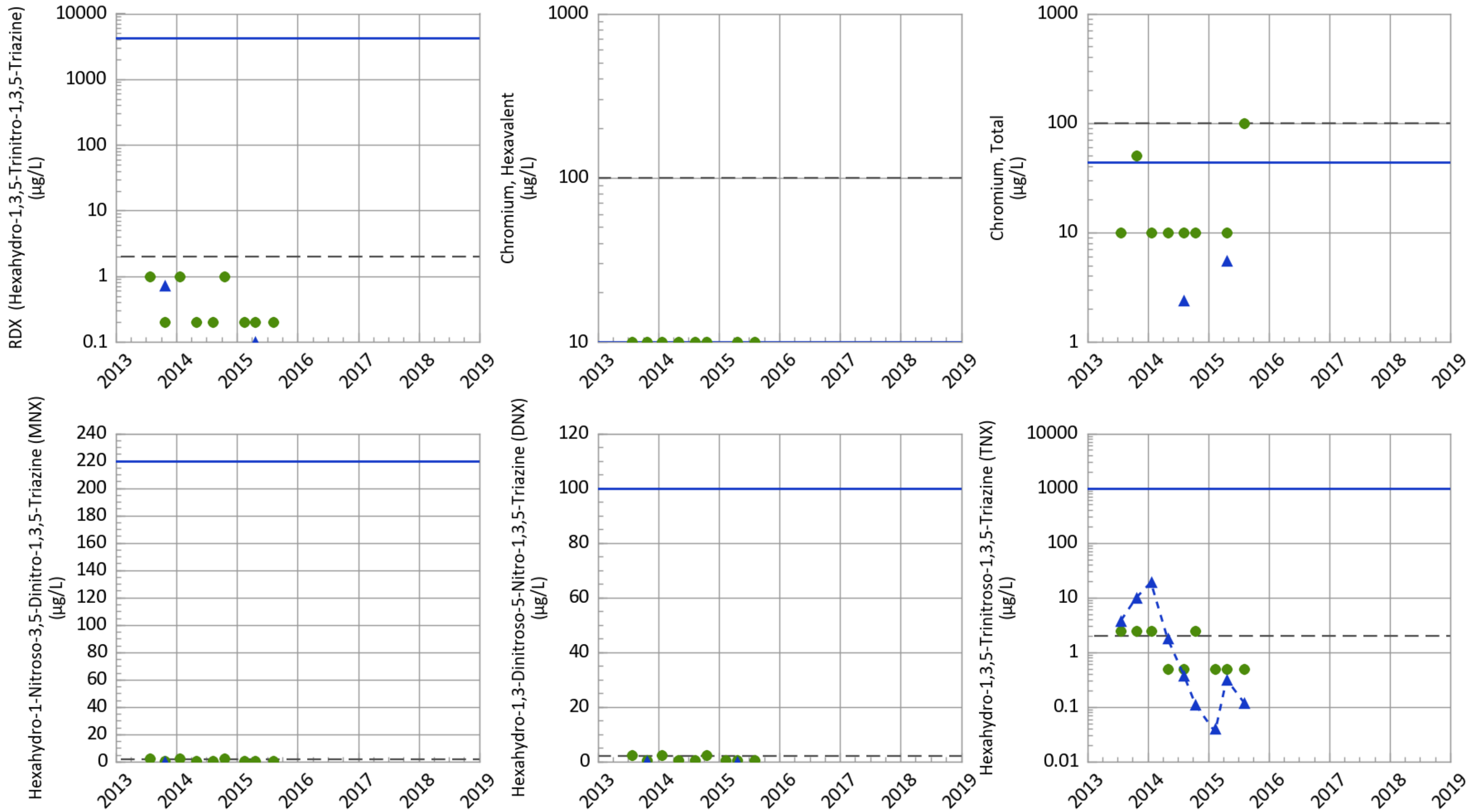
COC	Concentration (µg/L)	GWPS (µg/L)
RDX	Non-Detect	2.0
MNX	Non-Detect	2.0
CR-6	Non-Detect	100.0
DNX	Non-Detect	2.0
CR	Non-Detect	100.0
TNX	Non-Detect	2.0

▲ Measured Value
● Sample Detection Limit
- - - - Concentration Trend
—— Maximum Concentration
— — Groundwater Protection Standard

Well Location

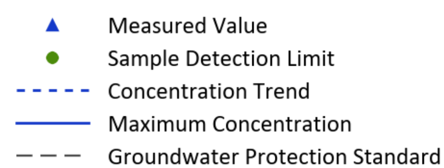


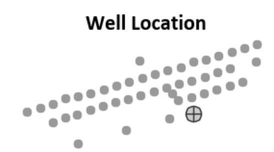
PTX06-1123 Downgradient Performance Indicators
Southeast In Situ Bioremediation System
USDOE/NNSA Pantex Plant



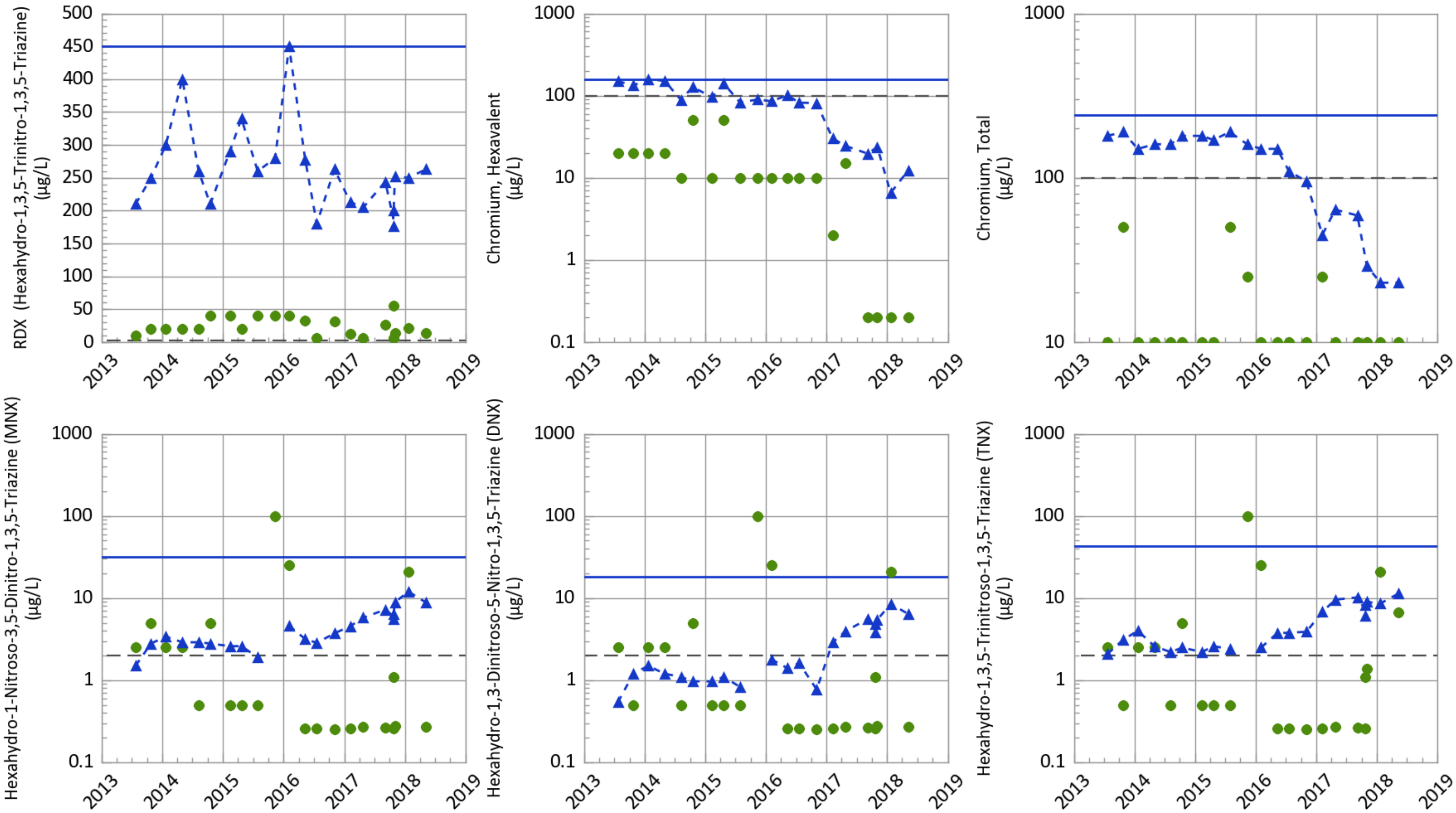
Most Recent Measured COC Concentrations (Aug 05, 2015)

COC	Concentration (µg/L)	GWPS (µg/L)
RDX	Non-Detect	2.0
MNX	Non-Detect	2.0
CR-6	Non-Detect	100.0
DNX	Non-Detect	2.0
CR	Non-Detect	100.0
TNX	0.12	2.0





PTX06-1153 Downgradient Performance Indicators
Southeast In Situ Bioremediation System
USDOE/NNSA Pantex Plant

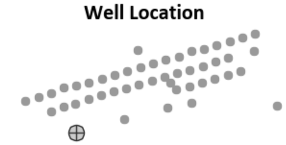


Most Recent Measured COC Concentrations (May 09, 2018)

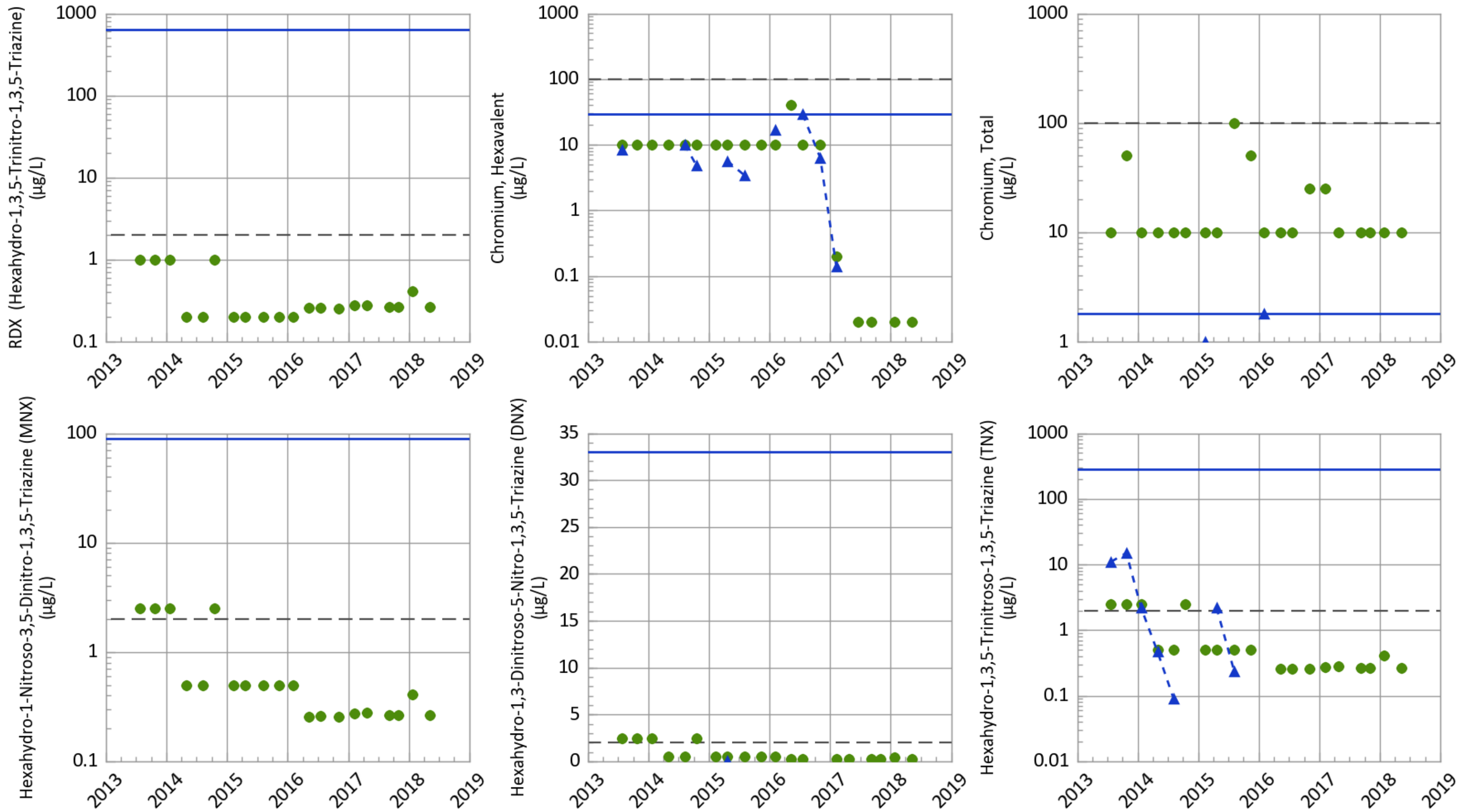
COC	Concentration (µg/L)	GWPS (µg/L)
RDX	263.0	2.0
MNX	8.82	2.0
CR-6	12.39	100.0
DNX	6.39	2.0
CR	23.0	100.0
TNX	11.3	2.0

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Maximum Concentration
— — Groundwater Protection Standard

Well Location



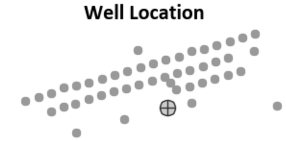
PTX06-1154 Downgradient Performance Indicators
Southeast In Situ Bioremediation System
USDOE/NNSA Pantex Plant



Most Recent Measured COC Concentrations (Aug 05, 2015)

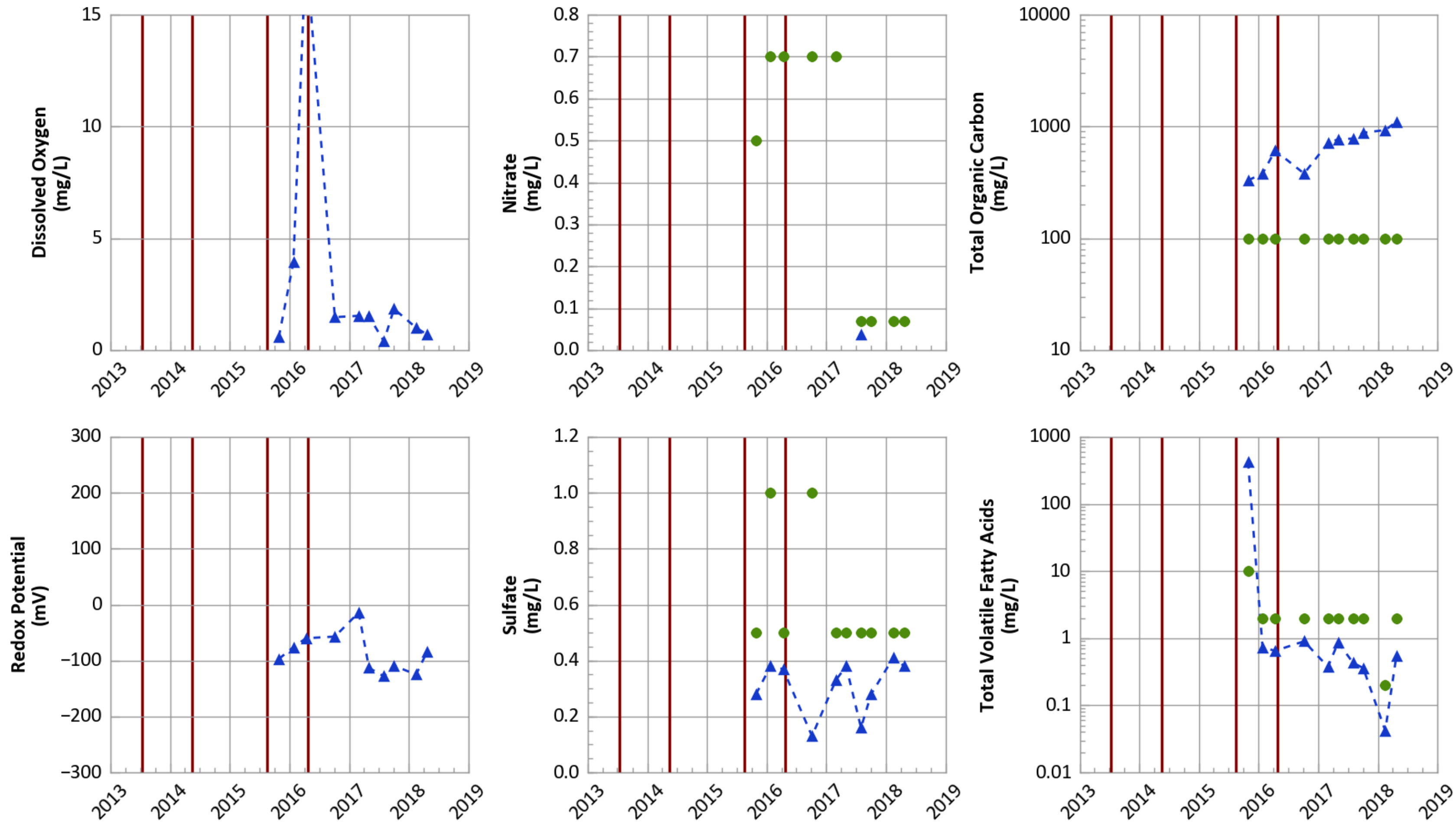
COC	Concentration (µg/L)	GWPS (µg/L)
RDX	Non-Detect	2.0
MNX	Non-Detect	2.0
CR-6	Non-Detect	100.0
DNX	Non-Detect	2.0
CR	Non-Detect	100.0
TNX	Non-Detect	2.0

Well Location



Zone 11 ISB Graphs

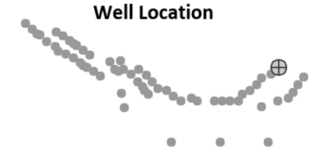
PTX06-ISB055 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

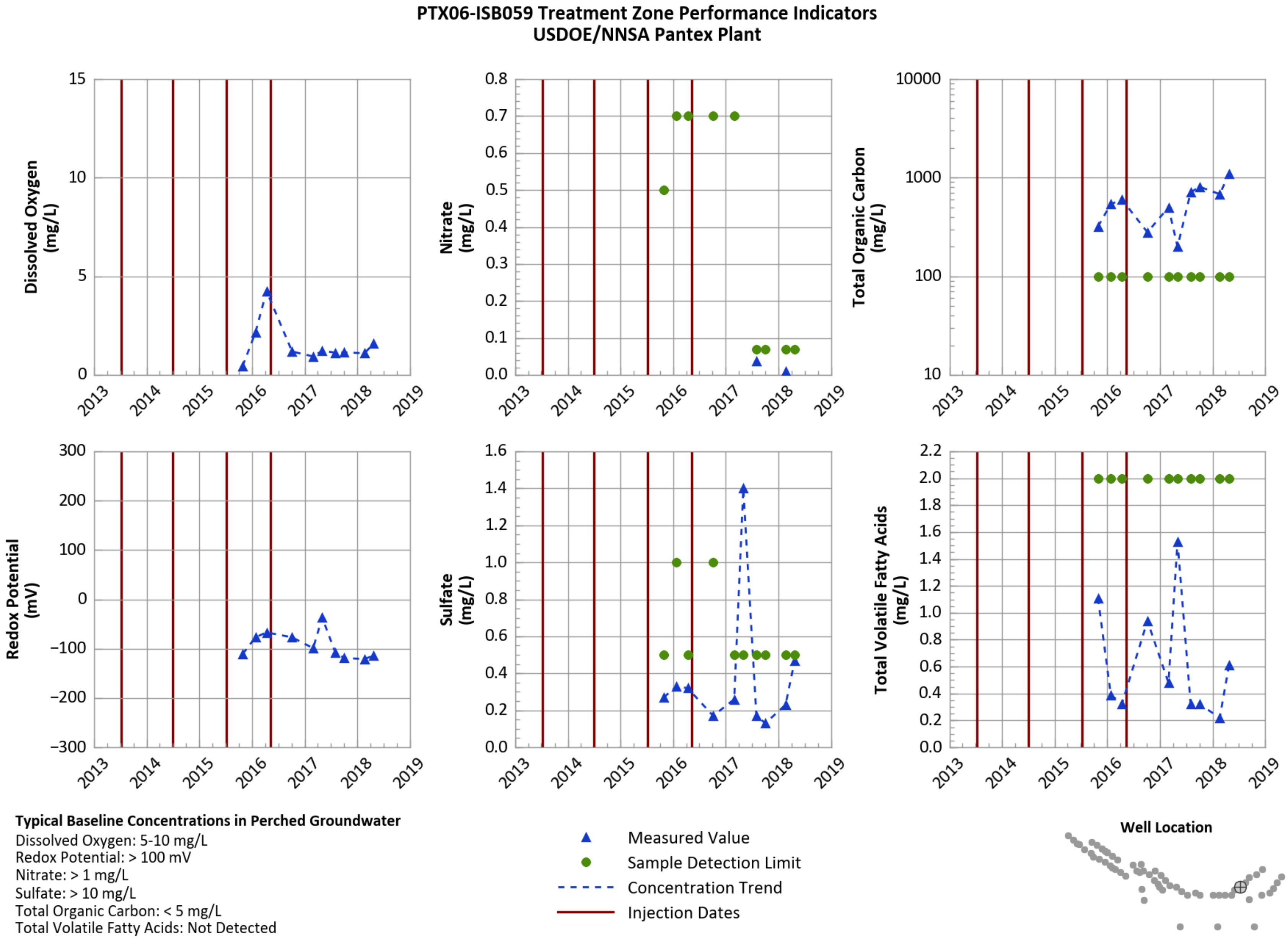


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

- ▲ Measured Value
- ● Sample Detection Limit
- - - - Concentration Trend
- ─── Injection Dates

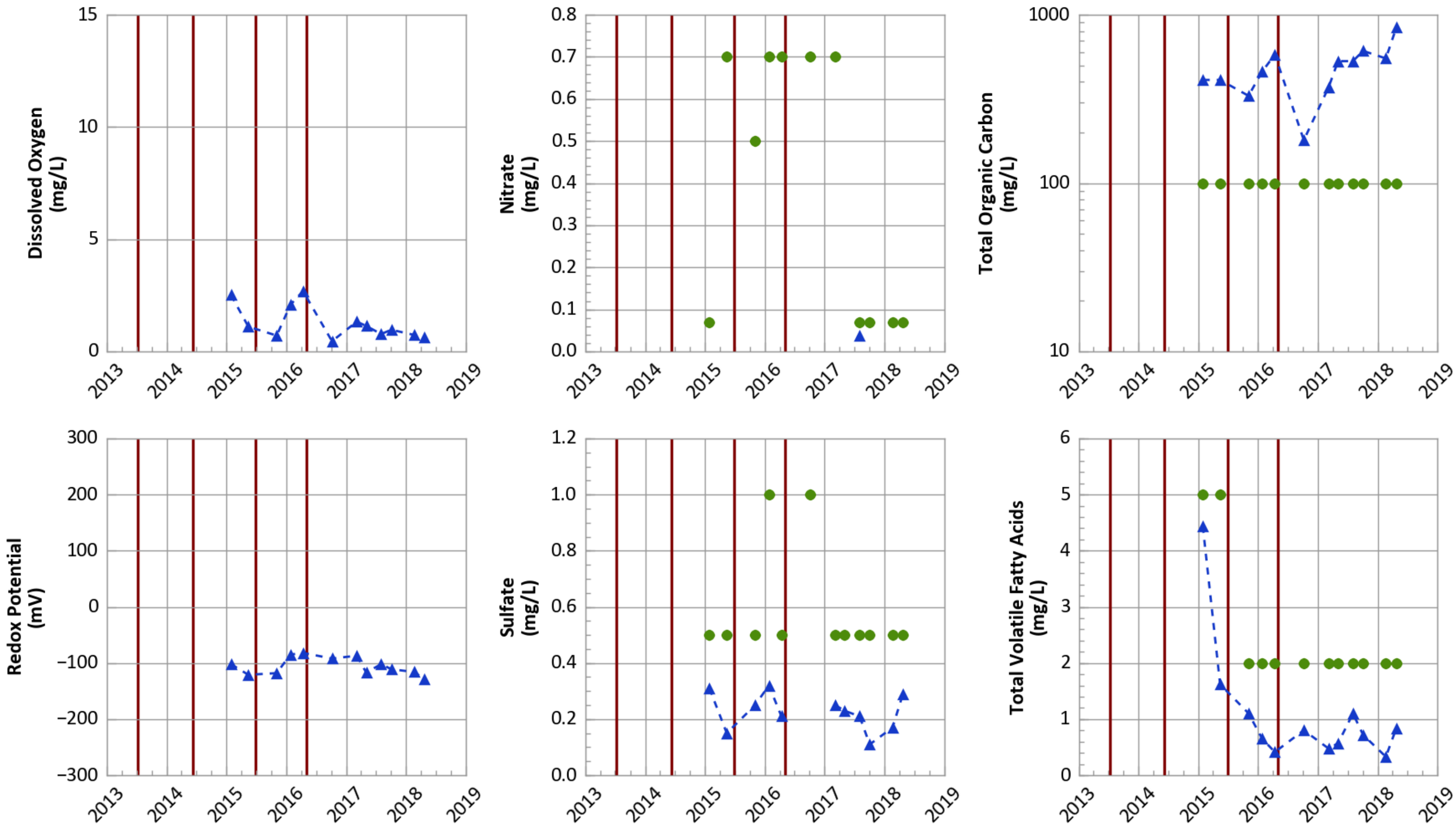
Well Location





Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

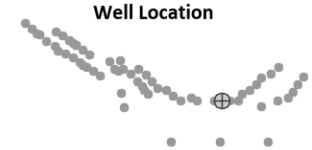
PTX06-ISB063 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

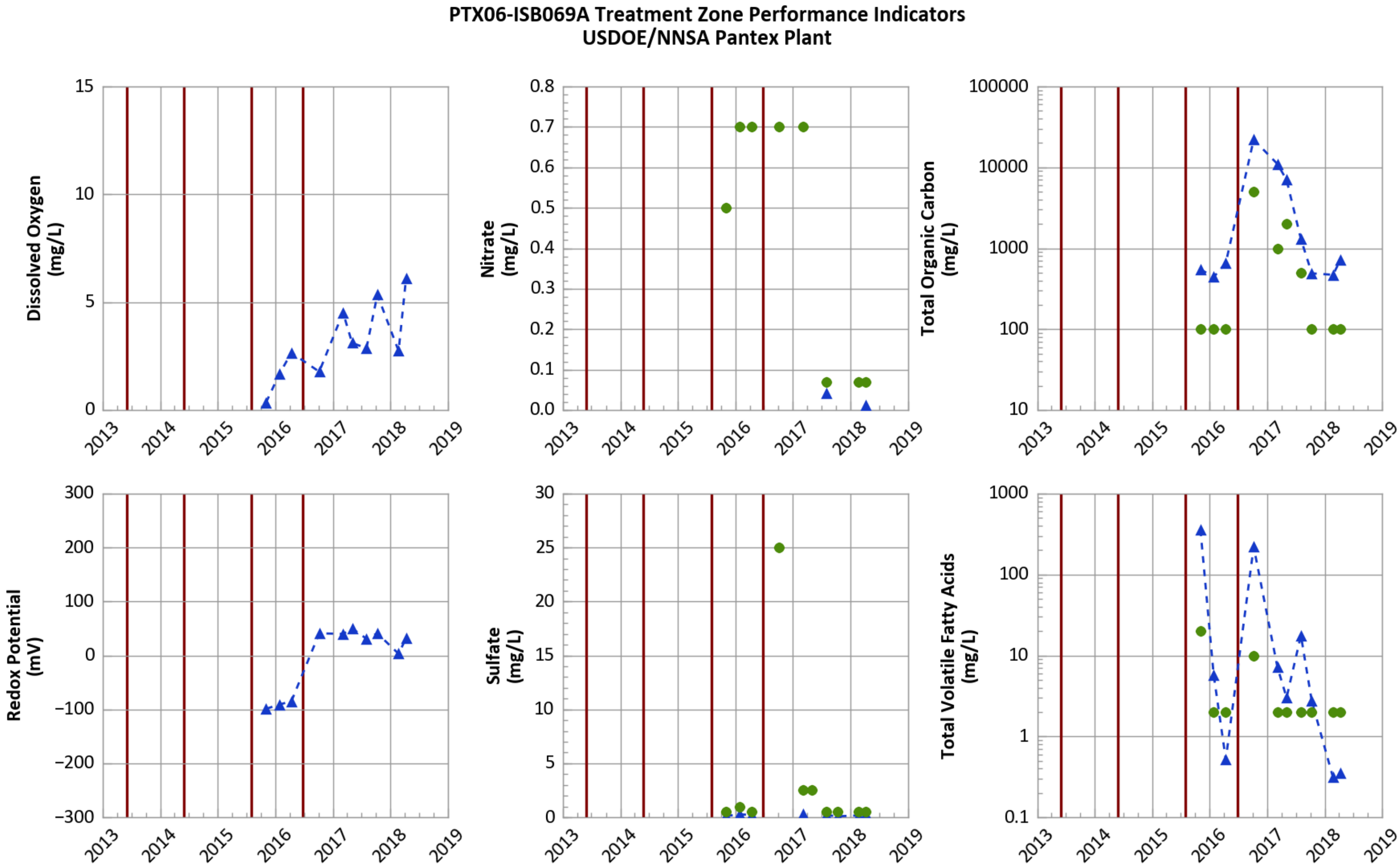


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

Measured Value
Sample Detection Limit
Concentration Trend
Injection Dates

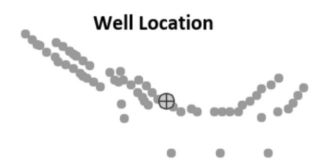
Well Location



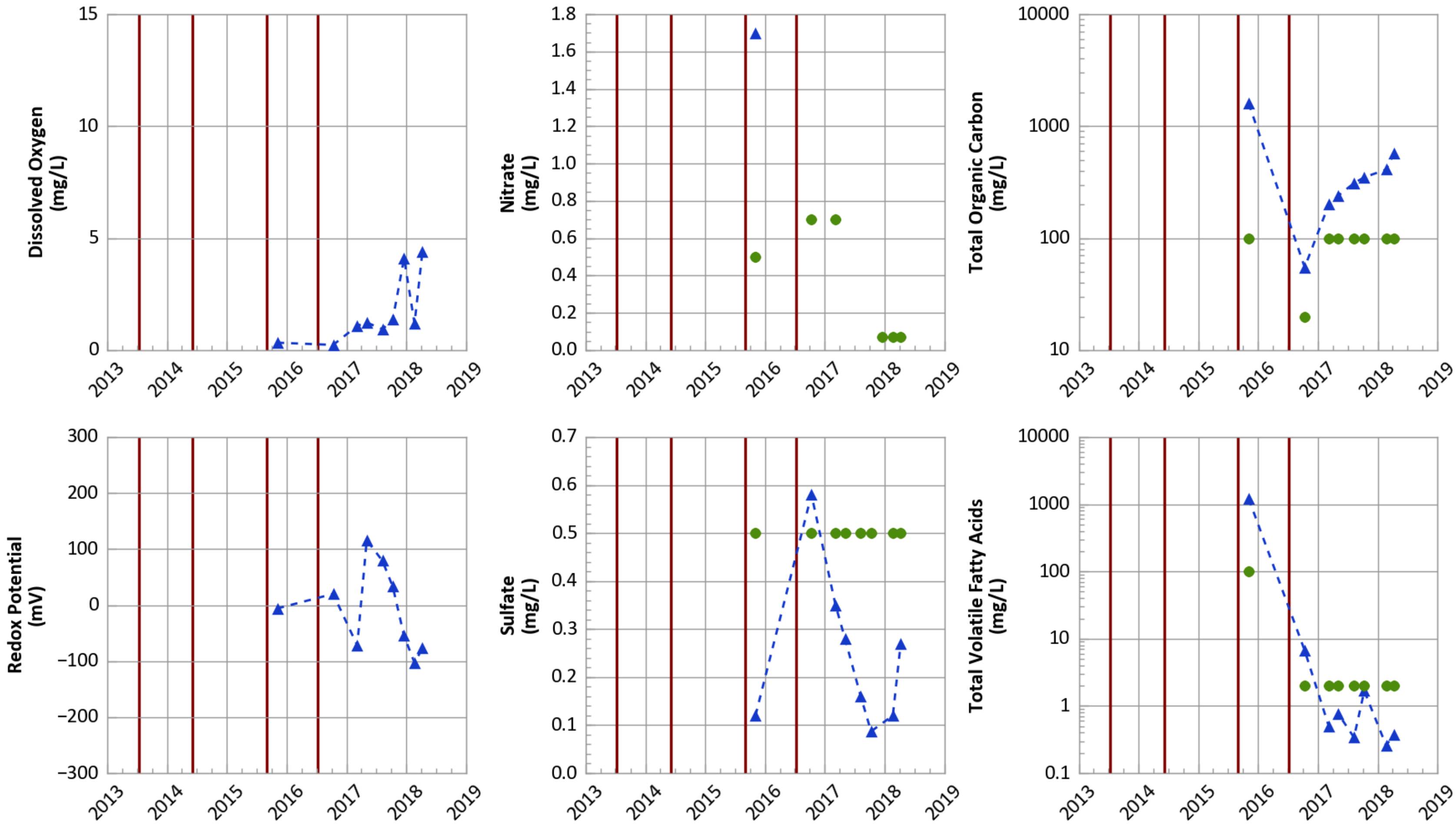


Typical Baseline Concentrations in Perched Groundwater

Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected



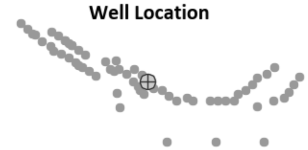
PTX06-ISB071 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

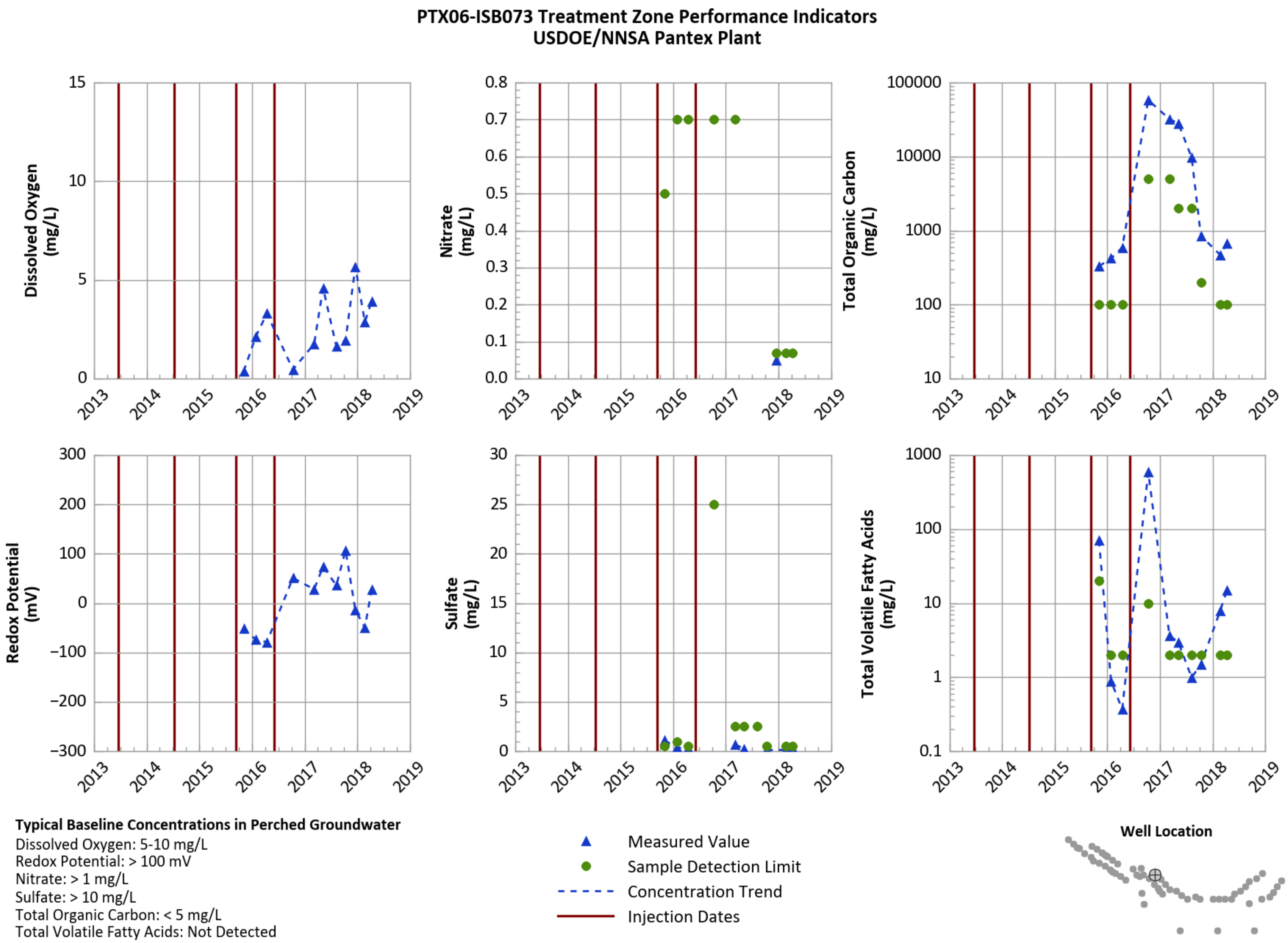


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Injection Dates

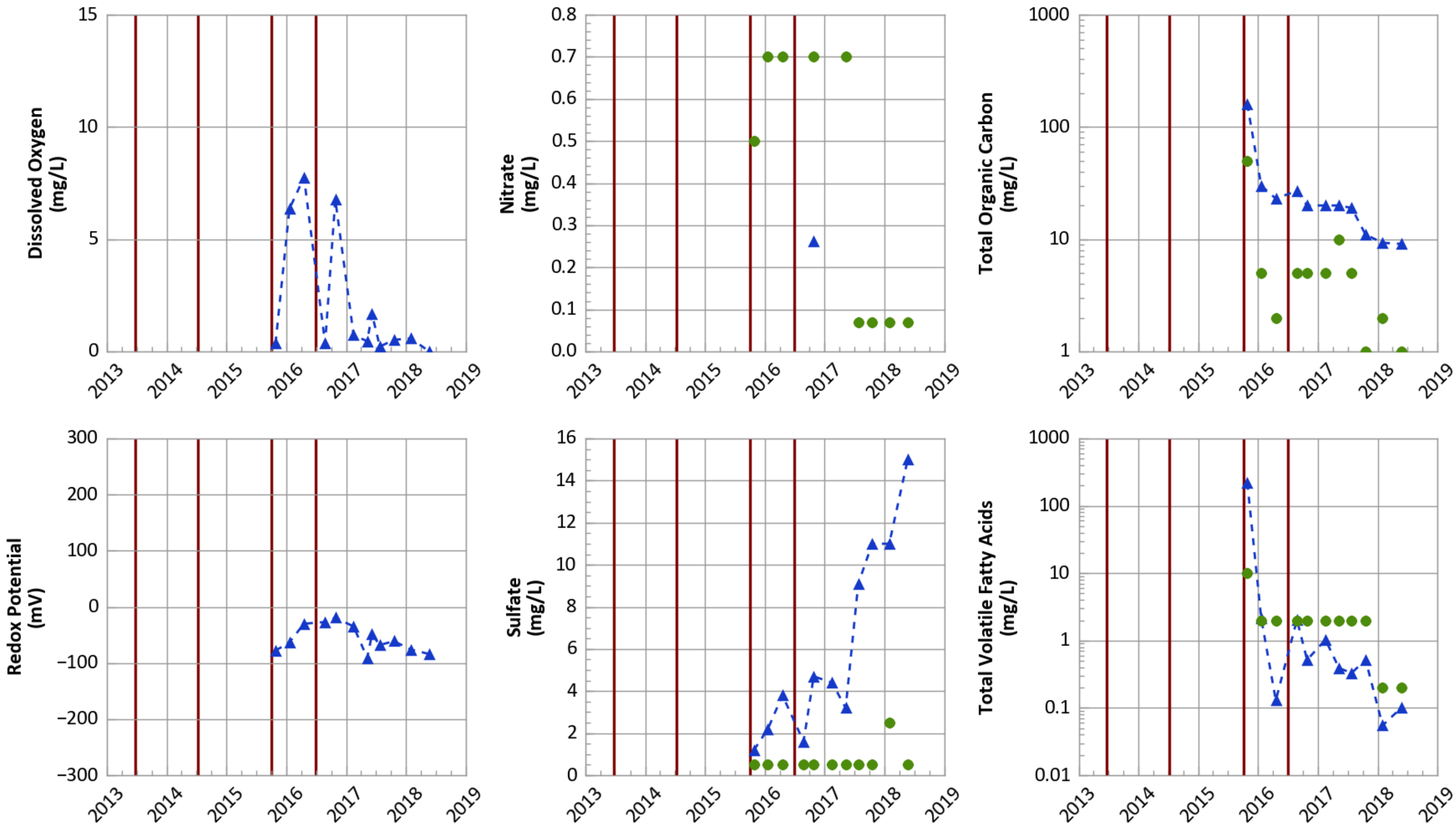
Well Location





Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

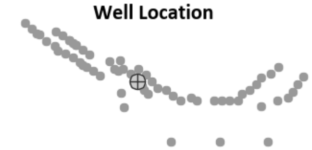
PTX06-ISB075 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

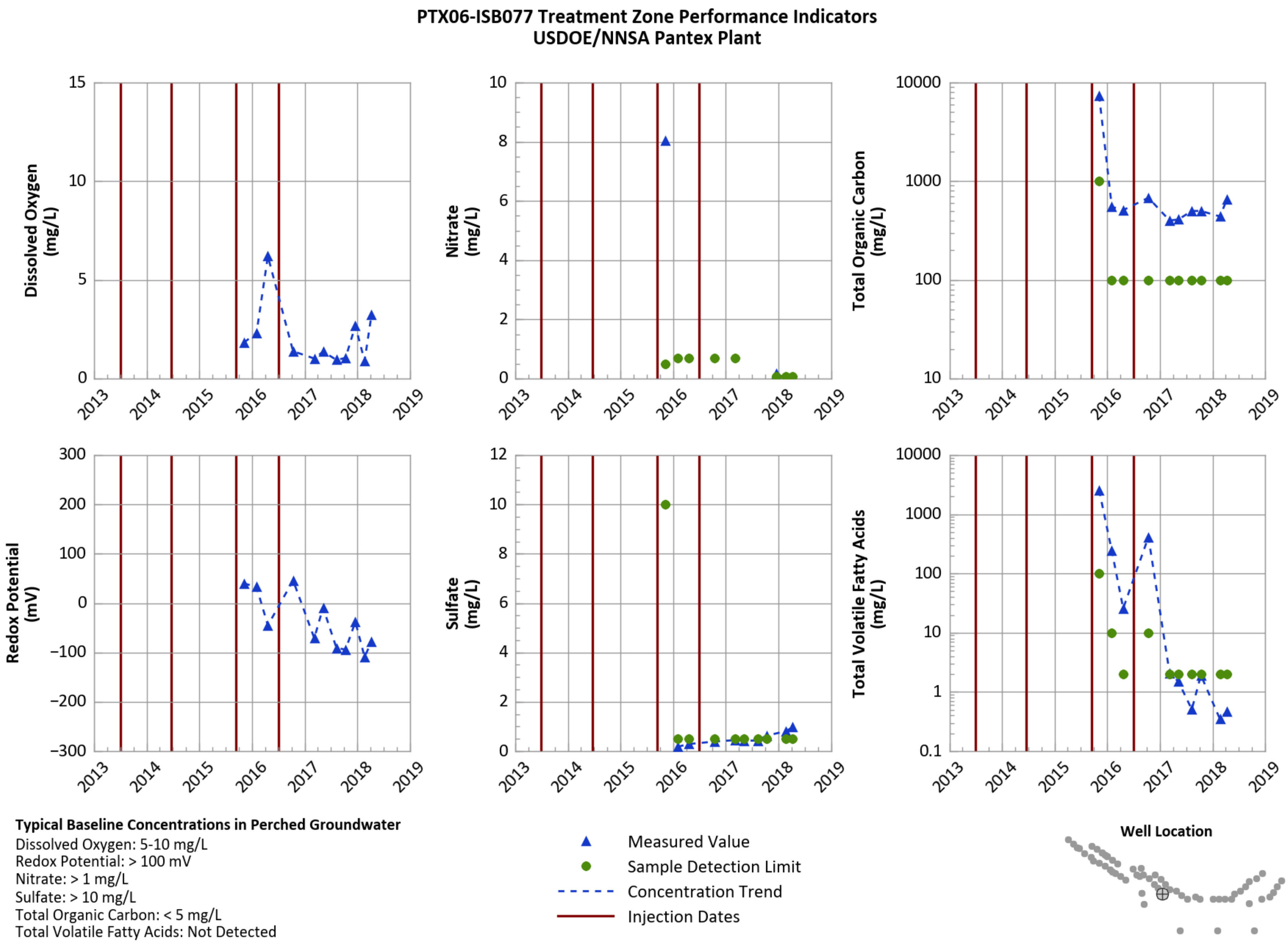


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

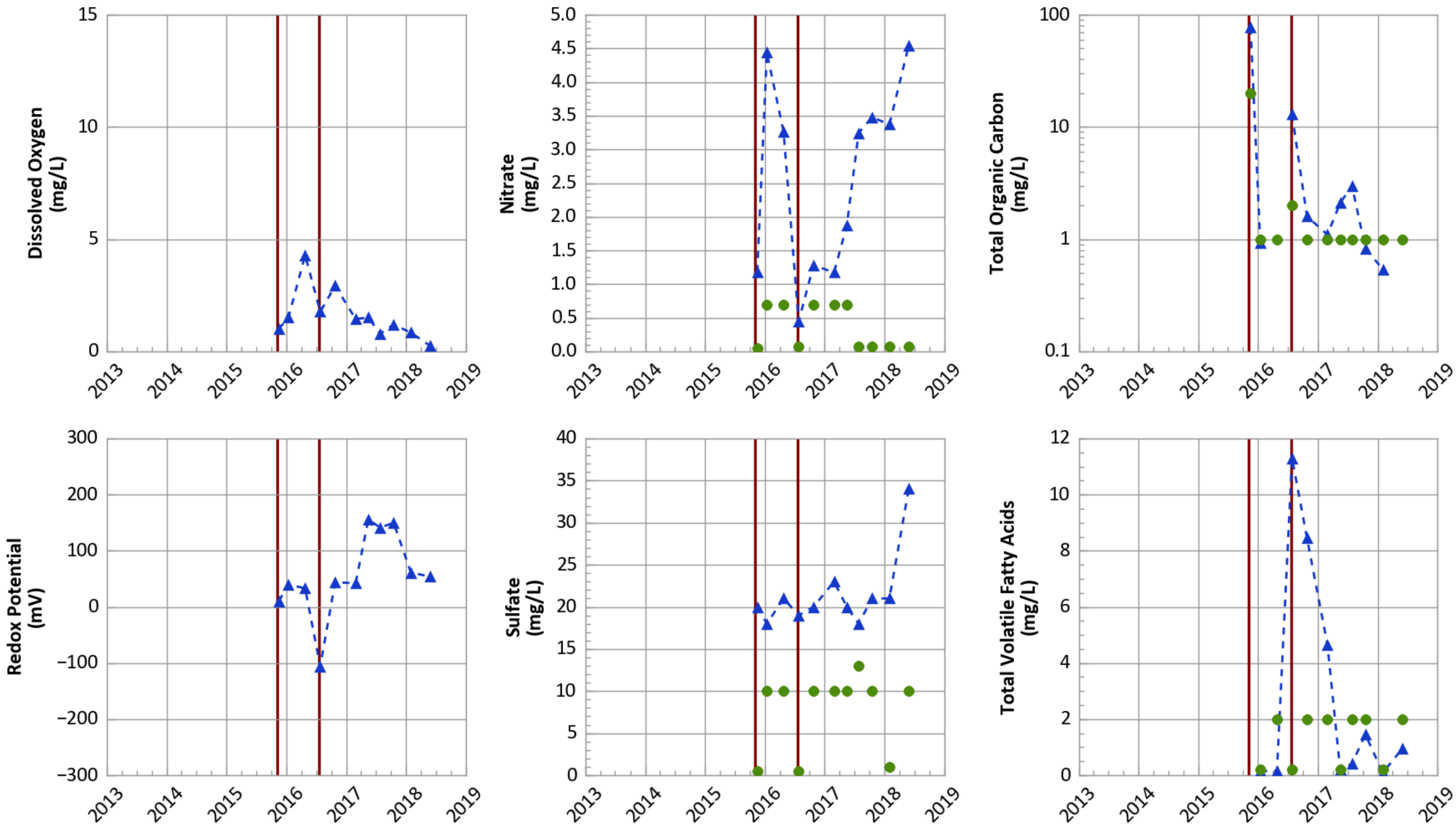
Measured Value
Sample Detection Limit
Concentration Trend
Injection Dates

Well Location




PTX06-ISB077 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant
Dissolved Oxygen (mg/L)
Nitrate (mg/L)
Total Organic Carbon (mg/L)
Redox Potential (mV)
Sulfate (mg/L)
Total Volatile Fatty Acids (mg/L)
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected
Measured Value
Sample Detection Limit
Concentration Trend
Injection Dates
Well Location

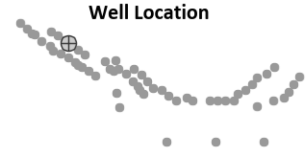
PTX06-1164 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



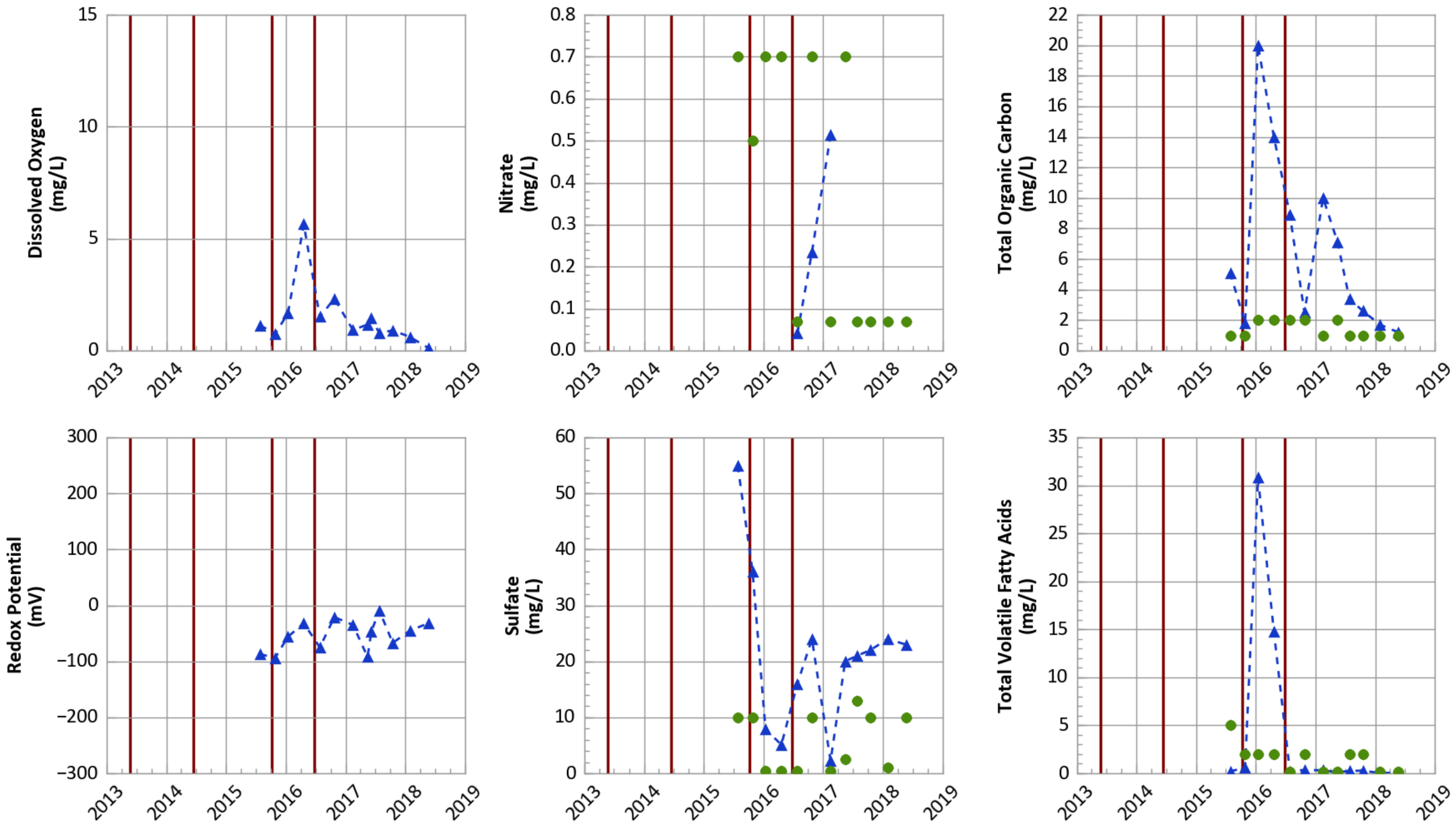
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Injection Dates

Well Location

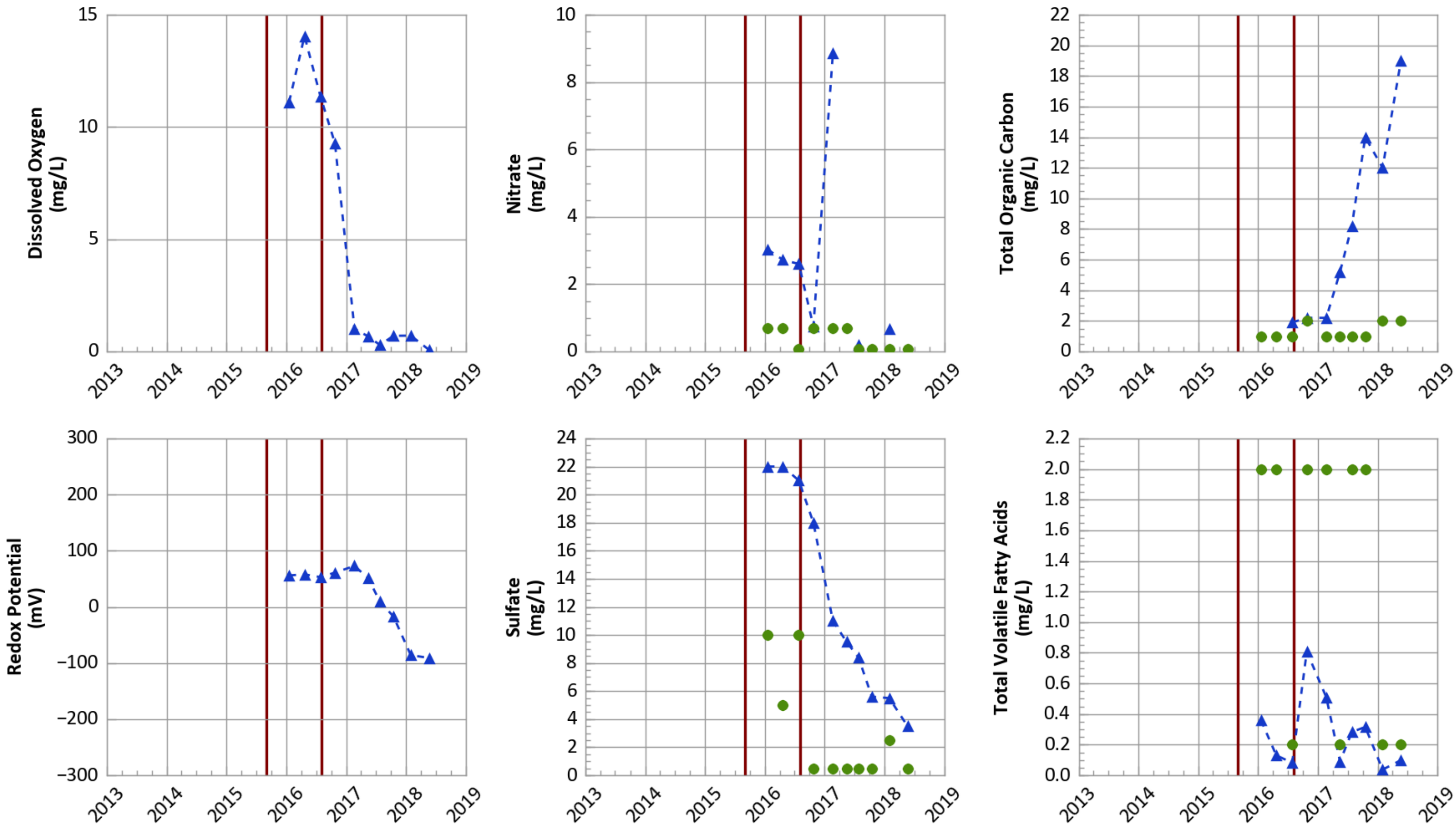


PTX06-1170 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

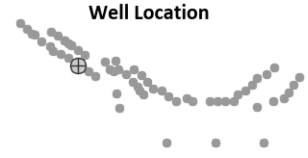
PTX06-1176 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant



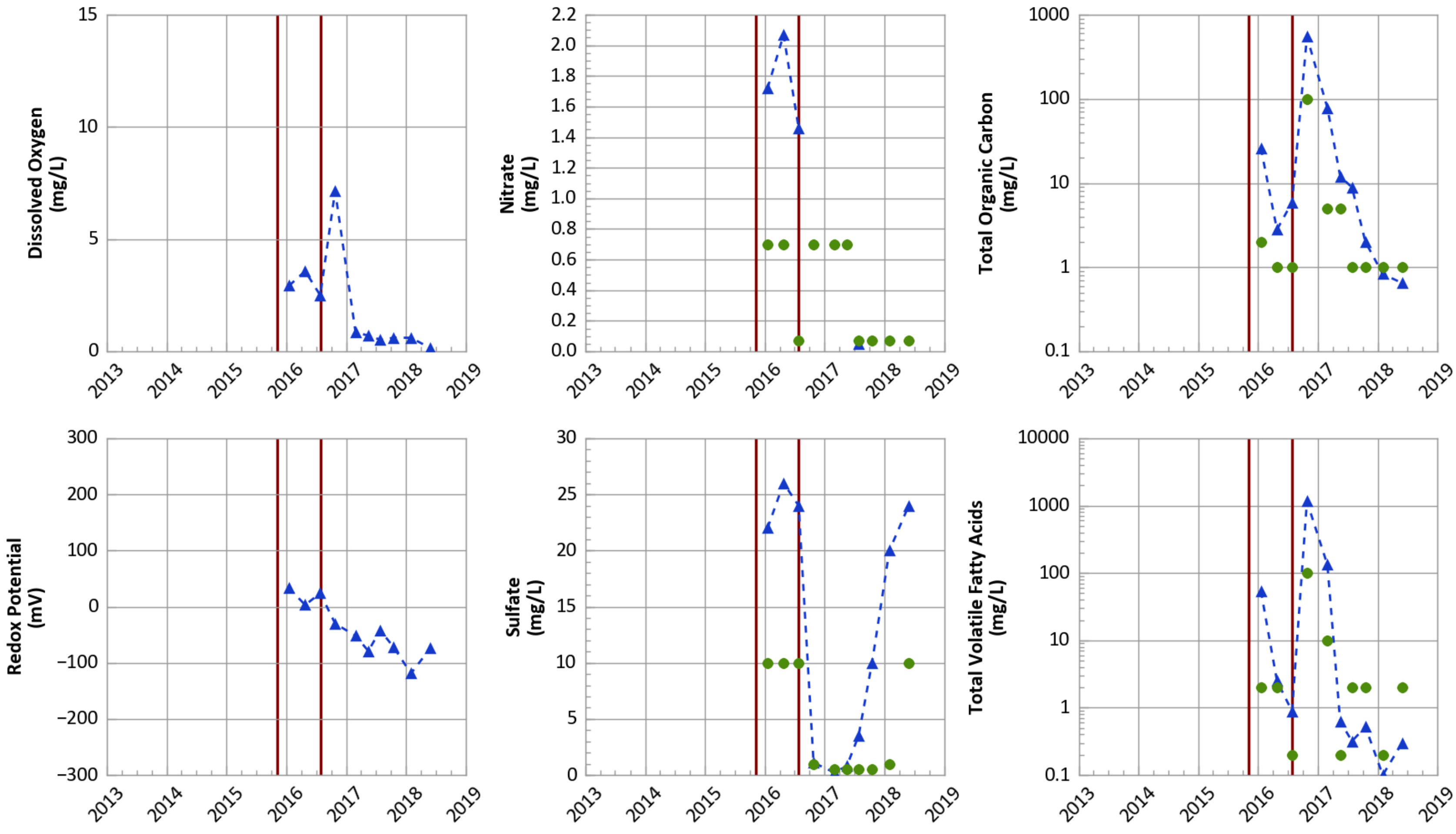
Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

Measured Value
Sample Detection Limit
Concentration Trend
Injection Dates

Well Location

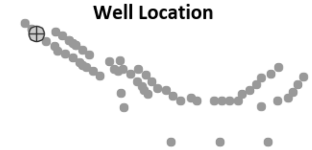


PTX06-1177 Treatment Zone Performance Indicators
USDOE/NNSA Pantex Plant

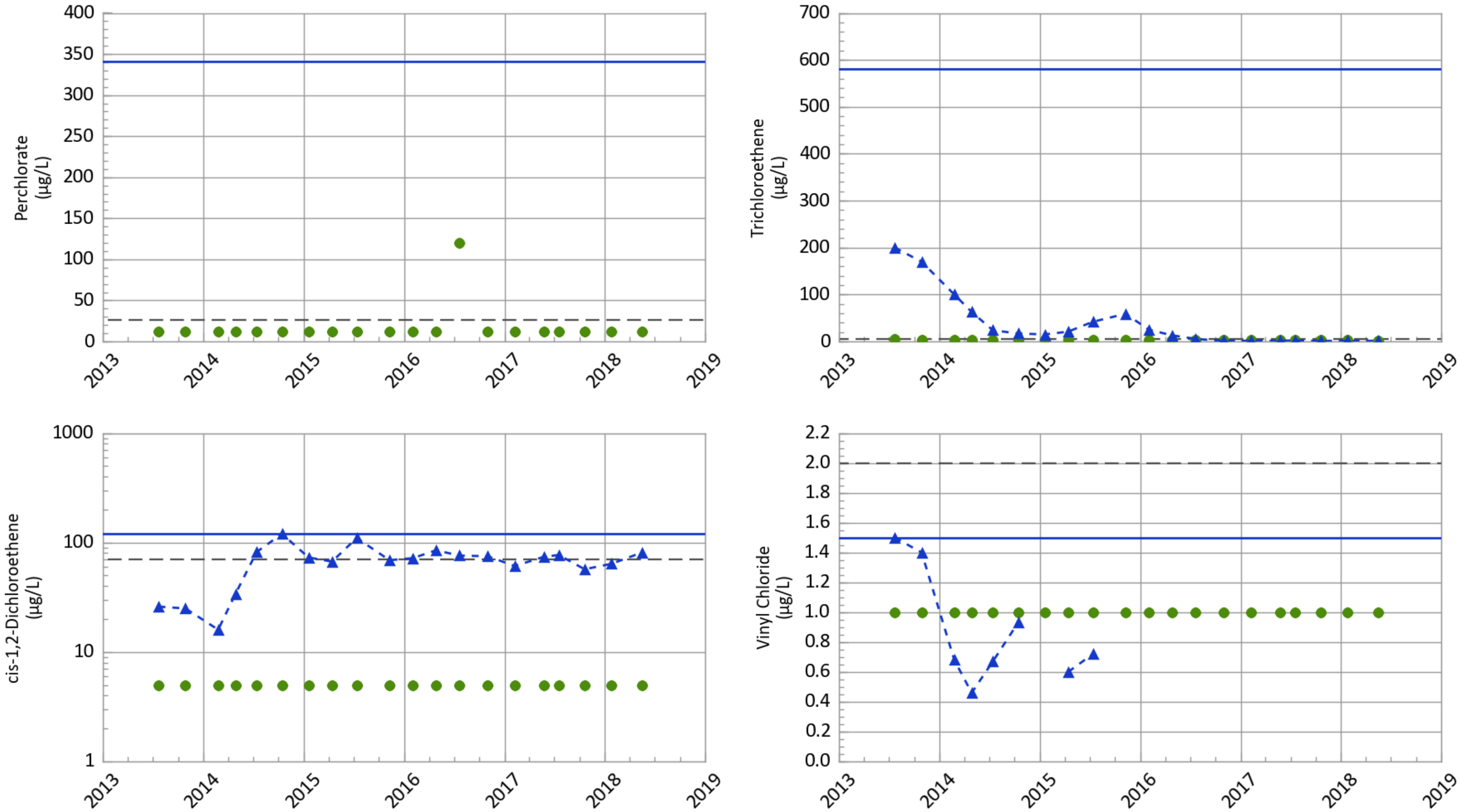


Typical Baseline Concentrations in Perched Groundwater
Dissolved Oxygen: 5-10 mg/L
Redox Potential: > 100 mV
Nitrate: > 1 mg/L
Sulfate: > 10 mg/L
Total Organic Carbon: < 5 mg/L
Total Volatile Fatty Acids: Not Detected

Well Location

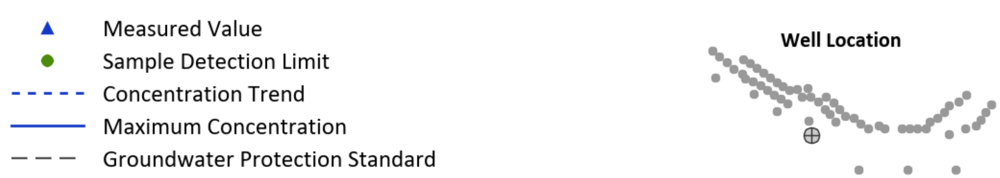


PTX06-1012 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

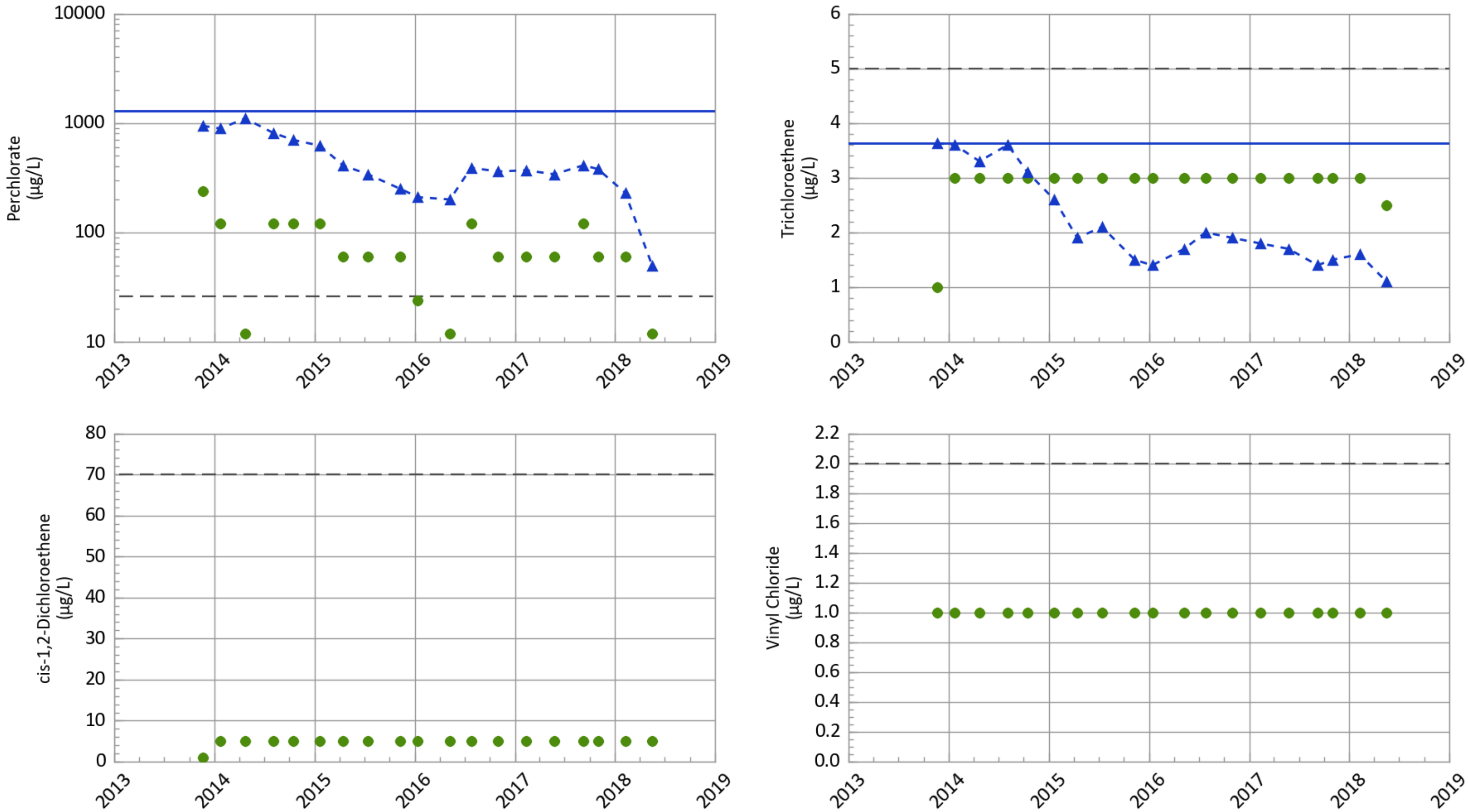


Most Recent Measured COC Concentrations (Jul 13, 2015)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	81.0	70.0
TCE	1.4	5.0
VC	Non-Detect	2.0

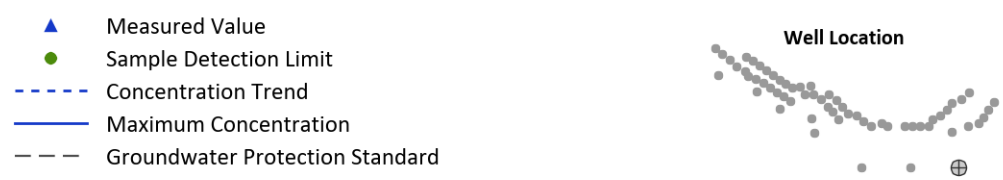


PTX06-1148 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

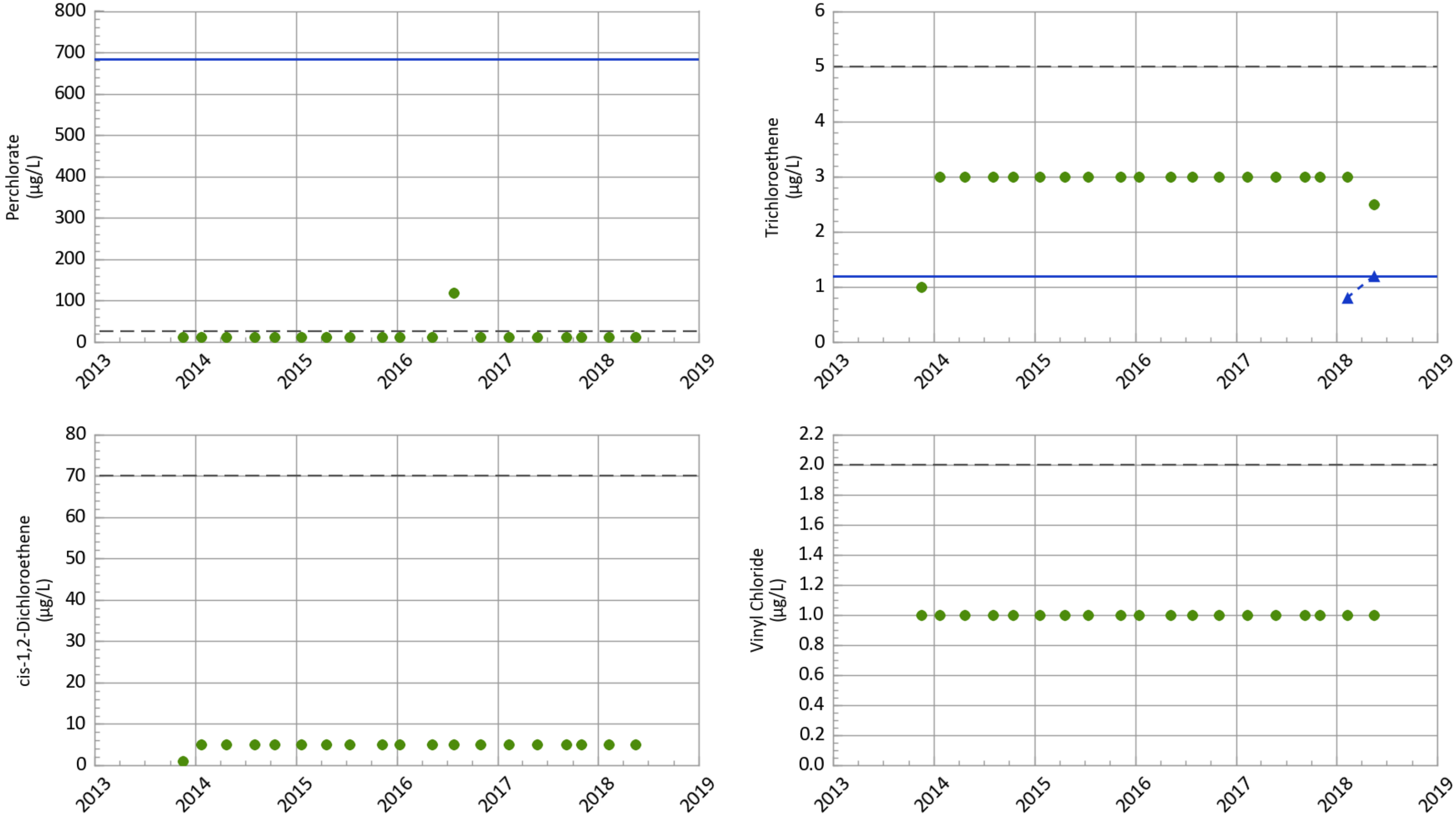


Most Recent Measured COC Concentrations (May 16, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	50.0	26.0
DCE12C	Non-Detect	70.0
TCE	1.1	5.0
VC	Non-Detect	2.0

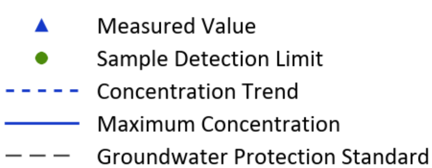


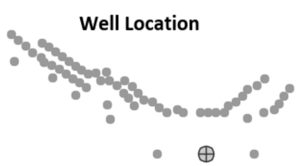
PTX06-1149 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

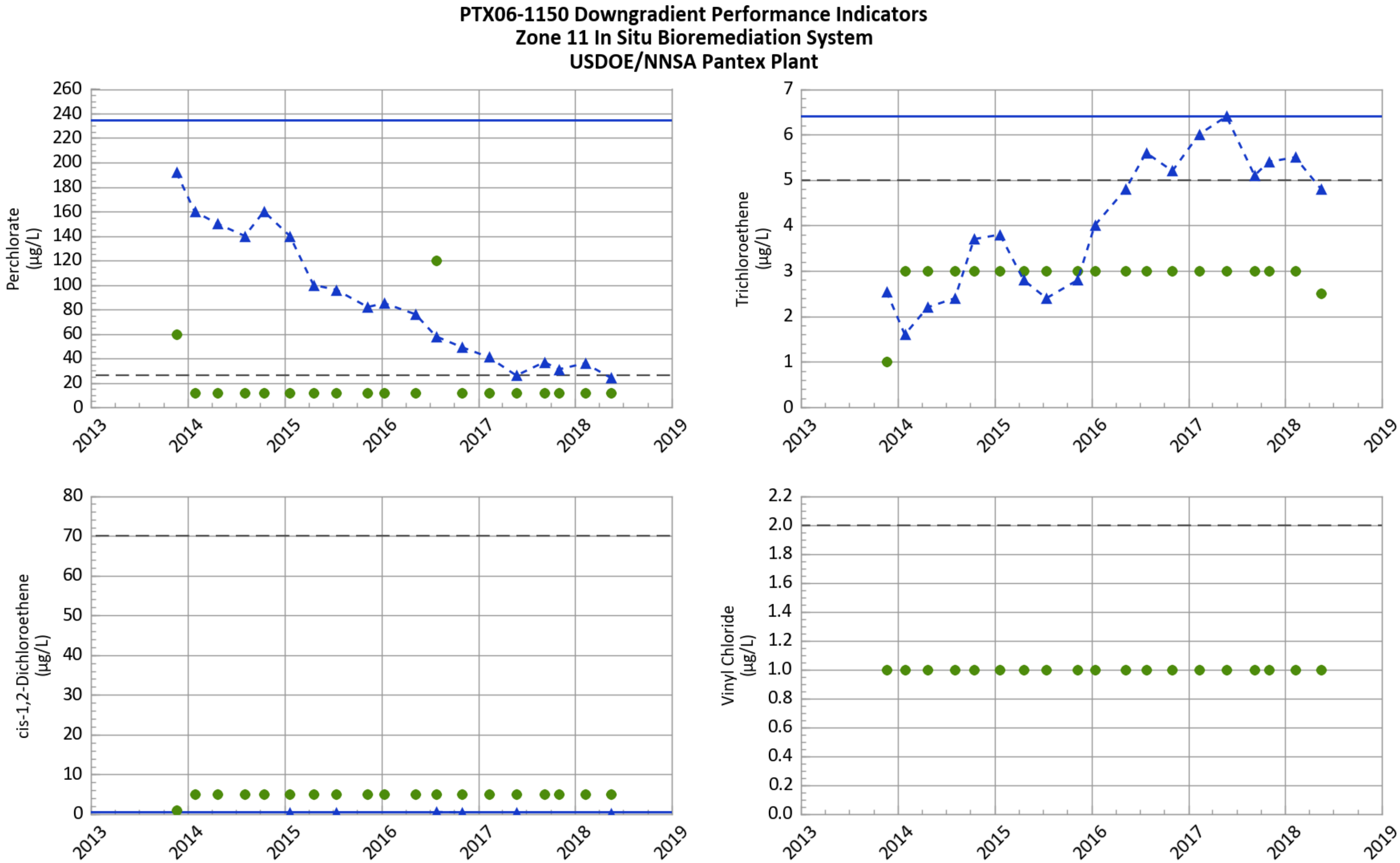


Most Recent Measured COC Concentrations (May 16, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	Non-Detect	70.0
TCE	1.2	5.0
VC	Non-Detect	2.0

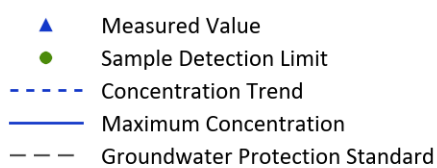


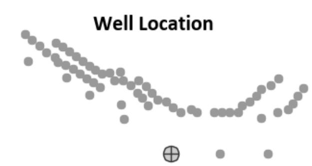




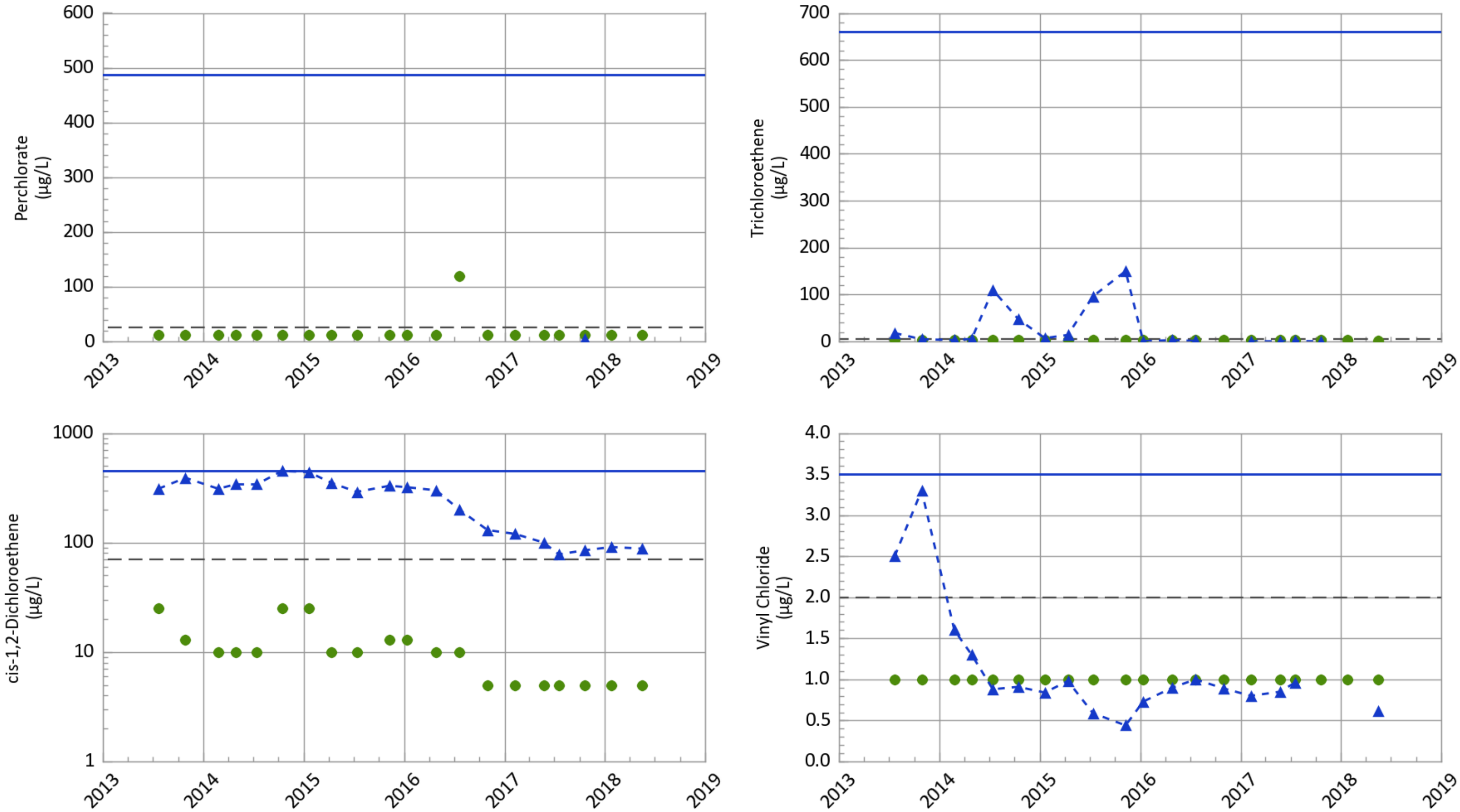
Most Recent Measured COC Concentrations (May 16, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	24.0	26.0
DCE12C	0.26	70.0
TCE	4.8	5.0
VC	Non-Detect	2.0





PTX06-1155 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

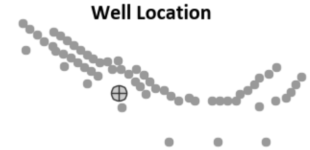


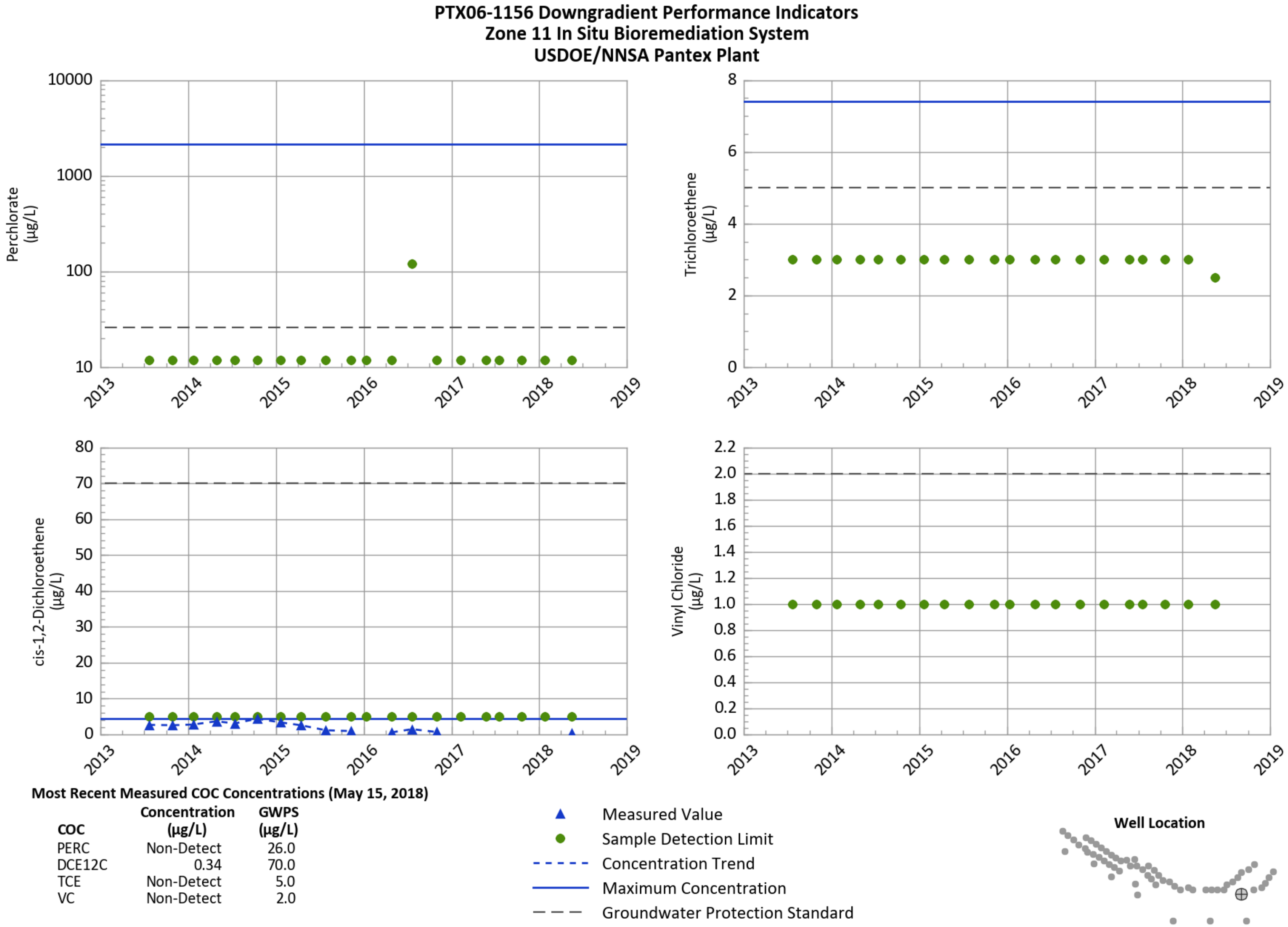
Most Recent Measured COC Concentrations (May 15, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	88.0	70.0
TCE	Non-Detect	5.0
VC	0.62	2.0

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
— Maximum Concentration
— — Groundwater Protection Standard

Well Location

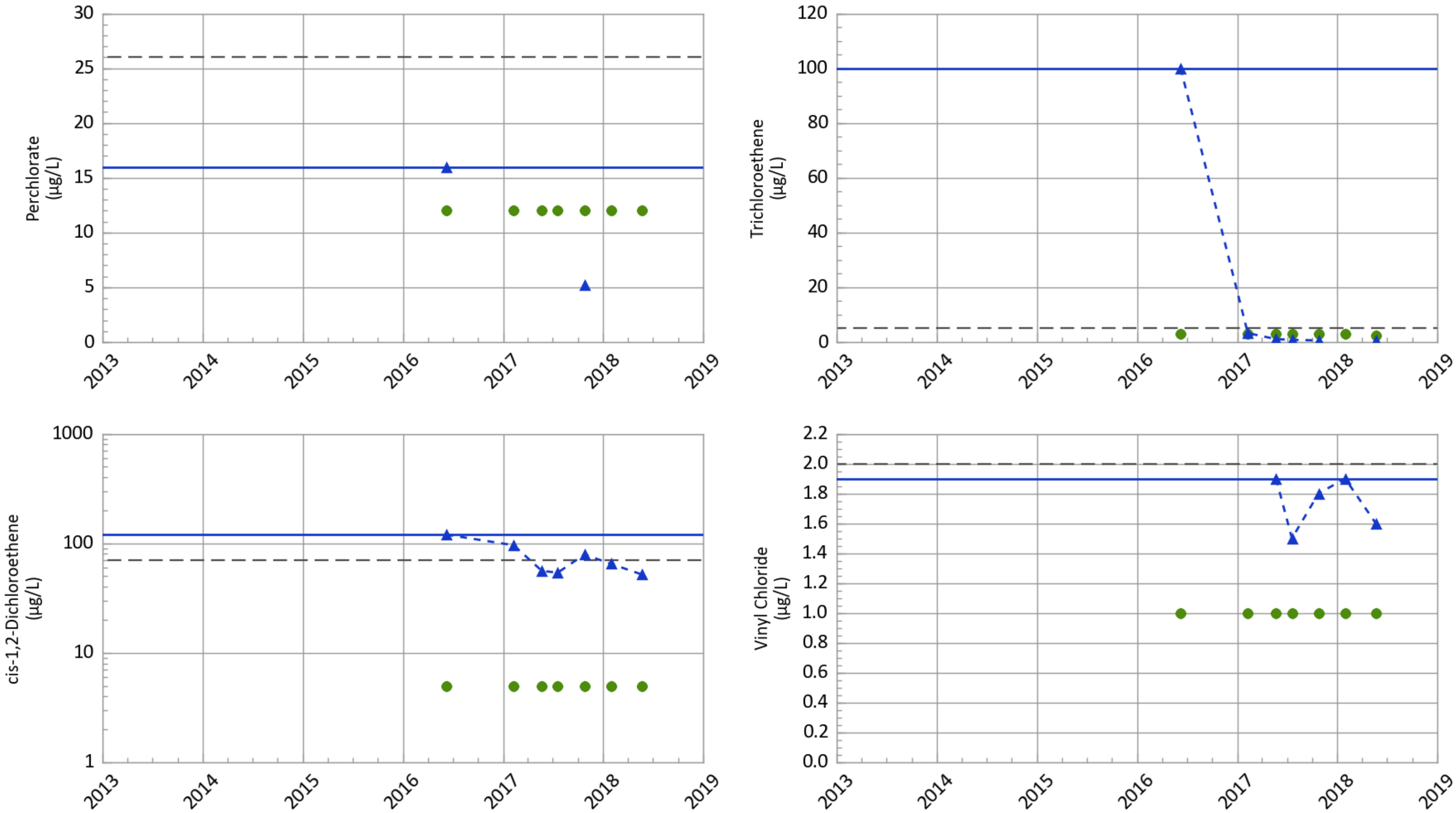




Most Recent Measured COC Concentrations (May 15, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	0.34	70.0
TCE	Non-Detect	5.0
VC	Non-Detect	2.0

PTX06-1173 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

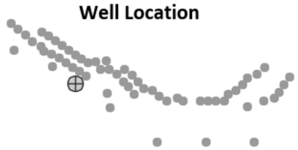


Most Recent Measured COC Concentrations (May 21, 2018)

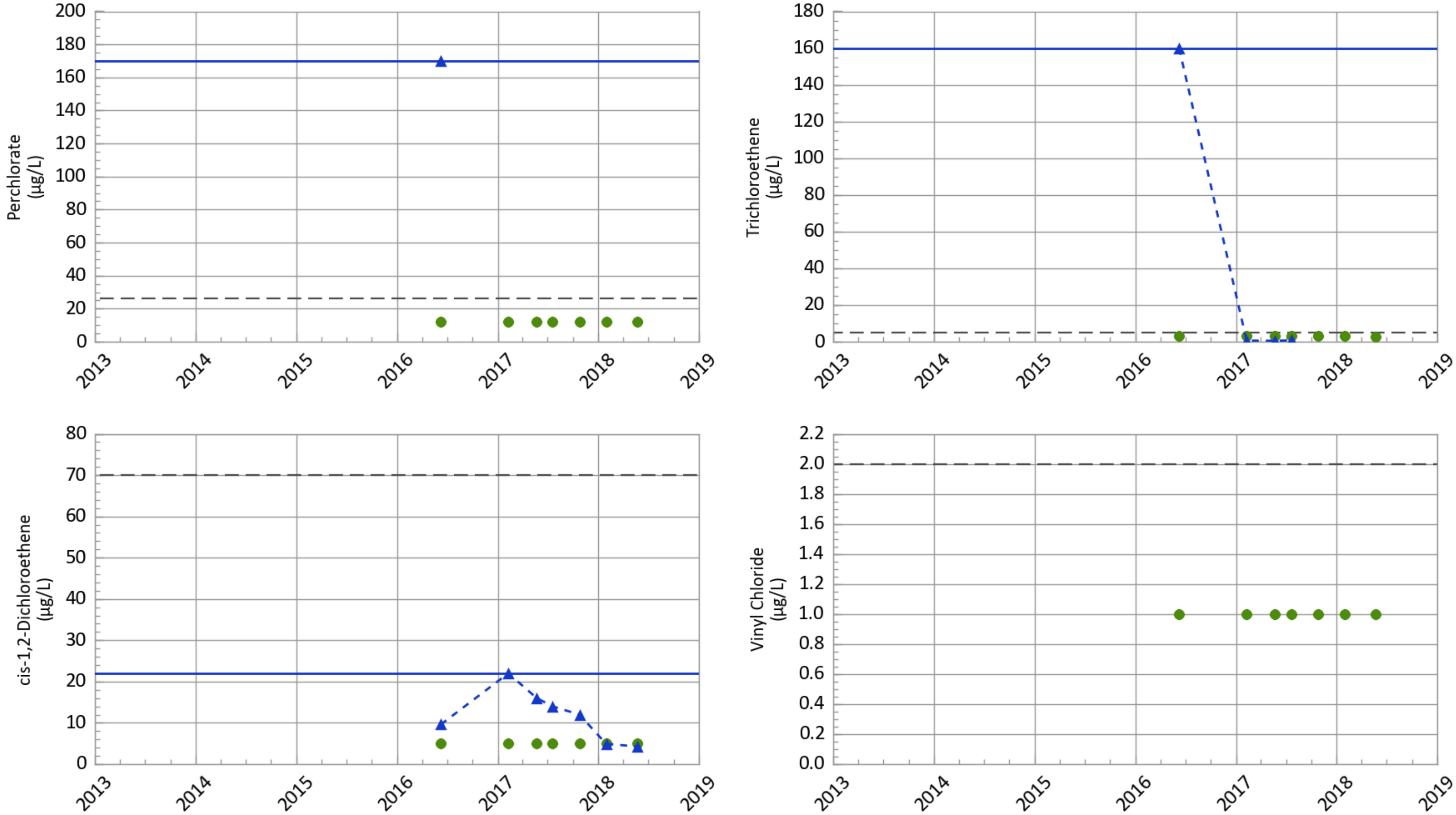
COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	52.0	70.0
TCE	0.65	5.0
VC	1.6	2.0

Measured Value
Sample Detection Limit
Concentration Trend
Maximum Concentration
Groundwater Protection Standard

Well Location



PTX06-1174 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

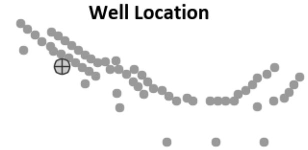


Most Recent Measured COC Concentrations (May 21, 2018)

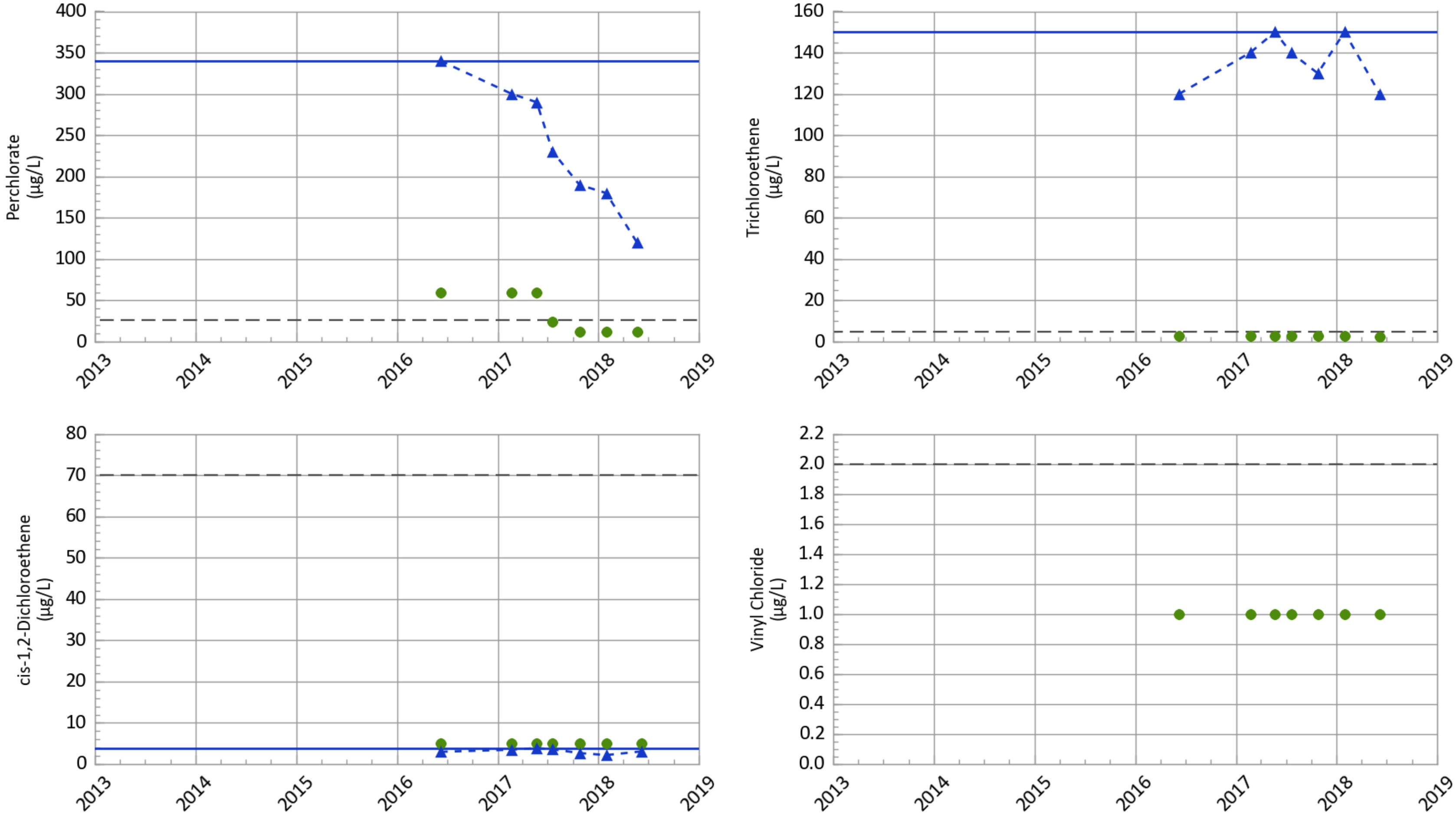
COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	4.3	70.0
TCE	Non-Detect	5.0
VC	Non-Detect	2.0

▲ Measured Value
● Sample Detection Limit
- - - Concentration Trend
—— Maximum Concentration
— — Groundwater Protection Standard

Well Location

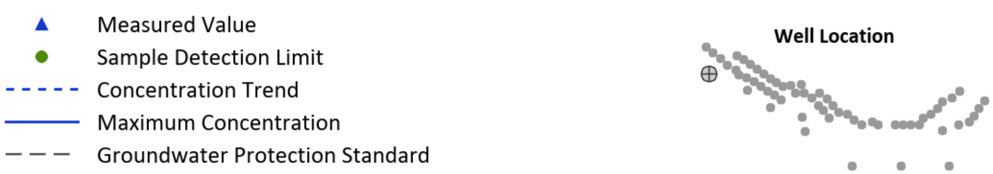


PTX06-1175 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

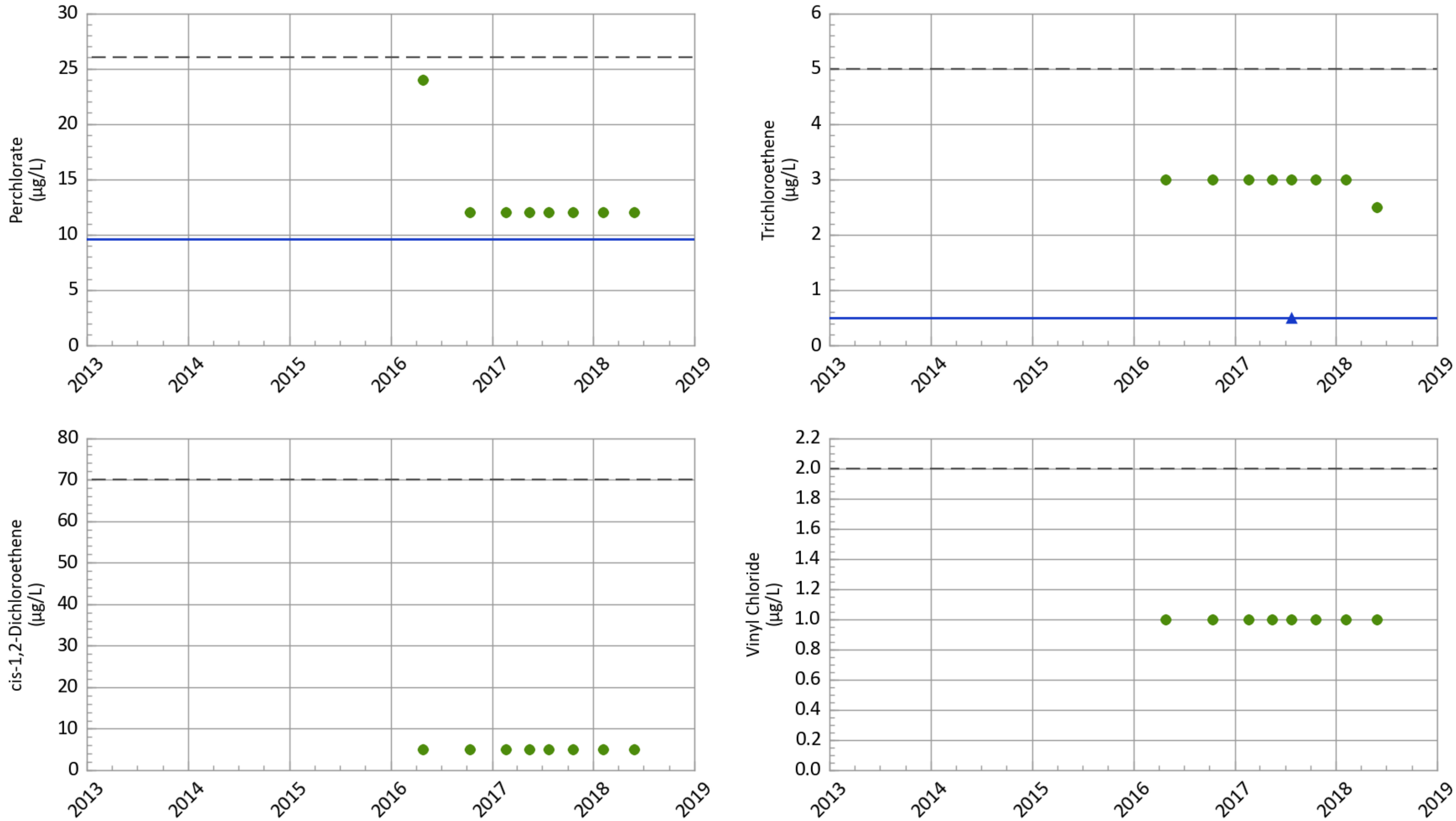


Most Recent Measured COC Concentrations (Jun 06, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	120.0	26.0
DCE12C	3.1	70.0
TCE	120.0	5.0
VC	Non-Detect	2.0



PTX06-ISB079 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

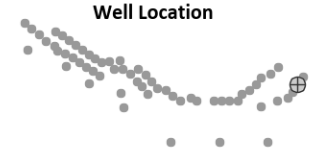


Most Recent Measured COC Concentrations (May 29, 2018)

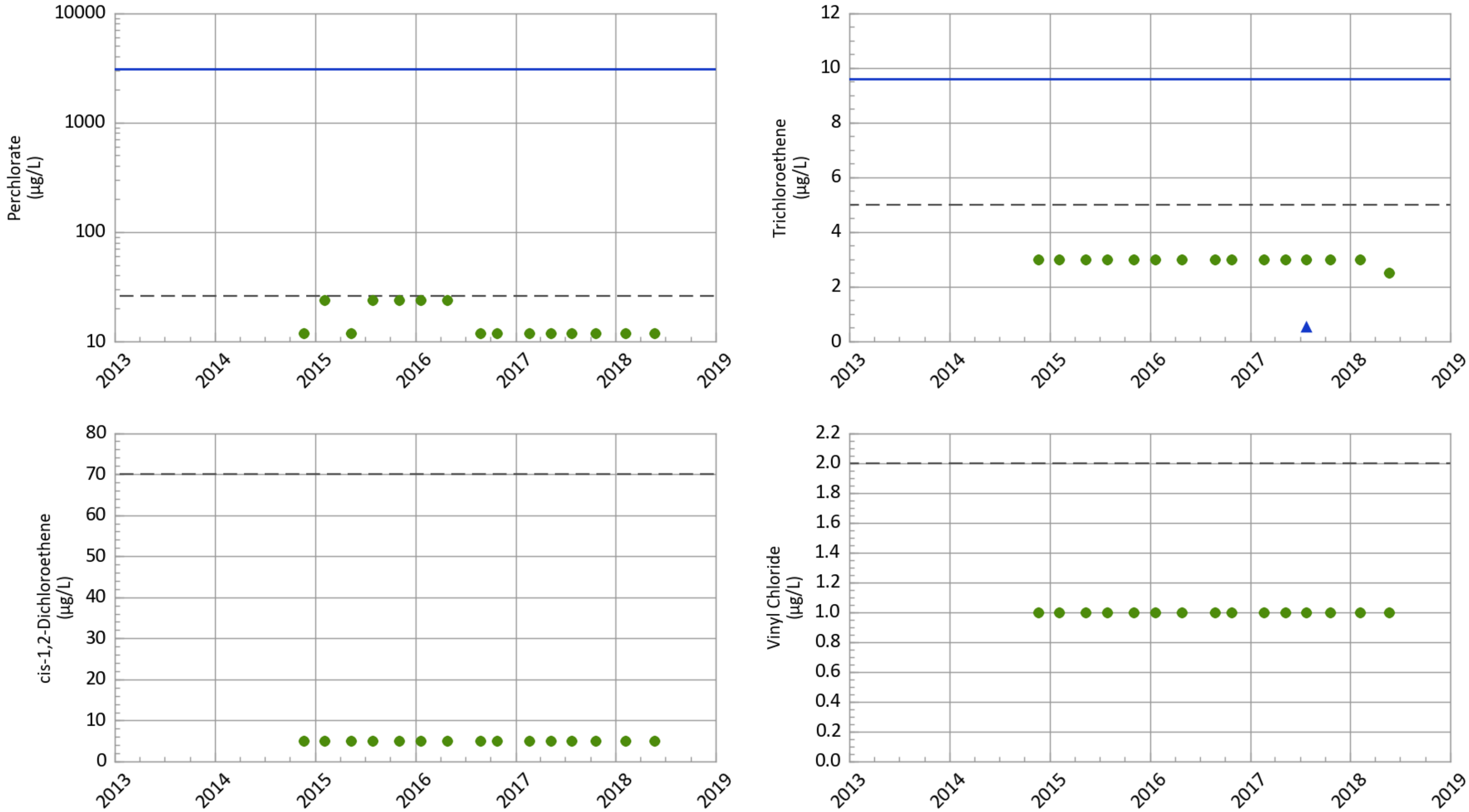
COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	Non-Detect	70.0
TCE	Non-Detect	5.0
VC	Non-Detect	2.0

▲ Measured Value
● Sample Detection Limit
- - - - Concentration Trend
—— Maximum Concentration
— — Groundwater Protection Standard

Well Location



PTX06-ISB082 Downgradient Performance Indicators
Zone 11 In Situ Bioremediation System
USDOE/NNSA Pantex Plant

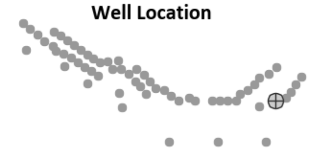


Most Recent Measured COC Concentrations (May 23, 2018)

COC	Concentration (µg/L)	GWPS (µg/L)
PERC	Non-Detect	26.0
DCE12C	Non-Detect	70.0
TCE	Non-Detect	5.0
VC	Non-Detect	2.0

▲ Measured Value
● Sample Detection Limit
- - - - Concentration Trend
—— Maximum Concentration
— — Groundwater Protection Standard

Well Location



Appendix D
HGL Report

Evaluation of Remedial Options for Plume Northwest of Zone 11 ISB

EVALUATION OF REMEDIAL OPTIONS FOR PLUME NORTHWEST OF ZONE 11 ISB CARSON COUNTY, TX

Prepared for:

Consolidated Nuclear Security, LLC
P.O. Box 30020
Pantex Plant
Amarillo, TX 79120-0020

Managed and Operated by Consolidated Nuclear Security, LLC

Purchase Order No. 0000070383 / Contract No. DE-NA0001942

Prepared by:

HydroGeoLogic, Inc.
11107 Sunset Hills Road, Suite 400
Reston, Virginia 20190

June 4, 2018

EVALUATION OF REMEDIAL OPTIONS FOR PLUME NORTHWEST OF ZONE 11 ISB
PANTEX PLANT, CARSON COUNTY, TX

Client:	Consolidated Nuclear Security, LLC P.O. Box 30020 Pantex Plant Amarillo, TX 79120-0020
Prepared by:	HydroGeoLogic, Inc. (HGL) 11107 Sunset Hills Road, Suite 400 Reston, VA 20190
Contract Number:	DE-NA0001942
Purchase Order Number:	0000070383
Preparation Date:	June 4, 2018

STATE OF TEXAS
JEFFREY DICK
122867
LICENSED
PROFESSIONAL ENGINEER

Jeffrey Dick, P.E.
Texas PE #122867 expires 03/31/2019
Supervising Engineer, HGL

06/04/2018
Date

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%	percent
AEC	Atomic Energy Commission
amsl	above mean sea level
ARAR	Applicable or Relevant and Appropriate Requirements
bgs	below ground surface
BWD	Blackwater Draw
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMS	corrective measures study
COC	contaminant of concern
DCE	dichloroethene
DO	dissolved oxygen
DOC	dissolved organic carbon
DPE	dual phase extraction
EVO	emulsified vegetable oil
FGZ	fine-grained zone
FM	Farm to Market Road
FS	feasibility study
ft	feet
GAC	granular-activated carbon
gpm	gallons per minute
GRA	general response action
GWPS	Groundwater Protection Standard
HAZWOPER	Hazardous Waste Operations and Emergency Response
HE	high explosives
HGL	HydroGeoLogic, Inc.
HMX	High Melting Explosive, octahydro-1,3,5,7-tetranitro-1,3,6,7-triazine
HSU	hydrostratigraphic unit
ICM	interim corrective measure
ISB	in situ bioremediation
ISCO	in situ chemical oxidation
LUC	land use control
μg/L	micrograms per liter
mg/L	milligrams per liter

mV	millivolts
NCP	National Oil and Hazardous Substances Pollution Contingency Plan, commonly known as the National Contingency Plan
NNSA	National Nuclear Security Administration
NPL	National Priority List
O&M	operation and maintenance
OMB	Office of Management and Budget
ORP	oxidation-reduction potential
OSWER	Office of Solid Waste and Emergency Response
PPE	personal protective equipment
RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RDX	Research Development Explosive, hexahydro-1,3,5-trinitro-1,3,5-triazine
RFI	RCRA Facility Investigation
RO	reverse osmosis
RoI	Radius of Influence
ROD	Record of Decision
RRR	Risk Reduction Rules
SEPTS	Southeast Pump and Treat System
TCE	trichloroethene
TCEQ	Texas Commission on Environmental Quality
TNT	trinitrotoluene
TOC	total organic carbon
TTU	Texas Tech University
UIC	Underground Injection Control
USDOE	U.S. Department of Energy
USEPA	U.S. Environmental Protection Agency
VC	vinyl chloride
VFA	volatile fatty acid
VOC	volatile organic compound
ZVI	zerovalent iron

EVALUATION OF REMEDIAL OPTIONS
FOR
PLUME NORTHWEST OF ZONE 11 ISB
PANTEX PLANT, ZONE 11
CARSON COUNTY, TEXAS

1.0 INTRODUCTION

HydroGeoLogic, Inc. (HGL) prepared this report on behalf of the Pantex Plant to evaluate remedial options for the plume northwest of the Zone 11 in situ bioremediation system (ISB) for the Pantex Plant. The work was completed under Purchase Order 0000070383 with Consolidated Nuclear Security, LLC. The goal of this evaluation is to support Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) activities at the Pantex Plant. The report was prepared in accordance with the RCRA Corrective Measures Study (CMS) Bulletin (U.S. Environmental Protection Agency [USEPA], 2011); *Guidance for Conducting Remedial Investigations and Feasibility Studies (FS) under CERCLA* (USEPA, 1988); *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (USEPA, 2000); and 40 Code of Federal Regulations (CFR) 300. Because the installation is regulated under both RCRA and CERCLA, this report combines elements of the CMS process and FS process.

1.1 PURPOSE AND ORGANIZATION

The purpose of this report is to develop and assess applicable remedial alternatives for groundwater and to recommend a corrective measure to be taken in the Zone 11 treatment area.

This report is organized as follows:

Section 1.0 – Introduction: Describes the site history and site characteristics.

Section 2.0 – Site Conceptual Model: Summarizes the site geology, hydrogeology, and historical release areas.

Section 3.0 – Performance of Existing Remedies: Summarizes existing remedies at the Pantex Plant near the area of remedial alternatives evaluation.

Section 4.0 – Identification and Screening of Remedial Technologies: Presents the remedial action objectives (RAOs), general response actions (GRAs), and initial screening and selection of remedial technologies, process options, and remedial alternatives to be evaluated.

Section 5.0 – Detailed Analysis of Remedial Alternatives: Presents and evaluates the remedial alternatives for the site.

Section 6.0 – Summary and Conclusions: Summarizes the development and findings of this evaluation.

Section 7.0 – References: Provides the references cited in preparation of this report.

Appendix A – Assumptions and Design Calculations: Presents the assumptions and design calculations used to complete conceptual designs and cost calculations.

1.2 SITE DESCRIPTION AND HISTORY

The Pantex Plant is located approximately 17 miles northeast of Amarillo, Texas in Carson County in USEPA Region VI. The primary mission of the Pantex Plant is to assemble, disassemble, and evaluate nuclear weapons from the U.S. stockpile; to develop, fabricate, and test explosives and explosive components; and to provide secure storage for material from the above activities.

The Pantex Plant main area of operations is bounded on the north by Farm to Market Road (FM) 293, on the east by FM 2373, and on the west by FM 683. In total, U.S. Department of Energy (USDOE)/National Nuclear Security Administration (NNSA) owns 17,559 acres including the main Plant area and adjacent property. The USDOE/NNSA-owned main property used for core operations covers 10,177 acres. Industrial operations occur on approximately 2,000 acres in the central portion of the Pantex Plant, and 6,000 acres are managed to support and secure the industrial operations, with significant portions currently used for agricultural purposes (Figure 1.1).

In addition, USDOE/NNSA has purchased property east of the main Plant along FM 2373 to control access to and remediate affected groundwater in the perched unit. USDOE/NNSA also owns Pantex Lake, which is 2.5 miles northeast of the Plant boundary.

Pantex Plant operations began in 1942 under the Army Ordnance Corps, manufacturing conventional munitions and high explosives (HE) such as trinitrotoluene (TNT). Pantex Plant was briefly deactivated at the end of the World War II, and the property sold to Texas Tech University (TTU). In 1951, the Atomic Energy Commission (AEC) reclaimed the site to produce both nuclear weapons and HE compounds. Radioactive materials have not been manufactured at the facility but components containing radioactive materials are managed at the site. Compounds such as TNT, High Melting Explosive ([HMX], octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) and Research Department Explosive ([RDX], hexahydro-1,3,5-trinitro-1,3,5-triazine) have been manufactured, tested, and disposed of at the site.

In 1988, the USEPA conducted a *RCRA Facility Assessment* of the Pantex Plant, identifying solid waste management units, supplemental verification sites, and areas of concern containing environmental media possibly subject to interim corrective measures (ICMs). The RCRA facility investigation (RFI) identified operational areas at the site and groupings of corrective action units in common watersheds termed waste management groups. The Pantex Plant was formally listed on the National Priority List (NPL) in 1994. The Pantex Plant is, therefore, subject to the provisions of CERCLA in addition to RCRA and State of Texas Risk Reduction Rules (RRR) requirements.

A CMS/FS was completed in 2007 and conditionally approved by the Texas Commission on Environmental Quality (TCEQ), and USEPA in 2008. The Pantex Plant Site-Wide Record of Decision (ROD) was finalized in September 2008. The CMS/FS and ROD outline interim corrective and stabilization measures and remedies selected to address contaminated media. Many interim remedial actions were implemented before 2008 and were included as selected remedies in the ROD.

Zone 11 is located in the southwestern portion of the Pantex Plant industrial complex (Figure 1.1). Industrial operations in Zone 11 were diverse, consisting of quality assurance testing and machining operations that included cleaning components with chlorinated solvents. Primary contaminants observed in the Zone 11 perched groundwater are trichloroethene (TCE), RDX, and perchlorate. In accordance with the remedy selected in the 2008 ROD, an ISB system was installed at Zone 11 (Figure 1.2). The initial amendment injection occurred in 2009. The ISB is located near the downgradient boundaries of the TCE and perchlorate plumes. The purpose of the ISB is to prevent further downgradient migration of the TCE and perchlorate plume to the south and southwest. From the ISB, the groundwater contamination extends upgradient east and north through the Zone 11 industrial area and along the western edge of Zone 12. The existing ISB acts as a treatment "wall" or "curtain" and is not intended to remediate the entire plume footprint. However, upgradient contamination will be treated as it moves downgradient and passes through this treatment wall.

Analytical results for recent groundwater samples indicate that TCE contamination is migrating around the western terminus of the Zone 11 ISB, which is defined by injection well PTX06-ISB098. This evaluation report focuses on the area where the TCE plume is bypassing the existing treatment system (Figure 1.2). For the remainder of the report, this area will be referred to as the treatment area. The western edge of the TCE plume in the treatment area is defined by monitoring wells PTX06-1160 and PTX06-1181, where all results were less than the Groundwater Protection Standard (GWPS) in 2016. TCE is the primary groundwater contaminant in the treatment area.

As noted above, the purpose of the existing ISB is to prevent further downgradient migration of the groundwater contaminants. Any treatment system installed adjacent to the existing ISB will have the same goal. Pantex Plant established a goal to remediate COC concentrations to meet GWPSs within 50 years. However, because there are continuing sources of groundwater contamination upgradient of the existing ISB and treatment area, any new remedial alternative will need to operate for at least 50 years.

Travel distance estimates for TCE indicate that contamination near PTX08-1005 would reach the treatment zone within 50 years but contamination farther upgradient would still be migrating towards the treatment zone. A large but dilute portion of the TCE plume occurs upgradient of PTX08-1005, and adsorption of TCE to the saturated matrix retards contaminant transport. Similar estimates for perchlorate show that nearly all of the plume footprint lies within the 50-year time of travel to the treatment zone. The perchlorate plume will travel faster because of very limited sorption/retardation of this anion in the perched groundwater. Much of the perchlorate plume occurs east of the TCE plume and a portion of this perchlorate plume may be diverted eastward because of the operation of pump and treat systems to the east. At a minimum, the TCE plume is not expected to be fully remediated within 50 years. Because the treatment area will be affected by upgradient contamination for an extended period of time, any remedial alternative will be expected to achieve the GWPSs (5 micrograms per liter [μg/L] for TCE and 26 μg/L for perchlorate) within and downgradient of the treatment zone, thereby providing a barrier to further plume migration. The remedial alternative is not intended, expected, or designed to remediate the source of contamination or upgradient plume.

2.0 CONCEPTUAL SITE MODEL

2.1 GEOLOGY AND HYDROGEOLOGY

The Pantex Plant lies on the High Plains portion of the Great Plains Physiographic Province in the Texas Panhandle. The area, known as the Llano Estacado, is a broad, flat, plateau with topographic elevation ranging between 3,501 feet (ft) above mean sea level (amsl) to 3,595 ft amsl. A distinguishing feature of the area is the presence of numerous shallow, circular basins called *playas* (Figure 1.1). Playas are ephemerally moist depressions that are the source of perched groundwater at the Pantex Plant. When inundated, the playas form shallow lakes and wetlands. The average topographic slope across the Pantex Plant area is approximately 0.006, and most Pantex Plant surface water tends to drain to the on-site playas.

Drainage ditches transport storm water runoff from developed areas and, historically, conveyed industrial wastewater discharges to the playas, which are the terminal points for all Site surface water drainage. These drainage ditches and playas are the primary transport pathways for contaminants in the perched groundwater. Playa 1 received the majority of the Plant wastewater discharge, including discharge from Zone 11. In the 1980s, all industrial discharges to ditches were terminated.

The hydrostratigraphy below the Pantex Plant is summarized in Table 2.1 below. The uppermost hydrostratigraphic unit (HSU) at the Pantex Plant is the Blackwater Draw (BWD). The BWD extends up to 90 ft below ground surface (bgs) at the site and is typically unsaturated. The unit consists of silts and sands and an approximately 20 ft thick lower unit composed of silty sand and caliche. The playas are depressions in the BWD.

The Ogallala Formation underlies the BWD. A Caprock Caliche layer, consisting of a hard, dense, and finely crystalline caliche, generally defines the top of the Ogallala Formation. Below the Caprock Caliche, the Ogallala Formation consists of upper and lower permeable units separated by a fine-grained zone (FGZ). Perched groundwater occurs in discontinuous units above and within the FGZ. The permeable units are composed of coarse-grained fluvial sequences including channel sands and gravels overlain by finer overbank deposits. A detailed description of geology at the Pantex Plant is provided in Attachment 7 of the Second Five Year Review (HGL, 2018).

Table 2.1
Pantex Plant Hydrostratigraphic Units

Name	Location/Elevation	Description
BWD	Surface at 3550 ft amsl to 3460 ft amsl (~90 ft bgs)	Unsaturated silts and sands, lower 20 ft interval of silty sand and caliche
Ogallala		
• Caprock Caliche	~3460 to 3450 ft amsl (0 to 30 ft thickness)	Hard, dense, and finely crystalline caliche
• Perched Groundwater Unit	Groundwater between 3305 and 3245 ft amsl (215 and 275 ft bgs, 0 to 60 ft saturated thickness)	Fine to medium sand, saturated sands with clays and gravel

Table 2.1 (continued)
Pantex Plant Hydrostratigraphic Units

Name	Location/Elevation	Description
• Fine-Grained Zone	3300 to 3200 ft amsl with variable thickness (10 to 150 ft thick)	Silts and clays, separate upper from lower Ogallala
• Lower Ogallala Unsaturated Zone	3200 to 3100 ft amsl with variable thickness	Coarse-grained fluvial, channel sands and gravels
• Lower Ogallala Saturated Zone (High Plains Aquifer)	3175 to 3100 ft amsl (400 to 500 ft bgs, 30 to 400 ft saturated thickness)	Coarse-grained sands, gravel, drinking water supply for Amarillo, irrigation water supply
• Red Beds/Dockum Group	3100 ft amsl dipping to 3050 ft amsl	Siltstone, confining layer

Elevations are approximate from (B&W Pantex, 2004) and 2016 Hydrographs

2.2 PERCHED GROUNDWATER

Perched groundwater is found in three main areas under the Pantex Plant. The largest area of perched groundwater is associated with recharge from Playas 1, 2, and 4 and below drainage ditches associated with Zones 11 and 12. Installation-wide perched groundwater flow directions and elevations are displayed on Figure 2.1. Flow in the main perched unit tends to be radial emanating from higher groundwater elevations below Playa 1. The treatment area for this report is adjacent to the western end of the Zone 11 ISB.

In the treatment area, the saturated thickness of the perched groundwater ranges from 10 to 20 ft and groundwater generally flows to the southwest. However, there is uncertainty regarding the flow direction over smaller scales because of the lack of wells and relatively flat hydraulic gradient in the treatment area. In addition, there is uncertainty in the lateral extent of the perched groundwater northeast of the treatment area. Groundwater elevations and flow directions for the vicinity of the treatment area and Zone 11 ISB from 2015 and 2017 are shown on Figures 2.2 and 2.3, respectively.

The 2015 groundwater elevation contours suggest a general southwesterly flow. However, the 2017 groundwater elevation contours suggest a bend in the flow direction around PTX06-1180. West of PTX06-1180, groundwater appears to flow to the southeast, but east of PTX06-1180 groundwater appears to flow to the southwest. Additionally, TCE concentrations at PTX06-1180 appear to be increasing (185 μg /L in December 2015 and 349 μg /L in August 2017), which suggests westerly plume migration. As discussed further in Section 5.2, understanding the groundwater flow direction is critical for remedy efficacy and optimization. It is recommended that wells be installed to better evaluate the hydraulic gradient and groundwater flow direction in the treatment area.

The perched groundwater unit beneath Pantex Plant meets the yield and water quality criteria to be considered a potential drinking water source in the state of Texas. However, no supply wells are drilled into the unit for either drinking water or industrial water supply on site. The perched groundwater does not discharge to surface water bodies, and hydraulic connection with the Lower Ogallala is impeded by the FGZ.

2.3 HISTORICAL RELEASE AREAS

The primary sources of contaminants of concern (COCs) at the Pantex Plant arose from industrial activities related to the manufacture and maintenance of munitions and weapons. Primary fate pathways include infiltration of historical wastewater discharges through areas of focused recharge to the vadose zone and perched groundwater unit discharges to soil from testing, treating, and sanitizing HE material; and land disposal of waste.

Historically, effluent from industrial processes, sanitary wastewater, cooling water discharge, and storm water runoff were released to unlined ditches and directed to Playas 1, 2 and 4, with the majority of releases to Playa 1. Subsequent infiltration has resulted in numerous co-mingled plumes and an artificially expanded perched groundwater unit under Playa 1 and areas southwest and southeast of the main industrial zones.

Zone 11 is a major historical and industrial area in the central portion of the Pantex Plant (Figure 1.1). Industrial operations in Zone 11 were diverse, consisting of quality assurance testing and machining operations that included cleaning components with chlorinated solvents. Discharges from Zone 11 also infiltrated along ditches to the north and to Playa 1 resulting in linear sources extending north to Playa 1. Constituents associated with Zone 11 include chlorinated solvents, such as TCE, and perchlorate. The groundwater flow from Zone 11 is predominantly to the south-southwest where the TCE and perchlorate plumes are located. 1,4-dioxane is also associated with releases from Zone 11; however, the 1,4-dioxane plume does not extend into the treatment area.

3.0 PERFORMANCE OF EXISTING REMEDIES

Remedies for perched groundwater already in place in and near Zone 11 include the Zone 11 ISB and the Southeast Pump and Treat System (SEPTS). The Zone 11 ISB (Figure 3.1) is located immediately adjacent to the treatment area and is degrading TCE and perchlorate through anaerobic biodegradation. The eastern edge of the treatment area is defined by the westernmost ISB amendment injection well, PTX06-ISB098. The performance of the existing Zone 11 ISB can be used to predict the efficacy of similar remedies in the treatment area. Additionally, the potential effect the selected remedy would have on the Zone 11 ISB (and vice versa) must be considered when screening technologies. These considerations are discussed in further detail throughout this report.

The SEPTS is located southeast of Zone 11. Although the SEPTS is too far from the treatment area to directly affect the potential remedy, the performance data for the SEPTS can be used to evaluate the effectiveness of remedial alternatives. In addition, the SEPTS may be affecting plume migration on the eastern edge of the Zone 11 ISB by moving the groundwater divide.

3.1 ZONE 11 ISB – REMEDY PERFORMANCE

Per the ROD, the Zone 11 remedy targets ISB of TCE and perchlorate. The Zone 11 ISB was initiated in March 2009 with the installation of 23 injection wells. Nine more wells were added in September 2009. In 2014, two wells that had been installed for aquifer pump testing were converted to injection wells, and 18 new injection wells were installed to the west of the initial system. Injection wells were installed one foot into the FGZ. The screened intervals were based on the saturated thickness at each location.

The amendment is an emulsified vegetable oil (EVO) that acts as an electron donor to support anaerobic biodegradation of TCE and perchlorate. There are two injection control trailers used to mix and deliver the amendment solution to the injection wells. The trailers are configured to allow 24-hour per day operation. The water for mixing the solution is obtained from the pump and treat systems and stored in frac tanks pending injection.

Carbon substrate amendment has been injected into the Zone 11 ISB eight times: June to November 2009; August to September 2010; August to October 2011; July to September 2012; May to July 2013; May to July 2014; May to November 2015; and March to July 2016. In 2014, 14 injection wells were bioaugmented with a commercial microbial culture capable of degrading TCE. Before each injection event, the injection wells were maintained for biofouling.

Several injection wells and monitoring wells have been used to assess the performance of the Zone 11 ISB. The primary groundwater COCs at the Zone 11 ISB are TCE and perchlorate. The analytical results for samples collected through October 2016 suggest the following conclusions:

- The eastern side of the Zone 11 ISB, where perchlorate is the dominant COC, appears to be functioning properly. COC concentrations in this area are less than the GWPS of 5 μg/L for TCE and 26 μg/L for perchlorate. At PTX06-1156, located immediately downgradient of the treatment zone, perchlorate has not been detected since July 2011

(Figure 3.1). Although the perchlorate concentration in downgradient well PTX06-1148 exceeds the cleanup goal, the concentration of this anion has decreased by 72 percent (%) from May 2012 to October 2016 (Figure 3.1). This concentration decrease indicates that remediated groundwater is exerting a beneficial effect on groundwater quality several hundred feet downgradient of the treatment zone. However, the perchlorate plume appears to be migrating to the east, bypassing the eastern side of the Zone 11 ISB to the north. Operation of the SEPTS is the likely cause of this plume migration, as described in Section 3.3. With respect to the TCE plume, the eastern portion of the Zone 11 ISB appears to be degrading any TCE that would be pulled to the southeast by the SEPTS, preventing the plume from expanding around the ISB.

- The central portion of the ISB appears to have mixed results. At some locations, such as PTX06-ISB071 and PTX06-ISB077, current concentrations are less than the GWPS. At other locations, such as new PTX06-ISB075, groundwater concentrations currently exceed the GWPS. At this well, the *cis*-1,2-dichloroethene (*cis*-1,2-DCE) concentration is slowly decreasing, but the TCE concentration periodically spikes to greater than the GWPS (Figure 3.2). Although the central portion of the Zone 11 ISB is reducing the TCE concentration, the degradation process appears to have stalled at *cis*-1,2-DCE at PTX06-1012 and to be proceeding slowly at PTX06-1155 (Figure 3.3), both of which are downgradient from the ISB injection zone. The central portion of the ISB appears to be remediating perchlorate, but not fully reducing TCE to its end products.
- As of October 2016, the western portion of the Zone 11 ISB, installed in 2014, did not yet appear to show the effects of the substrate injection. By October 2017, this area began to show TCE and perchlorate reduction. Both TCE and perchlorate concentrations in wells PTX06-1173 and PTX06-1174 were below the GWPS for four sampling events in 2017. In well PTX06-1173, *cis*-1,2-DCE concentrations in 2017 fluctuated above and below the GWPS and do not yet show a well-defined decreasing trend. VC was detected in this well at concentrations below the GWPS in 2017. In well PTX06-1174, *cis*-1,2-DCE concentrations initially spiked as TCE was reduced, but have shown a decreasing trend over the four 2017 sampling events and remain below the GWPS. *Cis*-1,2-DCE reduction does not appear to be generating VC at PTX06-1174.

It should be noted that the reducing conditions observed at Zone 11 ISB monitoring wells represent conditions farther away from injection wells. Conditions are likely more supportive of TCE and perchlorate reduction closer to injection wells.

In summary, the eastern portion of the Zone 11 ISB appears to be remediating the perchlorate contamination. In wells downgradient of this side of the ISB, the perchlorate contamination appears to be attenuating. The eastern portion of the Zone 11 ISB appears to be functioning as intended. However, the SEPTS may be causing the perchlorate plume to migrate to the southeast, bypassing the ISB remedy. The ISB remedy appears to be moderately successful at reducing TCE in the central portion of the system. There is some evidence of a *cis*-1,2-DCE ‘stall’, that may indicate that amendments are not being distributed effectively. The newest, western end of the ISB system appears to be lagging in efficacy, likely because of non-uniform substrate distribution throughout the treatment zone.

3.2 ZONE 11 ISB – GROUNDWATER GEOCHEMISTRY

Performance monitoring of the Zone 11 ISB includes sampling select wells for natural attenuation parameters (volatile fatty acids [VFAs], dissolved organic carbon [DOC]/total organic carbon [TOC], dissolved gases, alkalinity, manganese, iron, nitrate, sulfate). These parameters, along with pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP), can be used to assess whether the groundwater geochemistry is suitable for biological reduction of TCE and perchlorate in Zone 11. Recent data for these parameters are evaluated below.

Production of organic acids during VFA fermentation can decrease the groundwater pH unless there is enough alkalinity to buffer the acids. Since 2012, the alkalinity concentrations in the ISB injection wells have ranged from 177.6 to 3,656 milligrams per liter (mg/L). Only one result has been less than 500 mg/L. During the same time, pH values have ranged from 4.88 to 8.19, with 9 measurements less than the optimum pH range of 6 to 8. The acidic pH values are listed in Table 3.1. The pH values less than the optimum range appear to occur sporadically and are not indicative of widespread conditions that are too acidic for optimum reductive dechlorination. Current alkalinity results indicate sufficient buffering capacity to protect against future acid production.

Table 3.1
pH Values Less than 6, Zone 11 ISB

Well	Sample Date	pH Value	Comments
PTX06-ISB055	July 2013	4.88	All other pH measurements > 6
PTX06-ISB082	November 2012	5.11	All other pH measurements > 6
PTX06-ISB071	August 2013	5.19	All other pH measurements > 6
PTX06-ISB059	July 2013	5.20	All other pH measurements > 6
PTX06-ISB063	July 2013	5.64	pH > 6 throughout 2014 – 2017
PTX06-ISB077	November 2015	5.68	pH > 6 in 2017, alkalinity > 1,000 mg/L in 2017
PTX06-ISB063	October 2012	5.93	pH > 6 throughout 2014 – 2017
PTX06-ISB073	October 2016	5.94	All other pH measurements > 6, including in 2017
PTX06-ISB077	October 2016	5.94	pH > 6 in 2017, alkalinity > 1,000 mg/L in 2017

Between 2016 and 2017, DO concentrations in ISB injection wells ranged from 0.09 to 17.95 mg/L. The six highest DO readings, ranging from 6.2 to 17.95 mg/L, were associated with negative ORP measurements, suggesting that the DO readings may be erroneous. Even excluding these potentially erroneous measurements, several wells exhibited DO concentrations greater than 2 mg/L, indicating aerobic conditions. In addition, several positive ORP measurements were recorded, including the maximum of 116 millivolts (mV). These field data suggest that conditions at several injection wells are too aerobic for reductive processes.

Since 2012, most of the sulfate results for the injection wells have been approximately 1 mg/L or less, indicating that the groundwater at the injection locations is generally anaerobic enough to support sulfate reduction. The highest sulfate concentration, 24 mg/L, was reported in March 2015 for PTX06-ISB098. This result represents baseline, or pre-injection, conditions. Because the well has not been sampled since amendment injection in this area, it is not known if the sulfate concentration has decreased or if other geochemical parameters have changed since then.

At new PTX06-ISB75, located 18 ft from old PTX06-ISB075, which is used for amendment injection, the sulfate concentration has been stable between 3.2 and 9.1 mg/L. In October 2016 at wells PTX06-1164, PTX06-1170, and PTX06-1176, the sulfate concentrations were 18 to 24 mg/L. These results are not significantly lower than the upgradient concentrations of 23.7 to 29.4 mg/L reported for PTX06-1126, PTX06-1151, and PTX06-1171. The sulfate results for monitoring wells within the treatment zone suggest that, between the injection wells, groundwater geochemistry is not sufficiently anaerobic to support sulfate reduction. This observation suggests that EVO, the carbon substrate amendment used in the ISB, is not being adequately distributed throughout the treatment zone or, where the initial injection did achieve the necessary radius of influence (RoI), the application rate was too low to sustain anaerobic conditions. This hypothesis is supported by the following TOC, DOC, and total VFA data:

- PTX06-1164: EVO was injected into the adjacent injection wells in July 2016.
    - In July 2016 the maximum TOC and DOC concentrations were 13 mg/L and 12 mg/L, respectively.
    - By October 2016, the TOC and DOC concentrations had decreased to 1.6 mg/L and 1.3 mg/L, respectively.
    - The total VFA concentration was 11.3 mg/L in July 2016 and 0.46 mg/L in October 2016.
- PTX06-1170: EVO was injected into adjacent wells in May through June 2016.
    - In July 2016, the TOC and DOC concentrations were 8.9 mg/L and 8.8 mg/L, respectively.
    - By October 2016, the TOC concentration had decreased to 2.5 mg/L and the DOC concentration to 2.6 mg/L.
    - The total VFA concentrations were 0.215 mg/L in July and 0.351 mg/L in October.
- PTX06-1176: EVO was injected into the adjacent injection wells in August 2016.
    - In July 2016, the TOC and DOC concentration were 1.9 mg/L and 1.5 mg/L, respectively.
    - In October 2016, the TOC and DOC concentrations were 2.2 mg/L and 2 mg/L, respectively, slightly higher than the detections reported for July 2016.
    - The total VFA concentration was 0.808 mg/L in October, greater than the July result of 0.082 mg/L but still relatively low.

Conversely, at new PTX06-ISB075, the TOC and DOC detections for the 2016 samples ranged from 13 to 35 mg/L, suggesting sufficient carbon substrate to support complete sulfate reduction. Overall, the TOC, DOC, and VFA data suggest uneven EVO distribution throughout the western portion of the Zone 11 ISB, where TCE is the primary contaminant. This area is more affected by the EVO distribution because complete reduction of TCE to its end products ethene and ethane requires more strongly anaerobic conditions than reduction of perchlorate.

The presence of methane is another indicator of anaerobic conditions. In the injection wells, methane concentrations from 2012 through 2017 range from 1,200 to 25,000 μg/L. These results indicate that the vicinities of the injection wells are sufficiently anaerobic for methanogenesis. In the treatment zone monitoring wells PTX06-1164, PTX06-1176, and PTX06-1177, the methane concentration increased from less than 10 μg/L in January 2016 to between 3,400 and 9,100 μg/L in October 2016. At PTX06-1170, the methane concentration ranged between 3,400 and 6,100 μg/L in 2016. Similarly, at new PTX06-ISB075, the methane concentration was generally greater than 10,000 μg/L in 2016 and greater than 20,000 μg/L in February and July 2017. Methanogenesis appears to be occurring throughout the treatment zone.

In most samples collected from the injection wells between 2012 and 2018, nitrate was not detected or was generally detected at a concentration of approximately equal to or less than 1 mg/L. Nitrate concentrations less than 1 mg/L indicate that the groundwater is anoxic enough to support nitrate reduction in the area immediately surrounding injection wells.

July 2017 to February 2018 nitrate results from the treatment zone monitoring wells are generally less than 1 mg/L, and nitrate reduction appears to be supported in a majority of the Zone 11 ISB treatment zone. However, nitrate concentrations ranging from 3.24 mg/L to 3.48 mg/L observed at PTX06-1164 during this time period suggest insufficient substrate distribution near this well. As a whole, the nitrate and sulfate data suggest that while nitrate reduction may be occurring, substrate is not being distributed far enough away from injection wells to sustain both nitrate and sulfate reduction throughout the treatment zone.

Ethene and ethane are the final products of TCE reductive dechlorination. Since 2012, ethene has been detected in one sample and ethane has been detected in four samples collected from both injection wells and treatment zone monitoring wells. The limited presence of ethene and ethane indicate that complete reduction of TCE is limited. This conclusion is supported by the limited presence of VC, which is the intermediate product between *cis*-1,2-DCE and ethene/ethane.

In 2015, 14 injection wells (PTX06-ISB068 through PTX06-ISB077 and PTX06-ISB083 through PTX06-ISB086) were bioaugmented with a commercial inoculum containing *Dehalococcoides*, the only bacterium shown in the literature to reduce TCE to its fully dechlorinated end products. Bioaugmented wells PTX06-ISB069A, PTX06-ISB071, PTX06-ISB073, and PTX06-ISB077 were sampled both before and after bioaugmentation in 2015. Since 2012, these four injection wells have each had only one TCE detection greater than the GWPS with all other results less than the GWPS. The TCE exceedances of the GWPS were reported for October 2016 (PTX06-ISB073 and PTX06-069A) and November 2015 (PTX06-ISB077 and PTX06-ISB071), the month the wells were bioaugmented. Because of the limited presence of contamination in the injection wells before bioaugmentation, it is difficult to determine if bioaugmentation enhanced TCE degradation near the injection wells.

New wells PTX06-ISB075 and PTX06-1170 are located near the bioaugmented wells.

- At new PTX06-ISB075, the concentration trends for TCE, *cis*-1,2-DCE, and 1,2-DCA after bioaugmentation were similar to those observed before bioaugmentation (Figure 3.2). VC was detected at low concentrations both before and after bioaugmentation, and ethane was detected before and after bioaugmentation, with the highest concentration reported in 2014, before bioaugmentation.

- At PTX06-1170, the TCE concentration decreased and *cis*-1,2-DCE concentration increased immediately after bioaugmentation of the adjacent injection wells, but in 2016 the TCE concentration increased and the *cis*-1,2-DCE concentration decreased without any appearance of VC. These analytical results indicate that the 2015 bioaugmentation did not stimulate reductive dechlorination.

Typically, when groundwater changes from aerobic conditions to anaerobic conditions, iron and manganese oxides/hydroxides dissolve and increase the aqueous concentrations of both metals. Manganese concentrations in the Zone 11 ISB injection wells increased substantially after the initial EVO injection, then decreased gradually. The increase in manganese concentration was observed even in downgradient wells PTX06-1155 and PTX06-1156.

The injection well samples are analyzed for both ferric iron and ferrous iron. Iron concentrations vary throughout the treatment zone and at a given well, vary with time. However, the ferrous iron concentrations are generally greater than the ferric iron results, indicating that the groundwater geochemistry supports iron reduction.

3.3 INFLUENCE OF SEPTS ON ZONE 11 ISB

Perchlorate concentration trends and groundwater flow directions in the southeastern portion of the Zone 11 ISB indicate the SEPTS is causing plume migration in this portion of the site. Increasing concentrations of perchlorate at well PTX08-1008, northeast and outside of the influence of the Zone 11 ISB, suggest that the SEPTS may be pulling the perchlorate plume to the southeast, bypassing the ISB remedy. Perched groundwater flow directions at this well are to the southeast, towards the SEPTS, also suggesting influence of the SEPTS on the perchlorate plume.

The TCE plume does not appear to be affected by the SEPTS. Additionally, perched groundwater in the area of remedial alternatives evaluation (northwest of the ISB) flows south-southwesterly (Figures 2.2 and 2.3), indicating that neither TCE nor perchlorate in this area is directly influenced by the SEPTS.

4.0 IDENTIFICATION AND SCREENING OF REMEDIAL TECHNOLOGIES

This section identifies the technologies and process options used to assemble the remedial alternatives evaluated for the site.

4.1 REMEDIAL ACTION OBJECTIVES

The 2008 ROD developed the RAOs listed below to address two separate groundwater issues: 1) restoration of perched groundwater to drinking water standards, and 2) protection of the lower Ogallala Aquifer. While the overall remedy addresses both objectives, protection of the Ogallala Aquifer, which is a water supply for the City of Amarillo, Texas, is the primary goal of implementing remedial actions for groundwater at the Pantex Plant. For the treatment area, the primary objective is to achieve cleanup standards within and downgradient of the treatment area to prevent further growth of the perched groundwater contaminant plumes and to prevent contaminants from exceeding cleanup standards in the (Lower) Ogallala Aquifer. RAOs are as follows:

1. Reduce the risk of exposure to perched groundwater through contact prevention.
2. Achieve cleanup standards for all COCs (5 μg/L for TCE and 26 μg/L for perchlorate).
3. Prevent growth of the perched groundwater contaminant plumes.
4. Prevent contaminants from exceeding cleanup standards in the (Lower) Ogallala Aquifer (B&W Pantex, 2008).

4.2 REMEDIATION AREA

The maximum saturated thickness of the perched aquifer in the treatment area is approximately 20 ft. The TCE plume covers approximately 190 acres and the perchlorate plume covers 347 acres as of 2016. The treatment area spans the westernmost 550 ft (perpendicular to groundwater flow direction) of the TCE plume. Perchlorate is included because of the low level (less than the GWPS) of perchlorate detections within most of the area of interest and potential for low level contamination to migrate west around the current ISB. The plumes are shown on Figures 2.2 and 2.3.

4.3 GENERAL RESPONSE ACTIONS

General response action (GRA) describes a broad class of actions that can alone or in combination achieve the established cleanup goals for the site. GRAs must be defined for the medium in question (groundwater) and if appropriate, for the extent (for example, mass or volume) of the contamination.

USEPA requires that the “No Action” remedial alternative be included and evaluated. Further, the guidance recommends that at least one technology or process option be considered for each GRA, if applicable.

Natural attenuation is treated similarly to a GRA. Natural attenuation is introduced at this screening level because it can sometimes stand alone as an effective strategy to protect human health and the environment.

GRAs proposed for the site are as follows:

- **No Action.** No Action implies that the site is left in its present condition. This response action provides a baseline for comparison against all other remedies. A No Action remedial alternative is required for consideration by the National Oil and Hazardous Substances Pollution Contingency Plan (NCP).
- **Institutional Controls.** Institutional controls may reduce human health risks from site contaminants by restricting land use or activities at the site to prevent exposure or a complete pathway to the contaminants.
- **Monitoring**. Monitoring site conditions provides useful information about remediation progress. In addition to visually inspecting installed remedial measures, monitoring also includes sampling groundwater.
- **Containment.** Containment refers to physical processes that restrict contaminant mobility without changing their concentration or toxicity. Containment protects human health by controlling the routes of exposure and contaminant migration.
- **Removal**. Removal includes physically removing contaminated groundwater as an initial step for treatment and/or disposal.
- **Treatment**. Treatment may include any physical, chemical, or biological process that transforms, degrades, or destroys the contaminant. Treatment may occur in situ or ex situ.

4.4 INITIAL SCREENING OF REMEDIAL TECHNOLOGIES

The initial screening of remedial technologies and process options is presented in Table 4.1. The initial screening is based on technical implementability and eliminates those technologies not viable for the site and/or contaminants. Screening criteria were based on the specific contaminants of interest (perchlorate and TCE) and other site-specific conditions. Site-specific conditions included the depth to the perched groundwater (approximately 290 ft bgs) and chemistry of the perched groundwater (aerobic vs. anaerobic conditions). Screening criteria included general response actions that were required (e.g., no action), part of the status quo (e.g., institutional/land use controls), potentially viable (e.g., certain types of biological treatment) and not viable (large diameter auger). Technologies and process options retained after initial screening for Zone 11 groundwater include:

- No action (no process options)
- Land use controls (LUCs) – administrative controls
- Monitoring
    - Site inspections
    - Environmental monitoring
    - Natural attenuation

- Gradient control – extraction wells
- Pumping – extraction wells
- Extraction
  - Dual phase extraction (DPE)
  - High volume vacuum extraction
- Chemical/physical treatment
  - Ex situ chemical/physical treatment
  - In situ chemical reduction
  - In situ chemical oxidation (ISCO)
  - In situ chemical immobilization
  - Air sparging
- Thermal treatment – thermally enhanced vapor extraction
- Biological treatment
  - Ex situ biological treatment
  - In situ aerobic co-metabolism
  - In situ anaerobic bioremediation

As shown in Table 4.1, the following process options were not retained after initial screening and were eliminated from further consideration for the following reasons:

- Low permeability vertical wall – contamination is too deep for this technology to be technically or financially practical.
- Large diameter auger – contamination is too deep for this technology to be viable.
- In situ aerobic bioremediation – neither TCE nor perchlorate is directly biodegraded aerobically.

Each remedial technology process option retained after the initial screening is described in the following sections.

4.4.1 Administrative Controls – LUCs

LUCs are required to ensure that groundwater is not used as a potable water source or for other purposes as long as the COC concentrations exceed the GWPSs. The LUCs for groundwater are short term and only required until GWPSs are met. Institutional controls are already in place at the Pantex Plant and include restricting drilling into perched groundwater unit for purposes other than remedial action.

4.4.2 Site inspections

The purpose of the site inspections would be to confirm implementation of institutional controls (LUCs). Site inspections are currently performed as part of the existing remedy at Zone 11.

4.4.3 Environmental Monitoring

Groundwater monitoring would be used to assess the long-term performance of the implemented remedy. Monitoring is currently conducted as part of the existing Zone 11 ISB and will need to be expanded to include the treatment area.

4.4.4 Natural Attenuation

Under favorable environmental conditions, natural attenuation can reduce the mass, toxicity, mobility, volume, and/or concentration of contaminants in groundwater through physical, biological, and chemical processes. The physical processes include advection, dispersion, dilution, diffusion, volatilization, sorption, and desorption. The chemical processes include ion exchange, complexation, and abiotic transformation. Biological processes use indigenous microbes to completely mineralize contaminants through metabolism. Natural attenuation is viable for reducing concentrations of chlorinated ethenes and perchlorate but is dependent on certain site conditions.

Chlorinated volatile organic compounds (VOCs) such as TCE can readily be degraded via natural reductive dechlorination to achieve cleanup goals within a reasonable time frame. Natural reductive dechlorination occurs under anaerobic conditions where the indigenous microbes use chlorinated VOCs as the electron acceptor. During this process, chlorine atoms are replaced by electrons coupled to hydrogen atoms, which results in sequential dechlorination of chlorinated parent compounds (TCE) to daughter products (DCE, VC, and ethene). Reductive dechlorination can also occur abiotically on the surface of iron-bearing minerals. The natural degradation of TCE under the treatment area's aerobic conditions is unlikely because aerobic TCE biodegradation requires a co-metabolic substrate, as described in Section 4.4.1.16.

A diverse range of bacteria has been shown to degrade perchlorate. Similar to natural reductive dechlorination, bacteria degrade perchlorate under anaerobic conditions by using perchlorate as an electron acceptor. For natural perchlorate biodegradation to occur, a carbon source (electron donor) must be present in the site groundwater.

Groundwater in the treatment area is naturally aerobic. As described above, TCE and perchlorate only naturally degrade biologically under anaerobic conditions. Therefore, natural attenuation at Zone 11 would rely on physical and chemical processes, largely advection and dispersion.

4.4.5 Groundwater Extraction – Gradient Control

Hydraulic barriers using extraction wells can be installed and used to limit or eliminate lateral and vertical migration of groundwater contaminants by controlling the hydraulic gradient. These methods can include a network of extraction wells upgradient of the contaminant source or plume to overcome the natural hydraulic gradient, preventing further migration through groundwater flow. A network of extraction wells can also be installed downgradient of the contaminant plume to use the natural hydraulic gradient to assist with capture of the groundwater plume. Recovered contaminated groundwater would be treated using the ex situ chemical and physical methods described below. Treated water can be redirected for beneficial use (for example, irrigation), discharged to a nearby surface water body, or reinjected into the perched aquifer. For the latter, the groundwater can be injected in a manner to promote plume capture by the extraction network or can be injected at a distance far enough to avoid hydraulically influencing the extraction network.

4.4.6 Groundwater Extraction – Pumping

Extraction wells can be installed and used to extract groundwater that would then be treated using the ex situ chemical and physical treatment methods described below. The treated groundwater can be managed as described in gradient control in Section 4.4.5.

4.4.7 Groundwater Extraction – Dual Phase Extraction

DPE is similar to conventional pump and treat, except volatile contaminant mass is removed as both a vapor and a liquid. Because perchlorate is not volatile, it is only removed in the liquid phase; TCE can be removed in both vapor and liquid phases. Ex situ treatment and discharge of both extracted vapor and extracted groundwater is required.

4.4.8 Groundwater Extraction – High Volume Vacuum Extraction

High volume vacuum extraction is similar to pump and treat; however, a vacuum is applied to increase the RoI of extraction wells and to increase recovery rates. The vacuum extraction allows TCE mass to be removed in both vapor and liquid phases; however, perchlorate is not volatile and will only be removed with groundwater in the dissolved phase. Ex situ treatment and discharge of both extracted vapor and extracted groundwater is required.

4.4.9 Ex Situ Chemical/Physical Treatment

Extracted groundwater could be treated using chemical treatment methods. Chemical treatment process options include chemical oxidation and chemical reduction. Chemical oxidation involves introducing an oxidant to initiate a reduction-oxidation (redox) reaction and converting hazardous contaminants to nonhazardous or less toxic compounds and elements through the transfer of electrons from the contaminant to the oxidant. The oxidizing agents typically used for this process include hydrogen peroxide, potassium permanganate, and ozone. TCE is readily degraded by oxidants; however, chemical oxidation is not a viable option to treat perchlorate.

Chemical reduction involves adding strong reducing agents to convert hazardous contaminants to nonhazardous, innocuous compounds. One reducing agent that can be used for this process is zerovalent iron (ZVI). ZVI can reduce both TCE and perchlorate.

Ex situ physical treatment of groundwater involves processes that rely on physical equilibrium or physical interactions (without chemical reaction) to accomplish separations or enhance subtle differences in equilibrium. Potential process options include:

- *Air Stripping* — A mass transfer process that promotes movement of dissolved volatile components from the bulk liquid into the gas phase. A variety of methods can be used to enhance the mass transfer rate by exposing as much liquid surface as possible to the gas. Methods include spray ponds, aeration towers, packed stripper columns, and low-profile or mechanical rotary/centrifugal strippers. Air strippers effectively remove TCE from extracted groundwater, but do not remove perchlorate.

- *Adsorption via Granular-Activated Carbon (GAC)—* GAC is the most effective and economical adsorbent for removing low concentrations of a wide variety of organics from aqueous streams. Contaminated groundwater is pumped through a series of columns containing activated carbon. Organic contaminants such as TCE adsorb to the surface of the GAC, which requires periodic replacement/regeneration once saturated. GAC does not effectively remove perchlorate unless it is modified (USEPA, 2014). This modified GAC requires more frequent changeouts (as compared to ion exchange).
- *Ion Exchange* - Ion exchange removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They also may be inorganic and natural polymeric materials. After the resin capacity has been exhausted, resins can be regenerated for re-use. The effluent wastewater that is generated during regeneration of the resin requires treatment and disposal. Perchlorate-selective or nitrite-specific resins are required for removing perchlorate from groundwater. TCE is not removed from groundwater through ion exchange.
- *Reverse Osmosis (RO) and Nanofiltration–* RO uses a membrane through which water can pass but larger molecules, including TCE and perchlorate, cannot. Pressure forces groundwater through the membrane, contaminants are left on the inlet side of the membrane, and water on the outlet side is clean. Nanofiltration is similar to RO, although some larger molecules are able to pass through the membrane, which allows for greater water flux under less pressure as well as less fouling/scaling as compared to traditional RO. TCE and perchlorate molecules are both too large to pass through a nanofiltration membrane and are effectively removed from groundwater. Nanofiltration may be used as a pretreatment to RO to prevent fouling of the RO membrane.

4.4.10 In Situ Chemical Reduction

Chemical reduction involves the addition of strong reducing agents to convert hazardous contaminants to nonhazardous or less toxic substances. In situ chemical reduction is based on delivering to contaminated groundwater a reducing agent that destroys the contaminants by converting them to innocuous chemicals. The reducing agent typically used for this process is ZVI, which can be delivered by directly injecting it into the subsurface or by incorporating it into a permeable treatment wall, which treats contaminated groundwater as it passes through the wall. This technology can effectively remediate chlorinated VOCs as well as perchlorate.

4.4.11 In Situ Chemical Oxidation

This technology typically involves introducing an oxidant via injection to initiate a redox reaction, which can convert hazardous contaminants to nonhazardous or less toxic compounds and elements through the transfer of electrons from the contaminant to the oxidant. As a result, the contaminant is broken down. Water, carbon dioxide, chlorine, and other relatively nontoxic chemicals are the end products of the reaction. Typical oxidizing agents include potassium permanganate, hydrogen peroxide, and catalyzed sodium persulfate. Chlorinated ethenes, such as TCE and its daughter products, can be treated using this technology, but perchlorate cannot.

4.4.12 In Situ Chemical Immobilization

An amendment is injected to prevent plume migration. Typically, GAC is injected to immobilize TCE; however, the GAC must be modified to immobilize perchlorate (USEPA, 2014). Contaminants are removed from groundwater as the groundwater passes through the GAC and COCs sorb to the GAC surface. GAC does not remove contaminant mass from the subsurface, it merely captures it and prevents COCs from migrating downgradient with groundwater.

4.4.13 Air Sparging

Air is injected at a high rate to volatilize VOCs. As VOC mass is transferred from the dissolved phase to the vapor phase, groundwater concentrations decrease. Volatilized COCs must be captured and treated. Air sparging is a viable option for TCE because of its volatility but is not a potential remedial technology for perchlorate.

4.4.14 Thermally Enhanced Vapor Extraction

Groundwater temperatures are increased, causing VOCs to volatilize. Similar to air sparging, as COC mass is transferred to the vapor phase, groundwater concentrations decrease. Vapors must be captured and treated. Temperature increases do not cause perchlorate to volatilize, thus thermally enhanced vapor extraction is not a viable treatment option for perchlorate.

4.4.15 Ex Situ Biological Treatment

Ex situ biological treatment involves mixing the extracted groundwater with microbes and/or amendments in a reactor to promote biodegradation. Microorganisms use the contaminants as a food and/or energy source and degrade contaminants into nonhazardous compounds. Sometimes, microorganisms adapted for degradation of the specific contaminants are applied to enhance the process. Process options are described in the following paragraphs:

- *Fixed Film Reactor* — Provides a surface of a packed bed of stones or synthetic media for bacteria to grow and develop. As the water flows through the filter bed, the bacteria degrade the contaminants. The major advantages of a fixed film reactor are that it provides a large surface area on which the bacteria can grow and have intimate contact with the waste stream. It is also a means of aerating the waste stream, providing conditions for aerobic biological activity. Anaerobic bacteria can also grow underneath the aerobic bacterial slime if the slime layer grows thick enough, resulting in both anaerobic and aerobic reactions occurring within the same unit. Both TCE and perchlorate are degraded anaerobically. Therefore, for a fixed film reactor to be present, the layer of anaerobic bacteria must be present (see Section 4.4.4).
- *Fluidized-Bed Reactor* — Designed to maximize biodegradation by allowing greater concentrations of contaminants to come in contact with the media that support bacterial growth. These systems usually consist of a large cylindrical tank filled with waste (contaminated groundwater), air injection equipment, and small media particles. Air is

injected into the bottom of the tank where it flows upward through the extracted groundwater. As the air moves through the groundwater, it provides oxygen for aerobic degradation. More importantly, it acts as a mixing mechanism, which creates turbulence in the groundwater. The turbulence puts the small media particles in motion, causing the particles to constantly be in contact with new, higher concentration groundwater. This is not a viable method for perchlorate reduction and TCE cannot be treated unless a cometabolic substrate is present.

4.4.16 In Situ Biological Treatment

In situ bioremediation is a process in which microorganisms degrade organic contaminants found in groundwater, thus converting them to less toxic or innocuous end products. There are two general types of bioremediation: aerobic, which takes place in the presence of oxygen; and anaerobic, which takes place in the absence of oxygen. In addition, the reaction can represent direct metabolism, in which the microbe derives a direct metabolic benefit from the reaction (such as when a contaminant acts either as the electron donor or the electron acceptor); or co-metabolism, in which the microbe obtains no metabolic benefit. In co-metabolism, the enzymes produced by the microbe to metabolize one compound also act on the contaminant of interest, but the microbe does not receive any energy through this reaction.

Natural bioremediation relies on indigenous microorganisms under existing site conditions. Enhanced bioremediation is a process in which site conditions are modified to enhance the desired microbial activity. The addition of nutrients, oxygen, or other amendments (lactic acid, edible oil substrates, oxygen-releasing compounds, and similar elements) may be used to enhance bioremediation. Acclimated microorganisms also can be added to the system (bioaugmentation).

- *Aerobic Bioremediation and Aerobic Co-metabolism* — Aerobic bioremediation occurs when subsurface microorganisms degrade contaminants under aerobic conditions. TCE can be degraded through aerobic co-metabolism. TCE's intermediate products of reductive dechlorination, *cis*-1,2-DCE and VC, can degrade aerobically both through co-metabolism and direct metabolism. Direct aerobic metabolism of VC is common. Although literature provides examples of direct aerobic metabolism of *cis*-1,2-DCE, this process appears to be less common than direct metabolism of VC. To promote aerobic biodegradation, oxygen is added to the subsurface. Oxygen addition can occur through biosparging, in which air is injected into the subsurface at a low rate not intended to volatilize, or strip, the contaminants. Alternatively, an oxygen-releasing compound, such as the Regenesis product ORC™, can be injected into the subsurface. If the contaminant is degraded through co-metabolism, the co-metabolic substrate must be present or added to support production of the desired enzymes. Perchlorate is not biodegraded aerobically.
- *Anaerobic Bioremediation* — Anaerobic bioremediation occurs when subsurface microorganisms degrade contaminants under anoxic (when nitrate is the primary electron acceptor) or anaerobic conditions. Both TCE and perchlorate can be degraded anaerobically. A wide variety of products, such as Hydrogen Release Compound™, edible oil substrate, molasses, and lactic acid, can be injected as the substrate. Acetate is

also a commonly used electron donor/carbon source that facilitates the biodegradation of perchlorate.

4.5 EVALUATION AND SELECTION OF TECHNOLOGIES AND PROCESS OPTIONS

The remedial technologies and process options that were retained after the initial screening were evaluated on the basis of effectiveness, implementability, and cost. These three screening criteria are described below.

Effectiveness — The evaluation of the effectiveness of the technology or process option assesses the ability of the option to meet the RAOs and considers the following elements:

- Potential effectiveness in handling the areas/volumes of contaminated media and achieving the GWPS
- Potential impact on human health and the environment
- Reliability of the process with respect to contaminants and site conditions

Implementability — The evaluation of implementability encompasses the technical and administrative feasibility of applying the technology. Technical implementability was addressed primarily in the initial screening. Administrative feasibility considers the ability to meet substantive provisions of permit requirements; availability of treatment, storage, and disposal services; and availability of equipment and skilled workers.

Cost — The qualitative costs of construction and any long-term costs to operate and maintain the technology under consideration were evaluated. Technologies that provide effectiveness and implementability similar to that of another technology by employing a similar method of treatment or engineering control, but at greater cost, were eliminated.

From the initial screening results summarized in Table 4.1, an effectiveness, implementability, and cost evaluation was completed for the remedial technologies and process options that were considered viable to address groundwater contamination. This screening is presented in Table 4.2 and results are summarized below.

4.5.1 Administrative Controls – LUCs

LUCs are required as long as the COC concentrations exceed the GWPSs. LUCs have no influence on the contamination, but they can effectively eliminate exposure pathways and thus protect human health while remediation is ongoing. LUCs have minimal cost. LUCs are retained to be used in conjunction with another process option.

4.5.2 Site Inspections

Site inspections are typically implemented with LUCs as a means of monitoring LUC effectiveness. Site inspections have already been implemented at the site and have minimal costs. Site inspections do not affect the groundwater contamination. Site inspections are retained to be used in conjunction with another process option.

4.5.3 Environmental Monitoring

Monitoring does not achieve GWPSs but is a necessary component of all other process options to evaluate performance of the selected remedy. For minimal cost, the existing Zone 11 monitoring network can be expanded to include the treatment area.

4.5.4 Natural Attenuation

Both TCE and perchlorate are unlikely to degrade under the aerobic conditions naturally present in site groundwater. Therefore, advection and dispersion would be the main mechanisms for natural attenuation of the COCs. The lack of degradation and presence of an ongoing, upgradient source will significantly limit effectiveness and increase the amount of time required until GWPSs are met. Although natural attenuation is easily implemented and costs are minimal, it is eliminated from further screening because of its limited effectiveness.

4.5.5 Groundwater Extraction – Gradient Control

Extraction wells can effectively limit plume migration, but the system would not be designed to maximize mass removal. Extraction wells could potentially extract the amendment injected into the adjacent ISB wells, limiting the efficacy of the ISB. Groundwater extraction is implementable, with moderate to high capital and operations and maintenance (O&M) costs; costs are partially dependent on the treatment train. This process option is eliminated from further consideration in favor of the groundwater extraction option below, which puts more focus on plume remediation but also provides containment in that it will prevent further downgradient migration of the plume.

4.5.6 Groundwater Extraction – Pump

Groundwater extraction can be an effective way to remove contaminant mass from transmissive zones and reduce or prevent plume migration. The groundwater extraction system must be designed to limit its influence on the adjacent ISB. If extraction wells begin pulling substrate away from the ISB, the effectiveness of the ISB will be limited, and the extraction wells and/or ex situ treatment system could biofoul. Groundwater extraction is easily implemented; capital and O&M costs each range from moderate to high, depending on the treatment train. Groundwater extraction is retained for further evaluation to be used in conjunction with an ex situ chemical/physical treatment option, thereby comprising a pump and treat system.

4.5.7 Dual Phase Extraction

DPE is more effective at removing TCE than conventional extraction methods because it removes both liquid and vapor phase contaminant mass. DPE does not remove perchlorate more effectively than pump and treat. This process option is implementable; however, capital and O&M costs are higher than traditional pump and treat because of the need to augment the pump with a blower for vapor phase removal. This option also necessitates ex situ treatment for both vapor and liquid (as opposed to only liquid). Compared to pump and treat, the increased TCE mass removal achieved with DPE does not justify the added cost. Thus, DPE is eliminated from further screening.

4.5.8 High Volume Vacuum Extraction

Applying a vacuum to a groundwater extraction process more effectively removes contaminant mass, especially TCE, than conventional groundwater extraction. This is a result of the enhanced recovery of fluids due to the high vacuum placed at the well head which increases the extraction well yield. Because both liquid and vapors are extracted, both phases would need to be treated ex situ.

As with DPE, high volume vacuum extraction would be relatively expensive to install and operate due to the use of both pumps and blowers and of just pumps. Additionally, increasing removal rates is not necessarily more effective in this portion of the plume because of the potential for the system to affect the existing ISB and nearby 1,4-dioxane plume. The extent of groundwater extraction must be carefully monitored to prevent negative effects on the adjacent Zone 11 ISB and to prevent moving the 1,4-dioxane plume westward across the ISB. High extraction rates could remove substrate from the existing Zone 11 ISB treatment area (limiting ISB effectiveness) and biofoul extraction wells (limiting well production rates). For these reasons, high volume vacuum extraction was not retained.

4.5.9 Ex Situ Chemical/Physical Treatment

Ex situ treatment effectively removes TCE and perchlorate mass. This process option is implementable at the site and capital and O&M costs are both moderate to high, depending on the treatment train used. This process option is retained for further screening to be used in conjunction with groundwater extraction.

4.5.10 In Situ Chemical Reduction

In situ chemical reduction is an effective treatment option for both chlorinated ethenes and perchlorate. This process option is difficult to implement because the most common reducing agent, ZVI, is solid and cannot be injected through a screened injection well. With injection depths of 290 ft bgs, it would be difficult and very expensive to apply the ZVI. In situ chemical reduction is eliminated because of implementability.

4.5.11 In Situ Chemical Oxidation

In situ chemical oxidation is effective for TCE but not for perchlorate. Rapid rebound is likely to occur and frequent reapplication of amendment is required because oxidants are short-lived in the subsurface. This process option is implementable, although plugging of the injection wells is a concern. The capital cost is moderate to high, and the O&M cost is high because of the number of injection events required. In situ chemical oxidation was eliminated from further screening because of cost and the inability to degrade perchlorate.

4.5.12 In Situ Chemical Immobilization

This technology has not been widely used, making its effectiveness in large scale application uncertain. Additionally, in situ chemical immobilization does not degrade contaminants unless it is combined with another amendment. If immobilization is not combined with degradation, additional rounds of immobilization amendment would need to be applied as adsorption sites on the initial amendment volume are consumed. Immobilization capital costs are moderate to high. O&M costs are also moderate to high, depending on the rate at which adsorption sites are consumed. In situ chemical immobilization is eliminated from further consideration because of its inability to degrade contaminants without additional amendments.

4.5.13 Air Sparging

Air sparging is ineffective for perchlorate and the effectiveness for TCE is limited because of the tendency of vertical point air sparge systems to short circuit. This system is implementable at the site but would need to be combined with another process option to treat perchlorate. Capital and O&M costs are high. Air sparging is eliminated because of cost and its inability to treat perchlorate.

4.5.14 Thermally Enhanced Vapor Extraction

Thermally enhanced vapor extraction is effective for TCE, but ineffective for perchlorate. It is implementable in the treatment area but would need to be combined with another process option to remediate perchlorate. Capital and O&M costs are high. Thermally enhanced vapor extraction is eliminated from further screening because of its high cost and the inability to remediate perchlorate.

4.5.15 Ex Situ Biological Treatment

TCE and perchlorate can both degrade under anaerobic conditions. It would be possible to treat extracted groundwater using an ex situ biological reactor. These reactors, however, can be difficult and labor intensive to operate because of the need to maintain the appropriate redox conditions and microbial community, and to manage the resulting biosolids. This process option is eliminated from further consideration because of implementation difficulties.

4.5.16 In Situ Aerobic Co-Metabolism

Although aerobic co-metabolism is ineffective for perchlorate, it is possible to aerobically biodegrade TCE if a co-metabolic substrate is present. This process requires the injection of a substrate, such as propane, along with air. If the treatment zone is maintained under aerobic conditions to support TCE co-metabolism, then perchlorate would not degrade. With this process option, it would be necessary to create a downgradient, anaerobic treatment zone for perchlorate degradation. Given that both TCE and perchlorate degrade anaerobically, there would be no benefit to selecting an in situ aerobic process option for TCE. Therefore, in situ aerobic co-metabolism is eliminated from further evaluation.

4.5.17 In Situ Anaerobic Bioremediation

Injection of an electron donor will generate anaerobic conditions to support microbial reduction of contaminants. This is the same technology currently treating chlorinated ethenes and perchlorate at the adjacent Zone 11 ISB. This option can be combined with pump and treat (i.e. recirculation) by installing extraction wells to promote substrate distribution and limit the number of injection wells. If combined with pump and treat, ex situ treatment of extracted groundwater may be required. Extracted and treated groundwater can be reinjected with substrate, reinjected as chase water, or redirected for beneficial use. Direct injection and recirculation are both implementable at the site. Capital costs are moderate to high; recirculation requires fewer injection wells than direct injection, but may require an ex situ treatment system. O&M costs are moderate for both approaches. In situ anaerobic bioremediation was retained.

4.5.18 Conclusions

The following list summarizes process options retained for further consideration following screening for effectiveness, implementability, and cost. In addition to these options, "no action" is retained to satisfy statutory requirements and policy.

- Administrative controls - LUCs
- Site inspections
- Environmental monitoring
- Pump – groundwater extraction
- Ex situ chemical/physical treatment
- In situ anaerobic bioremediation

The following process options were eliminated from further consideration following this round of screening:

- Natural attenuation
- Gradient control – extraction wells
- Dual phase extraction
- High volume vacuum extraction
- In situ chemical reduction
- ISCO
- In situ chemical immobilization
- Air sparging
- Thermally enhanced vapor extraction
- Ex situ biological treatment
- In situ aerobic co-metabolism

The next step in the evaluation process involves combining the retained technologies into remedial alternatives for further screening, as described in Section 4.6.

4.6 IDENTIFICATION OF REMEDIAL ALTERNATIVES TO BE EVALUATED

The process options retained in Section 4.5.18 above were combined into the following remedial alternatives to meet all RAOs in the treatment area:

- Remedial Alternative 1: No Action

- Remedial Alternative 2: Groundwater extraction with ex situ chemical/physical treatment (pump and treat)
- Remedial Alternative 3: In situ anaerobic bioremediation (expanded ISB)
- Remedial Alternative 4: In situ anaerobic bioremediation with groundwater extraction and ex situ chemical/physical treatment (recirculation with ex situ treatment)
- Remedial Alternative 5: In situ anaerobic bioremediation with groundwater extraction, without ex situ chemical/physical treatment (recirculation without ex situ treatment)

Except for the No Action remedial alternative (Remedial Alternative 1), the remedial alternatives listed above include LUCs, site inspections, and environmental monitoring until RAOs are achieved. Detailed descriptions of each remedial alternative are provided in the following section.

5.0 DETAILED ANALYSIS OF REMEDIAL ALTERNATIVES

The detailed analyses presented in this section are designed to provide sufficient information about each potential remedial alternative in order to select an appropriate remedy for the treatment area. The detailed analysis begins with a description of three threshold criteria (overall protection of human health and the environment, attainment of media cleanup standards, and source control), five balancing criteria (long-term effectiveness and permanence; reduction of toxicity, mobility, or volume through treatment; short-term effectiveness; implementability; and cost), and two modifying criteria (state acceptance and community acceptance) presented in Section 5.1. Section 5.2 describes each remedial alternative and its assessment with respect to the threshold and balancing criteria is presented. The detailed analysis concludes with a comparative analysis of the remedial alternatives (Section 5.3).

5.1 EVALUATION OF THRESHOLD AND BALANCING CRITERIA FOR REMEDIAL ALTERNATIVES

5.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether a remedy provides adequate protection and describes how risks posed through each pathway are eliminated, reduced, or controlled through treatment, engineering controls, or LUCs.

5.1.2 Compliance with ARARs

This criterion addresses whether a remedy will meet all of the Applicable or Relevant and Appropriate Requirements (ARARs) and/or provide grounds for invoking a waiver. Groundwater ARARs as defined in the 2008 ROD are listed below:

- Safe Drinking Water Act (SDWA, P. L. 104-182, 40 CFR Part 141, et. seq.)
- Resource Conservation and Recovery Act (40 CFR parts 260-280, 42 USC § 6901-6933)
- Compliance Plan (CP-50284) (TSWDA, Texas Health & Safety Code, Chapter 361; 30 TAC Chapters 305, 335 and 350)
- General Regulations Incorporated into Permits (30 TAC 305 and 30 TAC 319) and Chapter 26 of the Texas Water Code
- Texas Water Code, Chapter 26, 30 TAC 305
- Section 402 of the Clean Water Act and Chapter 26 of the Texas Water Code (TPDES MSGP, TXR 150000)
- Underground Injection Control (UIC) (40 CFR Parts 144-148, et. seq.;30 TAC 331)

5.1.3 Attainment of Media Cleanup Standards

This criterion addresses whether a remedy will meet the media cleanup standards. Each alternative is evaluated for its ability to meet the cleanup standards within and downgradient of the treatment area. As discussed previously, the dilute plumes extend substantial distances upgradient from the treatment area and adjacent Zone 11 ISB. None of the alternatives will meet the cleanup standards for the entire plume footprints for TCE and perchlorate; source control would be required to meet GWPSs throughout the plume.

5.1.4 Source Control

Source control evaluates the ability of a remedy to reduce or eliminate source area contaminant concentration or volume. As described in Section 1.2, the purpose of the remedial option for the treatment area is to prevent further downgradient migration of groundwater contaminants, thereby supporting attainment of the third and fourth RAOs listed in Section 4.1. Because the treatment area is located downgradient of the source areas, none of the remedial alternatives will affect source area contaminant concentrations or volume. For this reason, source control is not evaluated in the detailed analysis of each remedial alternative.

5.1.5 Long-Term Effectiveness and Permanence

Long-term effectiveness and permanence refers to the magnitude of residual risk and the ability of a remedy to maintain reliable protection of human health and the environment over time after the cleanup goals have been met. Long-term effectiveness and permanence is evaluated with respect to the ability of a remedial alternative to reduce concentrations of COCs to below GWPSs within the treatment area and prevent further plume migration.

5.1.6 Reduction of Toxicity, Mobility, or Volume through Treatment

Reduction of toxicity, mobility, or volume through treatment is evaluated by the anticipated performance of the treatment technologies that may be employed in a remedy. The factors to be considered include the extent to which total mass, volume, and/or mobility of contaminants are reduced; the toxicity of residuals resulting from the remedy; and to what extent the effects of treatment are irreversible.

5.1.7 Short-Term Effectiveness

This criterion refers to how quickly the remedy achieves protection and the remedy’s potential to pose adverse effects to human health and the environment during construction and implementation.

5.1.8 Implementability

Implementability is the technical and administrative feasibility of a remedy, including the availability of materials and services needed to implement the chosen solution. The ease or difficulty of implementing each remedial alternative is also assessed.

5.1.9 Community Acceptance

If a ROD amendment is prepared, public concerns are assessed following a review of the public comments received on the Proposed Plan and will be addressed in the ROD amendment. Thus, community acceptance is not considered in the detailed remedial alternatives evaluation presented in this report.

5.1.10 State Acceptance

This criterion indicates whether the state concurs with, opposes, or has no comment on the preferred remedial alternative. This criterion will be addressed during preparation of a ROD amendment or explanation of significant difference.

5.1.11 Cost

Cost estimates were developed according to *A Guide to Developing and Documenting Cost Estimates during the Feasibility Study* (USEPA, 2000). Assumptions of the project scope and duration are defined for each remedial alternative as needed to support a cost estimate that has a certainty of +50% / -30%. Important assumptions specific to each remedial alternative are summarized in the description of the remedial alternative. The net present value of each remedial alternative was evaluated using a 30-year performance period. It is anticipated, however, that without source control measures, any remedial alternative implemented in the treatment area would need to operate for longer than the 30-year performance period as upgradient contamination continues to migrate into the treatment area.

The levels of detail employed in making these estimates are conceptual but are considered appropriate for making choices among remedial alternatives. The information provided in the cost estimate is based on the best-available information regarding the anticipated scope of the remedial alternatives.

The costs are evaluated with respect to the following categories:

- *Capital Costs* — These are the expenditures initially incurred to construct a remedial action, for example, install a monitoring well. They exclude costs required to operate or maintain the action throughout its lifetime. Capital costs encompass all labor, equipment, and material costs (including contractor markups, such as overhead and profit) associated with activities. These activities could include mobilization/demobilization, monitoring site work, installation of extraction or treatment systems, and disposal. Capital costs also include expenditures for professional/technical services that are necessary to support the remedial action (for example, project management, remedial design, etc.).
- *Annual O&M Costs* — These are post-construction costs necessary to ensure or verify the continued effectiveness of a remedial action. Examples of these costs include labor, equipment, and material costs, and contractor overhead and profit costs associated with activities such as monitoring, operating, and maintaining treatment systems. Annual O&M costs also include expenditures for professional/technical services necessary to support O&M activities, such as data analysis.
- *Periodic Costs* — These are costs that occur sporadically or only once (for example, five-year reviews or monitoring well repairs) during the remedial timeframe. These costs may be either capital costs or O&M costs; however, because of their periodic nature, it is more practical to consider them separately from other capital or O&M costs in the estimating process.

- *Present-Value Cost* — Provides the basis for the cost comparison among the final remedial alternatives. The present-value cost represents the amount of money that, if invested in the initial year of the remedial action at a given rate, would provide the funds required to make future payments to cover all costs associated with the remedial action over its planned life. Future O&M and periodic costs are included and reduced by a present-value discount rate. The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in the Office of Solid Waste and Emergency Response (OSWER) Directive 9355.3-20 (Revisions to Office of Management and Budget [OMB] Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis; OMB, 2017). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94. For a 30-year term, the real interest rate revised as of December 2017 is 2.6%. This rate was used for the present-value analysis.

5.2 DESCRIPTION AND ANALYSIS OF REMEDIAL ALTERNATIVES

In this section, remedial alternatives identified in Section 4.6 are described and evaluated in detail. Each remedial alternative is assessed using the threshold and balancing criteria presented in Section 5.1. Design calculations are summarized in Appendix A along with assumptions.

5.2.1 Remedial Alternative 1: No Action

5.2.1.1 Remedial Alternative Description

Remedial Alternative 1, no action, must be evaluated but acts only as a baseline for comparison with other remedial alternatives. Under Remedial Alternative 1, no action aside from maintaining the status quo will be taken to remediate the plume by-passing the existing Zone 11 ISB to the west. It is assumed that the existing monitoring wells will continue to be monitored and maintained as they normally are as part of the existing Zone 11 ISB, but no additional tasks will be performed.

5.2.1.2 Detailed Analysis

Overall protection of human health and the environment — This remedial alternative does not provide adequate protection to human health or the environment because no action will be taken in the treatment area.

Compliance with ARARs — This remedial alternative does not comply with chemical-specific ARARs. The action-specific and location-specific ARARs will not be triggered because a remedial action will not occur.

Attainment of media cleanup standards — This remedial alternative does not provide any means to achieve cleanup standards within the treatment area. Contaminants will likely continue to bypass the western edge of the existing Zone 11 ISB because no action within the treatment area will be taken.

Long-term effectiveness and permanence — This remedial alternative does not provide long-term effectiveness and permanence in the treatment area. Although the risk associated with contaminants may decrease through advection and dispersion, it will take a significant amount of time. The existing ISB will remain in operation and contamination passing through the ISB will be treated. However, the potential for future contaminant migration further west and downgradient of the existing Zone 11 ISB will be present because no action will be taken.

Reduction of toxicity, mobility, or volume through treatment — No reduction occurs, as this remedial alternative does not involve any additional active treatment beyond continued operation of the Zone 11 ISB.

Short-term effectiveness — There will be no additional risks posed to the community, workers, or the environment as a result of implementing this remedial alternative.

Implementability — This remedial alternative is readily implementable.

Cost — The total estimated capital and O&M cost (present worth) of the No Action remedial alternative is $0.

5.2.2 Site Inspections, Land Use Controls, and Environmental Monitoring

5.2.2.1 Description

This section provides a description of the site inspections, LUCs, and environmental monitoring that are part of each remedial alternative involving active treatment. The cost of this component is the same for Remedial Alternatives 2, 3, 4, and 5. The No Action remedial alternative does not incorporate site inspections, LUCs, or environmental monitoring.

LUCs are currently in place at the Pantex Plant and will continue within the treatment area. Site inspections can be conducted concurrently with routine O&M activities or monitoring events.

It is assumed that two new monitoring wells will be installed to assess the performance of Remedial Alternatives 2, 3, 4, and 5. These capital costs are provided in Table 5.1. It is assumed that monitoring well installation will occur on the same mobilization for installation of the extraction/injection wells associated with each remedial alternative. This assumption decreases driller mobilization/demobilization costs. Suggested monitoring well locations for each remedial alternative are presented on Figures 5.1, 5.2, and 5.3.

Monitoring wells for Remedial Alternative 2 are placed such that:

- Migration of the 1,4-dioxane plume east of the extraction wells is monitored so that the extraction system can be shut down if the 1,4-dioxane plume migrates towards the extraction wells or an additional treatment unit can be installed to remove 1,4-dioxane.
- The area downgradient of the extraction wells is monitored to evaluate remedy performance.

Monitoring wells for Remedial Alternatives 3, 4, and 5 are placed such that:

- The remedy efficacy on the effluent/downgradient side of the treatment zone is monitored.
- The treatment zone is monitored to confirm thorough substrate distribution.

For each of the remedial alternatives, the northwest extent of the TCE plume will continue to be delineated and monitored by existing wells PTX06-1160, PTX06-1180, and PTX06-1181 through the current monitoring program.

5.2.2.2 Annual O&M Activities

The new monitoring wells should be sampled quarterly for COCs, field parameters, and monitored natural attenuation parameters in conjunction with the existing Zone 11 ISB sampling program. Site inspections will also be conducted and reported in conjunction with sampling events. Annual costs are detailed in Table 5.2.

5.2.2.3 Periodic Activities

For each alternative, five-year reviews are expected to occur six times over the 30-year timeframe considered for cost evaluations. However, the cost of a five-year review is incorporated into the costs for each of the remedial alternatives described in previous sections.

5.2.2.4 Cost

The costs for environmental monitoring, LUCs, and site inspections are summarized in Table 5.3, in terms of capital, O&M, periodic, and total present-worth costs. The present value of annual O&M costs is estimated at $409,000. There are no periodic costs. The present value of capital costs is estimated at $160,000. The total present-worth cost for this component is estimated at $569,000.

5.2.3 Remedial Alternative 2: Pump and Treat

5.2.3.1 Remedial Alternative Description

Remedial Alternative 2 consists of:

- LUCs, site inspections, and environmental monitoring;
- Groundwater extraction;
- Ex situ physical/chemical treatment; and
- Reinjection of treated water.

For the purposes of the cost estimate, it was assumed that Remedial Alternative 2 will require installing two extraction wells within the treatment area, two injection wells west of the treatment area, and a treatment system comprised of a GAC unit and ion exchange unit. The proposed layout is shown on Figure 5.1. Well installation, treatment system, and other capital costs are presented in Table 5.4.

Site conditions were evaluated to estimate pumping rates and associated capture zones of extraction wells. The capture zone is the area surrounding the extraction well within which all groundwater is expected to be extracted. The capture zone extends further upgradient than it does downgradient. There are two distinct differences between drawdown and capture zone; (1) drawdown extends radially around a well, and (2) not all locations where drawdown is observed result in groundwater transport to an extraction well for removal, as shown in Exhibit 5.1, below (USEPA, 2008).

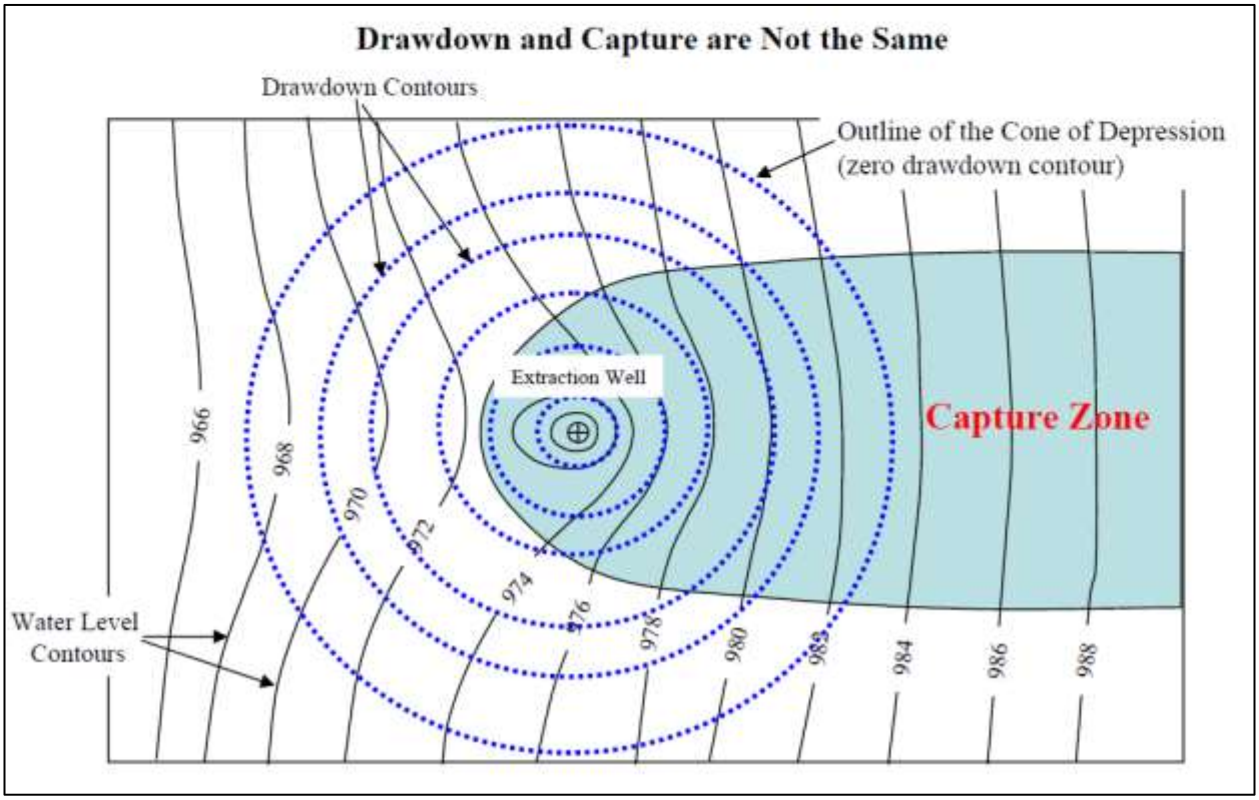

Exhibit 5.1
Capture Zone vs Drawdown

The capture zone can be expanded by increasing the pumping rate or pumping time at a given well. Maintaining a capture zone of 570 ft across, perpendicular to the groundwater flow direction, is sufficient to cover the treatment area, extending from PTX06-ISB098 to the western edge of the plume (Figure 5.1). Based on modeling, it is estimated that an initial pumping rate of 25 gallons per minutes (gpm) for 30 consecutive days will establish this capture zone. Once the capture zone is established, it is estimated that a reduced pumping rate of 5.3 gpm will maintain the capture zone. Each time the system is shut down for maintenance or other reasons, the capture zone must be re-established by using an elevated pumping rate (e.g. 25 gpm for 30 days). Although it is possible for a single extraction well to create a capture zone of this size to cover the lateral extent of the plume, it is recommended that two extraction wells be installed and operated. A second extraction well will:

- Minimize the potential for stagnation zones that could escape remediation;

- Account for uncertainties and changes to site conditions over time (including the extent of contamination, plume migration, and assumed site parameters); and
- Provide an added safety measure if one well is underperforming and unable to achieve the target capture zone.

The two extraction wells must be placed such that:

- The entire extent of the plume west of existing well PTX06-ISB098 is captured, preventing plume migration;
- Substrate injected into the adjacent Zone 11 ISB is not pulled away from the ISB treatment area (which would limit the effectiveness of the ISB) and extracted (which could biofoul extraction wells and the treatment system); and
- The 1,4-dioxane plume is not captured by the extraction wells. Neither GAC nor ion exchange will treat 1,4-dioxane.

Extracted groundwater will be treated on site with a GAC unit and an ion exchange unit. The GAC unit will remove TCE from extracted groundwater. Because of the proximity of the RDX plume (Figure 5.1), the carbon used in the GAC must have an affinity for both TCE and RDX. As TCE breakthrough is observed in the treatment system effluent, the carbon must be replaced. Spent carbon can be regenerated and reused. Ion exchange removes perchlorate through the use of perchlorate selective or nitrite specific resin. The resin must be periodically replaced when contaminant breakthrough is observed. For this remedial alternative, it was assumed that the spent resin will be disposed of. Inclusion of an on-site resin regeneration system would increase the cost and complexity of the treatment system.

Treated water could potentially be redirected to the Texas Tech Property and used as flood irrigation, thereby achieving Pantex Plant's beneficial reuse goal. However, current circumstances suggest the required permits for flood irrigation would not be obtained within an appropriate timeframe. Therefore, it is assumed that all treated water will be reinjected into the perched aquifer.

In typical pump and treat systems, treated water may be reinjected upgradient of the extraction wells to increase the hydraulic gradient and improve contaminant removal rates. This layout is not recommended for the proposed system because of risks associated with the unknown extent of the perched aquifer upgradient of the extraction wells, as described in Section 2.2.

Reinjection wells must be placed such that treated water injected back into the perched aquifer does not negatively impact the plume or Zone 11 ISB. Treated water will be aerobic. Introducing aerobic water near the ISB system, which relies on anaerobic groundwater conditions, could reduce the effectiveness of the ISB. Additionally, injecting large volumes of water in an area where the perched groundwater elevations and extent of the plume are uncertain (Section 2.2) could alter groundwater flow directions and result in uncontrolled plume migration. Therefore, treated groundwater will be reinjected approximately 975 feet downgradient, southwest of the Zone 11 ISB, where it will not impact any plumes or treatment areas (Figure 5.1).

One reinjection well is expected to achieve injection rates sufficient for all treatment system effluent during a majority of pump and treat operation time. However, two wells were assumed for the conceptual design to allow for redundancy and increased extraction rates. The proposed layout for a pump and treat system is presented on Figure 5.1 and assumptions are provided in Appendix A.

5.2.3.2 Annual O&M Activities

The treatment system should be monitored and optimized based on pumping rates and changes to the extent of the plume. Annual O&M activities include sampling treatment system influent and effluent, collecting operational data, and performing routine maintenance. The pump and treat system should be inspected twice per week to locate inefficiencies or broken components and to make the necessary repairs.

5.2.3.3 Periodic Activities

As discussed in Section 5.2.2.1, both the carbon and ion exchange resin will need periodic replacement. The carbon is estimated to need replacement every 22 months. The perchlorate concentration in most of the treatment area does not currently exceed the GWPS but does exceed the GWPS to the east and upgradient of the treatment area. The ion exchange system will be present as an added precaution to protect against potential plume migration or plume boundary uncertainty. Ion exchange resin will need replaced approximately every three years, because the resin tends to break down after that time. Five-year reviews already address the existing Zone 11 ISB; however, there will be additional cost associated with evaluating the selected remedy in the treatment area. Five-year reviews are expected to occur six times over the 30-year timeframe considered for cost evaluations.

5.2.3.4 Detailed Analysis

Remedial Alternative 2 will have the site inspections, land use controls, and environmental monitoring outlined in Section 5.2.2.

Overall protection of human health and the environment — This remedial alternative will protect human health and the environment by actively treating the groundwater contamination in the treatment area and preventing direct contact with contaminated groundwater while remediation is ongoing. Migration of contaminated groundwater will be reduced or eliminated through groundwater extraction and ex situ treatment.

Compliance with ARARs — This remedial alternative will comply with federal and state chemical-specific ARARs for groundwater. Pump and treat systems can be implemented and operated in accordance with CP-50284 and UIC requirements. Institutional controls prevent exposure to the contaminants until cleanup is achieved.

Attainment of media cleanup standards — This remedial alternative is designed to reduce COC concentrations to the GWPSs within the treatment area.

Long-term effectiveness and permanence — This remedial alternative provides long-term effectiveness and permanence. Two existing pump and treat systems at the Pantex Plant have effectively removed significant contaminant mass and generally show stable to decreasing COC concentration trends. These results suggest that a pump and treat system can reduce COC concentrations to GWPSs within the treatment area and prevent further plume migration. Pump and treat system efficacy depends largely on understanding the extent of the plume and groundwater flow direction in the area.

Reduction of toxicity, mobility, or volume through treatment — The treatment system will reduce contaminant mobility and volume through transferring contaminant mass from the extracted groundwater to the adsorption or ion exchange medium. Thermal regeneration of GAC will destroy TCE. Contaminant mass of perchlorate associated with the spent resin will be disposed in a landfill.

Short-term effectiveness — Because of the nature of construction activities, short-term risks to site workers and Pantex Plant personnel will be present during remedy implementation and maintenance. Short-term risks include exposure of on-site personnel to contaminated media and physical risks associated with standard construction activities. Hazardous Waste Operations and Emergency Response (HAZWOPER) training, personal protective equipment (PPE), and standard practices will be used to mitigate short-term risks. Hazards will be minimized by developing and implementing a comprehensive health and safety plan that conforms to industry standards. Environmental impacts will be minimized by following appropriate practices for work.

Implementability — This remedial alternative is readily implementable. The required technology, equipment, and procedures are readily available and widely accepted. Permits will be required for groundwater extraction and reinjection.

Cost — Annual and periodic costs for Remedial Alternative 2 are shown in Table 5.5. The costs for this remedial alternative are summarized in Table 5.6 in terms of capital, annual O&M, periodic costs, and the total present-worth costs. The present value of annual O&M costs is estimated at $3,261,000. The present value of periodic costs is estimated at $780,000. The present value of capital costs is estimated at $1,147,000. Site inspections, land use controls, and environmental monitoring is estimated at $569,000. The total present-worth cost for this remedial alternative is estimated at $5,757,000.

5.2.4 Remedial Alternative 3: In Situ Anaerobic Bioremediation

5.2.4.1 Remedial Alternative Description

The remedial components of Remedial Alternative 3 include:

- LUCs, site inspections, and environmental monitoring; and
- In situ anaerobic bioremediation of COCs through injection of an electron donor.

An electron donor amendment will be injected through a series of injection wells spanning the treatment area. The cost estimate is based on injecting the same amendment, EVO, as used in the Zone 11 ISB. The amendment will establish the anaerobic conditions required for reductive dechlorination of TCE and perchlorate reduction. This remedial alternative is an expansion of the existing Zone 11 ISB. Performance monitoring data for the existing Zone 11 ISB were used to identify the design parameters used for the cost estimate.

The treatment width for in situ anaerobic bioremediation is defined as the distance parallel to the groundwater flow direction that substrate must span to achieve contaminant reduction to GWPSs. If substrate does not span a wide enough area, COCs will not have sufficient contact time (residence time within the treatment zone) with substrate and bacteria to be effectively reduced. The required treatment width for the ISB expansion is estimated as 157 ft. Detailed calculations are provided in Appendix A.

Sustaining a minimum TOC concentration of 20 mg/L is recommended to support reductive dechlorination of TCE. TOC data for wells located within the Zone 11 ISB treatment zone indicate that the amendment and injection approach used in the ISB achieve an ROI of 40 ft. Based on this ROI, the estimated treatment width for in situ anaerobic bioremediation, estimated western extent of the plume, and estimated groundwater flow directions, 15 new injection wells are required to distribute substrate across the treatment area. The proposed injection well layout is provided on Figure 5.2. The amendment will also support RDX degradation in the event the nearby RDX plume migrates west into the treatment area. Injection well spacing is designed to prevent the distribution issues observed in the existing ISB.

The GWPS for *cis*-1,2-DCE was used as the design effluent concentration for total chlorinated ethenes in the calculation of the treatment zone width. Assumptions are provided in Appendix A. In this case, "effluent" refers to the concentration on the downgradient edge of the treatment zone, where the groundwater will not be further treated. It is reasonable to assume that if the *cis*-1,2-DCE GWPS is met, the respective GWPSs for TCE and vinyl chloride will also be met because:

- Microbes obtain far more energy from TCE than they do from *cis*-1,2-DCE, meaning microbes reduce TCE before they reduce *cis*-1,2-DCE. By the time *cis*-1,2-DCE is reduced to the GWPS, TCE will have already met the respective GWPS; and
- Low or non-detect concentrations of VC observed in the existing ISB treatment area, suggest *cis*-1,2-DCE is being reduced through another pathway that does not produce VC, such as co-metabolism.

For the purposes of cost estimating, it is assumed that amendment injection for Remedial Alternative 2 will occur in conjunction with injection at the existing Zone 11 ISB. This assumption decreases amendment and shipping costs and equipment mobilization/demobilization costs. It is also assumed that the treatment area will be dosed in accordance with the calculated hydrogen demand, 0.0006 gallons amendment per cubic foot of aquifer, during the first two years. After anaerobic conditions are established, it is assumed that the dosage will be reduced by 20%. Detailed capital cost estimates are provided in Table 5.7. Detailed annual O&M and periodic costs are presented in Table 5.8.

5.2.4.2 Annual O&M Activities

The treatment system should be monitored and optimized based on changes to the extent of the plume. Based on the injection schedule for the Zone 11 ISB, initial EVO injections are expected to occur annually. As the plume shrinks and ideal anaerobic/reducing conditions are established, amendment dosing requirements and the number of injection wells used during an injection event are expected to decrease. General well and equipment maintenance is expected to be required annually.

5.2.4.3 Periodic Activities

Five-year reviews are expected to occur six times over the 30-year timeframe considered for cost evaluations.

5.2.4.4 Detailed Analysis

Remedial Alternative 3 will have the site inspections, LUCs and environmental monitoring outlined in Section 5.2.2.

Overall protection of human health and the environment — This remedial alternative will protect human health and the environment by actively treating the groundwater contamination in the treatment area and by preventing direct contact with contaminated groundwater while remediation is ongoing. Migration of contaminated groundwater will be reduced or eliminated through in situ treatment.

Compliance with ARARs — This remedial alternative will eventually meet cleanup standards within the treatment area. The ISB can be implemented and operated in accordance with UIC requirements, well construction requirements, and Safe Drinking Water Act MCLs. Institutional controls prevent exposure to the contaminants until cleanup is achieved.

Attainment of media cleanup standards — This remedial alternative is designed to reduce COC concentrations to the GWPSs within the treatment area.

Long-term effectiveness and permanence — This remedial alternative provides long-term effectiveness and permanence. Analytical data from the existing Zone 11 ISB, as discussed in Sections 3.1 and 3.2, suggests that with proper amendment distribution Remedial Alternative 3 will effectively reduce contaminant concentrations through reductive dechlorination and perchlorate reduction. Microbial degradation is irreversible and provides a permanent solution for contaminants.

Reduction of toxicity, mobility, or volume through treatment — This remedial alternative will decrease contaminant toxicity, mobility, and volume through biodegradation. Groundwater passing through the treatment area is expected to be remediated to below GWPSs.

Short-term effectiveness — Because of the nature of construction activities, short-term risks to site workers and Pantex Plant personnel will be present during remedy implementation and maintenance. Short-term risks include exposure of on-site personnel to contaminated media and physical risks associated with standard construction activities. HAZWOPER training, PPE, and standard practices will be used to mitigate short-term risks. Hazards will be minimized by developing and implementing a comprehensive health and safety plan that conforms to industry standards. Environmental impacts will be minimized by following appropriate practices for work.

Implementability — This remedial alternative is readily implementable. The required technology, equipment, and procedures are available and widely accepted, as demonstrated by the successful operation of the adjacent Zone 11 ISB.

Cost — The costs for this remedial alternative are summarized in Table 5.9 in terms of capital, annual O&M, periodic costs, and the total present-worth costs. The present value of annual O&M costs is estimated at $4,314,000. The present value of periodic costs is estimated at $945,000. The present value of capital costs is estimated at $1,688,000. Site inspections land use controls and environmental monitoring is estimated at $569,000. The total present-worth cost for this remedial alternative is estimated at $7,516,000.

5.2.5 Remedial Alternative 4: In Situ Anaerobic Bioremediation with Recirculation and Ex Situ Treatment

5.2.5.1 Remedial Alternative Description

Remedial Alternative 4 consists of:

- LUCs, site inspections, and environmental monitoring;
- In situ anaerobic bioremediation of COCs through injection of an electron donor;
- Groundwater extraction;
- Ex situ physical/chemical treatment; and
- Augmentation of the treated groundwater with electron donor and injection into the treatment zone.

This remedial alternative is similar to Remedial Alternative 3 in that an electron donor will be injected to support anaerobic biodegradation of the COCs. The difference in the two remedial alternatives is that Remedial Alternative 4 includes extraction with ex situ treatment, augmentation of the treated groundwater with the electron donor followed by re-injection. The amendment will be distributed throughout the treatment zone using groundwater recirculation instead of injection wells alone.

The in situ anaerobic bioremediation treatment width (157 ft) and injection well RoI (40 ft) used for Remedial Alternative 3 was assumed for Remedial Alternative 4. Similar to Remedial Alternative 2, the capture zone was evaluated to determine the appropriate number of extraction wells for recirculating the amendment. The conceptual design on Figure 5.3 depicts a capture zone of 300 ft being established after 7 days of groundwater extraction at 28 gpm. Two extraction wells are required to span the width and length of the treatment area. The capture zone width, which is perpendicular to groundwater flow direction, may be altered during each recirculation event by changing the pumping rate and/or extraction time.

It is assumed that all extracted groundwater will be reinjected with the amendment or as chase water to flush substrate away from injection wells and prevent biofouling. For this remedial alternative, it is assumed that the extracted groundwater will require treatment prior to reinjection. Ex situ treatment will use GAC to remove TCE and, if present, RDX. The GAC unit will be purchased and carbon is expected to need replaced every 20 years for this remedial alternative. An ion exchange system, incorporated into annual O&M costs, will remove perchlorate.

For purposes of the cost estimate, it was assumed that each recirculation event would occur in conjunction with injection at the existing Zone 11 ISB. This assumption reduces amendment and shipping costs and equipment mobilization/demobilization costs. Amendment dosing and volumes will be the same as described for Remedial Alternative 3. Detailed capital cost estimates are provided in Table 5.10. Detailed annual O&M and periodic costs are presented in Table 5.11.

5.2.5.2 Annual O&M Activities

The treatment system should be monitored and optimized based on changes to the extent of the plume. Recirculation events are expected to occur annually. As the plume shrinks and ideal anaerobic/reducing conditions are established, amendment dosing requirements and/or the number of wells used during a given recirculation event are expected to decrease. General equipment and well maintenance is expected annually. The ion exchange component of the treatment train will be an annual purchase. The ion exchange system should not be reused for this remedial alternative due to the tendency of resin to biofoul during periods of down time. For costing, it is assumed that the GAC can be drained and re-used the next year.

5.2.5.3 Periodic Activities

Five-year reviews are expected to occur six times over the 30-year timeframe considered for cost evaluations. Carbon, ion exchange resin, extraction pumps, and motors will need periodic replacement.

5.2.5.4 Detailed Analysis

Remedial Alternative 4 will have the site inspections, LUCs and environmental monitoring outlined in Section 5.2.2.

Overall protection of human health and the environment — This remedial alternative will protect human health and the environment by actively treating the groundwater contamination in the treatment area and preventing direct contact with contaminated groundwater while remediation is ongoing. Migration of contaminated groundwater will be reduced or eliminated through in situ treatment.

Compliance with ARARs — This remedial alternative will eventually meet cleanup standards within the treatment area. The injection component can be implemented and operated in accordance with UIC requirements, well construction requirements, and Safe Drinking Water Act MCLs. The extraction component can be implemented and operated in accordance with CP-50284 and UIC requirements. Institutional controls prevent exposure to the contaminants until cleanup is achieved.

Attainment of media cleanup standards — This remedial alternative is designed to reduce COC concentrations to the GWPSs within the treatment area.

Long-term effectiveness and permanence — This remedial alternative provides long-term effectiveness and permanence. The recirculation system will effectively reduce contaminant concentrations through reductive dechlorination and perchlorate reduction within the treatment area. Microbial degradation is irreversible and provides a permanent solution for contaminants.

Reduction of toxicity, mobility, or volume through treatment — This remedial alternative will decrease contaminant toxicity, mobility, and volume through in situ biodegradation. In addition, this remedial alternative will reduce contaminant mobility and volume through ex situ treatment of the extracted groundwater. Groundwater passing through the treatment area is expected to be remediated to below GWPSs.

Short-term effectiveness — Due to the nature of construction activities, short-term risks to site workers and Pantex Plant personnel will be present during remedy implementation and maintenance. Short-term risks include exposure of on-site personnel to contaminated media and physical risks associated with standard construction activities. HAZWOPER training, PPE, and standard practices will be used to mitigate short-term risks. Hazards will be minimized by developing and implementing a comprehensive health and safety plan that conforms to industry standards. Environmental impacts will be minimized by following appropriate practices for work.

Implementability — This remedial alternative is readily implementable. The required technology, equipment, and procedures are readily available and widely accepted.

Cost — The costs for this remedial alternative are summarized in Table 5.12, in terms of capital, O&M, periodic, and total present-worth costs. The present value of annual O&M costs is estimated at $3,860,000. The present value of periodic costs is estimated at $514,000. The present value of capital costs is estimated at $1,100,000. Site inspections land use controls and environmental monitoring is estimated at $569,000. The total present-worth cost for this remedial alternative is estimated at $6,043,000.

5.2.6 Remedial Alternative 5: In Situ Anaerobic Bioremediation with Recirculation – without Ex Situ Treatment

5.2.6.1 Remedial Alternative Description

The components of Remedial Alternative 5 include:

- LUCs, site inspections, and environmental monitoring;

- In situ anaerobic bioremediation of COCs through injection of an electron donor; and
- Groundwater extraction, augmentation with the electron donor, and reinjection.

Similar to Remedial Alternative 4, an electron donor amendment, assumed to be EVO, will be injected through a series of injection wells spanning the treatment area. Substrate will be distributed throughout the treatment zone through the use of extraction wells. The difference between Remedial Alternative 5 and Remedial Alternative 4 is that Remedial Alternative 5 does not include treatment of the extracted groundwater prior to reinjection as substrate solution make-up water or chase water.

The assumed extraction and injection well layout is presented on Figure 5.3. Detailed capital cost estimates are provided in Table 5.13. Detailed annual O&M and periodic costs are presented in Table 5.14.

5.2.6.2 Annual O&M Activities

Recirculation events are expected to occur annually. As the plume shrinks and ideal anaerobic/reducing conditions are established, amendment dosing requirements and/or the number of wells used during a given recirculation event are expected to decrease. General equipment and well maintenance is expected to be required annually.

5.2.6.3 Periodic Activities

Five-year reviews are expected to occur six times over the 30-year timeframe considered for cost evaluations.

5.2.6.4 Detailed Analysis

Remedial Alternative 5 will have the site inspections, LUCs and environmental monitoring outlined in Section 5.2.2.

Overall protection of human health and the environment — This remedial alternative will protect human health and the environment by actively treating the groundwater contamination in the treatment area and preventing direct contact with contaminated groundwater while remediation is ongoing. Migration of contaminated groundwater will be reduced or eliminated through in situ treatment.

Compliance with ARARs — This remedial alternative will eventually meet cleanup standards within the treatment area. The injection component can be implemented and operated in accordance with UIC requirements, well construction requirements, and Safe Drinking Water Act MCLs. The extraction component can be implemented and operated in accordance with CP-50284 and UIC requirements. Institutional controls prevent exposure to the contaminants until cleanup is achieved.

Attainment of media cleanup standards — This remedial alternative is designed to reduce COC concentrations to the GWPSs within the treatment area.

Long-term effectiveness and permanence — This remedial alternative provides long-term effectiveness and permanence. The recirculation system will effectively reduce contaminant concentrations through reductive dechlorination and perchlorate reduction within the treatment area. Although the extracted groundwater will not be treated to remove the contaminants, it will be amended with an electron donor and injected back into the treatment zone (from whence it came), where the anaerobic conditions created by the amendment will degrade the contaminants. For this reason, Alternative 5 will be as effective as Alternative 4 in degrading contaminants within the treatment zone. Microbial degradation is irreversible and provides a permanent solution for contaminants.

Reduction of toxicity, mobility, or volume through treatment — This remedial alternative will decrease contaminant toxicity, mobility, and volume through in situ biodegradation. Groundwater passing through the treatment area is expected to be remediated to below GWPSs.

Short-term effectiveness — Because of the nature of construction activities, short-term risks to site workers and Pantex Plant personnel will be present during remedy implementation and maintenance. Because extracted groundwater will not be treated prior to reinjection, additional risks (as compared to Remedial Alternative 4) to personnel on site during injection activities will be present and mitigated through the use of PPE. Short-term risks include exposure of on-site personnel to contaminated media and physical risks associated with standard construction activities. HAZWOPER training, PPE, and standard practices will be used to mitigate short-term risks. Hazards will be minimized by developing and implementing a comprehensive health and safety plan that conforms to industry standards. Environmental impacts will be minimized by following appropriate practices for work.

Implementability — This remedial alternative is readily implementable. The required technology, equipment, and procedures are readily available. Appropriate UIC permitting will be required for the injection of untreated groundwater back into the perched aquifer.

Cost — The costs for this remedial alternative are summarized in Table 5.15, in terms of capital, O&M, periodic, and total present-worth costs. The present value of annual O&M costs is estimated at $2,259,000. The present value of periodic costs is estimated at $506,000. The present value of capital costs is estimated at $1,054,000. Site inspections land use controls and environmental monitoring is estimated at $569,000. The total present-worth cost for this remedial alternative is estimated at $4,388,000.

5.3 COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

The information presented in the sections above was used to compare the key advantages and disadvantages of each remedial alternative.

5.3.1 Overall Protection of Human Health and the Environment

The No Action remedial alternative (Remedial Alternative 1) will not satisfy this threshold criterion and, therefore, is not eligible for selection. Remedial Alternatives 2, 3, 4, and 5 offer similar protection of human health and the environment.

5.3.2 Compliance with ARARs

Remedial Alternative 1 will not achieve chemical-specific ARARs because no action will be taken. Injection and/or extraction components of Remedial Alternatives 2, 3, 4, and 5 can be implemented and operated in accordance with federal and state ARARs. Institutional controls prevent exposure to the contaminants until cleanup is achieved.

5.3.3 Attainment of Media Cleanup Standards

Aside from the No Action option, all of the remedial alternatives are designed to reduce COC concentrations to the GWPSs within the treatment area.

5.3.4 Long Term Effectiveness and Permanence

Remedial Alternative 1 will not provide a long-term effective and permanent means of addressing the contaminated groundwater that is bypassing the Zone 11 ISB. Because of the uncertainty or possibly changing groundwater flow directions, Remedial Alternative 2 (the pump and treat option) provides the highest capture efficiency in terms of preventing plume migration. The pump and treat extraction wells cover a greater extent of the plume from north to south. Therefore, western migration of the northwest edge of the plume near PTX06-1180 is more likely to be prevented by Remedial Alternative 2 than Remedial Alternatives 3, 4, and 5, which do not span the plume north to south. This is an important consideration given the uncertainty in groundwater flow direction and apparent flow direction changes over time (Figures 2.2 and 2.3). Remedial Alternatives 3, 4, and 5 provide similar levels of long-term effectiveness and permanence.

5.3.5 Reduction of Toxicity, Mobility, and Volume through Treatment

Remedial Alternative 1 does not include active treatment. Remedial Alternatives 3, 4, and 5 provide similar levels of contaminant reduction. Remedial Alternative 2 removes contamination from the source area, but the carbon and ion exchange resin contain contaminants. If carbon is regenerated, TCE is destroyed. However, perchlorate contaminated resin must be disposed of in a landfill; the perchlorate is never destroyed. In this way, Remedial Alternative 2 provides less contaminant reduction than Remedial Alternatives 3, 4, and 5. Alternative 4 also includes ex situ treatment for perchlorate. Given the short period during which the ex situ treatment system will operate, the amount of perchlorate mass removed via ion exchange will be a fraction of that to be degraded in situ in the treatment zone. Therefore, the reduction in contaminant toxicity, mobility, and volume that will be achieved by Alternative 4 will not be substantially lower than that achieved by Alternatives 3 and 5.

5.3.6 Short-Term Effectiveness

Remedial Alternative 1 will involve no construction related activities that could affect workers or the community.

Remedial Alternatives 2, 3, 4, and 5 provide similar short-term effectiveness. Hazards for all remedial alternatives will be minimized through HAZWOPER training, the use of PPE, and by developing and implementing a comprehensive health and safety plan that conforms to industry standards. Environmental impacts will be minimized by following appropriate practices for work.

5.3.7 Implementability

Remedial Alternative 1 is the easiest to implement, as it requires no action. Remedial Alternatives 2, 3, 4, and 5 are all readily implementable with standard construction techniques, equipment, technology, and permits.

5.3.8 Cost

Each remedial alternative was evaluated in terms of estimated capital costs, annual costs, periodic costs, and total present worth costs (total of capital and present-worth annual and periodic costs) over a 30-year period. The following table (Table 5.16) summarizes the estimated cost for each remedial alternative. Site inspections, LUCs, and environmental monitoring are not included in the present value costs below, but they are the same for each remedial alternative and are included as a separate line item below.

Table 5.16
Remedial Alternative Cost Comparison

Remedial Alternative		Present Value Annual O&M Cost	Present Value Periodic O&M Costs	Present Value Capital Costs	Site Inspections, LUCs, and Environmental Monitoring	Total Present Value Cost
1	No Action	NA	NA	NA	NA	NA
2	Pump and Treat	$3,261,000	$780,000	$1,147,000	$569,000	$5,757,000
3	In Situ Anaerobic Bioremediation	$4,314,000	$945,000	$1,688,000	$569,000	$7,516,000
4	Recirculation with Ex Situ Treatment	$3,860,000	$514,000	$1,100,000	$569,000	$6,043,000
5	Recirculation without Ex Situ Treatment	$2,259,000	$506,000	$1,054,000	$569,000	$4,388,000

A +50% to a -30% range of cost is typically used for evaluating cost estimates. The following table (Table 5.17) summarizes the +50% to -30% range of estimated present value costs of the viable remedial alternative, which include present value costs for site inspections, LUCs, and environmental monitoring.

Table 5.17
Cost Sensitivity – Remedial Alternatives 2, 3, 4, and 5

Remedial Alternative		Cost Basis -30%	Base Cost	Cost Basis +50%
2	Pump and Treat	$4,030,000	$5,757,000	$8,636,000
3	In Situ Anaerobic Bioremediation	$5,261,000	$7,516,000	$11,274,000
4	Recirculation with Ex Situ Treatment	$4,230,000	$6,043,000	$9,065,000
5	Recirculation without Ex Situ Treatment	$3,072,000	$4,388,000	$6,582,000

As shown above, Remedial Alternative 5 is the least expensive alternative, while Remedial Alternative 3 is the most expensive. Injection approaches (Remedial Alternatives 3, 4, and 5) have the potential to reduce costs long-term because once treatment is initiated, substrate volumes and/or injection frequency may be reduced. Due to the nature of pump and treat, operations are unlikely to be reduced long term.

6.0 SUMMARY AND CONCLUSIONS

This report evaluated groundwater data for the treatment area and the adjacent Zone 11 ISB to evaluate potential remedial alternatives for the groundwater contamination that is by-passing the western end of the Zone 11 ISB. Based on the technology screening process, the following medium-specific alternatives were identified for detailed analysis:

- Remedial Alternative 1: No Action
- Remedial Alternative 2: Pump and Treat
- Remedial Alternative 3: In Situ Anaerobic Bioremediation
- Remedial Alternative 4: In Situ Anaerobic Bioremediation with Groundwater Recirculation and Ex Situ Treatment
- Remedial Alternative 5: In Situ Anaerobic Bioremediation with Groundwater Recirculation, without Ex Situ Treatment

LUCs are currently conducted at the Pantex Plant and will continue as planned. Remedial Alternatives 2 – 5 include additional site inspections and environmental monitoring until GWPSs are achieved. Remedial Alternative 1 does not include additional site inspections or environmental monitoring aside from what is already conducted for existing remedies.

With the exception of No Action (Remedial Alternative 1), all remedial alternatives meet the threshold criteria of protecting human health and the environment and achieving federal and state ARARs. No remedial alternatives provide source control because the treatment area is located downgradient of the source area and outside the zone of influence for each Remedial Alternative.

Remedial Alternatives 3, 4, and 5 have similar degrees of long-term effectiveness and permanence because all of them will use physical and/or biological processes to remediate the contaminants. Remedial Alternative 2 may have a slight advantage in long-term effectiveness because it provides the greatest capture efficiency by spanning the plume north to south as well as east to west in order to prevent plume migration.

Because the source area is not treated, the remedial alternatives presented in this document will not completely remediate either COC plume. The remedial alternatives are designed to reduce COC concentrations to levels below the GWPS within the treatment area and provide a downgradient barrier to prevent further plume migration. Remedial Alternatives 3, 4, and 5 provide similar levels of reduction of toxicity, mobility, and volume through treatment. A drawback to Remedial Alternative 2 is that it provides the least contaminant reduction because the perchlorate mass removed by the ex situ treatment system is not destroyed.

Short-term risks include hazards associated with equipment, treatment chemicals, and the potential for traffic accidents during transport of materials. These short-term risks can be mitigated through engineering controls, PPE, HAZWOPER training, and standard industry practices. The short-term risks are similar among Remedial Alternatives 2, 3, 4, and 5.

Remedial Alternatives 2, 3, 4, and 5 are all technically implementable. Appropriate permits for groundwater extraction and/or injection are required for each alternative. The equipment, materials, and personnel required to implement each groundwater remedial alternative are readily available.

Remedial Alternative 1 requires No Action and, therefore, has no associated project costs. Based on the present-value cost comparison for groundwater remedial alternatives, the Remedial Alternatives are listed:

- Remedial Alternative 2 – $5.76 million
- Remedial Alternative 3 - $7.52 million
- Remedial Alternative 4 – $6.04 million
- Remedial Alternative 5 – $4.39 million

Remedial Alternative 3 is the most expensive remedial alternative, while Remedial Alternative 5 is the least expensive.

Aside from cost, there are no significant differences in terms of the threshold and balancing criteria between Remedial Alternatives 2, 3, 4, and 5. Remedial Alternative 5, in situ anaerobic bioremediation with groundwater recirculation, without ex situ treatment, is the recommended Remedial Alternative. Remedial Alternative 5 has the lowest estimated cost, and has the potential for reduced long-term costs because injection events can be minimized once anaerobic reducing conditions are established; Remedial Alternative 2 does not have this opportunity. Additionally, distribution issues observed in the existing Zone 11 ISB appear to be limiting it's effectiveness; the recirculation component of Remedial Alternative 5 can aide in substrate distribution and addresses this problem; Remedial Alternative 3 would not address this problem.

7.0 REFERENCES

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TABLES

Table 4.1
Identification and Screening of Remedial Technologies and Process Options
Pantex Zone 11
Amarillo, TX

General Response Action	Remedial Technology	Process Option	Description	Viability
No Action	No Action	No Action	No additional action would be taken beyond the existing remedy.	Required Alternative.
Institutional Controls	Land Use Controls	Administrative Controls	In accordance with the 2008 Record of Decision, institutional controls have already been implemented at the Pantex Plant to prevent exposure to contaminated groundwater.	Part of the status quo (no action alternative).
Monitoring	Monitoring	Site Inspections	Conduct inspections to confirm implementation of land use controls. These inspections are already performed as part of the existing remedy.	Part of the status quo (no action alternative).
		Environmental Monitoring	Collect groundwater samples to assess remedy performance. Environmental monitoring is already being conducted as part of the existing remedy. The monitoring network, however, does not include wells in the area under evaluation.	Potentially viable.
		Natural Attenuation	Natural processes are used to achieve GWPSs for TCE and perchlorate. These processes include dilution through advection and dispersion, and abiotic and biotic degradation. Under anaerobic conditions, certain microbes can use TCE or perchlorate as electron receptors. In this situation, TCE can be reduced through cis-1.2-DCE and vinyl chloride to ethene, and perchlorate can be reduced to chloride and oxygen through chlorate and chlorite. Reductive dechlorination of TCE can also occur abiotically on the surface of iron-bearing minerals. The site groundwater is naturally aerobic. Under aerobic conditions, TCE and perchlorate are unlikely to degrade.	Potentially viable, although effectiveness would be limited due to reliance on advection and dispersion.
Containment	Vertical Barrier	Low Permeability Vertical Wall	Install a low permeability perimeter wall (i.e., slurry wall, sheet pile wall, grout curtain, geomembrane wall) to limit lateral migration of contaminated groundwater.	Not viable. The saturated zone is approximately 260 to 290 feet below ground surface. Installing a vertical barrier at this depth is technically and financially impractical.
	Gradient Control	Extraction Wells	Install extraction wells to limit migration of contaminated groundwater.	Potentially viable.
Removal	Pump	Extraction Wells	Install extraction wells to remediate the groundwater plume. Must be combined with ex situ treatment.	Potentially viable.
	Extraction	Dual Phase Extraction	Simultaneous extraction of groundwater and vapor phase. Requires ex situ treatment of the extracted fluids.	Potentially viable. More effective for TCE than perchlorate because of TCE's volatile nature.
		High Volume Vacuum Extraction	Use of high volume vacuum extraction to enhance the radius of influence of extraction wells. Must be combined with ex situ treatment.	Potentially viable.
	Excavation	Large Diameter Auger	Use of large diameter auger to remove the saturated material and backfill with clean fill or flowable fill. Large diameter auger can also be used for steam injection and/or amendment injection.	Not viable due to depth to the saturated zone (260 - 290 feet bgs).
Treatment	Chemical/Physical Treatment	Ex Situ Chemical/ Physical Treatment	Reductants can be introduced to extracted groundwater to reduce TCE or perchlorate. TCE can be removed from extracted groundwater through air stripping (a mass transfer process that promotes movement of dissolved volatile components from the bulk liquid into the gas phase) or adsorption to a series of columns containing granular activated carbon. Perchlorate can be removed from extracted groundwater through ion exchange which removes ions from the aqueous phase by the exchange of cations or anions between the contaminants and the exchange medium. Reverse osmosis and nanofiltration can remove both TCE and perchlorate from extracted groundwater, both of which utilizes a membrane through which water can pass but larger molecules, including TCE and perchlorate, cannot.	Potentially viable.
		In Situ Chemical Reduction	Inject reducing materials, such as zero valent iron, into groundwater to reduce organic and inorganic contaminants.	Potentially viable.
		In Situ Chemical Oxidation	Inject oxidizing materials, such as sodium persulfate, into groundwater to oxidize organic contaminants.	Potentially viable for TCE. Not viable for perchlorate.
		In Situ Chemical Immobilization	Inject an amendment to prevent further migration of the groundwater contaminants. Injection of activated carbon can immobilize TCE. Typically, perchlorate is not well adsorbed by GAC. It is possible to modify the GAC to adsorb perchlorate. This technology has been tested but has not been widely used.	Potentially viable.
		Air Sparging	High rate air injection to volatilize VOCs and transport the vapors to the ground surface. Often combined with SVE to allow capture of the volatilized constituents.	Potentially viable for TCE. Not viable for perchlorate.
	Thermal Treatment	Thermally Enhanced Vapor Extraction	In situ heating of groundwater to promote volatilization of organic contaminants, followed by extraction via SVE.	Potentially viable for TCE. Not viable for perchlorate.
	Biological Treatment	Ex Situ Biological Treatment	Fixed film reactors or fluidized-bed reactors use an external treatment vessel and microorganisms to biodegrade contaminants into non-hazardous compounds. Fixed film reactors provide a surface for bacteria to grow and develop using a packed bed of stones or synthetic media. As the water flows through the filter bed, contaminants are degraded by the bacteria. Fluidized-bed reactors allow contaminants to come in contact with the media that support bacterial growth, and usually consist of a cylindrical tank that is filled with contaminated groundwater, air injection equipment, and small media particles. Air is injected through the extracted groundwater and provides oxygen for aerobic degradation.	Potentially viable.
		In Situ Aerobic Bioremediation	Injection of an oxygen release compound or air to support aerobic biodegradation.	Not viable. Neither TCE nor perchlorate can be directly biodegraded under aerobic conditions.
		In Situ Aerobic Co-metabolism	TCE can be biodegraded aerobically if a co-metabolic substrate, such as propane, is injected. This technology would include injection of air or oxygen with a co-metabolic substrate.	Potentially viable for TCE. Not viable for perchlorate.
		In Situ Anaerobic Bioremediation	Inject an electron donor to generate anaerobic conditions that would support microbial reduction of TCE and perchlorate. Amendment can be delivered through injection wells. This approach can be combined with pump-and-treat to enhance amendment distribution through recirculation.	Potentially viable.

Notes:
DCE = dichloroethene
GAC= granulated activated carbon
GWPS = Groundwater Protection Standard
SVE = soil vapor extraction
TCE = trichloroethene
VOC = volatile organic compound

Table 4.2
Effectiveness, Implementability, and Cost Screening
Pantex Zone 11
Amarillo, TX

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained or Eliminated
No Action	No Action	No Action	No additional action would be taken beyond the existing remedy.	Will not achieve GWPSs. No action is a required alternative.	Easily implemented.	None.	Retained; required alternative.
Institutional Controls	Land Use Controls	Administrative Controls	In accordance with the 2008 Record of Decision, institutional controls have already been implemented at the Pantex Plant to prevent exposure to contaminated groundwater.	Prevents human exposure to contamination but does not meet GWPSs.	Already implemented.	Minimal O&M cost.	Retained, to be used in conjunction with another process option until GWPSs are met.
Monitoring	Monitoring	Site Inspections	Conduct inspections to confirm implementation of land use controls. These inspections are already performed as part of the existing remedy.	Effectively assesses compliance with LUCs, but inspections per se do not achieve GWPSs.	Already implemented.	Minimal cost.	Retained, to be used in conjunction with another process option until GWPSs are met.
		Environmental Monitoring	Collect groundwater samples to assess remedy performance. Environmental monitoring is already being conducted as part of the existing remedy. The monitoring network that is routinely sampled, however, does not include wells in the area under evaluation.	Does not achieve GWPSs, but monitoring is necessary for evaluating remedy efficacy.	The monitoring network currently used to collect groundwater samples can easily be expanded to include the area under evaluation.	Minimal cost.	Retained, to be used in conjunction with another process option until GWPSs are met.
		Natural Attenuation	Natural processes are used to achieve GWPSs for TCE and perchlorate. These processes include dilution through advection and dispersion, and abiotic and biotic degradation. Under anaerobic conditions, certain microbes can use TCE or perchlorate as electron acceptors. In this situation, TCE can be reduced through cis-1.2-DCE and vinyl chloride to ethene, and perchlorate can be reduced to chloride and oxygen through chlorate and chlorite. Reductive dechlorination of TCE can also occur abiotically on the surface of iron-bearing minerals. The site groundwater is naturally aerobic. Under aerobic conditions, TCE and perchlorate are unlikely to degrade.	Due to the aerobic nature of site groundwater, TCE and perchlorate are unlikely to degrade naturally. Any attenuation would be through advection and dispersion, both of which would require a long time to meet GWPSs, particularly given the presence of an ongoing, upgradient source.	Easily implemented.	Minimal cost.	Eliminated due to limited effectiveness.
Containment	Gradient Control	Extraction Wells	Install extraction wells to limit lateral and vertical migration of contaminated groundwater. The difference between this option and use of groundwater extraction to remediate the plume in the treatment zone is the degree to which the pumping system is designed to capture and remove contaminant mass and groundwater. With hydraulic control, the system is designed to remove only as much water as is necessary to prevent further contaminant migration. This process would need to be combined with ex situ treatment of the extracted groundwater.	Extraction wells can effectively provide hydraulic control of contamination. Would not be designed to maximize mass removal. Depending on well placement and pumping rate, this process could extract the electron donor amendment injected into the adjacent ISB, which would be counter to the effective functioning of the ISB.	Implementable. Would require onsite treatment and discharge or beneficial reuse of treated groundwater.	Moderate to high capital cost. Moderate to high O&M cost, depending on the treatment train.	Eliminated in favor of groundwater extraction for plume remediation.
Removal	Pumping	Extraction Wells	Install extraction wells to remediate the groundwater contamination in the treatment zone. Under this option, the extraction system would be designed to maximize mass removal while preventing lateral and vertical contaminant migration. This process would need to be combined with ex situ treatment of the extracted groundwater.	Groundwater extraction can effectively remove contaminant mass in addition to preventing further contaminant migration. Typically, groundwater extraction is not effective at achieving cleanup goals because of its limited ability to remove contaminant mass that is adsorbed to the solid matrix or contained in the less permeable zones. Groundwater extraction is effective, however, at removing contaminant mass from the transmissive zone(s). Because the treatment area is downgradient of an ongoing contaminant source(s), it will be necessary to operate any treatment system until the contaminant source(s) has been remediated. In this situation, groundwater extraction can be an effective option for preventing contaminant migration and removing contaminant mass. Because of the potential for the extraction wells to pull electron donor amendment from the adjacent ISB into the treatment zone, it would be necessary to design the system to minimize its influence on the ISB. Extraction of electron donor amendment could cause biofouling of the extraction wells and ex situ treatment system.	Implementable. Would require onsite treatment and discharge or beneficial reuse of treated groundwater.	Moderate to high capital cost. Moderate to high O&M cost, depending on the treatment train.	Retained, to be used in conjunction with Ex-Situ Chemical/Physical Treatment option below.
	Extraction	Dual Phase Extraction	Simultaneous extraction of groundwater and vapor phase. Requires ex situ treatment of the extracted fluids.	Could increase removal of TCE mass through volatilization and extraction of the vapors. Would not increase perchlorate mass removal because this anion is not volatile. Perchlorate mass would be removed with extracted groundwater, but not with vapor. DPE is most cost effective when light non-aqueous phase liquid is present, which is not the case at Zone 11.	Implementable; requires ex-situ treatment vapor and water, and discharge or beneficial reuse of treated groundwater.	High capital and O&M costs, largely due to the need to treat both extracted vapor and liquid phases.	Eliminated because the increased mass removal relative to conventional groundwater extraction is offset by the increased cost.
		High Volume Vacuum Extraction	Application of a vacuum to enhance the recovery rate and radius of influence of an extraction well. Must be combined with ex situ treatment of the extracted fluids.	As with DPE, applying a vacuum can enhance removal of TCE mass through volatilization and extraction in the vapor phase in addition to its removal through groundwater extraction. Because perchlorate is not volatile, its removal would not be enhanced relative to that associated with conventional groundwater extraction. Because of the potential for vapor phase removal of TCE, this approach would be more effective than conventional groundwater extraction. However, the potential enhancement of TCE mass removal is offset by the potential effects of a more aggressive groundwater extraction system on the adjacent ISB.	Implementable. Would require onsite treatment of extracted water and vapor, and discharge or beneficial reuse of treated groundwater.	High capital and O&M costs, largely due to the need to treat both extracted vapor and liquid phases.	Eliminated because the increased mass removal relative to conventional groundwater extraction is offset by the increased cost.

Table 4.2 (continued)
Effectiveness, Implementability, and Cost Screening
Pantex Zone 11
Amarillo, TX

General Response Action	Remedial Technology	Process Option	Description	Effectiveness	Implementability	Cost	Retained or Eliminated
Treatment	Chemical/Physical Treatment	Ex Situ Chemical/ Physical Treatment	Reductants can be introduced to extracted groundwater to reduce TCE or perchlorate. TCE can be removed from extracted groundwater through air stripping or adsorption to granular activated carbon. Perchlorate can be removed from extracted groundwater through ion exchange. Reverse osmosis and nanofiltration can remove both TCE and perchlorate from extracted groundwater.	TCE and perchlorate in extracted groundwater can effectively be treated ex situ. This process option must be combined with a groundwater extraction method.	Implementable. Would require groundwater extraction and onsite discharge or beneficial reuse of treated groundwater.	Moderate to high capital and O&M costs, depending on treatment train.	Retained, to be used in conjunction with groundwater extraction.
		In Situ Chemical Reduction	Inject reducing materials, such as zero valent iron (ZVI), into groundwater to reduce organic and inorganic contaminants.	Effective for chlorinated ethenes and perchlorate. Chemical reduction requires direct contact between reducing materials (ZVI) and COCs. For this reason, uniform amendment distribution throughout the treatment area is required for effective contaminant degradation. ZVI has a high longevity in the subsurface, which means that amendment re-injection would be infrequent.	ZVI is a solid material which would be difficult to inject at the depths required for the site. Adequate distribution would require a tight injection point spacing. Difficult to implement.	High capital cost due to injection requirements. Moderate O&M cost due to infrequency of amendment re-application.	Eliminated due to cost.
		In Situ Chemical Oxidation	Inject oxidizing materials, such as sodium persulfate, into groundwater to oxidize organic contaminants. Requires direct contact between the contaminant and oxidant for the reaction to occur.	Not effective for perchlorate. Effective for TCE. Effective treatment would require uniform oxidant distribution throughout the treatment zone. Oxidants are relatively short-lived in the subsurface, leading to contaminant rebound once the oxidant has been consumed. Multiple injections are necessary at relatively frequent intervals.	Implementable, though injection wells are prone to fouling. Would need to be combined with another process option for perchlorate.	Moderate to high capital cost and high O&M cost due to the number of injection events required.	Eliminated due to cost and inability to degrade perchlorate.
		In Situ Chemical Immobilization	Inject an amendment to prevent further migration of the groundwater contaminants. Injection of activated carbon can immobilize TCE. Typically, perchlorate is not well adsorbed by GAC. It is possible to modify the GAC to adsorb perchlorate. This technology has been tested but has not been widely used.	Because this technology has not been widely used, its effectiveness in a large scale application is uncertain. Unless combined with an amendment to support biotic or abiotic degradation, immobilization will not degrade the contaminants.	Implementable. Without contaminant degradation, additional rounds of immobilization amendment would need to be injected to provide additional adsorption sites once the sites on the amendment originally injected have been consumed.	Moderate to high capital cost to achieve uniform distribution throughout treatment zone. Moderate to high O&M cost depending on rate at which the adsorption sites are consumed.	Eliminated due to limited effectiveness for perchlorate, and inability to degrade TCE without additional amendments.
		Air Sparging	High rate air injection to volatilize VOCs and transport the vapors to the ground surface. Often combined with SVE to allow capture of the volatilized constituents.	Effective for TCE, but ineffective for perchlorate. Prone to short-circuiting, which would reduce effectiveness for TCE.	Implementable, but would need to be combined with another process option for perchlorate.	Moderate capital and O&M costs.	Eliminated due to inability to remediate perchlorate.
	Thermal Treatment	Thermally Enhanced Vapor Extraction	In situ heating of groundwater to promote volatilization of organic contaminants, followed by extraction via SVE.	Effective for TCE, but ineffective for perchlorate.	Implementable, but would need to be combined with another process option for perchlorate.	High capital cost, high O&M cost.	Eliminated due to inability to remediate perchlorate and high cost.
	Biological Treatment	Ex Situ Biological Treatment	Use an external treatment vessel and microorganisms to biodegrade contaminants into non-hazardous compounds.	Biological treatment under anaerobic conditions is effective for TCE and perchlorate.	Difficult to implement because of the need to maintain a biological reactor.	Moderate capital and O&M cost.	Eliminated due to difficulty implementing.
		In Situ Aerobic Co-metabolism	TCE can be biodegraded aerobically if a co-metabolic substrate, such as propane, is injected. This technology would include injection of air or oxygen with a co-metabolic substrate.	Effective for TCE, but ineffective for perchlorate.	Implementable, but would need to be combined with another process option for perchlorate.	Moderate capital cost and O&M cost.	Eliminated due to inability to remediate perchlorate.
		In Situ Anaerobic Bioremediation	Inject an electron donor to generate anaerobic conditions that would support microbial reduction of TCE and perchlorate. Amendment can be delivered through injection wells. This approach can be combined with pump-and-treat to enhance amendment distribution through recirculation.	As demonstrated by the adjacent Zone 11 ISB, effective for both chlorinated ethenes and perchlorate. Incorporating recirculation will reduce the number of injection wells necessary, but will require an ex situ treatment system.	Implementable.	Moderate to high capital cost depending on approach used to distribute amendment (direct injection vs re-circulation). Moderate O&M cost.	Retained.

Shaded cells indicate process is removed from further
DCE = dichloroethene
O&M = operations and maintenance
TCE = trichloroethene
VOC = volatile organic compound
SVE = soil vapor extraction

Table 5.1

Capital Cost Estimate - Site Inspections, Land Use Controls, and Environmental Monitoring - For All Remedial Alternatives

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: Zone 11
Date: 6/4/2018

Description: MNA and LUCs
Two new monitoring wells will be installed and sampled to monitor remedy performance. Well installation will occur in conjunction with remedy implementation of the selected alternative. Site inspections, LUCs, and environmental monitoring are the same for all alternatives, and are detailed in the annual cost tables.
2 weeks to install wells, 5 working days per week
-Site inspections, LUCs, and environmental monitoring until GWPS's are met
-Assume installation and quarterly monitoring of two additional monitoring wells

CAPITAL COSTS (Base Year, Year 0)

	DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Implementation									
	Installation of 2 new monitoring wells, installed concurrently with selected remedy well installation	1	LS	$96,000	1	1	$	96,000	Professional judgement
	Construction Debris Disposal (assume 30-yd roll-off, includes delivery and 4-tons disposal)	1	each	$328	1	1	$	328	Vendor Estimate
	Field Engineer or Geologist	2	week	$2,300	0.821	1	$	3,777	2018 RSMeans, 01 31 13.20 0120
Contingency									
	15% scope, 10% bid	1	Percent	25%	1	1	$	25,026.15	EPA's Feasibility Study Cost Guidance
Professional Services									
	Project Management	1	Percent	6%	1	1	$	7,507.85	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
	Remedial Design	1	Percent	12%	1	1	$	15,015.69	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
	Technical Support	1	Percent	10%	1	1	$	12,513.08	EPA's Feasibility Study Cost Guidance
Total Base Year Costs							**$**	**160,167**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ft - foot
GAC - granular activated carbon
LS - lump sum
QTY - quantity
TX - Texas
yd - yard

Table 5.2

Annual and Periodic Cost Estimate - Site Inspections, Land Use Controls, and Environmental Monitoring

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Two new monitoring wells will be installed and sampled to monitor remedy performance. Well installation will occur in conjunction with remedy implementation of the selected alternative. Site inspections, LUCs, and environmental monitoring are the same for all alternatives. It is assumed that sampling the two new wells will occur in conjunction with sampling at the remainder of the Zone 11 ISB.
1 day of sampling each quarter
-Site inspections, LUCs, and environmental monitoring until GWPS's are met
-Assume installation and quarterly monitoring of three additional monitoring wells

ANNUAL COSTS (30 Years)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL	NOTES
Annual O&M Costs							
Quarterly Monitoring							
Laboratory Analysis (VOCs, explosives, water quality, perchlorate)	4	event	$ 1,058	1	1	$ 4,232	Professional judgement
Data Validation	4	event	$ 290	1	1	$ 1,160	Professional judgment
Field Staff	4	day	$ 350	1	1	$ 1,400	2018 RSMeans 01 31 13.20 0100
Sample Equipment	4	event	$ 630	1	1	$ 2,520	Vendor Estimate
Sample Shipping	4	event	$ 600	1	1	$ 2,400	UPS Estimate
Contingency							
15% scope, 15% bid	1	Percent	30%	1	1	$ 3,514	EPA's Feasibility Study Cost Guidance
Professional Services							
Project management	1	Percent	10%	1	1	$ 1,523	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	20%	1	1	$ 3,045	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost						**$ 19,793**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
GWPS - Groundwater Protection Standard
EPA - U.S. Environmental Protection Agency
ISB - In Situ Bioremediation
LUC - land use control
LS - lump sum
O&M - operations and maintenance
QTY - quantity
TX - Texas
VOC - volatile organic carbon

Table 5.3
Site Inspections, Land Use Controls, and Environmental Monitoring - Present Value Analysis
Zone 11
Pantex Plant

Site Inspections, Land Use Controls, and Environmental Monitoring							
Year	**Annual O&M Costs**	**Present Value of Annual O&M Costs**	**Periodic Costs**	**Present Value of Periodic Costs**	**Capital Costs**	**Present Value of Capital Costs**	**Cumulative Present Value**
0	$0	$0	$0	$0	$160,167	$160,167	$160,167
1	$19,793	$19,292	$0	$0	$0	$0	$179,459
2	$19,793	$18,803	$0	$0	$0	$0	$198,262
3	$19,793	$18,326	$0	$0	$0	$0	$216,588
4	$19,793	$17,862	$0	$0	$0	$0	$234,450
5	$19,793	$17,409	$0	$0	$0	$0	$251,859
6	$19,793	$16,968	$0	$0	$0	$0	$268,827
7	$19,793	$16,538	$0	$0	$0	$0	$285,365
8	$19,793	$16,119	$0	$0	$0	$0	$301,484
9	$19,793	$15,711	$0	$0	$0	$0	$317,195
10	$19,793	$15,312	$0	$0	$0	$0	$332,507
11	$19,793	$14,924	$0	$0	$0	$0	$347,432
12	$19,793	$14,546	$0	$0	$0	$0	$361,978
13	$19,793	$14,178	$0	$0	$0	$0	$376,155
14	$19,793	$13,818	$0	$0	$0	$0	$389,974
15	$19,793	$13,468	$0	$0	$0	$0	$403,442
16	$19,793	$13,127	$0	$0	$0	$0	$416,569
17	$19,793	$12,794	$0	$0	$0	$0	$429,363
18	$19,793	$12,470	$0	$0	$0	$0	$441,833
19	$19,793	$12,154	$0	$0	$0	$0	$453,987
20	$19,793	$11,846	$0	$0	$0	$0	$465,833
21	$19,793	$11,546	$0	$0	$0	$0	$477,379
22	$19,793	$11,253	$0	$0	$0	$0	$488,632
23	$19,793	$10,968	$0	$0	$0	$0	$499,600
24	$19,793	$10,690	$0	$0	$0	$0	$510,290
25	$19,793	$10,419	$0	$0	$0	$0	$520,709
26	$19,793	$10,155	$0	$0	$0	$0	$530,864
27	$19,793	$9,898	$0	$0	$0	$0	$540,762
28	$19,793	$9,647	$0	$0	$0	$0	$550,409
29	$19,793	$9,403	$0	$0	$0	$0	$559,812
30	$19,793	$9,164	$0	$0	$0	$0	$568,976
TOTAL		$408,809		$0		$160,167	**$568,976**

Notes:
MNA - monitored natural attenuation
LUCs - land use controls
O&M - operations and maintenance
2.6% Discount Rate Applied
The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in OSWER Directive 9355.3-20 (Revisions to Office of Management and Budget Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94.

Table 5.4 **Capital Cost Estimate - Remedial Alternative 2: Pump and Treat**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 2
Groundwater will be extracted and treated ex situ. Chlorinated ethenes will be removed from extracted water in a GAC unit, although perchlorate is not expected to exceed the GWPS, it will be removed through ion exchange as a precaution. Treated water will be reinjected into the perched aquifer.

4.6 weeks to complete construction, including well installation, 5 working days per week
Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

CAPITAL COSTS (Base Year, Year 0)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Corrective Measures Implementation								
Installation of 2 extraction wells and 2 injection wells	1	LS	$228,000	1	1	$	228,000	Professional judgement
3-Field Engineers or Geologists	13.8	week	$4,600	0.821	1	$	52,117	2018 RSMeans, 01 31 13.20 0120
Extraction well pump and motor	2	each	$1,611	1	1	$	3,222	Vendor estimate
Extraction well vault (4 ft by 6 ft by 6 ft)	2	each	$3,775	0.821	1	$	6,199	2018 RSMeans, 33 05 63.13 0040
Treatment unit (includes installation, 3 ion exchange cannisters, 2 GAC vessels, 2 equalization tanks, transfer pumps, filters, Conex box, flow meters, pressure gauges, valves, etc)	1	LS	$200,000	1	1	$	200,000	Vendor estimates and professional judgement
Main service drop (includes conductors and poles and associated permit and inspection fees)	1	LS	$4,050	1	1	$	4,050	Professional judgement
Wiring to extraction wells (includes PVC conduits, labor, equipment, materials, restoration, etc, assumes 2 ft burial depth)	1	LS	$4,000	1	1	$	4,000	Professional judgement
PVC, 2-inch piping from extraction wells to treatment system, and from treatment system to reinjection, buried in same trenches as wiring	2400	foot	$32.5	0.821	1	$	64,038	2018 RSMeans, 22 11 13.74 4460
Electrician	5	days	$696	0.821	1	$	2,857	2018 RSMeans crew labor rate
Construction Debris Disposal (assume 30-yd roll-off, includes delivery and 4-tons disposal)	4	each	$328	1	1	$	1,312	Vendor estimate
Startup/Shakedown testing (assume one week of 2 engineer staff)	2	week	$2,300	0.821	1	$	3,777	2018 RSMeans, 01 31 13.20 0120
Forklift	4.6	week	$325	0.821	1	$	1,227	2018 RSMeans, 01 54 33 2045
Gravel access road to treatment plant plus gravel pad (30 ft by 11 ft road, 45 ft by 25 ft pad)	162	square yard	$8.50	0.821	1	$	1,128	2018 RSMeans, 01 55 23.50 0050
Equipment Mobilization/Demobilization (excluding well installation and treatment system)	1	LS	$1,640.00	0.821	1	$	1,346	2018 RSMeans, 01 54 36.50 1400

Table 5.4 (continued) **Capital Cost Estimate - Remedial Alternative 2: Pump and Treat**

CAPITAL COSTS (Base Year, Year 0) DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Contingency								
25% scope, 15% bid	1	Percent	40%	1	1	$	229,309.33	EPA's Feasibility Study Cost Guidance
Documents and Reporting								
Health and Safety Plan	1	LS	$20,000	1	1	$	20,000	Professional judgement
Corrective Measures Implementation Report	1	LS	$35,000	1	1	$	35,000	Professional judgement
Professional Services								
Project Management	1	Percent	6%	1	1	$	48,154.96	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Remedial Design	1	Percent	12%	1	1	$	96,309.92	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Construction Management	1	Percent	8%	1	1	$	64,206.61	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	10%	1	1	$	80,258.27	EPA's Feasibility Study Cost Guidance
Total Base Year Costs						**$**	**1,146,512**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ft - foot
GAC - granular activated carbon
LS - lump sum
QTY - quantity
TX - Texas
yd - yard

Table 5.5 **Annual and Periodic Cost Estimate - Remedial Alternative 2: Pump and Treat**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 2
Groundwater will be extracted and treated ex situ. Chlorinated ethenes will be removed from extracted water in a GAC unit, although perchlorate is not expected to exceed the GWPS, it will be removed through ion exchange as a precaution. Treated water will be reinjected into the perched aquifer.

Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

ANNUAL COSTS (30 Years)								
DESCRIPTION	**QTY**	**UNIT**	**UNIT COST**	**Locality Factor**	**Inflation Factor**		**TOTAL**	**NOTES**
Annual O&M Costs (Years 1 - 30)								
General system maintenance and replacement parts	1	quarterly	$2,000	1	1	$	2,000	Professional judgement
Field Engineer, two full days per week	104	daily rate	$460	0.821	1	$	39,277	2018 RSMeans 01 31 13.20 0120
Electrician, one full day per year	1	daily rate	$696	0.821	1	$	571	2018 RSMeans crew labor rate
Electricity	12	per month	$600	0.821	1	$	5,911	Based on utility rates and projected usage
Monthly sampling of GAC and ion exchange influents and effluents (includes all associated sampling/analysis costs)	12	per month	$3,000	1	1	$	36,000	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	37,692	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	12,145	EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	20%	1	1	$	24,290	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost for Years 1 - 30						**$**	**157,886**	

Table 5.5 (continued) **Annual and Periodic Cost Estimate - Remedial Alternative 2: Pump and Treat**

PERIODIC COSTS (30 Years)

Year	DESCRIPTION	QTY	Contingency	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL PER ITEM	TOTAL PER YEAR	NOTES
1			35%					$0	$0	
2	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
3	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$70,875	Vendor Estimate
4	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
5	Five Year Review	1	35%	LS	20000	1	1	$27,000	$97,875	Professional Judgement
6	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$84,375	Vendor Estimate
	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500		Vendor Estimate
7			35%					$0	$0	
8	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
9	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$70,875	Vendor Estimate
10	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$37,125	Vendor Estimate
	Five Year Review	1	35%	LS	17500	1	1	$23,625		Vendor Estimate
11	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
12	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$70,875	Vendor Estimate
13	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
14			35%					$0	$0	
	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875		Vendor Estimate
15	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$108,000	Vendor Estimate
	Five Year Review	1	35%	LS	17500	1	1	$23,625		Vendor Estimate
16			35%					$0	$0	
17	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
18	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$70,875	Vendor Estimate
19	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
20	Five Year Review	1	35%	LS	17500	1	1	$23,625	$23,625	Vendor Estimate
21	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$84,375	Vendor Estimate
	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875		Vendor Estimate
22	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
23			35%					$0	$0	
24	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$84,375	Vendor Estimate
	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875		Vendor Estimate
25	Five Year Review	1	35%	LS	17500	1	1	$23,625	$23,625	Vendor Estimate
26	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
27	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875	$70,875	Vendor Estimate
28	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$13,500	Vendor Estimate
29			35%					$0	$0	
	Replace ion exchange canisters	3	35%	LS	17500	1	1	$70,875		Vendor Estimate
30	Replace carbon in GAC	2	35%	LS	5000	1	1	$13,500	$108,000	Vendor Estimate
	Five Year Review	1	35%	LS	17500	1	1	$23,625		Vendor Estimate
	Total Periodic Costs								**$1,140,750**	

Notes:
GAC is expected to be replaced every 22 months. Ion exchange resin is expected to be replaced every 3 years.
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
GAC - granular activated carbon
LS - lump sum
O&M - operations and maintenance
QTY - quantity
TX - Texas

Table 5.6
Remedial Alternative 2 - Present Value Analysis
Zone 11
Pantex Plant

Pump and Treat							
Year	**Annual O&M Costs**	**Present Value of Annual O&M Costs**	**Periodic Costs**	**Present Value of Periodic Costs**	**Capital Costs**	**Present Value of Capital Costs**	**Cumulative Present Value**
0	$0	$0	$0	$0	$1,146,512	$1,146,512	$1,146,512
1	$157,886	$153,885	$0	$0	$0	$0	$1,300,397
2	$157,886	$149,986	$13,500	$12,824	$0	$0	$1,463,207
3	$157,886	$146,185	$70,875	$65,622	$0	$0	$1,675,014
4	$157,886	$142,480	$13,500	$12,183	$0	$0	$1,829,677
5	$157,886	$138,870	$97,875	$86,086	$0	$0	$2,054,633
6	$157,886	$135,351	$84,375	$72,332	$0	$0	$2,262,316
7	$157,886	$131,921	$0	$0	$0	$0	$2,394,236
8	$157,886	$128,578	$13,500	$10,994	$0	$0	$2,533,808
9	$157,886	$125,319	$70,875	$56,256	$0	$0	$2,715,383
10	$157,886	$122,144	$37,125	$28,721	$0	$0	$2,866,247
11	$157,886	$119,048	$13,500	$10,179	$0	$0	$2,995,475
12	$157,886	$116,031	$70,875	$52,086	$0	$0	$3,163,592
13	$157,886	$113,091	$13,500	$9,670	$0	$0	$3,286,353
14	$157,886	$110,225	$0	$0	$0	$0	$3,396,579
15	$157,886	$107,432	$108,000	$73,487	$0	$0	$3,577,498
16	$157,886	$104,710	$0	$0	$0	$0	$3,682,208
17	$157,886	$102,056	$13,500	$8,726	$0	$0	$3,792,990
18	$157,886	$99,470	$70,875	$44,652	$0	$0	$3,937,112
19	$157,886	$96,949	$13,500	$8,290	$0	$0	$4,042,351
20	$157,886	$94,492	$23,625	$14,139	$0	$0	$4,150,982
21	$157,886	$92,098	$84,375	$49,217	$0	$0	$4,292,298
22	$157,886	$89,764	$13,500	$7,675	$0	$0	$4,389,737
23	$157,886	$87,489	$0	$0	$0	$0	$4,477,226
24	$157,886	$85,272	$84,375	$45,570	$0	$0	$4,608,068
25	$157,886	$83,111	$23,625	$12,436	$0	$0	$4,703,616
26	$157,886	$81,005	$13,500	$6,926	$0	$0	$4,791,547
27	$157,886	$78,952	$70,875	$35,442	$0	$0	$4,905,941
28	$157,886	$76,952	$13,500	$6,580	$0	$0	$4,989,473
29	$157,886	$75,002	$0	$0	$0	$0	$5,064,474
30	$157,886	$73,101	$108,000	$50,004	$0	$0	$5,187,579
Subtotal		$3,260,969		$780,098		$1,146,512	$5,187,579
SIs, LUCs, Environmental Monitoring		$408,809		n/a		$160,167	
TOTAL		**$3,669,778**		**$780,098**		**$1,306,679**	**$5,756,555**

Notes:
O&M - operations and maintenance
SI - site inspection
LUC - land use control
2.6% Discount Rate Applied
The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in OSWER Directive 9355.3-20 (Revisions to Office of Management and Budget Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94.

Table 5.7 — **Capital Cost Estimate - Remedial Alternative 3: In Situ Anaerobic Bioremediation**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 3
In situ anaerobic bioremediation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Injection events will occur annually in conjunction with the existing Zone 11 ISB injections.

16 weeks to complete well installation, assume 5 working days per week
Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

CAPITAL COSTS (Base Year, Year 0)								
DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Corrective Measures Implementation								
Installation of 15 injection wells	1	LS	$885,000	1	1	$	885,000	Professional judgement
Construction Debris Disposal (assume 30-yd roll-off, includes delivery and 4-tons disposal)	4	each	$328.00	1	1	$	1,312	Vendor estimate
Field Engineer or Geologist	16	week	$2,300	0.821	1	$	30,590	2018 RSMeans, 01 31 13.20 0120
Contingency								
25% scope, 15% bid	1	Percent	40%	1	1	$	366,760.98	EPA's Feasibility Study Cost Guidance
Professional Services								
Project Management	1	Percent	6%	1	1	$	77,019.81	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Remedial Design	1	Percent	12%	1	1	$	154,039.61	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	10%	1	1	$	128,366.34	EPA's Feasibility Study Cost Guidance
Documents and Reporting								
Health and Safety Plan	1	LS	$10,000	1	1	$	10,000	Professional judgement
Corrective Measures Implementation Report	1	LS	$35,000	1	1	$	35,000	Professional judgement
Total Base Year Costs						**$**	**1,688,089**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ISB - In Situ Bioremediation
LS - lump sum
QTY - quantity
TX - Texas
yd - yard

Table 5.8 **Annual and Periodic Cost Estimate - Remedial Alternative 3: In Situ Anaerobic Bioremediation**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 3

In situ anaerobic biodegradation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Injection events will occur annually in conjunction with the existing Zone 11 ISB injections. The first two injection events (Years 1 and 2) are dosed according to the calculated hydrogen demand given current site conditions (0.0006 gal amendment per cubic foot aquifer). Once anaerobic and reducing conditions are established, amendment dosing will be less aggressive (assume 80% of the dose applied in years 1 and 2).

Length of injection event Years 1 and 2: 25 days
Length of injection event Years 3 - 30: 25 days

Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

ANNUAL COSTS (30 Years)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Annual O&M Costs, assume 1 injection event per year								
Years 1 and 2								
Purchase and Shipping of Amendment	1,240	gallon	$7.73	1	1	$	9,582	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	50	day	$48	1	1	$	2,395	Vendor Estimate
2-Field Staff Personnel	5	week	$3,500	0.821	1	$	14,368	2018 RSMeans, 01 31 13.20 0100
Field Engineer	5	week	$2,300	0.821	1	$	9,442	2018 RSMeans, 01 31 13.20 0120
Forklift	5	week	$325	0.821	1	$	1,334	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	328	1	1	$	328	Vendor estimate
Equipment mobilization/demobilization	1	LS	$590.00	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1300
Equipment/well maintenance and repairs, including well development to manage biofouling.	15	well	$4,500	1	1	$	67,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	50,795	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	16,367	EPA's Feasibility Study Cost Guidance
Technical Support (including field preparations and progress reporting)	1	Percent	20%	1	1	$	32,735	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost Years 1 and 2						**$**	**212,775**	
Years 3 - 30								
Purchase and Shipping of Amendment	992	gallon	$7.73	1	1	$	7,666	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	50	day	$48	1	1	$	2,395	Vendor Estimate
2-Field Staff Personnel	5.0	week	$3,500	0.821	1	$	14,368	2018 RSMeans, 01 31 13.20 0100
Field Engineer	5.0	week	$2,300	0.821	1	$	9,442	2018 RSMeans, 01 31 13.20 0120
Forklift	3.6	week	$325	0.821	1	$	953	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	$328	1	1	$	328	Vendor estimate
Equipment mobilization/demobilization	1	LS	$590	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1300
Equipment/well maintenance and repairs, including well development to manage biofouling.	15	well	$4,500	1	1	$	67,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	49,761	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	16,034	EPA's Feasibility Study Cost Guidance
Technical Support (including field preparations and progress reporting)	1	Percent	20%	1	1	$	32,068	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost for years 3-30						**$**	**208,444**	

Table 5.8 (continued) **Annual and Periodic Cost Estimate - Remedial Alternative 3: In Situ Anaerobic Bioremediation**

PERIODIC COSTS (30 Years)

Year	DESCRIPTION	QTY	Contingency	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL	NOTES
1			35%					$0	
2			35%					$0	Professional judgement
3			35%					$0	
4	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1	$165,510	Professional judgement
5	Five Year Review	1	35%	LS	$ 20,000	1	1	$27,000	Professional judgement
6			35%					$0	Professional judgement
7			35%					$0	
8	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1	$165,510	Professional judgement
9			35%					$0	
10	Five Year Review	1	35%	LS	$ 20,000	1	1	$27,000	Professional judgement
11			35%					$0	
12	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1	$165,510	Professional judgement
13			35%					$0	
14			35%					$0	Professional judgement
15	Five Year Review	1	35%	LS	$ 20,000	1	1	$27,000	Professional judgement
16	Replace three injection wells (installation plus oversight)	3	35%	LS	$ 61,300	1	1	$248,265	Professional judgement
17			35%					$0	
18			35%					$0	Professional judgement
19			35%					$0	
20	Five Year Review	1	35%	LS	$ 20,000	1	1	$192,510	Professional judgement
	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1		Professional judgement
21			35%					$0	
22			35%					$0	Professional judgement
23			35%					$0	
24	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1	$165,510	Professional judgement
25	Five Year Review	1	35%	LS	$ 20,000	1	1	$27,000	Professional judgement
26			35%					$0	Professional judgement
27			35%					$0	
28	Replace two injection wells (installation plus oversight)	2	35%	LS	$ 61,300	1	1	$165,510	Professional judgement
29			35%					$0	
30	Five Year Review	1	35%	LS	$ 20,000	1	1	$27,000	Professional judgement
	Total Periodic Costs							**$1,403,325**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ISB - In Situ Bioremediation
LS - lump sum
O&M - operations and maintenance
QTY - quantity
TX - Texas
yd - yard

Table 5.9
Remedial Alternative 3 - Present Value Analysis
Zone 11
Pantex Plant

In Situ Anaerobic Bioremediation							
Year	**Annual O&M Costs**	**Present Value of Annual O&M Costs**	**Periodic Costs**	**Present Value of Periodic Costs**	**Capital Costs**	**Present Value of Capital Costs**	**Cumulative Present Value**
0	$0	$0	$0	$0	$1,688,089	$1,688,089	$1,688,089
1	$212,775	$207,383	$0	$0	$0	$0	$1,895,472
2	$212,775	$202,128	$0	$0	$0	$0	$2,097,600
3	$208,444	$192,996	$0	$0	$0	$0	$2,290,596
4	$208,444	$188,105	$165,510	$149,360	$0	$0	$2,628,061
5	$208,444	$183,338	$27,000	$23,748	$0	$0	$2,835,147
6	$208,444	$178,692	$0	$0	$0	$0	$3,013,840
7	$208,444	$174,164	$0	$0	$0	$0	$3,188,004
8	$208,444	$169,751	$165,510	$134,786	$0	$0	$3,492,540
9	$208,444	$165,449	$0	$0	$0	$0	$3,657,989
10	$208,444	$161,256	$27,000	$20,888	$0	$0	$3,840,133
11	$208,444	$157,170	$0	$0	$0	$0	$3,997,303
12	$208,444	$153,187	$165,510	$121,634	$0	$0	$4,272,124
13	$208,444	$149,305	$0	$0	$0	$0	$4,421,429
14	$208,444	$145,521	$0	$0	$0	$0	$4,566,951
15	$208,444	$141,834	$27,000	$18,372	$0	$0	$4,727,156
16	$208,444	$138,240	$248,265	$164,648	$0	$0	$5,030,044
17	$208,444	$134,736	$0	$0	$0	$0	$5,164,780
18	$208,444	$131,322	$0	$0	$0	$0	$5,296,102
19	$208,444	$127,994	$0	$0	$0	$0	$5,424,097
20	$208,444	$124,751	$192,510	$115,214	$0	$0	$5,664,061
21	$208,444	$121,589	$0	$0	$0	$0	$5,785,651
22	$208,444	$118,508	$0	$0	$0	$0	$5,904,159
23	$208,444	$115,505	$0	$0	$0	$0	$6,019,664
24	$208,444	$112,578	$165,510	$89,390	$0	$0	$6,221,632
25	$208,444	$109,725	$27,000	$14,213	$0	$0	$6,345,569
26	$208,444	$106,945	$0	$0	$0	$0	$6,452,514
27	$208,444	$104,234	$0	$0	$0	$0	$6,556,748
28	$208,444	$101,593	$165,510	$80,667	$0	$0	$6,739,009
29	$208,444	$99,019	$0	$0	$0	$0	$6,838,027
30	$208,444	$96,509	$27,000	$12,501	$0	$0	$6,947,038
Subtotal		$4,313,527		$945,422		$1,688,089	$6,947,038
SIs, LUCs, Environmental Monitoring		$408,809		n/a		$160,167	
TOTAL		**$4,722,336**		**$945,422**		**$1,848,256**	**$7,516,014**

Notes:
O&M - operations and maintenance
SI - site inspection
LUC - land use control
2.6% Discount Rate Applied
The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in OSWER Directive 9355.3-20 (Revisions to Office of Management and Budget Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94.

Table 5.10 **Capital Cost Estimate - Remedial Alternative 4: In Situ Anaerobic Bioremediation with Groundwater Recirculation and Ex Situ Treatment**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 4
In situ anaerobic bioremediation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Injection events will occur annually in conjunction with the existing Zone 11 ISB injections, utilizing existing injection equipment. Amendment dosing is in accordance with the Design Basis Document (2007). Groundwater extraction will occur simultaneously with injections to aid in substrate distribution. Extracted groundwater will be treated through a GAC unit for chlorinated ethenes and perchlorate will be removed through ion exchange. Treated water will be reinjected as either make-up water for substrate solutions or as chase water.
11 weeks to complete well installation, assume 5 working days per week
Land use controls will be maintained while groundwater COCs are being remediated.

CAPITAL COSTS (Base Year, Year 0)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL	NOTES
Corrective Measures Implementation							
Installation of 7 injection wells and 2 extraction wells	1	LS	$523,000	1	1	$ 523,000	Professional judgement
Extraction well vault (4 ft by 6 ft by 6 ft)	2	each	$3,775	0.821	1	$ 6,199	2018 RSMeans, 33 05 63.13 0040
Field Engineer or Geologist	11	per week	$2,300	0.821	1	$ 20,016	2018 RSMeans, 01 31 13.20 0120
2-inch PVC from extraction wells to frac tank location, plus fittings, couplings, elbows, valves, pressure gauges, flow meters, hoses for connection to treatment, etc	1	LS	$9,988	0.821	1	$ 8,200	Vendor estimates and various 2018 RSMeans, 22 11 13 entries
Trencher rental for extraction well PVC (2 ft deep, 4-inches wide, 245 ft total length)	1	day	$169.00	1	1	$ 169	Vendor Estimate
Extraction well pump and motor	2	each	$1,611	1	1	$ 3,222	Vendor estimate
Construction Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	2	each	$328	1	1	$ 656	Vendor estimate
GAC Unit (includes 2 vessels, carbon, and associated delivery costs)	1	LS	$22,000	1	1	$ 22,000	Vendor estimate
Forklift	1	week	$325	0.821	1	$ 267	2018 RSMeans, 01 54 33 2045
Gravel access road to treatment plant plus gravel pad (30 ft by 11 ft road, 45 ft by 10 ft pad)	87	square yard	$8.50	0.821	1	$ 605	2018 RSMeans, 01 55 23.50 0050
Equipment Mobilization/Demobilization (excluding well installation and treatment system)	1	LS	$1,640.00	0.821	1	$ 1,346	2018 RSMeans, 01 54 36.50 1400
Contingency							
25% scope, 15% bid	1	Percent	40%	1	1	$234,271.73	EPA's Feasibility Study Cost Guidance
Professional Services							
Project Management	1	Percent	6%	1	1	$ 49,197.06	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Remedial Design	1	Percent	12%	1	1	$ 98,394.13	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	10%	1	1	$ 81,995.11	EPA's Feasibility Study Cost Guidance
Documents and Reporting							
Health and Safety Plan	1	LS	$15,000	1	1	$ 15,000	Professional judgement
Corrective Measures Implementation Report	1	LS	$35,000	1	1	$ 35,000	Professional judgement
Total Base Year Costs						**$ 1,099,537**	

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ft - foot
GAC - granular activated carbon
ISB - In Situ Bioremediation
LS - lump sum
QTY - quantity
TX - Texas
yd - yard

Table 5.11 **Annual and Periodic Cost Estimate - Remedial Alternative 4: In Situ Anaerobic Bioremediation with Groundwater Recirculation and Ex Situ Treatment**

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 4

In situ anaerobic bioremediation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Groundwater extraction will occur simultaneously to distribute substrate downgradient. Extracted groundwater will be treated in GAC and ion exchange units before reinjection as either make-up water for substrate solutions or chase water. Recirculation events will occur annually in conjunction with the existing Zone 11 ISB injections. The first two recirculation events (Years 1 and 2) are dosed according to the calculated hydrogen demand given current site conditions (0.0006 gal amendment per cubic foot aquifer). Once anaerobic and reducing conditions are established, amendment dosing will be less aggressive (assume 80% of the dose applied in years 1 and 2).

Length of injection event Years 1 and 2: 15 days
Length of injection event Years 3 - 30: 15 days

Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

ANNUAL COSTS (30 Years)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Annual O&M Costs, assume 1 recirculation event per year								
Years 1 and 2								
Purchase and Shipping of Amendment	1,240	gallon	$7.73	1	1	$	9,582	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	30	day	$48	1	1	$	1,437	Vendor Estimate
2-Field Staff Personnel	3.0	per week	$3,500	0.821	1	$	8,621	2018 RSMeans, 01 31 13.20 0100
Field Engineer	3.0	per week	$2,300	0.821	1	$	5,665	2018 RSMeans, 01 31 13.20 0120
Forklift	3.0	per week	$334	0.821	1	$	823	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	$328	1	1	$	328	Vendor estimate
Ion Exchange Unit (includes resin and associated delivery and disposal costs)	1	LS	$35,000	1	1	$	35,000	Vendor Estimate
Equipment mobilization/demobilization	1	LS	$590	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1400
Equipment/well maintenance and repairs, including well development to manage biofouling	7	per well	$4,500	1	1	$	31,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	45,398	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	14,628	EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	20%	1	1	$	29,257	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost Years 1 and 2						**$**	**190,169**	
Years 3 - 30								
Purchase and Shipping of Amendment	992	gallon	$7.73	1	1	$	7,666	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	30	day	$48	1	1	$	1,437	Vendor Estimate
2-Field Staff Personnel	3.0	per week	$3,500	0.821	1	$	8,621	2018 RSMeans, 01 31 13.20 0140
Field Engineer	3.0	per week	$2,300	0.821	1	$	5,665	2018 RSMeans, 01 31 13.20 0120
Forklift	3.0	per week	$334	0.821	1	$	823	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	328	1	1	$	328	Vendor estimate
Ion Exchange Unit (includes resin and associated delivery and disposal costs)	1	LS	$35,000	1	1	$	35,000	Vendor Estimate
Equipment mobilization/demobilization	1	LS	$590.00	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1400
Equipment/well maintenance and repairs, including well development to manage biofouling	7	per well	$4,500	1	1	$	31,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	44,536	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	14,351	EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	20%	1	1	$	28,701	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost for Years 3 - 30)						**$**	**186,557**	

Table 5.11 (continued)

Annual and Periodic Cost Estimate - Remedial Alternative 4: In Situ Anaerobic Bioremediation with Groundwater Recirculation and Ex Situ Treatment

PERIODIC COSTS (30 Years)										
Year	DESCRIPTION	QTY	Contingency	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL PER ITEM	TOTAL PER YEAR	NOTES
1			35%					$ -	$ -	
2			35%					$ -	$ -	
3			35%					$ -	$ -	
4	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
5	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
6			35%					$ -	$ -	
7			35%					$ -	$ -	
8	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
9			35%					$ -	$ -	
10	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 31,350	Professional Judgement
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
11			35%					$ -	$ -	
12	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
13			35%					$ -	$ -	
14			35%					$ -	$ -	
15	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
16	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
17			35%					$ -	$ -	
18			35%					$ -	$ -	
19			35%					$ -	$ -	
20	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 127,605	Professional Judgement
	Replace carbon in GAC	2	35%	LS	$ 5,000	1	1	$ 13,500		Vendor Estimate
	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755		Professional Judgement
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
21			35%					$ -	$ -	
22			35%					$ -	$ -	
23			35%					$ -	$ -	
24	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
25	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
26			35%					$ -	$ -	
27			35%					$ -	$ -	
28	Replace one injection well (installation plus oversight	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
29			35%					$ -	$ -	
30	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 31,350	Professional Judgement
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
	Total Periodic Costs								**$ 767,834**	

Notes:

Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
GAC - granular activated carbon
ISB - In Situ Bioremediation
LS - lump sum
O&M - operations and maintenance
QTY - quantity
TX - Texas
yd - yard

Table 5.12
Remedial Alternative 4 - Present Value Analysis
Zone 11
Pantex Plant

In Situ Anaerobic Bioremediation with Groundwater Recirculation and Ex Situ Treatment							
Year	**Annual O&M Costs**	**Present Value of Annual O&M Costs**	**Periodic Costs**	**Present Value of Periodic Costs**	**Capital Costs**	**Present Value of Capital Costs**	**Cumulative Present Value**
0	$0	$0	$0	$0	$1,099,537	$1,099,537	$1,099,537
1	$190,169	$185,350	$0	$0	$0	$0	$1,284,887
2	$190,169	$180,653	$0	$0	$0	$0	$1,465,540
3	$186,557	$172,730	$0	$0	$0	$0	$1,638,270
4	$186,557	$168,353	$82,755	$74,680	$0	$0	$1,881,303
5	$186,557	$164,087	$27,000	$23,748	$0	$0	$2,069,138
6	$186,557	$159,929	$0	$0	$0	$0	$2,229,067
7	$186,557	$155,876	$0	$0	$0	$0	$2,384,943
8	$186,557	$151,926	$82,755	$67,393	$0	$0	$2,604,262
9	$186,557	$148,076	$0	$0	$0	$0	$2,752,338
10	$186,557	$144,323	$31,350	$24,253	$0	$0	$2,920,914
11	$186,557	$140,666	$0	$0	$0	$0	$3,061,580
12	$186,557	$137,102	$82,755	$60,817	$0	$0	$3,259,499
13	$186,557	$133,627	$0	$0	$0	$0	$3,393,126
14	$186,557	$130,241	$0	$0	$0	$0	$3,523,367
15	$186,557	$126,940	$27,000	$18,372	$0	$0	$3,668,679
16	$186,557	$123,724	$82,755	$54,883	$0	$0	$3,847,286
17	$186,557	$120,588	$0	$0	$0	$0	$3,967,874
18	$186,557	$117,533	$0	$0	$0	$0	$4,085,407
19	$186,557	$114,554	$0	$0	$0	$0	$4,199,961
20	$186,557	$111,651	$127,605	$76,369	$0	$0	$4,387,981
21	$186,557	$108,822	$0	$0	$0	$0	$4,496,803
22	$186,557	$106,064	$0	$0	$0	$0	$4,602,867
23	$186,557	$103,376	$0	$0	$0	$0	$4,706,244
24	$186,557	$100,757	$82,755	$44,695	$0	$0	$4,851,695
25	$186,557	$98,203	$27,000	$14,213	$0	$0	$4,964,111
26	$186,557	$95,715	$0	$0	$0	$0	$5,059,826
27	$186,557	$93,289	$0	$0	$0	$0	$5,153,116
28	$186,557	$90,925	$82,755	$40,334	$0	$0	$5,284,374
29	$186,557	$88,621	$0	$0	$0	$0	$5,372,996
30	$186,557	$86,375	$31,350	$14,515	$0	$0	$5,473,886
Subtotal		$3,860,077		$514,271		$1,099,537	$5,473,886
SIs, LUCs, Environmental Monitoring		$408,809		n/a		$160,167	
TOTAL		**$4,268,886**		**$514,271**		**$1,259,704**	**$6,042,862**

Notes:
O&M - operations and maintenance
SI - site inspection
LUC - land use control
2.6% Discount Rate Applied
The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in OSWER Directive 9355.3-20 (Revisions to Office of Management and Budget Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94.

Table 5.13

Capital Cost Estimate - Remedial Alternative 5: In Situ Anaerobic Bioremediation with Groundwater Recirculation, No Ex Situ Treatment

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 5
In situ anaerobic bioremediation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Injection events will occur annually in conjunction with the existing Zone 11 ISB injections, utilizing existing injection equipment. Amendment dosing is in accordance with the Design Basis Document (2007). Groundwater extraction will occur simultaneously with injections to aid in substrate distribution. Extracted groundwater will not be treated prior to reinjection as either make-up water for substrate solutions or as chase water.
10 weeks to complete well installation, assume 5 working days per week
Land use controls will be maintained while groundwater COCs are being remediated.

CAPITAL COSTS (Base Year, Year 0)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor	TOTAL	NOTES
Corrective Measures Implementation							
Installation of 7 injection wells and 2 extraction wells	1	LS	$523,000	1	1	$ 523,000	Professional judgement
Extraction well vault (4 ft by 6 ft by 6 ft)	2	each	$3,775	0.821	1	$ 6,199	2018 RSMeans, 33 05 63.13 0040
2-inch PVC from extraction wells to frac tank location, plus fittings, couplings, elbows, valves, pressure gauges, flow meters, hoses for connection to treatment, etc	1	LS	$9,988	0.821	1	$ 8,200	Vendor estimates and various 2018 RSMeans, 22 11 13 entries
Trencher rental for extraction well PVC (2 ft deep, 4-inches wide, 245 ft total length)	1	day	$169.00	1	1	$ 169	Vendor Estimate
Field Engineer or Geologist	10	per week	$2,300	0.821	1	$ 18,883	2018 RSMeans, 01 31 13.20 0120
Extraction well pump and motor	2	each	$1,611	1	1	$ 3,222	Vendor estimate
Construction Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	2	each	$328	1	1	$ 656	Vendor estimate
Contingency							
25% scope, 15% bid	1	Percent	40%	1	1	$ 224,131.32	EPA's Feasibility Study Cost Guidance
Professional Services							
Project Management	1	Percent	6%	1	1	$ 47,067.58	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Remedial Design	1	Percent	12%	1	1	$ 94,135.15	Exhibit 5-8, EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	10%	1	1	$ 78,445.96	EPA's Feasibility Study Cost Guidance
Documents and Reporting							
Health and Safety Plan	1	LS	$15,000	1	1	$ 15,000	Professional judgement
Corrective Measures Implementation Report	1	LS	$35,000	1	1	$ 35,000	Professional judgement
Total Base Year Costs						**$ 1,054,108**	
			8635.5				

Notes:
Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ft - foot
ISB - In Situ Bioremediation
LS - lump sum
QTY - quantity
TX - Texas
yd - yard

Table 5.14

Annual and Periodic Cost Estimate - Remedial Alternative 5: In Situ Anaerobic Bioremediation with Groundwater Recirculation, No Ex Situ Treatment

Site: Zone 11
Location: Pantex Plant, Carson County, TX
Phase: CMS
Base Year: 2019
Date: 6/4/2018

Description: Alternative 5

In situ anaerobic bioremediation of COCs in groundwater using an electron donor and carbon source amendment (emulsified vegetable oil). Groundwater extraction will occur simultaneously to distribute substrate downgradient. Extracted groundwater will be not be treated prior to reinjection as either make-up water for substrate solutions or chase water. Recirculation events will occur annually in conjunction with the existing Zone 11 ISB injections. The first two recirculation events (Years 1 and 2) are dosed according to the calculated hydrogen demand given current site conditions (0.0006 gal amendment per cubic foot aquifer). Once anaerobic and reducing conditions are established, amendment dosing will be less aggressive (assume 80% of the dose applied in years 1 and 2).

Length of injection event Years 1 and 2: 10 days
Length of injection event Years 3 - 30: 10 days

Land use controls and groundwater monitoring will be maintained while groundwater COCs are being remediated.

ANNUAL COSTS (30 Years)

DESCRIPTION	QTY	UNIT	UNIT COST	Locality Factor	Inflation Factor		TOTAL	NOTES
Annual O&M Costs, assume 1 recirculation event per year								
Years 1 and 2								
Purchase and Shipping of Amendment	1,240	gallon	$7.73	1	1	$	9,582	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	20	day	$48	1	1	$	958	Vendor Estimate
2-Field Staff Personnel	2.0	per week	$3,500	0.821	1	$	5,747	2018 RSMeans, 01 31 13.20 0100
Field Engineer	2.0	per week	$2,300	0.821	1	$	3,777	2018 RSMeans, 01 31 13.20 0120
Forklift	2.0	per week	$334	0.821	1	$	548	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	328	1	1	$	328	Vendor estimate
Equipment mobilization/demobilization	1	LS	$590	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1400
Equipment/well maintenance and repairs, including well development to manage biofouling	7	per well	$4,500	1	1	$	31,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	27,167	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	6%	1	1	$	5,252	EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	10%	1	1	$	8,754	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost Years 1 and 2						**$**	**101,543**	
Years 3 - 30								
Purchase and Shipping of Amendment	992	gallon	$7.73	1	1	$	7,666	Vendor Estimate
Frac Tank delivery, pickup, cleaning, labor, fittings	2	each	$3,723	1	1	$	7,446	Vendor Estimate
Frac Tank Rental (2 tanks)	20	day	$48	1	1	$	958	Vendor Estimate
2-Field Staff Personnel	4.0	per week	$1,750	0.821	1	$	5,747	2018 RSMeans, 01 31 13.20 0140
Field Engineer	2.0	per week	$2,300	0.821	1	$	3,777	2018 RSMeans, 01 31 13.20 0120
Forklift	2.0	per week	$334	0.821	1	$	548	2018 RSMeans, 01 54 33 2045
Debris Disposal (assume 30-yd roll-offs, includes delivery and up to 4-tons disposal)	1	each	328	1	1	$	328	Vendor estimate
Equipment mobilization/demobilization	1	LS	$590.00	0.821	1	$	484	2018 RSMeans, 01 54 36.50 1400
Equipment/well maintenance and repairs, including well development to manage biofouling	7	per well	$4,500	1	1	$	31,500	Professional judgement
Contingency (25% scope, 20% bid)	1	Percent	45%	1	1	$	26,304	EPA's Feasibility Study Cost Guidance
Project Management	1	Percent	10%	1	1	$	8,476	EPA's Feasibility Study Cost Guidance
Technical Support	1	Percent	20%	1	1	$	16,952	EPA's Feasibility Study Cost Guidance
Total Annual O&M Cost Years 3 - 30						**$**	**110,186**	

Table 5.14 (continued)

Annual and Periodic Cost Estimate - Remedial Alternative 5: In Situ Anaerobic Bioremediation with Groundwater Recirculation, No Ex Situ Treatment

PERIODIC COSTS (30 Years)										
Year	**DESCRIPTION**	**QTY**	**Contingency**	**UNIT**	**UNIT COST**	**Locality Factor**	**Inflation Factor**	**TOTAL PER ITEM**	**TOTAL PER YEAR**	**NOTES**
1			35%					$ -	$ -	
2			35%					$ -	$ -	
3			35%					$ -	$ -	
4	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
5	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
6			35%					$ -	$ -	
7			35%					$ -	$ -	
8	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
9			35%					$ -	$ -	
	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000		Professional Judgement
10	Replace ion exchange cannisters	0	35%	LS	$ 17,500	1	1	$ -	$ 31,350	Vendor Estimate
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
11			35%					$ -	$ -	
12	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
13			35%					$ -	$ -	
14			35%					$ -	$ -	
15	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
16	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
17			35%					$ -	$ -	
18			35%					$ -	$ -	
19			35%					$ -	$ -	
	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000		Professional Judgement
20	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 114,105	Professional Judgement
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
21			35%					$ -	$ -	
22			35%					$ -	$ -	
23			35%					$ -	$ -	
24	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
25	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000	$ 27,000	Professional Judgement
26			35%					$ -	$ -	
27			35%					$ -	$ -	
28	Replace one injection well (installation plus oversight)	1	35%	LS	$ 61,300	1	1	$ 82,755	$ 82,755	Professional Judgement
29			35%					$ -	$ -	
	Five Year Review	1	35%	LS	$ 20,000	1	1	$ 27,000		Professional Judgement
30	Replace ion exchange cannisters	0	35%	LS	$ 17,500	1	1	$ -	$ 31,350	Vendor Estimate
	Replace extraction well pumps and motors	2	35%	LS	$ 1,611	1	1	$ 4,350		Vendor Estimate
	Total Periodic Costs								**$ 754,334**	

Notes:

Locality factors based on 2018 RSMeans for Amarillo, Texas
RSMeans weekly rates are based on 5-day work weeks

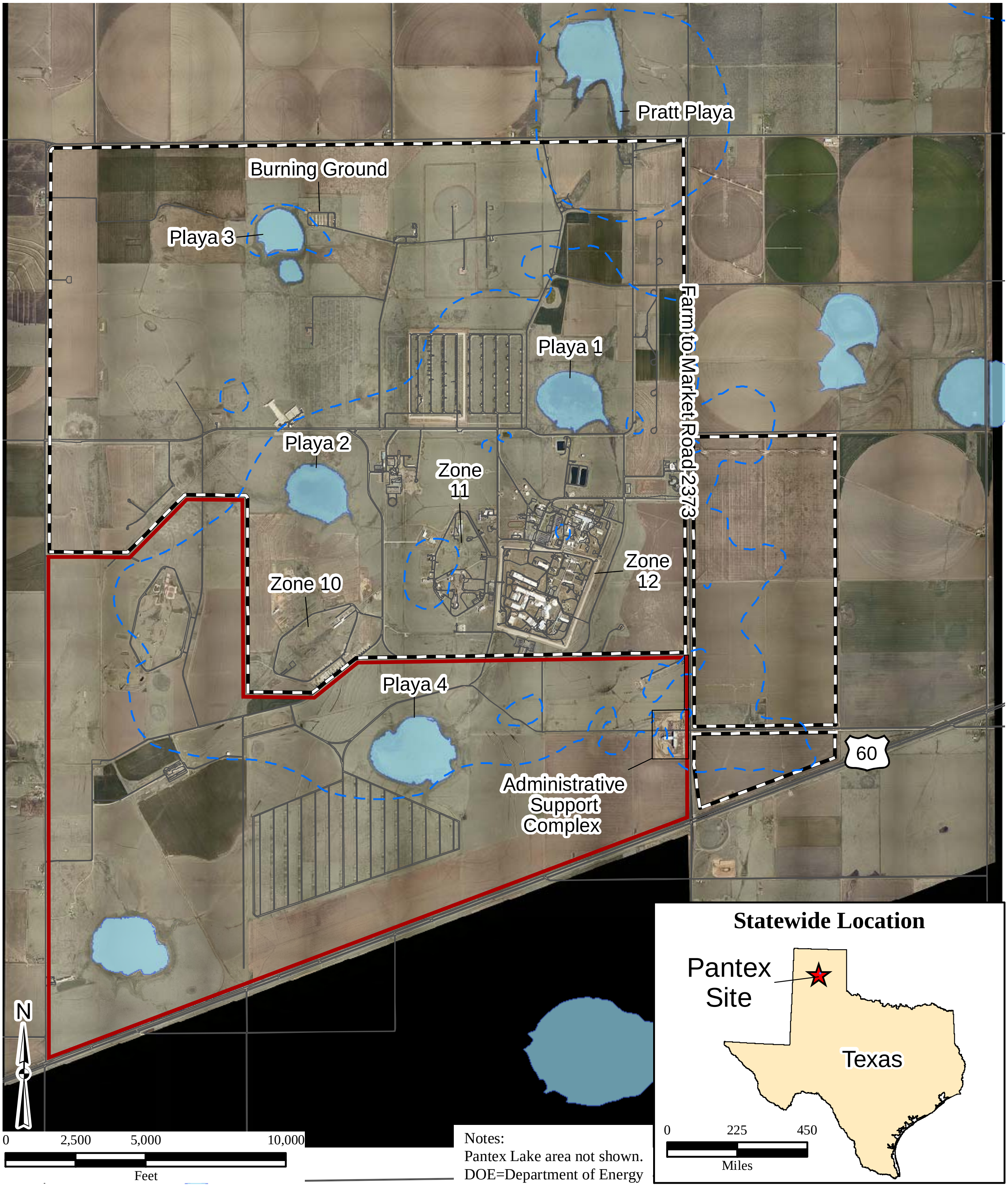
CMS - corrective measures study
COC - contaminant of concern
EPA - U.S. Environmental Protection Agency
ISB - In Situ Bioremediation
LS - lump sum
O&M - operations and maintenance
QTY - quantity
TX - Texas
yd - yard

Table 5.15
Remedial Alternative 5 - Present Value Analysis
Zone 11
Pantex Plant

In Situ Anaerobic Bioremediation with Groundwater Recirculation, No Ex Situ Treatment							
Year	**Annual O&M Costs**	**Present Value of Annual O&M Costs**	**Periodic Costs**	**Present Value of Periodic Costs**	**Capital Costs**	**Present Value of Capital Costs**	**Cumulative Present Value**
0	$0	$0	$0	$0	$1,054,108	$1,054,108	$1,054,108
1	$101,543	$98,970	$0	$0	$0	$0	$1,153,078
2	$101,543	$96,462	$0	$0	$0	$0	$1,249,540
3	$110,186	$102,020	$0	$0	$0	$0	$1,351,559
4	$110,186	$99,434	$82,755	$74,680	$0	$0	$1,525,674
5	$110,186	$96,915	$27,000	$23,748	$0	$0	$1,646,336
6	$110,186	$94,459	$0	$0	$0	$0	$1,740,795
7	$110,186	$92,065	$0	$0	$0	$0	$1,832,859
8	$110,186	$89,732	$82,755	$67,393	$0	$0	$1,989,984
9	$110,186	$87,458	$0	$0	$0	$0	$2,077,442
10	$110,186	$85,242	$31,350	$24,253	$0	$0	$2,186,937
11	$110,186	$83,082	$0	$0	$0	$0	$2,270,018
12	$110,186	$80,976	$82,755	$60,817	$0	$0	$2,411,812
13	$110,186	$78,924	$0	$0	$0	$0	$2,490,736
14	$110,186	$76,924	$0	$0	$0	$0	$2,567,660
15	$110,186	$74,975	$27,000	$18,372	$0	$0	$2,661,007
16	$110,186	$73,075	$82,755	$54,883	$0	$0	$2,788,964
17	$110,186	$71,223	$0	$0	$0	$0	$2,860,187
18	$110,186	$69,418	$0	$0	$0	$0	$2,929,605
19	$110,186	$67,659	$0	$0	$0	$0	$2,997,264
20	$110,186	$65,944	$114,105	$68,290	$0	$0	$3,131,499
21	$110,186	$64,273	$0	$0	$0	$0	$3,195,772
22	$110,186	$62,645	$0	$0	$0	$0	$3,258,417
23	$110,186	$61,057	$0	$0	$0	$0	$3,319,474
24	$110,186	$59,510	$82,755	$44,695	$0	$0	$3,423,679
25	$110,186	$58,002	$27,000	$14,213	$0	$0	$3,495,893
26	$110,186	$56,532	$0	$0	$0	$0	$3,552,425
27	$110,186	$55,099	$0	$0	$0	$0	$3,607,525
28	$110,186	$53,703	$82,755	$40,334	$0	$0	$3,701,561
29	$110,186	$52,342	$0	$0	$0	$0	$3,753,904
30	$110,186	$51,016	$31,350	$14,515	$0	$0	$3,819,434
Subtotal		$2,259,134		$506,192		$1,054,108	$3,819,434
SIs, LUCs, Environmental Monitoring		$408,809		n/a		$160,167	
TOTAL		**$2,667,943**		**$506,192**		**$1,214,275**	**$4,388,410**

Notes:
O&M - operations and maintenance
SI - site inspection
LUC - land use control
2.6% Discount Rate Applied
The use of discount rates for present-value cost analyses is stated in the preamble to the NCP (55 Federal Register 8722) and in OSWER Directive 9355.3-20 (Revisions to Office of Management and Budget Circular A-94 on Guidelines and Discount Rates for Benefit-Cost Analysis). For federal facility sites, it is generally appropriate to apply the real discount rates found in Appendix C of OMB Circular A-94.

FIGURES

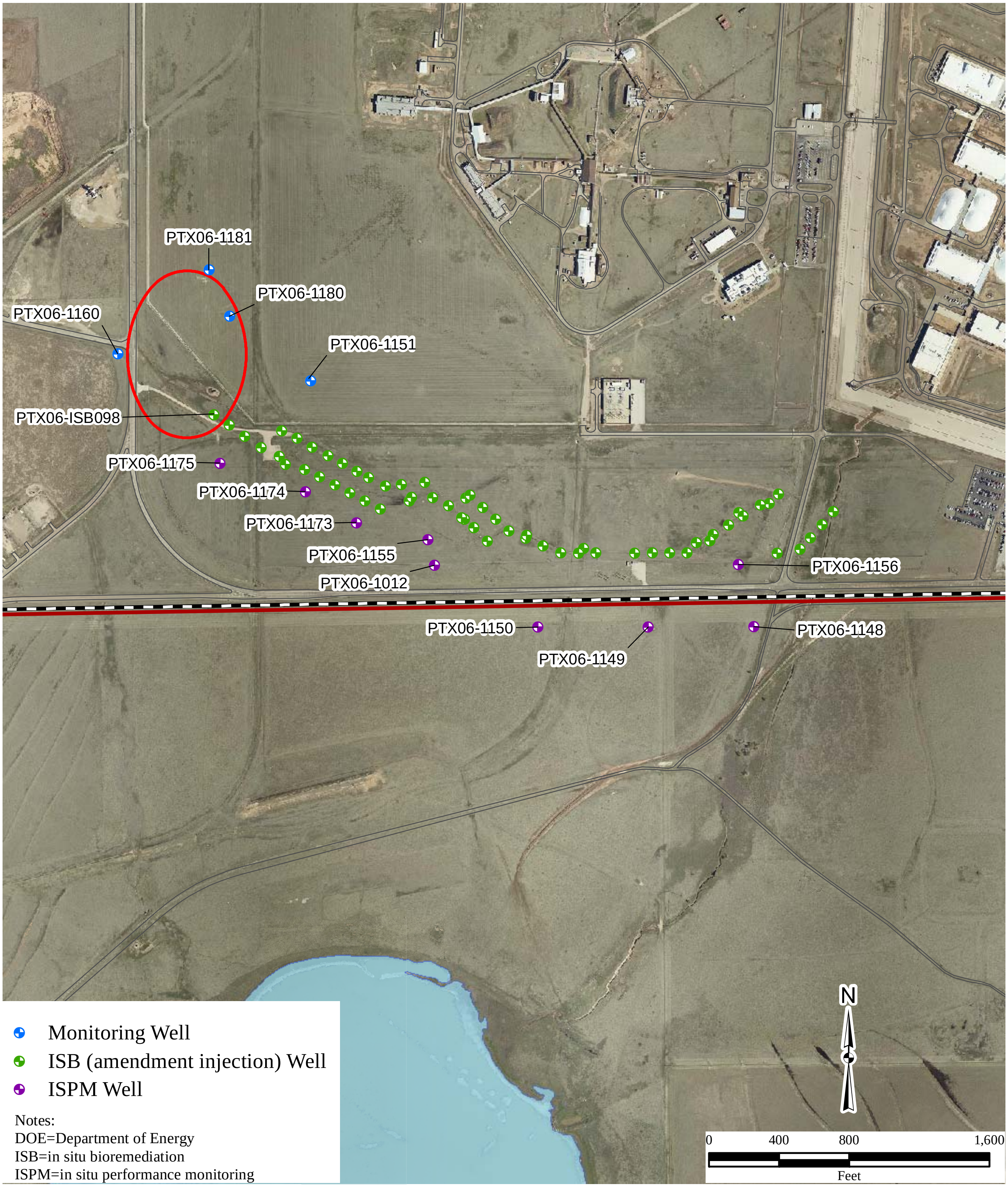


Notes:
Pantex Lake area not shown.
DOE=Department of Energy

\\Gst-srv-01\HGLGIS\Pantex_MSIW\CMS\(1-01)Pantex_Site.mxd
5/24/2018 TH
Source: HGL, CNS, NNSA. Imagery dated 2017.

Legend
- Road Outline
- Playa
- Perched Groundwater Extent
- DOE Property
- Texas Tech University Property

Figure 1.1
Pantex Site Area



Monitoring Well
ISB (amendment injection) Well
ISPM Well

Notes:
DOE=Department of Energy
ISB=in situ bioremediation
ISPM=in situ performance monitoring

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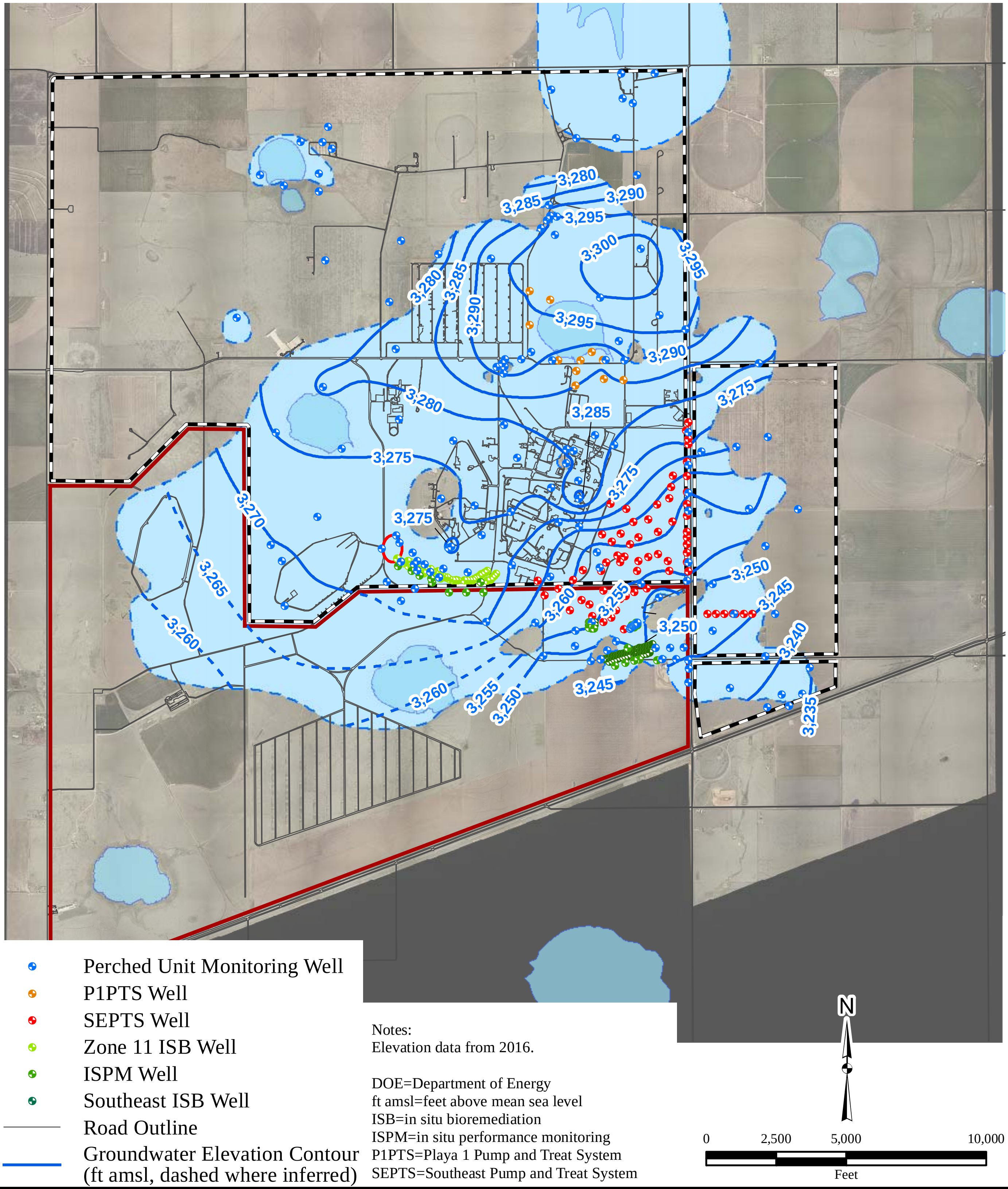
5/24/2018 TH
Source: HGL, CNS, NNSA. Imagery dated 2017.

Legend

Road Outline
Treatment Area
DOE Property
Texas Tech University Property

Figure 1.2
Zone 11 ISB



- Perched Unit Monitoring Well
- P1PTS Well
- SEPTS Well
- Zone 11 ISB Well
- ISPM Well
- Southeast ISB Well
- Road Outline
- Groundwater Elevation Contour (ft amsl, dashed where inferred)

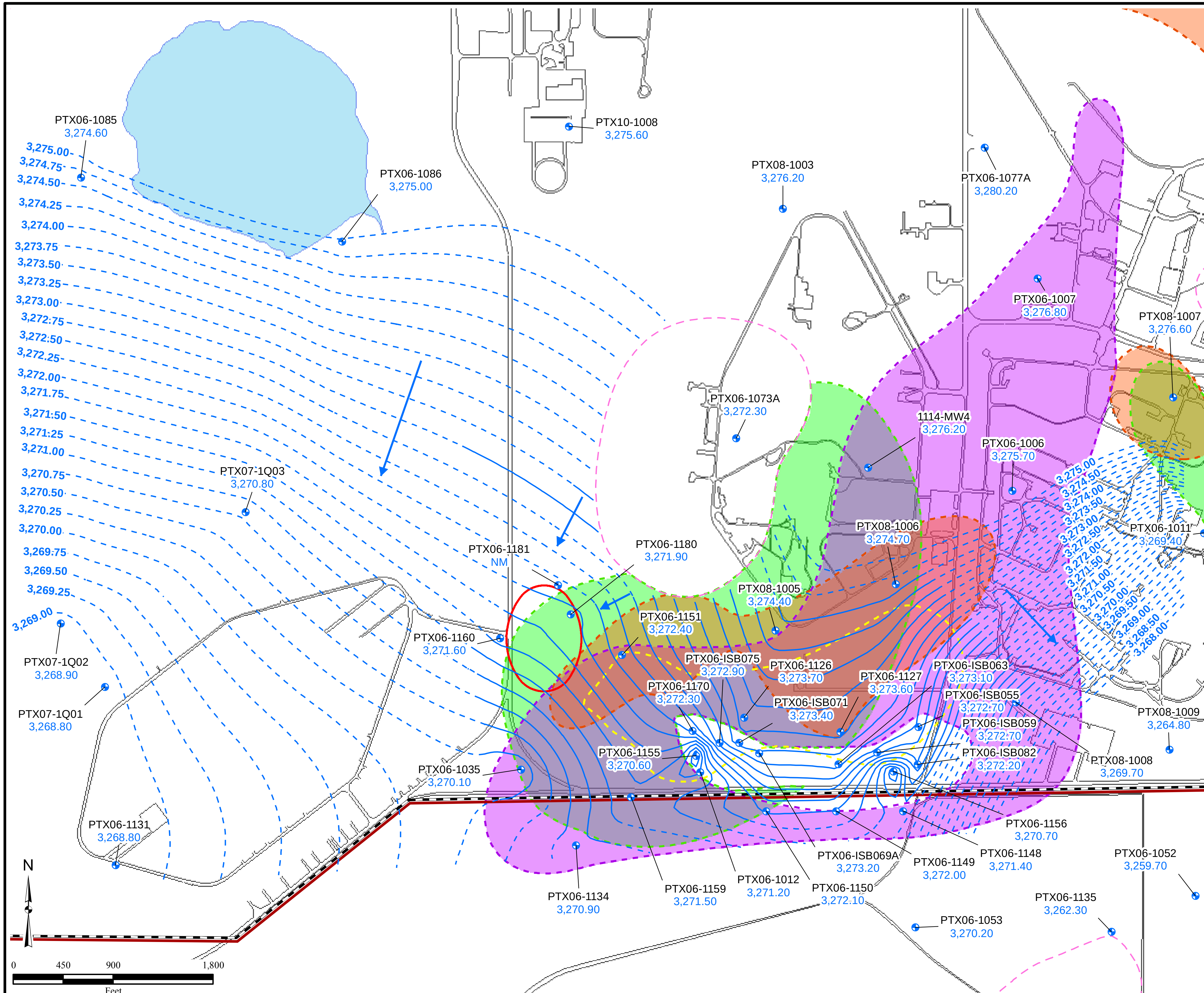
Notes:
Elevation data from 2016.

DOE=Department of Energy
ft amsl=feet above mean sea level
ISB=in situ bioremediation
ISPM=in situ performance monitoring
P1PTS=Playa 1 Pump and Treat System
SEPTS=Southeast Pump and Treat System

\\Gst-srv-01\HGLGIS\Pantex_MSIW\CMS\ (2-01)GW_Extent.mxd
6/1/2018 TH
Source: HGL, CNS, NNSA.

Legend
- Playa
- Perched Groundwater Extent
- Treatment Area
- DOE Property
- Texas Tech University Property

Figure 2.1
Perched Groundwater Extent and Elevations



HGL—Zone 11 Corrective Measures Study
Pantex Plant, Carson County, TX

Figure 2.2
Groundwater Elevations
Site Wide
December 2015

Legend

●	Well
PTX07-1Q03 3,270.80	Well Identification; Groundwater Elevation (ft amsl, Dec. 2015)
—	Groundwater Elevation Contour (ft amsl, Dec. 2015, dashed where inferred)
→	Groundwater Flow
—	Road Outline
▭	Treatment Area
▭	1,4-Dioxane above 7.7 µg/L (estimated)
▭	Perchlorate above 26 µg/L (estimated)
▭	RDX above 2 µg/L (estimated)
▭	TCE above 5 µg/L (estimated)
▭	Perched Groundwater Extent Uncertain
▭	DOE Property
▭	Texas Tech University Property

Notes:
Plumes based on 2016 sampling data, with the exception of PTX06-1160, PTX06-1180, and PTX06-1181 which are based on 2017 sampling data.

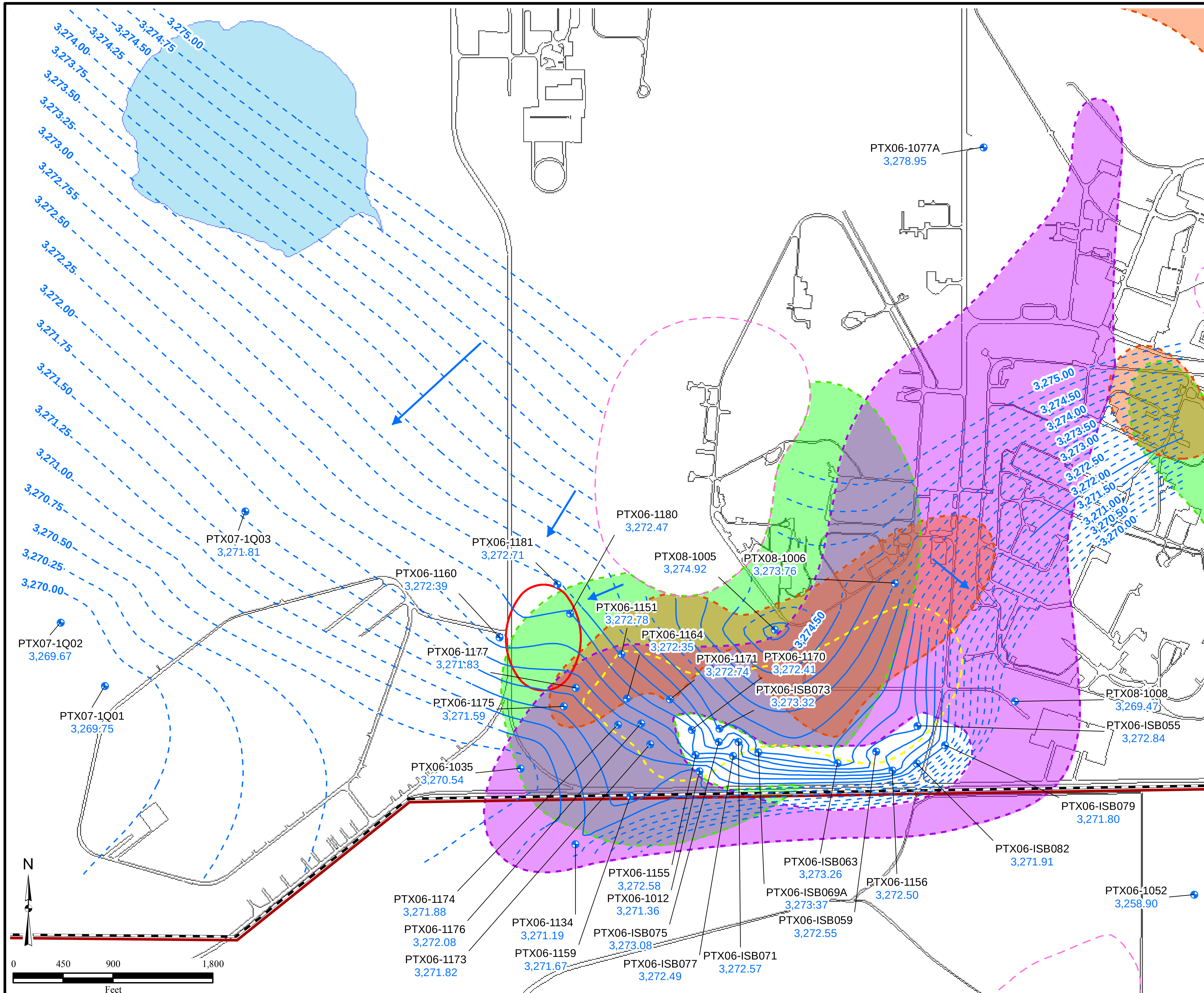
µg/L=micrograms per liter
DOE=Department of Energy
ft amsl=feet above mean sea level
NM=not measured
RDX=hexahydro-1,3,5-trinitro-1,3,5-triazine
TCE=trichloroethene

\\Gst-srv-01\HGLGIS\Pantex_MSIW\CMS\(2-02)2015_GWE.mxd
5/11/2018 JG
Source: HGL

PANTEX
HGL
HydroGeoLogic, Inc.

HGL—Zone 11 Corrective Measures Study
Pantex Plant, Carson County, TX

Figure 2.3
Groundwater Elevations
Site Wide
July/August 2017



Legend

- Well
- PTX08-1005 3,274.92 Well Identification Groundwater Elevation (ft amsl, July/Aug. 2017)
- Groundwater Elevation Contour (ft amsl, July/Aug. 2017, dashed where inferred)
- Groundwater Flow
- Road Outline
- Treatment Area
- 1,4-Dioxane above 7.7 µg/L (estimated)
- Perchlorate above 26 µg/L (estimated)
- RDX above 2 µg/L (estimated)
- TCE above 5 µg/L (estimated)
- Perched Groundwater Extent Uncertain
- DOE Property
- Texas Tech University Property

Notes:
Plumes based on 2016 sampling data, with the exception of PTX06-1160, PTX06-1180, and PTX06-1181 which are based on 2017 sampling data.

µg/L=micrograms per liter
DOE=Department of Energy
ft amsl=feet above mean sea level
RDX=hexahydro-1,3,5-trinitro-1,3,5-triazine
TCE=trichloroethene

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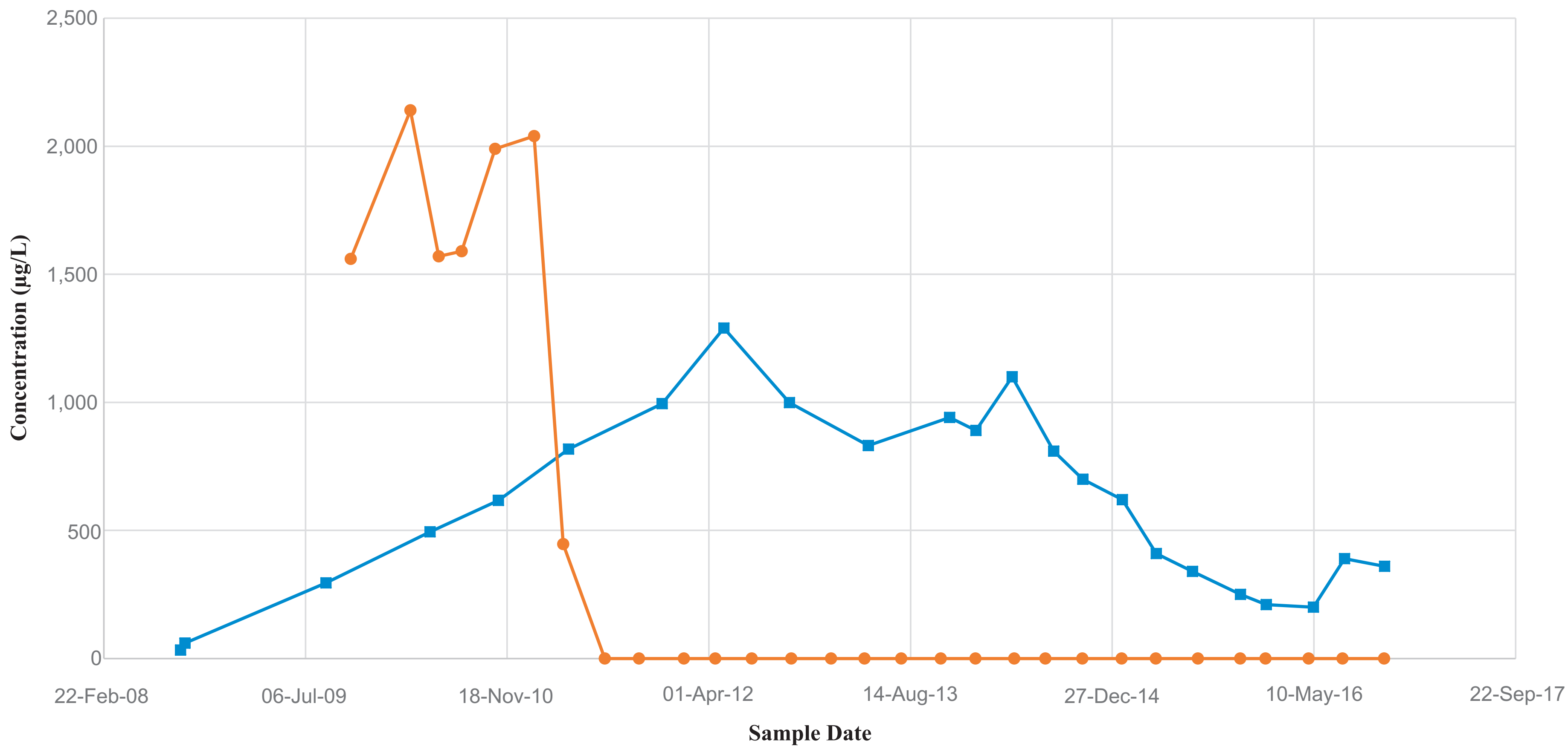
5/11/2018 JG
Source: HGL



\\Gst-srv-01\HGLGIS\Pantex_MSIW\CMS\(3-01)Perchlorate_Eastern11ISB.cdr
5/3/2018 JG
Source: HGL

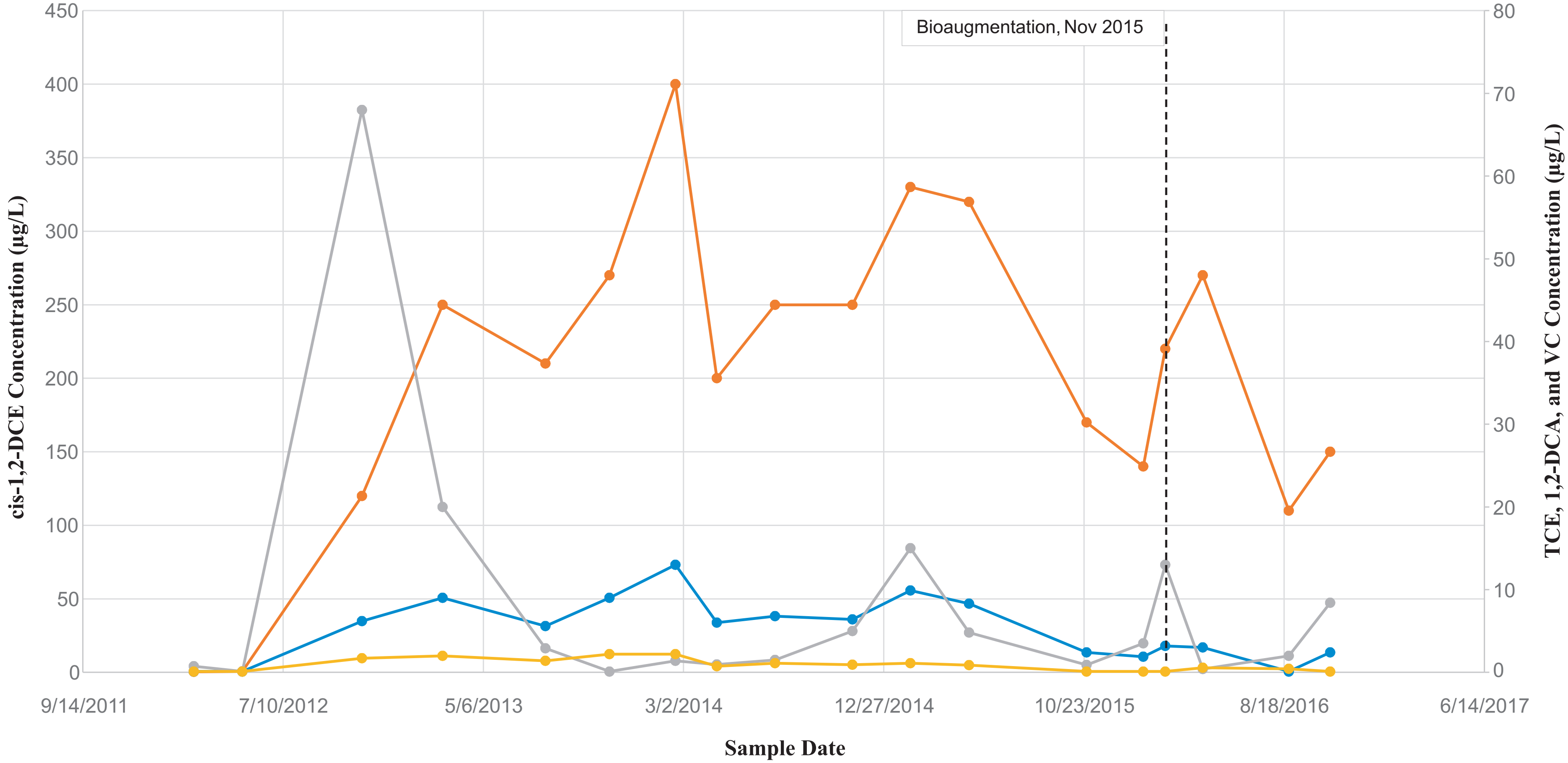
Legend

PTX06-1156

PTX06-1148

Notes:
µg/L=micrograms per liter
ISB=in situ bioremediation

Figure 3.1
Perchlorate Concentrations in the Eastern Zone 11 ISB



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(3-02)Chlorinated_Ethene_ISB075.cdr
5/3/2018 JG
Source: HGL

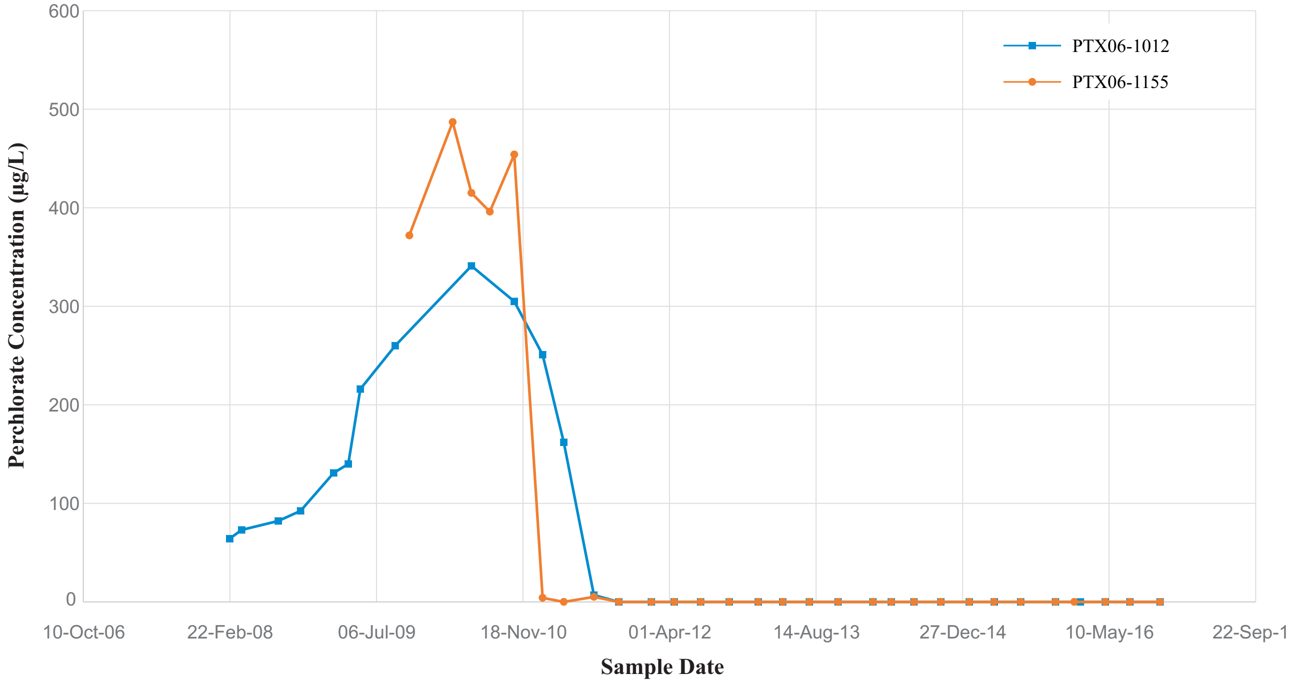
Legend

cis-1,2-DCE
TCE
1,2-DCA
VC

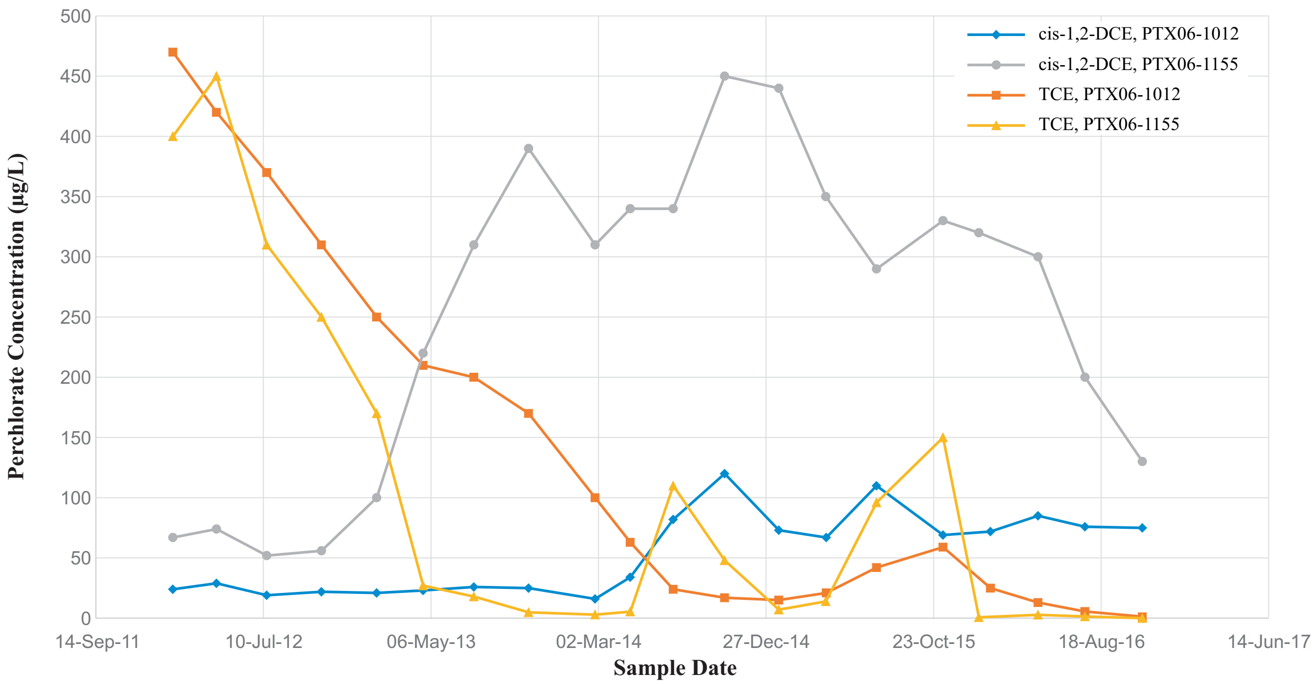
Notes:
µg/L=micrograms per liter
ISB=in situ bioremediation
DCA=dichloroethane
TCE=trichloroethene
DCE=dichloroethene
VC=vinyl chloride

Figure 3.2
Chlorinated Ethene Concentrations at Well PTX06-ISB075

Perchlorate Concentrations at Wells in the Central Zone 11 ISB



Chlorinated Ethene Concentrations at Wells in the Central Zone 11 ISB

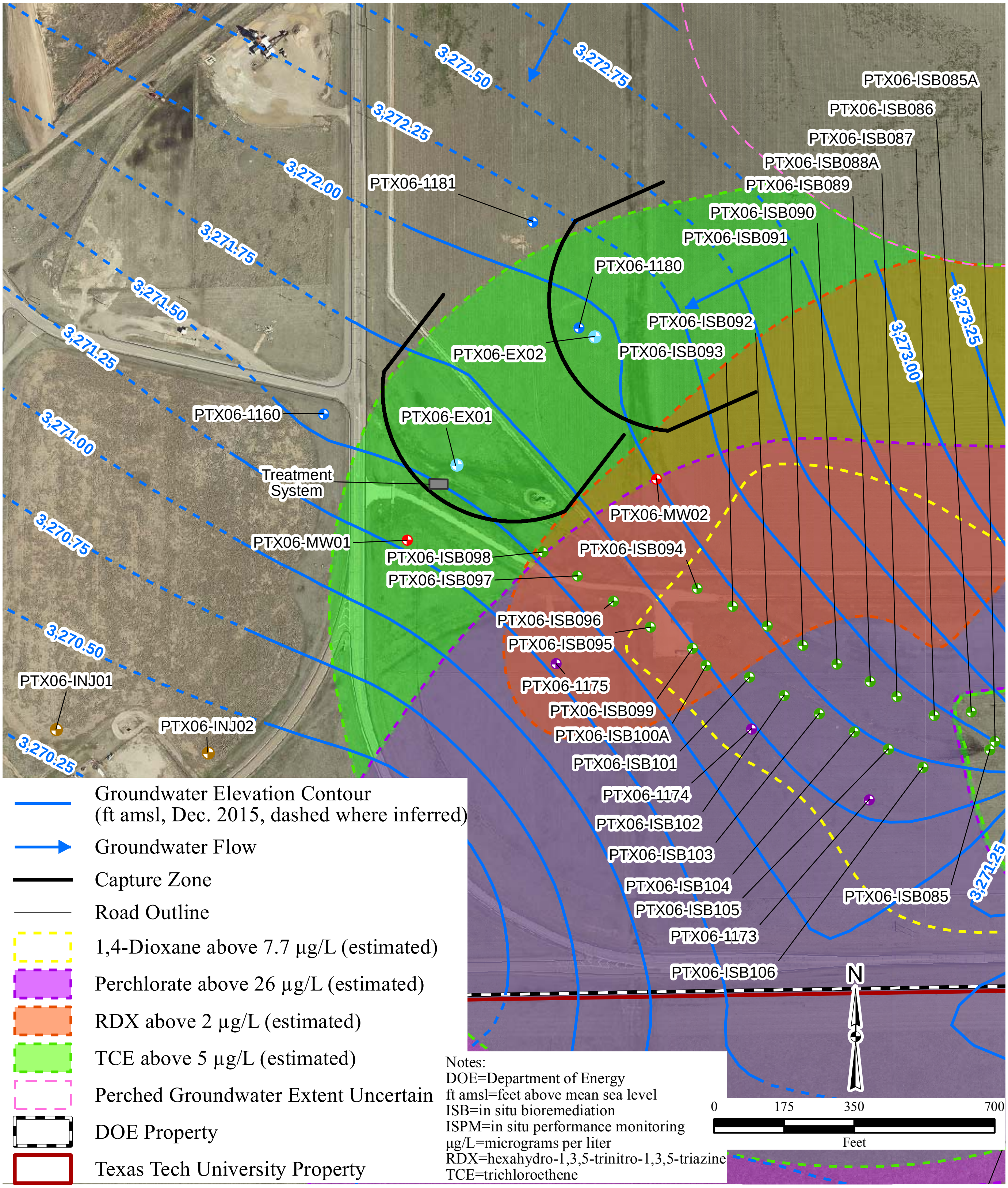


Notes:
µg/L=micrograms per liter ISB=in situ bioremediation
DCE=dichloroethene TCE=trichloroethene

\\Gst-srv-01\HGLGIS\Pantex_MSIW\CMS
(3-03)Remedy_Perf_Central_11ISB.cdr
5/3/2018 JG
Source: HGL

Pantex
HGL HydroGeoLogic, Inc

Figure 3.3
Remedy Performance
Central Zone 11 ISB



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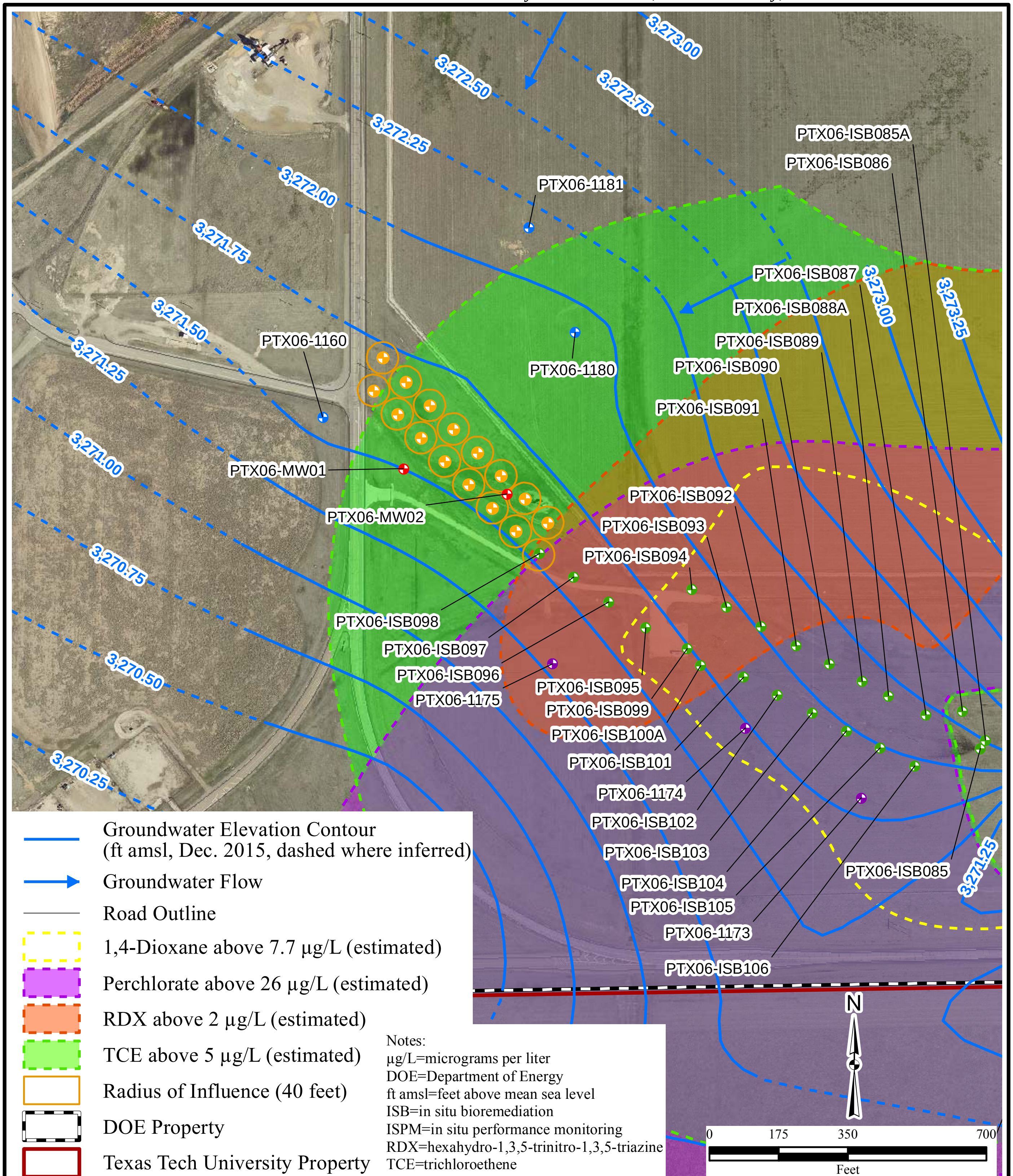
5/11/2018 JG
Source: HGL, CNS, NNSA. Imagery dated 2017.

Legend

- Well
- ISB (amendment injection) Well
- ISPM Well
- Proposed Extraction Well Locations
- Proposed Reinjection Well Locations
- Proposed Monitoring Well

Figure 5.1
Pump-and-Treat Layout

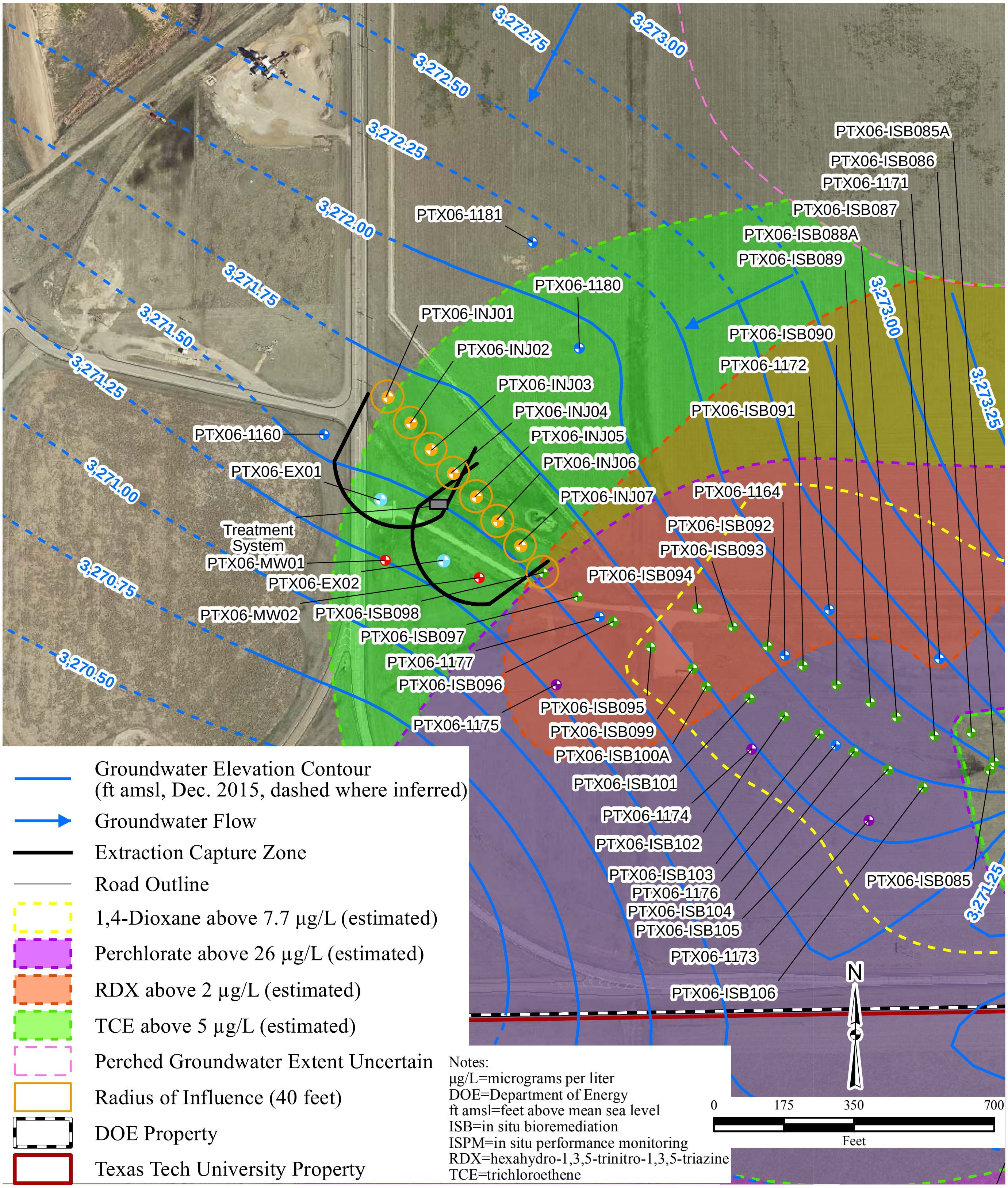


\\Gst-srv-01\HGLGIS\Pantex_MSIW\RAER_Presentation\(5-02)Exp_ISB_Layout-2015.mxd
5/4/2018 JG
Source: HGL, CNS, NNSA. Imagery dated 2017.

Legend

- Well
- ISB (amendment injection) Well
- ISPM Well
- Proposed Injection Well
- Proposed Monitoring Well

Figure 5.2
Expanded ISB Layout



\\Gst-srv-01\HGLGIS\Pantex_MSIW\RAER_Presentation\(5-03)Recirculation_Layout-2015.mxd
5/11/2018 JG
Source: HGL, CNS, NNSA. Imagery dated 2017.

Legend

- Well
- ISB (amendment injection) Well
- ISPM Well
- Proposed Injection Well
- Proposed Extraction Well
- Proposed Monitoring Well

Figure 5.3 Recirculation Layout

APPENDIX A

ASSUMPTIONS AND DESIGN CALCULATIONS

ABBREVIATIONS AND ACRONYMS

%	percent
μmol/L	micromole per liter
b	saturated thickness
C	final observed concentration
C_0	initial observed concentration
COC	contaminant of concern
DCE	dichloroethene
ft	feet
ft/ft	feet per foot
GAC	granular activated carbon
gpm	gallons per minute
GWPS	Groundwater Protection Standard
in	inch
ISB	in situ anaerobic bioremediation
k	first-order decay rate
K	hydraulic conductivity
L	distance along pair of pressure heads
n	effective porosity
Q	pumping rate
Q’	imaginary pumping rate
Q_o	discharge potential
r	radius of the extraction well
ROI	radius of influence
s	drawdown (unconfined aquifer)
S	storage
s’	drawdown (confined aquifer)
SEPTS	Southeast Pump and Treat System
SF	safety factor
t	time
T	Transmissivity
TOC	total organic carbon
v	groundwater seepage velocity
X_{stag}	length of the capture zone parallel to the hydraulic head gradient
Y_{div}	length of the capture zone perpendicular to the hydraulic head gradient
ϕ	pressure head

A.1 Introduction

This appendix presents design assumptions, equations, and calculations for Remedial Alternatives 2 through 5. This includes estimates of the capture zones for Remedial Alternatives 2, 4, and 5, estimates of the treatment width for Remedial Alternatives 3, 4, and 5, and other assumptions used in estimating costs (e.g., lifespan of treatment systems and discount rates used in design costs).

A.2 Capture Zone Estimation

Analytical methodology was employed to determine the pumping rates (modified Cooper-Jacob [1946] solution for unconfined aquifers) and capture zone (Yang et al. [1995]) for alternatives 2, 4, and 5. As a check, the single-layer perched groundwater flow model developed during the CMS/FS (BWXT Pantex, 2007) was used to simulate the pumping rates and resultant drawdown. As this model has not been updated to reflect data collected since 2007, the calculations completed represent a qualitative comparison to the analytical solutions. The model produced similar capture zones to the analytical solutions described below and indicted that groundwater re-injection to the west/southwest improves capture.

Estimates of the capture zone depends on multiple factors including pumping rate, pumping duration, and numerous hydrogeologic parameters such as hydraulic conductivity, porosity, and saturated thickness. The saturated thickness of the perched aquifer varies near the treatment area from approximately 15 to 25 feet. For the capture zone calculations, the initial saturated thickness determined from measured water levels is 20 feet (ft). The available drawdown is assumed to be 15 ft leaving a safety factor of 5 ft (in case the saturated thickness is less than 20 ft in the treatment area). The pumping rate required to maintain 15 ft of drawdown and the associated capture zone was calculated based upon the hydraulic properties of the perched groundwater flow system.

The amount of drawdown for a confined aquifer is given by the Cooper-Jacob (1946) solution:

$$s' = \frac{2.3 \cdot Q}{4\pi T} \log_{10}\left(\frac{2.25 \cdot Tt}{r^2 S}\right) \qquad \text{(A-1)}$$

where s' is the drawdown (for a confined aquifer), Q is the pumping rate, T is the transmissivity, t is the time, r is the radius of the well, and S is the storage. Equation A-1 for a confined aquifer is adjusted to account for the drawdown in unconfined aquifers such as for the perched groundwater in the treatment area. In unconfined aquifers, the storage is approximated to the specific yield. To account for drawdown in an unconfined aquifer, the unconfined drawdown will be estimated by (Schwartz and Zhang, 2003):

$$s = b - (b^2 - 2s'b)^{\frac{1}{2}} \qquad \text{(A-2)}$$

where s is the drawdown for an unconfined aquifer and b is the original saturated thickness of the unconfined aquifer in the treatment area. Equation A-2 can be re-written:

$$s' = \frac{2bs - s^2}{2b} \quad \text{(A-3)}.$$

All values are known, assumed, or calculated except the pumping rate (Q). Equation A-1 is rewritten for the amount of pumping required to yield the desired drawdown (15 feet):

$$Q = \frac{s' 4\pi T}{2.3 \cdot log_{10}\left(\frac{2.25 \cdot Tt}{r^2 S}\right)} \quad \text{(A-4)}.$$

These calculated values of drawdown and pumping rates allow for estimation of the radius of influence. The radius of influence is symmetrical and does not incorporate the hydraulic head gradient, whereas estimates of the capture zone do incorporate the hydraulic head gradient (Exhibit 5.1 of the main text). However, estimation of the capture zone requires additional steps.

Capture zone is estimated with select equations from Yang et al. (1995). These equations have a few assumptions including

1. Infinite, isotropic, and homogeneous aquifer with a horizontal base
2. Dupuit assumption of negligible vertical flow
3. Fully penetrating recovery well with constant pumping rate.

These assumptions are approximated for the small treatment area and corrections are made for an unconfined aquifer (Equation A-2). The capture zone is defined by a component perpendicular (Equation A-5) and a component parallel (Equation A-6) to groundwater flow:

$$Y_{div} = \pm \frac{Q'}{2Q_o} \quad \text{(A-5)}$$

$$X_{stag} = \frac{Q'}{2\pi Q_o} \quad \text{(A-6)}$$

where Y_{div} and X_{stag} are the size of the capture zone perpendicular to the hydraulic head gradient and parallel and perpendicular to the line of wells in the area of alternatives evaluation, respectively; Q' (ft^3/day) is the imaginary pumping rate. The imaginary pumping rate is not associated with any particular well; rather, the imaginary pumping rate is a calculated variable that is used to determine the extent of the capture zone and holds no corresponding physical representation. The imaginary pumping rate is used to account for the change in the capture zone due to the hydraulic head gradient under transient conditions. Q_o is the discharge potential (ft^2/day). The discharge potential is given by:

$$Q_o = K \frac{(\varphi_2^2 - \varphi_1^2)}{2L} \quad \text{(A-7)}$$

where K is the hydraulic conductivity and ϕ_2 and ϕ_1 are pressure heads at two locations, separated by a distance L, along the hydraulic gradient. The imaginary pumping rate is given by:

$$Q' = 2\pi Q_o \Delta x \quad \text{(A-8)}$$

The desired time, t, is assumed and Δx is solved by iteration of the following equation:

$$t = -\frac{bn}{Q_o}\Delta x - \frac{bnQ}{2\pi Q_o^2}\ln\left(1 - \frac{2\pi Q_o}{Q_w}\Delta x\right) \qquad \text{(A-9)}$$

where b is the initial saturated thickness (20 ft) and n is the effective porosity. The component of the capture zone perpendicular to groundwater flow, Y_{div} (ft), is estimated from equation A-5 given the estimates from Equations A-7 and A-8. The capture zone width is twice Y_{div}, and the capture zone was calculated for different durations for Remedial Alternatives 2, 4, and 5. Assumed or calculated parameters for estimation of the capture zone Remedial Alternative 2 are shown in Table A-1. Assumed or calculated parameters for estimation of the capture zone of Remedial Alternatives 4 and 5 are shown in Table A-2.

A.3 Treatment Width for In Situ Anaerobic Bioremediation

The treatment width for in situ anaerobic bioremediation (ISB) (Alternatives 3, 4, and 5) is defined as the distance parallel to the groundwater flow direction that substrate must span to achieve contaminant reduction to Groundwater Protection Standards (GWPSs). If substrate does not span a wide enough area, contaminants of concern (COCs) will not have sufficient contact time (residence time within the treatment zone) with substrate and bacteria to be effectively reduced. The required treatment width for the ISB expansion is estimated from decay rates observed in the existing Zone 11 ISB.

Decay rate is calculated from the change in total chlorinated ethene molar concentrations over time at a given well. PTX06-1155 from November 2015 through October 2016 was selected because the contaminant reduction trend is well defined over this time period, as shown in Exhibit A-1.

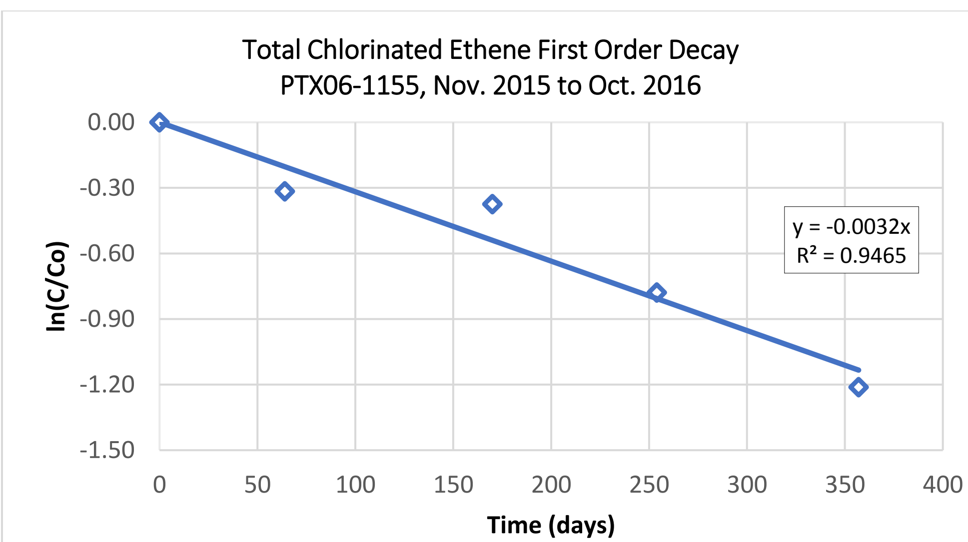


Exhibit A-1.
Total Chlorinated Ethene First Order Decay

The first-order decay rate, k is estimated from:

$$k = -\frac{\ln(C/C_0)}{t} \qquad \text{(A-10)}$$

where C is the final observed concentration, C_0 is the initial observed concentration, and t is time. The calculated decay rate is 3.2E-3 day^{-1}. The required residence time (or COC contact time with substrate and bacteria) is estimated by:

$$t = -\frac{\ln(C/C_0)}{k} \qquad \text{(A-11)}$$

where k is the calculated decay rate from Equation A-10, C_0 is the initial treatment zone total chlorinated ethene molar concentration (observed at PTX06-1180 in August 2017), and C is the *cis*-1,2-dichloroethene (DCE) GWPS. The resulting residence time is 417 days. Finally, treatment width (d) can be calculated by:

$$d = vt(1 + SF) \qquad \text{(A-12)}$$

where v is the groundwater seepage velocity, t is the residence time calculated in Equation A-11, and SF is a safety factor of 0.25. The resulting treatment width is 157 ft. The assumptions and calculations are shown in Table A-3.

A.4 Other Assumptions

Radius of Influence: Amendment Injection (Remedial Alternatives 3-5)

The injection well radius of influence (ROI) determines well placement and number of wells required in order to achieve thorough substrate distribution. The ROI is estimated from total organic carbon (TOC) data observed at wells PTX06-1164, PTX06-1170, PTX06-1176, PTX06-1177, and new PTX06-ISB075. Elevated TOC concentrations in these wells indicate the presence of substrate, meaning the monitoring well is within the ROI of a nearby injection well. The assumed ROI is shown in Table A-4.

Other Assumptions (Cost Estimates)

Assumptions made that directly influence the costs for different Remedial Alternatives are shown in Table A-4. The lifespan of treatment system components (granular activated carbon [GAC] and ion exchange) is a significant cost driver for Remedial Alternatives 2 and 4. The lifespan is based on the sorption capacity of the treatment medium, the COC concentrations from within or near the treatment area, and vendor input. Other assumptions include limiting recirculation events such that freeze protection is not required and assuming a Discount Rate of 2.6 percent (%) in accordance with Circular A-94, Appendix C (Office of Management and Budget, 2017).

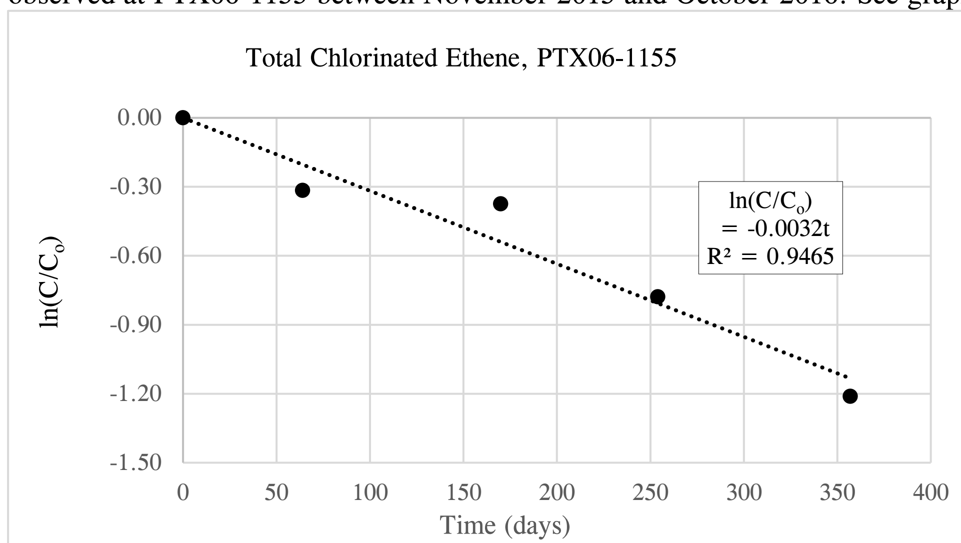
Table A-1. Assumptions and Calculations for Determining Capture Zone Dimensions (Remedial Alternative 2)

Assumptions and Calculations for Determining Capture Zone Dimensions (Remedial Alternative 2)		
Parameter	**Value**	**Note/Source**
Hydraulic Conductivity (ft/day)	30	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Assumed Effective Porosity (-)	0.25	*Corrective Measure Study/Feasibility Study for the U.S. Department of Energy/National Nuclear Security Administration, Pantex Plant, Amarillo, Texas, Volume II, September 2007*
Hydraulic Gradient (ft/ft)	0.0025	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Saturated Thickness (ft)	20	Based on range of measured saturated thicknesses near this location
Drawdown (ft)	15	Set value that leaves 5 ft of saturated thickness as a safety factor if the saturated thickness is below average at this location
Well diameter (inch [in])	6	Assumed
Operational goal	90%	Operational goal for the Southeast Pump and Treat System (SEPTS) from 2015 Annual Progress Report, Remedial Action Progress
Initial pumping rate (gallons per minute [gpm])	25	Calculated given the drawdown and hydraulic parameters for 30 days; similar to the upper range of the pumping rates at the SEPTS
Capture zone, perpendicular to groundwater flow, 30 days (ft)	570	Calculated given the drawdown, other hydraulic parameters, and 25 gpm pumping rate
Capture zone, 30 days, downgradient from well, parallel to groundwater flow (ft)	90	Calculated given the drawdown, other hydraulic parameters, and 25 gpm pumping rate
Capture zone, perpendicular to groundwater flow, 300 days (ft)	570	Calculated given the drawdown, other hydraulic parameters, and 5.3 gpm pumping rate
Capture zone, 300 days, downgradient from well, parallel to groundwater flow (ft)	90	Calculated given the drawdown, other hydraulic parameters, and 5.3 gpm pumping rate

Table A-2. Assumptions and Calculations for Determining Capture Zone Dimensions (Remedial Alternative 4 and 5)

Assumptions and Calculations for Determining Capture Zone Dimensions (Alternative 4 and 5)		
Parameter	**Value**	**Note/Source**
Hydraulic Conductivity (ft/day)	30	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Assumed Effective Porosity (-)	0.25	*Corrective Measure Study/Feasibility Study for the U.S. Department of Energy/National Nuclear Security Administration, Pantex Plant, Amarillo, Texas, Volume II, September 2007*
Hydraulic Gradient (ft/ft)	0.0025	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Saturated Thickness (ft)	20	Based on range of measured saturated thicknesses near this location
Drawdown (ft)	15	Set value that leaves 5 ft of saturated thickness as a safety factor if the saturated thickness is below average at this location
Well diameter (in)	6	Assumed
Initial pumping rate (gpm)	28	Calculated given the drawdown and hydraulic parameters for 7 days
Capture zone, perpendicular to groundwater flow, 7 days (ft)	300	Calculated given the drawdown, other hydraulic parameters, and 28 gpm pumping rate
Capture zone, 7 days, downgradient from well, parallel to groundwater flow (ft)	50	Calculated given the drawdown, other hydraulic parameters, and 28 gpm pumping rate

Table A-3. Assumptions and Calculations for Determining Treatment Width (Remedial Alternatives 3, 4, and 5)

Assumptions and Calculations for Determining Treatment Width (Remedial Alternatives 3, 4, and 5)		
Parameter	**Value**	**Note/Source**
Hydraulic Conductivity (ft/day)	30	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Assumed Effective Porosity (-)	0.25	*Corrective Measure Study/Feasibility Study for the U.S. Department of Energy/National Nuclear Security Administration, Pantex Plant, Amarillo, Texas, Volume II, September 2007*
Hydraulic Gradient (ft/ft)	0.0025	*Updated Conceptual Site Model Report, In-situ Bioremediation Operations and Maintenance, Pantex Plant, Amarillo, Texas, January 31, 2017, Trihydro Corporation*
Groundwater Seepage Velocity (ft/day)	0.30	Directly calculated based on hydraulic conductivity, effective porosity, and hydraulic gradient
Assumed Total Chlorinated Ethene Decay Rate (day^{-1})	0.0032	First order decay rate calculated from total chlorinated ethene molar concentrations observed at PTX06-1155 between November 2015 and October 2016. See graph. 

Assumptions and Calculations for Determining Treatment Width (Remedial Alternatives 3, 4, and 5)		
Parameter	**Value**	**Note/Source**
		Notes: C/C_o – Measured concentration, *C*, per initial concentration, C_0 R^2 – regression coefficient t – time, in days
Influent Total Chlorinated Ethene Concentration (micromole/L [μmol/L])	2.75	August 2017 total chlorinated ethene molar concentration observed at PTX06-1180
Effluent Total Chlorinated Ethene Concentration (μmol/L)	0.722	GWPS for *cis*-1,2-DCE
Total Chlorinated Ethene Residence Time (days)	417	Days required to meet *cis*-1,2-DCE GWPS, calculated using the first order decay rate, influent, and effluent concentrations from above
Treatment Width (ft)	157	Treatment width parallel to groundwater flow direction, calculated using the groundwater seepage velocity, residence time, and a safety factor of 0.25.

Table A-4. Other Assumptions

Other Assumptions		
Parameter	**Value**	**Note/Source**
Radius of Influence (ft)	40	Estimated injection well radius of influence, based on observed TOC data within the existing Zone 11 ISB. Specifically, data from wells PTX06-1164, PTX06-1170, PTX06-1176, PTX06-1177, and PTX06-ISB075, new were evaluated.
Pump and Treat GAC Lifespan (months)	22	Estimated based on vendor input and sorption capacity.
Recirculation GAC Lifespan (years)	20	Estimated based on vendor input and sorption capacity.
Pump and Treat Ion Exchange Lifespan (years)	3	Per canister, 3 disposable canisters required, based on vendor input.
General Recirculation Assumptions	N/A	Recirculation events will not occur in winter (i.e. freeze protection is not required).
Amendment	N/A	Amendment for the expanded ISB and the recirculation alternatives will be purchased and shipped with amendment for the other Pantex Plant ISB systems.
Discount Rate (%)	2.6	Office of Management and Budget (OMB), 2017. Circular A-94, Appendix C, "*Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analysis*," revised December 2017.

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Appendix E
Passive Flux Meter Calculated Velocities

Calculated Velocities from Passive Flux Meters

Well_ID	Darcy Velocity (cm/day)	Darcy Velocity (ft/day)	Darcy Velocity (ft/yr)	Seepage Velocity (n = 0.4) (ft/yr)	Seepage Velocity (n=0.25) (ft/yr)	Seepage Velocity (Avg n) (ft/yr)
PTX06-1034	**5.8**	**0.19**	**69.6**	**173.9**	**278.2**	**226**
PTX06-1147	**3.1**	**0.10**	**36.9**	**92.1**	**147.4**	**120**
PTX06-1182	**4.0**	**0.13**	**47.8**	**119.4**	**191.1**	**155**
PTX06-1185	**4.5**	**0.15**	**53.9**	**134.8**	**215.7**	**175**
PTX06-ISB107	**6.0**	**0.20**	**71.8**	**179.4**	**287.1**	**233**
PTX06-ISB124	**6.2**	**0.20**	**74.0**	**185.1**	**296.2**	**241**
PTX06-EW-87	**3.7**	**0.12**	**44.3**	**110.7**	**177.2**	**144**
PTX06-EW-88	**4.4**	**0.14**	**52.57**	**131.42**	**210.27**	**171**

Darcy velocity in cm/day were reported from Enviroflux. Calculated seepage velocities were obtained by dividing the Darcy velocity by the porosity.

n = porosity