



Effectiveness Monitoring Report (EMR) for the P-Area Groundwater (PAGW) Operable Unit (OU) Zero Valent Iron Permeable Reactive Barrier (ZVI-PRB) Removal Action (U)

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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
List of Figures.....	iv
List of Tables	iv
List of Appendices.....	v
List of ABBREVIATIONS AND ACRONYMS.....	vi
1.0 Introduction.....	1
2.0 Operable Unit Description and History	2
2.1 Physiographic Setting	2
2.2 Hydrogeologic Setting.....	3
2.3 Nature and Extent of Contamination.....	3
2.4 Removal Action Implementation and Monitoring Goals.....	6
2.5 PAGW OU NTC RA Monitoring Network	8
3.0 Monitoring Results and Deviations	10
3.1 Deviations from the Monitoring Plan	10
3.2 Upper Aquifer Zone.....	10
3.2.1 Groundwater Elevation Measurements and Groundwater Flow Direction	10
3.2.2 Chlorinated Volatile Organic Compounds.....	11
3.2.3 Geochemical Analyses	14
3.2.4 Field Measurements.....	17
3.3 Lower Aquifer Zone	18
3.3.1 Groundwater Elevation Measurements and Groundwater Flow Direction	18
3.3.2 Chlorinated Volatile Organic Compounds.....	18
3.3.3 Geochemical Analyses	19
3.3.4 Field Measurements.....	21
4.0 Monitoring Performance and Effectiveness Discussions.....	21
4.1 Groundwater Elevation and Flow Path	21
4.2 ZVI-PRB cVOC Degradation	22
4.3 ZVI-PRB Health and Longevity	24
4.4 ZVI-PRB Reducing Environment	25
4.5 ZVI-PRB Impact on the LAZ.....	27
5.0 Summary and Recommendations.....	27
6.0 References.....	30

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
Figure 1.	Location of P Area at the Savannah River Site.....	33
Figure 2.	P-Area Groundwater Operable Unit Boundary Map	35
Figure 3.	Total Annual Rainfall at 100-P Rain Gauge with a 3-Year Moving Average Trendline	36
Figure 4.	Trichloroethylene Plume Map for the Upper Aquifer Zone of the Upper Three Runs Aquifer (2018/2024 Data)	37
Figure 5.	Trichloroethylene Plume Map for the Lower Aquifer Zone of the Upper Three Runs Aquifer (2018/2024 Data)	38
Figure 6.	TCE Plume North-South Cross-Section with ZVI-PRB Injection Wells (2020)	39
Figure 7.	Effectiveness Monitoring Plan Locations	40
Figure 8.	Baseline Concentrations of TCE in the PAGW OU EMP Monitoring Wells	41
Figure 9.	Regional UAZ Groundwater Elevations and Flow Direction (1Q24)	42
Figure 10.	UAZ Water Elevations for 1Q24 at PAGW OU RA EMP Monitoring Wells	43
Figure 11.	TCE Results for ZVI-PRB UAZ Monitoring Wells Sampled in 1Q24	44
Figure 12.	Time-Series Plot for TCE at UAZ Monitoring Well Clusters for P002U, PRW002, and PRW004	45
Figure 13.	Time-Series Plot for TCE at UAZ Monitoring Well Clusters for PRW005, PRW006, and PRW007	46
Figure 14.	Regional LAZ Groundwater Elevations and Flow Direction (1Q24)	47
Figure 15.	Time-Series Plot for TCE at LAZ Monitoring Wells of the PAGW OU NTC RA EMP	48
Figure 16.	TCE Results for ZVI-PRB LAZ Monitoring Wells Sampled in 1Q24.....	49
Figure 17.	Cis-DCE Concentration Over Time for LAZ Monitoring Wells.....	50
Figure 18.	CVOC Degradation at P002U.....	51

LIST OF TABLES

<u>Table</u>		<u>Page</u>
Table 1.	Maximum Concentrations of PCE, TCE, and cis-DCE in the Three Plume Areas.....	53
Table 2.	Effectiveness Monitoring Plan Well Details	54
Table 3.	Baseline Concentrations for cVOCs and Geochemical Analytes	55
Table 4.	Baseline Concentration Comparison with Most Recent Results for UAZ (1Q24)	56
Table 5.	Baseline Concentration Comparison with Most Recent Results for LAZ (1Q24).....	57

LIST OF APPENDICES

<u>Appendix</u>		<u>Page</u>
Appendix A	PAGW OU RA EMR Analytical Data 2022-2023	A-1
Appendix B	PAGW OU RA EMR Hydrographs	B-1
Appendix C	PAGW OU RA EMR Time-Series Plots	C-1

LIST OF ABBREVIATIONS AND ACRONYMS

~	approximately
1Q19	first quarter of 2019
1Q20	first quarter of 2020
1Q21	first quarter of 2021
1Q22	first quarter of 2022
1Q23	first quarter of 2023
1Q24	first quarter of 2024
2Q20	second quarter of 2020
2Q22	second quarter of 2022
2Q23	second quarter of 2023
3Q20	third quarter of 2020
4Q20	fourth quarter of 2020
4Q21	fourth quarter of 2021
4Q22	fourth quarter of 2022
4Q23	fourth quarter of 2023
ac	acre
amsl	above mean sea level
cis-DCE	cis-1,2-dichloroethylene
cm	centimeter
cm/yr	centimeter per year
cVOC	chlorinated volatile organic compound
1,1-DCE	1,1-dichloroethylene
DO	dissolved oxygen
DOC	dissolved organic carbon
EMP	Effectiveness Monitoring Plan
EMR	Effectiveness Monitoring Report
ft	feet/foot
ft/d	feet per day
ft/yr	feet per year
GA	Gordon Aquifer
ha	hectare
HPIT	Hydraulic Pulse Interference Testing
IDW	investigation-derived waste
in.	inch
in./yr	inch per year
km	kilometer
LAZ	Lower Aquifer Zone
m	meter
m/d	meter per day
m/yr	meter per year
MCL	maximum contaminant level
MDL	maximum detection limit
mg/L	milligram per liter
mi	mile

mV	millivolt
NTC	non-time critical
ORP	oxidation-reduction potential
OU	Operable Unit
PAGW	P-Area Groundwater
PAOU	P-Area Operable Unit
PCE	tetrachloroethylene
PDI	Pre-Design Investigation
PQL	practical quantification limit
PRB	permeable reactive barrier
P-RBC	P-Reactor Building Complex (105-P)
PRSB	P-Area Reactor Seepage Basin
PSA	potential source area
RA	removal action
RADP	Removal Action Design Plan
RAO	Removal Action Objective
RAR	Removal Action Report
RSER/EE/CA	Removal Site Evaluation Report/Engineering Evaluation/Cost Analysis
SAP	Sampling and Analysis Plan
SCDES	South Carolina Department of Environmental Services ¹
SRNL	Savannah River National Laboratory
SRNS	Savannah River Nuclear Solutions, LLC
SRS	Savannah River Site
TCCZ	Tan Clay Confining Zone
TCE	trichloroethylene
TOC	total organic carbon
trans-DCE	trans-1,2-dichloroethylene
UAZ	Upper Aquifer Zone
µg/L	microgram per liter
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
UTRA	Upper Three Runs Aquifer
VC	chloroethylene (vinyl chloride)
V&V	Verified and Validated
WSRC	Washington Savannah River Company, LLC
yr	year
ZVI	zero-valent iron

¹ South Carolina Department of Environmental Services (SCDES) was known as South Carolina Department of Health and Environmental Control (SCDHEC) prior to July 1, 2024.

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1.0 INTRODUCTION

The P-Area Groundwater (PAGW) Operable Unit (OU) encompasses approximately (~) 2,226 hectares (ha) (5,500 acres [ac]) of groundwater beneath Savannah River Site's (SRS) P Area. Groundwater in the PAGW OU is contaminated with chlorinated volatile organic compounds (cVOCs), primarily trichloroethylene (TCE), and tritium. With approval from the United States Environmental Protection Agency (USEPA) and the South Carolina Department of Environmental Services (SCDES²), the United States Department of Energy (USDOE) conducted a non-time critical (NTC) removal action (RA) at the PAGW OU.

Field activities in support of the PAGW OU NTC RA were completed on January 14, 2020, in accordance with the approved Removal Action Design Plan (RADP) (Savannah River Nuclear Solutions, LLC [SRNS] 2019). The NTC RA consisted of emplacing ~672 metric tons (741 U.S. tons) of zero-valent iron (ZVI) to construct an 80.5 meter (m) (264 feet [ft]) long permeable reactive barrier (PRB) with an average thickness greater than 10.2 centimeters (cm) (4 inches [in.]), as detailed in the Removal Action Report (RAR) (SRNS 2020). Baseline sampling was conducted in March of 2019 and effectiveness monitoring began in February 2020 following construction of the ZVI-PRB. Effectiveness monitoring is being conducted in accordance with the approved Effectiveness Monitoring Plan (EMP) for the PAGW OU NTC RA (SRNS 2019). This Effectiveness Monitoring Report (EMR) is the fourth of five annual reports to document performance and effectiveness of the NTC RA technology. After the fifth annual EMR, the reporting frequency will be re-evaluated with the Core Team (i.e., representatives from the SCDES, USEPA, and USDOE).

Historical data, including field parameter data, are available in Appendix A of ZVI-PRB EMRs for previous years. Hydrographs for the monitoring well network wells are presented in Appendix B. Time-series plots that depict the historical data for key constituents are provided in Appendix C of this report. Consistent with SRS EMRs, data presented in this report are for one year of data, collected from April 2023 (second quarter of 2023 [2Q23]) through March 2024 (first quarter of 2024 [1Q24]).

² South Carolina Department of Environmental Services (SCDES) was known as South Carolina Department of Health and Environmental Control (SCDHEC) prior to July 1, 2024.

2.0 OPERABLE UNIT DESCRIPTION AND HISTORY

P Area is located in the central portion of the SRS ~4.0 kilometers (km) (2.5 miles [mi]) east-southeast of the geographic center of the SRS and about 6.4 km (4 mi) west of the nearest site boundary (Figure 1). P Area consists of a closed nuclear reactor building complex and several surface OUs and structures that were previously characterized and identified as sources to soil and groundwater contamination (Washington Savannah River Company, LLC [WSRC] 2006).

The P Area surface units identified as posing a risk to human health, the environment, and contributing to groundwater contamination were remediated as part of the P-Area Operable Unit (PAOU), including the P-Area Reactor Building Complex (P-RBC) (105-P) (SRNS 2008). Remedial actions associated with surface units included in the PAOU have been completed and are documented in the PAOU Post Construction Report (SRNS 2012c). In particular, one surface unit, potential source area (PSA)-3A, was determined to be the source of TCE plumes discharging to Steel Creek. PSA-3A was remediated in 2011 and remedial goals were met using soil vapor extraction enhanced with soil fracturing and In-Situ Chemical Oxidation injection.

Groundwater beneath P Area was impacted due to reactor and facility operations between 1954 and 1991. The PAGW OU was established for the purposes of groundwater modeling and encompasses the groundwater beneath P Area, northwest to Steel Creek, northeast toward PAR Pond and SRS Road F, and southeast to Meyers Branch (Figure 2). Groundwater plumes are present in the PAGW OU Upper Aquifer Zone (UAZ) and Lower Aquifer Zone (LAZ) of the Upper Three Runs Aquifer (UTRA). Localized impact to the Gordon Aquifer (GA) is currently exhibited at the P-Area Reactor Seepage Basins (PRSBs).

2.1 Physiographic Setting

Topography of the PAGW OU ranges from 101 m (330 ft) above mean sea level (amsl) near P Area to 57.9 m (190 ft) amsl at the downstream end of Meyers Branch and Steel Creek. The area near the P-RBC is higher in elevation than the surrounding land. Surface drainage on the west side of the P-RBC is to the west, towards Steel Creek. Surface drainage on the east side of the P-RBC drains to unnamed tributaries that drain to PAR Pond. Surface drainage on the south side drains to wetlands and unnamed tributaries to Meyers Branch.

2.2 Hydrogeologic Setting

A detailed description of the hydrostratigraphy of the PAGW OU can be found in the 2013 Sampling and Analysis Plan (SAP) for the PAGW OU (SRNS 2013). The groundwater encompassed by the PAGW OU is in the Floridan aquifer system. The aquifer of interest for this NTC RA is the UTRA, which is divided into the UAZ and the LAZ by a leaky, semi-confining aquitard, the Tan Clay Confining Zone (TCCZ). The near-surface groundwater in P Area is isolated by PAR Pond to the east, Steel Creek to the west, and Meyers Branch to the south and east.

The 30-year (yr) average (1993 - 2023) rainfall for SRS is 119 centimeter per year (cm/yr) (46.8 inches per year [in./yr]) (Savannah River National Laboratory [SRNL] 2024). P Area received 160 cm (62.9 in.) of rainfall in 2023 based on data from the 100-P rain gauge (Figure 3). Above average rainfall was experienced throughout the summer of 2023 (May-August) and at the end of August, with 16.8 cm (6.62 in) of rainfall resulting from Hurricane Idalia. The P-RBC area is a zone of local groundwater recharge, therefore a portion of rainfall in the area translates to shallow groundwater by moving vertically downward (WSRC 2008). Regionally, UAZ water levels have increased from 2Q23 to 1Q24 due to increased rainfall in 2023. Annual rainfall in 2023 (160 cm [62.9 in.]) was greater than the SRS average (119 cm/yr [46.8 in/yr]) based on the 100-P rain gauge, resulting in the observed increase in the UAZ synchronous water levels through 1Q24. During 1Q24, the rainfall total was 30.2 cm (11.9 in) based on the 100-P rain gauge, which is within the expected average amount for this time period. Since baseline water elevation measurements in 2019, water elevations have decreased on average by ~1.5 m (5 ft). The synchronous water level trends are reflected in ZVI-PRB monitoring wells, as demonstrated on hydrographs in Appendix B.

2.3 Nature and Extent of Contamination

The nature and extent of contamination was investigated for the PAGW OU using groundwater monitoring wells, direct-push technology, and surface water samples (SRNS 2013 and SRNS 2018b). Groundwater contamination associated with cVOCs is primarily exhibited in a narrow band north of the P-RBC and extends to the west to Steel Creek, where impact is known, and east towards an unnamed tributary to PAR Pond. Several areas in the P Area facility area were determined to be PSAs for the cVOC plumes, primarily tetrachloroethylene (PCE) and TCE. TCE contamination originating from P Area impacts the PAGW OU and follows groundwater flow of the UAZ and LAZ of the UTRA,

shown in Figure 4 and Figure 5, respectively. It should be noted that the TCE groundwater plumes include recent 1Q24 groundwater monitoring well data and data collected from the 2018 SAP Addendum investigation (SRNS 2018b). The groundwater plumes were updated with 2024 PAGW OU Long-Term Monitoring well and surface water reporting data (to be reported in the 2024 groundwater report for the PAGW OU). The 2018 SAP Addendum data were retained to illustrate the extent and magnitude of TCE contamination in the low permeability zones in the distal area downgradient of the ZVI-PRB (SRNS 2018b). The data obtained as a result of the 2018 SAP Addendum investigation was more comprehensive. As such, Figures 4 and 5 were constructed with data from the 2018 investigation and updated with 2024 groundwater monitoring well data. In the UAZ, groundwater flows west-southwest from the P-RBC toward Steel Creek as shown on Figure 4. The UAZ TCE plume impacts surface water in Steel Creek around surface water station SC-03. Impact on groundwater concentrations associated with the ZVI-PRB are not having a current impact on surface water cVOC concentrations in Steel Creek. SRS believes this is not unexpected as groundwater flow is slow at the ZVI-PRB and there is significant cVOC mass entrained in the low-permeability sediments between the ZVI-PRB and Steel Creek. Therefore, it will take some time before cVOC concentrations are reduced in Steel Creek as a result of the ZVI-PRB.

The groundwater plume from the P-RBC to Steel Creek has been divided into three sections: the source area, the neck area, and the distal area (Figures 4 and 5). The source area encompasses the portion of the plume where the source initially impacts groundwater and is centered northwest of the P-RBC within the P Area facility area. The neck area represents the area where the cVOC groundwater plumes are controlled by a buried geologic feature thus creating a narrowing of the groundwater plumes and is located to the west just outside of the P Area facility area. In this zone, the UAZ and upper LAZ contain large cobblestones in a sandy-clay matrix, promoting a narrowed zone of preferential groundwater flow. The plume then reaches further toward Steel Creek, where it begins to expand. This is in the distal area where the source of contamination has been cut-off by the ZVI-PRB. The distal area is where a large amount of mass is now concentrated and is largely bound up in low-permeability sediments in the subsurface, as determined by investigation as part of the 2018 SAP Addendum (SRNS 2018b). These low-permeability sediments continue to diffuse cVOC mass into groundwater, thereby impacting groundwater concentrations and plume movement and ultimately impacting Steel Creek.

Maximum contaminant level (MCL) exceedances in groundwater occur over an area of ~8.3/12 ha (21/29 ac) for TCE in the UAZ/LAZ, respectively (SRNS 2023). PCE and cis-1,2-dichloroethylene (cis-DCE) plumes present in the UAZ and LAZ are contained within the TCE plume area as described and shown in the SAP Addendum (SRNS 2018b). Table 1 lists the maximum reported concentrations in the first half of 2019 for TCE, PCE, and cis-DCE in the UAZ and LAZ within the three sections prior to implementation of the PAGW OU NTC RA. Due to the highly aerobic nature of SRS groundwater, incomplete degradation of PCE/TCE is occurring as evident by buildup of cis-DCE and no detection of other degradation byproducts. Surface water in Steel Creek is impacted by discharges of TCE-contaminated groundwater above the MCL of 5 micrograms per liter ($\mu\text{g/L}$). The area of impact is localized to the upper section of the creek at surface water location SC-03 (Figure 4) and confirmed through characterization completed as part of the 2018 SAP Addendum (SRNS 2018b). Maximum TCE concentrations in Steel Creek were observed at 28.3 $\mu\text{g/L}$ in 2013 (surface water station SC-03). The most recent (1Q24) measured TCE concentration at SC-03 was 18.6 $\mu\text{g/L}$.

The Core Team determined the PAGW OU contamination warranted a NTC RA to reduce cVOC mass flux. Installation of a ZVI-PRB to intersect TCE plume(s) in the neck area was chosen as the preferred method in the *Removal Site Evaluation Report/Engineering Evaluation/Cost Analysis for Trichloroethylene Plumes Discharging to Steel Creek in P-Area Groundwater Operable Unit (NBN) (U)* (SRNS 2018a). The selected NTC RA was presented to the public in the *Action Memorandum and Responsiveness Summary for the Non-Time Critical Removal Action for the P-Area Groundwater Operable Unit (U)* (USDOE 2018). The Removal Action Objective (RAO), as presented in the PAGW OU Action Memorandum, is to protect human health and the environment by reducing the mass and down-gradient transport of the PAGW OU TCE groundwater plume. As stated in the *Removal Site Evaluation Report/Engineering Evaluation/Cost Analysis (RSER/EE/CA)*, a TCE mass flux reduction of 80% should be sufficient to achieve the MCL in Steel Creek over time (SRNS 2018a).

In support of the PAGW OU NTC RA, a Pre-Design Investigation (PDI) was performed in the neck area of the TCE plumes to confirm site lithology, hydrogeologic, geochemical characteristics, and confirm extent of cVOC contamination as it relates to design, construction, and performance of the ZVI-PRB. During the RSER/EE/CA process, the assumption was that both the UAZ and LAZ TCE plumes would be targeted with the ZVI-PRB (SRNS 2018a). Data from the PDI indicated that TCE concentrations in the LAZ were lower than in the UAZ and that groundwater flow direction of the

LAZ was much more northerly than what was expected (SRNS 2019). Considering that the LAZ groundwater flow direction would lead to inefficient capture of the TCE plume by the ZVI-PRB proposed, and the TCE concentration data which showed ~95% of the TCE mass is present in the UAZ, focus was placed on constructing a ZVI-PRB to target the UAZ TCE plume. However, as a result of ZVI-PRB installation, fracking did propagate into the top of the LAZ and therefore injection of ZVI did occur in the lower unit. This did not diminish the overall performance of the ZVI-PRB on its effectiveness in removing cVOCs from the UAZ, rather placement of ZVI in the upper portion of the LAZ has aided in the treatment of cVOCs that were identified in the LAZ as part of the PDI.

2.4 Removal Action Implementation and Monitoring Goals

Design and construction details for the final design are provided in the RADP and the RAR for the PAGW OU NTC RA (SRNS 2019 and SRNS 2020). ZVI injections were completed on December 11, 2019, with the emplacement of ~672 metric tons (741 US tons) of ZVI. ZVI was mixed with hydroxypropylguar prior to injection to produce a viscous solution able to be injected into the subsurface. Additionally, sodium chloride was added to the solution to increase the conductivity of the injected solution and allowed for resistance mapping of the injections. Details of the mix and injections are provided in the RADP (SRNS 2019). The completed ZVI-PRB is estimated to be 80.5 m (264 ft) long and has a cross-sectional area of 2,140 square meters (23,040 square feet) intersecting groundwater flow in the UAZ (Figure 6). Figure 6 is a North-South cross-section of the ZVI-PRB trace (Figure 7) and soil concentrations for the plume are based on soil plug samples collected from soil cores collected along the ZVI-PRB trace as part of the PDI. There are high cVOC concentrations entrained within the low-permeability sediments of the area, which are reflected in soil plug samples. However, monitoring wells are screened in more permeable zones and therefore groundwater samples indicate lower concentrations. Field activities were completed with closure of the injection wells on January 14, 2020.

Groundwater monitoring in support of the PAGW OU NTC RA was planned to begin the first month following implementation and follow the frequency outlined in the EMP, as summarized in Table 2. The monitoring plan approved in the RADP with EMP (SRNS 2019) will provide results that allow for assessment of the ZVI-PRB technology's effectiveness in destruction of cVOCs. A key component of assessment is four in-wall monitoring wells, which will provide direct results from the center of the

implemented technology. The takeaways from this assessment will provide useful insight in the technology's potential applicability for future actions on site, or at other sites within the USDOE Complex. The primary focus of the EMP will be to assess performance of the PAGW OU NTC RA in meeting the RAO. This EMR is the fourth of five planned reports on the performance and effectiveness of the ZVI-PRB NTC RA (SRNS 2019).

The implemented ZVI-PRB is anticipated to reduce the mass flux of TCE through the neck area of the PAGW OU TCE plume by at least 80% in order to meet the RAO. This is assessed through the monitoring of cVOC concentrations over time in 26 monitoring wells identified in the EMP for performance monitoring (Figure 7). In addition, installation activities for two surface water flow monitoring stations on Steel Creek were completed in September 2024. The flow stations will aid in accurate water balance calculations for the PAGW OU and will be useful in calculation of mass flux of TCE. ZVI is a recognized technology for reducing high level cVOCs (e.g., PCE and TCE) to harmless end-products without the build-up of harmful intermediates, such as cis-DCE, trans-1,2-dichloroethylene (trans-DCE), and chloroethene (vinyl chloride [VC]). In addition to TCE and PCE, degradation by-products are also monitored.

Important geochemical and field measurements are monitored to assess geochemical changes in the target zone. The high reducing potential of ZVI presents the favorable possibility of flipping an aerobic aquifer to anaerobic, reducing conditions, traveling down-gradient as a reducing front over time. An anaerobic, reducing environment is conducive to the potential formation of natural anaerobic microbial activity, which are often heavy consumers of organic compounds, including the targeted contaminant TCE. The presence of guar that was used to inject the ZVI will provide a reliable carbon source aiding in further destruction of cVOCs. The presence of a reducing environment in the UAZ of the PAGW OU will be measured by oxidation-reduction potential (ORP). Negative ORP values indicate a reducing environment, with higher negative numbers indicating the strength of the reducing agents in groundwater. In an environment with promising conditions for anaerobic microbes, the presence of intermediate cVOC degradation products are indicators of natural biodegradation, as ZVI is not anticipated to form a large mass of intermediates.

Additional analytes were selected to provide data on the health of the ZVI-PRB. Nitrate, calcium, and sulfate are commonly occurring constituents in groundwater and are found in detectable

concentrations within the UAZ of the UTRA in the PAGW OU. In literature, at the interface between groundwater and ZVI, nitrate has been observed to interact with the ZVI and result in a lessened reactivity, and therefore a decreased performance known as passivation (Ritter, Odziemkowski, and Gillham 2002; Mishra and Farrell 2005). A decrease in nitrate concentrations down-gradient of the ZVI-PRB may indicate consumption of the ion by ZVI, and therefore may be indications of passivation. Sulfate and calcium ions in a reducing, high pH environment more readily precipitate out of solution. Precipitation within the ZVI-PRB leads to a decreased performance as the porosity, and therefore the retention time within the barrier, will decrease. This reduces the contact time of cVOCs with ZVI, and therefore reduces the potential for complete degradation. However, based on the treatability study performed during design activities of the ZVI-PRB, it was concluded that it was unlikely, unless conditions changed, that the ZVI-PRB would exhibit reduced effectiveness due to passivation and/or precipitation. However, over time under normal circumstances, it is expected that ZVI will lose some of its reactivity.

2.5 PAGW OU NTC RA Monitoring Network

As outlined in the RADP with EMP (SRNS 2019), the PAGW OU NTC RA monitoring network includes 26 monitoring wells. Table 2 provides construction details for the monitoring network and Figure 7 shows the locations for each monitoring point. Eight of the monitoring wells (PRW001C/DL/DU, PRW003C/DL/DU, and P003U/L) are located to the east of the ZVI-PRB and 14 wells (PRW002C/DL/DU, PRW004C/DL/DU, PRW005DL/DU, PRW006C/DL/DU, PRW007DL/DU, and P002U) are located to the west. The P003 well cluster is located farther to the east of the ZVI-PRB than the other wells and is considered a background monitoring well for monitoring in support of the PAGW OU RA EMP.

A baseline analysis was completed at 15 of the monitoring well locations in March of 2019 prior to construction of the ZVI-PRB. Baseline results are presented in Table 3. Baseline results are not presented for the PRW005, PRW006, or PRW007 well clusters because these monitoring wells were installed after installation of the ZVI-PRB and therefore do not represent baseline conditions. Figure 8 presents baseline TCE results at the ZVI-PRB monitoring locations. Comparisons of baseline contaminant concentrations with monitoring well results east and west of the ZVI-PRB allows for assessment of the NTC RA performance in reducing TCE mass flux. In addition to the 22 monitoring

wells on either side of the ZVI-PRB, four ZVI injection wells were retrofit with 2.5 cm (1 in.) diameter monitoring wells (PIW001D, PIW002D, PIW003D, and PIW004D). The “in-wall” monitoring wells (i.e., wells located within the ZVI-PRB) present a key perspective, allowing for assessment of the conditions within the barrier itself. The approved EMP for the PAGW OU NTC RA outlined the analytes and frequency to be followed for the 26 monitoring wells as shown in Table 2 and Figure 7 (SRNS 2019).

For the four in-wall monitoring wells, the approved EMP for the PAGW OU NTC RA proposed sampling bimonthly for the first quarter, monthly sampling for the second quarter, and quarterly sampling for the remainder of the five year monitoring plan. This frequency was proposed with intentions of observing rapid changes in geochemical parameters and then to track these parameters over time. All other monitoring wells, with the exception of the PRW006 cluster, are sampled quarterly. The PRW006 well cluster is set farther west of the ZVI-PRB and is sampled annually. Groundwater sampling activities associated with the ZVI-PRB may generate aqueous investigation-derived waste (IDW). Aqueous IDW may consist of decontamination rinses, well purge water, and sample residues. As discussed in the EMP (SRNS 2019), IDW generated during sampling activities will be managed in accordance with the *SRS Investigation-Derived Waste Management Plan* (WSRC 2013).

Monitoring results are presented in Section 3.0 and discussed in Section 4.0. The complete data sets are presented in the appendices. Appendix A tabulates monitoring data from 2Q23 to 1Q24 for all regular samples collected to monitor in accordance with the PAGW OU NTC RA EMP. Field notes are recorded by groundwater samplers in special cases, such as when a well pumps dry during purging, turbidity does not stabilize below threshold for sending some samples, etc. When field notes are present for the reported data, the field notes are defined by alphanumeric codes which are presented in a “Field Code” column of Table A and explained below the table. For the 2Q23 to 1Q24 reporting period, there were no relevant field codes reported for the data. Appendix B presents hydrographs of water levels at the PAGW OU NTC RA monitoring wells from 2018 to present. Appendix C consists of time-series plots for select constituents from 2018 to present of the outlined analytes for the EMP to support the PAGW OU NTC RA.

3.0 MONITORING RESULTS AND DEVIATIONS

Data reported in this EMR were collected in accordance with the *Removal Action Design Plan (RADP) with Effectiveness Monitoring Plan (EMP) for the P-Area Groundwater (PAGW) Operable Unit (OU)* (SRNS 2019). All data collected conform to the approved *Area Completion Projects Quality Assurance Project Plan for Environmental Data Collection and Management* (SRNS 2012b). Only groundwater data is collected in support of monitoring at the PAGW OU ZVI-PRB and is sent to SCDES certified laboratories for analyses. The data quality level for permanent groundwater monitoring well stations and field duplicate samples is Verified and Validated (V&V) level data (SRNS 2012a and SRNS 2012b).

3.1 Deviations from the Monitoring Plan

Monitoring wells included in the PAGW OU NTC RA were sampled and analyzed as outlined in the RADP with EMP, with no deviations between 2Q23 to 1Q24 (SRNS 2019). Monitoring results from 2Q23 to 1Q24 are tabulated in Appendix A.

3.2 Upper Aquifer Zone

3.2.1 Groundwater Elevation Measurements and Groundwater Flow Direction

Hydrographs for UAZ monitoring wells of the EMP are presented in Appendix B. Recent increases in water elevations from 2Q23 to 1Q24 are reflective of increased precipitation in 2023, as shown in Figure 3. Regional water elevations and the potentiometric surface for the UAZ is presented in Figure 9 using 1Q24 synchronous water level data. The regional groundwater flow direction in the UAZ is to the west towards Steel Creek. Hydraulic conductivity was calculated to be 10.59 meters per day (m/d) (34.76 feet per day [ft/d]) for the UAZ within the ZVI-PRB area through Hydraulic Pulse Interference Testing (HPIT) (SRNS 2019). The hydraulic gradient was calculated between PMW005DL and PGW026DL as 0.0124 ft/ft. Using an estimated effective porosity of 0.2 for the UAZ in P Area (SRNS 2019), the resulting regional groundwater flow velocity is 239.8 meters per year (m/yr) (786.6 feet per year [ft/yr]) in the NTC RA area. In Figure 10, focus is placed on the ZVI-PRB localized area within the UAZ potentiometric surface. In the vicinity of the ZVI-PRB, the hydraulic gradient is estimated between PMW005DL and PRW006DU to get 0.0040 ft/ft. This results in an estimated groundwater flow velocity of 77.3 m/yr (253.7 ft/yr). Groundwater flow velocity in the vicinity of the ZVI-PRB is much slower than the flow velocity for the UAZ to the west towards Steel

Creek. The slower groundwater flow velocity can be attributed to the location of the ZVI-PRB near P Area, close to the groundwater divide and also because of the impact the ZVI-PRB is having on localized groundwater flow. This is illustrated on Figures 9 and 10 as evident by further spaced potentiometric surface contours west of the ZVI-PRB around the PRW002 monitoring well cluster. The variability in the UAZ potentiometric surface near the ZVI-PRB indicates localized slowing of groundwater flow and is consistent with regional groundwater elevation changes across P Area. This observation is not expected to negatively impact the performance of the ZVI-PRB, as upgradient water is flowing towards/into the permeable barrier.

Groundwater depth measurements are not included in Appendix A for the P00 series monitoring wells due to the diameter of the monitoring well and size of the installed pump, which does not allow access of a groundwater tape for measurement.

3.2.2 Chlorinated Volatile Organic Compounds

In accordance with the EMP for the PAGW OU NTC RA (SRNS 2019), all monitoring wells were sampled and analyzed quarterly for select cVOCs, including PCE, TCE, cis-DCE, trans-DCE, 1,1-dichloroethylene (1,1-DCE), and VC. Between 2Q23 and 1Q24, 78 samples were collected and analyzed for cVOCs at the PAGW UAZ EMP wells. Results above the practical quantification limit (PQL) were detected in low frequency for trans-DCE (two [2] detections) and VC (three [3] detections). There were no detections above the PQL for 1,1-DCE, and the maximum estimated result (J qualification) was 0.85 µg/L. The maximum detected results between 2Q23 and 1Q24 were 9.00 µg/L for trans-DCE (estimated result; maximum result above PQL was 6.83 µg/L) and 1.59 µg/L for VC (Appendix A).

For the PAGW OU NTC RA, the primary constituent is TCE. Baseline concentrations are summarized in Table 3 for all cVOCs in the UAZ and LAZ prior to installation of the ZVI-PRB. To better understand the effect of the ZVI-PRB, baseline concentrations from wells located east and west of the ZVI-PRB and in-wall wells are compared to 1Q24 results in Table 4.

Data from east of the ZVI-PRB are upgradient and were intended to provide influent groundwater conditions, unimpacted by the ZVI-PRB. However, because of the proximity of the PRW001 cluster to the ZVI-PRB, the data reported for key indicators are elevated relative to baseline conditions. For

instance, chloride, dissolved organic carbon (DOC), ethane, methane, and total organic carbon (TOC) are all elevated. This is primarily due to the impact of the ZVI-PRB on groundwater surrounding this well cluster. Field data from this well cluster also support the relative impact the ZVI-PRB is having on groundwater as illustrated by the low ORP and dissolved oxygen (DO) results (Appendix A). West of the ZVI-PRB, the data indicates impact of the NTC RA on groundwater as shown by increases in TCE degradation by-products (e.g., cis-DCE and ethane) as well as increases in chloride, iron, and methane. The data also indicates elevated levels of TCE remain, which is not unexpected. As cVOCs are removed by the ZVI-PRB from groundwater, the cleaner groundwater moves through the higher permeability material downgradient of the ZVI PRB, and TCE is diffused from the low permeable sediments through “back diffusion” into the cleaner groundwater. Back diffusion is a phenomenon where cVOCs, such as TCE, have adsorbed into low permeability sediments and seeks equilibrium with the “clean” groundwater front that leaves the treatment area. A concentration gradient then persists that promotes TCE diffusion from the low permeability sediments and into the groundwater. This phenomenon is beneficial, as it results in more TCE mass being removed from the subsurface, but it is also likely to result in elevated TCE results in monitoring wells west of the ZVI-PRB for some time until most of the cVOC mass has diffused out of the low permeable sediments. Therefore, data from the in-wall monitoring wells provide the best indication of the effect the technology is having on groundwater as it passes through the ZVI-PRB. The primary contaminants are mostly not detected and there are elevated concentrations of the end by-products, chloride, ethane, and ethylene.

Trichloroethylene

For the UAZ, 1Q24 TCE results are presented in Figure 11. TCE concentrations in the background monitoring wells P003U and P003L were 452 µg/L and 3,260 µg/L, respectively. TCE concentrations in eastern UAZ monitoring wells ranged from 1.06 to 499 µg/L in 1Q24, with the maximum detection at PRW003DL. In western UAZ monitoring wells, TCE ranged from 0.42 to 281 µg/L, with the maximum at PRW007DU. The second highest TCE result in western UAZ monitoring wells was 101 µg/L, recorded at PRW004DL. TCE time-series plots are presented in Appendix C, Figures C.33 to C.46.

The concentration of TCE in groundwater monitoring wells west of the ZVI-PRB with baseline data (P002U, PRW002 and PRW004 clusters) has generally decreased compared to baseline (Figure 12).

Rebounding of TCE concentrations have been observed, with the most significant at PRW004DL in fourth quarter of 2021 (4Q21) and again in 1Q24 and at PRW004DU in 2Q23. Rebounding at PRW004DL and at PRW004DU approached or exceeded baseline TCE concentrations. Rebounding of TCE concentrations were not lasting at all wells, with most decreasing down to or below 10 µg/L in the 1Q24 data. One exception is PRW004DL, which has increased over the last three quarters to 101 µg/L in 1Q24, but remains below the baseline result of 254 µg/L. Although TCE rebounding is observed at PRW004DL, degradation is occurring as evidenced by presence of degradation products (e.g., cis-DCE and ethane). TCE concentrations in the remaining monitoring well clusters west of the ZVI-PRB (PRW005, PRW006, and PRW007 clusters) are presented in Figure 13. Concentrations have remained steady below the MCL (5 µg/L) at PRW005DL and PRW005DU, with the lone exception in third quarter of 2022, where both wells increased to 9.25 µg/L and 14.8 µg/L, respectively. TCE concentrations remained at the MCL (5 µg/L) at PRW006DU in first quarter of 2021 (1Q21) and first quarter of 2022 (1Q22) but decreased to 1.7 µg/L in first quarter of 2023 (1Q23) and 1.8 µg/L in 1Q24. TCE concentrations have a decreasing trend at PRW006DL and PRW007DU. TCE concentrations at PRW007DL have remained above the MCL since sampling began in third quarter of 2020 (3Q20), and had a 1Q24 result of 31.1 µg/L.

The four in-wall monitoring wells (PIW series) were sampled for TCE starting in second quarter of 2020 (2Q20), post-completion of the ZVI-PRB (Appendix Figures C.36 – C.39). Initially, TCE results in the in-wall monitoring wells were low, with only 3 of 12 sample results in 2020 above the PQL and a maximum of 5.03 µg/L (PIW003D in fourth quarter of 2020 [4Q20]). TCE concentrations at PIW001D, PIW002D, and PIW004D remained below detection for all 12 samples collected between 2Q23 and 1Q24. TCE concentrations at in-wall monitoring well PIW003D remained above PQL for all four samples from 2Q23 to 1Q24, with a maximum detection of 7.90 µg/L (fourth quarter of 2023 [4Q23]). The maximum result of the in-wall monitoring wells (7.90 µg/L) is 98.4% lower than the maximum 1Q24 result east of the ZVI-PRB (499 µg/L). It is important to note that the in-wall monitoring wells are located within the ZVI-PRB. Therefore, the detected results are located in the middle of the barrier and further degradation of detected cVOCs is likely to occur before groundwater exits the ZVI-PRB.

Tetrachloroethylene and Cis-1,2-Dichloroethylene

From 2Q23 to 1Q24, 13 of 78 samples collected for the UAZ EMP wells reported PCE detections above the method detection limit (MDL). All PCE results from 2Q23 to 1Q24 were below the maximum PCE baseline of 5.15 µg/L and the MCL of 5 µg/L. The maximum PCE detection in the UAZ ZVI-PRB monitoring wells, was 1.92 µg/L at PRW006DL, located farthest west of the ZVI-PRB.

Cis-DCE was detected above the MDL in 53 of 78 samples collected from UAZ EMP wells between 2Q23 and 1Q24. In the 1Q24 sampling event, the maximum UAZ result for cis-DCE was 556 µg/L at background monitoring well P003L. The maximum 1Q24 result east of the ZVI-PRB, excluding the background wells, was 285 µg/L at PRW003DL. The maximum result west of the ZVI-PRB was 116 µg/L at PRW004DL. West of the ZVI-PRB, cis-DCE concentrations have increased from baseline and remained steady ranging between 0.73 and 116 µg/L in the 1Q24 sampling event. The presence of cis-DCE and ethane west of the ZVI-PRB indicates conditions are supportive for further degradation of TCE and PCE. Cis-DCE time-series plots are presented in Appendix C, Figures C.5 to C.18, for the PAGW OU NTC RA monitoring wells.

Out of the four in-wall monitoring wells, PIW003D is the only monitoring well with consistent detections of cis-DCE. Concentrations in the two most recent sampling events were 81.0 µg/L and 49.1 µg/L (4Q23 and 1Q24, respectively). Cis-DCE concentrations in P003U and P002U decreased slightly from July 2007 until monitoring began post-construction of the ZVI-PRB. P003L remained steady around the detection limit over the same time. Concentrations increased significantly in P003L during the baseline (892 µg/L), decreased slightly until 1Q22 (382 µg/L), increased to around baseline concentrations with a 1Q23 result of 720 µg/L, and have decreased again this reporting period, with a 1Q24 result of 326 µg/L. Cis-DCE concentrations at P003U have decreased from a baseline result of 13.3 µg/L to a 1Q24 result of 7.7 µg/L. Concentrations in P002U have increased since completion of the ZVI-PRB, with a 1Q24 result of 71.6 µg/L compared to the baseline result of 28.4 µg/L.

3.2.3 Geochemical Analyses

Samples collected in support of the ZVI-PRB monitoring were analyzed for select geochemical analytes in line with the approved EMP, summarized in Table 2. During the baseline sampling event, all completed monitoring wells were sampled and analyzed for geochemical analytes in order to

establish a baseline for the groundwater. In ongoing sampling events, only the in-wall monitoring wells were sampled for geochemical analyses.

Chloride, Ethylene, and Ethane Results

The breakdown of cVOCs produces end-products such as chloride, ethylene, and ethane. However, because salt (e.g., NaCl) was added to the injectate material (e.g., guar and ZVI) to aid in resistivity monitoring during injections, observed chloride concentrations in groundwater downgradient of the ZVI-PRB could be influenced by salt additions. However, observed trends of chloride concentrations immediately after injection show a significant decrease in concentrations indicating that the salt was being flushed from the area around the monitoring network. More recent increases in chloride concentrations in some wells are observed which may indicate reductive dechlorination of the TCE.

The maximum chloride concentration in baseline sampling of the UAZ monitoring wells was 3.64 milligram per liter (mg/L) at PRW002DU. Chloride concentrations in western groundwater monitoring wells are increasing slightly, with a 1Q24 maximum at PRW007DU of 33.5 mg/L. The maximum background chloride concentration from 2Q23 to 1Q24 was 2.74 mg/L at P003U in 1Q24.

MDLs for ethane and ethylene analyses remained elevated due to laboratory and analytical method capabilities until the 1Q23 sampling event. SRNS is continuing to coordinate with the contracted laboratories to ensure the lowest possible MDLs are achieved, which was 10 µg/L for ethane and ethylene from 4Q21 to fourth quarter of 2022 (4Q22). The corresponding PQL was 25 µg/L. Since 1Q23, laboratories were able to achieve MDLs lower than 1.0 µg/L for ethane and ethylene, and PQLs of 5.0 µg/L or lower. In UAZ monitoring wells, the maximum baseline ethane result was 0.17 µg/L. Ethane results in background wells have remained below the MDL until 1Q24, where detected ethane results were 3.4 µg/L at P003U and 5.5 µg/L at P003L. For all UAZ results west of the ZVI-PRB in 1Q24, the ethane results ranged from 4.7 to 40.8 µg/L, with the maximum detection at PRW007DU. In-wall monitoring wells ranged from 8.6 µg/L to 70.5 µg/L in 1Q24, with the maximum detection at PIW003D.

The baseline ethylene concentration in UAZ monitoring wells was 0.55 µg/L. Ethylene was detected above the MDL in all 21 UAZ groundwater monitoring wells for 1Q24, ranging from 0.81 µg/L to 39.2 µg/L, with the maximum at PIW003D.

Methane

Methane concentrations remained elevated in the UAZ between 2Q23 and 1Q24. The maximum methane concentration in the baseline sampling was 2,400 µg/L and the 1Q24 background monitoring well results (P003U and P003L) were 7.3 µg/L and 7.5 µg/L, respectively. Of the 78 samples collected in the UAZ between 2Q23 and 1Q24, there were 63 detections above the MDL (3.8 µg/L).

In 1Q24, detectable results in the UAZ ranged from 5.3 µg/L to 16,400 µg/L, with the maximum at PRW001DL. In 1Q24, methane concentrations west of the ZVI-PRB are elevated at monitoring wells PRW002DU, PRW002DL, PRW004DU, and PRW007DU (ranging from 6,390 µg/L to 11,000 µg/L). At PRW002DL and PRW004DU, 1Q24 methane concentrations are the highest observed since monitoring began. Methane concentrations remain elevated in the in-wall monitoring wells and ranged from 313 µg/L to 3,980 µg/L in 1Q24. PIW003D had the maximum and remains elevated following ZVI-PRB completion. Elevated methane levels were not unexpected due to ZVI reactivity with cVOCs and anaerobic processes utilizing the food-grade guar material. The elevated methane levels are not expected to negatively impact the performance of the ZVI-PRB.

Nitrate, Sulfate, Calcium, and Iron

Certain cations and anions in groundwater are useful to make assessments of ZVI-PRB health, as well as to assess if anaerobic conditions are present. Nitrate, sulfate, and calcium are analyzed for in-wall monitoring wells only. Nitrate concentrations have decreased to below MDL (0.17 mg/L) in all samples, down from a maximum UAZ baseline concentration of 2.82 mg/L. Sulfate also saw a decrease in concentration with the maximum 1Q24 result of 1.39 mg/L, down from the maximum first quarter of 2019 (1Q19) baseline result of 13.4 mg/L. Total iron concentrations for the in-wall monitoring wells have decreased from a maximum baseline of 741 µg/L to a 1Q24 maximum of 448 µg/L at PIW003D. Total iron concentrations in all UAZ monitoring well clusters west of the ZVI-PRB have remained elevated with a 1Q24 maximum of 19,100 µg/L at PRW002DL. The only exceptions were PRW007DL and the PRW006 monitoring well cluster, which had 1Q24 total iron results below MDL (33 µg/L). The PRW006 monitoring well cluster is located farther west of the ZVI-PRB. The decreasing concentrations of nitrate and sulfate in ZVI-PRB monitoring wells are indicators that passivation may be possible, however the insignificant baseline concentrations are favorable indicators

that passivation of the ZVI-PRB is not a major concern. This is further supported by the treatability study that was performed as part of the PDI.

Concentrations of calcium have increased significantly from baseline and remain elevated in 1Q24. The maximum calcium concentration in the ZVI-PRB monitoring well baseline event was 4,810 µg/L in the UAZ. The 1Q24 calcium results for in-wall monitoring wells ranged from 38,000 µg/L to 76,200 µg/L. Refer to Section 4.3 of this report for further discussion on calcium.

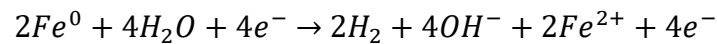
3.2.4 Field Measurements

In addition to analytes listed in the PAGW OU NTC RA EMP, field measurements are collected during each sampling event and at each sampling location. These measurements are collected to ensure the samples have reached stability and the sample collected is representative of the targeted groundwater. However, the values collected during field measurements are also useful in assessment of conditions in the aquifer. Field measurements of ORP have significantly decreased from baseline in 1Q19 to 1Q24.

Negative ORP is a favorable condition created by ZVI which promotes reductive dechlorination. During the baseline sampling, the range of UAZ ORP values was +124 millivolts (mV) to +428 mV. In 1Q24, the range of recorded ORP values for in-wall monitoring wells was -345 mV to -312 mV. The range of 1Q24 ORP results in UAZ monitoring wells west of the ZVI-PRB (excluding PRW006 cluster) was -107 mV to +125 mV. At the PRW006 monitoring well cluster further to the west, effects of a reducing front are not obvious, with ORP results consistent within background and baseline results. This is primarily due to the distance of this well cluster from the ZVI-PRB. In reducing conditions, negative ORP values are typically associated with DO results at or below 0.5 mg/L.

Impacts to groundwater pH were observed following the ZVI-PRB installation. During baseline sampling, the maximum pH of the UAZ monitoring wells was 6.5. The range of pH at in-wall monitoring wells for 1Q24 was 12.6 to 13.3. UAZ monitoring wells west of the ZVI-PRB had a slight increase initially, with a maximum pH in first quarter of 2020 (1Q20) of 8.8 for UAZ monitoring wells. The pH in these wells has since returned to near baseline levels with a 1Q24 maximum of 6.6 at P002U. Initially, after installation of the ZVI-PRB the observed increase in pH at monitoring wells west of the ZVI-PRB was primarily associated with installation activities with construction of the

ZVI-PRB (i.e., cement grout used during construction of injection wells). However, pH in the in-wall wells remains elevated because these wells are installed within the ZVI-PRB and influenced by ongoing ZVI-groundwater interactions. The primary interaction believed to be affecting pH levels in impacted groundwater is the following half-reaction:



This interaction produces hydroxide, thus raising the pH. Elevated pH levels associated with ZVI have been well documented at other sites and the elevated levels are not expected to have an impact on ZVI-PRB performance. For monitoring wells located further west of the ZVI-PRB, pH levels were not significantly affected.

3.3 Lower Aquifer Zone

3.3.1 Groundwater Elevation Measurements and Groundwater Flow Direction

The regional water elevations and potentiometric contours are mapped for the LAZ in Figure 14 using 1Q24 synchronous water level data. Potentiometric contours indicate a northward groundwater flow direction in the vicinity of the ZVI-PRB, leading to a groundwater divide sending groundwater west to Steel Creek, or east toward P-Area facility area. Using the potentiometric surface, a hydraulic gradient of 0.0111 ft/ft was calculated between PGW020C and PRW003C. The calculated hydraulic conductivity for the LAZ in HPIT testing was 10.82 m/d (35.51 ft/d). Assuming a porosity of 0.2, the groundwater flow velocity toward the ZVI-PRB, flow south to north, was calculated as 219.2 m/yr (719.3 ft/yr) for the LAZ. Groundwater flow in the vicinity of the ZVI-PRB is slower than regional flow in the LAZ, which flows to the west toward Steel Creek, and to the east toward P Area.

3.3.2 Chlorinated Volatile Organic Compounds

During installation of the ZVI injection wells, the bottom expansion joints were installed at the base of the TCCZ to ensure total capture of groundwater in the UAZ. As a result of fracking during the installation of the ZVI-PRB when keying the ZVI-PRB into the semi-confining TCCZ that separates the UAZ and LAZ, some ZVI was emplaced in the upper part of the LAZ. Secondarily to the main objective to treat groundwater in the UAZ, this emplacement provided added benefit by reducing TCE and other cVOCs present in the LAZ.

Trichloroethylene

There are five LAZ monitoring wells in the EMP (PRW001C, PRW002C, PRW003C, PRW004C, and PRW006C). TCE concentrations over time in the LAZ monitoring wells are shown in Figure 15. Excluding PRW006C, generally TCE concentrations are overall decreasing in the LAZ monitoring wells compared to baseline levels. In the LAZ monitoring wells east of the ZVI-PRB (PRW001C and PRW003C), TCE concentrations have increased in 2022 reporting events. These observed increases remained below baseline concentrations and both have observed decreases in TCE concentrations from 2Q23 to 1Q24. West of the ZVI-PRB, concentrations at PRW002C have decreased steadily since installation of the ZVI-PRB with four of the last five results below detection limit. Following ZVI-PRB construction, PRW004C initially decreased below 1 µg/L in 4Q20 and has increased gradually with a 1Q24 result of 9.38 µg/L. The maximum baseline detection from LAZ monitoring wells for TCE was 664 µg/L at eastern well location PRW003C. In the 1Q24 sampling event, the maximum TCE concentration in the same four LAZ monitoring wells was 15.4 µg/L (PRW003C). Concentrations at PRW006C increased from 24.3 µg/L in 3Q20 to 110 µg/L in 1Q23, then decreased to 37.8 µg/L in the 1Q24 sample. TCE results for 1Q24 in the LAZ compared to baseline are shown in Figure 16.

Tetrachloroethylene, Cis-1,2-Dichloroethylene, and Chloroethene

For the LAZ, the maximum baseline PCE result was at monitoring well PRW002C with a detection of 1.6 µg/L. From 2Q23 to 1Q24, there were 17 samples collected for LAZ monitoring wells with no detections above the MDL for PCE.

The maximum baseline cis-DCE result for the LAZ was 138 µg/L at PRW003C. The maximum cis-DCE result in 1Q24 was 35.4 µg/L at PRW003C. Cis-DCE concentrations in the LAZ monitoring wells are presented over time in Figure 17.

Of the 17 samples collected from LAZ monitoring wells from 2Q23 to 1Q24, no samples were above the MDL for VC.

3.3.3 Geochemical Analyses

Although baseline samples collected in the LAZ to support the ZVI-PRB monitoring were analyzed for the entire geochemical analyte list, post-installation samples were not analyzed for the entire

geochemical analyte list in accordance with the EMP (Table 2). However, a select list of geochemical analyses was performed for post-installation samples including total iron, chloride, and dissolved gases (ethane, ethylene, and methane).

For baseline LAZ sampling, iron ranged from 80.1 µg/L to 496 µg/L. In the 1Q24 sampling event, iron results west of the ZVI-PRB at PRW002C and PRW004C were 21,500 µg/L and 3,830 µg/L, respectively. Total iron concentrations in the LAZ initially increased following ZVI-PRB installation, and have followed decreasing trends since, however total iron remains elevated compared to baseline. Total iron farther west at PRW006C increased to above detection with a 1Q24 result of 498 µg/L, which is at the maximum baseline total iron concentration observed in the LAZ.

LAZ chloride concentrations in 1Q24 range from 8.1 mg/L to 13.1 mg/L in monitoring wells near the ZVI-PRB. The maximum baseline concentration in the LAZ was 3.03 mg/L. Chloride concentrations are decreasing since an initial spike following completion of the ZVI-PRB, however concentrations remain elevated near the ZVI-PRB compared to baseline. Results from PRW006C, located farther west of the ZVI-PRB, remained consistent with baseline concentrations until 1Q24, with a result of 31.7 mg/L. The increase in the latest sampling event is an indicator of dechlorination occurring upgradient of PRW006C, at the ZVI-PRB.

With the exception of PRW006C, ethane concentrations remain elevated in the LAZ, ranging from 50.2 µg/L to 338 µg/L in 1Q24. Likewise, ethylene concentrations remain elevated in 1Q24, ranging from 5.8 µg/L to 102 µg/L. Baseline LAZ concentrations for both ethane and ethylene were below 1 µg/L.

Baseline concentrations for methane in the LAZ ranged from 0.64 µg/L to 2.0 µg/L. The 1Q24 results in nearby LAZ monitoring wells ranged from 862 µg/L to 6,870 µg/L. Methane concentrations remain elevated in the LAZ monitoring wells near the ZVI-PRB for 1Q24 and are consistent with previously reported trends, with the exception of PRW002C. Methane concentrations in PRW002C has consistently increased from a 1Q22 result of 895 µg/L to a 1Q24 result of 6,870 µg/L. Farther west of the ZVI-PRB at PRW006C, the 1Q24 methane result was 32.8 µg/L, an increase from all previous results and from the 1Q23 result of 6.5 µg/L. This increase at PRW006C represents the first increase in methane observed throughout monitoring of the ZVI-PRB.

3.3.4 Field Measurements

Field measurements taken in the LAZ monitoring wells present evidence of ZVI-PRB effects. In baseline sampling, the range of ORP in the LAZ was +181 mV to +294 mV. In 1Q24, ORP in the LAZ monitoring wells nearby to the ZVI-PRB ranged from -284 mV to -28 mV. ORP results in the LAZ have demonstrated an increase overall from a 1Q23 range of -337 mV to -135 mV. Located further to the west at PRW006C, the ORP in 1Q24 was +301 mV.

In the LAZ monitoring wells, baseline pH values ranged from 5.3 to 7.2. Immediately following ZVI-PRB construction in 1Q20, the maximum pH in the LAZ was 10.5. From 2Q23 to 1Q24, pH remained around baseline levels for LAZ monitoring wells PRW002C, PRW003C, and PRW006C with a range from 4.5 to 6.5. At PRW001C, pH has gradually increased since third quarter of 2021 with a 1Q24 pH of 9.9. At PRW004C, pH ranged from 6.2 in 1Q21 to 6.8 in 1Q22, which was consistent with pH at PRW002C and PRW003C. From third quarter of 2022 to present, pH has increased at PRW004C with a 1Q24 result of 8.4. As discussed in Section 3.2.4 for the UAZ, Elevated pH levels are associated with groundwater interaction with the ZVI. The elevated levels are not expected to have a negative impact on performance of the ZVI-PRB.

4.0 MONITORING PERFORMANCE AND EFFECTIVENESS DISCUSSIONS

4.1 Groundwater Elevation and Flow Path

Groundwater flow across the ZVI-PRB in the UAZ is westerly towards Steel Creek, as expected, with groundwater velocity calculated as 77.3 m/yr (253.7 ft/yr) in 1Q24 (Figure 10). After four years of monitoring, impact to the UAZ groundwater potentiometric surface remains minimal. The ZVI-PRB installation does appear to slow groundwater flow west of the ZVI-PRB, as indicated by the potentiometric surface between the PRW001 cluster and the PRW006 cluster. This impact is not expected to affect the ZVI-PRB performance, as the groundwater flow direction was ultimately not impacted, and flow through the ZVI-PRB in the UAZ is supported by the 1Q24 data.

The 1Q24 LAZ potentiometric surface (Figure 14) indicates a northward groundwater flow direction in the vicinity of the ZVI-PRB. The 1Q24 LAZ potentiometric surface is consistent with the 1Q23 potentiometric surface presented in last year's report, including the groundwater divide north of the

ZVI-PRB (~261 ft amsl). This has resulted in a much more northerly groundwater flow direction in the vicinity of the ZVI-PRB.

By design, the ZVI-PRB was intended to target the UAZ, and the bottom was intended to key into the TCCZ that splits the UAZ and LAZ. However, due to variability in the TCCZ elevation and the method for ZVI injections, the ZVI-PRB extends through the TCCZ and does break through into the LAZ, likely at multiple locations along the length (Figure 6). Therefore, the higher permeability ZVI provides a conduit for groundwater flow between the UAZ and LAZ, which could impact the potentiometric surface in either unit. However, this impact is minimal, due to the nature of the TCCZ, which is understood to be an incompetent confining zone. Additionally, the connection between the UAZ and LAZ created by the ZVI-PRB is not anticipated to increase the extent of contamination, as any groundwater traveling along this conduit will experience an increased contact time with the reductive ZVI media, resulting in enhanced dechlorination of VOCs in groundwater entering the LAZ.

4.2 ZVI-PRB cVOC Degradation

Effectiveness of the ZVI-PRB technology is demonstrated best by the in-wall monitoring well TCE results. East of the ZVI-PRB, UAZ TCE concentrations remain elevated, with a 1Q24 maximum of 499 µg/L (PRW003DL) and a maximum background concentration of 3,260 µg/L (P003L). The only 1Q24 in-wall TCE detection above the PQL was 4.44 µg/L at PIW003D, which demonstrates greater than 99% reduction in groundwater concentration from 499 µg/L. Across the entire ZVI-PRB, the reduction of TCE in the UAZ, based on average 1Q24 concentrations of monitoring wells east of the ZVI-PRB (179.8 µg/L) and of in-wall monitoring wells (1.86 µg/L; used PQL for non-detects), equates to an estimated TCE reduction of ~99%. This supports a mass flux reduction greater than the RAO of 80%, although there is uncertainty associated with a mass flux estimate since flow is difficult to directly measure across the entire ZVI-PRB cross-sectional area. TCE concentrations have varied around the MCL at PIW003D from 2Q23 to 1Q24, from a low of 1.71 µg/L in third quarter of 2023 and a high of 7.90 µg/L in 4Q23, to 4.44 µg/L in 1Q24. Out of the four in-wall monitoring wells, PIW003D is screened within the zone of highest contamination based on PDI soil concentrations (Figure 6 and Table 2).

Overall, TCE concentrations are decreasing in UAZ monitoring well clusters west of the ZVI-PRB (Figure 11, Figure 12, and Figure 13). Excluding monitoring wells PRW004DU, PRW004DL, and

PRW007DL, TCE concentrations have decreased in all western UAZ monitoring wells since installation of the ZVI-PRB. At the PRW004 monitoring well cluster, TCE rebounds are observed. TCE concentrations in PRW004DU increased following the 1Q22 sampling event from below MCL (5 µg/L) to 15.2 µg/L in second quarter of 2022 (2Q22) and continued increasing to a maximum of 33.1 µg/L in 2Q23. The last three quarters have showed a decrease with a 1Q24 result of 10.4 µg/L. PRW004DL initially decreased to a non-detection in 2Q20, then increased gradually to 72.5 µg/L in 1Q22 before decreasing to 3.10 µg/L in 1Q23. TCE has rebounded again at PRW004DL in the last three quarters, with a 1Q24 result of 101 µg/L. The rebound observed at both wells was potentially due to the back-diffusion of TCE out of low permeability sediments and into the clean groundwater front leaving the ZVI-PRB, an expected condition discussed in Section 3.2.2. Back diffusion of TCE from the low-permeability sediments will ultimately aid in reduction of cVOCs in groundwater migrating to the distal area of the plume.

Monitoring well cluster PRW006 is located further from the ZVI-PRB than the other western monitoring well clusters. PRW007 monitoring wells are ~12.2 m (40 ft) from the ZVI-PRB centerline, which is double the distance of the other monitoring well clusters. The small increase in distance may be enough for back diffusion to slow the observed decrease in TCE concentrations. This is evidenced by the in-wall monitoring wells PIW003D and PIW004D demonstrating almost complete TCE degradation, while PRW007DU and PRW007DL continue to present appreciable TCE concentrations. TCE concentrations at PRW007DU have a gradual decreasing trend since ZVI-PRB construction, with a 1Q24 result of 281 µg/L.

Similarly, PRW006 monitoring wells, located ~36.6 m (120 ft) from the ZVI-PRB (~36.6 m [120 ft]) have had delayed effect, likely due to back-diffusion. Recent TCE results at the PRW006 monitoring well cluster do suggest reduced concentrations (Figure 13). The 1Q22 result was 4.59 µg/L, while the 1Q23 and 1Q24 results were 1.70 µg/L and 1.81 µg/L, respectively. Similarly, monitoring well PRW006DL has showed a decreasing trend from 267 µg/L in 3Q20 to 70.0 µg/L in 1Q24.

Reductive dechlorination by-products, chloride and ethylene, were included in the ZVI-PRB sampling. For P002U, the parent and daughter products of reductive dechlorination are plotted over time in Figure 18. P002U was chosen because it is located in close proximity west of the ZVI-PRB and depicts the best example of expected trends. Chloride concentrations increased following ZVI-PRB

completion but have maintained a gradually decreasing trend since 3Q20. An increase in chloride is expected with dechlorination of cVOCs, however the immediate and sharp increase observed may be more related to injection of sodium chloride during ZVI-PRB construction. Ethylene increased slightly from baseline to 1Q20, however a change in available laboratory for dissolved gas analyses led to an elevated MDL (25 µg/L and above) in all results from 2Q20 to 4Q22. Starting in 1Q23, lower ethylene MDLs were able to be achieved by the laboratory in order to get meaningful results. The only UAZ location with ethylene results above the PQL from 2Q22 to 4Q22 was PIW003D. With the lower MDL achieved, all monitoring wells had detectable results in 1Q24. At P002U, the 4Q23 and 1Q24 ethylene results were above the MDL with estimated results 1.1 µg/L and 1.6 µg/L, respectively. PIW003D also remained elevated with a 1Q24 result of 39.2 µg/L. The elevated ethylene result for in-wall monitoring well PIW003D indicates reductive dechlorination by the ZVI-PRB, primarily in the well within the highest zone of TCE contamination (Figure 6).

4.3 ZVI-PRB Health and Longevity

In literature and studies of past ZVI-PRB installations, it was noted that the presence of some geochemical analytes in large concentrations can lead to precipitation within a ZVI-PRB, as well as coating of ZVI media resulting in reduced reactivity, known in literature as passivation (He, Wilson, and Wilkin 2008; Gu et al. 2001; Ritter 2000). Specific analytes of interest include, but are not limited to, sulfate, calcium, and nitrate.

Influent concentrations and concentrations within the ZVI-PRB are believed to be low enough to conclude that precipitation and/or passivation of the ZVI-PRB is not a concern (Battelle 2002; Yabusaki et al. 2001; Wilkin, Puls, and Sewell 2003; Gu et al. 2001). Influent concentrations shown to cause short term effects on performance were sulfate concentrations above 1,000 mg/L and nitrate on the order of 120 mg/L. In addition, a treatability study was conducted prior to ZVI-PRB installation to verify the geochemistry of the site groundwater and subsurface would not result in a significant loss in ZVI-PRB performance (SRNS 2019). The following conclusions were made from the treatability study results:

- Geochemistry of site groundwater, site soils, and ZVI material are favorable for extended long-term performance;

- No observation of mineral precipitation causing loss in reactivity towards cVOCs; and
- No expectation of precipitation/clogging causing a significant loss in permeability, and therefore performance.

Based on the results of the treatability study and observations of other ZVI-PRB applications (SRNS 2019), the longevity of the ZVI-PRB is expected to be at least 25 years, maintaining effectiveness and sufficient performance to meet the RAO.

Calcium concentrations have increased significantly, from a maximum UAZ baseline of 4,810 ug/L to a 1Q24 maximum of 76,200 µg/L for in-wall monitoring wells. The significant spike in calcium concentration is most likely related to the amount of grout used to complete the injection wells for ZVI-PRB construction. There were 22 injection wells installed to construct the ZVI-PRB, with all of the annulus space filled with grout to ensure the specialized expansion casings propagated the ZVI fractures correctly. This quantity of grout cement is likely to leach calcium due to the high pH levels created by the ZVI. The volume of grout used accounts for only 1.48% of the total volume of ZVI injected, therefore the performance of the ZVI-PRB is not anticipated to be impacted by the resulting calcium levels. Monitoring of changes in the calcium concentrations will continue for the ZVI-PRB to assess health of the ZVI-PRB, as calcium can precipitate out and result in a loss in ZVI-PRB porosity, and therefore reduce contact time with cVOCs.

4.4 ZVI-PRB Reducing Environment

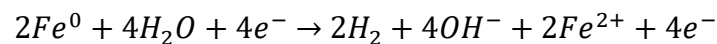
Within the ZVI-PRB, reducing conditions are evidenced by high negative ORP values between -345 and -312 mV in 1Q24. Baseline ORP results in the UAZ ranged from +124 to +428 mV. The results indicate the conditions within the ZVI-PRB has flipped from an oxidizing environment to a reducing environment. The highly reducing environment created by the ZVI promotes reductive dechlorination of cVOCs entering the ZVI-PRB.

The flip to reducing conditions in the aquifer support natural reductive dechlorination of cVOCs by microbial degradation as the anaerobic conditions extend out from the ZVI-PRB. However, the natural presence of anaerobic microbial species which degrade cVOCs is not guaranteed. General conditions that can support anaerobic microbial activity capable of cVOC degradation include:

- Depleted DO, nitrate, and sulfate
- Elevated ferrous iron, manganese, methane, ethylene, ethane, chloride, and alkalinity
- Negative ORP
- Substrate availability (TOC/DOC concentrations)
- Presence of cVOCs
- pH range between ~6-8

Based on the results from 1Q24 sampling, evidence exists of conditions in the vicinity of the ZVI-PRB that may support further microbial degradation of cVOCs (i.e., reducing conditions, increasing and/or elevated TOC and methane). However, the focus of this RA is abiotic degradation of cVOCs by ZVI reactions and microbial degradation is not required to meet the RAO. Abiotic reductive dechlorination via interaction with ZVI is supported by the multiple lines of evidence presented in this report, however, there is not clear evidence of microbial degradation of cVOCs. The buildup of methane and potential microbial activity is not believed to play a significant role in cVOC degradation or to result in any performance reduction of the ZVI-PRB at this time.

The reducing conditions created by the ZVI also result in alkaline groundwater (pH > 9.5) as evident by the in-wall monitoring wells. West of the ZVI-PRB, pH remained within a range of 4.7 to 6.6 in the UAZ, consistent with baseline pH values. The primary source of elevated pH levels in the anoxic conditions of the ZVI-PRB is associated with the reaction of ZVI and water:



Secondary to this process, when considering leaching of the cement grout used to construct the injection wells could also be contributing to the increased pH levels, it appears that the contribution is significantly less when comparing the volume of grout in the injection wells to the volume of ZVI injected. Volumetrically, the total amount of grout for each of the 22 injection wells accounts for only 1.48% of the total ZVI volume injected. Therefore, even though leaching of the grout could be occurring, high groundwater pH is primarily attributed to groundwater interactions with ZVI.

4.5 ZVI-PRB Impact on the LAZ

The ZVI-PRB design intended injection wells to key into the TCCZ as a means of hydraulic control, however the potential for penetration into the LAZ was recognized and therefore LAZ monitoring was retained in the EMP.

Groundwater elevation measurements and potentiometric surface mapping for the LAZ indicate there is not a significant impact from the ZVI-PRB (Figure 14). Changes to the groundwater flow direction in the vicinity of the ZVI-PRB are believed to be due to natural variations in local groundwater elevations. The LAZ groundwater flow direction at the ZVI-PRB is more northerly based on the 1Q24 potentiometric surface, and therefore groundwater flow does not intersect the ZVI-PRB, but instead flows parallel.

Monitoring results for TCE in the LAZ indicate a decrease in concentrations since installation of the ZVI-PRB, with TCE decreasing from a baseline maximum of 664 µg/L to a 1Q24 maximum of 37.8 µg/L. The drop in TCE concentrations, combined with the flip in ORP values from high positive to negative (-284 mV to -28 mV in PRW001C to PRW004C), are indications of the ZVI-PRB impacts on groundwater geochemistry in the LAZ. The observed impacts to the LAZ at this time are positive, demonstrating TCE degradation, which was not expected from the ZVI-PRB since it was primarily designed to target the UAZ. This is further supported by significant 1Q24 ethylene concentrations in PRW001C and PRW002C of 102 µg/L and 38.3 µg/L, respectively. Ethylene concentrations at this level are a strong indicator of reductive dechlorination.

Effects on the LAZ will continue to be monitored in future reporting.

5.0 SUMMARY AND RECOMMENDATIONS

The PAGW OU NTC RA was completed in January 2020 with the construction of an 80.5 linear meter (264 linear feet) long ZVI-PRB, designed to intersect groundwater flow in the UAZ of the UTRA to degrade cVOCs, primarily TCE. The RAO for the PAGW OU NTC RA is to protect human health and the environment by reducing the mass and down-gradient transport of the PAGW OU TCE groundwater plume. A TCE mass flux reduction of 80% was determined to be sufficient to meet the RAO.

After three years of effectiveness monitoring of ZVI-PRB performance, the effectiveness in the immediate vicinity of the PRB is highlighted by the following results:

- Groundwater elevation data and potentiometric surfaces for the UAZ and LAZ indicate that the ZVI-PRB is having minimal impact to groundwater flow, as it was designed. Therefore, there is no indication that contaminated groundwater is by-passing the ZVI-PRB.
- In-wall monitoring well results indicate a TCE concentration reduction greater than 99% is achieved and an estimated TCE mass flux reduction across the entire ZVI-PRB is greater than the RAO of 80%.
- To the west of the ZVI-PRB in the UAZ, TCE concentrations are overall following a decreasing trend. However, because of back diffusion of TCE into the groundwater front leaving the ZVI-PRB, it will take some time before an overall impact to TCE concentrations can be realized. The 1Q24 data shows the first evidence of impact at the PRW006 monitoring well cluster.
- ORP results for the in-wall wells indicate a strong reductive environment is present, extending to the west in the UAZ monitoring wells. The reductive environment is favorable for promoting additional reductive dechlorination of TCE in conjunction with the abiotic cVOC degradation by emplaced ZVI.
- The installed ZVI-PRB also beneficially impacts the LAZ, evidenced by observed reducing conditions, reduced TCE concentrations, and elevated ethylene concentrations.

In-wall monitoring wells continue to provide the strongest evidence of the ZVI-PRB effectiveness. Results from the in-wall monitoring wells consistently show greater than 95% reduction in TCE concentrations compared to baseline, which supports 80% mass flux reduction to meet the RAO. Analytical results to the west of the ZVI-PRB provide evidence of a reducing environment traveling away from the barrier with groundwater flow. Monitoring results indicate that the ZVI-PRB is impacting cVOC concentrations to the west of the ZVI-PRB with observations of back diffusion apparent in PRW004DL and the PRW007 monitoring well cluster. As more cVOC mass is removed by the ZVI-PRB and clean groundwater flushes out cVOCs adsorbed to the low permeability

sediments, the ZVI-PRB will continue to reach peak optimization. As indicated in the RADP and RAR, this is anticipated to take 3-5 years from ZVI-PRB installation (SRNS 2019 and SRNS 2020). Most recent 1Q24 results west of the ZVI-PRB indicate greater than 80% reduction in TCE concentration compared to baseline is being achieved in all monitoring wells with the exception of PRW007DU, PRW007DL, and in the PRW006 monitoring well cluster. Impact at the PRW006 well cluster is beginning to be apparent, with decreasing TCE levels and degradation by-products observed in the 1Q24 sampling. Impacts in the PRW006 monitoring well cluster are not as significant due to the distance it is located from the ZVI-PRB. Based on the PDI work performed in 2019 in support of ZVI-PRB design, significant cVOC mass was observed entrained in low permeability zones that exist between the ZVI-PRB and the PRW006 well cluster. It will take some time for the mass to diffuse out of these zones and therefore significantly impact the TCE concentrations at this well cluster. No baseline data are available for the PRW007 well cluster because this well cluster was installed post-construction of the ZVI-PRB. Data collected from this well cluster are observed to be low concentrations. When these data are compared to upgradient PRW001 well cluster, it is impossible to discern mass removal between the clusters. This is because the concentrations observed at the PRW001 well cluster are impacted by groundwater reaction with the ZVI and therefore the concentrations are lower than the baseline.

SRS recommends continued analytical monitoring in accordance with the approved EMP for the PAGW OU NTC RA.

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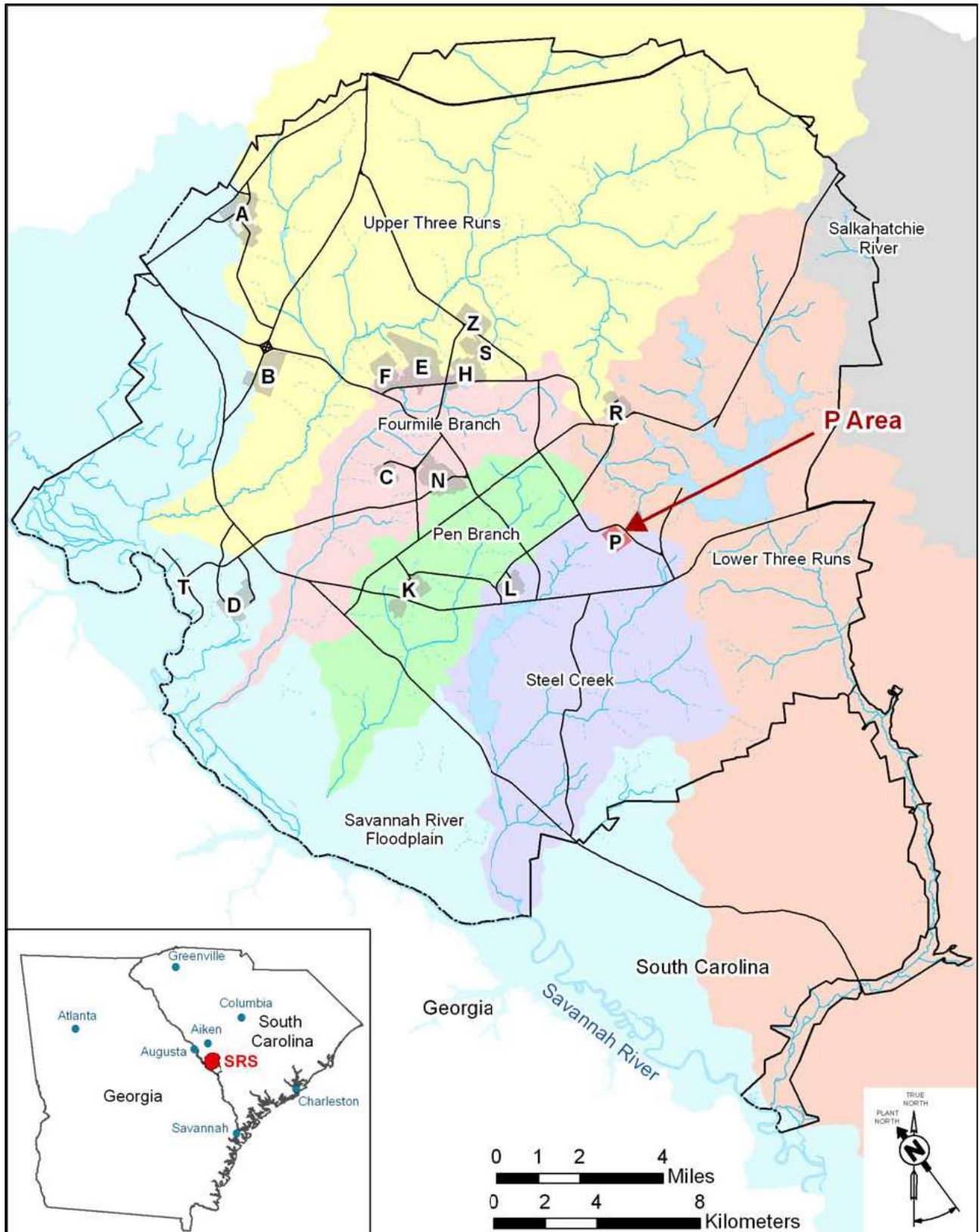


Figure 1. Location of P Area at the Savannah River Site

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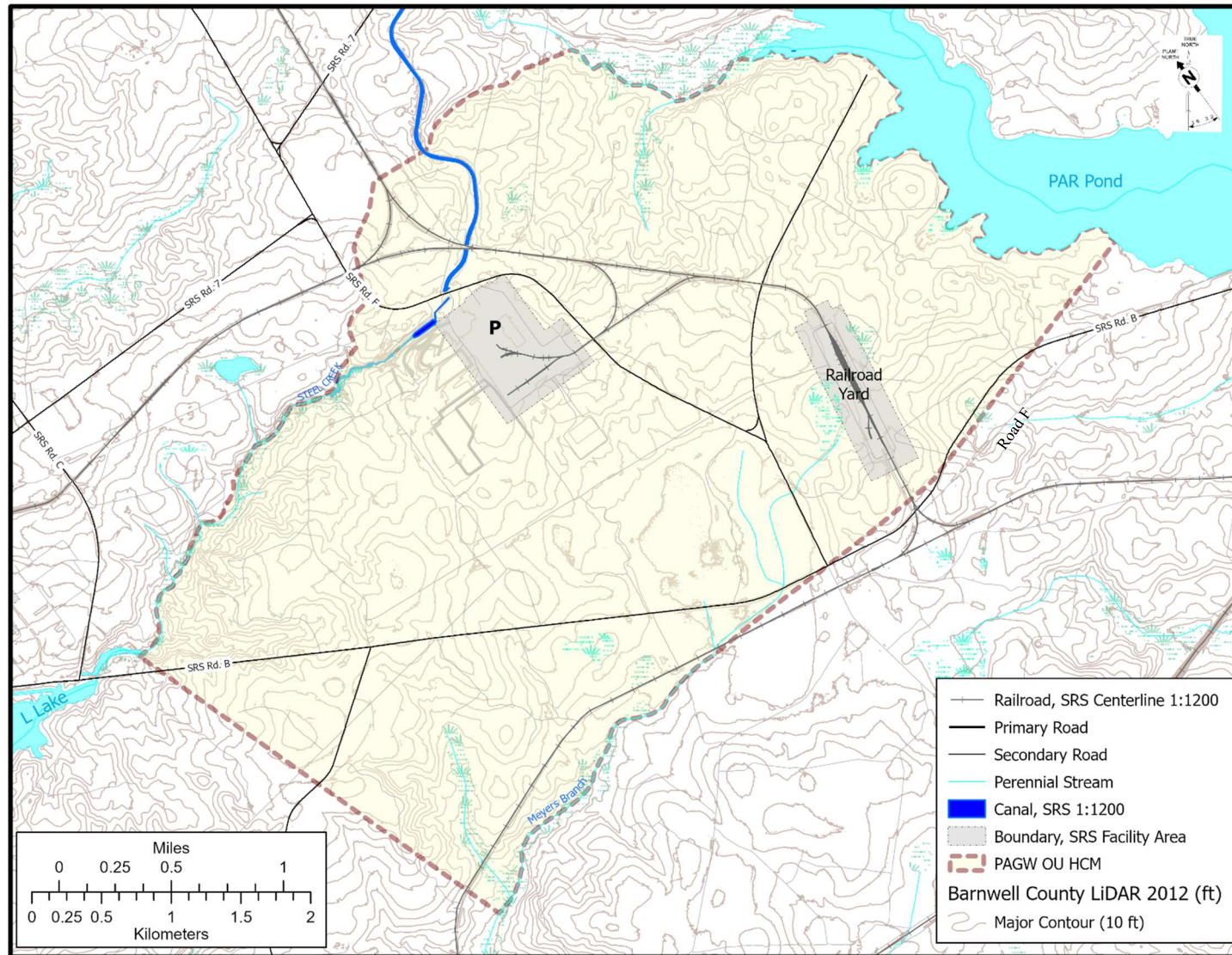


Figure 2. P-Area Groundwater Operable Unit Boundary Map

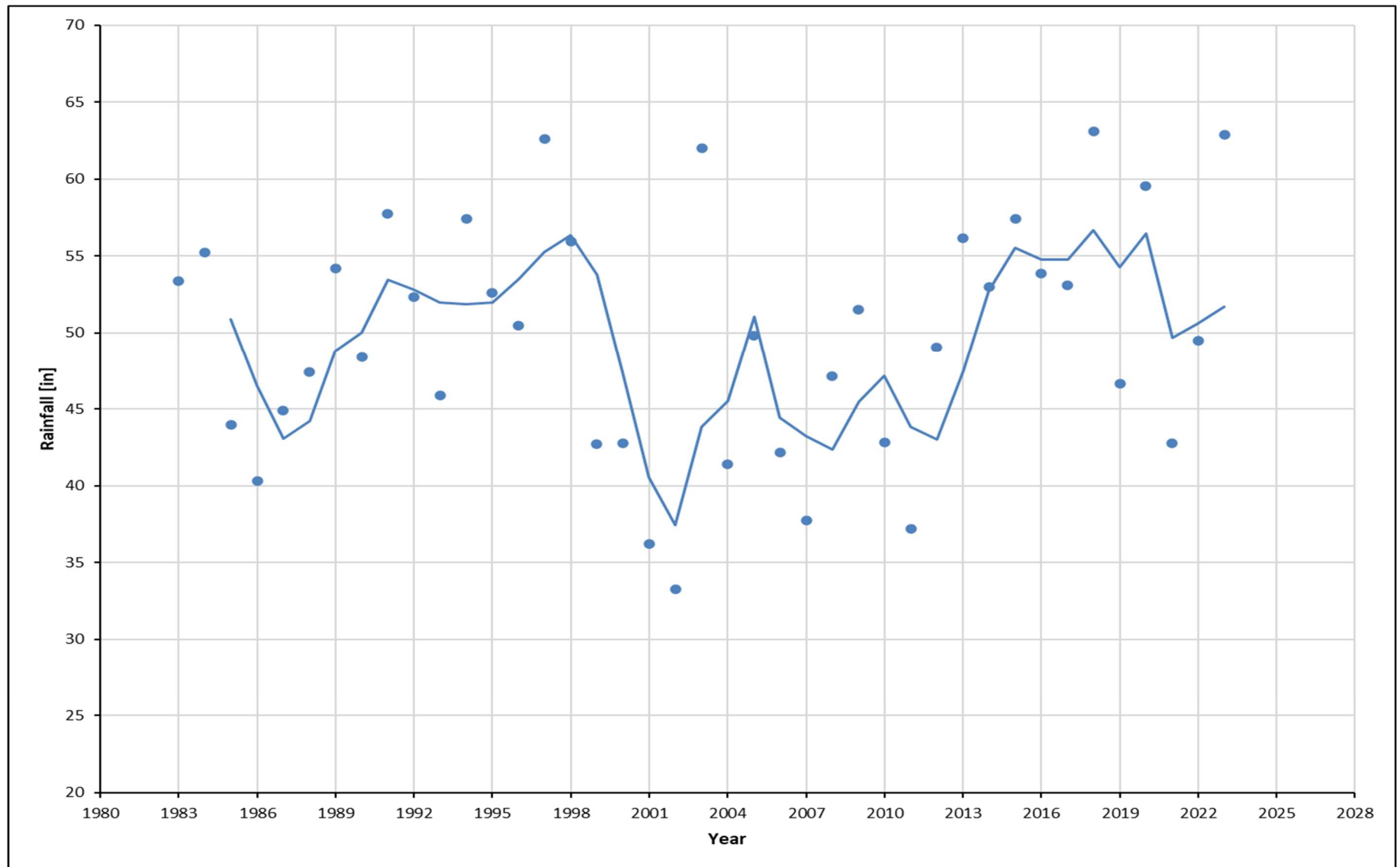


Figure 3. Total Annual Rainfall at 100-P Rain Gauge with a 3-Year Moving Average Trendline

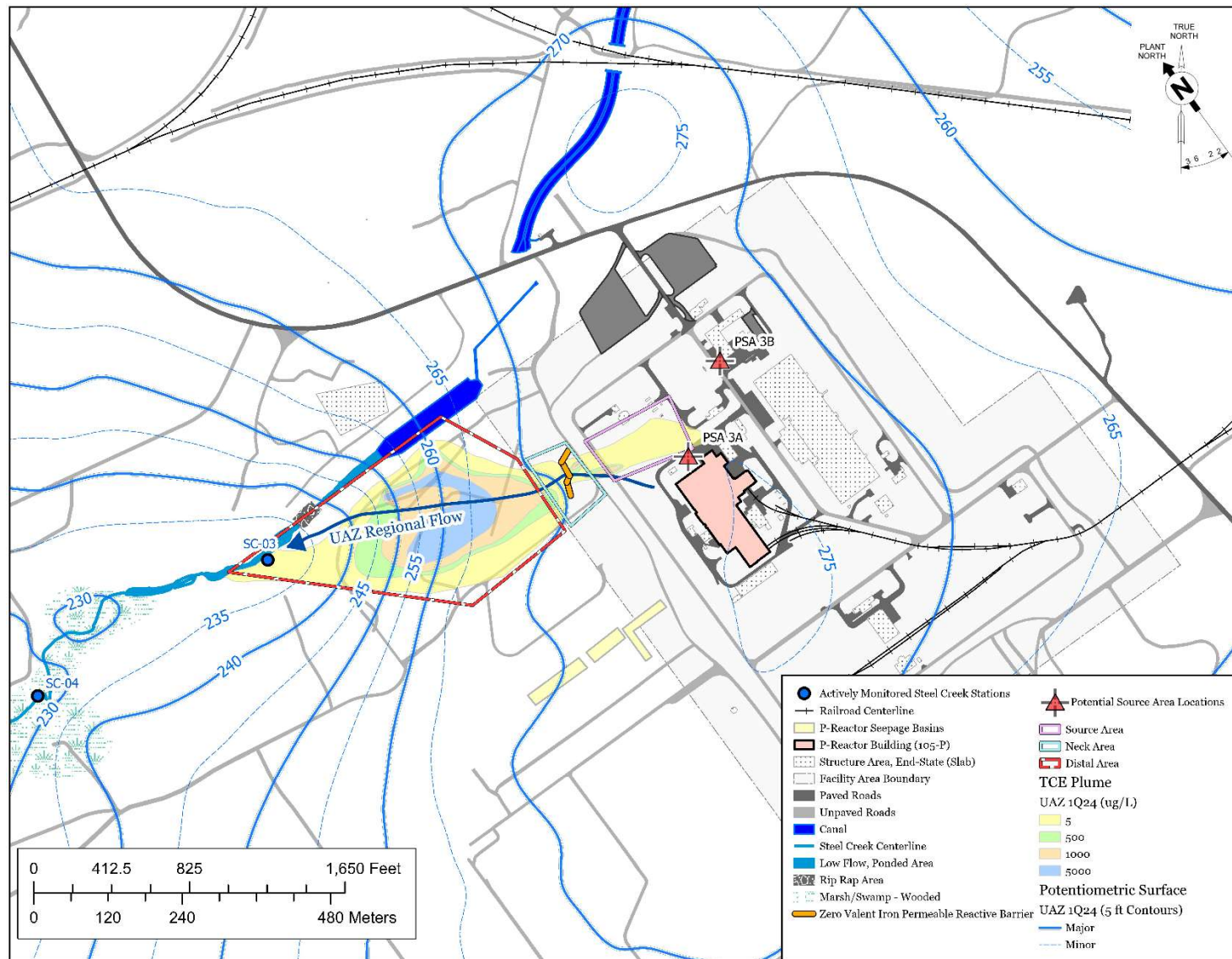


Figure 4. Trichloroethylene Plume Map for the Upper Aquifer Zone of the Upper Three Runs Aquifer (2018/2024 Data)

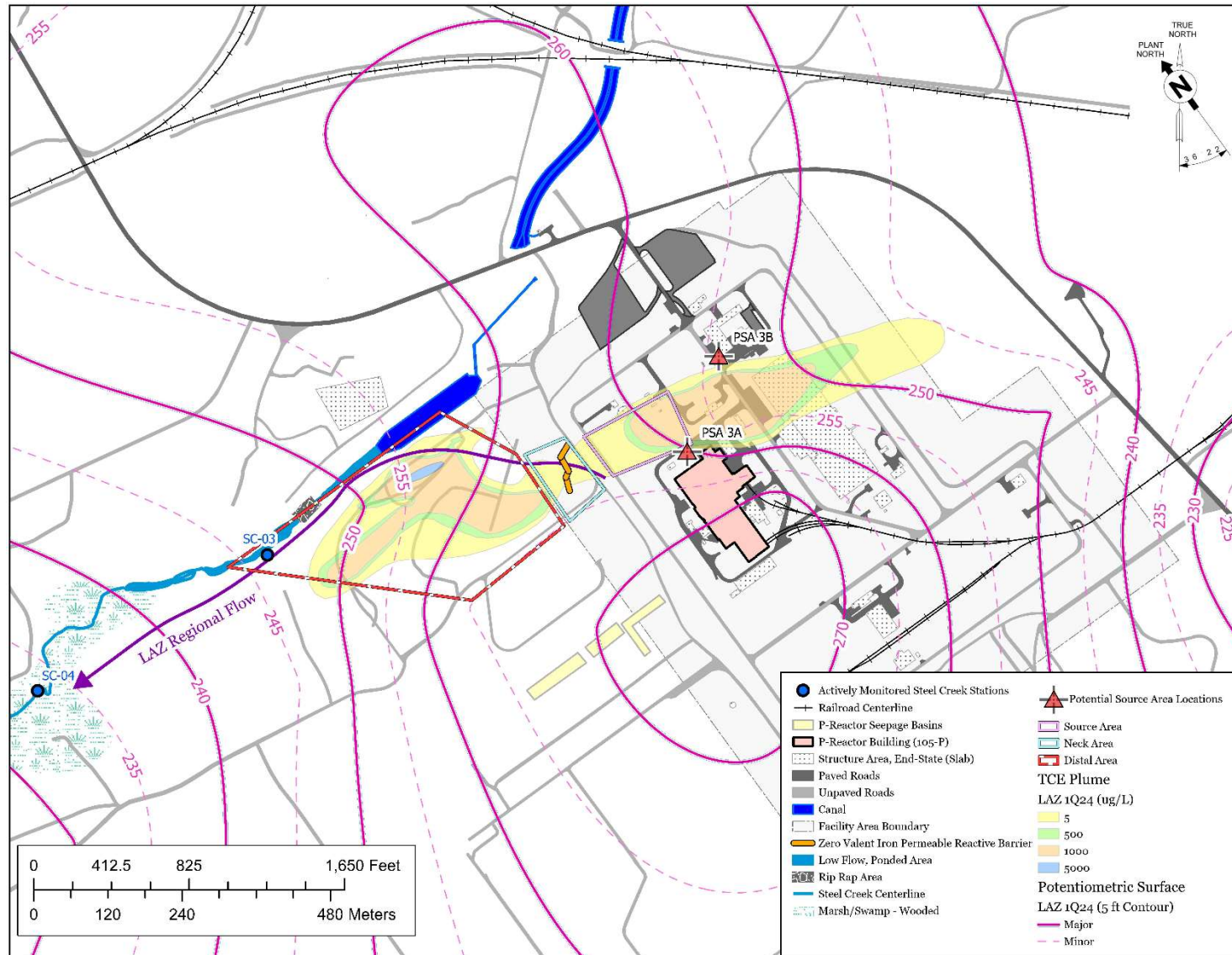


Figure 5. Trichloroethylene Plume Map for the Lower Aquifer Zone of the Upper Three Runs Aquifer (2018/2024 Data)

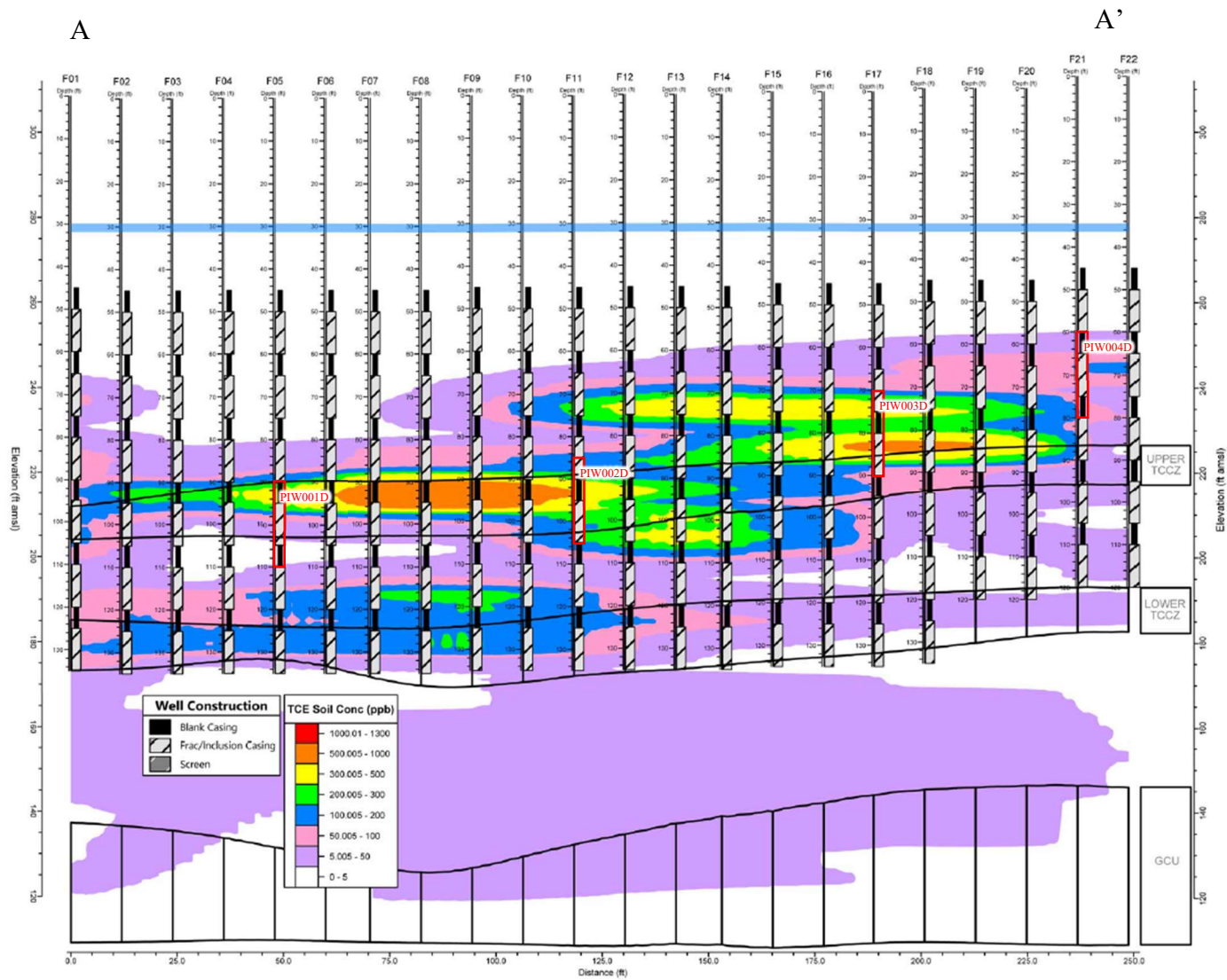


Figure 6. TCE Plume North-South Cross-Section with ZVI-PRB Injection Wells (2020)

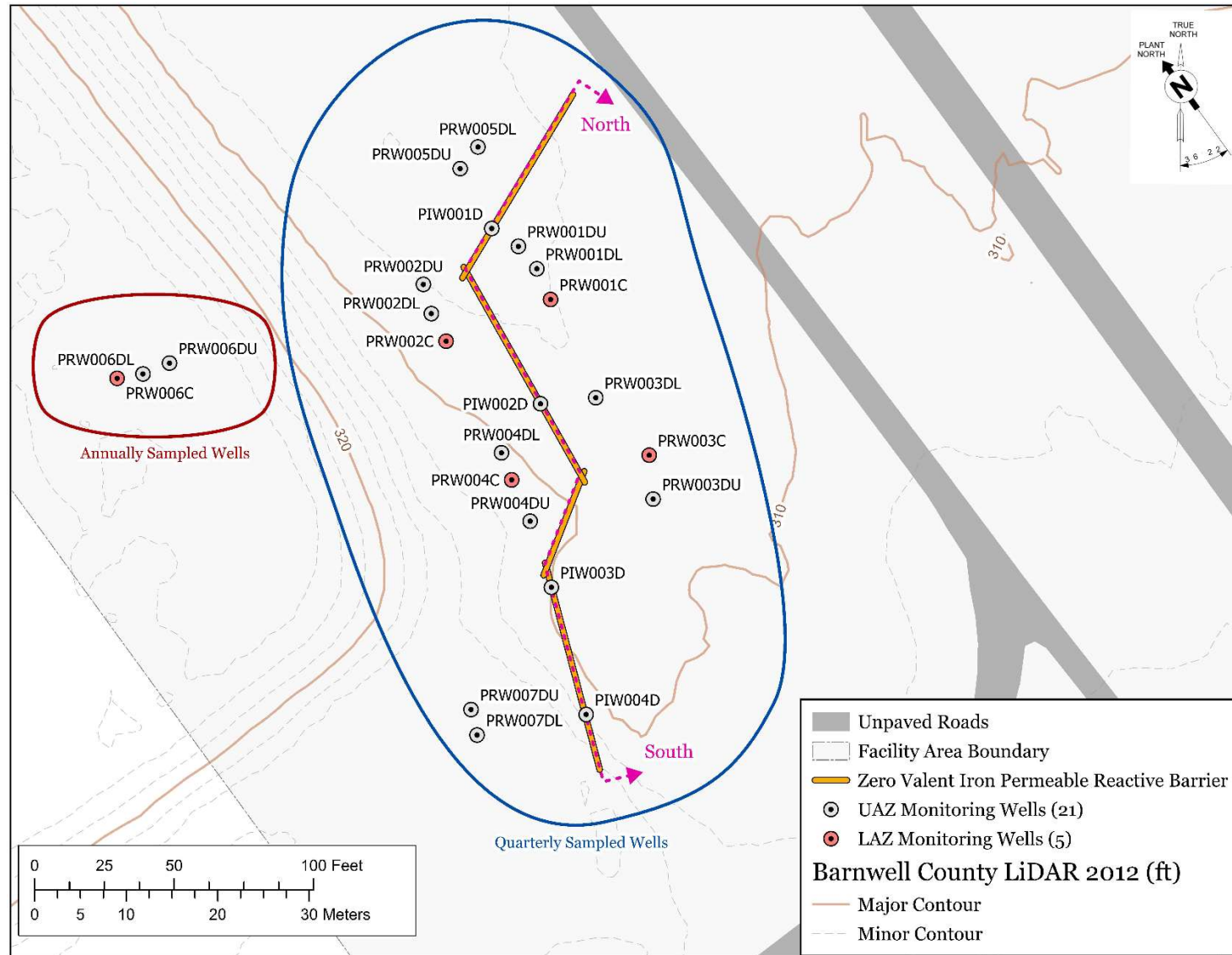


Figure 7. Effectiveness Monitoring Plan Locations

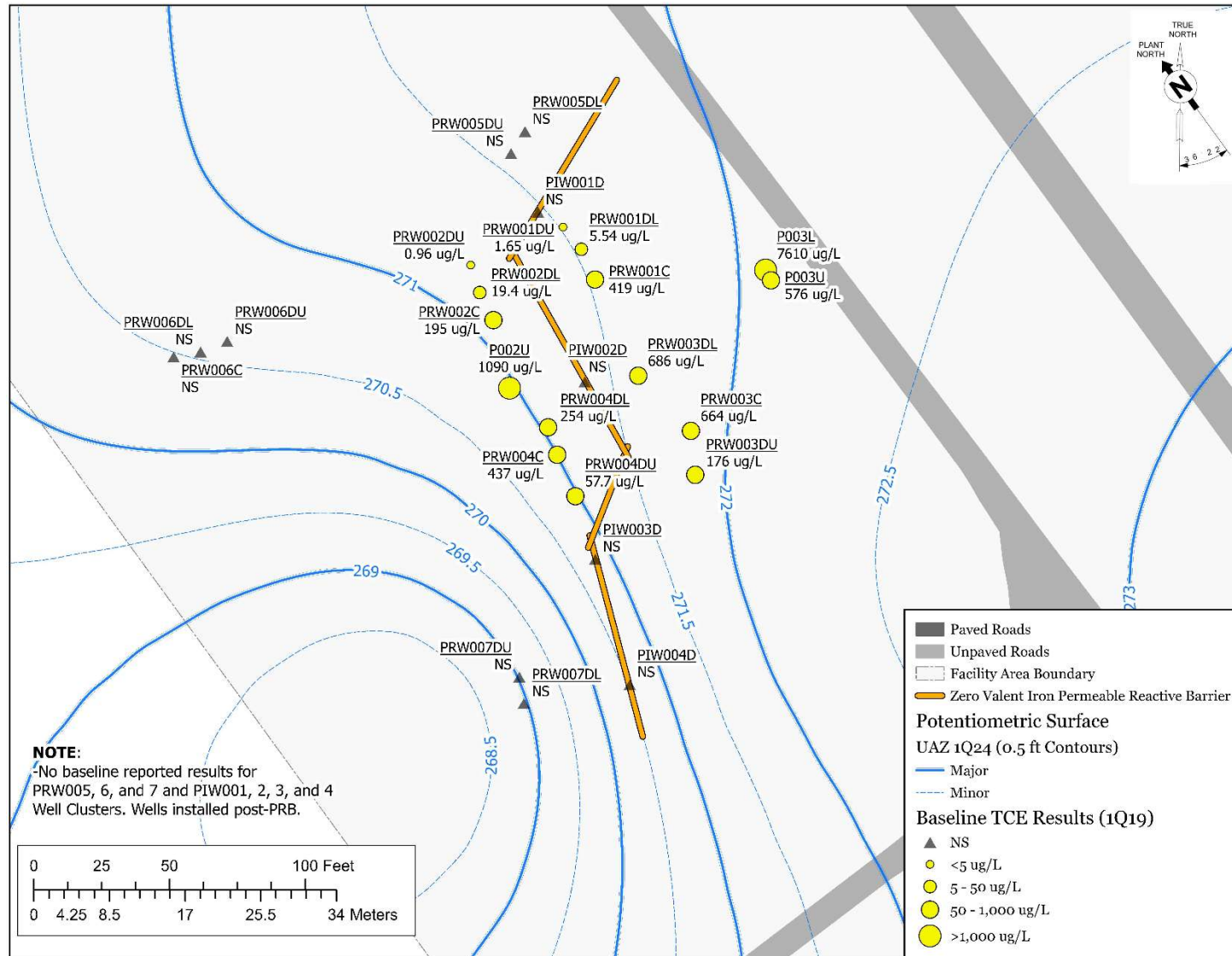


Figure 8. Baseline Concentrations of TCE in the PAGW OU EMP Monitoring Wells

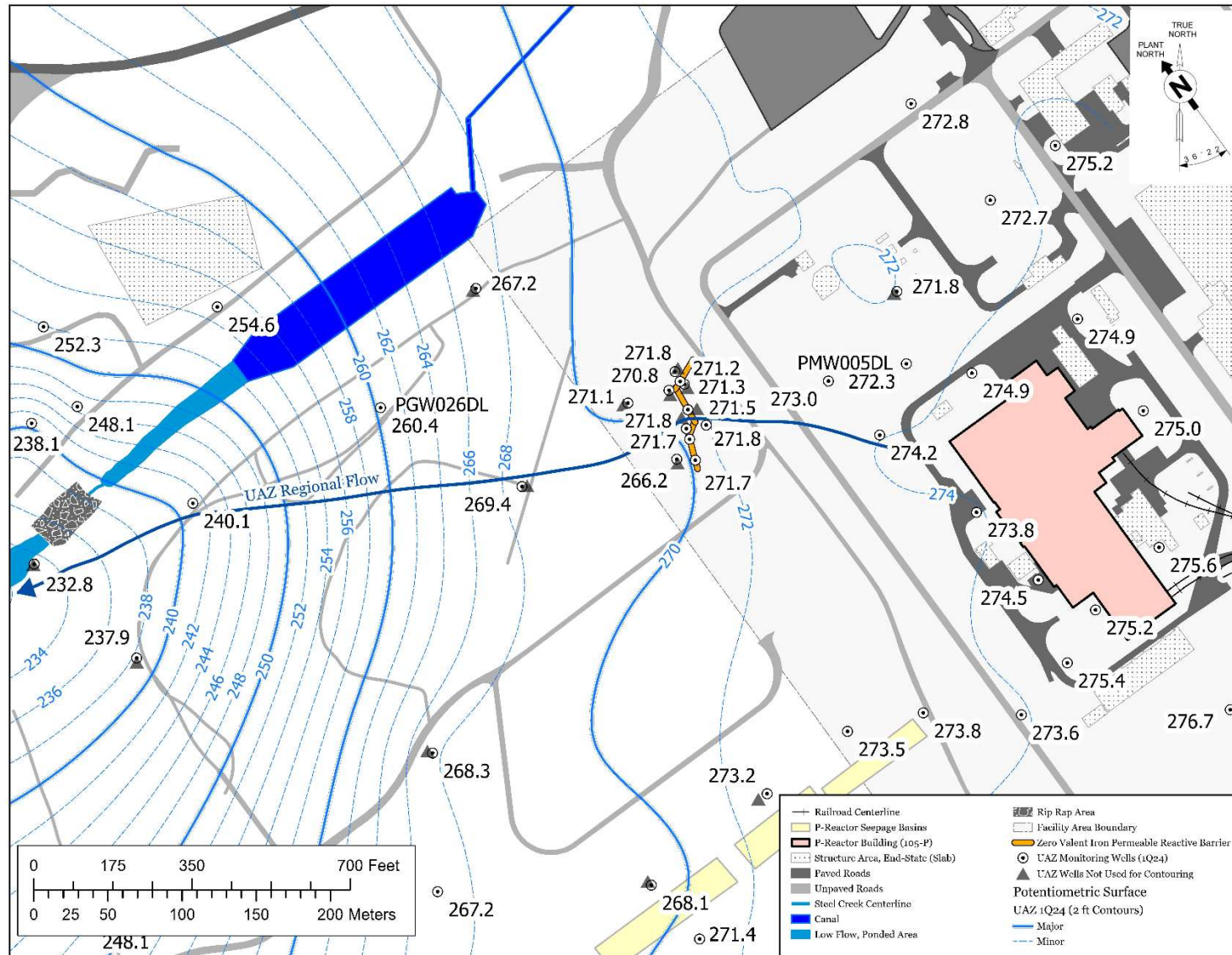


Figure 9. Regional UAZ Groundwater Elevations and Flow Direction (1Q24)

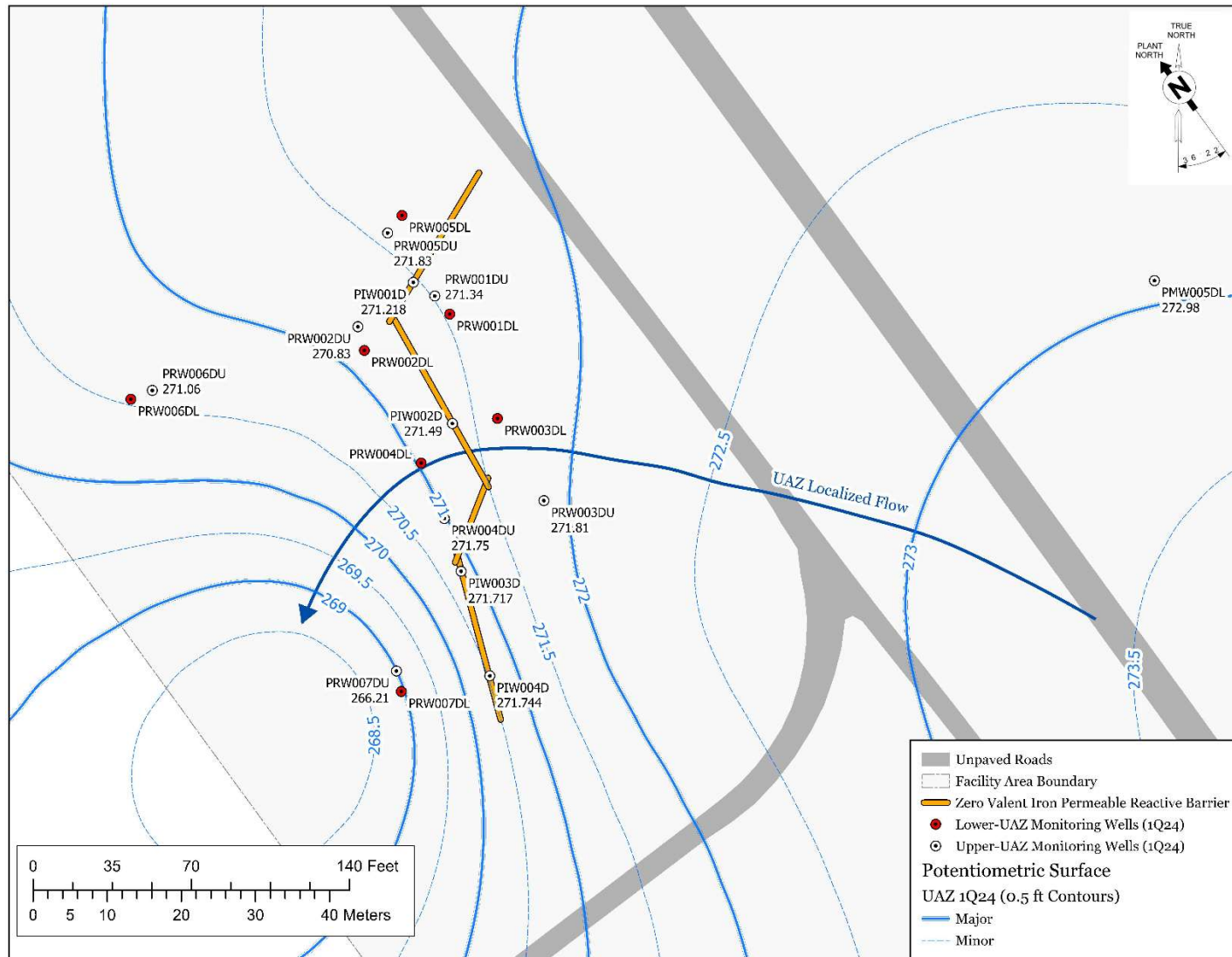


Figure 10. UAZ Water Elevations for 1Q24 at PAGW OU RA EMP Monitoring Wells

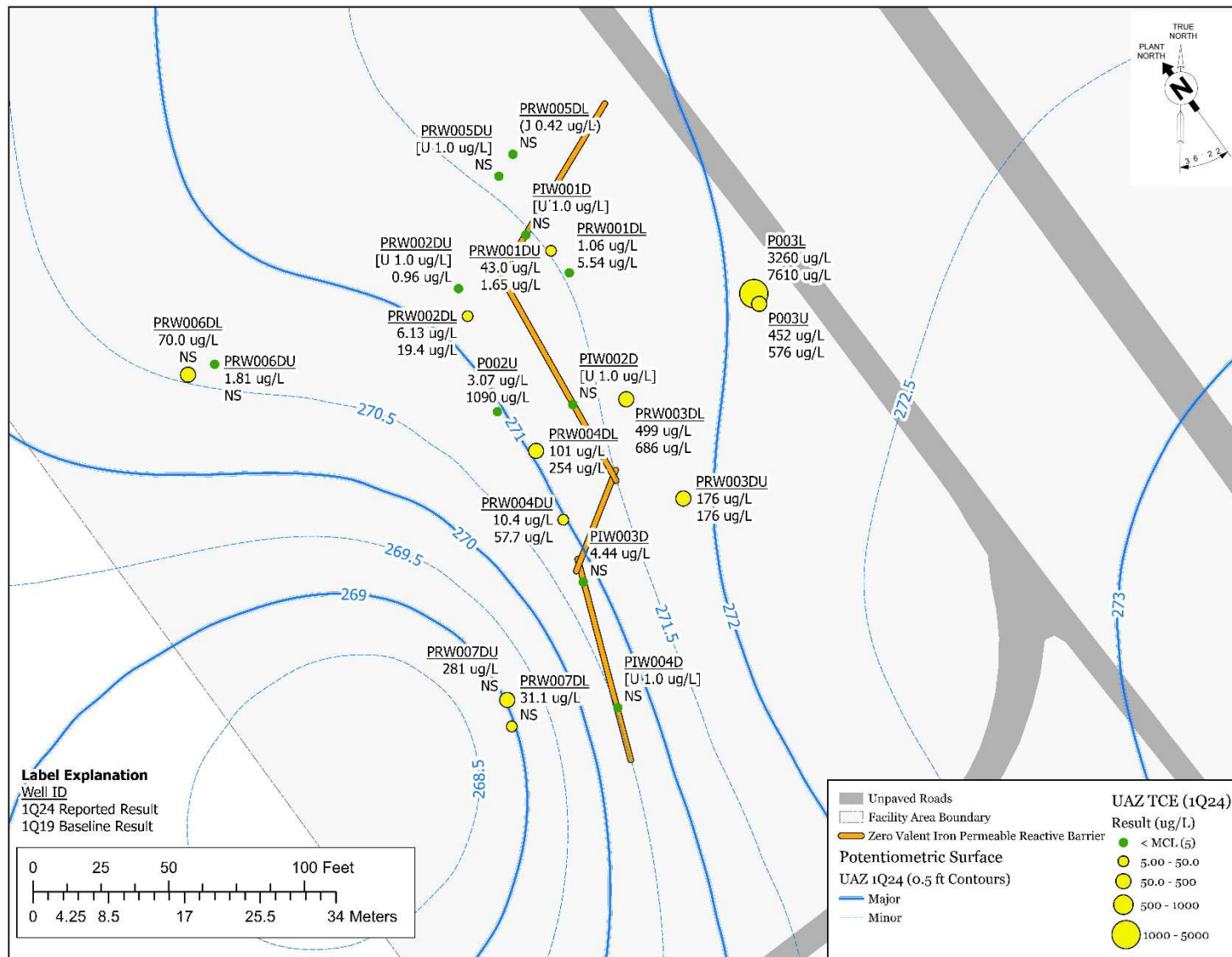


Figure 11. TCE Results for ZVI-PRB UAZ Monitoring Wells Sampled in 1Q24

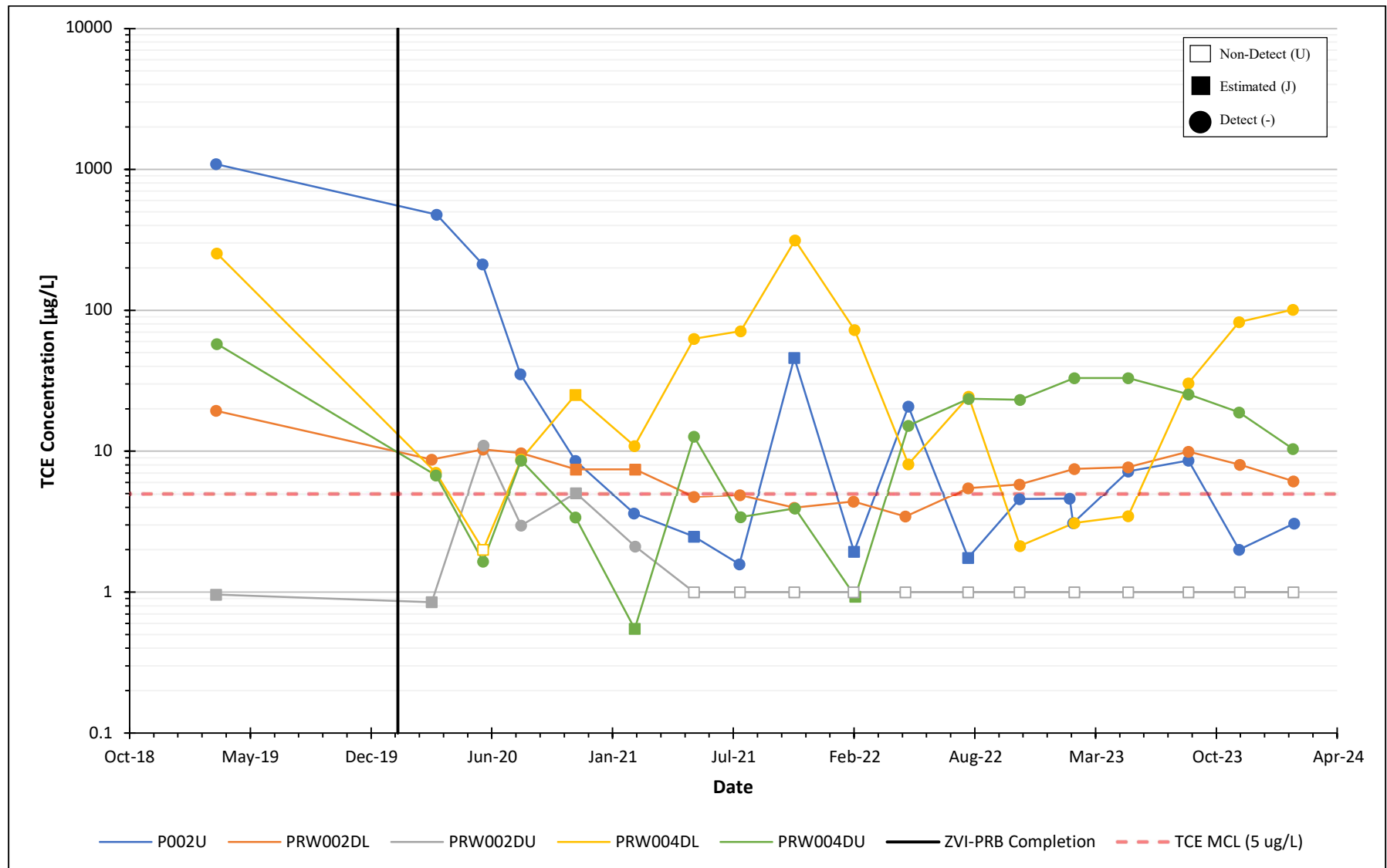


Figure 12. Time-Series Plot for TCE at UAZ Monitoring Well Clusters for P002U, PRW002, and PRW004

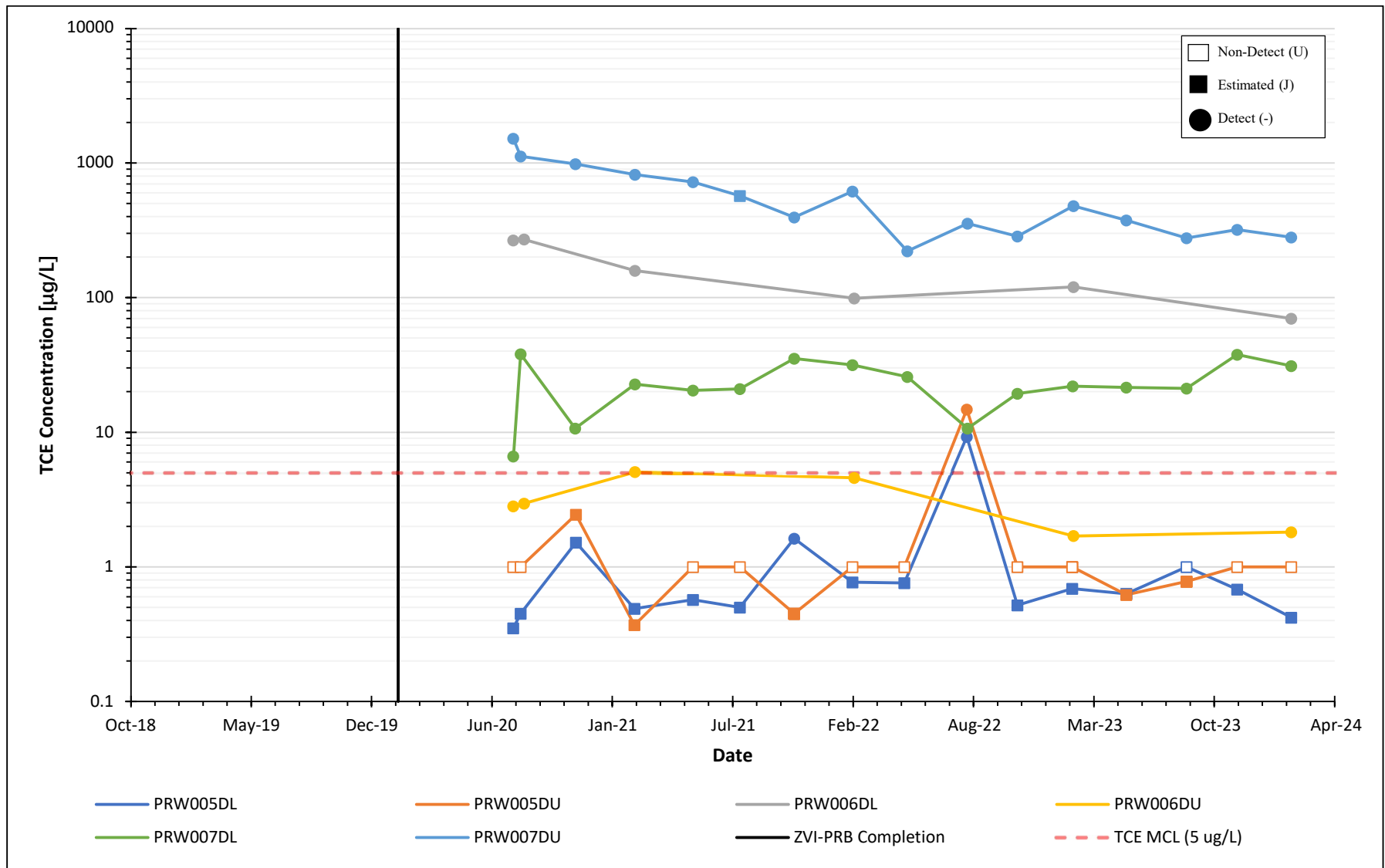


Figure 13. Time-Series Plot for TCE at UAZ Monitoring Well Clusters for PRW005, PRW006, and PRW007

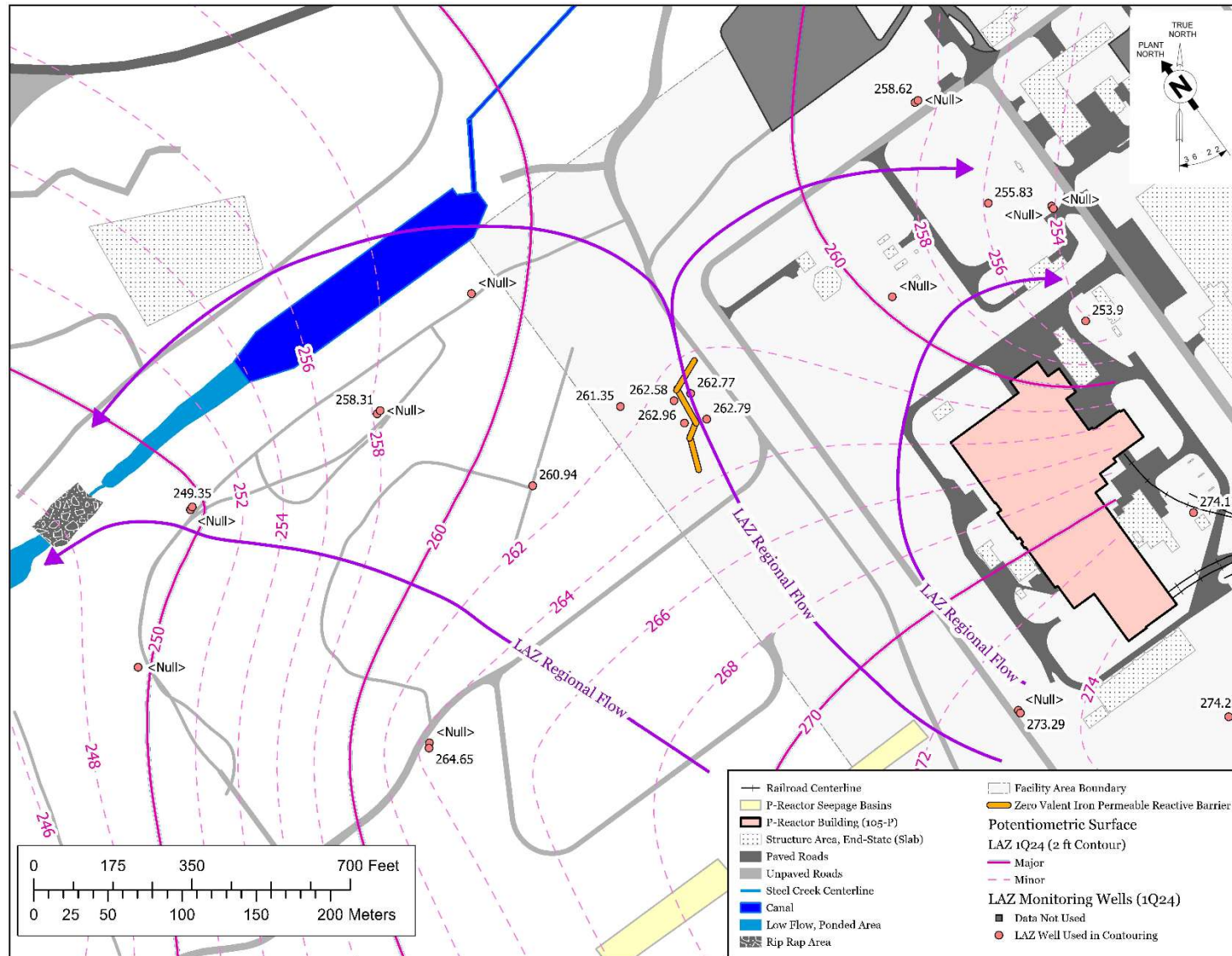


Figure 14. Regional LAZ Groundwater Elevations and Flow Direction (1Q24)

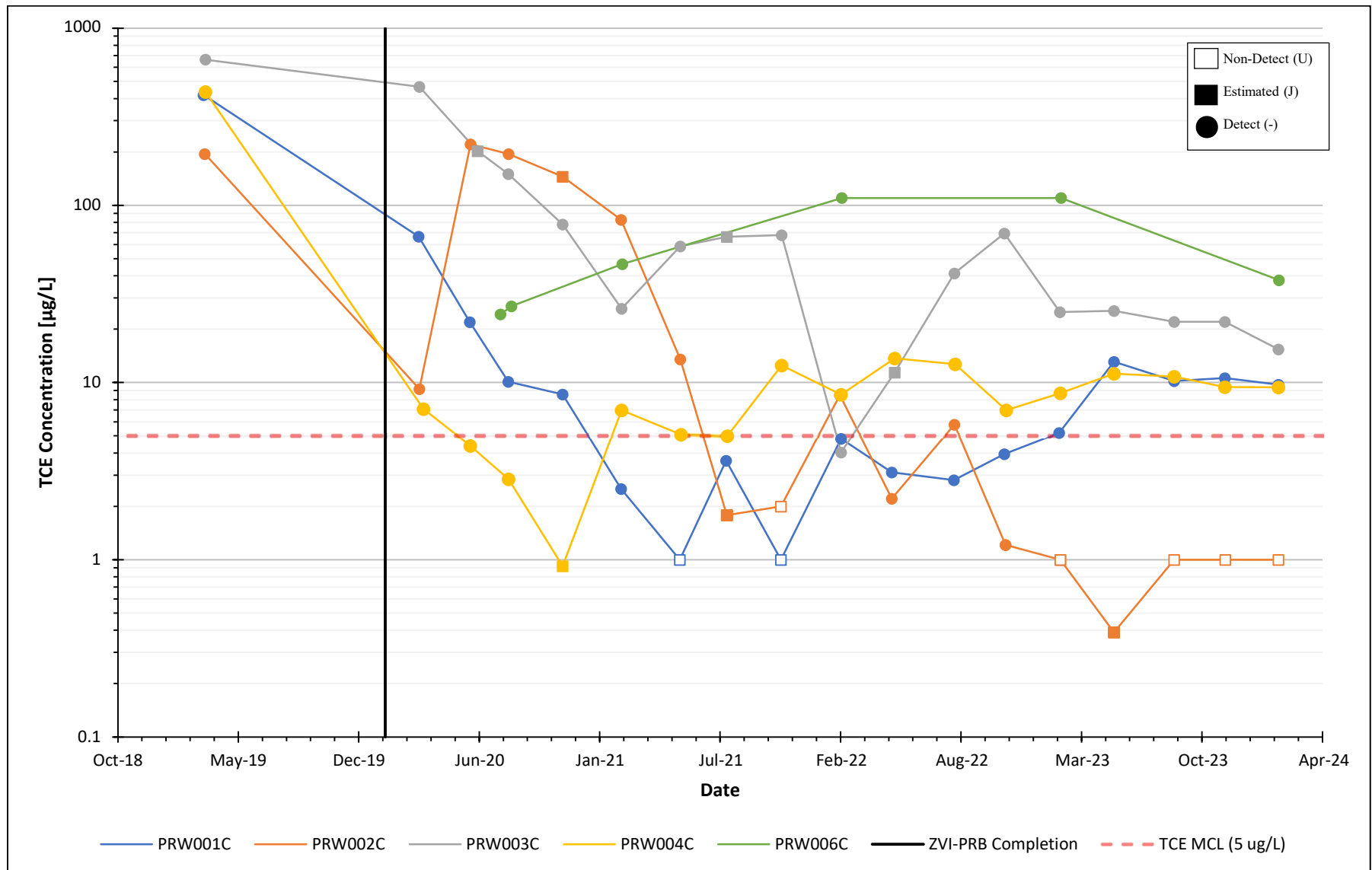


Figure 15. Time-Series Plot for TCE at LAZ Monitoring Wells of the PAGW OU NTC RA EMP

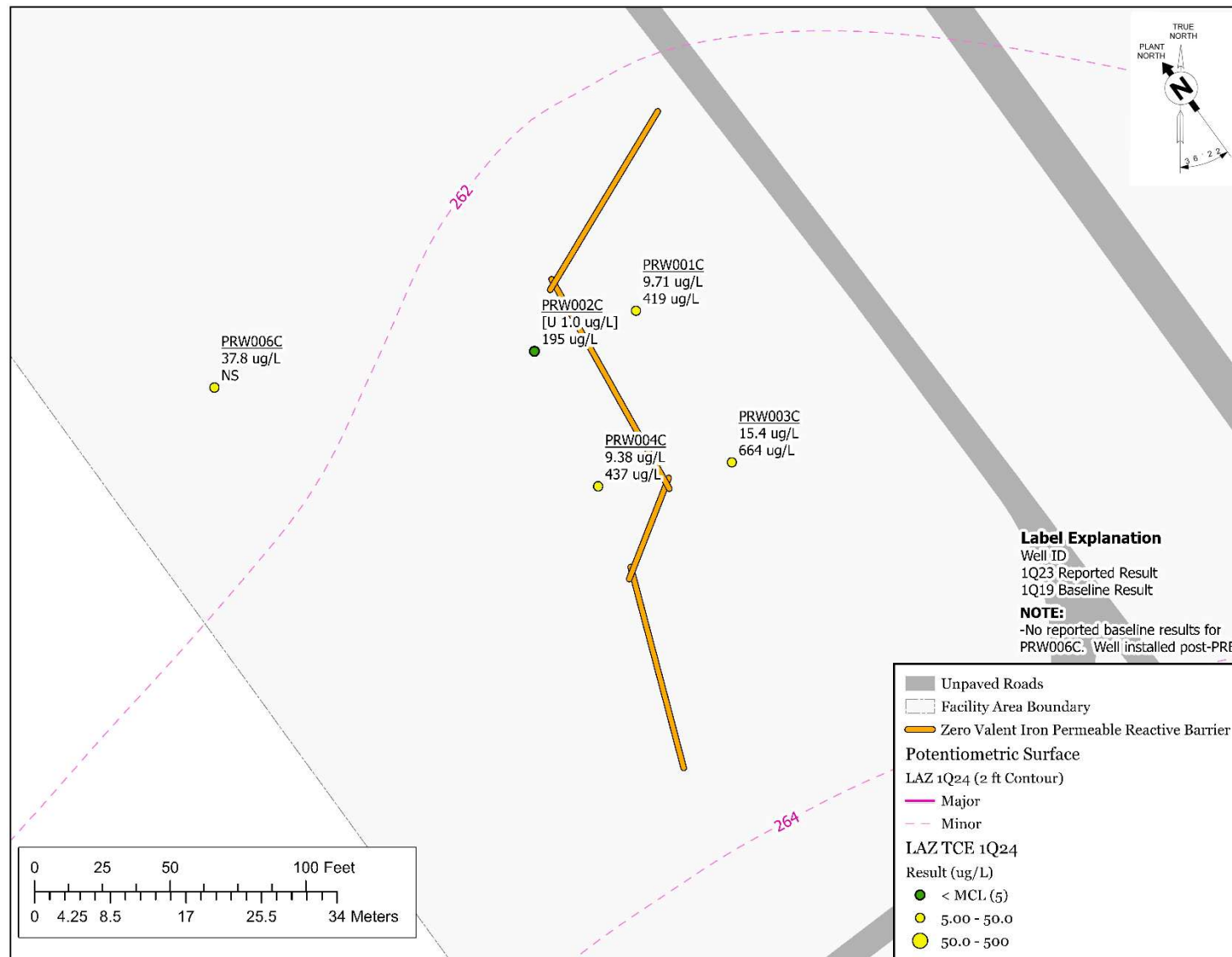


Figure 16. TCE Results for ZVI-PRB LAZ Monitoring Wells Sampled in 1Q24

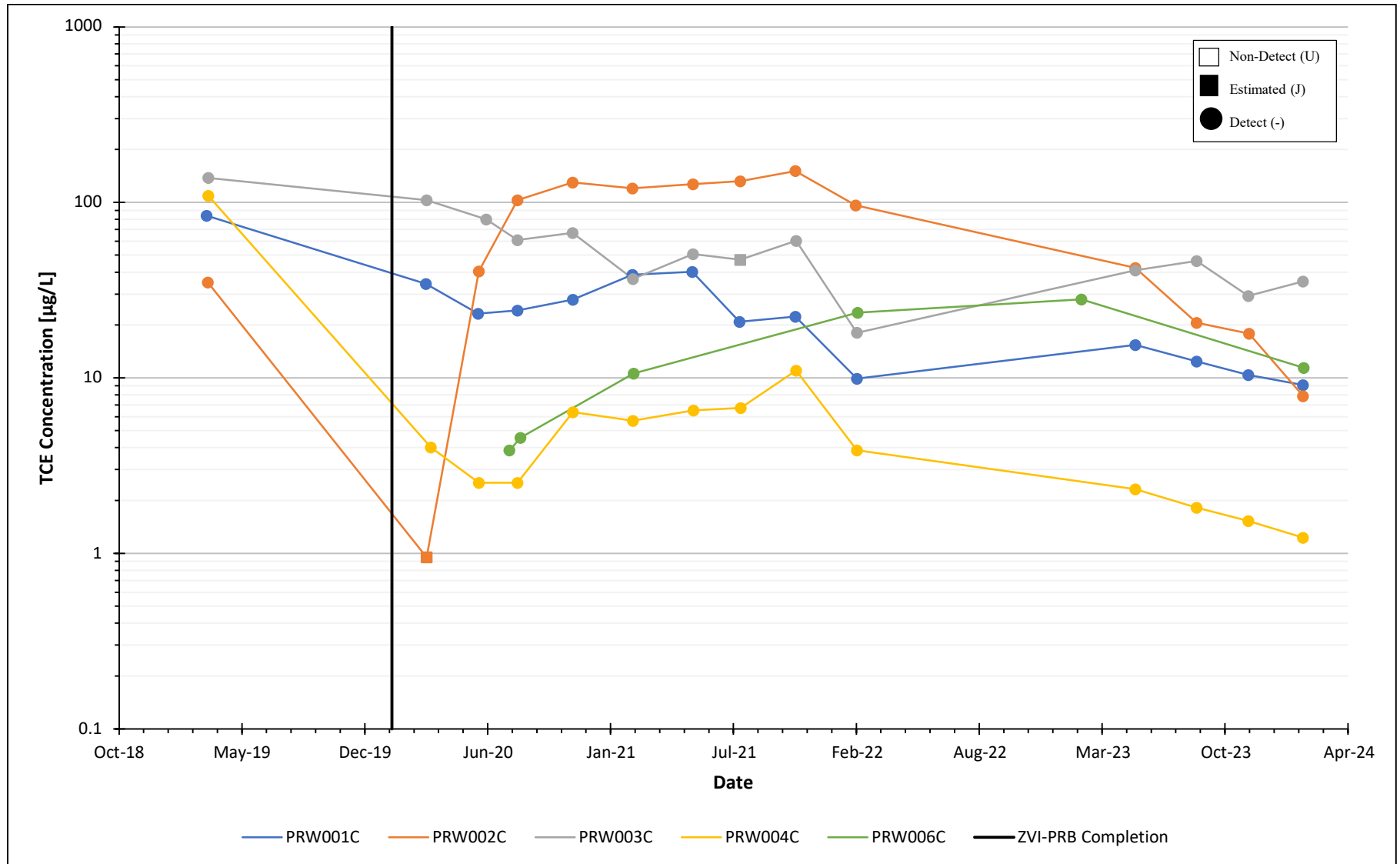


Figure 17. Cis-DCE Concentration Over Time for LAZ Monitoring Wells

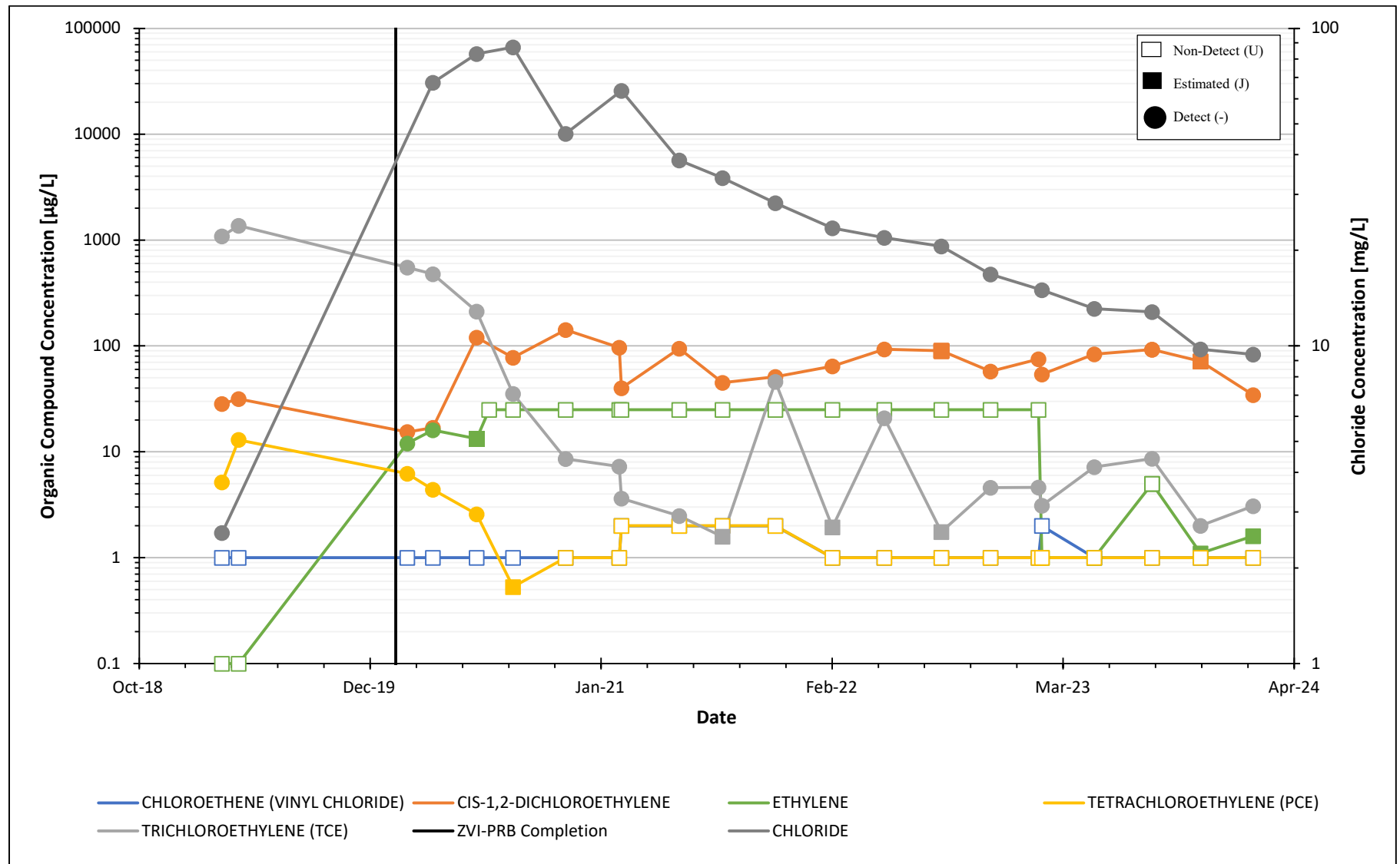


Figure 18. CVOC Degradation at P002U

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Table 1. Maximum Concentrations of PCE, TCE, and cis-DCE in the Three Plume Areas

Contaminant	MCL [µg/L]	Sample Event	Maximum Concentration in UAZ [µg/L]			Maximum Concentration in LAZ [µg/L]		
			Source Area	Neck Area	Distal Area	Source Area	Neck Area	Distal Area
PCE	5	1Q19	80.6	13.0	1.32	4.85	1.77	17
		1Q24	32.4	2.45	13.9	3.39	ND [1.0]	8.66
TCE	5	1Q19	2,150	7,730	6,320	5,180	(791)	5,560
		1Q24	4,480	5,240	4,830	4,180	37.8	5,980
cis-DCE	70	1Q19	195	892	(300)	69.0	138	168
		1Q24	277	532	165	70.2	35.4	122

MCL – maximum contaminant level
 ND – no detections; practical quantitation limit in brackets.
 Parentheses indicate estimated values (J-qualified data).

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914

Rev. 0

Page 54 of 58

Table 2. Effectiveness Monitoring Plan Well Details

Station ID	Role/ Location	EMP Analytes	Sampling Frequency	Aquifer Zone	UTM NAD27 Coordinates		Screen Interval [ft bgs]
					Northing	Easting	
PRW001DU	East/ Upgradient	1	Quarterly	UAZ	445596.3162	3676631.902	81.64 – 91.64
PRW001DL	East/ Upgradient	1	Quarterly	UAZ	445598.3731	3676629.427	109.78 – 119.67
PRW001C	East/ Upgradient	1	Quarterly	LAZ	445599.9071	3676626.031	146 – 156
PRW002DU	West/ Downgradient	1	Quarterly	UAZ	445585.9390	3676627.649	80.66 – 90.66
PRW002DL	West/ Downgradient	1	Quarterly	UAZ	445586.9572	3676624.563	107.21 – 117.21
PRW002C	West/ Downgradient	1	Quarterly	LAZ	445588.4929	3676621.475	148.06 – 158.06
PRW003DU	East/ Upgradient	1	Quarterly	UAZ	445611.1735	3676604.102	61.82 – 71.82
PRW003DL	East/ Upgradient	1	Quarterly	UAZ	445604.7647	3676615.225	94.85 – 104.85
PRW003C	East/ Upgradient	1	Quarterly	LAZ	445610.6833	3676609.033	136.58 – 146.58
PRW004DU	West/ Downgradient	1	Quarterly	UAZ	445597.7006	3676601.714	64.91 – 74.91
PRW004DL	West/ Downgradient	1	Quarterly	UAZ	445594.6377	3676609.430	111.45 – 121.45
PRW004C	West/ Downgradient	1	Quarterly	LAZ	445595.6558	3676606.345	144.38 – 154.38
PRW005DU	West/ Downgradient	1	Quarterly	UAZ	445590.1508	3676640.252	86 – 96
PRW005DL	West/ Downgradient	1	Quarterly	UAZ	445591.9763	3676642.705	108 – 118
PRW006DU	West/ Downgradient	1	Annually	UAZ	445558.1963	3676619.181	90 – 100
PRW006DL	West/ Downgradient	1	Annually	UAZ	445555.3423	3676617.965	120 – 130
PRW006C	West/ Downgradient	1	Annually	LAZ	445552.4918	3676617.365	160 – 170
PRW007DU	West/ Downgradient	1	Quarterly	UAZ	445591.1164	3676581.425	65 – 75
PRW007DL	West/ Downgradient	1	Quarterly	UAZ	445591.8774	3676578.649	100 – 110
P002U	West/ Downgradient	1	Quarterly	UAZ	445590.2617	3676613.766	87.5 – 92.5
P003U	Background	1	Quarterly	UAZ	445619.5780	3676625.921	84.3 – 89.3
P003L	Background	1	Quarterly	UAZ	445619.0672	3676627.156	113.6 – 118.6
PIW001D	In Wall	1, 2	Quarterly	UAZ	445593.7400	3676634.072	90 – 110
PIW002D	In Wall	1, 2	Quarterly	UAZ	445599.0687	3676614.949	85 – 105
PIW003D	In Wall	1, 2	Quarterly	UAZ	445600.2528	3676595.233	70 – 90
PIW004D	In Wall	1, 2	Quarterly	UAZ	445604.3150	3676581.044	60 – 80

ft bgs – feet below ground surface

- 1 Volatile Organic Compounds: tetrachloroethylene (PCE), trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-DCE), trans-1,2-dichloroethylene (trans-DCE), chloroethene (vinyl chloride [VC]), and 1,1-dichloroethylene (1,1-DCE)
- 2 Geochemical Analyses: Dissolved Organic Carbon (DOC), Total Organic Carbon (TOC), Total Dissolved Solids (TDS), alkalinity, chloride, nitrate-nitrite as nitrogen, sulfate, sulfide, methane, ethane, ethylene, phosphate, calcium, iron, ferrous iron (Fe²⁺), ferric iron (Fe³⁺), potassium, manganese, magnesium, sodium

Table 3. Baseline Concentrations for cVOCs and Geochemical Analytes

Analyte	Units	UAZ		LAZ	
		Range	Location of Maximum	Range	Location of Maximum
PCE	µg/L	0.34 – 5.15	P002U	0.65 – 1.60	PRW002C
TCE	µg/L	0.96 – 7610	P003L	195 – 664	PRW003C
cis-DCE	µg/L	0.45 – 892	P003L	35.0 – 138	PRW003C
trans-DCE	µg/L	0.54 – 15.3	P003L	1.08 – 2.84	PRW003C
1,1-DCE	µg/L	1.96 ^A	P003L	ND (1.0) ^B	
VC	µg/L	1.10 ^A	P003L	ND (1.0) ^B	
Alkalinity	mg/L	2.00 – 38.4	PRW004DL	6.00 – 40.8	PRW001C
Calcium	µg/L	536 – 4810	PRW001DL	804 – 13500	PRW001C
Chloride	mg/L	2.11 – 3.64	PRW002DU	2.20 – 3.03	PRW003C
DOC	mg/L	0.461 – 0.683	P002U	0.410 – 0.531	PRW002C
Ethane	µg/L	0.12 – 0.17	P003L	0.12 – 0.14	PRW002C
Ethylene	µg/L	0.11 – 0.55	PRW003DU	0.15 – 0.25	PRW002C
Ferric Iron	mg/L	ND (0.50) ^B		ND (0.50) ^B	
Ferrous Iron	mg/L	0.87 ^A	PRW004DU	ND (0.50) ^B	
Total Iron	µg/L	104 – 852	P003L	80.1 – 496	PRW002C
Magnesium	µg/L	341 – 1360	PRW003DU	237 – 312	PRW003C
Manganese	µg/L	4.72 – 174	PRW004DU	55.1 – 262	PRW002C
Methane	µg/L	0.93 – 2400	PRW003DU	0.64 – 2.0	PRW002C
Nitrate	mg/L	0.217 – 2.82	PRW003DU	0.448 – 0.856	PRW003C
Phosphate	mg/L	0.045 – 0.089	PRW002DL	0.076 – 0.097	PRW002C
Potassium	µg/L	255 – 16800	PRW004DL	929 – 2810	PRW001C
Sodium	µg/L	2000 – 14400	PRW001DL	3370 – 9880	PRW004C
Sulfate	mg/L	0.533 – 13.4	PRW001DL	0.828 – 8.12	PRW003C
TDS	mg/L	4.29 – 65.7	PRW004DU	18.6 – 111	PRW001C
TOC	mg/L	0.362 – 0.595	PRW004DU	0.354 – 0.463	PRW001C

^A Only one detection above the method detection limit (MDL)

^B All results were non-detect; practical quantitation limit (PQL) in parenthesis

Reported baseline values are from the following monitoring wells:

- UAZ: P002U, P003U, P003L, PRW001DU, PRW001DL, PRW002DU, PRW002DL, PRW003DU, PRW003DL, PRW004DU, PRW004DL
- LAZ: PRW001C, PRW002C, PRW003C, PRW004C

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

Table 4. Baseline Concentration Comparison with Most Recent Results for UAZ (1Q24)

Analyte	Units	East of ZVI-PRB ^A		West of ZVI-PRB ^A		In-Wall ^A
		Baseline	1Q24	Baseline	1Q24	1Q24
PCE	µg/L	0.34 – 1.43	1.40 ^B	0.70 – 5.15	1.90 – 1.92	ND (1) ^C
TCE	µg/L	1.65 – 686	1.06 – 499	0.96 – 1,090	0.42 – 281	4.44 ^B
cis-DCE	µg/L	0.45 – 47.5	0.380 – 285	2.08 – 28.4	0.73 – 116	49.1 ^B
trans-DCE	µg/L	0.57 ^B	ND (25) ^C	0.54 ^B	ND (5) ^C	ND (1) ^C
1,1-DCE	µg/L	ND (1) ^C	ND (25) ^C	ND (1) ^C	ND (5) ^C	ND (1) ^C
VC	µg/L	ND (1) ^C	ND (25) ^C	ND (1) ^C	ND (5) ^C	1.01 ^B
Alkalinity	mg/L	5.80 – 37	0.0 – 99	2.20 – 38.4	0.0 – 52.0	58.0 – 128
Calcium	µg/L	1,190 – 4,810	NS ^D	850 – 2,230	NS ^D	38,000 – 76,200
Chloride	mg/L	2.82 – 3.18	3.52 – 49.7	2.11 – 3.64	3.49 – 32.0	9.99 – 23.5
DO						
DOC	mg/L	0.46 – 0.64	1.59 – 6.15	0.49 – 0.68	0.442 – 2.67	17.3 – 31.3
Ethane	µg/L	0.12 ^B	4.6 – 24.7	ND (0.1) ^C	4.70 – 40.8	8.6 – 70.5
Ethylene	µg/L	0.55 ^B	1.1 – 3.9	0.11 ^B	1.20 – 3.90	0.81 – 39.2
Ferric Iron	mg/L	ND (0.5) ^C	NS ^D	ND (0.5) ^C	NS ^D	0.42 – 1.70
Ferrous Iron	mg/L	ND (0.5) ^C	NS ^D	0.87 ^B	NS ^D	ND (0.05) ^C
Total Iron	µg/L	53.3 – 178	NS ^D	148 – 741	1,790 – 19,100	36.0 – 448
Magnesium	µg/L	341 – 1,360	NS ^D	376 – 1,070	NS ^D	10.5 – 72.4
Manganese	µg/L	9.10 – 24.1	NS ^D	5.07 – 174	NS ^D	1.59 – 11.2
Methane	µg/L	0.93 – 2,400	5.3 – 16,400	1.90 – 600	74.4 – 11,000	313 – 3,980
Nitrate	mg/L	0.22 – 2.82	NS ^D	0.28 – 2.60	NS ^D	ND (0.5) ^C
ORP	mV					
Phosphate	mg/L	0.05 – 0.07	NS ^D	0.04 – 0.09	NS ^D	ND (0.05) ^C
Potassium	µg/L	255 – 11,000	NS ^D	556 – 16,800	NS ^D	691 – 1,740
Sodium	µg/L	2,630 – 14,400	NS ^D	3,240 – 12,200	NS ^D	5,240 – 14,000
Sulfate	mg/L	0.53 – 13.4	NS ^D	0.59 – 6.22	NS ^D	0.455 – 1.29
TDS	mg/L	40.0 – 47.1	NS ^D	4.29 – 65.7	NS ^D	130 – 352
TOC	mg/L	0.36 – 0.53	1.54 – 5.94	0.38 – 0.60	0.41 – 2.89	17.7 – 31.6

^A Wells included in each set are:

East of ZVI-PRB: PRW001DU, PRW001DL, PRW003DU, PRW003DL

West of ZVI-PRB: PRW002DU, PRW002DL, PRW004DU, PRW004DL (Baseline and 1Q24)

PRW005DU, PRW005DL, PRW006DU, PRW006DL, PRW007DU, PRW007DL (1Q24 Only)

In-Wall: PIW001D, PIW002D, PIW003D, PIW004D

^B Only one value reported above method detection limit (MDL).

^C No detections; Maximum practical quantitation limit (PQL) reported in parenthesis.

^D Not sampled.

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

Table 5. Baseline Concentration Comparison with Most Recent Results for LAZ (1Q24)

Analyte	Units	East of ZVI-PRB ^A		West of ZVI-PRB ^A	
		Baseline	1Q24	Baseline	1Q24
PCE	µg/L	0.65 - 1.15	ND (1) ^B	0.86 – 1.6	ND (1) ^B
TCE	µg/L	419 - 664	9.71 – 15.4	195 - 437	9.38 – 37.8
cis-DCE	µg/L	84.1 - 138	9.11 – 35.4	35.0 - 109	1.23 – 11.4
trans-DCE	µg/L	2.13 - 2.84	0.72 ^C	1.08 – 2.63	ND (1) ^B
1,1-DCE	µg/L	ND (1) ^B	ND (1) ^B	ND (1) ^B	ND (1) ^B
VC	µg/L	ND (1) ^B	ND (1) ^B	ND (1) ^B	ND (1) ^B
Alkalinity	mg/L	9.6 - 40.8	9.0 – 42	3.0 – 6.8	0.0 – 110
Chloride	mg/L	2.20 - 3.03	8.10 – 11.3	2.32 – 2.39	12.7 – 31.7
DOC	mg/L	0.410 - 0.426	0.35 – 16.0	0.480 - 0.531	1.25 – 13.8
Ethane	µg/L	0.12 ^C	50.2 – 273	0.14 ^C	13.9 – 338
Ethylene	µg/L	0.15 - 0.18	5.80 – 102	0.25 ^C	5.0 – 38.3
Total Iron	µg/L	80.1 - 188	NS ^D	361 - 496	498 – 21,500
Methane	µg/L	0.64 - 1.7	862 – 1,430	2.0 ^C	32.8 – 6,870
TOC	mg/L	0.382 - 0.463	15.8 ^C	0.35 - 0.43	1.13 – 13.9

^A Wells included in each set are:

East of ZVI-PRB: PRW001C and PRW003C (Baseline and 1Q24)

West of ZVI-PRB: PRW002C, PRW004C (Baseline and 1Q24)

PRW006C (1Q24 Only)

^B No detections; Maximum practical quantitation limit (PQL) reported in parenthesis.

^C Only one value reported above method detection limit (MDL).

^D Not sampled.

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APPENDIX A

PAGW OU RA EMR Analytical Data 2023-2024

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APPENDIX B

PAGW OU RA EMR Hydrographs

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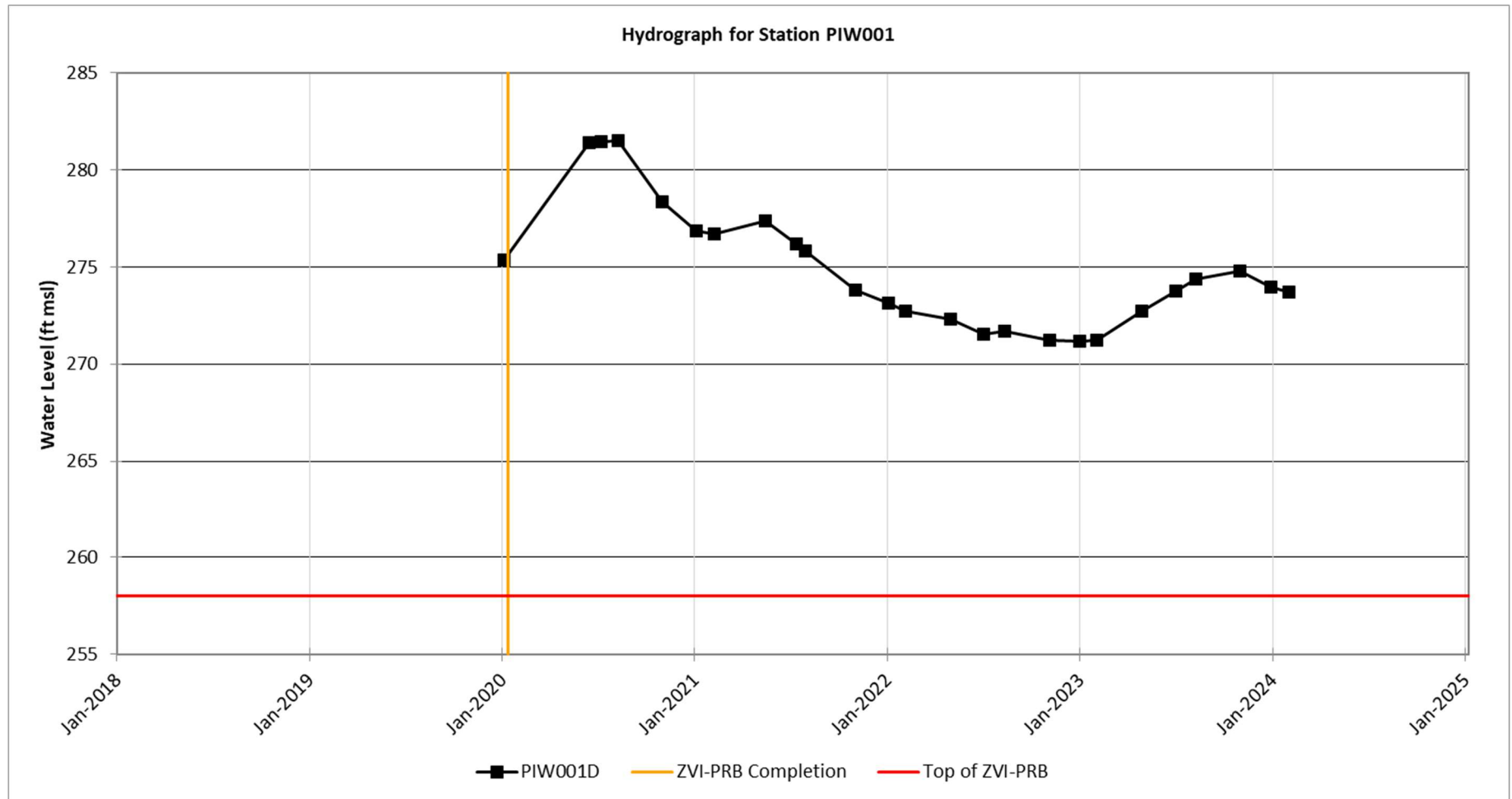


Figure B.1. Hydrograph for PIW001D

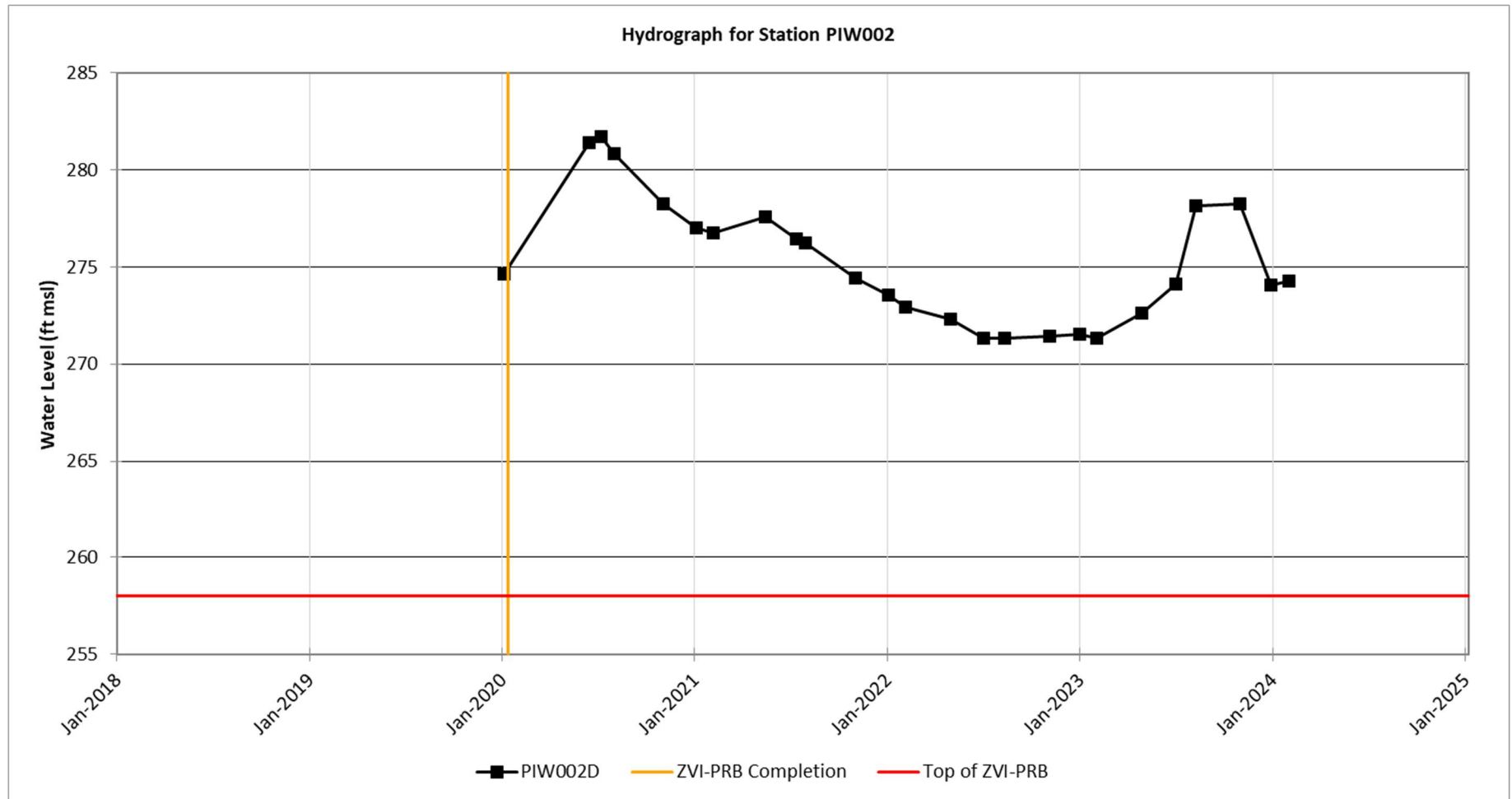


Figure B.2. Hydrograph for PIW002D

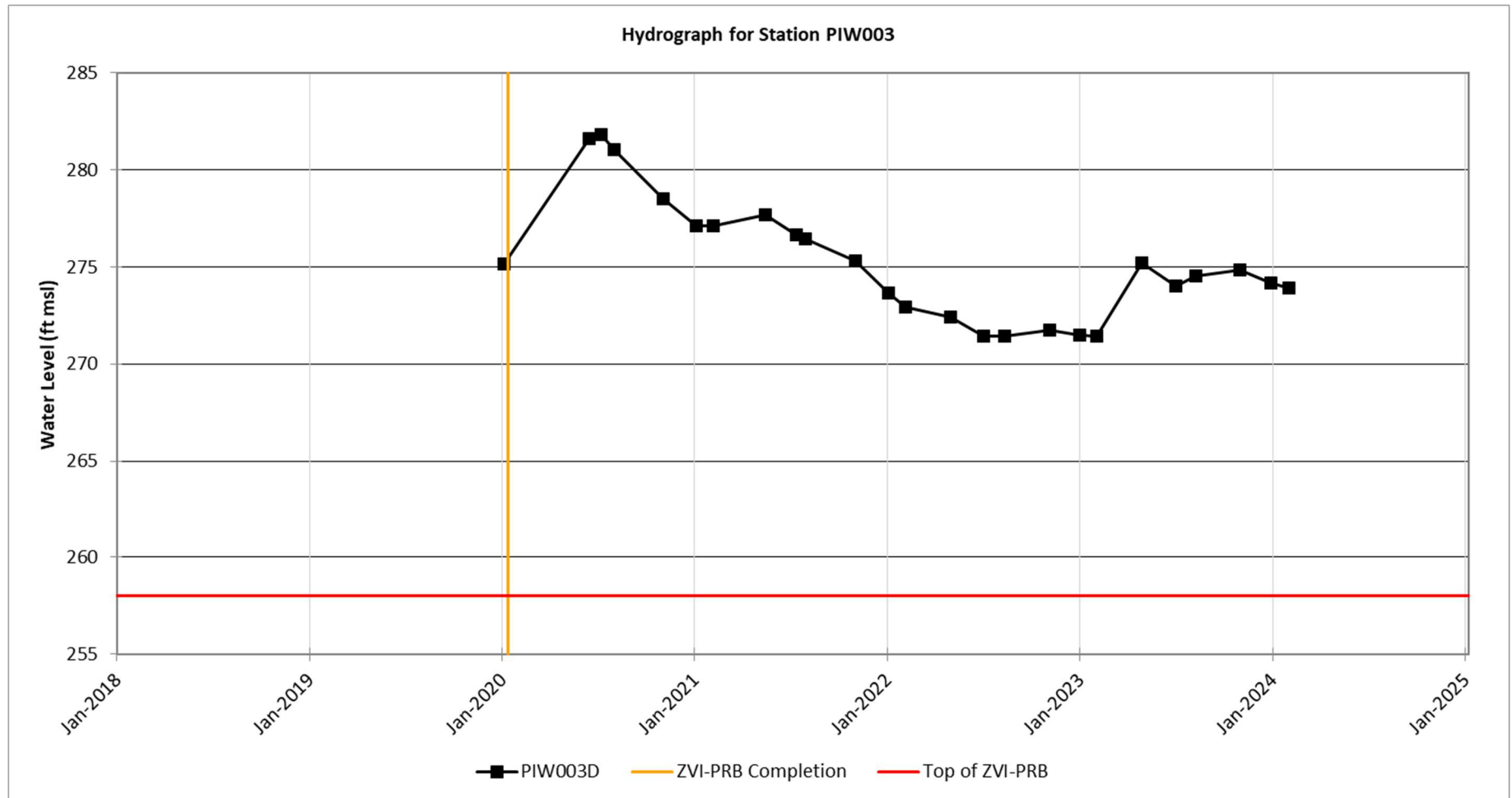


Figure B.3. Hydrograph for PIW003D

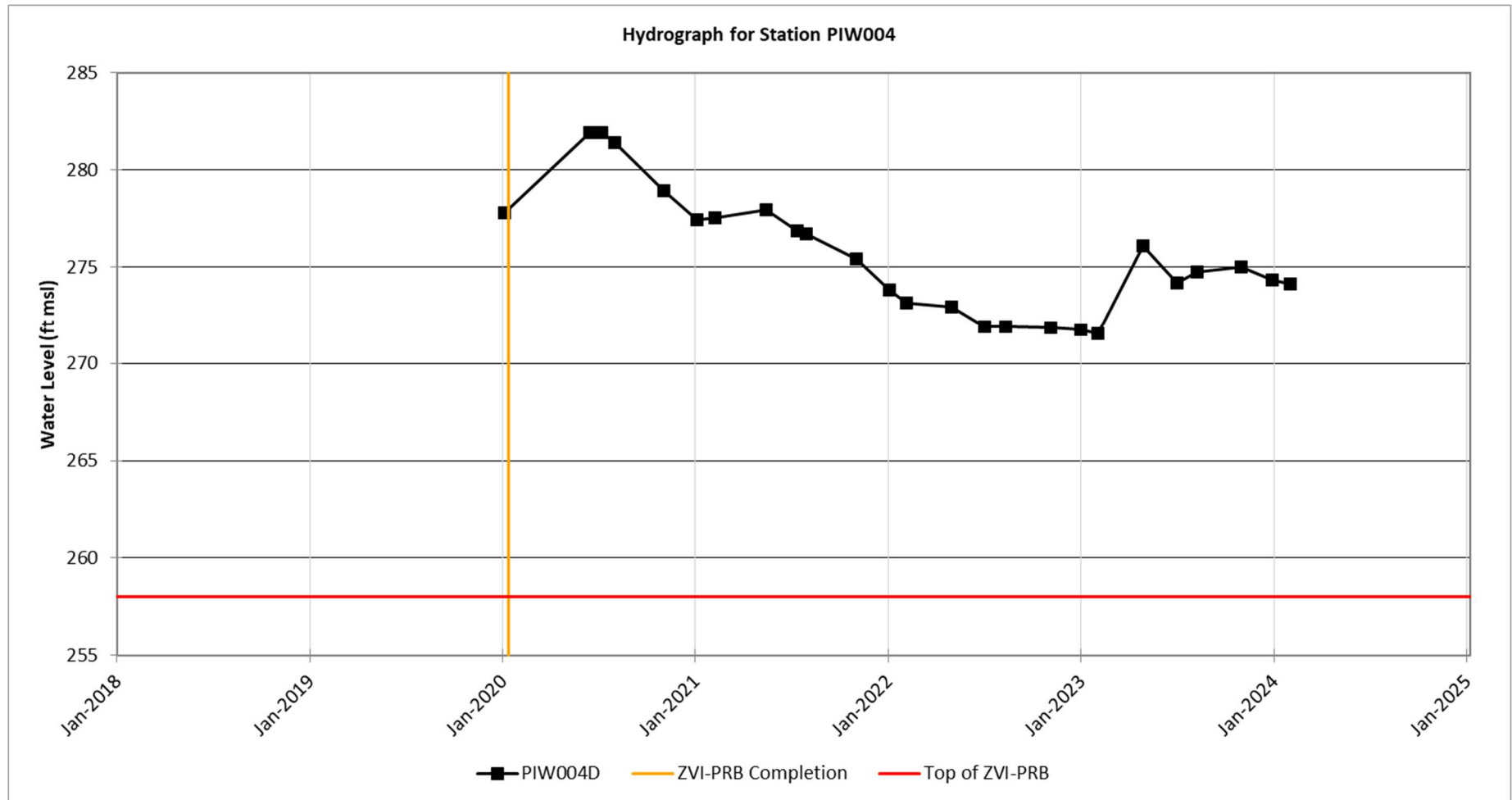


Figure B.4. Hydrograph for PIW004D

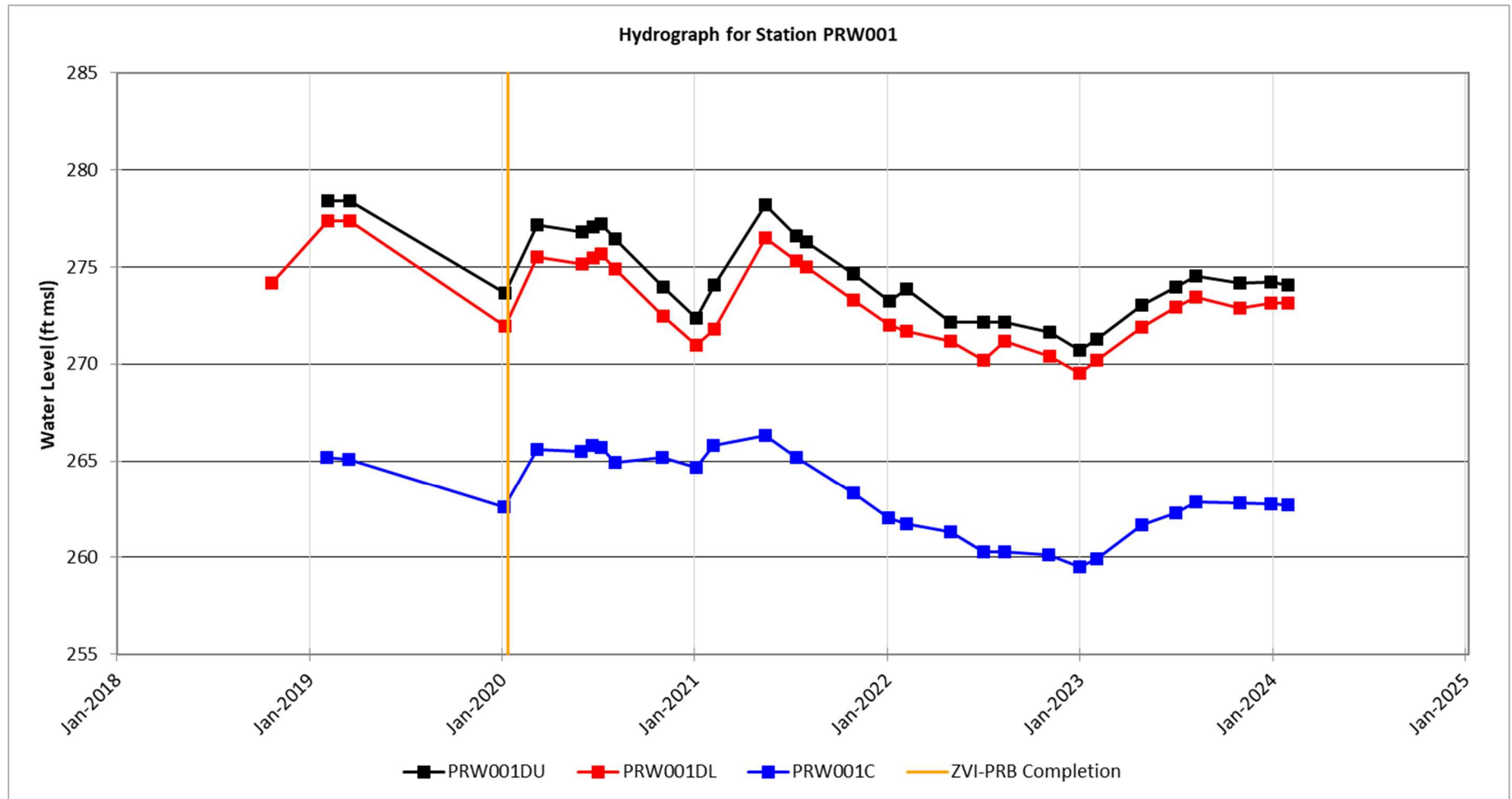


Figure B.5. Hydrograph for PRW001 Cluster

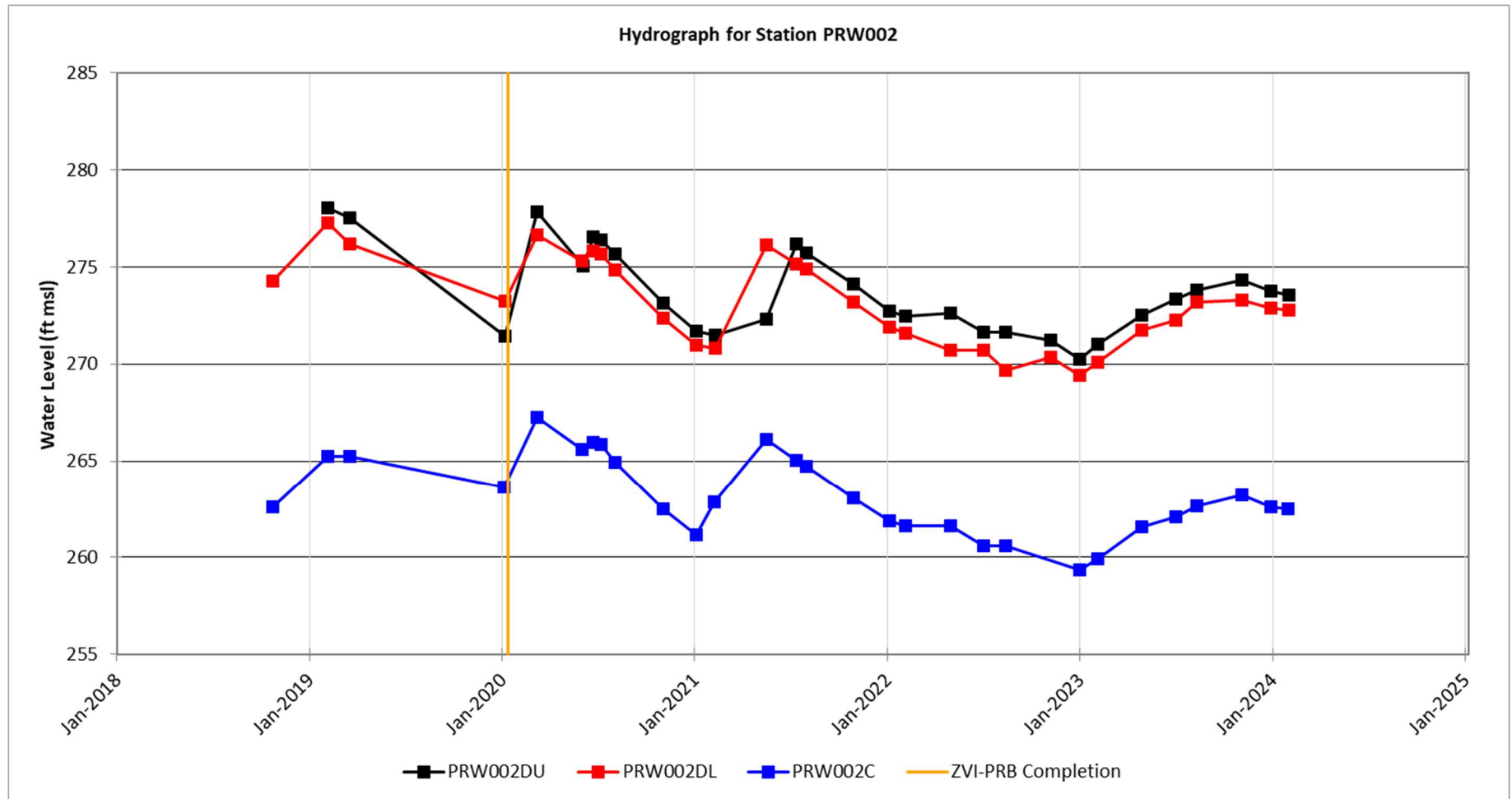


Figure B.6. Hydrograph for PRW002 Cluster

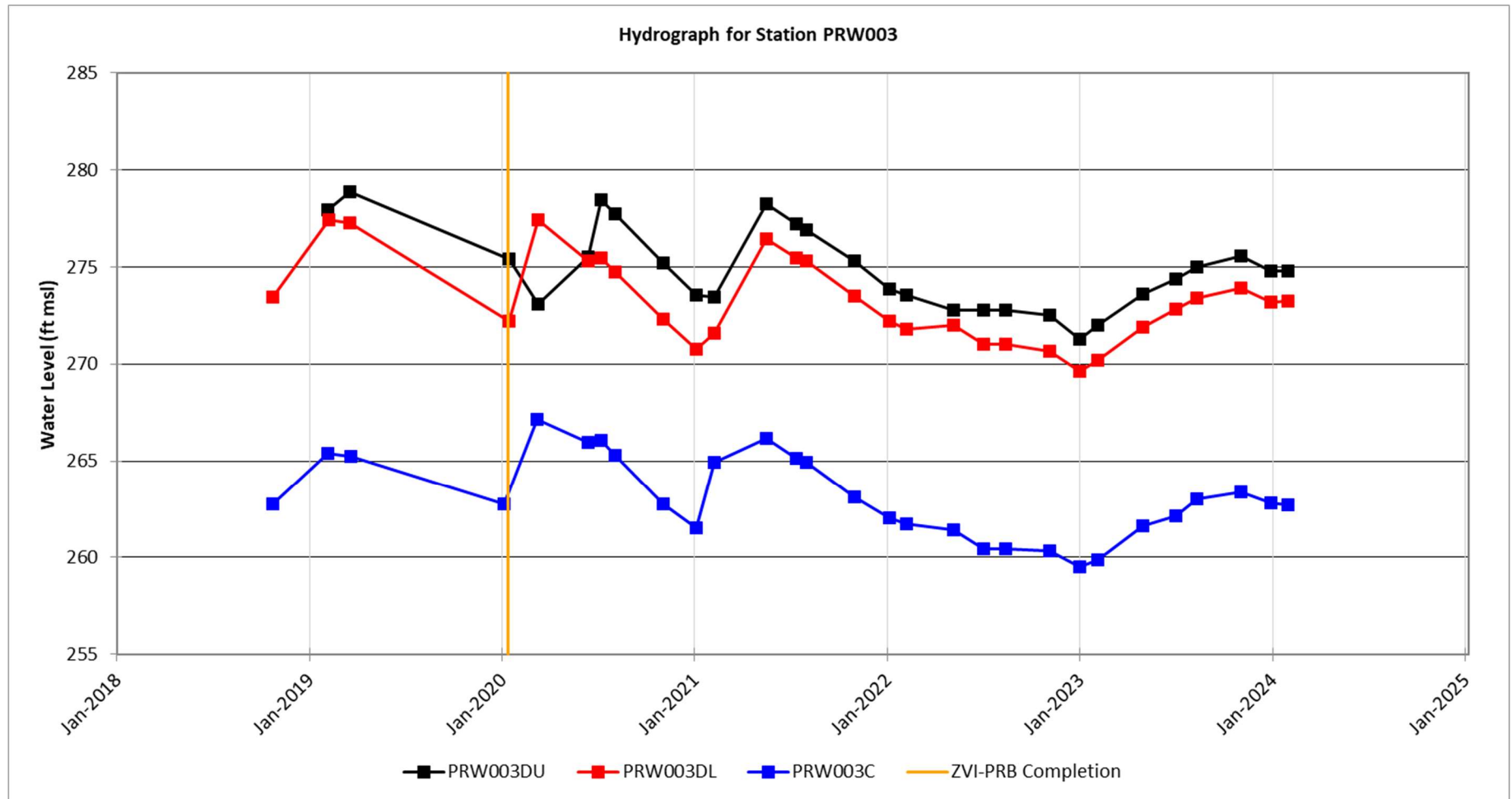


Figure B.7. Hydrograph for PRW003 Cluster

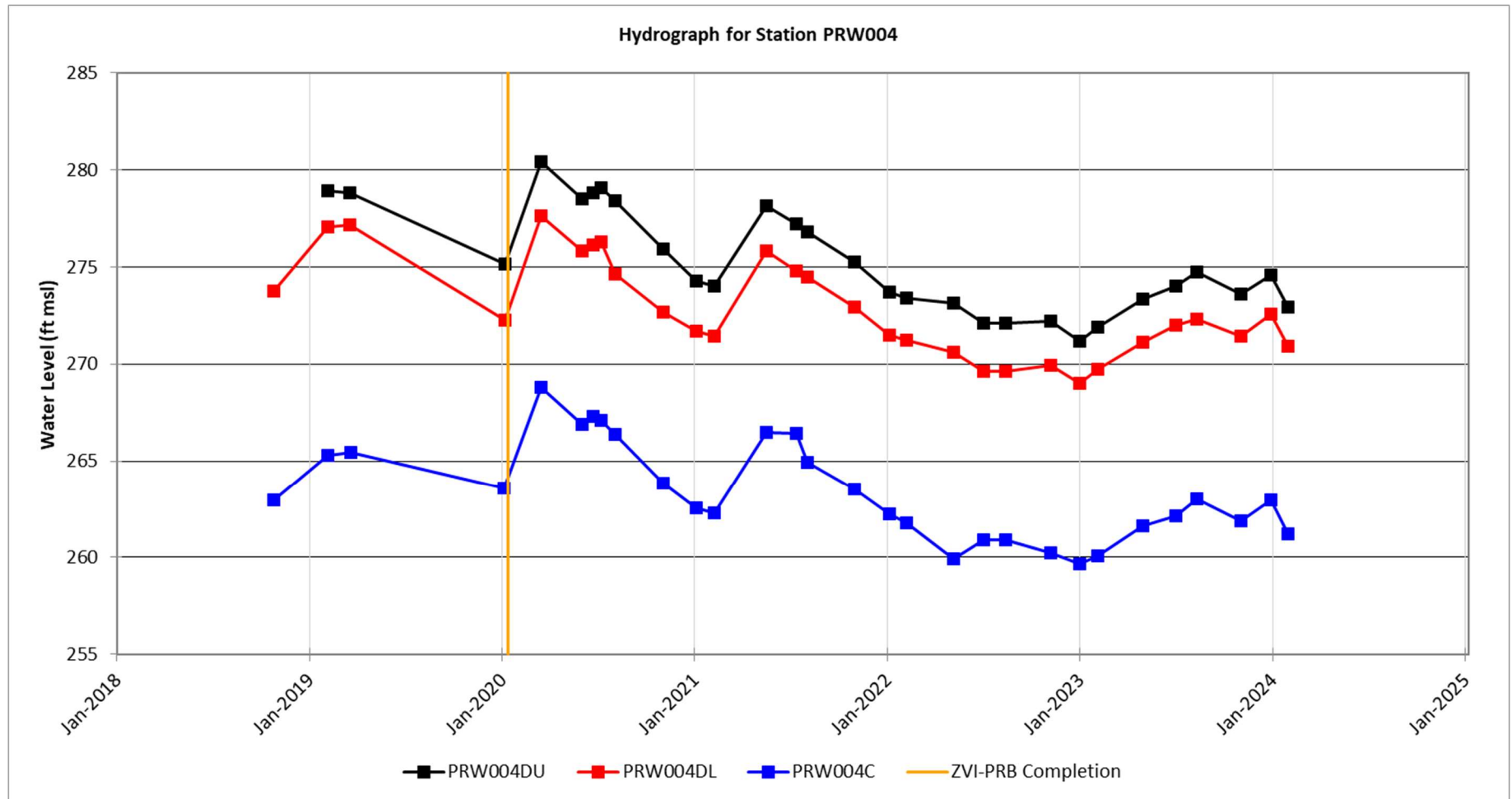


Figure B.8. Hydrograph for PRW004 Cluster

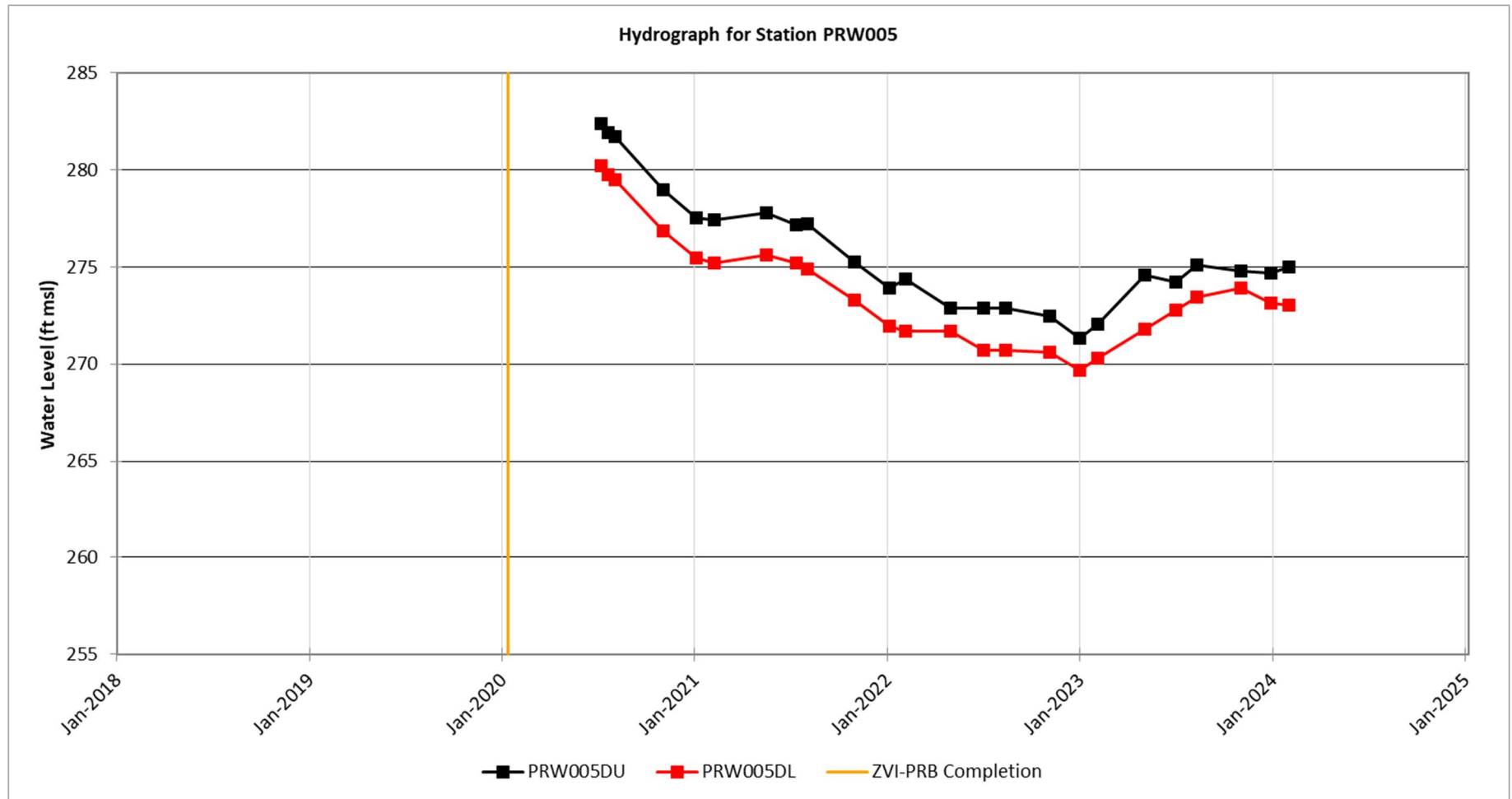


Figure B.9. Hydrograph for PRW005 Cluster

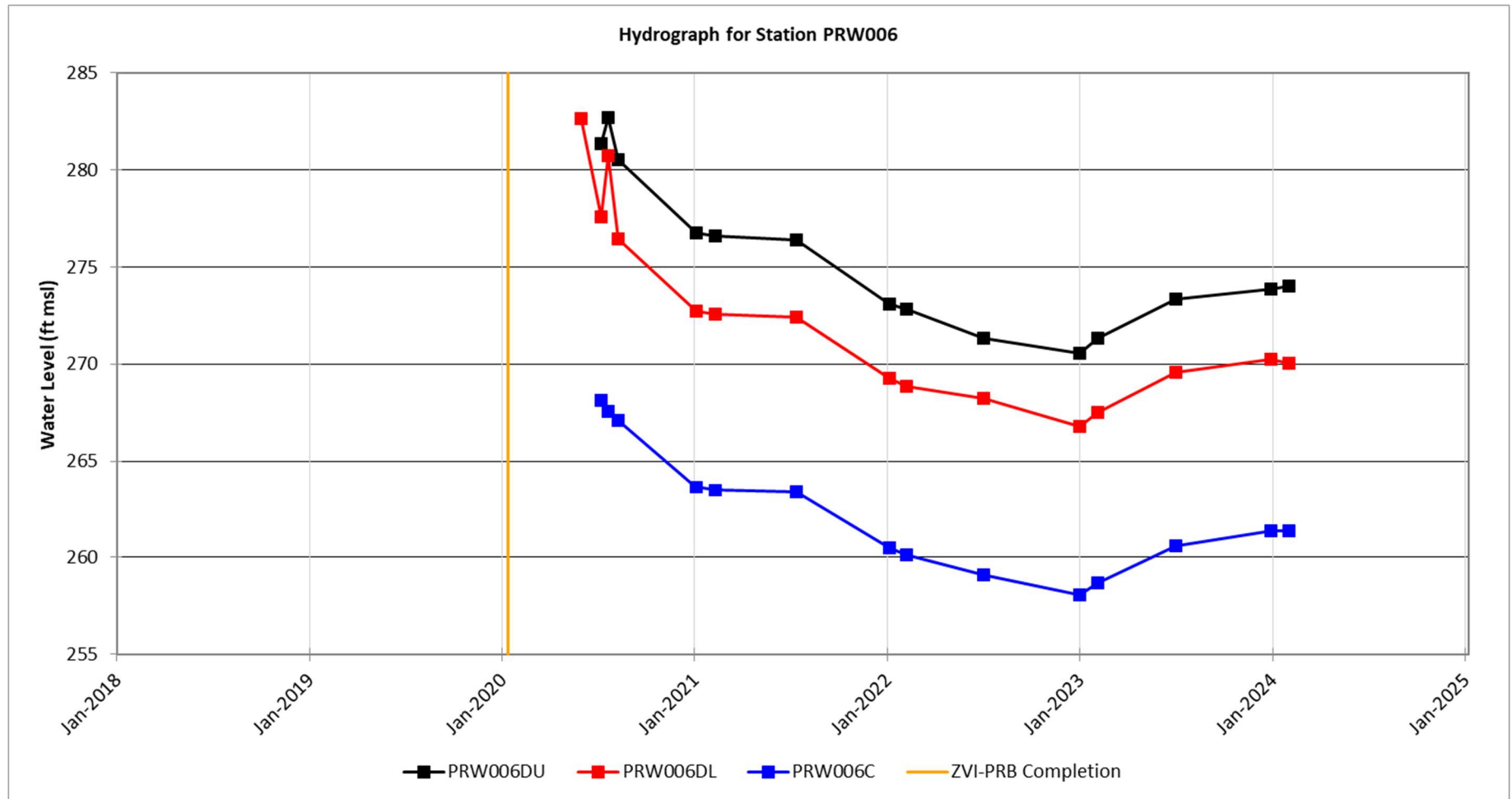


Figure B.10. Hydrograph for PRW006 Cluster

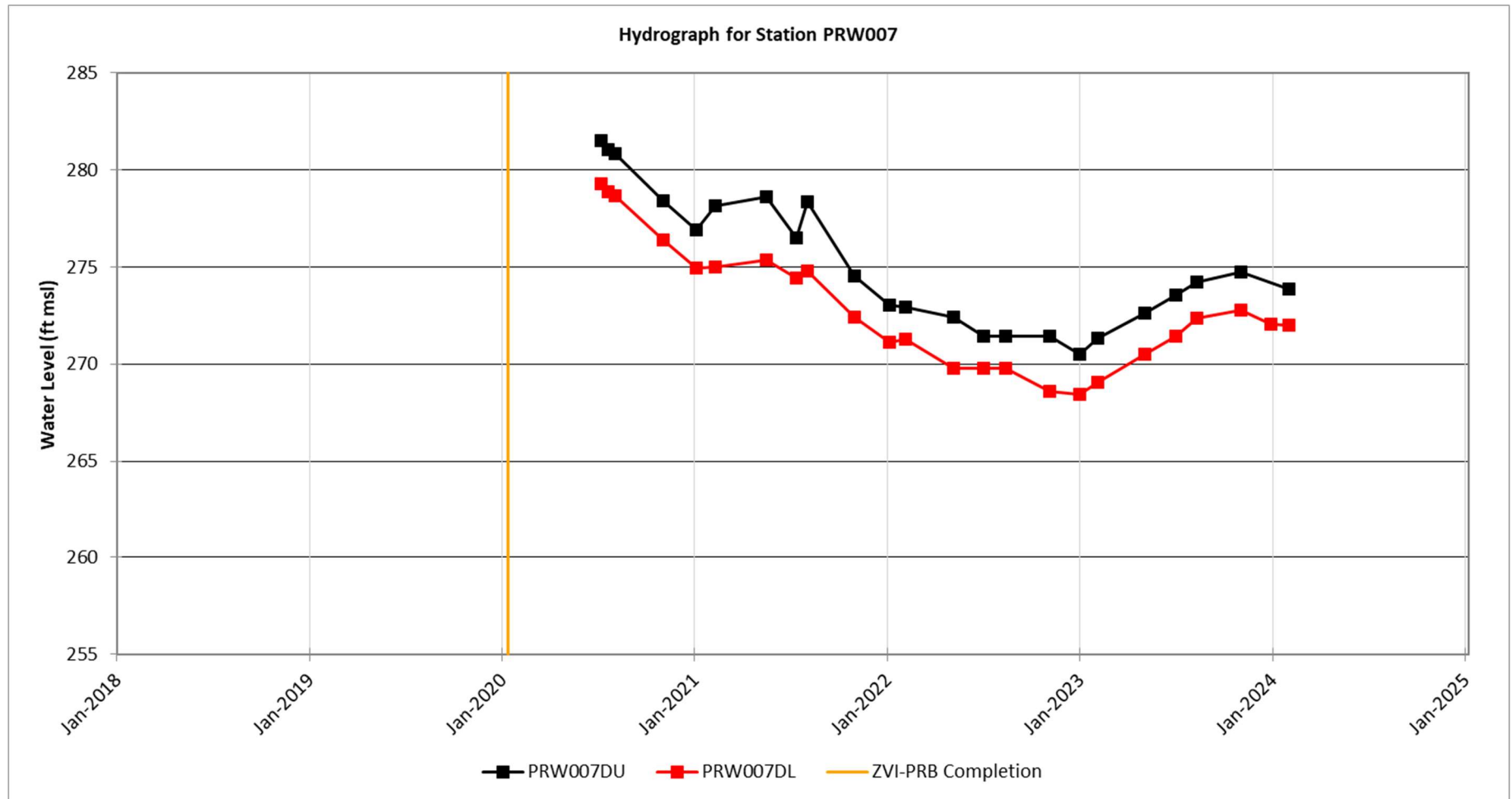


Figure B.11. Hydrograph for PRW007 Cluster

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APPENDIX C

PAGW OU RA EMR Time-Series Plots

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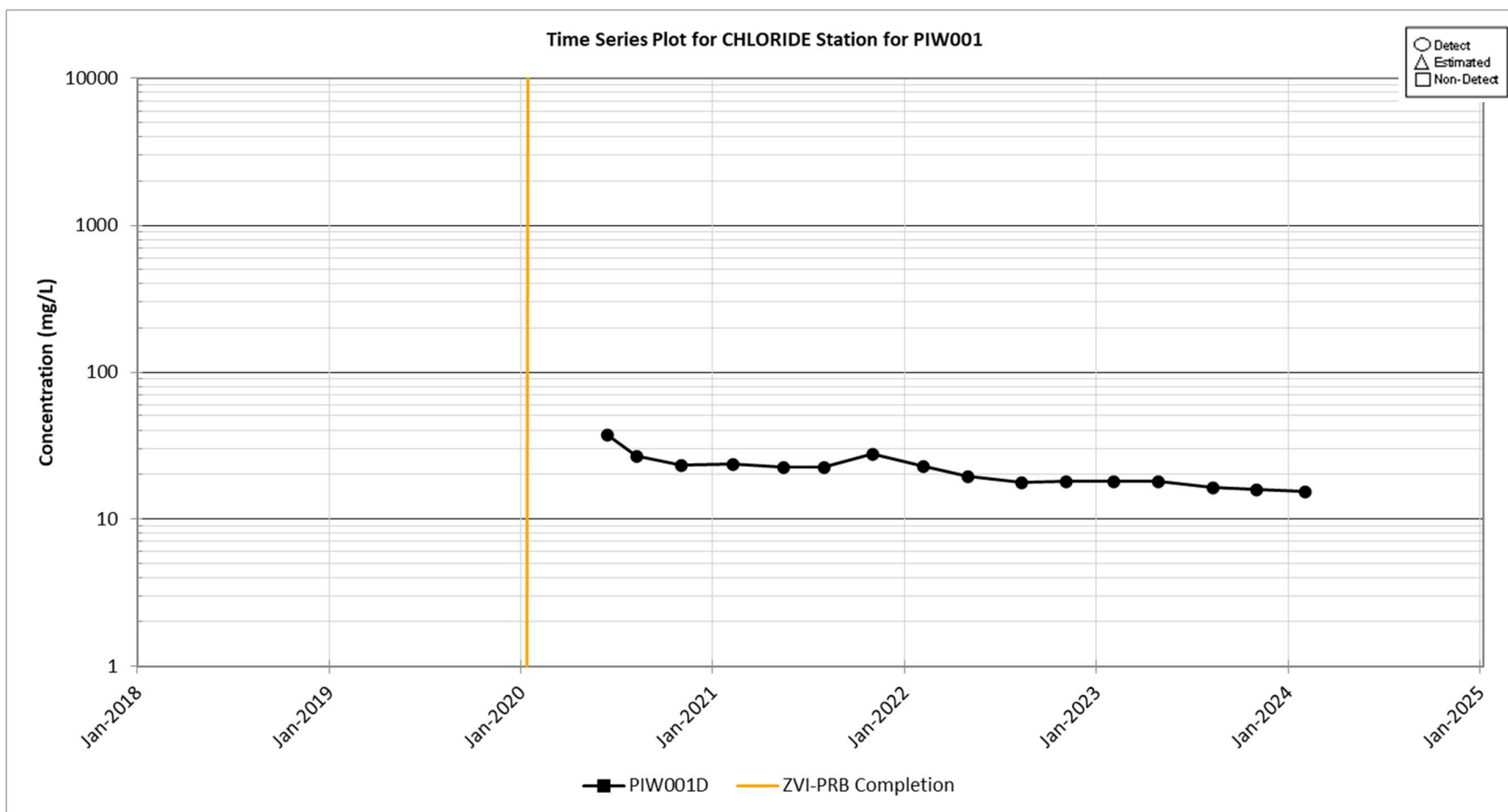


Figure C.1. Time Series Plot for Chloride at Monitoring Well PIW001D

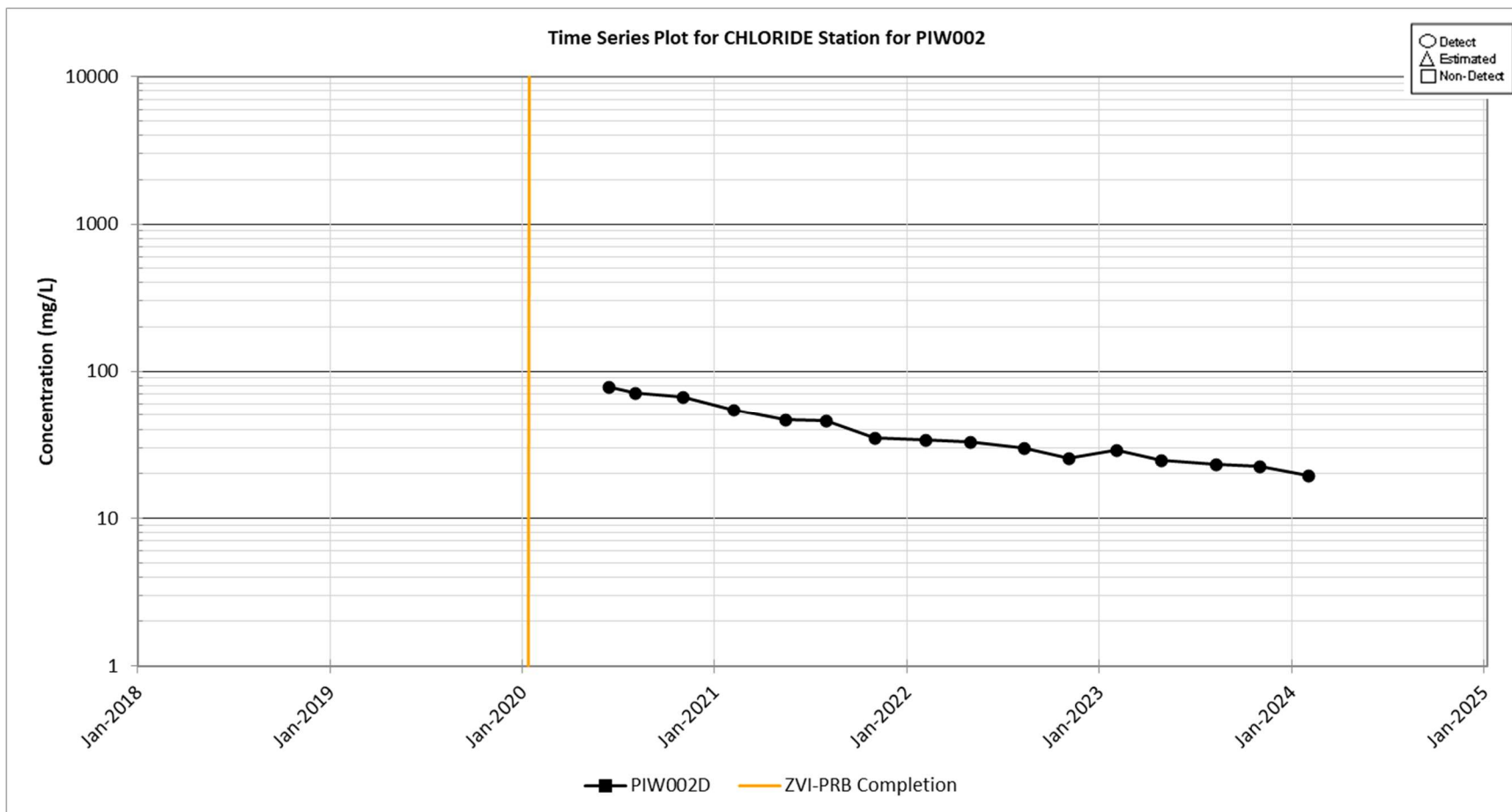


Figure C.2. Time Series Plot for Chloride at Monitoring Well PIW002D

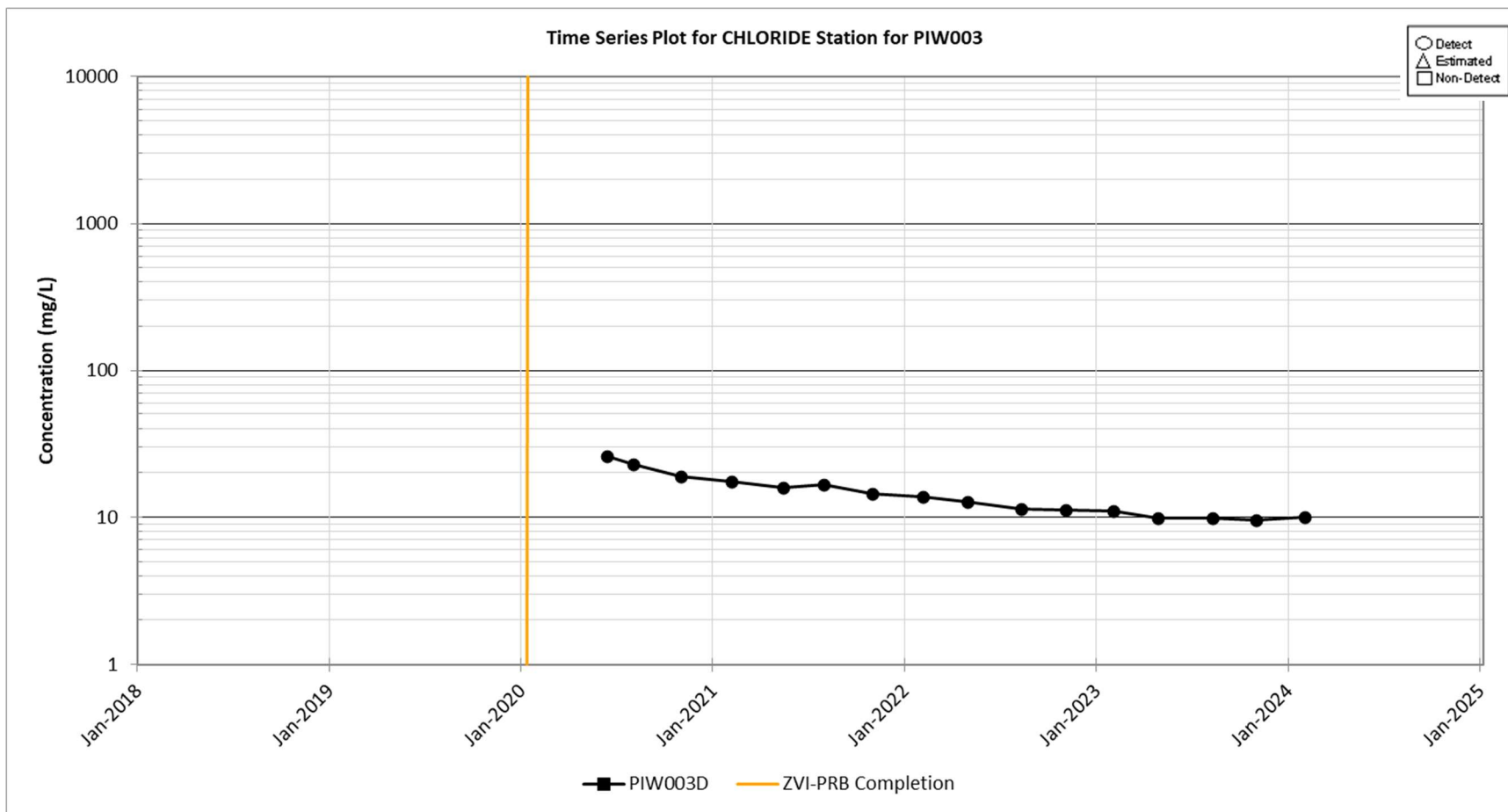


Figure C.3. Time Series Plot for Chloride at Monitoring Well PIW003D

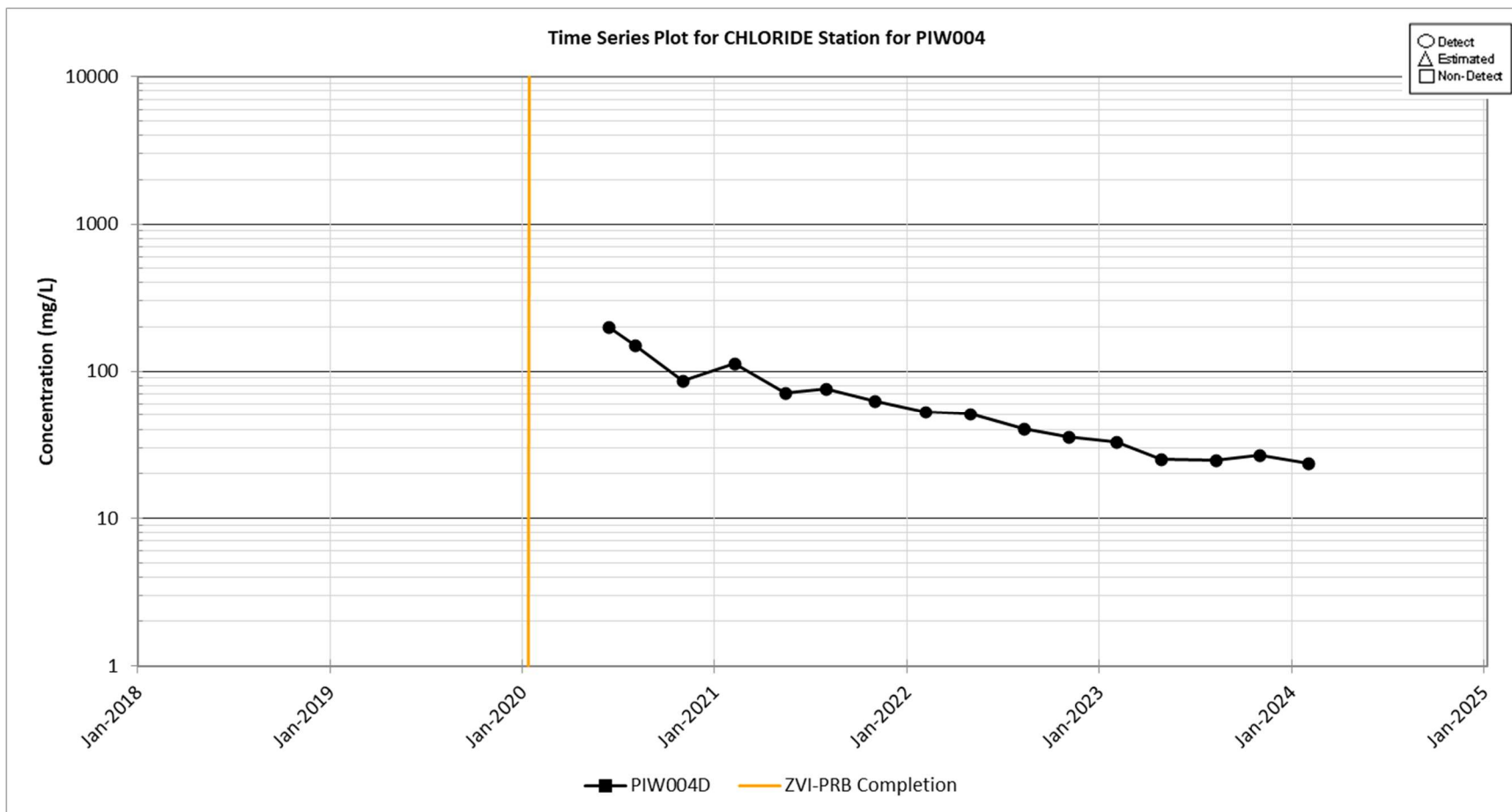


Figure C.4. Time Series Plot for Chloride at Monitoring Well PIW004D

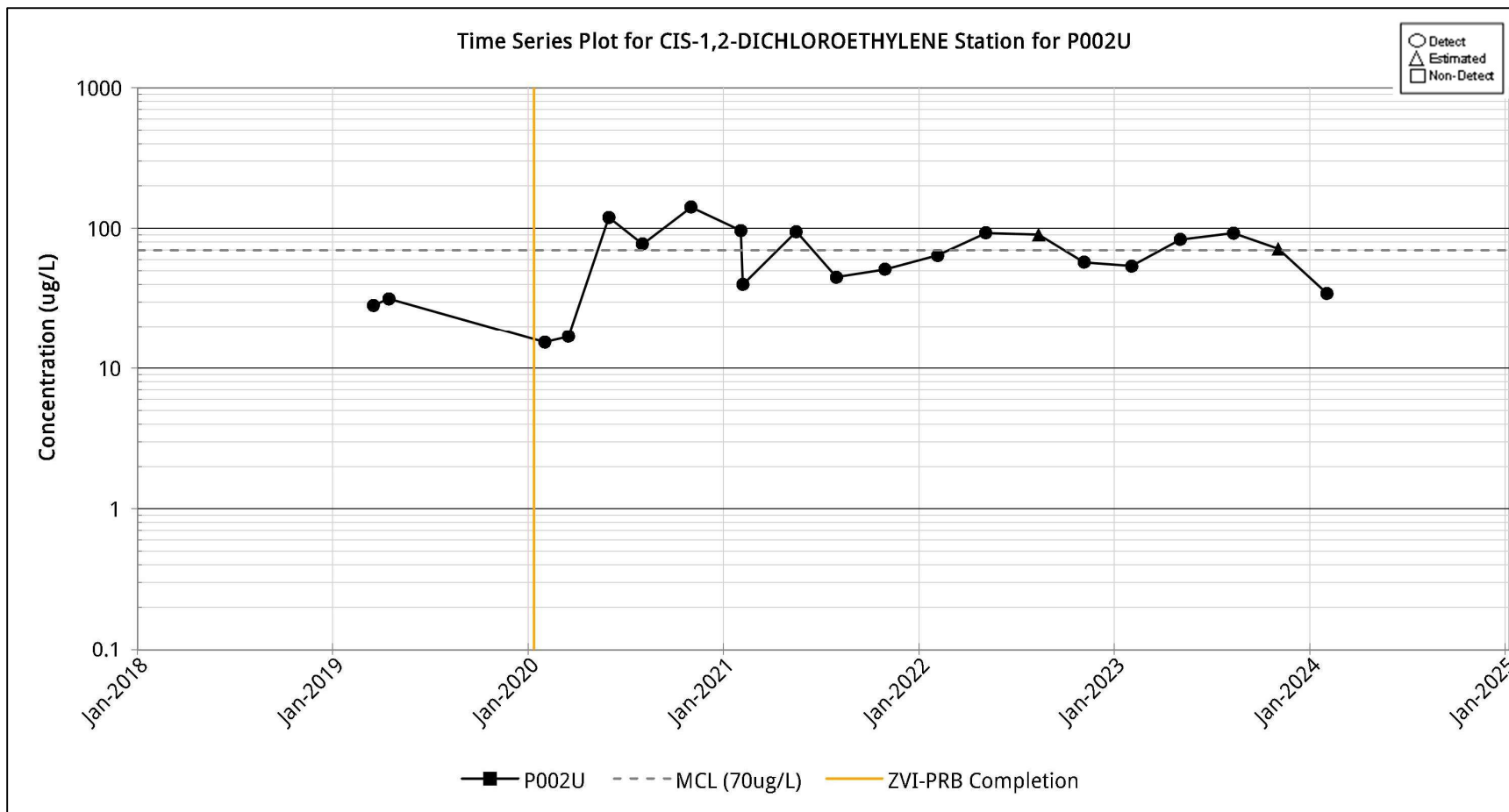


Figure C.5. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well P002U

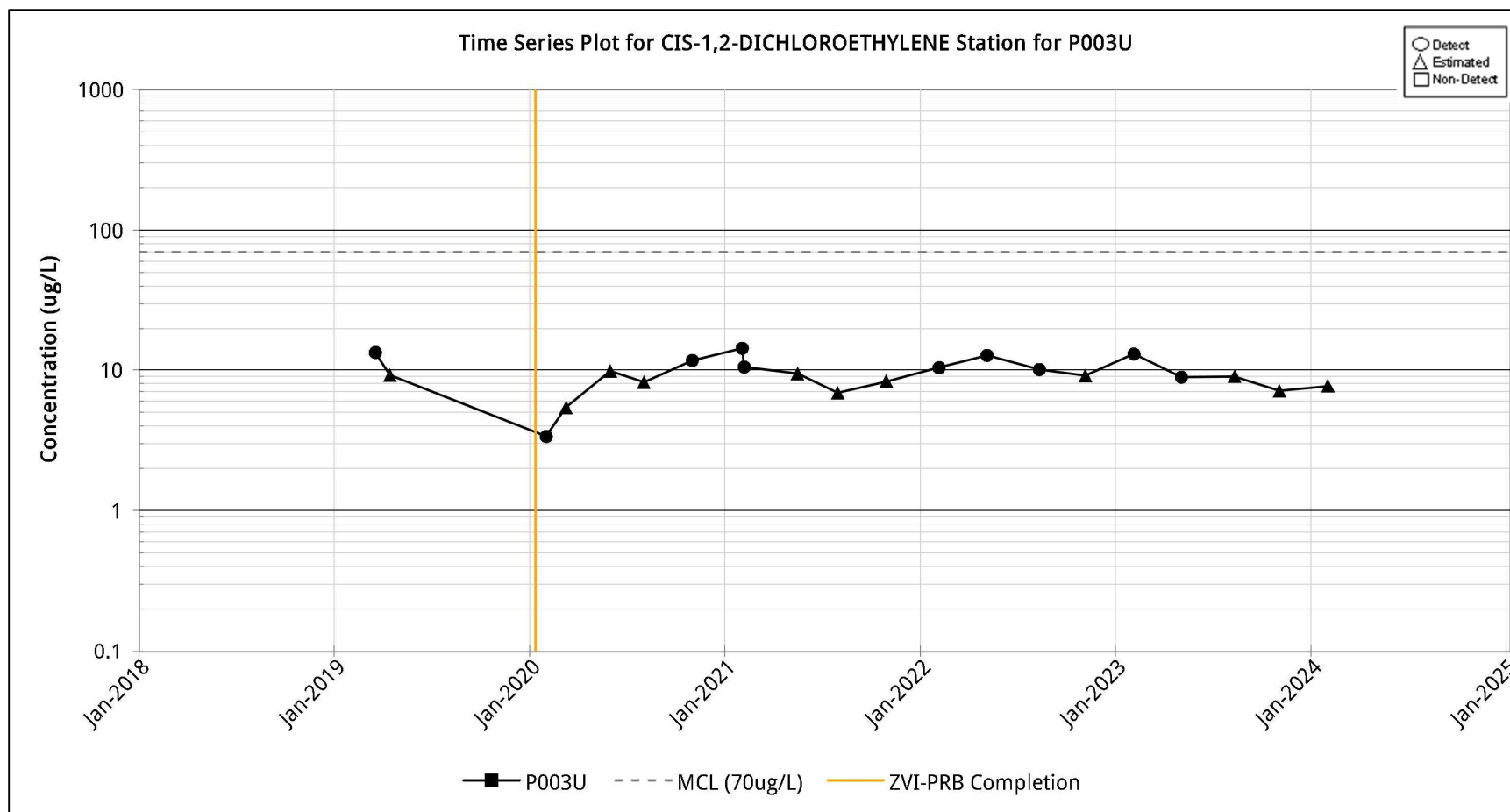


Figure C.6. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well P003U

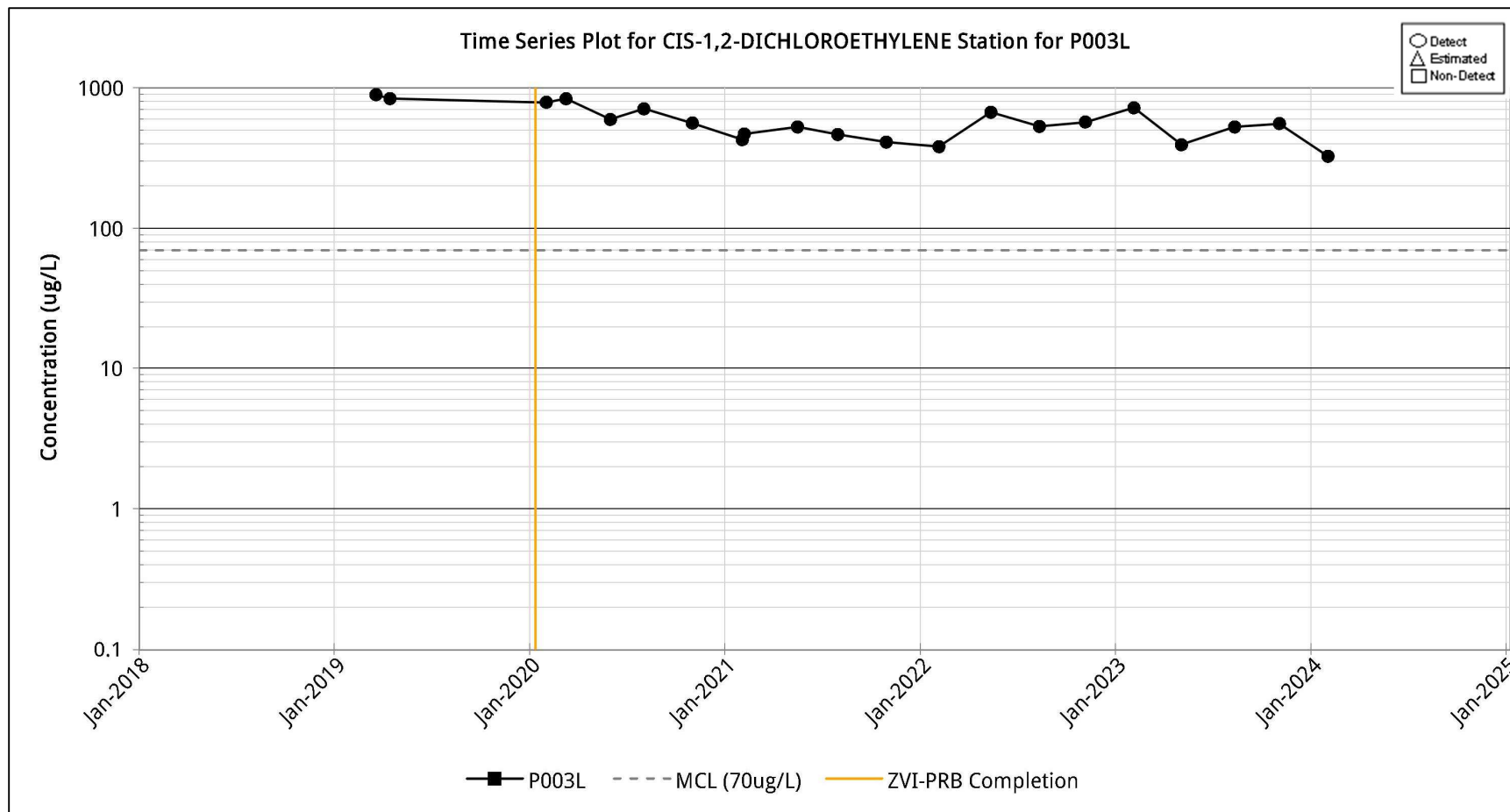


Figure C.7. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well P003L

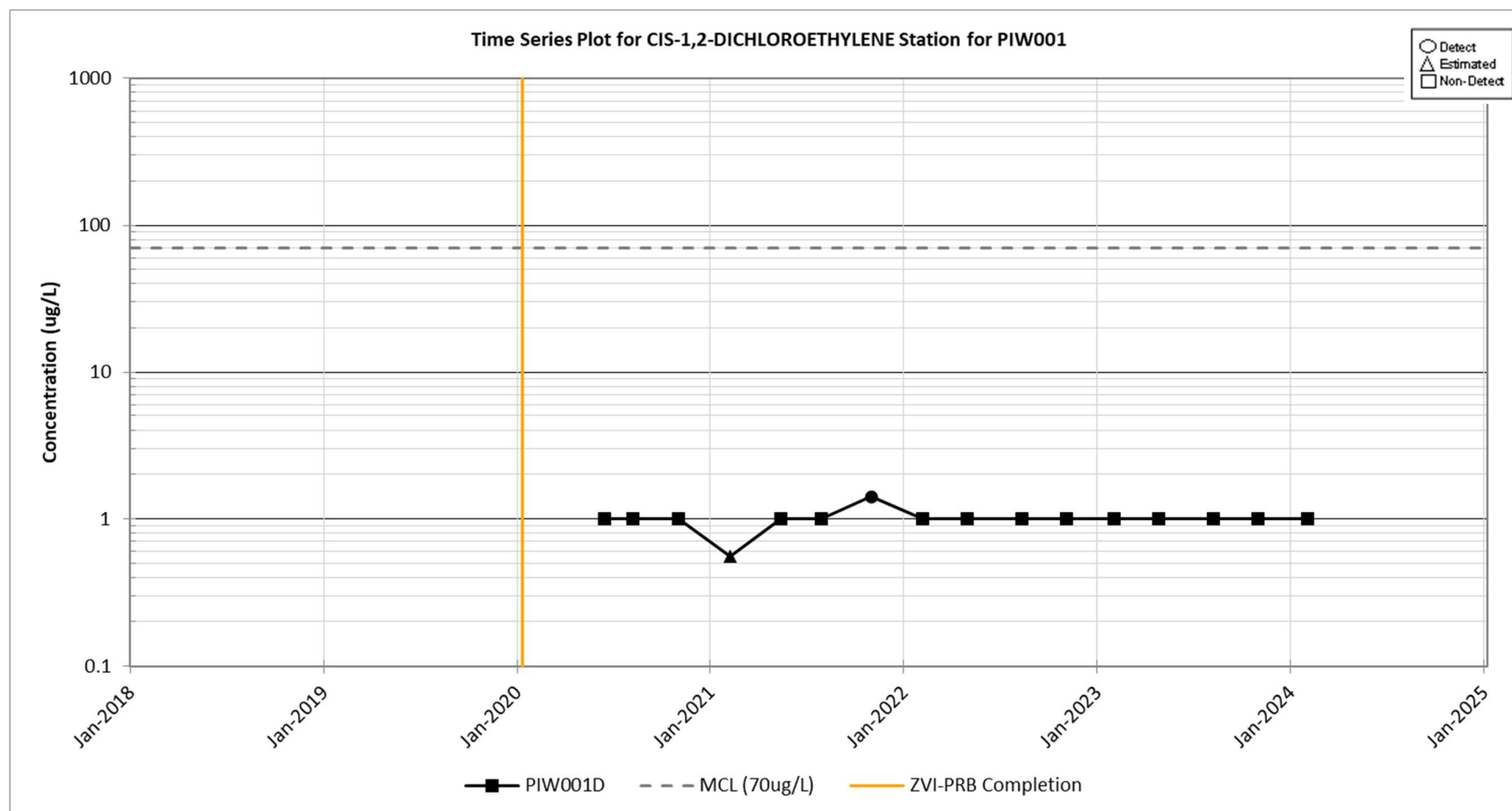


Figure C.8. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well PIW001D

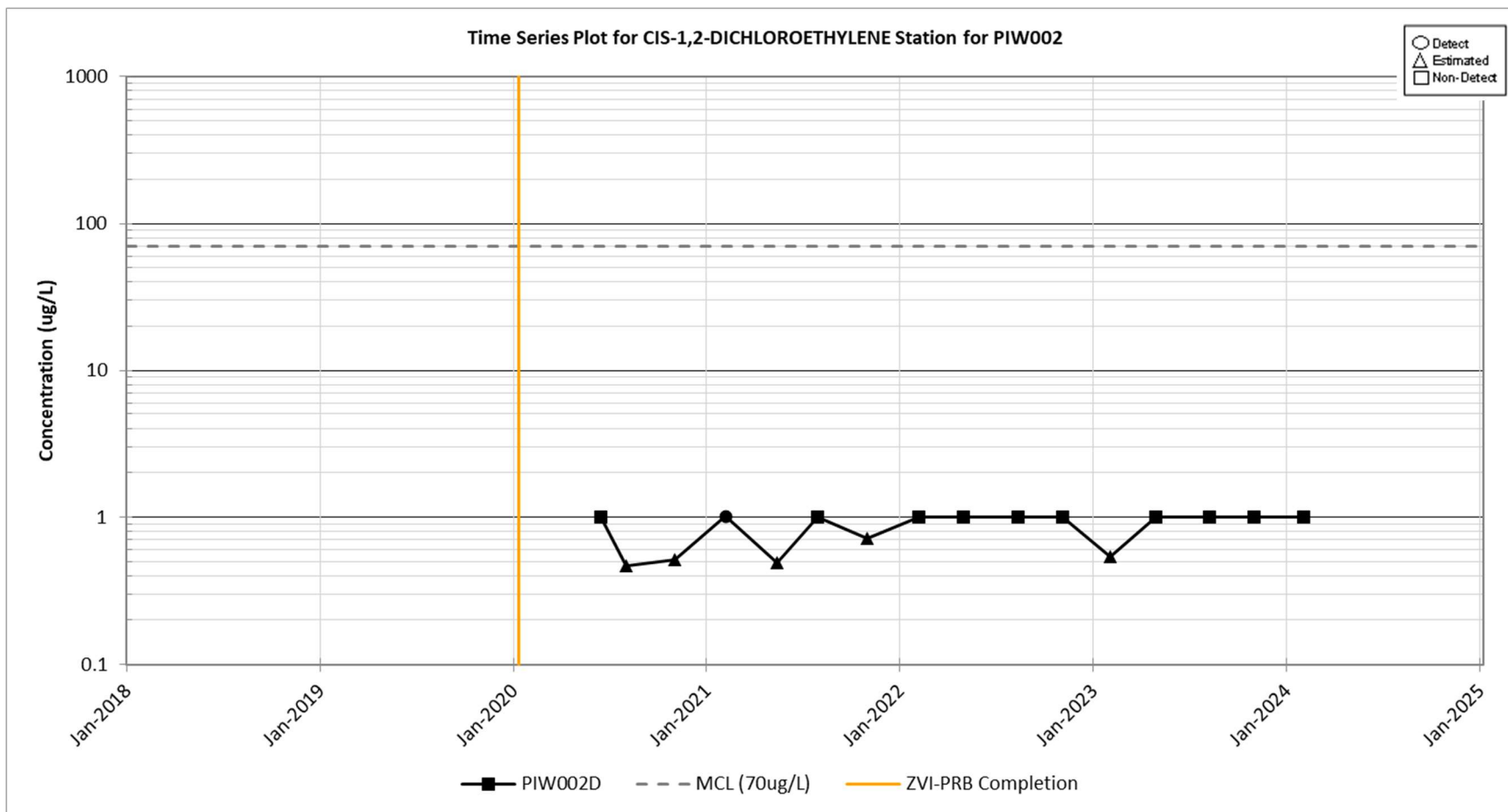


Figure C.9. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well PIW002D

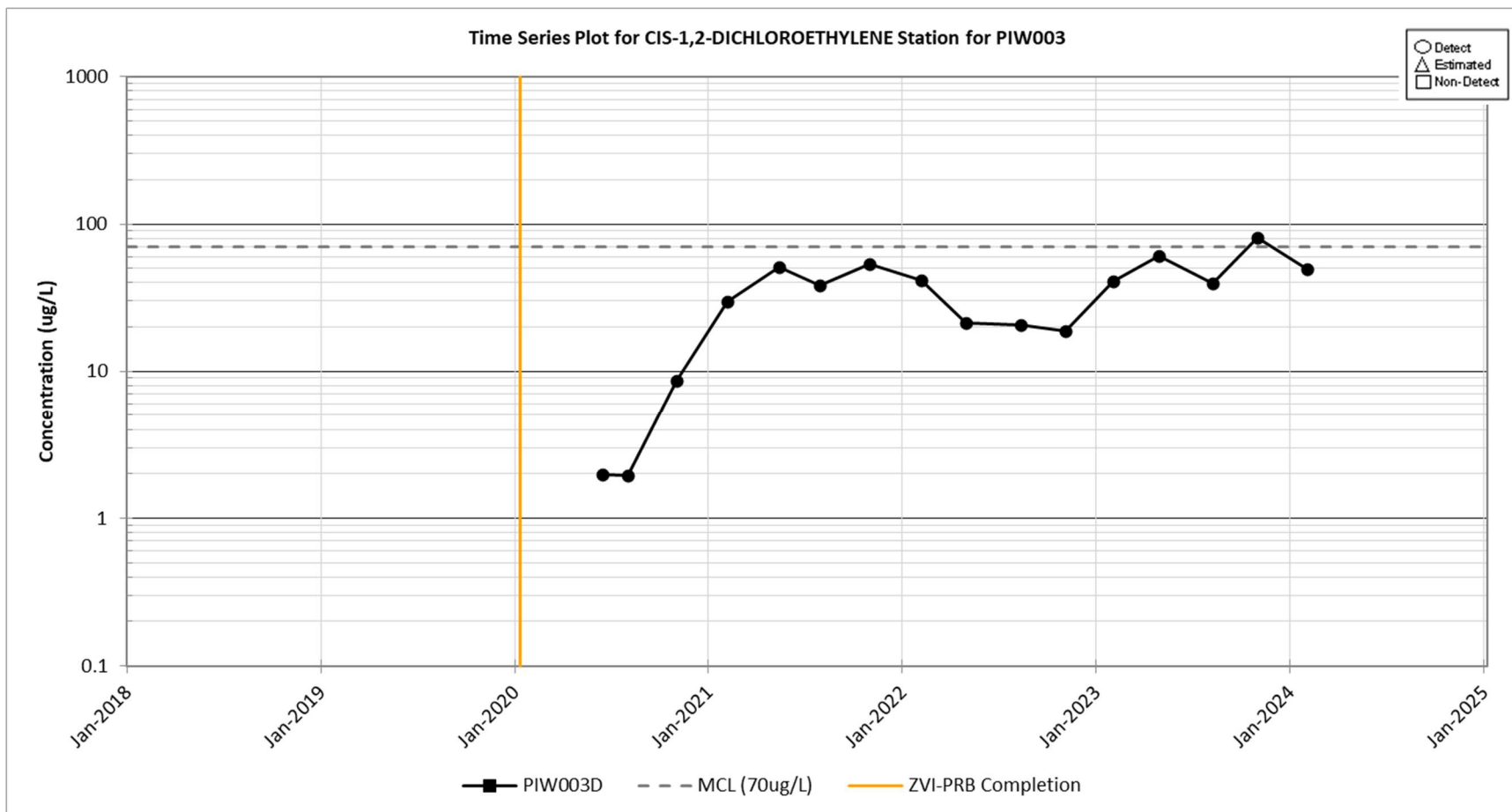


Figure C.10. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well PIW003D

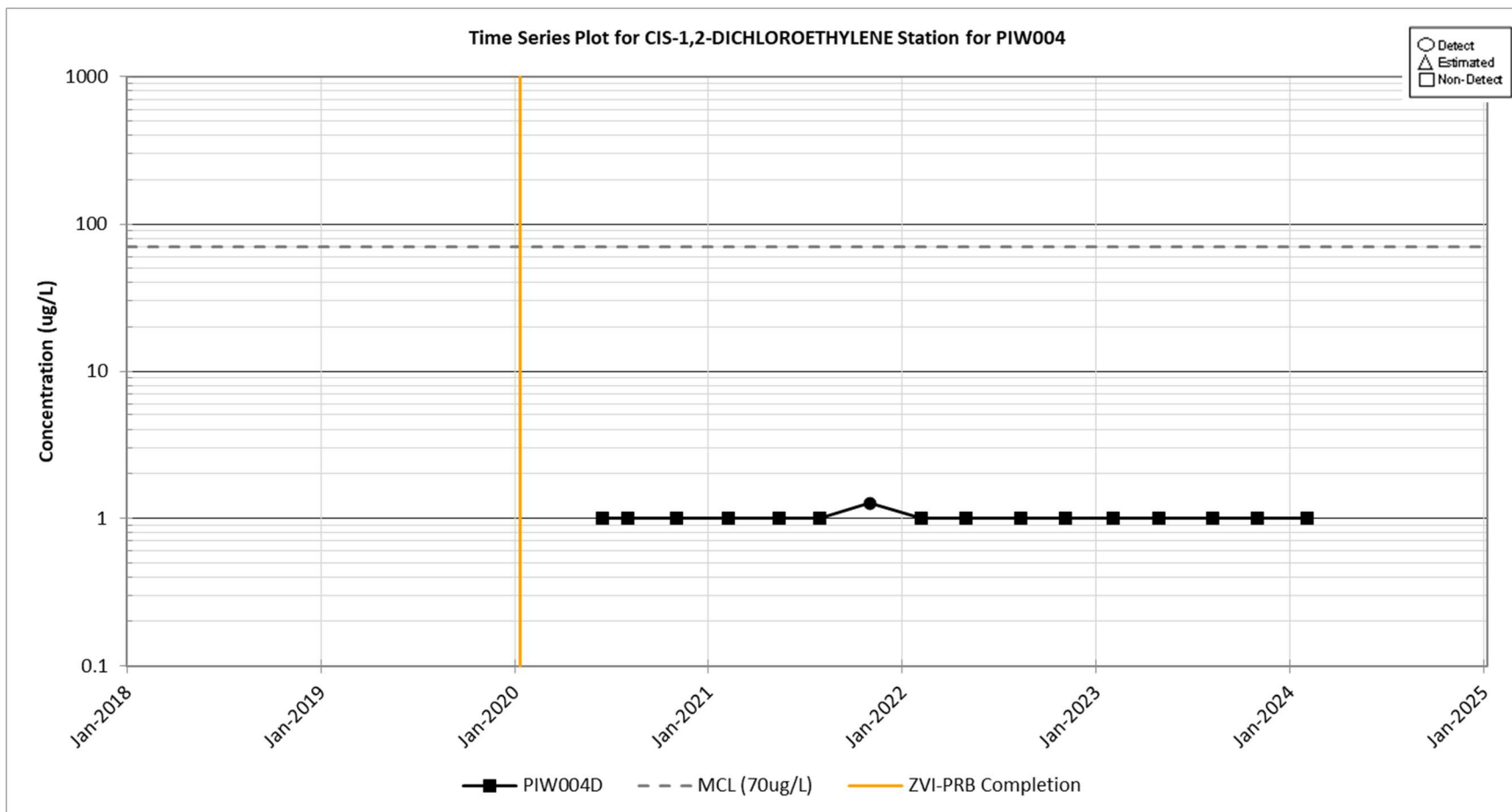


Figure C.11. Time Series Plot for Cis-1,2-Dichloroethylene at Monitoring Well PIW004D

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914
Rev. 0

Appendix C, Page C-14 of C-48

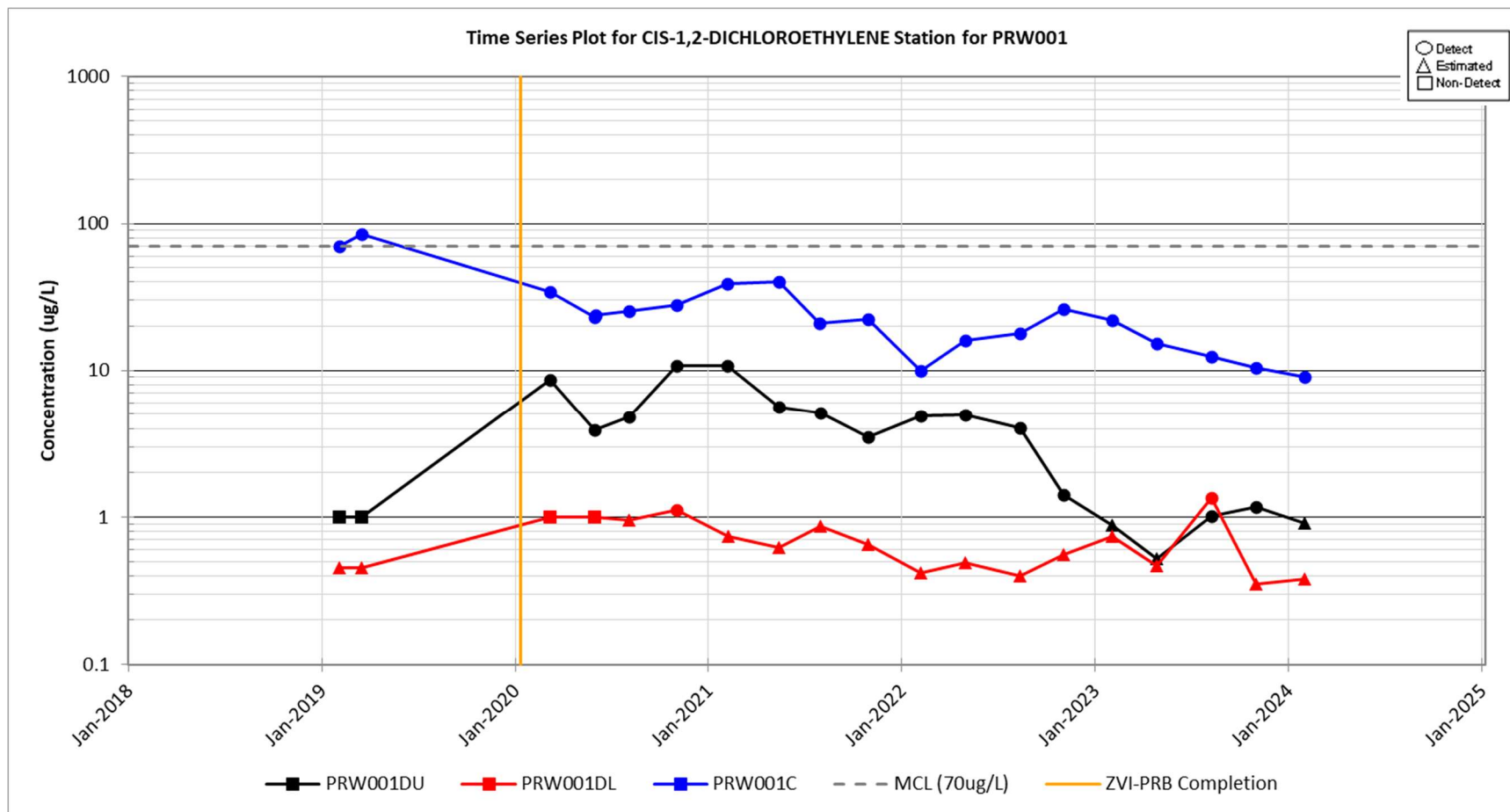


Figure C.12. Time Series Plot for Cis-1,2-Dichloroethylene at PRW001 Series Monitoring Wells

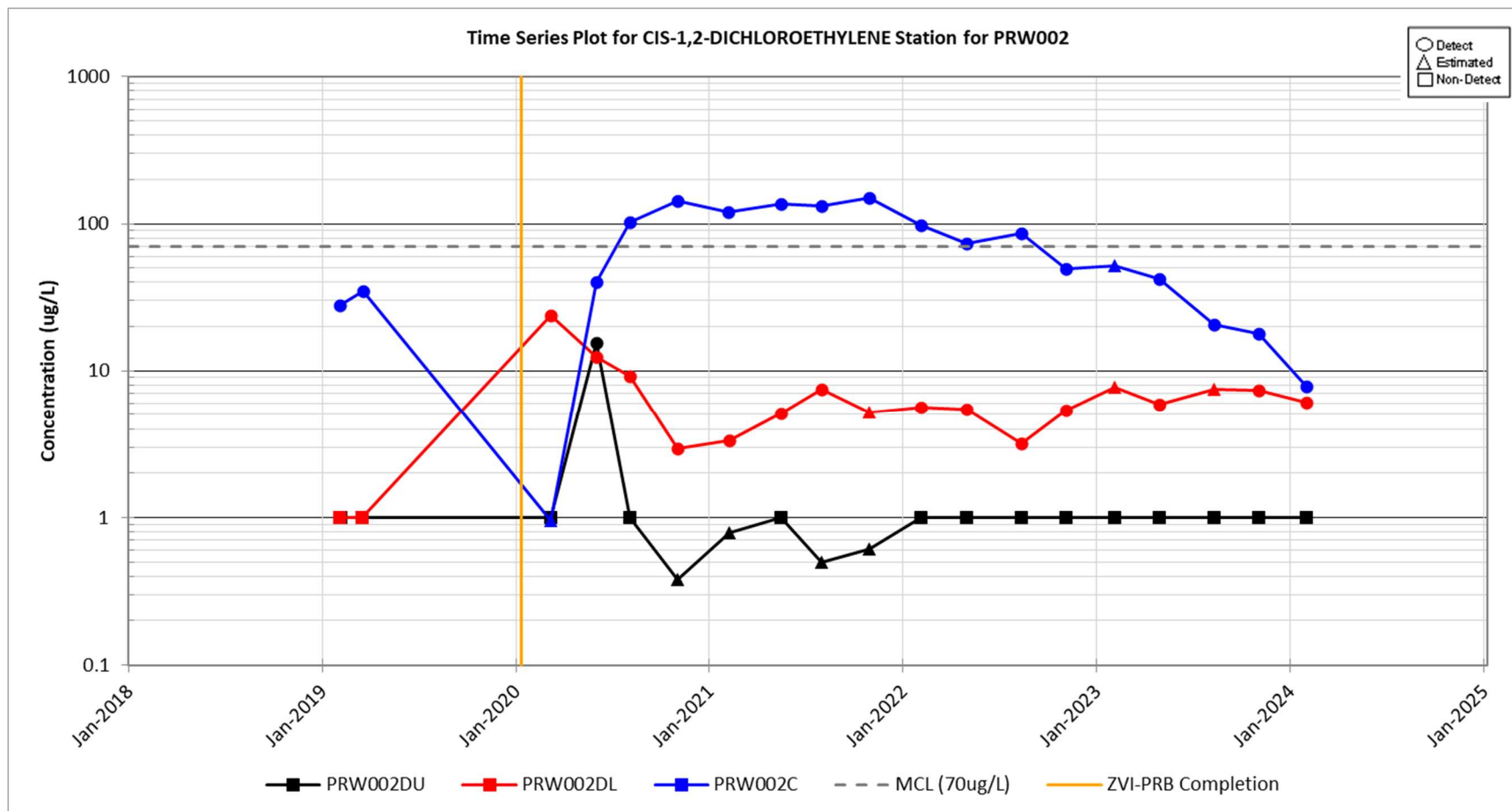


Figure C.13. Time Series Plot for Cis-1,2-Dichloroethylene at PRW002 Series Monitoring Wells

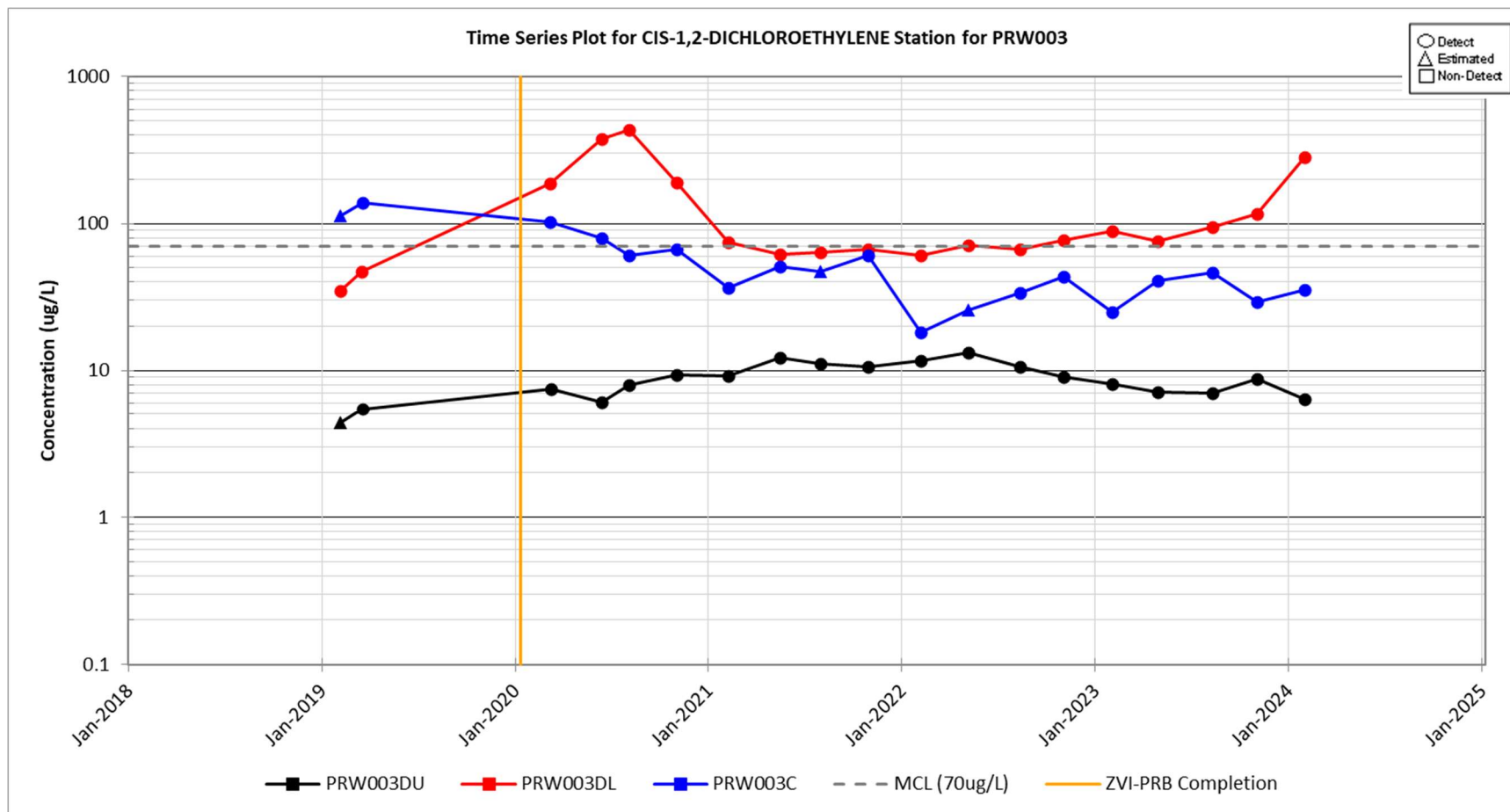


Figure C.14. Time Series Plot for Cis-1,2-Dichloroethylene at PRW003 Series Monitoring Wells

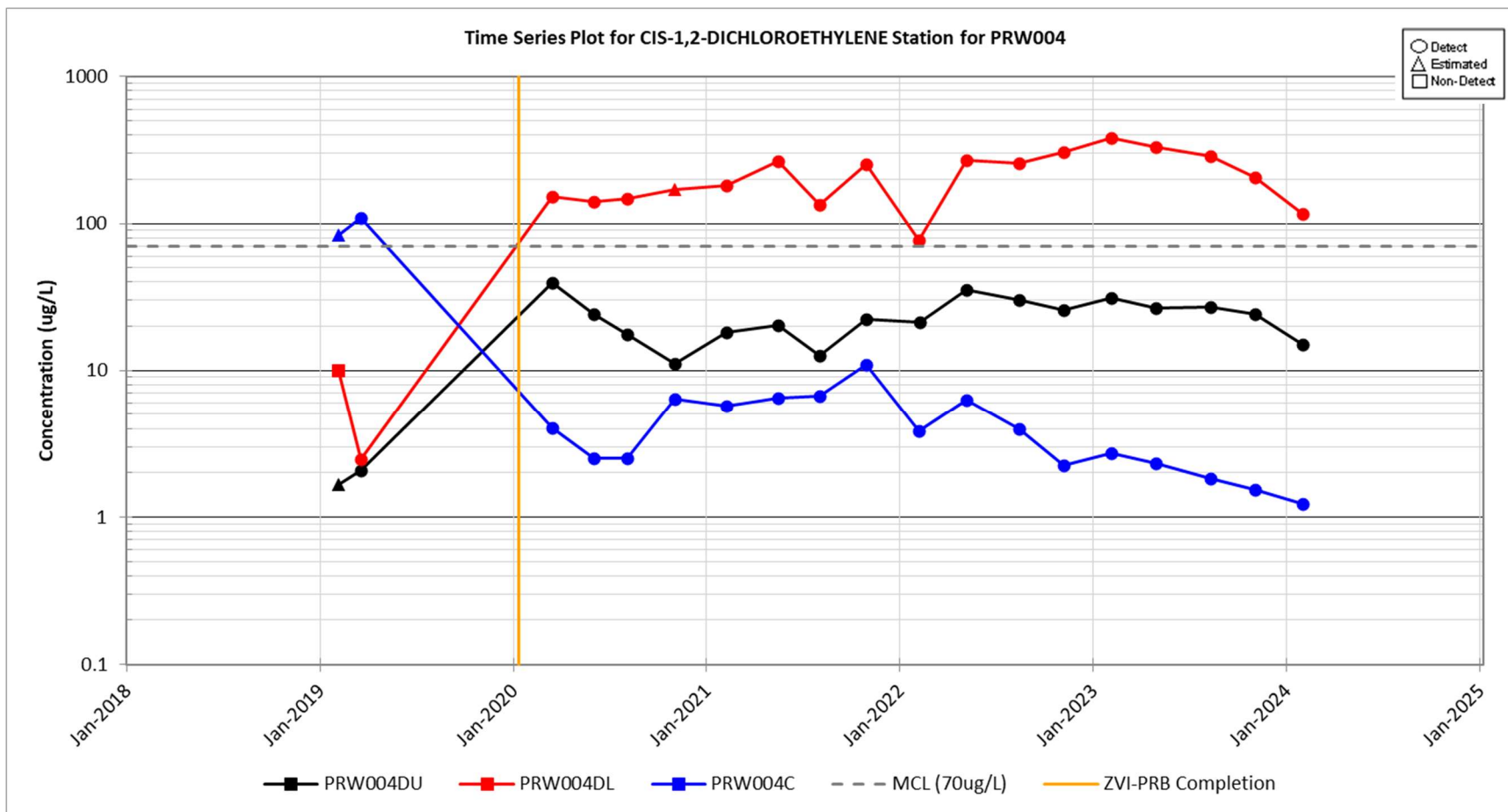


Figure C.15. Time Series Plot for Cis-1,2-Dichloroethylene at PRW004 Series Monitoring Wells

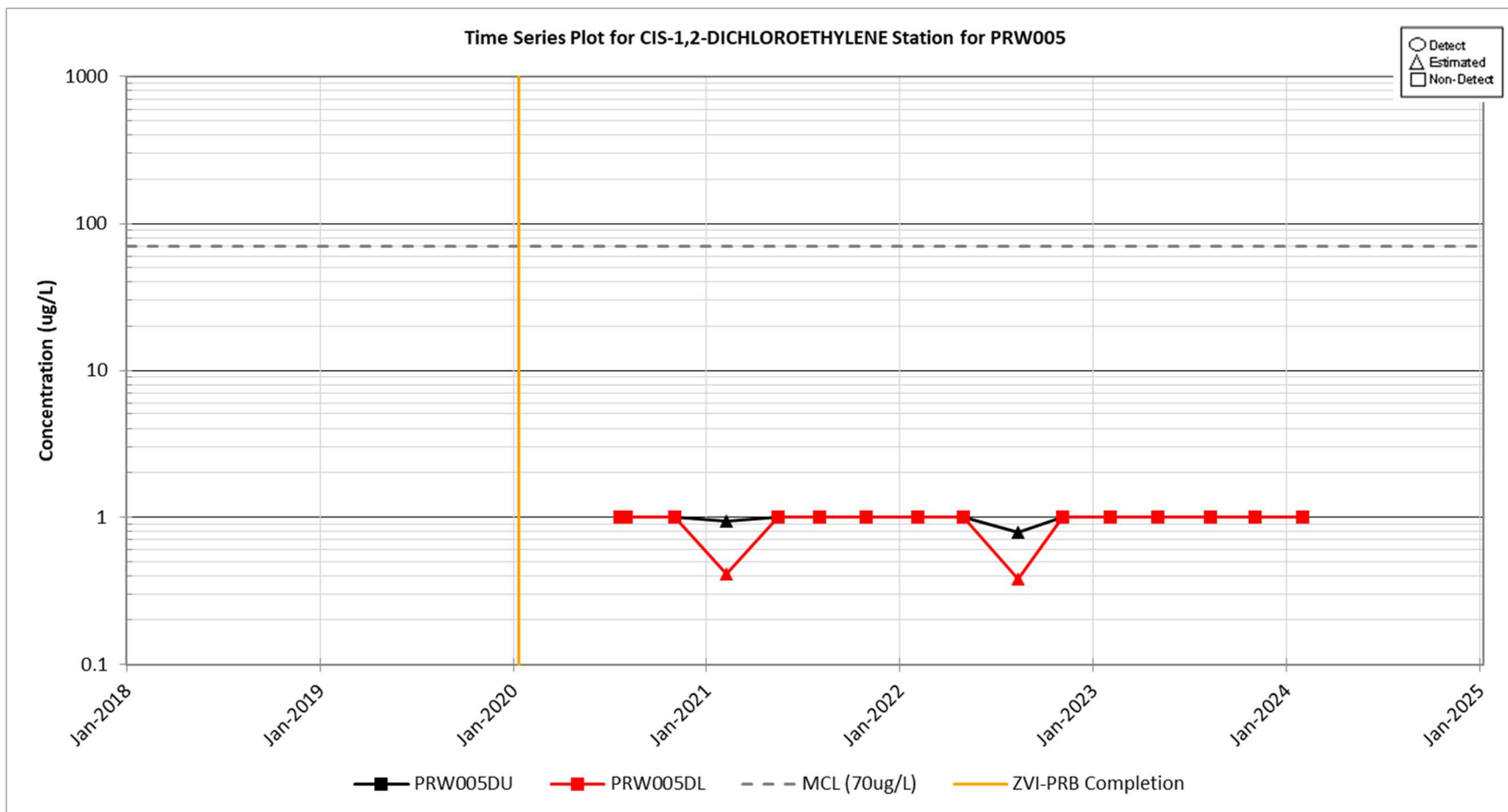


Figure C.16. Time Series Plot for Cis-1,2-Dichloroethylene at PRW005 Series Monitoring Wells

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914
Rev. 0

Appendix C, Page C-19 of C-48

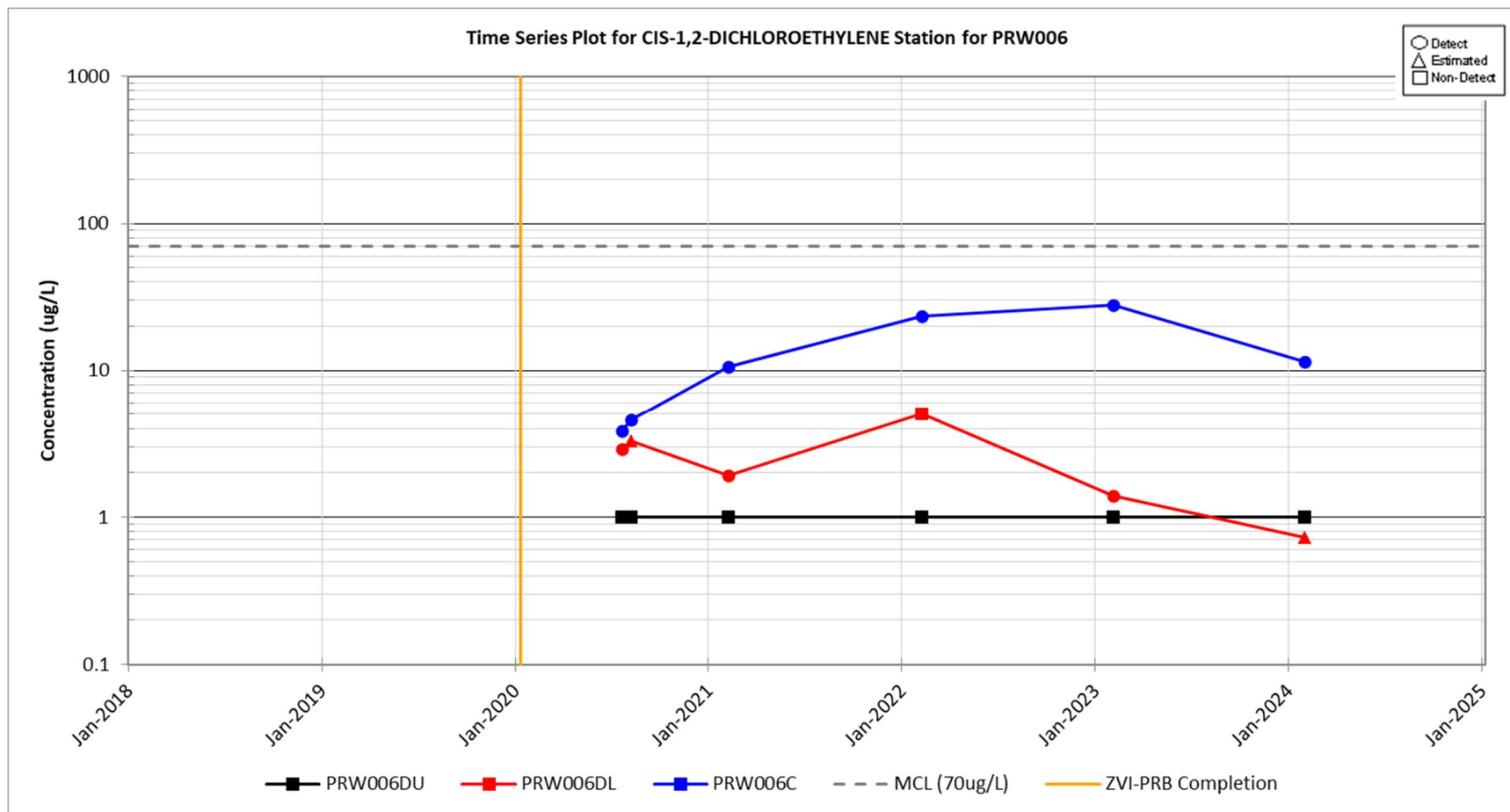


Figure C.17. Time Series Plot for Cis-1,2-Dichloroethylene at PRW006 Series Monitoring Wells

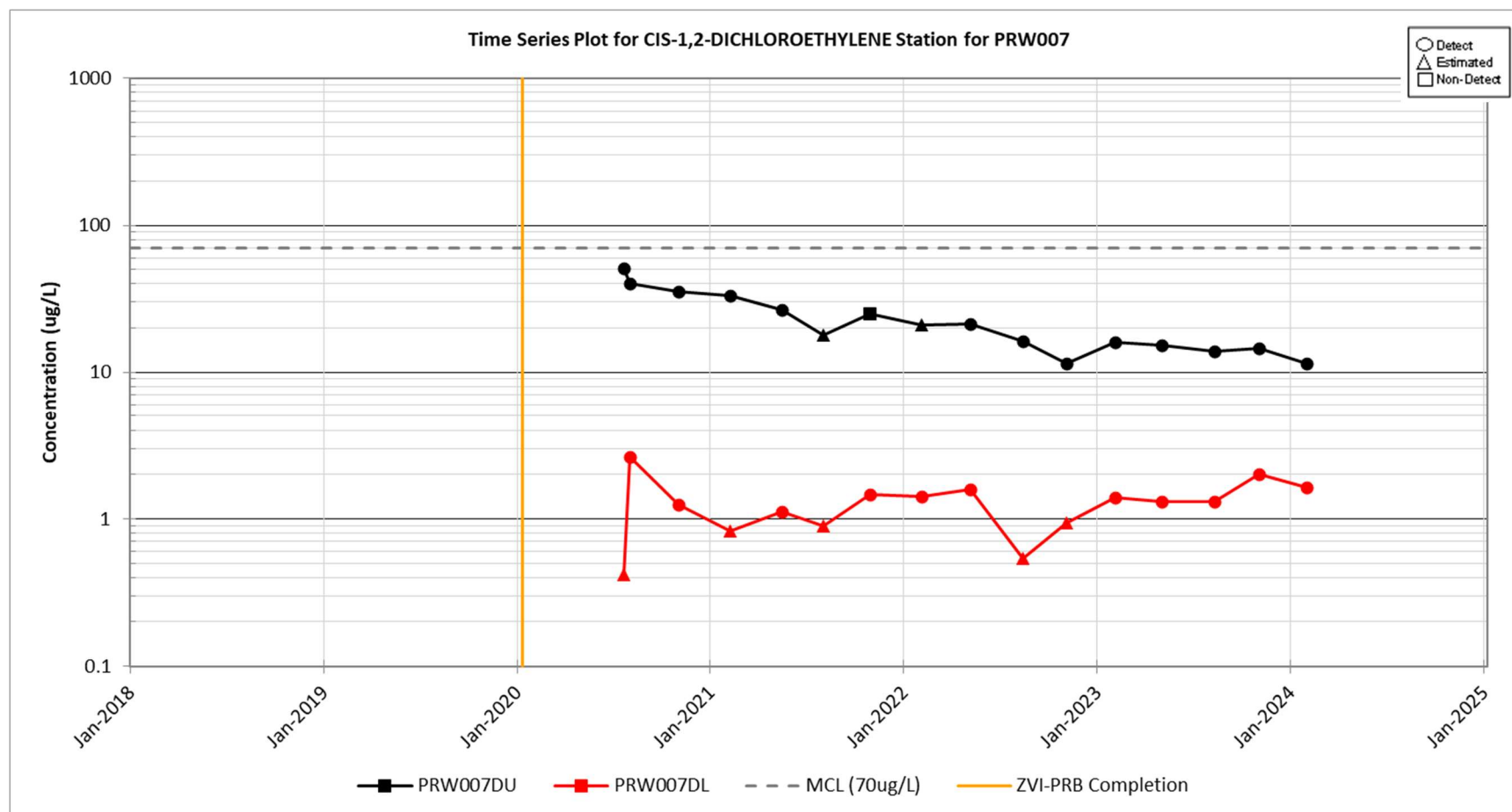


Figure C.18. Time Series Plot for Cis-1,2-Dichloroethylene at PRW007 Series Monitoring Wells

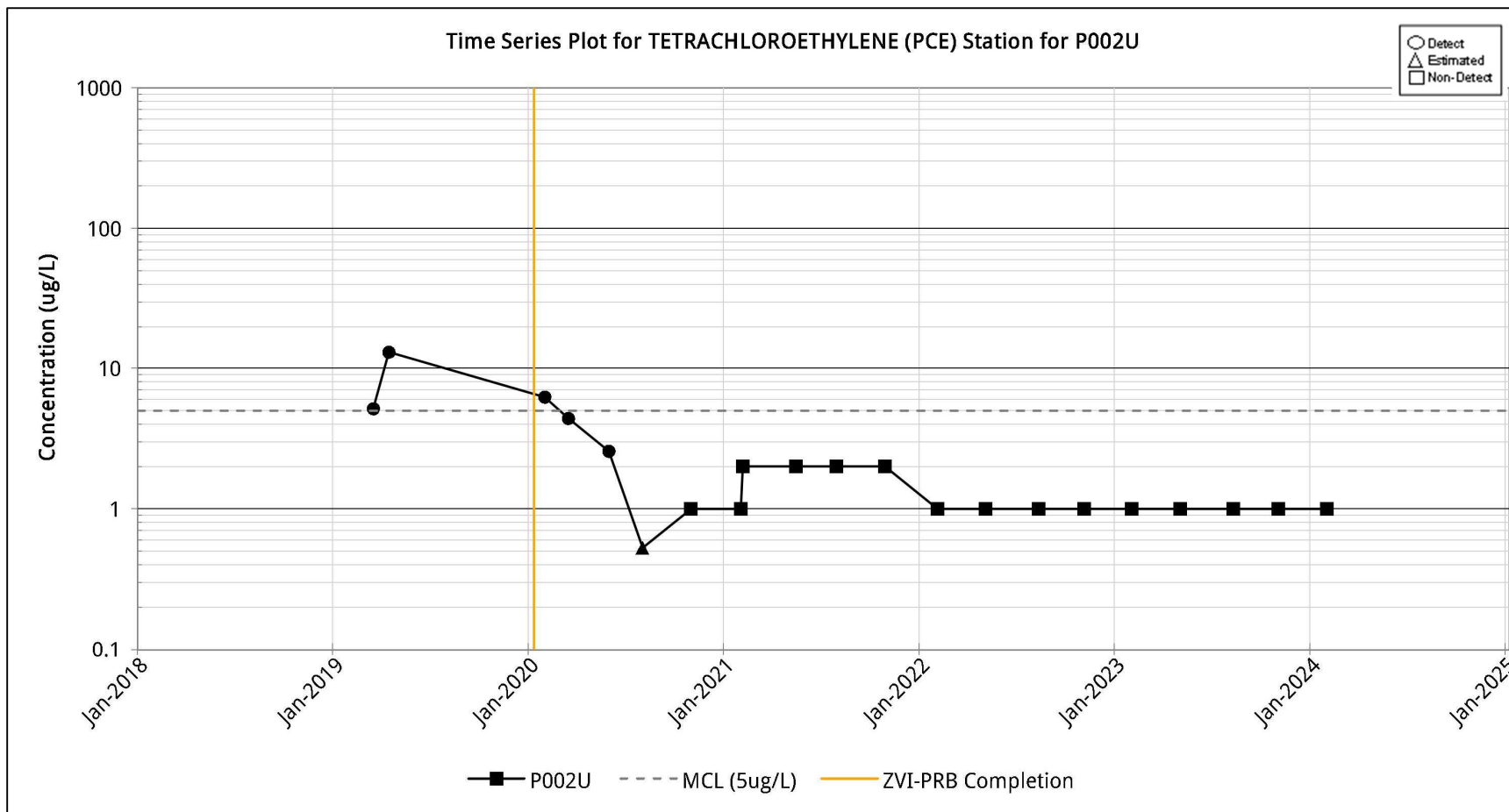


Figure C.19. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well P002U

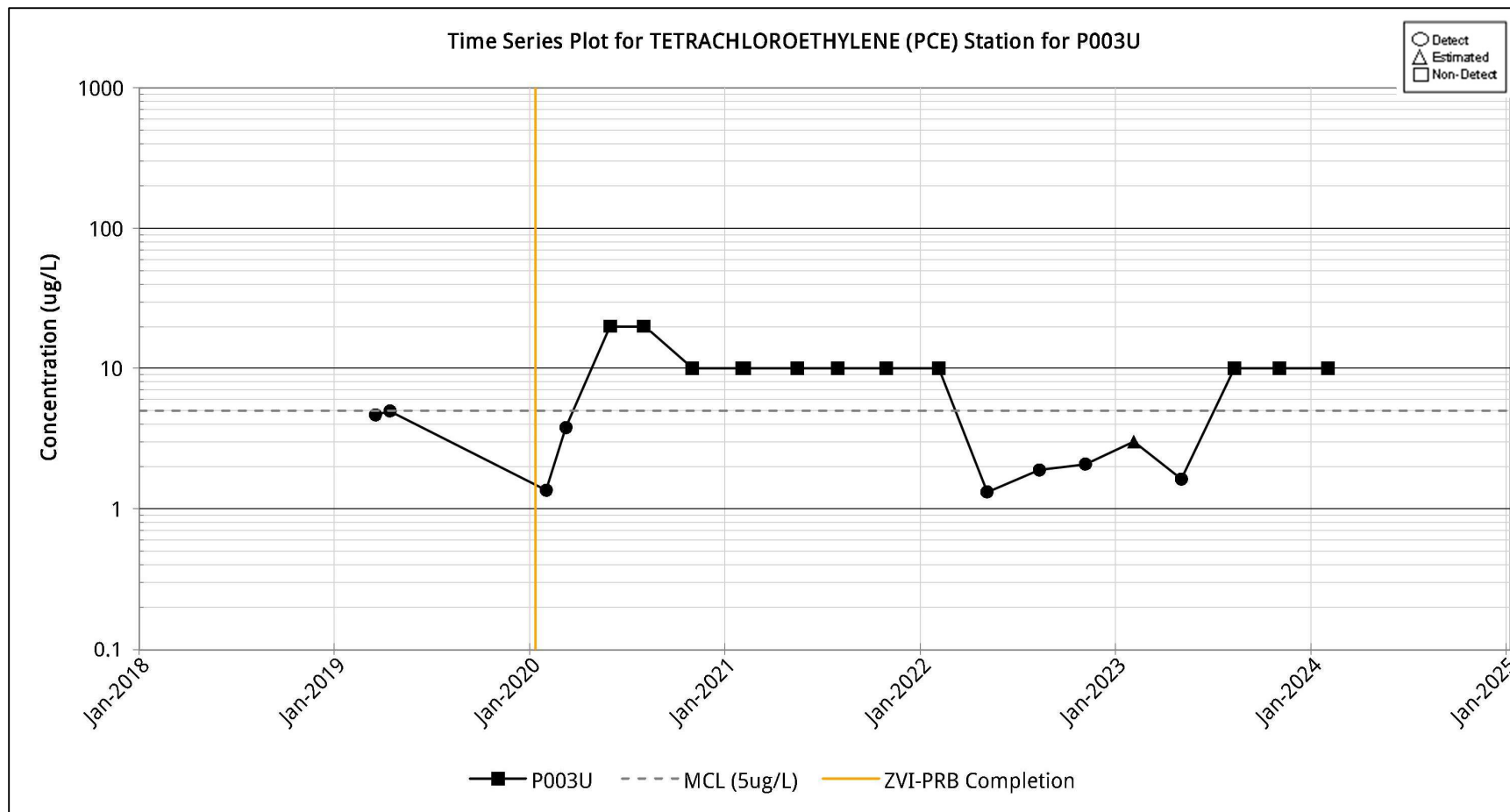


Figure C.20. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well P003U

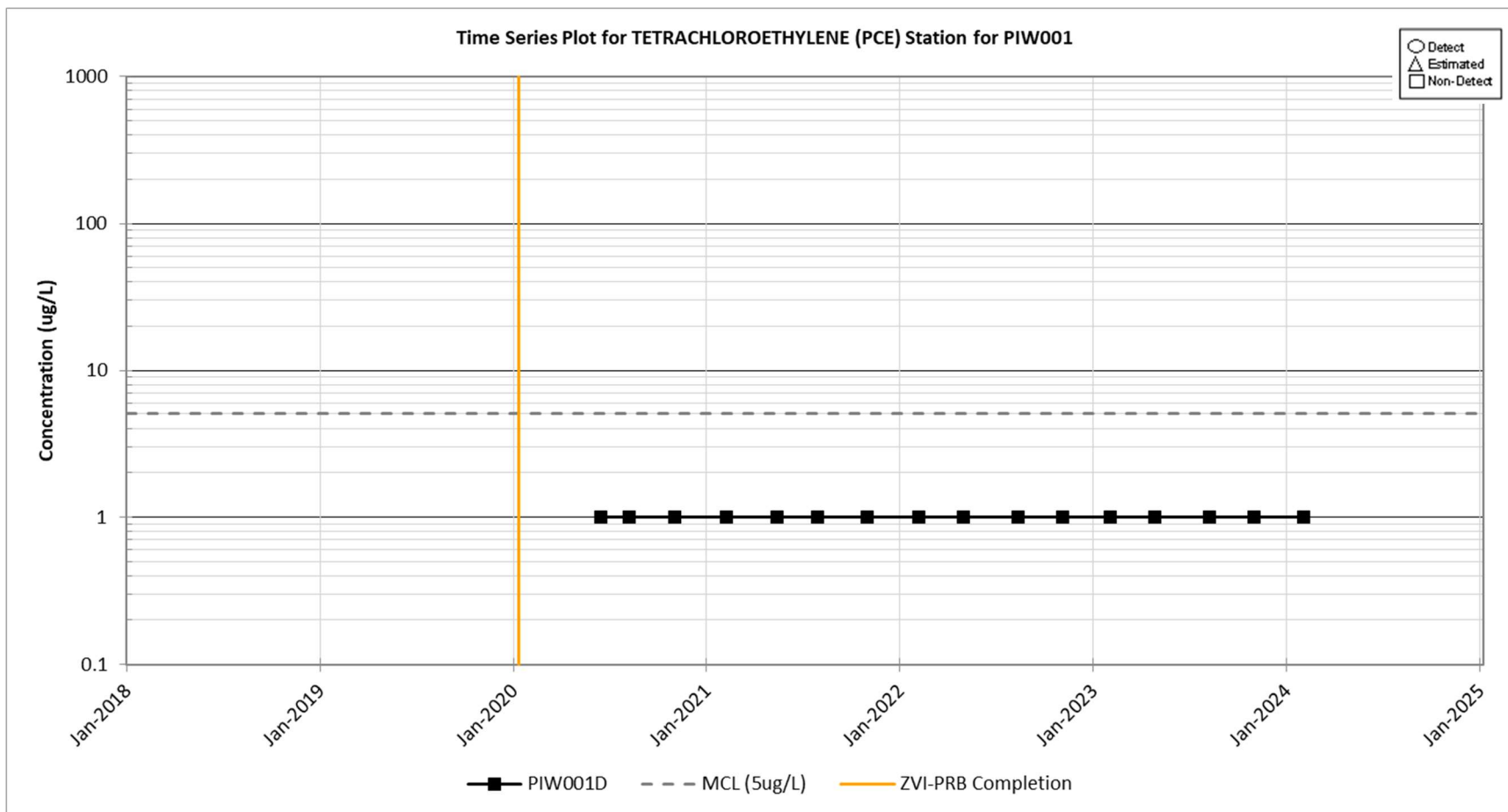


Figure C.22. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well PIW001D

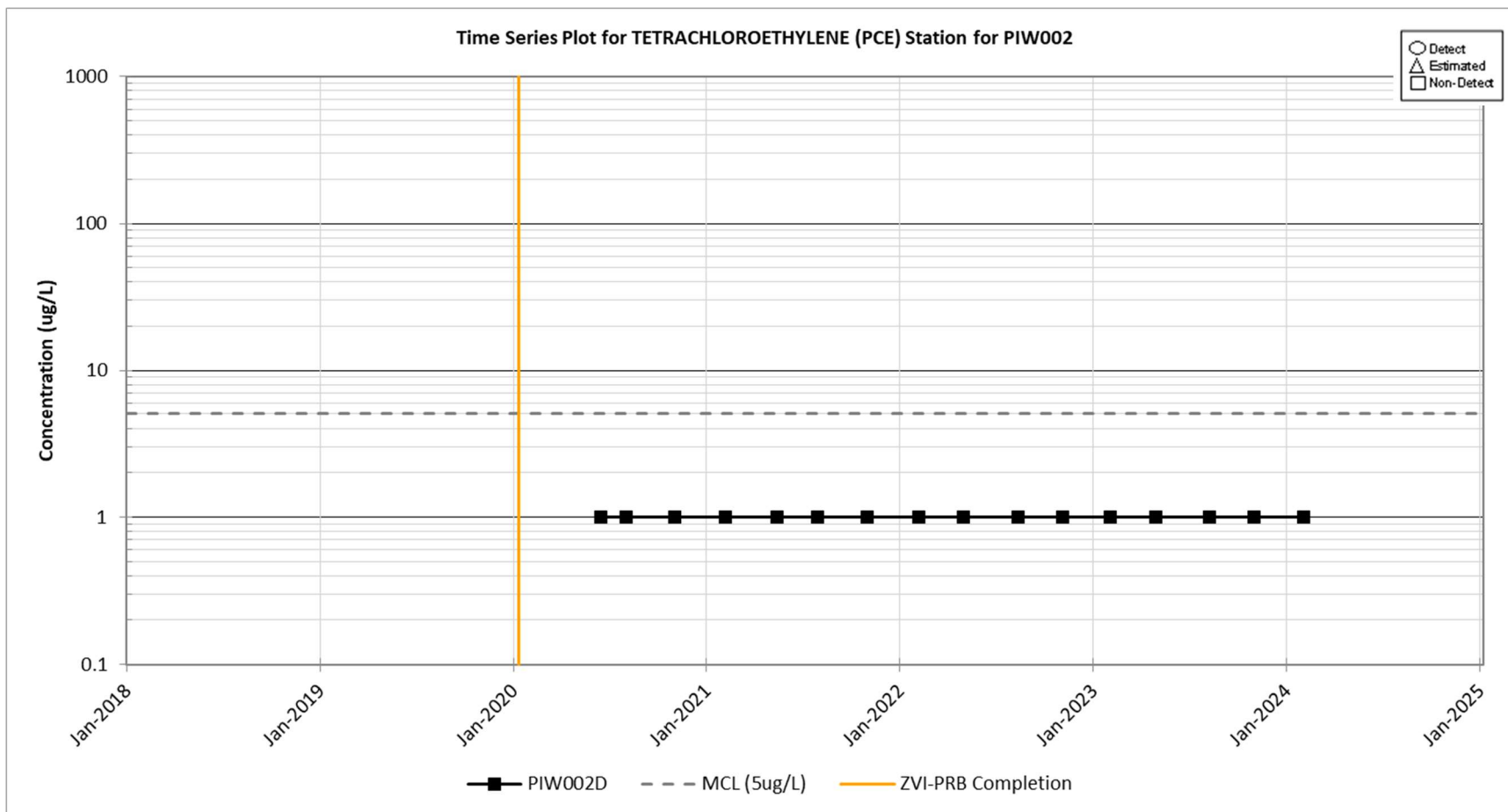


Figure C.23. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well PIW002D

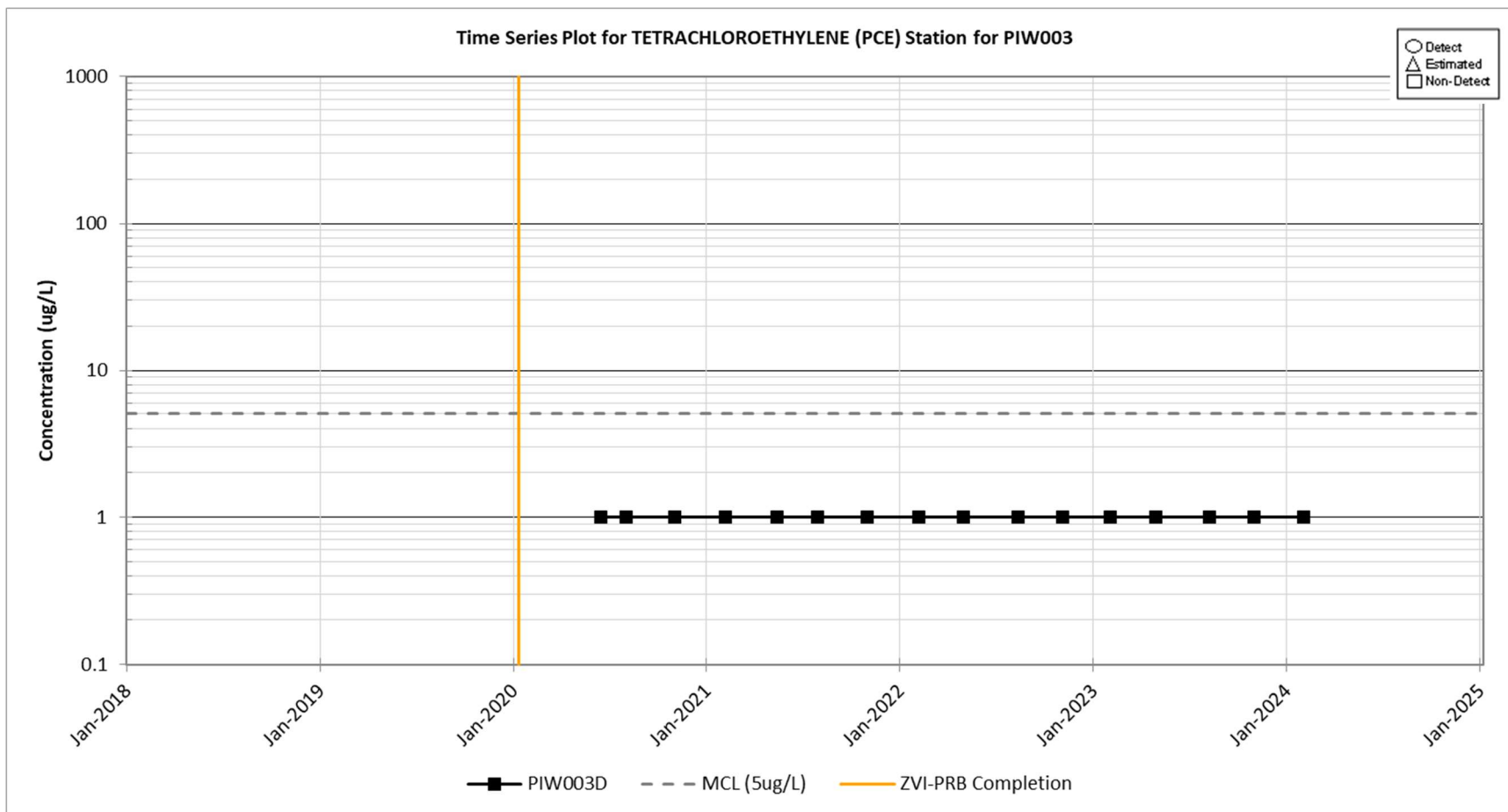


Figure C.24. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well PIW003D

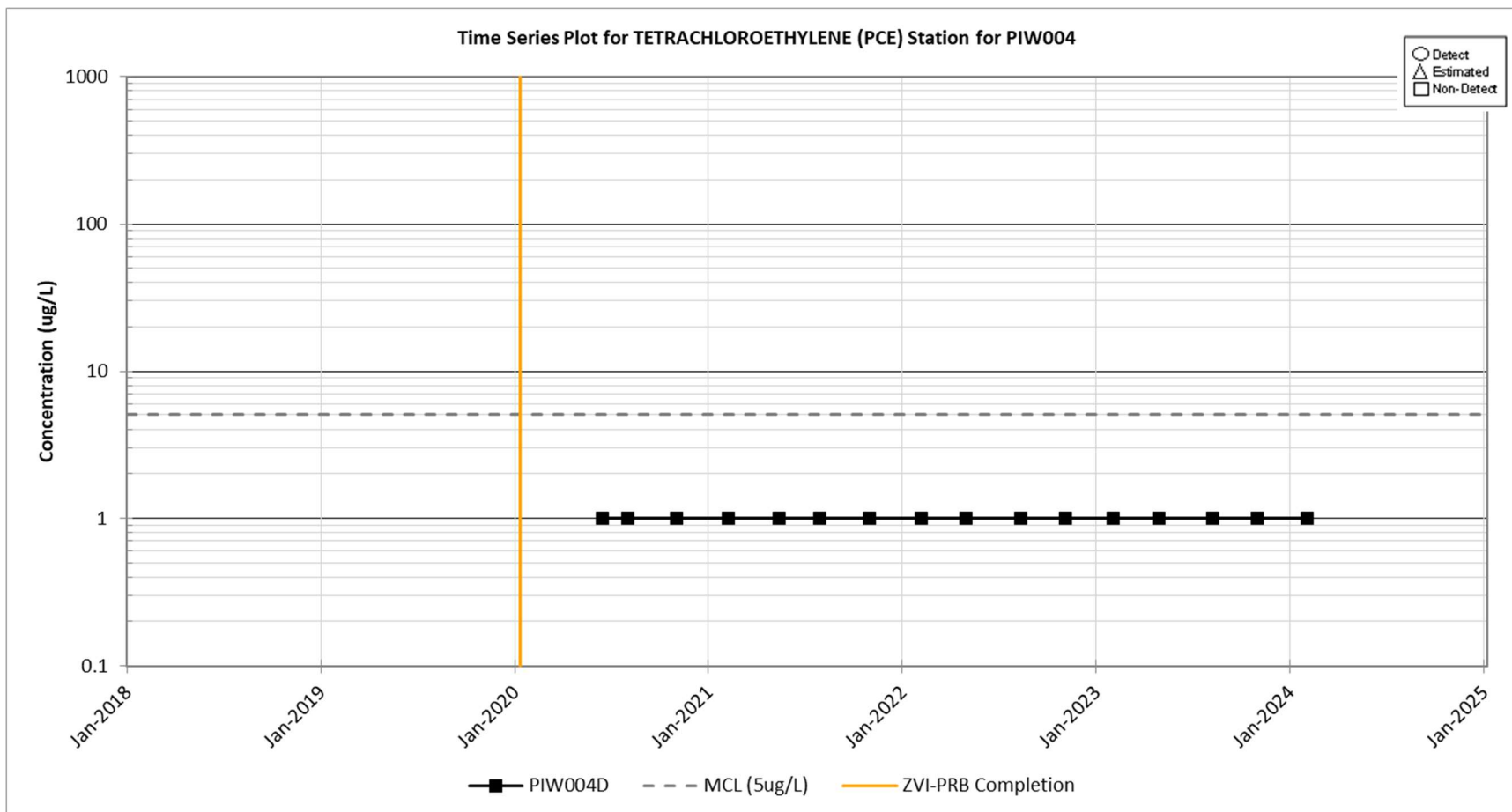


Figure C.25. Time Series Plot for Tetrachloroethylene (PCE) at Monitoring Well PIW004D

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914
Rev. 0

Appendix C, Page C-28 of C-48

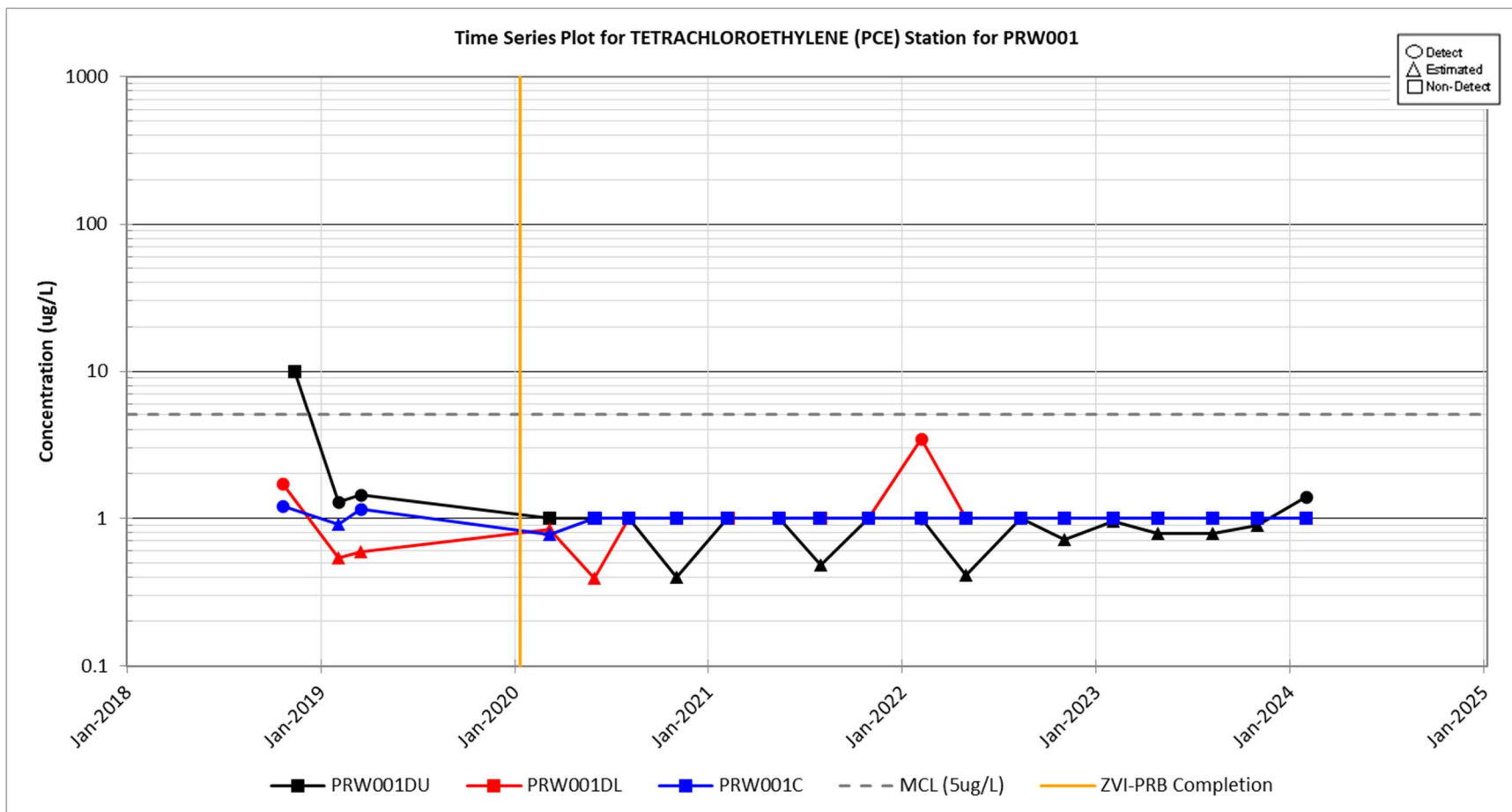


Figure C.26. Time Series Plot for Tetrachloroethylene (PCE) at PRW001 Series Monitoring Wells

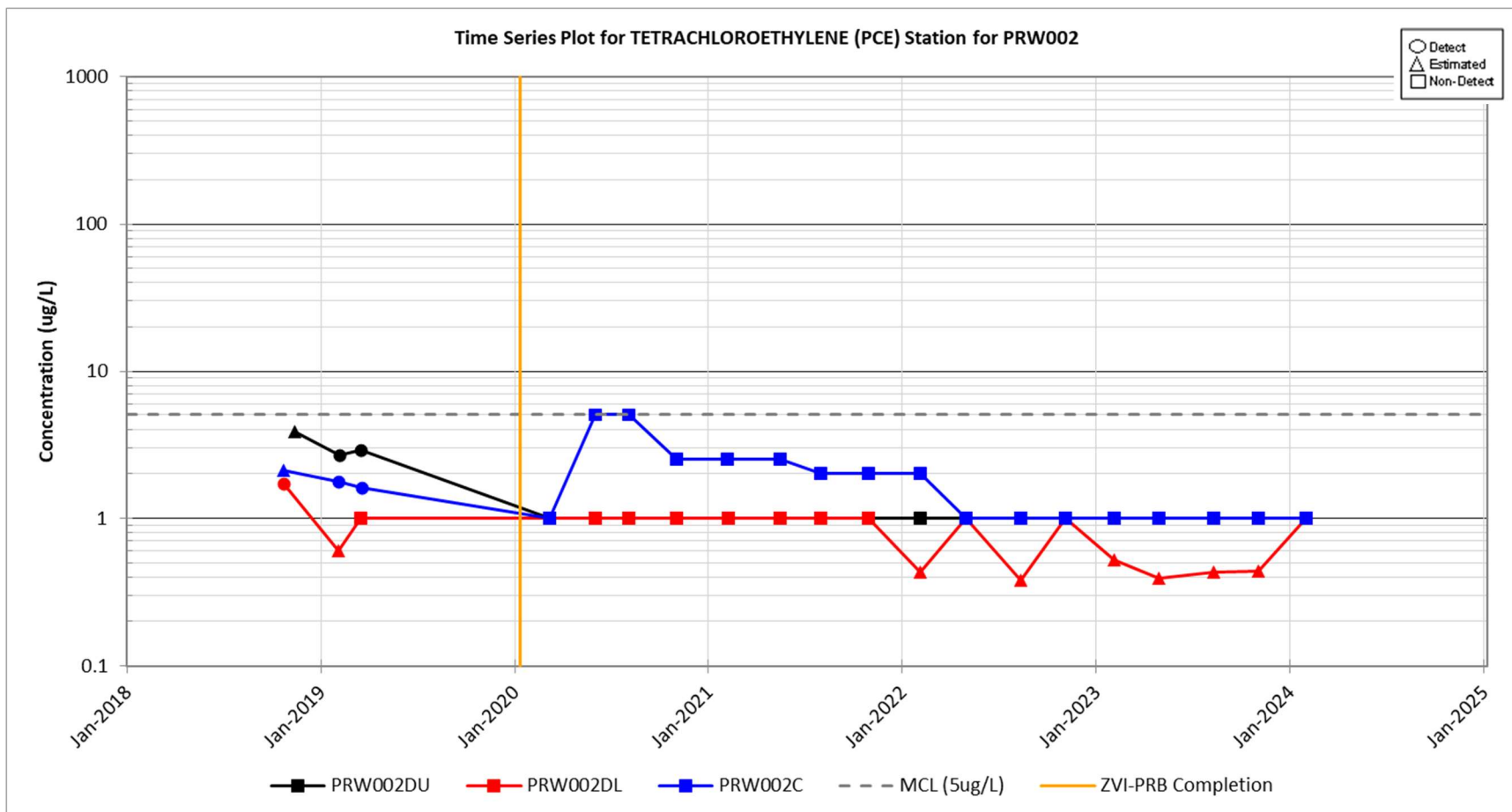


Figure C.27. Time Series Plot for Tetrachloroethylene (PCE) at PRW002 Series Monitoring Wells

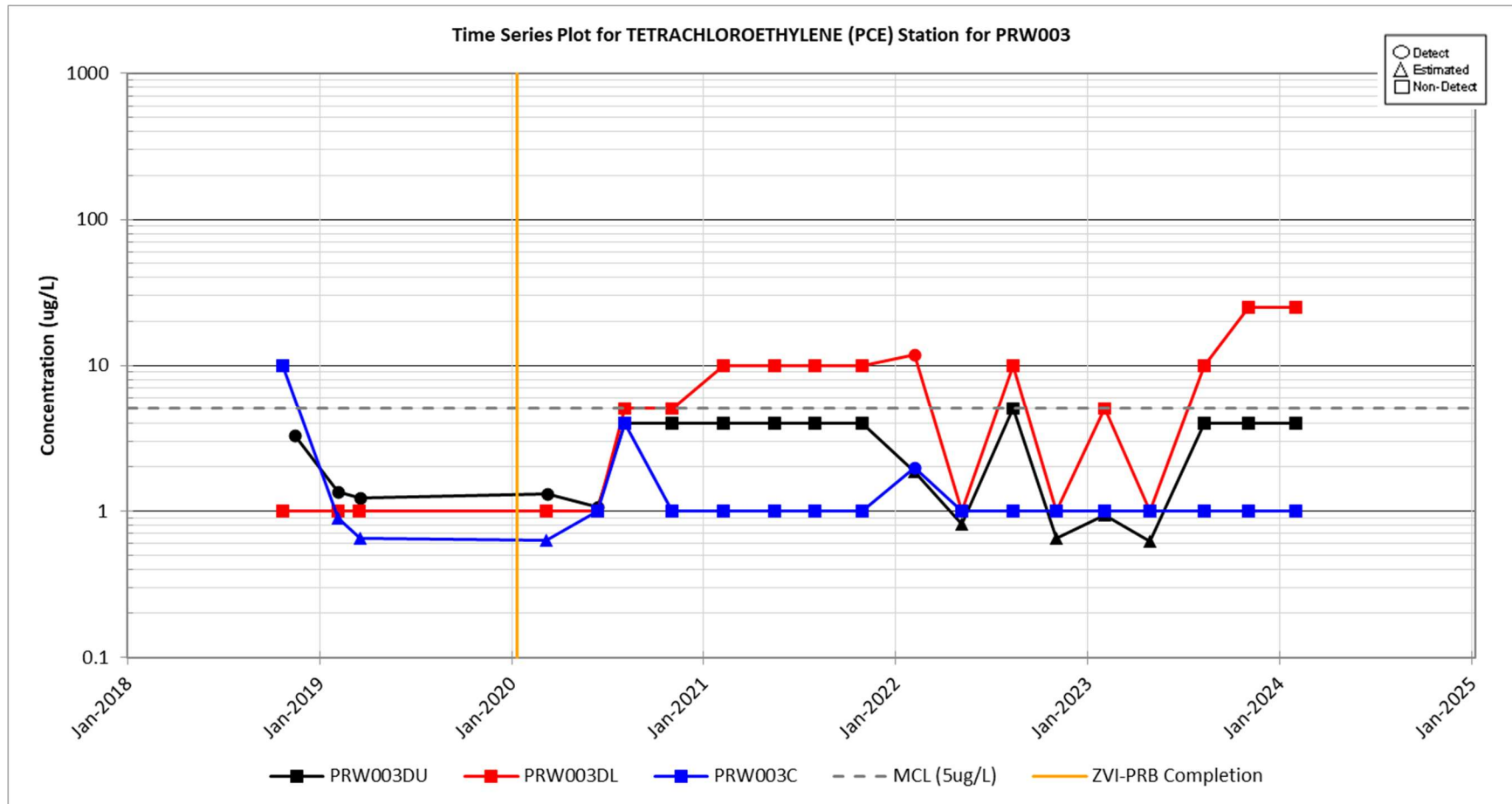


Figure C.28. Time Series Plot for Tetrachloroethylene (PCE) at PRW003 Series Monitoring Wells

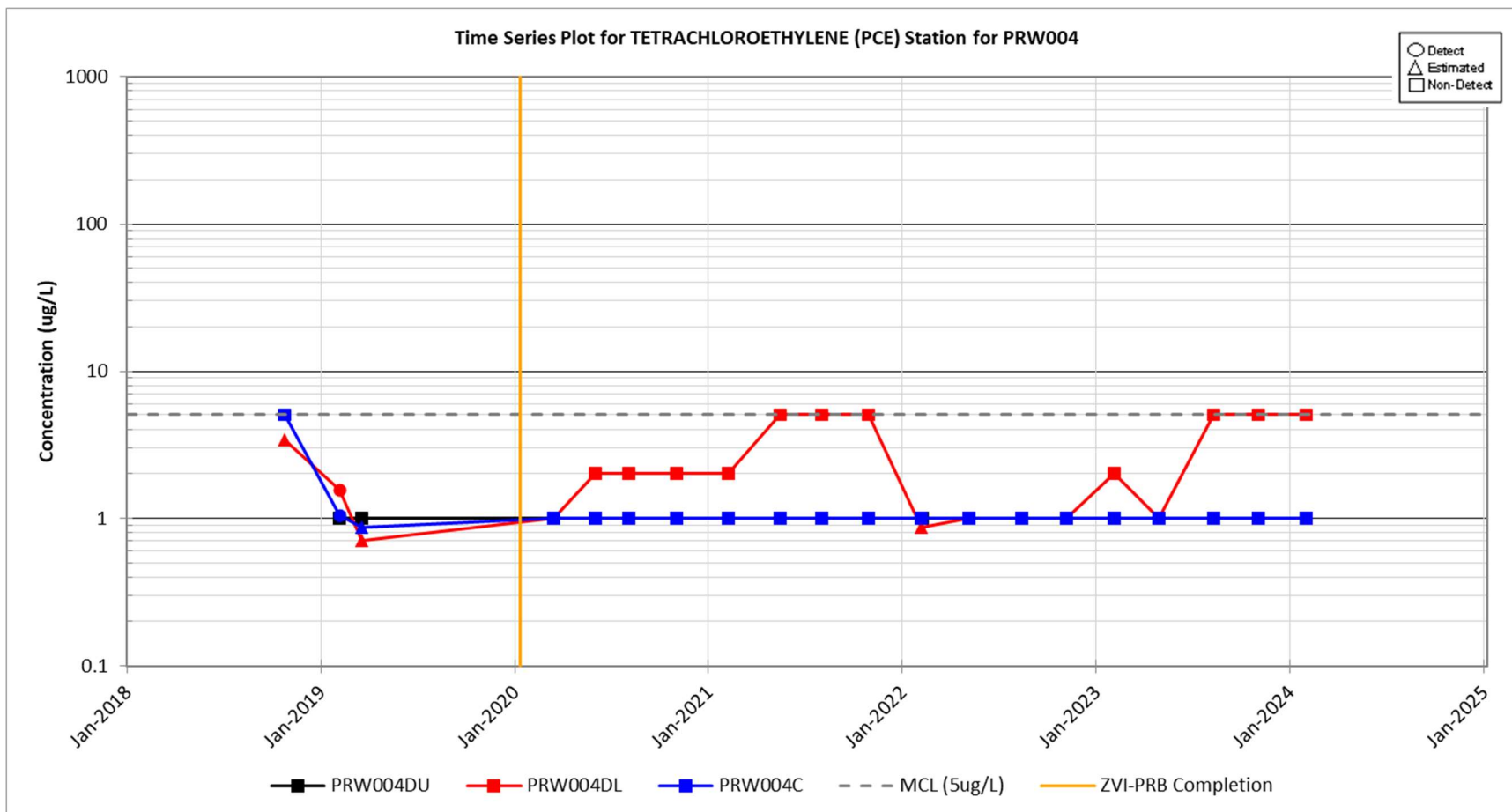


Figure C.29. Time Series Plot for Tetrachloroethylene (PCE) at PRW004 Series Monitoring Wells

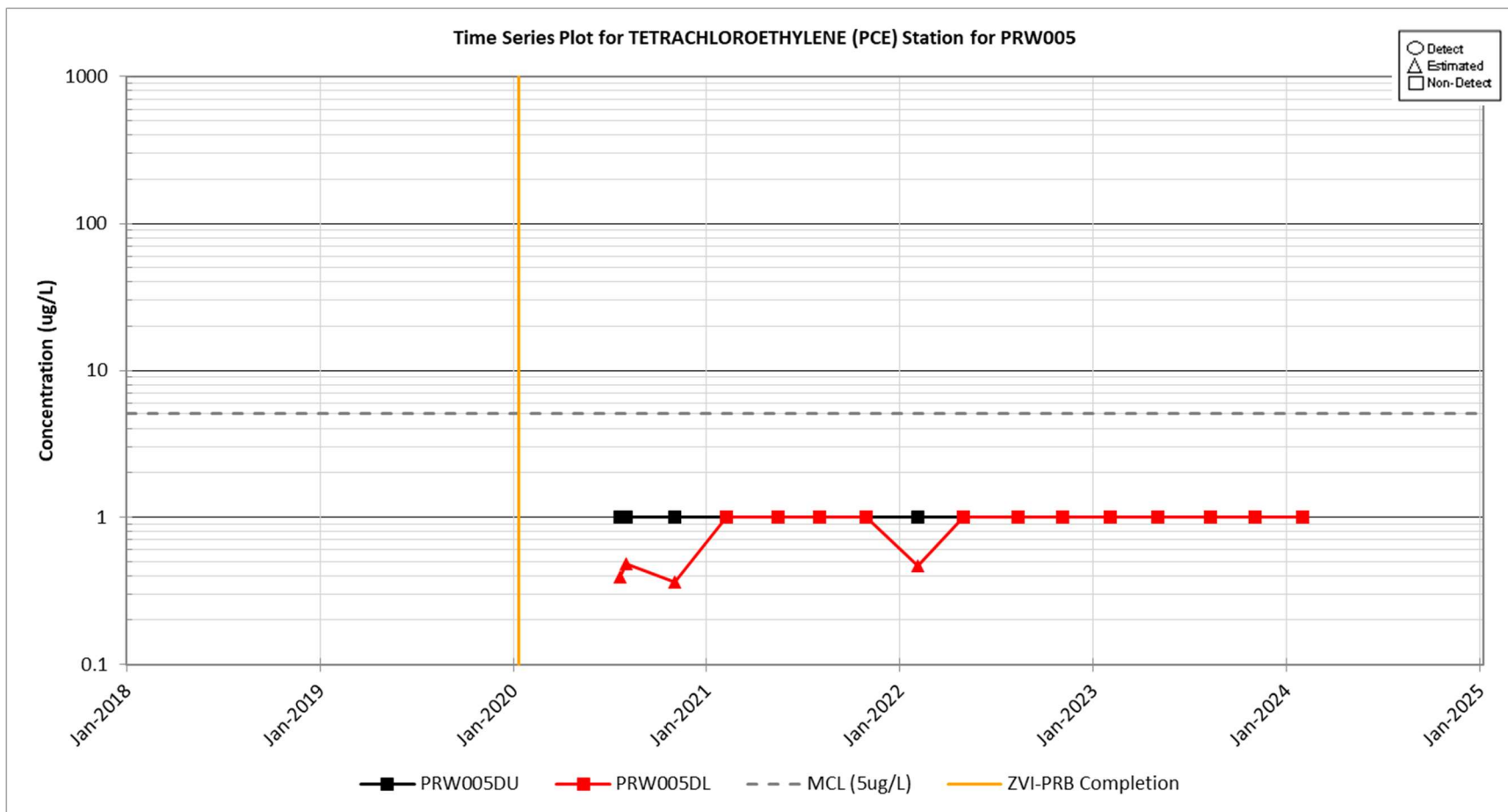


Figure C.30. Time Series Plot for Tetrachloroethylene (PCE) at PRW005 Series Monitoring Wells

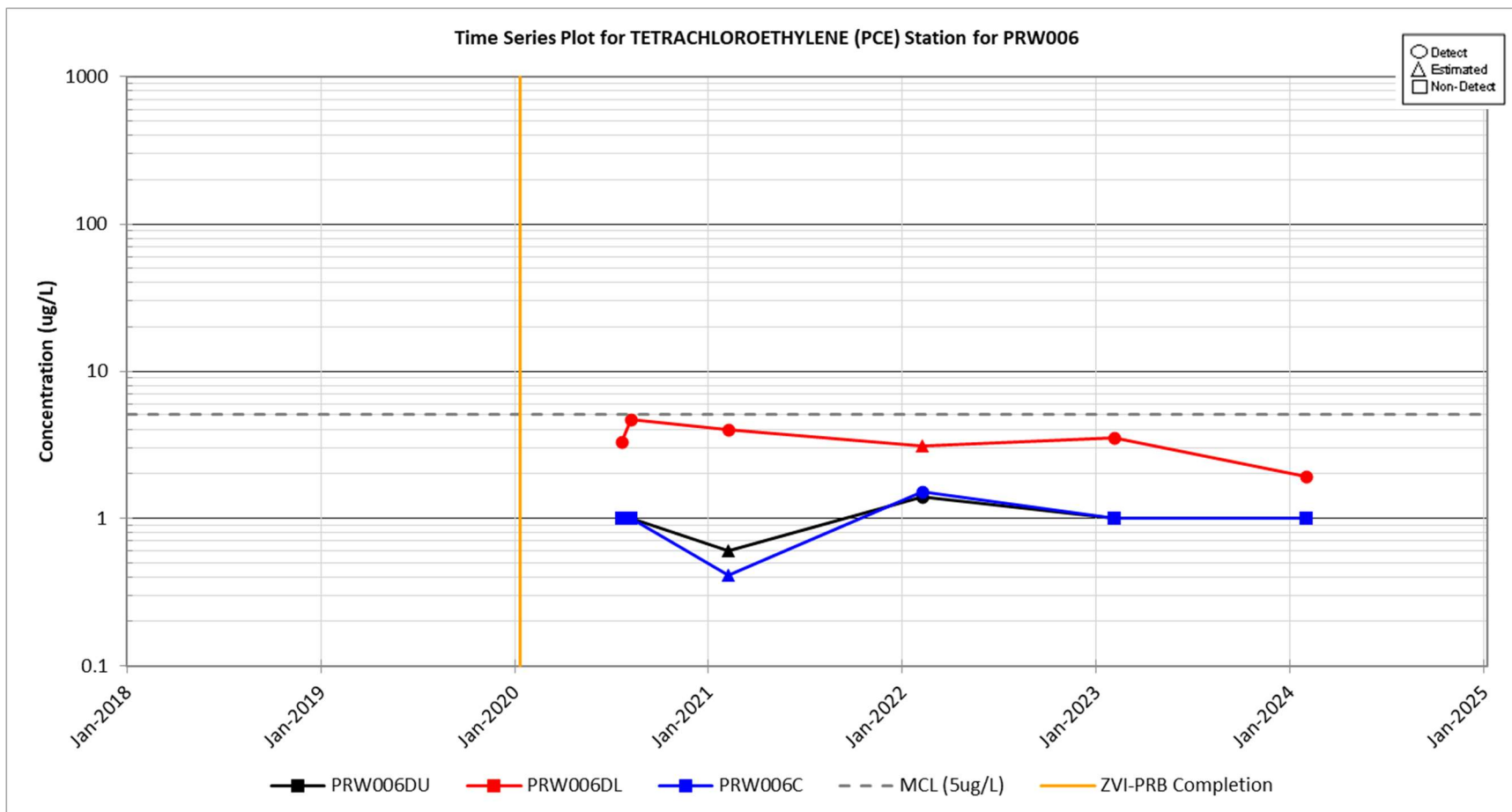


Figure C.31. Time Series Plot for Tetrachloroethylene (PCE) at PRW006 Series Monitoring Wells

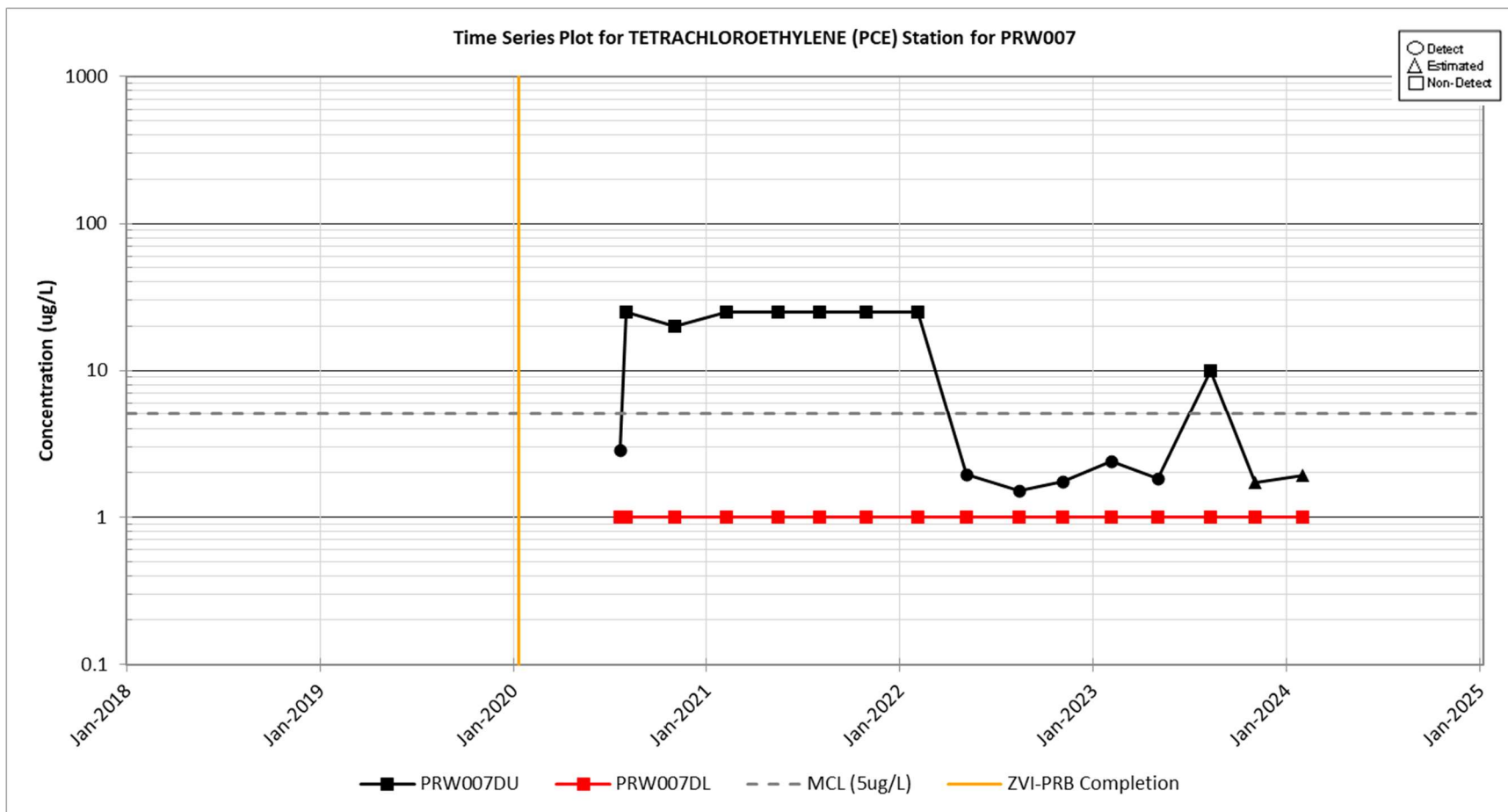


Figure C.32. Time Series Plot for Tetrachloroethylene (PCE) at PRW007 Series Monitoring Wells

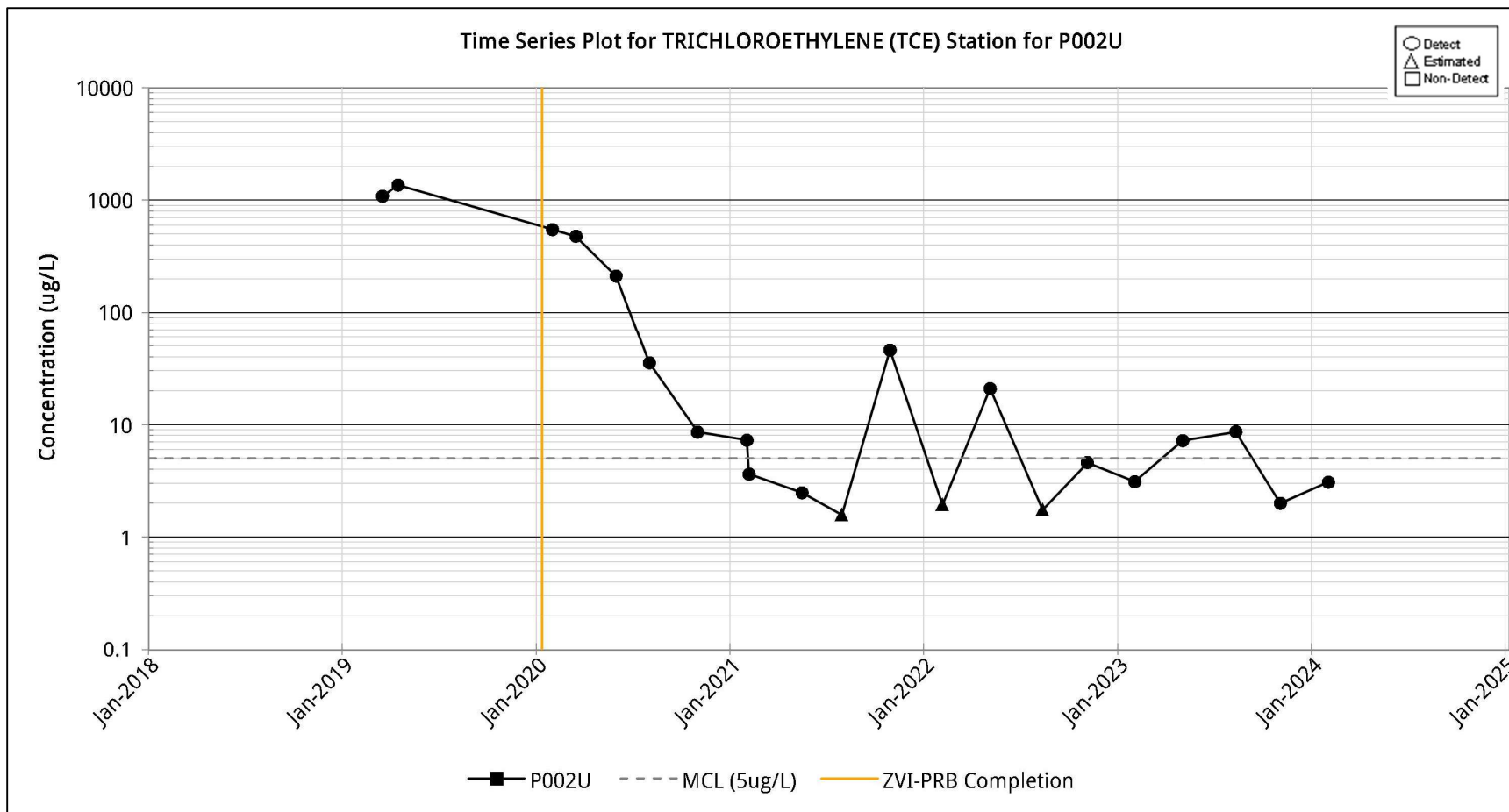


Figure C.33. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well P002U

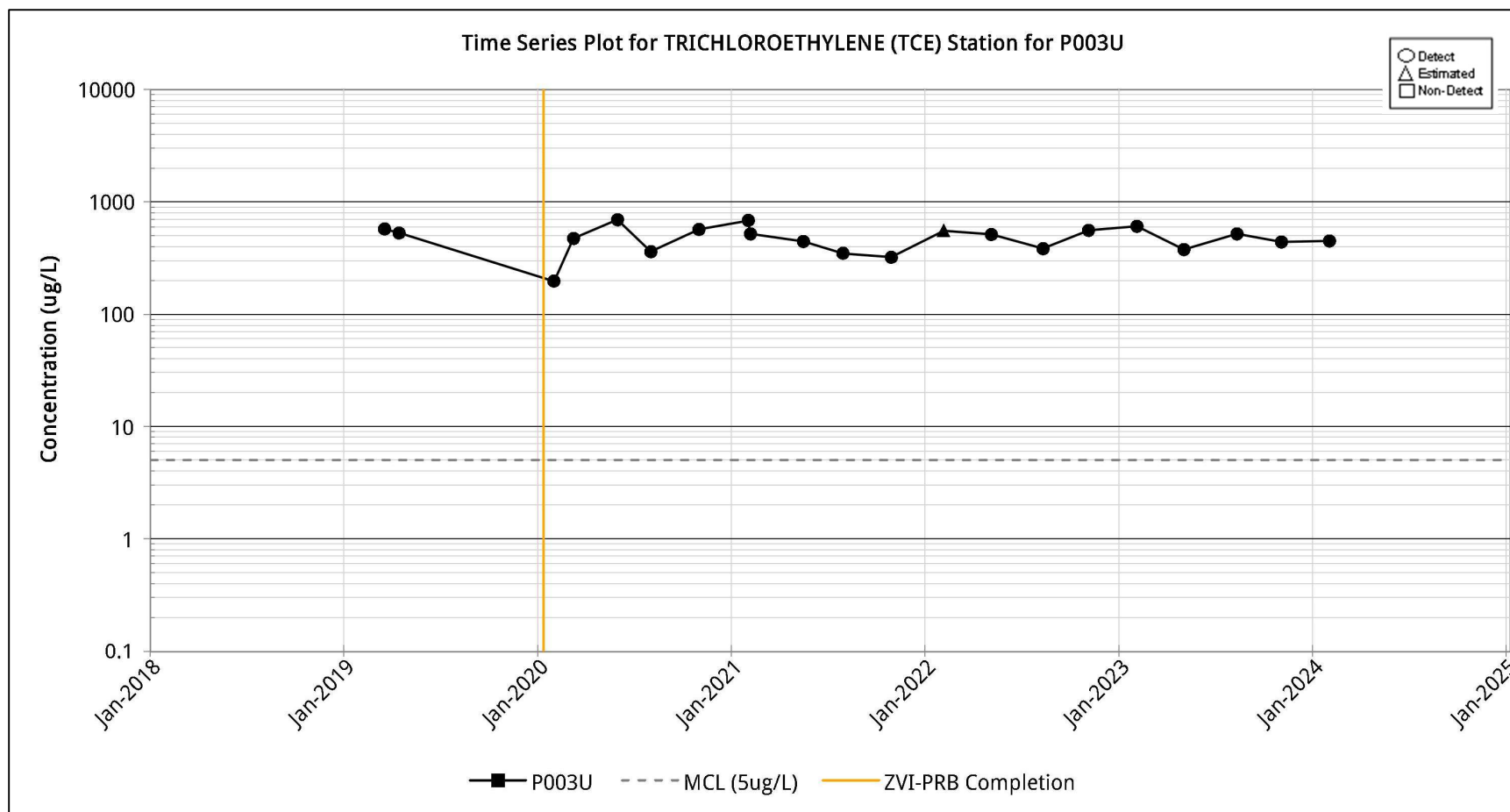


Figure C.34. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well P003U

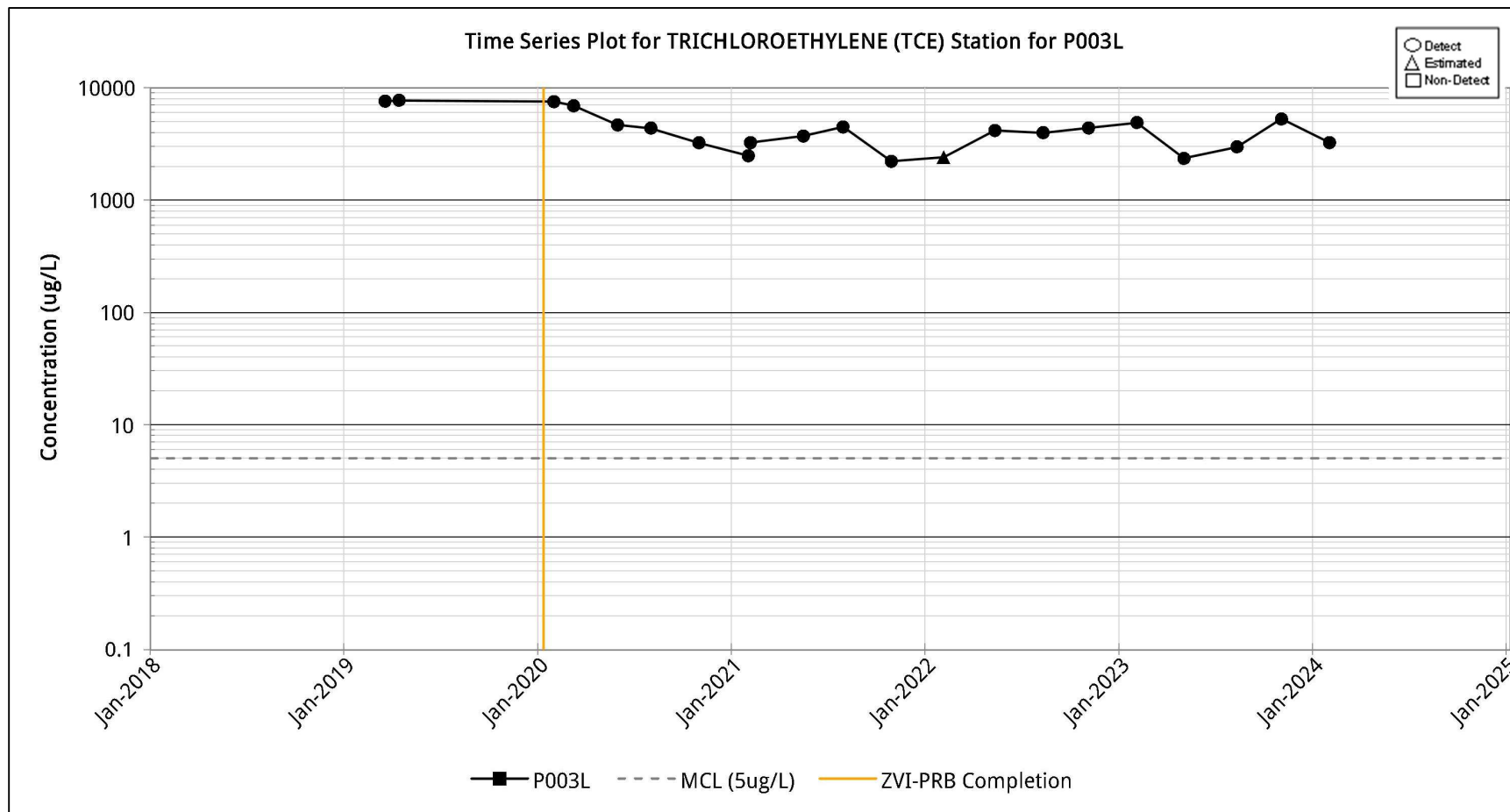


Figure C.35. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well P003L

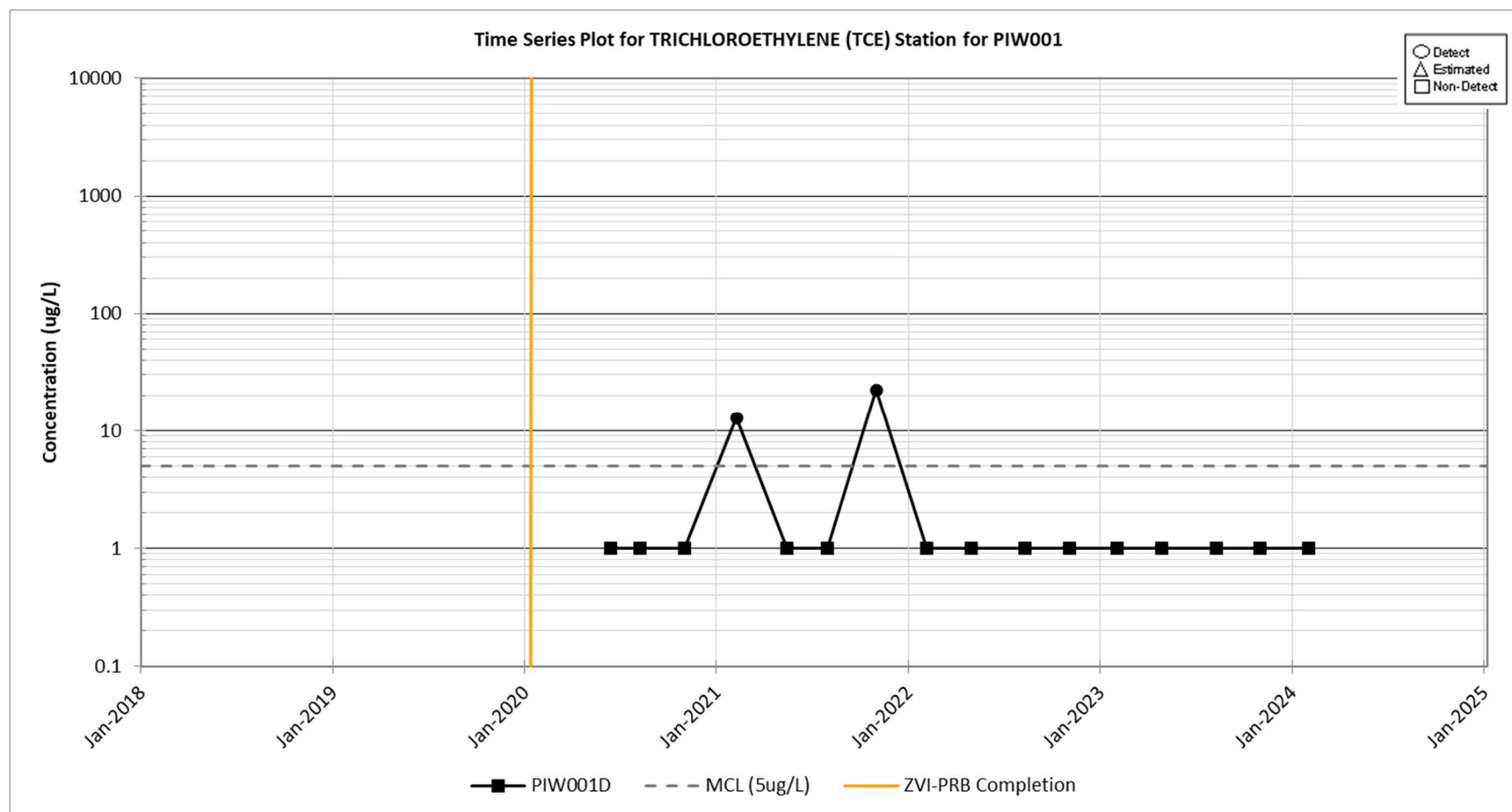


Figure C.36. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well PIW001D

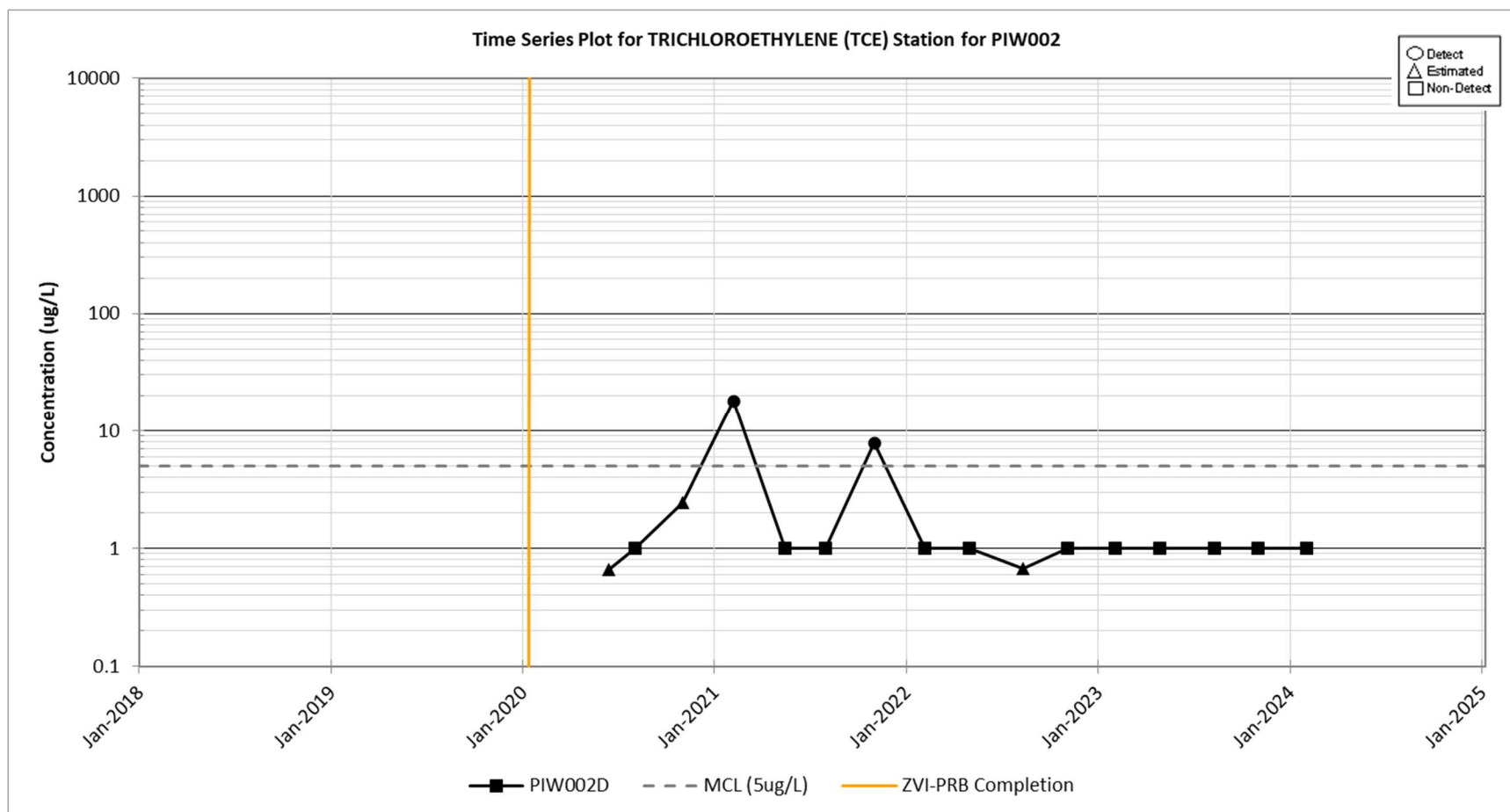


Figure C.37. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well PIW002D

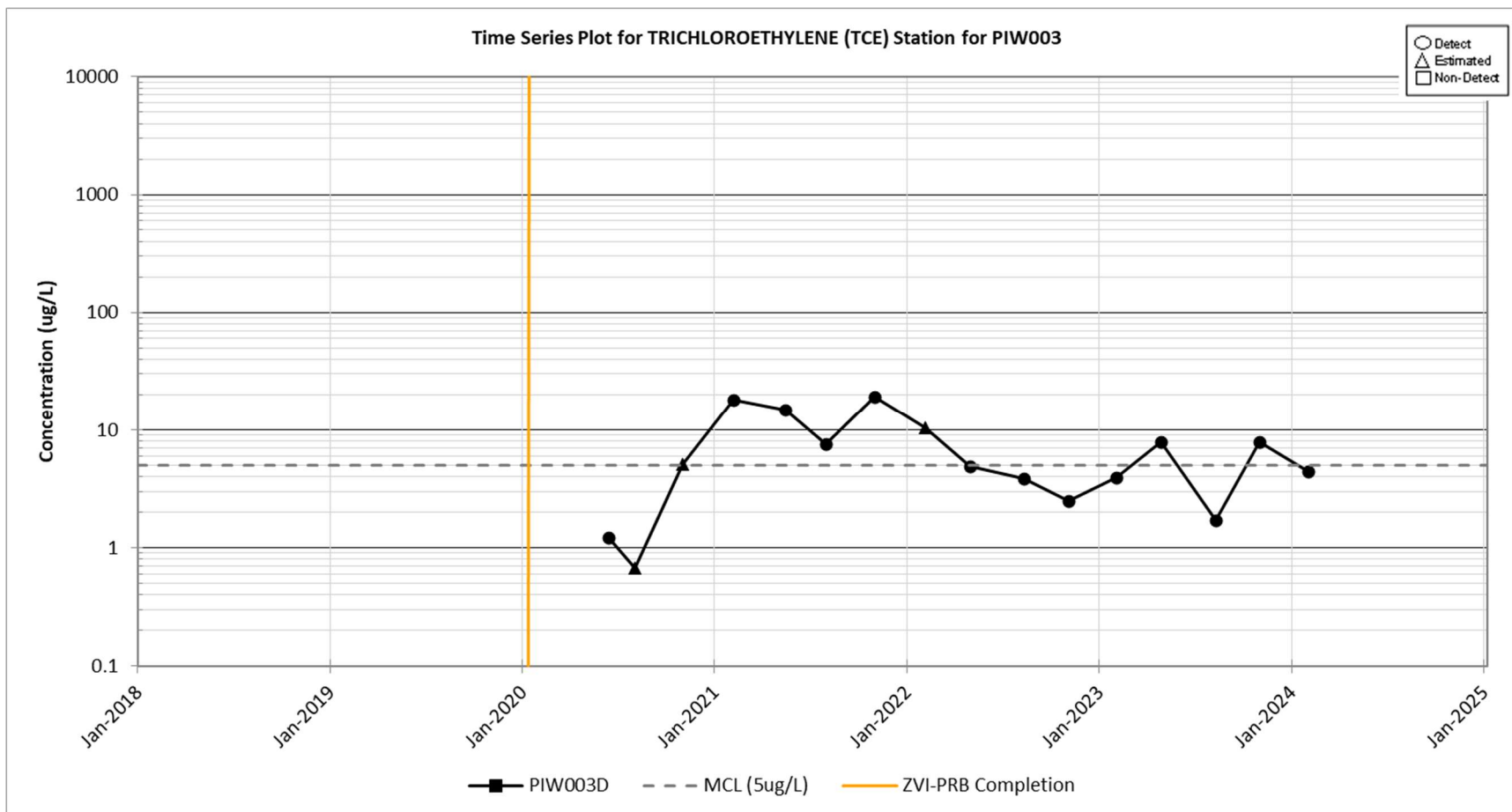


Figure C.38. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well PIW003D

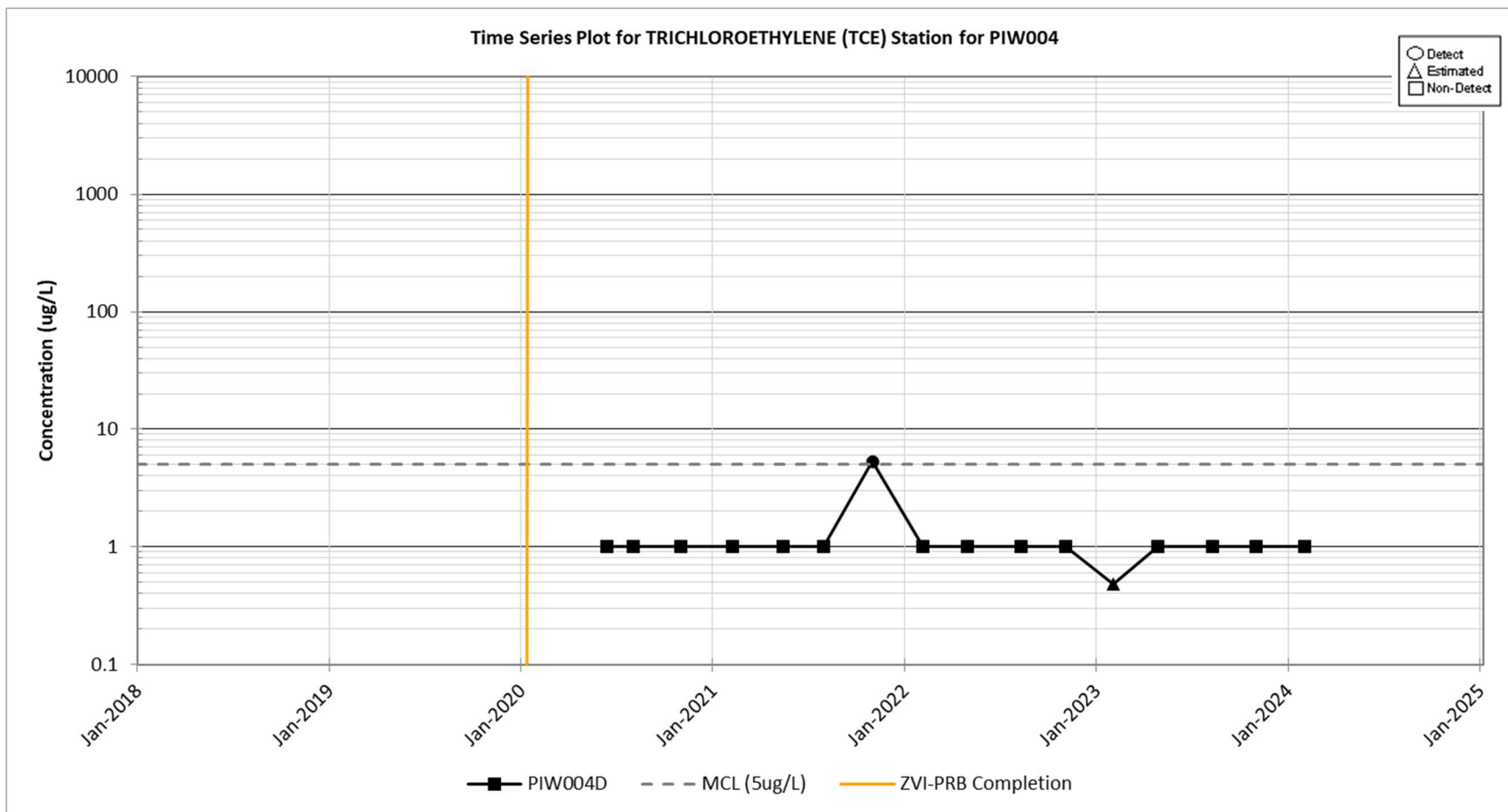


Figure C.39. Time Series Plot for Trichloroethylene (TCE) at Monitoring Well PIW004D

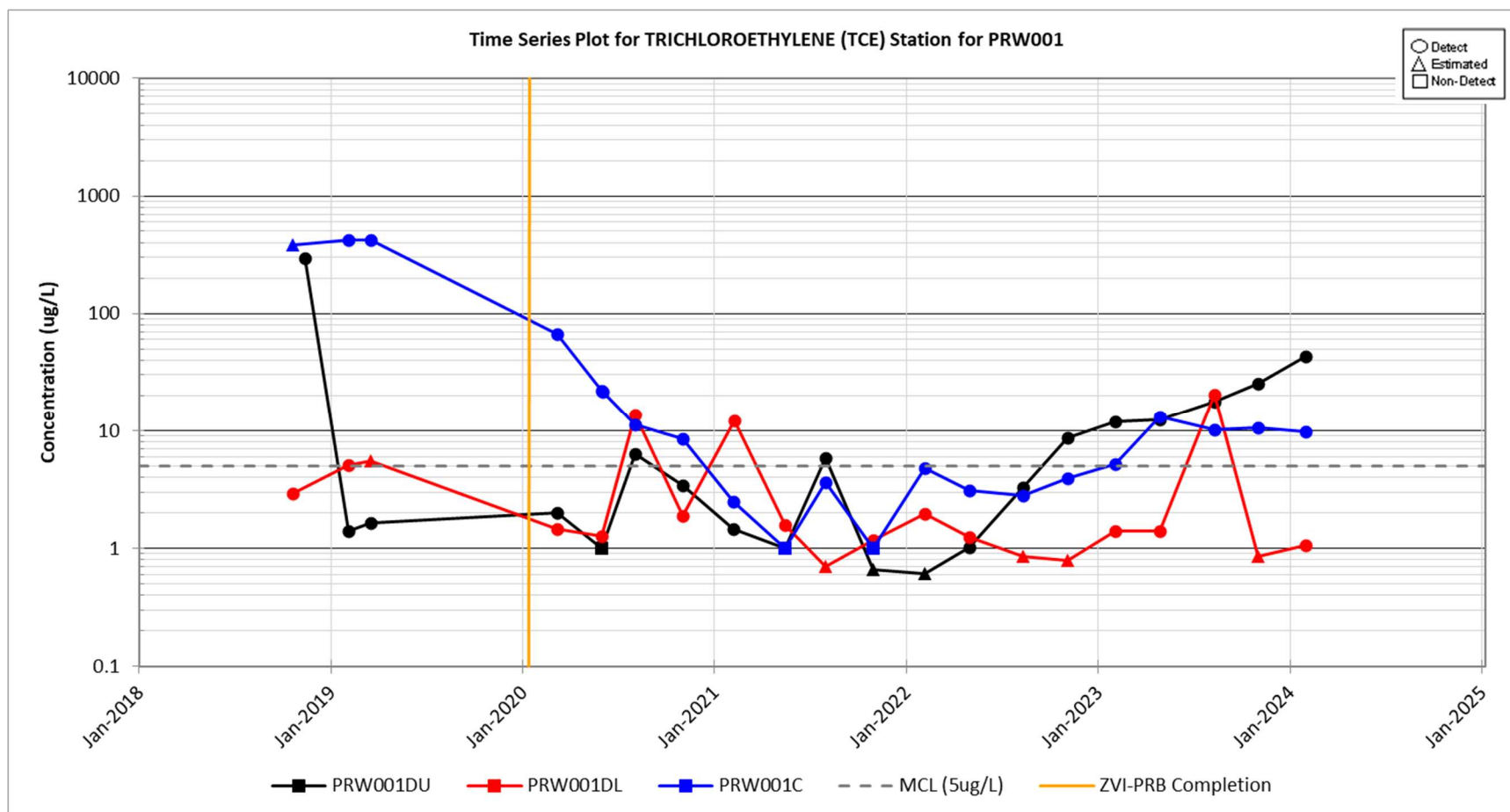


Figure C.40. Time Series Plot for Trichloroethylene (TCE) at PRW001 Series Monitoring Wells

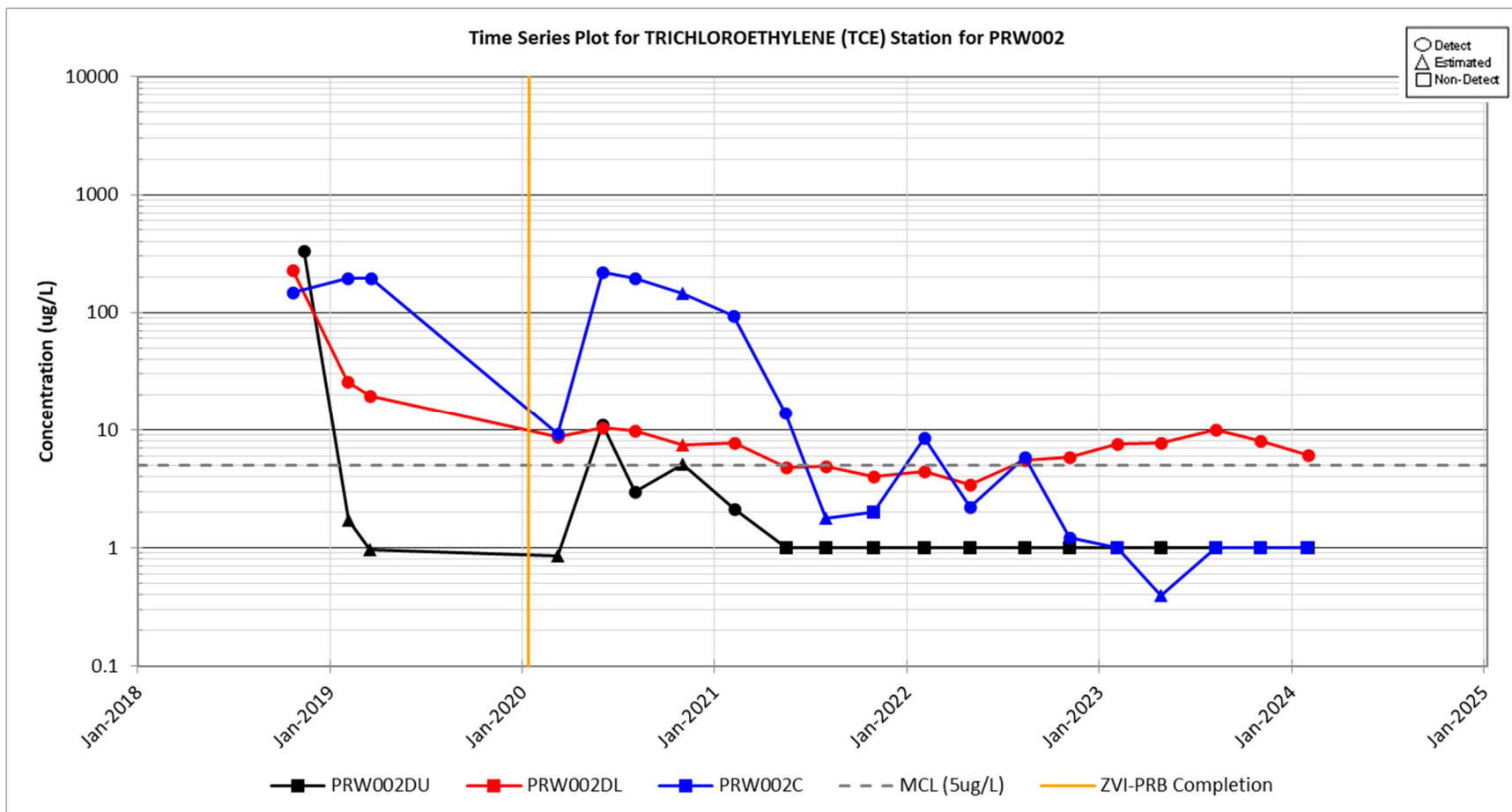


Figure C.41. Time Series Plot for Trichloroethylene (TCE) at PRW002 Series Monitoring Wells

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914
Rev. 0

Appendix C, Page C-44 of C-48

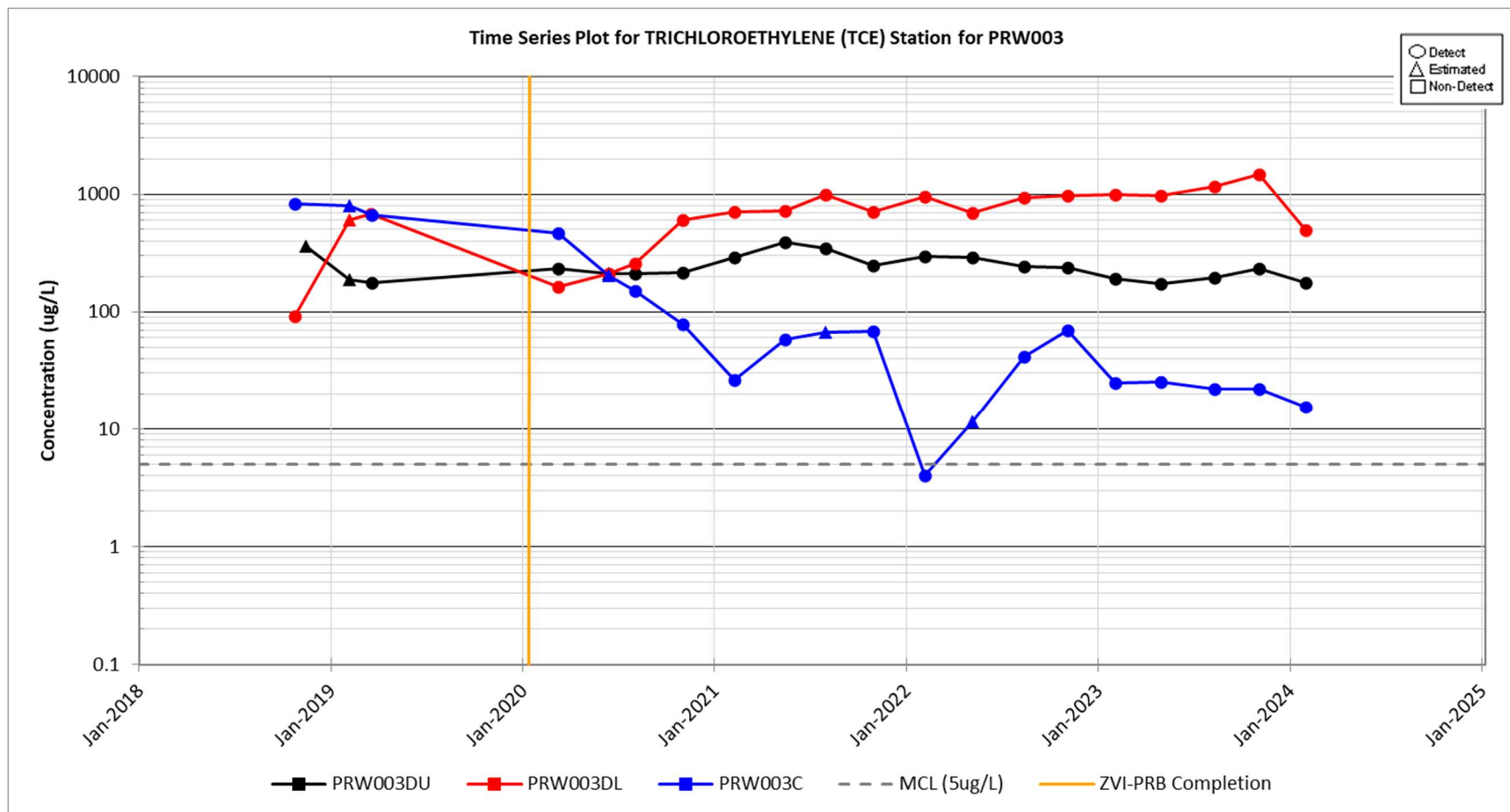


Figure C.42. Time Series Plot for Trichloroethylene (TCE) at PRW003 Series Monitoring Wells

EMR for the PAGW OU ZVI-PRB RA (U) 2023-2024
Savannah River Site
December 2024

SRNS-RP-2024-00914
Rev. 0

Appendix C, Page C-45 of C-48

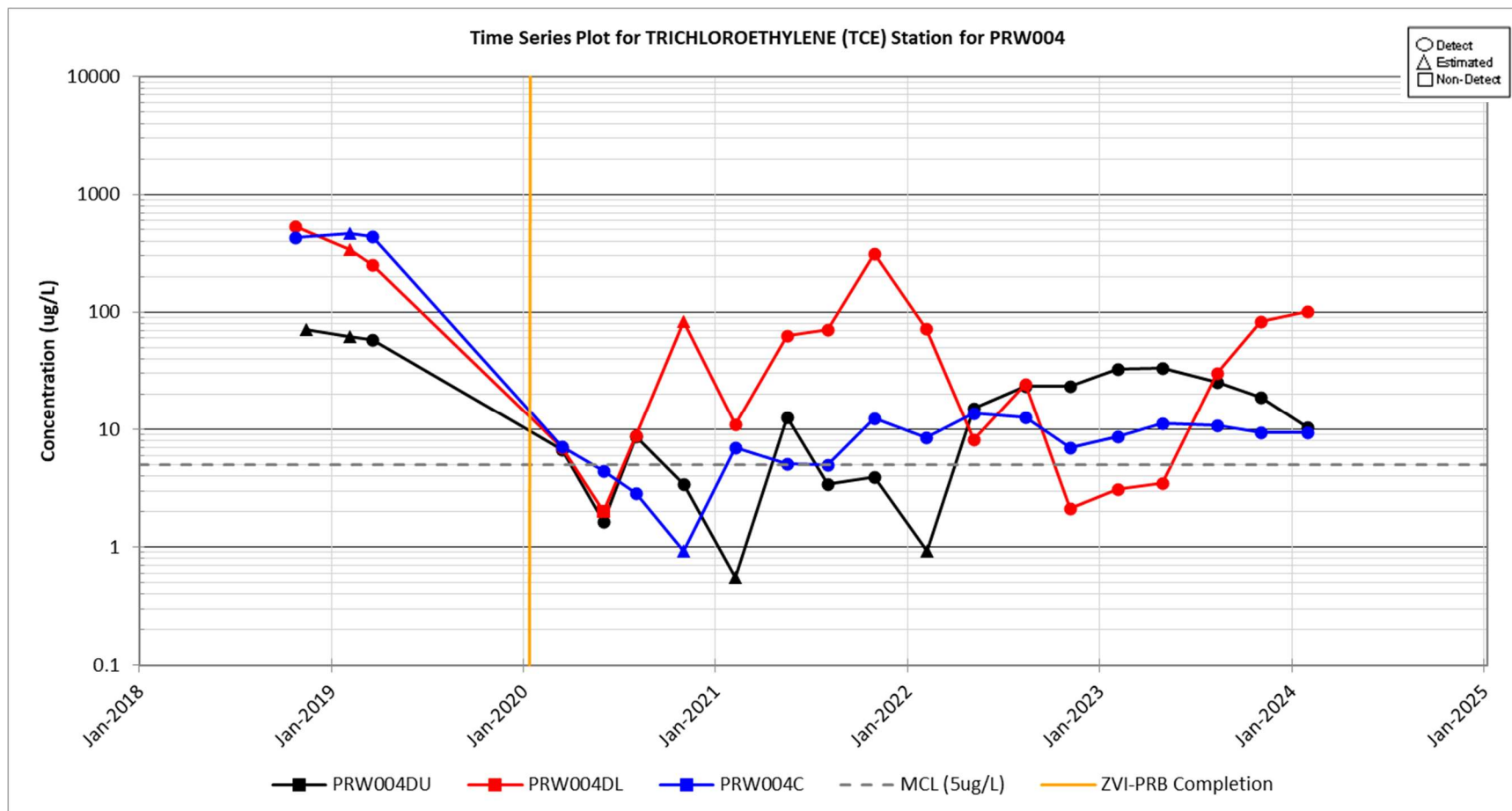


Figure C.43. Time Series Plot for Trichloroethylene (TCE) at PRW004 Series Monitoring Wells

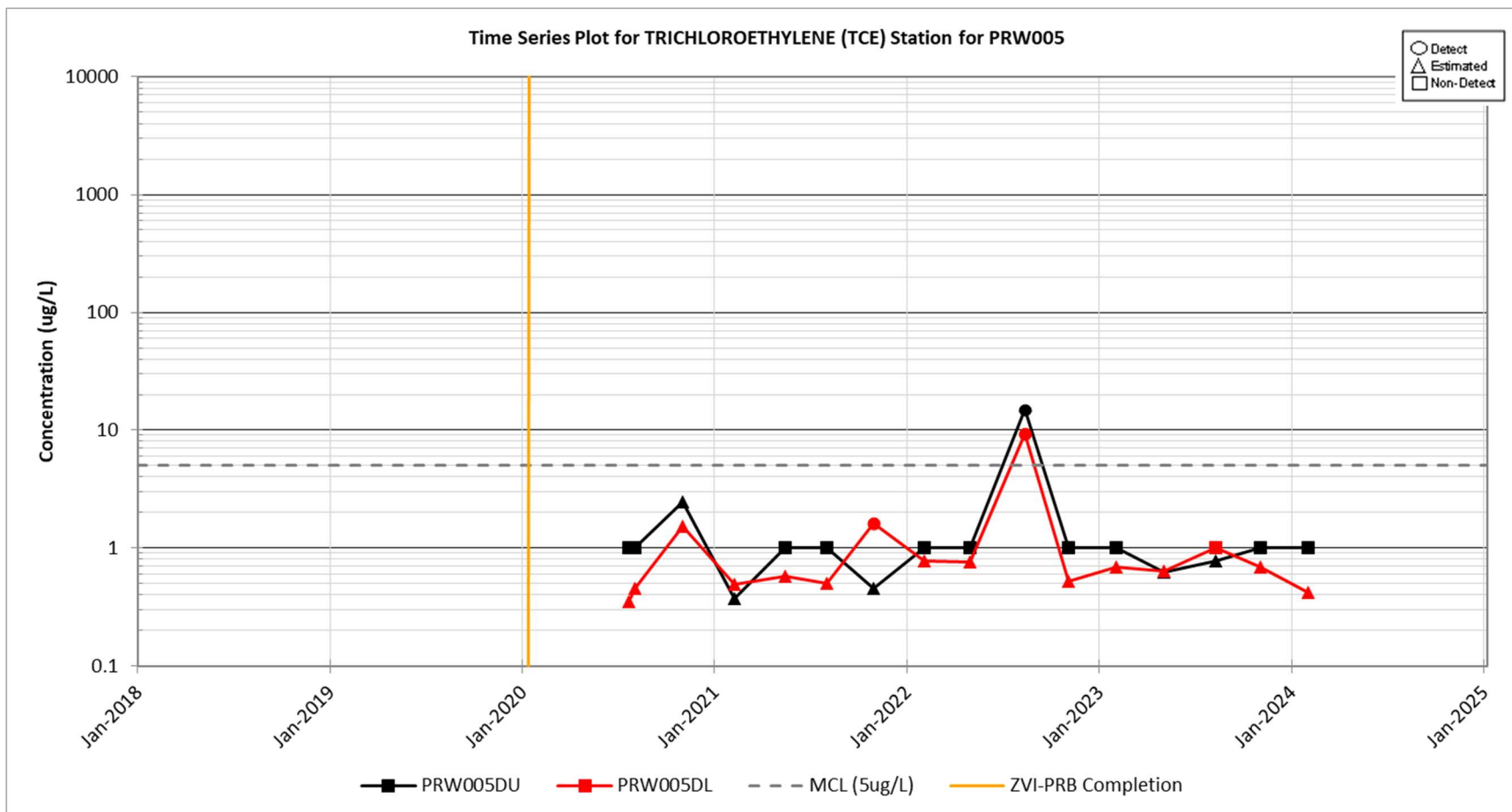


Figure C.44. Time Series Plot for Trichloroethylene (TCE) at PRW005 Series Monitoring Wells

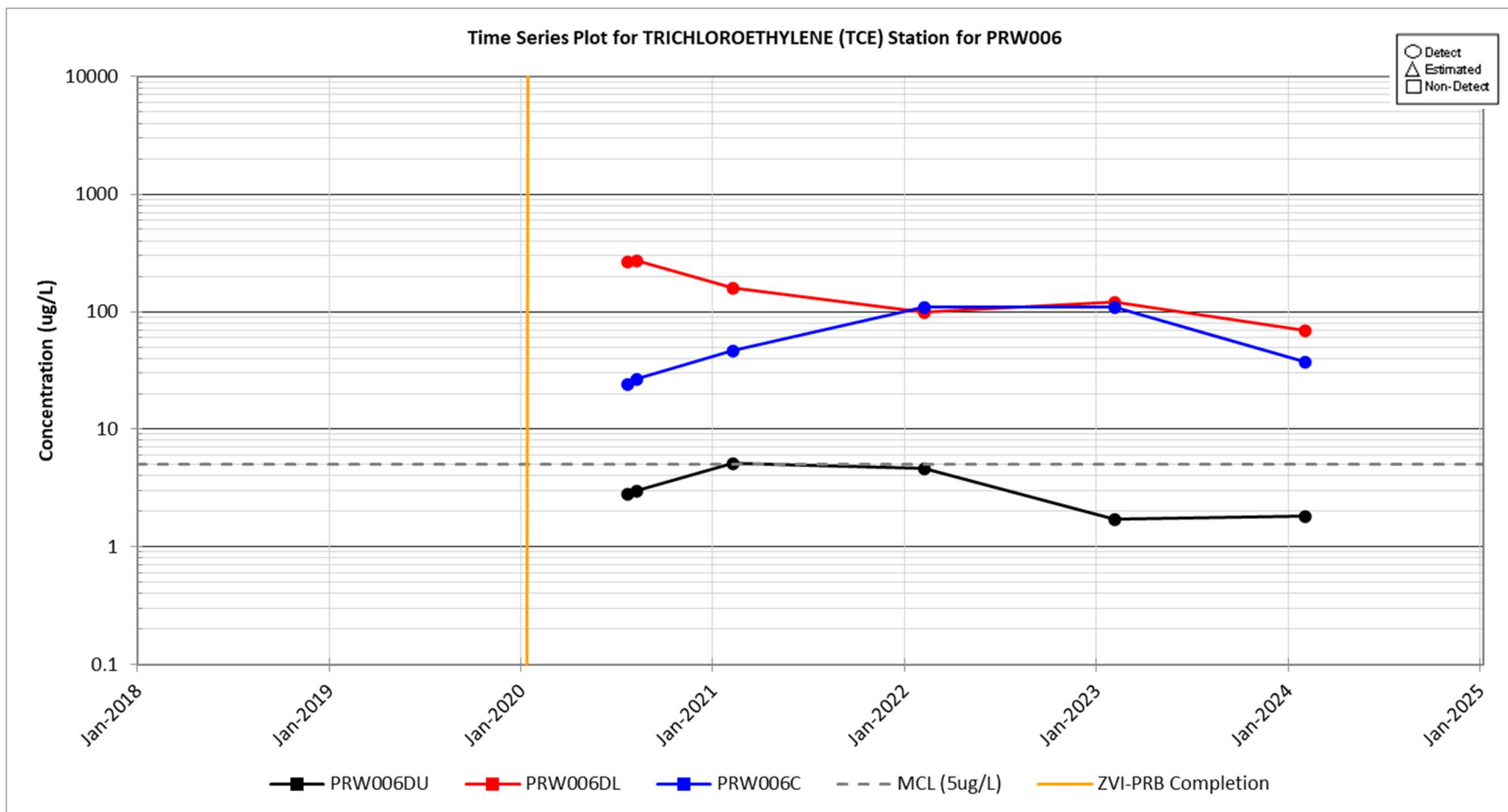


Figure C.45. Time Series Plot for Trichloroethylene (TCE) at PRW006 Series Monitoring Wells

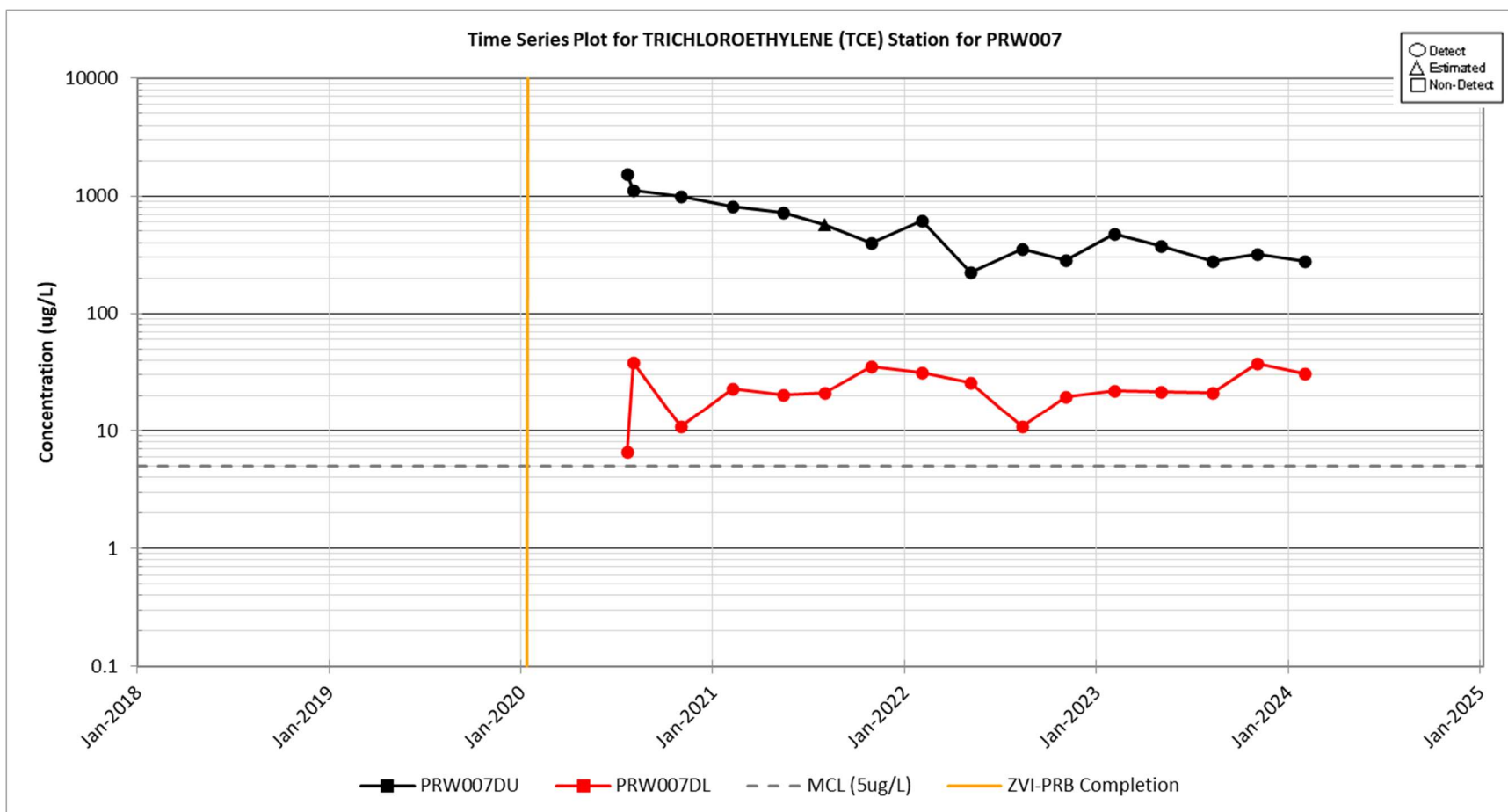


Figure C.46. Time Series Plot for Trichloroethylene (TCE) at PRW007 Series Monitoring Wells