GEMINI
ENVIRONMENTAL
STRATEGIES LLC

MEMORANDUM

To: Katie Daugherty, RG   Date: February 6, 2024

From: James J. Maul RG, LHG

RE: Risk Exposure Pathways and Plume Stability - Locality of Facility for Groundwater- Permapost Products, Inc., ORD 009 041 187, ECSI #148

The purpose of this memorandum is to provide the Oregon Department of Environmental Quality (DEQ) with the evidence supporting no changes to the Conceptual Site Model (CSM) as described in the DEQ-approved Technical Memorandum #9 – *Revised Conceptual Site Model Update and Contaminant Screening Technical Memo*[1] and the Locality of Facility (LOF) as described in DEQ-approved Technical Memorandum #4 – *Permapost Groundwater and NAPL Locality of Facility*[2] for the Permapost Site. The CSM was approved by the DEQ in its letter to Permapost dated May 23, 2023.[3]

The LOF is defined by DEQ as "*any point where a human or ecological receptor contacts or is reasonably likely to come into contact with facility-related hazardous substances...", taking into account the nature of the contaminant, contaminant migration, human and biological activity, and time*[4]. Therefore, the LOF at Permapost is defined in terms of a complete or potentially complete exposure pathway and the possible exposure to human or ecological receptors. As described in the technical memos, studies completed at Permapost demonstrated that the only potentially complete exposure pathway and resultant receptor of facility-related hazardous substances within the LOF is to excavation workers from direct contact to shallow groundwater in an area immediately downgradient of the Resource Conservation and Recovery Act (RCRA) closed former surface impoundments. DEQ has raised a concern that pentachlorophenol (PCP) could someday reach monitoring wells P-18a or P-18b. As described below, PCP in P-18a has not been detected in almost 40 years of monitoring (even in the early years of closure when PCP was detected in P-18b). However, current and historical data, presented below and in the attached

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[1] Memorandum to Katie Daugherty, RG from Phil Wiescher and Tim Browning. Revised Conceptual Site Model Update and Contaminant Screening Technical Memo. April 12, 2023.
[2] Memorandum to Katie Daugherty, RG from Phil Wiescher, Tim Browning, and James J. Maul. Permapost Groundwater and NAPL Locality of Facility – March 2022 Revision. March 10, 2022.
[3] Letter from Katie Daugherty, RG to Jayne Bond. Revised Conceptual Site Model Update and Contaminant Screening Technical Memo Permapost Products, ECSI No 148.
[4] OAR 340-122—0115(35).

memorandum from Hans Stroo, show that it is unlikely that PCP will reach either of the P-18 wells at any time in the future. Further, in the unlikely event that PCP is detected at P-18b, there are no potentially complete exposure pathways beyond the current LOF.

BACKGROUND

Permapost is currently preparing a feasibility study (FS). In comments on the approved FS workplan[5], DEQ requested that the FS must include the identification and evaluation of contingency remedial actions to be implemented if PCP is detected in groundwater monitoring wells in P-18a or P-18b (see General Comment #2). This request assumes that the plume could be expanding and that PCP detections in P-18a or P-18b monitoring wells may indicate migration beyond the Oregon Water Resources Department (WRD) 500-foot water supply restriction[6] (see Figure 1). The DEQ also noted that if the plume expands beyond the 500-foot WRD restriction, certain groundwater pathways and receptors would no longer be eliminated.

The CSM and discussion below show that there are no human or ecological groundwater receptors of facility-related chemicals (e.g. PCP) outside the current LOF that would lead to a requirement to develop the requested FS contingency plan. This includes an evaluation of groundwater receptors beyond monitoring wells P-18a and P-18b (and the WRD 500-foot restriction). In addition, the data also show it is not reasonably likely that PCP will reach shallow monitoring well P-18a and the area beyond the WRD restriction.

GROUNDWATER RECEPTORS

As shown by extensive site characterization and monitoring over the last 40 years and described in the previously submitted RI[7] report and subsequent supplemental Technical Memorandums, there are no current or reasonably foreseeable future beneficial uses of groundwater within or beyond the current LOF. The only potential exposure pathway would be to an excavation worker immediately downgradient of the RCRA cap.

In response to the DEQ request for a remedial contingency plan if P-18 wells contain detectable PCP, Permapost has reevaluated possible receptor exposure of groundwater beyond the current LOF and, in particular, beyond the 500-foot WRD restriction:

Human Health: Groundwater Water Supply Wells (domestic and irrigation): Based on the Updated Permapost Beneficial Use Determination (Appendix C in the *RCRA Permit Focused Remedial Investigation Report* dated June 19, 2019), there are no current or reasonably likely future beneficial uses of groundwater **within or beyond** the WRD 500-foot water supply restriction. Valley Memorial Cemetery (VMC) and the WRD restriction are hydraulically downgradient of the P-18 monitoring wells. VMC has been operational since the early 1960s and receives its domestic water from the City of Hillsboro. Also, groundwater beneath the cemetery is likely unsuitable for human consumption due to historical and current cemetery operations. The Oregon Health Authority recognizes this potential for sanitary hazards posed by cemetery groundwater by not allowing a public service water well system within 100 feet of a cemetery (OAR 333-061-0050(2)(a)(E). VMC also holds

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[5] Letter from Katie Daugherty, R.G. to Jayne Bond. Feasibility Study Work Plan Permapost Products, ECSI No. 148. October 26, 2023.
[6] OAR 690-210-0030
[7] Permapost 2019, RCRA Permit Focused Remedial Investigation Report, ORD 009 041 187, June 19.

and utilizes two surface water irrigation rights from Rock Creek, eliminating the potential need for a groundwater irrigation well.

Human Health: Shallow Groundwater Exposure to Excavation Workers (0-15 feet below ground surface): Groundwater from monitoring well P-18a, screened at 10-20 feet below ground surface (bgs), represents the groundwater that could potentially contact excavation workers at VMC. Monitoring well P-18b, screened from 30-40 feet bgs is too deep to contact excavation workers.

Historical groundwater sampling data over the past 38 years from the monitoring well P-18a indicate that monitoring well P-18a will never contain concentrations of PCP above the 53 μg/L risk-based concentration (RBC) for excavation workers set by DEQ (see Table 1).

This conclusion is based on the following:

- From 1986 to 2023, groundwater from well P-18a was sampled 47 times without a single detectable PCP concentration.
- The P-18b data show the PCP groundwater impacts were localized vertically below the 15-foot excavation worker receptor pathway, both ***before, during,*** and ***after*** the RCRA pump and treat corrective action.
    - In the early 1990s, ***before*** the start of the RCRA corrective action and approximately 25-30 years after the installation of the RCRA impoundments, the concentration of PCP in groundwater from adjacent deep well P-18b typically ranged between 500 and 2,500 μg/L. During that time, PCP measured in groundwater from shallow well P-18a was not detectable (<5 μg/L).
    - During the initial ***operation*** of the RCRA corrective action from 1995 to 2004 (the last year P-18a required sampling), PCP in groundwater from adjacent deep well P-18b typically ranged between 1,200 and 2,000 μg/L. Again, PCP measured in groundwater from shallow well P-18a was not detectable (<5 μg/L). From approximately 2005 to 2018 the PCP concentration in P-18b to decreased to non-detect (<0.5 μg/L) levels (see Table 2).
    - Recent groundwater sampling in 2023 of both P-18b and P-18a, seven years ***after*** ceasing operation of the RCRA corrective action, did not detect PCP in either well (<0.4 μg/L). Current data from P-18b show PCP has not been detectable in groundwater for the past 4 years.

There are no relevant receptors of groundwater at any location downgradient of the P-18 wells, and, as a result, there are no additional groundwater pathways or receptors beyond the WRD 500-foot buffer to address in the FS. Even without the 500-foot WRD well installation restriction there is no reasonable scenario for a water-well to be installed anywhere downgradient of Permapost now or in the future.

PLUME STABIITY & ATTENUATION

DEQ has expressed concerns that data variability in monitoring well P-19b represents significant overall plume expansion. Land use directly downgradient of P-19b includes the active railroad tracks, the Tualatin Valley Highway, and VMC. Permapost retained Stroo Consulting, LLC (Dr. Stroo) to evaluate if recent PCP concentration trends represent an expanding PCP plume, and any impact on natural attenuation within the plume.

Hans Stroo has over 30 years of experience in groundwater remediation, including as a principal consultant with Remediation Technologies Inc. (RETEC) and HydroGeoLogic Inc. (HGL), and as a senior technical advisor to the United States Department of Defense's Strategic Environmental Research and Development Program (SERDP). He has a PhD from Cornell University, and has managed several remediation projects at wood-treating sites. He authored some of the earliest publications on natural attenuation of pentachlorophenol, and participated in several ITRC teams on DNAPL site remediation. As a consultant to Marsh Insurance, Dr. Stroo served as the technical expert on some of the largest remediation cost cap insurance projects ever placed, including several over $1B. He has edited four books on in situ remediation, and authored 12 book chapters and over 30 journal articles (including several on natural attenuation of a range of contaminants).

Dr. Stroo's report is presented in the Attachment. The report includes a statistical review on concentration trends within key monitoring wells along with discussion of historical data from each well. Dr. Stroo also provides evidence of attenuation both pre and post shutdown of the RCRA pump and treat corrective action.

Important conclusions presented in the Dr. Stoo's report include (see Attachment),

- The PCP plume continues to shrink at the fringes and limits any areal expansion of the plume.
- Both aerobic and anaerobic biodegradation are still occurring.
- It is unlikely that the plume will again reach P-18 monitoring wells.
- Rebound in shallow monitoring well P-14a may continue, but any rebound away from this well will be limited because of biodegradation.

SUMMARY

Permapost is currently preparing a FS consistent with comments from DEQ[8] on the FS workplan. In General Comment #2, DEQ stipulated that the FS should include identification and evaluation of contingency remedial actions if PCP is detected in monitoring wells P-18a or P-18b. This request is based on DEQ's assumption that the plume is expanding and that PCP detections in P-18a or P-18b monitoring wells may indicate migration beyond the Oregon Water Resources Department (WRD) 500-foot water supply restriction (see Figure 1). DEQ also noted that if the plume expands beyond the 500-foot WRD restriction, certain groundwater pathways and receptors would no longer be eliminated.

The site beneficial use investigation has shown that there are no human or ecological groundwater receptors of facility-related chemicals (i.e., PCP) outside the current LOF, no risk because there are no current of future exposure pathways, and therefore, no remedy required. It is also **not** reasonably likely that PCP will ever reach shallow monitoring well P-18a and the area beyond the WRD restriction. Without relevant exposure pathways there is no risk beyond the current LOF making the requested FS contingency plan unnecessary. Even without the 500-foot WRD well installation restriction there is no reasonable scenario for a water-well to be installed anywhere downgradient of Permapost now or in the future.

Dr. Stroo evaluated if recent PCP concentration trends represent an expanding PCP plume and any impact on natural attenuation within the plume. Dr. Stroo concluded that since shut down of the RCRA pump and treat

[8] Letter from Katie Daugherty, RG to Jayne Bond. RE: Feasibility Study Work Plan, Permapost Products, ECSI No. 148. October 26, 2023.

corrective action in 2016, the PCP plume continues to shrink at the fringes. Also, there has been no expansion of the plume and it is unlikely that the PCP plume will again reach the P-18 (namely P-18b) monitoring wells in the future because of ongoing natural attenuation.

In addition to continued natural attenuation, PCP is unlikely to again reach P-18b because the PCP source has been significantly diminished. During operation of the surface impoundments from the early 1960s to 1980s, the PCP groundwater plume reached monitoring well P-18b. When the impoundments were closed in 1984, Permapost removed approximately 500 tons of contaminated soil, backfilled, and closed the impoundments with an engineered asphalt cap. Permapost subsequently removed approximately 60 million gallons of contaminated groundwater and 4,000 gallons of LNAPL mixed with water over 30 years of operation. Site data and analysis by Dr. Stroo show that the 30-year pump and treat corrective action allowed the natural PCP degraders to acclimate to the presence of PCP and increase sufficiently to support long term plume degradation, which continues to limit any potential plume expansion.

TABLES

Table 1
Permapost
P-18a Pentachlorophonol
(well screened 10-20 feet bgs)

Sampling Date		Pentachlorophenol mg/L	
12/17/85		0.001	
04/04/86		0.0003	
07/09/86		0.005	U
10/16/86		0.005	U
01/06/87		0.0002	U
12/10/87		0.005	U
10/07/88		0.005	U
12/15/88		0.005	U
04/07/89		0.005	U
11/16/89		0.005	U
02/07/90		0.005	U
05/07/90		0.005	U
08/31/90		0.005	U
11/05/90		0.005	U
05/15/91		0.005	U
08/06/91		0.005	U
08/06/91	D	0.005	U
02/15/92		0.005	U
04/23/92		0.005	U
07/22/92		0.005	U
10/13/92		0.005	U
01/07/93		0.005	U
03/23/93		0.005	U
06/28/93		0.02	U
09/20/93		0.005	U
12/20/93		0.005	U
03/29/94		0.005	U
06/29/94		0.005	U
09/20/94		0.005	U
03/15/95		0.005	U
09/18/95		0.005	U
03/22/96		0.005	U
09/17/96		0.005	U
03/26/97		0.005	U
09/23/97		0.005	U
03/25/98		0.005	U
09/10/98		0.005	U
03/12/99		0.005	U
10/08/99		0.005	U
03/07/00		0.005	U
09/19/00		0.005	U
03/14/01		0.0048	U
09/12/01		0.0049	UJ
03/19/02		0.005	U
09/26/02		0.0049	U
03/05/03		0.0048	U
09/15/03		0.005	U
03/12/04		0.0025	U
09/24/04		0.0048	U
09/18/23		0.00009	U

D = Duplicate sample collected.
bgs = below ground surface
U = undetected

Table 2
Permapost
P-18b Pentachlorophenol
(well screened 30-40 feet bgs)

Sampling Date		Pentachlorophenol mg/L		Sampling Date	Pentachlorophenol mg/L	
01/06/87		1.010		03/07/00	2.600	
03/12/87		1.029		09/19/00	1.700	
12/10/87		0.415		03/14/01	1.500	
10/07/88		0.060		09/12/01	1.400	
12/15/88		0.121		03/19/02	1.900	
04/07/89		0.610		09/26/02	1.500	
11/16/89		0.640		03/05/03	1.200	
02/07/90		1.300		09/30/03	1.800	
05/07/90		3.400		03/12/04	0.930	
08/30/90		1.390		09/24/04	0.890	
11/05/90		1.480		03/14/05	1.200	
05/16/91		4.200		09/08/05	1.200	
05/16/91	D	2.000		03/06/06	0.880	
02/15/92		0.010	U	09/25/06	0.680	
02/15/92	D	0.010	U	03/07/07	0.740	
04/23/92		2.000		08/23/07	0.900	
07/22/92		0.950		03/11/08	0.620	
10/13/92		2.020		09/24/08	0.550	
01/07/93		1.500		02/28/09	0.500	
03/23/93		1.260		10/07/09	0.400	
03/23/93	D	0.940		03/30/10	0.430	
06/28/93		0.660		10/01/10	0.310	
09/20/93		1.800		03/11/11	0.189	
09/20/93	D	1.600		09/17/11	0.137	
12/20/93		3.000		03/29/12	0.108	
12/20/93	D	3.300		09/27/12	0.076	
03/29/94		2.350		03/29/13	0.096	
03/29/94	D	2.300		09/17/13	0.0677	
06/29/94		2.400		03/26/14	0.0367	
06/29/94	D	2.500		09/30/14	0.0127	
09/20/94		3.500		03/30/15	0.0126	
09/20/94	D	2.600		11/18/15	0.0083	
03/15/95		1.600		03/09/16	0.0068	
03/15/95	D	1.800		09/08/16	0.0035	
09/18/95		1.500		03/08/17	0.0012	
03/20/96		1.300		09/18/17	0.0036	
03/20/96	D	1.460		03/20/18	0.0005	U
09/17/96		1.500		09/25/18	0.0005	U
03/26/97		2.300		04/02/19	0.0016	
03/26/97	D	2.000		09/24/19	0.0005	U
09/23/97		7.000		03/16/20	0.0005	U
03/25/98		2.500		09/22/20	0.0005	U
09/10/98		1.900		03/23/21	0.0005	U
03/12/99		1.700		09/15/21	0.0005	U
10/08/99		1.900		03/22/22	0.0005	U
				09/20/22	0.0076	U
				03/21/23	0.0004	U
				09/18/23	0.0004	U

D = Duplicate sample collected.
bgs = below ground surface
U = undetected

FIGURE

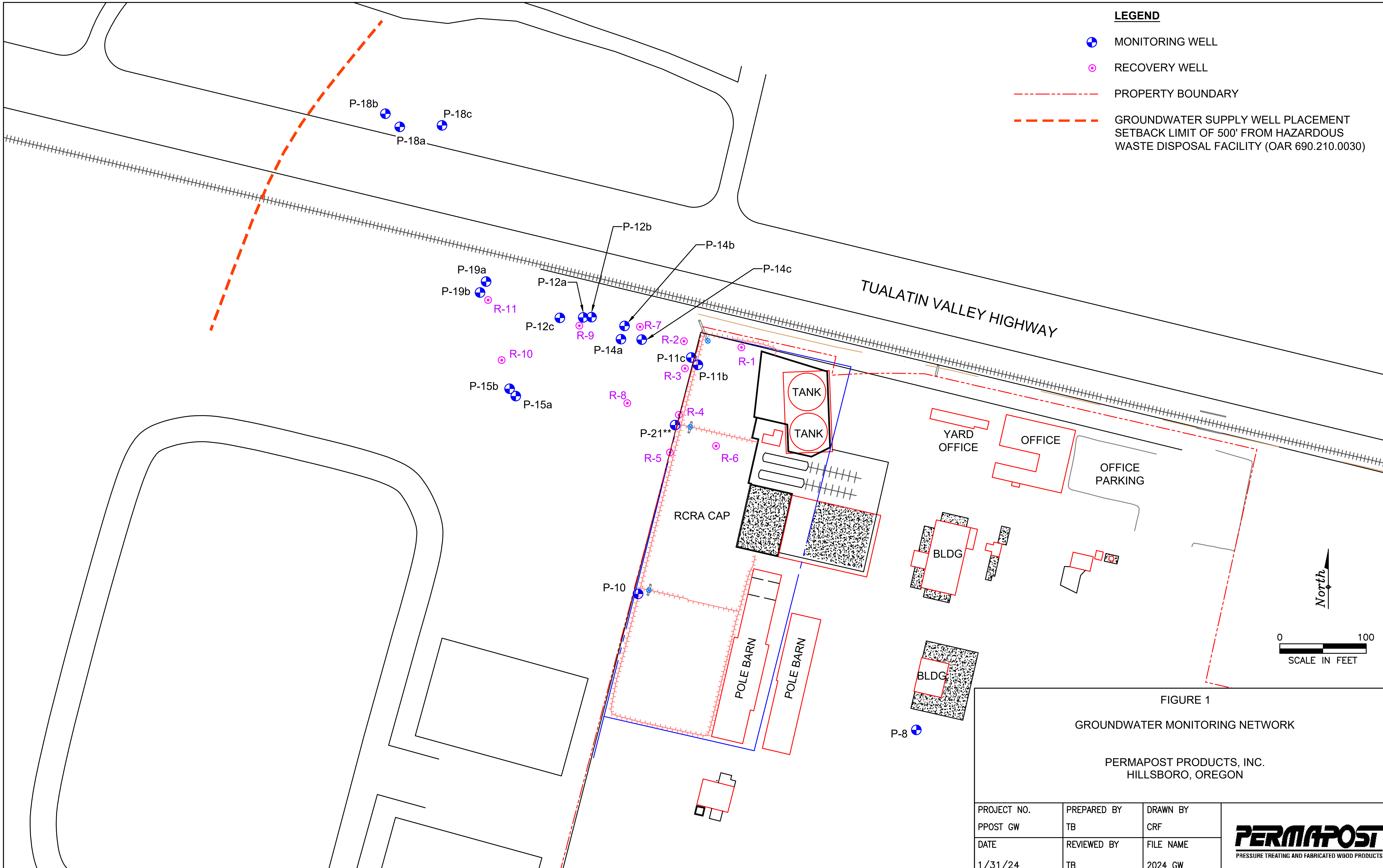

FIGURE 1

GROUNDWATER MONITORING NETWORK

PERMAPOST PRODUCTS, INC.
HILLSBORO, OREGON

PROJECT NO. PPOST GW	PREPARED BY TB	DRAWN BY CRF
DATE 1/31/24	REVIEWED BY TB	FILE NAME 2024 GW

PERMAPOST
PRESSURE TREATING AND FABRICATED WOOD PRODUCTS

ATTACHMENT-STROO CONSULTING, LLC REPORT

Stroo Consulting, LLC

Environmental Science
Site Remediation
Expert Review

Hans F. Stroo, Ph.D

February 6, 2024

Jayne Bond
Permapost Products Inc.
P.O. Box 100
Hillsboro, OR 97123

Subject: Attenuation of the Permapost Pentachlorophenol Plume

Stroo Consulting, LLC has prepared this memorandum to update the prior evaluation of natural attenuation within the pentachlorophenol (PCP) plume (Permapost, 2016) and assess the PCP concentration trends since ending groundwater recovery. This analysis places the recent increases in PCP concentrations in some wells, notably P-19b, in a long-term context to evaluate whether attenuation is continuing. Some increased concentrations are likely after stopping removal of contaminated groundwater, and some plume expansion may even occur, but the question is whether any such rebound will be adequately contained by natural processes.

1. INTRODUCTION

The Permapost site includes a pentachlorophenol (PCP) plume in groundwater downgradient of the closed Resource Concentration and Recovery Act (RCRA) impoundments. The plume has been monitored for nearly 40 years, with steadily decreasing concentrations over that time. Figure 1 shows a 2017 plume map with the locations of the key monitoring wells.

From the early 1990s until 2015, the plume was controlled by a pump and treat system comprised of nine recovery wells that operated downgradient of the closed impoundments. The pump and treat system was shut down in two phases, the first in 2015 and the second in 2016. This shutdown was based on evidence that in situ microbial degradation of PCP was occurring, and it was likely reducing the size of the PCP groundwater plume (Permapost, 2016). Groundwater monitoring has continued, to ensure protectiveness and to evaluate the impacts of natural attenuation in groundwater.

To understand the plume response to shutting down the groundwater recovery system, trends in PCP concentrations were evaluated, with a statistical analysis of these trends for 7 years before the initial shutdown (2009-2015) and 7 years after complete shutdown (2017-2023). Because the plume was shrinking steadily prior to the shutdown, this 15-year period was chosen as the most realistic comparison of pre- and post-shutdown trends. The results vary with season and between years. Such variability is common at contaminated sites, and long-term analyses are often needed to draw meaningful conclusions (McHugh et al., 2011). The 15-year record at this site clearly shows that the near source area PCP levels increased soon after shutdown, but the plume overall has continued to shrink at the edges and PCP has remained below detectable concentrations (5 µg/L) in well P-18b since 2019.

2. CONCENTRATION TRENDS AT KEY WELLS

The trends since 2009 for the well locations are presented in Figures 2 through 9, and the average PCP concentrations, with the standard deviations (sd), for the 7 years before shutdown and the 7 years afterwards are presented in Table 1. PCP concentrations were decreasing throughout the plume prior to shutdown though there appears to be some rebound in wells P-14a and P-12b.

TABLE 1

AVERAGE PCP BEFORE AND AFTER SHUTDOWN

Well	Mean PCP Concentration (mg/L)			
	2009-2015	(sd)	2017-2023	(sd)
14a	11.8	(11.8)	40.7*	(20.3)
14b	4.84	(1.43)	3.79	(1.46)
14c	0.038	(0.05)	0.095	(0.08)
12b	0.013	(0.04)	0.18	(0.37)
12c	0.31	(0.38)	0.001*	(0.001)
15b	0.16	(0.10)	0.11	(0.06)
19b	1.44	(0.09)	0.60	(0.32)
18b	0.16	(0.001)	0.17	(0.001)

* Statistically different at $p<0.05$

There is obvious seasonal variability, with higher concentrations typically in September (at the end of the dry season) and decreases in March (at the end of the wet season). Prior to shutdown, the plume was clearly shrinking, a trend that continued until at least 2017 (Permapost, 2019). The following discussion starts with the assumed "source area" (reflected by groundwater data from P-14 wells located immediately downgradient of the closed RCRA impoundments), and then analyzes other downgradient wells within the plume (e.g., P-12b), wells at the plume fringes (P-12c, P-15b, and P-19b), and finally the previously-impacted downgradient well P-18b.

2.1 P-14 WELL CLUSTER

These wells have historically had the highest concentrations, particularly in the upper and intermediate sections of the uppermost water-bearing zone. The well cluster consists of three wells (P-14a, P-14b, and P-14c). All three wells have been impacted by PCP above the criteria of 0.053 mg/L.

2.1.1 Well P-14a

Increases in PCP concentrations are most noticeable at shallow monitoring well P-14a. Figure 2 shows the concentrations were generally in the range of 5 to 20 mg/L prior to shutdown, but increased to approximately 20-40 mg/L since 2017 (with a couple of significant spikes). The trends before and after shutdown are essentially flat, given the variability between sampling times.

The PCP concentrations after shutdown were significantly higher than during the prior 7 years. The average concentrations were about 12 mg/L from 2009-2015, and 41 mg/L from 2017-2023. This rapid and consistent increase after stopping active recovery amounts to roughly a tripling of the PCP concentrations in this area, and therefore increased PCP concentrations at downgradient wells might be expected even with natural attenuation. However, groundwater monitoring data has consistently shown no increase in PCP concentrations in downgradient shallow wells.

2.1.2 Well P-14b

The PCP concentrations in the intermediate portion of the uppermost water-bearing zone declined noticeably following the shutdown (Figure 3). Stopping pumping may have reduced the downward migration of PCP in this area, partly explaining the increase in Well P-14a. The average concentration in Well P-14b prior to shutdown was 4.8 mg/L, while the average after shutdown was 1.4 mg/L. However, the concentrations fell below 1 mg/L from 2018 onwards, and the most recent (September 2023) PCP concentration was 0.2 mg/L.

This decrease in the intermediate portion of the uppermost water-bearing zone cannot account for the entire increase in the upper portion (Well P-14a). However, it does emphasize that any attenuation estimates must consider the entire PCP-impacted depth, particularly at this location.

2.1.3 Well P-14c

Well P-14c monitors groundwater in deepest portion of the uppermost water-bearing zone at the Well P-14 well cluster. Prior to shutdown, PCP concentrations varied over 2 orders of magnitude, from roughly 0.001 to 0.1 mg/L, with no evidence of any trend over that time period (Figure 4). Since the shutdown, the concentrations have been much less variable, with a slightly increasing trend that is not statistically significant.

2.2 Well P-12b

P-12b is located downgradient of the P-14 well cluster. Although it has exhibited a high degree of seasonal variability, the average and peak PCP concentrations were steadily decreasing at an exponential rate prior to shutdown, to near non-detectable levels (Figure 5). The exponential rate factor for the decrease in concentration ($e^{-0.001x}$) corresponds to 0.1% per day, or a half-life of almost 2 years (693 days). Since shutdown, the concentrations have returned to 2009 levels. The average concentration since shutdown has been 0.18 mg/L, although many of the sampling dates (spring sampling events) were below detection levels.

2.3 Well P-12c

This well monitors the lower fringe of the plume north of the plume's core. PCP was near 1 mg/L in 2009 but decreased rapidly over the following 7 years (Figure 6). The decrease was exponential, falling 3 orders of magnitude to below 0.001 mg/L (non-detect) within 7 years. The exponential rate factor ($e^{-0.004x}$) was relatively rapid, corresponding to a half-life of almost 6 months (173 days). These results were strong evidence for natural attenuation at the plume edges prior to shutdown. Since 2017, concentrations have remained essentially nondetectable, indicating that natural attenuation is continuing to limit vertical migration at this location.

2.4 WELL P-19b

P-19b is located downgradient of P-12b. The Oregon Department of Environmental Quality raised a concern because of a recent increase in PCP concentrations in P-19b. However, a long-term analysis shows that the PCP concentrations decreased dramatically to nondetectable levels very quickly after shutdown (Figure 7), and then returned to the prior (2009-2015) concentrations in the last 2 years. The apparent increase in March 2023 (1.5 mg/L) has since decreased. It is hard to explain this dramatic decrease after shutdown, or the recent return to pre-shutdown levels. Stopping groundwater recovery may have shifted groundwater flow paths or isolated this region temporarily. The increase is probably not a result of increased PCP upgradient in P-14a. The increases at P-14a were only 3-fold higher, but the concentrations increased within a year by over two orders of magnitude at P-19b.

The fact that concentrations decreased almost immediately to non-detect levels, but have returned to the pre-shutdown concentrations is not consistent with plume expansion following shutdown. The most likely explanation is a short-term hydrologic response to the shutdown, before a re-establishment of the earlier conditions. Whatever the reasons, to date the recent rebound has not exceeded the concentrations before shutdown.

2.5 Well P-15b

P-15b is on the northwestern edge of the groundwater plume. PCP concentrations at P-15b remained relatively constant throughout 2009-2023 (Figure 8). Concentrations have been in the range of 0.1-0.25 mg/L for most of the last 15 years, and have been below that level for the last 2 years. There is little evidence for any plume expansion in this area, and in fact, the slow decrease in concentrations has continued since shutdown, indicating ongoing shrinkage of the plume in this area.

2.6 Well P-18b

P-18b is located across the Tualatin Valley Highway, downgradient of P-19b. PCP concentrations at P-18b were decreasing rapidly during the last years of pumping operations, falling almost 3 orders of magnitude (1000-fold) since 2009 (Figure 9). This exponential decline was at a rate of $e^{-0.002x}$, or 0.2% per day, a half-life of about a year (346 days). PCP concentrations decreased at the same rate after shutdown, and have been below detection levels for the last 4 years.

The consistent long-term exponential decrease at this well suggests natural attenuation processes are still occurring in this anaerobic region of the groundwater. PCP concentrations were well below applicable criteria before shutdown, and have remained nondetectable. The results suggest that a significant increase in plume size and concentrations will be needed to impact groundwater downgradient of P-18b.

The sustained increase in daughter products as PCP has continued to degrade (Figure 10) is evidence that anaerobic biodegradation has been responsible for the plume shrinking in this area, and also indicates that the anaerobic biodegradation is still occurring. These daughter products (tetra-, tri- and dichlorophenols) are also biodegradable and should disappear downgradient.

3. ATTENUATION EVIDENCE

3.1. Attenuation Pre-Shutdown

Earlier work established that the plume was attenuating largely through biodegradation of the PCP by both aerobic and anaerobic bacteria (Permapost 2016). Key evidence supporting this biodegradation included biomarkers for aerobic and anaerobic PCP genes in the groundwater.

Aerobic biodegradation is generally more rapid than anaerobic biodegradation, although both were occurring. The fact that PCP biodegradation proceeds rapidly in the presence of oxygen has been repeatedly observed, with reports extending over 40 years (Martinson et al., 1984). Aerobic biodegradation has been the basis for several natural and enhanced attenuation remedies for PCP-contaminated sites (Stroo et al.; Vernalia et al 1997).

Results at the time also indicated the importance of aerobic biodegradation. Figure 11 is a conceptual depiction of the plume prior to shutdown, using average PCP concentrations from 2009-2015. The figure also shows the dissolved oxygen (DO) concentrations, first taken in 2014. There are two important observations. First, available oxygen was rapidly consumed where PCP is present in the upper wells, near the water table (notably at well P-14a). Second, in the downgradient wells, PCP was not detectable in the upper zone, and DO penetrated further into the groundwater. The sole exception is the P-18a and P-18b wells, where there is no PCP but DO appears to be rapidly consumed, possibly by natural oxygen demand associated with the cemetery.

Overall, PCP was near or below detectable levels in wells with >2 mg/L DO, and all wells with PCP above the relevant standard (0.053 mg/L) also had DO levels below 2 mg/L. These results strongly suggest that natural attenuation was primarily due to aerobic biodegradation, and the rate of natural attenuation rate was largely a function of oxygen availability.

3.2. Attenuation Post-Shutdown

Follow-up sampling and analysis in 2017 showed that these biomarkers were still present after well shutdown, although the markers for aerobic biodegradation genes were somewhat lower post-shutdown than during the earlier sampling (Table 2).

TABLE 2

PCP BIODEGRADATION MARKERS BEFORE AND AFTER SHUTDOWN

Well	Date	PCPb (aerobic) (Genes/mL)	pcpR (aerobic) (Genes/mL)	pcpE (anaerobic) (Genes/mL)	DHC* (cells/mL)
P-12b	3/2015	9,810	3,160	15.7	2.7
	3/2017	53,400	2,570	134	<0.9
	8/2017	72.1	<5	<5	<0.5
P-12c	3/2015	12,700	12,500	24	104,000
	3/2017	3,710	5,750	555	450
	8/2017	7,370	646	45.7	747
P-15a	3/2015	327,000	145,000	651	<25
	3/2017	4,170	2,250	67.7	<0.5
	8/2017	3,770	224	1.2	<0.5
P-15b	3/2015	349,000	203,000	256	<25
	3/2017	2,640	2,250	95.6	0.1 J
	8/2017	1,760	276	8.1	66.6
P-18a	3/2015	92,500	23,500	216	158
	3/2017	60,100	33,700	1,480	<0.5
	8/2017	9,220	431	30	0.8

*DHC = *Dehalococcoides mccartyi* (anaerobic dechlorinating bacteria)

One approach to estimating attenuation rates is to use concentrations or mass discharge at transects across the plume (ITRC, 2010). Unfortunately, the variability in concentrations at the PCP-impacted wells, and the low number of sampling locations within the plume itself, makes such an analysis impossible at this time.

Another approach to evaluating attenuation rates and mechanisms is to estimate PCP transport without attenuation. The average measured seepage velocity was 0.46 ft/day, or 168 ft/yr (Permapost, 2019). PCP transport in groundwater (without biodegradation) may not be retarded at concentrations above 10 mg/L, but at lower concentrations it is retarded due to sorption, with retardation factors of 5-10 being typical, both at this site and others (Maul Foster and Alongi, 2001; Schwarzenbach et al., 1983; Subramanian et al. 2006). Thus, a sustained 3-fold increase in upgradient PCP concentrations could move downgradient at near the groundwater velocity (e.g., from P-14a toward P-19b), while beyond the core (e.g., between P-19b and P-18b), PCP should be transported at about 17-34 ft/yr and therefore could be detected approximately 120 to 240 ft downgradient over 7 years. No such increase has been observed, and in fact, the concentrations at both P-19b and P-18b are lower than during the 7 years before the shutdown. This result is strong evidence that biodegradation is contributing to the observed attenuation.

Ultimately, the most critical evidence at this point is the current plume size and strength compared to the pre-shutdown conditions. Figure 12 presents the estimated current plume along the transect shown in Figure 11, using 2022-2023 data to provide a conservative comparison to the pre-shutdown plume extent. Results from Wells P-12c, P-15b and P-18b indicate plume shrinkage has continued at the edges of the plume, despite an increase in upgradient concentrations (notably at P-14a).

Oxygen appears to be the factor limiting the extent of biodegradation, because solubility is low relative to the maximum PCP concentrations, the rate of oxygen penetration through soils and groundwater is slow relative to demand, and there are likely many sources of oxygen demand other than PCP biodegradation. However, anaerobic biodegradation can also be effective in shrinking the plume at the edges where PCP concentrations are low.

4. SUMMARY

While PCP concentrations in groundwater at Permapost have been consistently variable throughout the last four decades of monitoring, the trends over time are clear. The plume was shrinking before the shutdown, and it has continued to shrink since shutdown. Despite the increased concentrations at some locations near and within the PCP plume (especially at monitoring well P-14a), the plume has continued to shrink at the fringes. Importantly, PCP concentrations have remained below levels of concern at monitoring well P-18b since shutdown, and concentrations at P-15b have continued to decline at the same rate as before shutdown.

PCP migration rates are slow, even in the absence of biodegradation, and the evidence indicates both anaerobic and aerobic biodegradation are still occurring, particularly at the edges of the plume. Given the continued attenuation and ongoing plume shrinkage, it seems unlikely that the plume will again reach the P-18 monitoring wells. Certainly, there is no evidence that there is any threat to well P-18a, which has not had detectable PCP since 1987 (40+ sampling events).

With respect to recent results from well P-19b, the rapid decrease to non-detect levels following shutdown has been followed by a recent return to near the average levels during the last 7 years of groundwater recovery. The most likely explanation is a short-term change in groundwater flow paths followed by a return to pre-shutdown conditions. Current concentrations have remained slightly lower than the pre-shutdown average concentration, suggesting natural attenuation is continuing to contain the plume.

Finally, the measured and expected rate of change within the plume is slow, as PCP migration is likely to be slow, particularly when biodegradation is contributing to the retardation. As a result, the contamination in the P-14 area will likely persist, but any rebound beyond that area will be limited due to continued biodegradation.

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FIGURES

FIGURE 1

PERMAPOST MONITORING WELLS AND 2017 PLUME

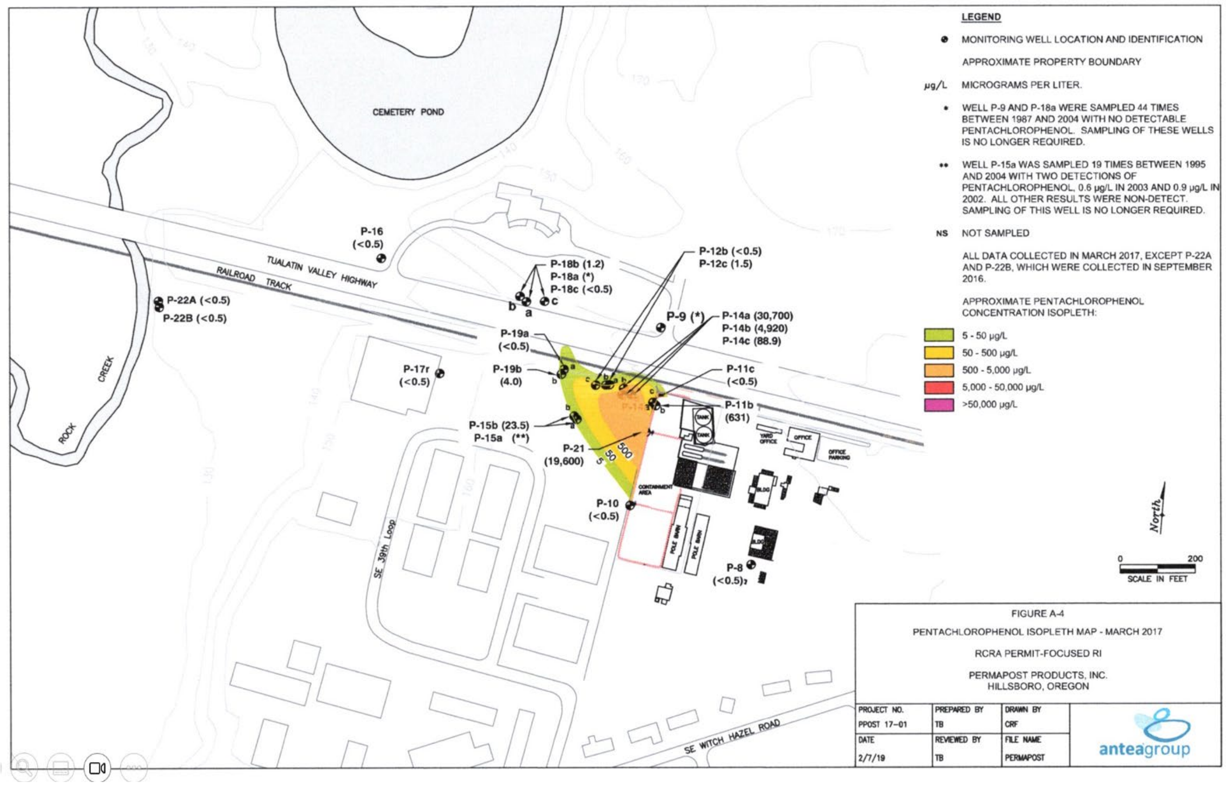

FIGURE 2

PCP CONCENTRATIONS AT WELL P-14a

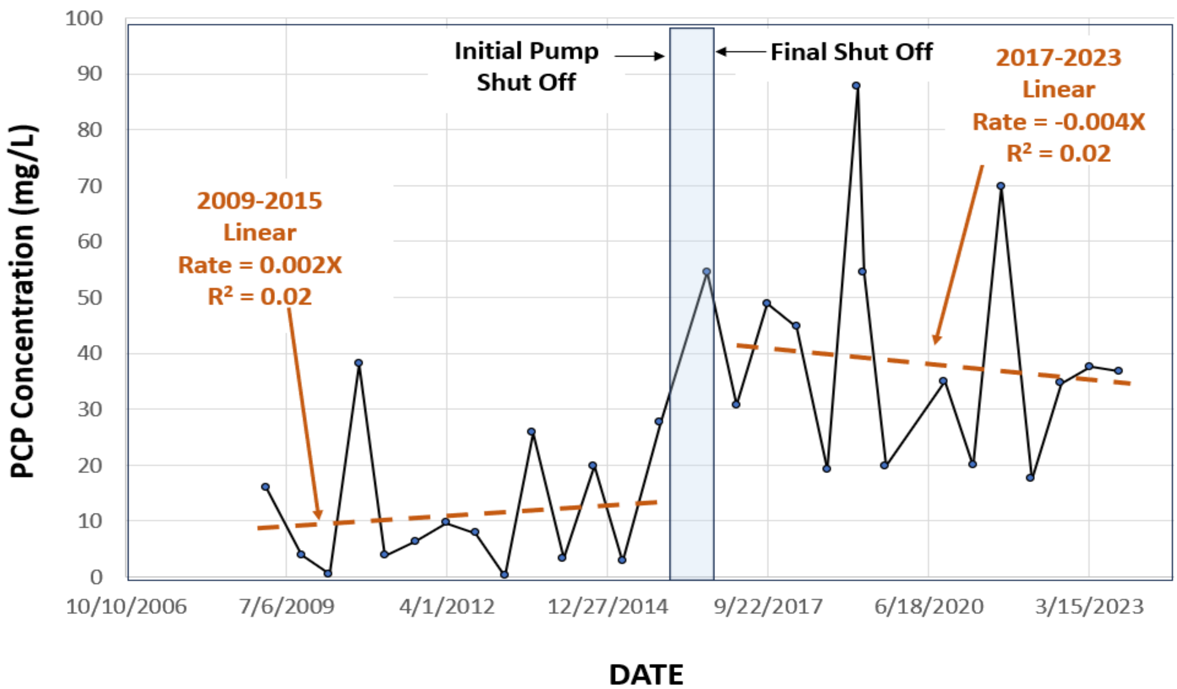

FIGURE 3

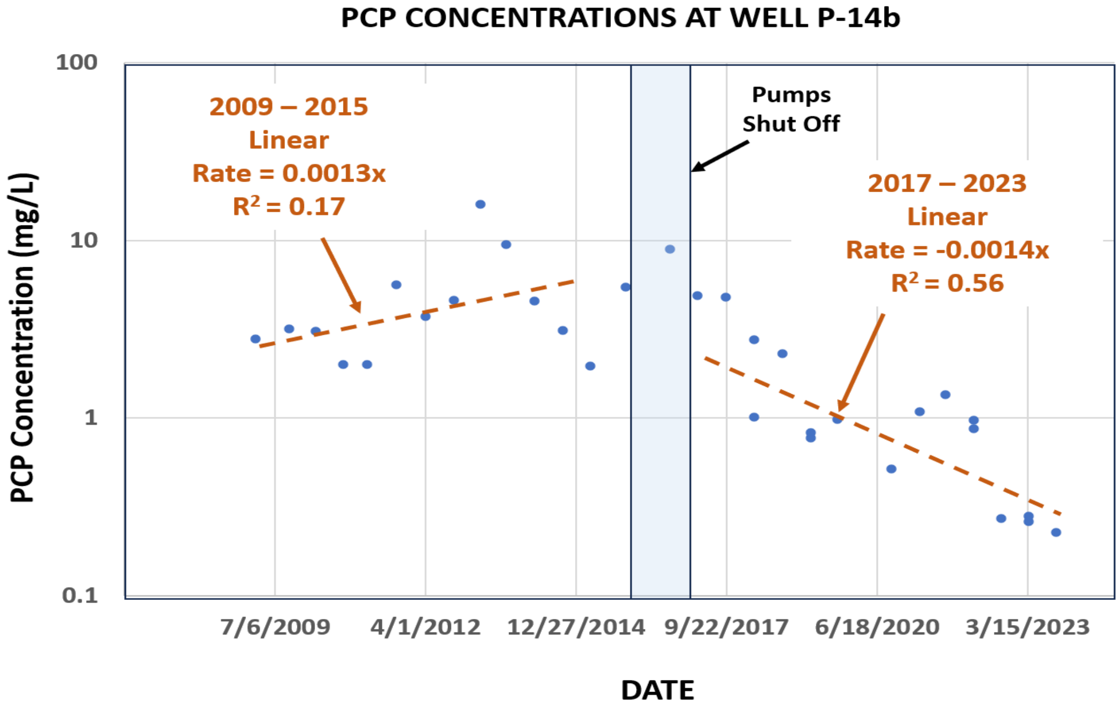

FIGURE 4

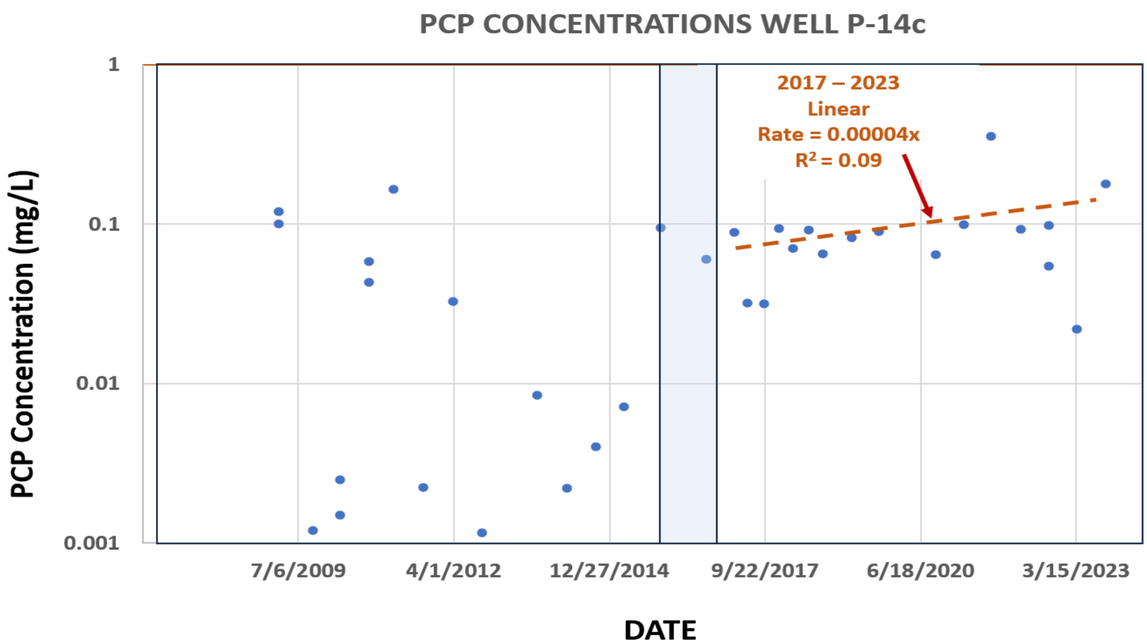

FIGURE 5

PCP CONCENTRATIONS AT WELL P-12b

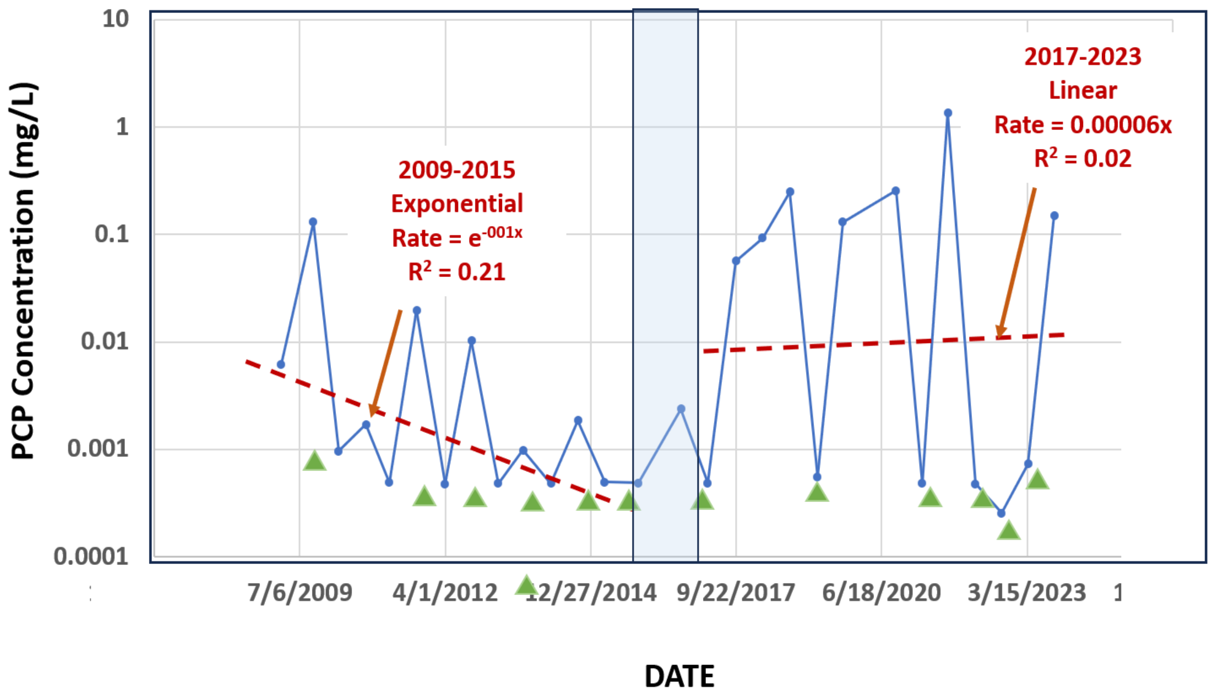

FIGURE 6

PCP CONCENTRATIONS AT WELL P-12c

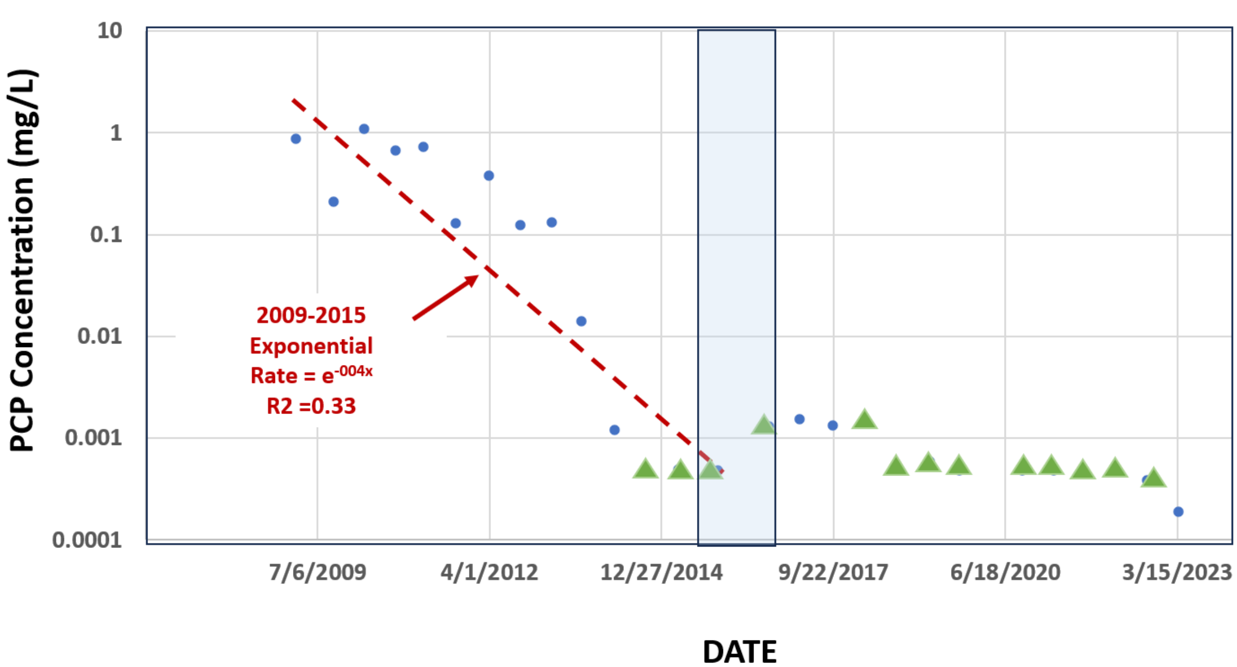

FIGURE 7

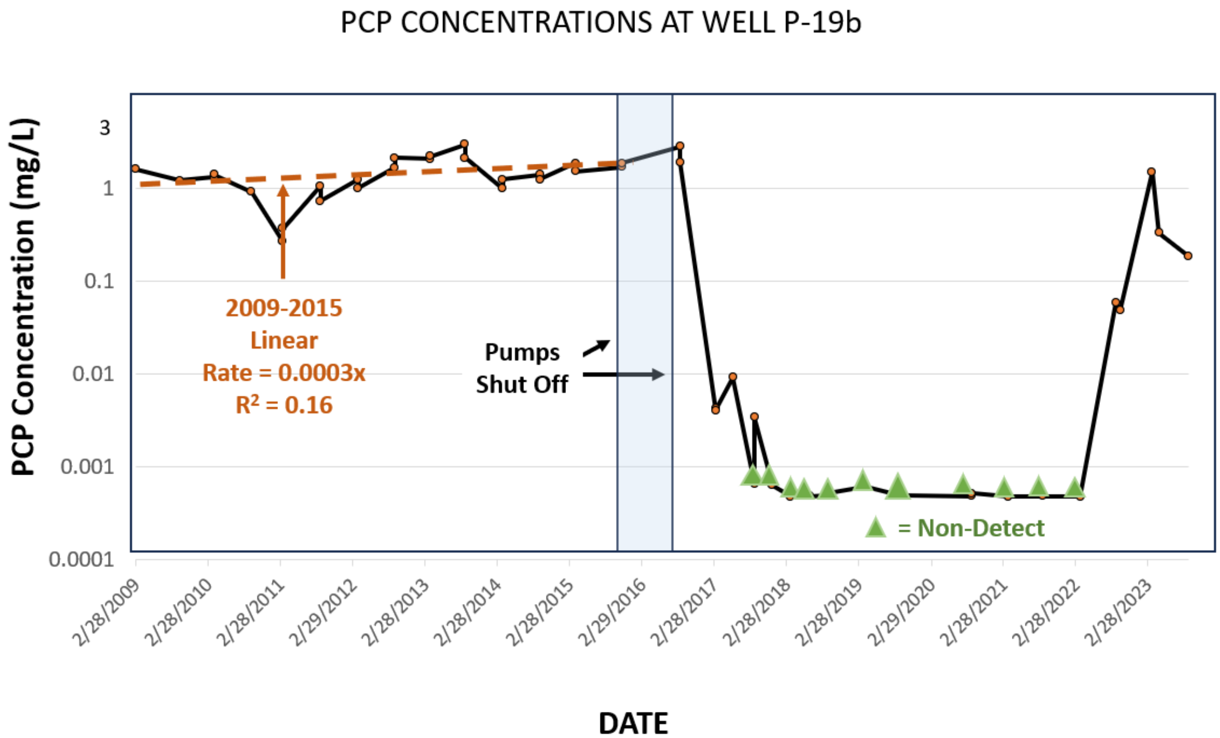

FIGURE 8

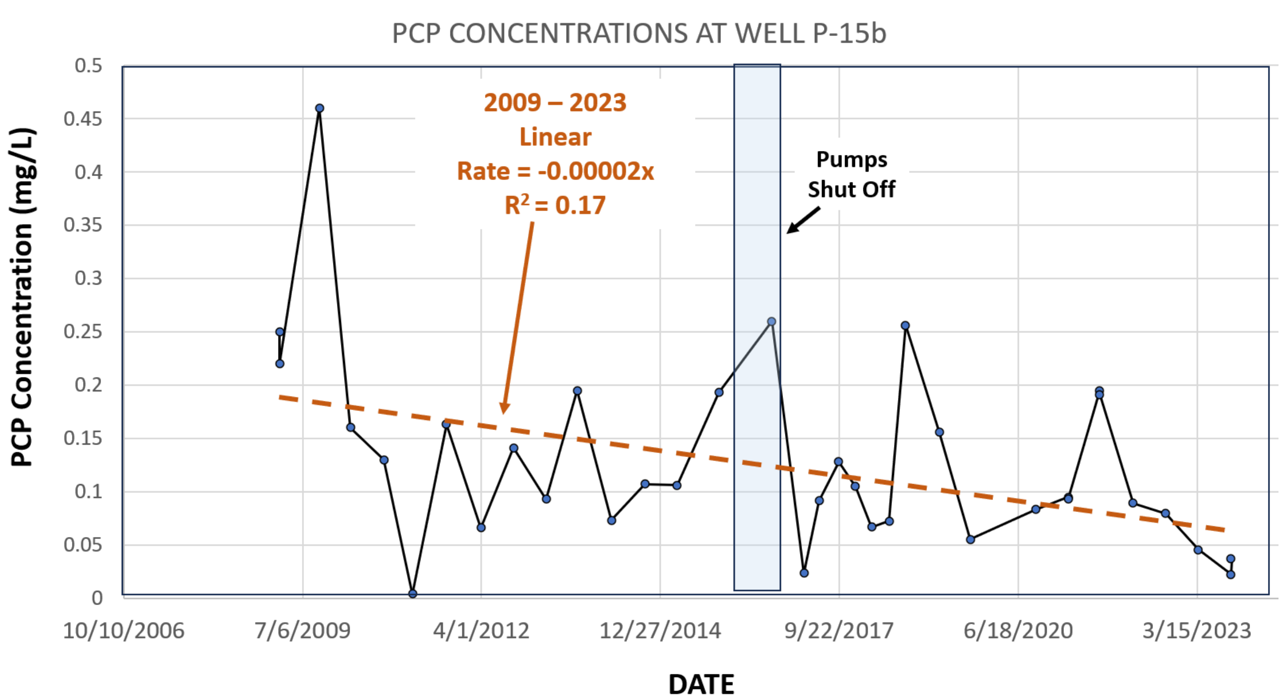

FIGURE 9

PCP CONCENTRATIONS AT WELL P-18b

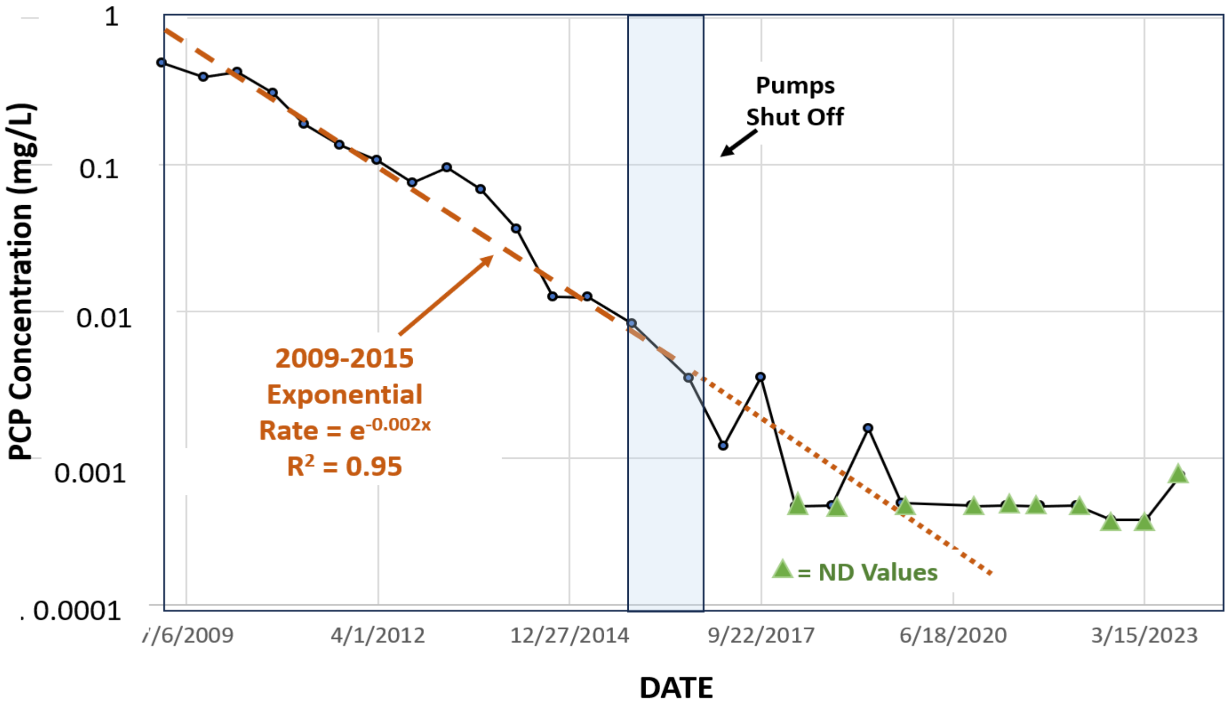

FIGURE 10

Mole Fraction of Daughter Products vs. PCP in Well P-18b

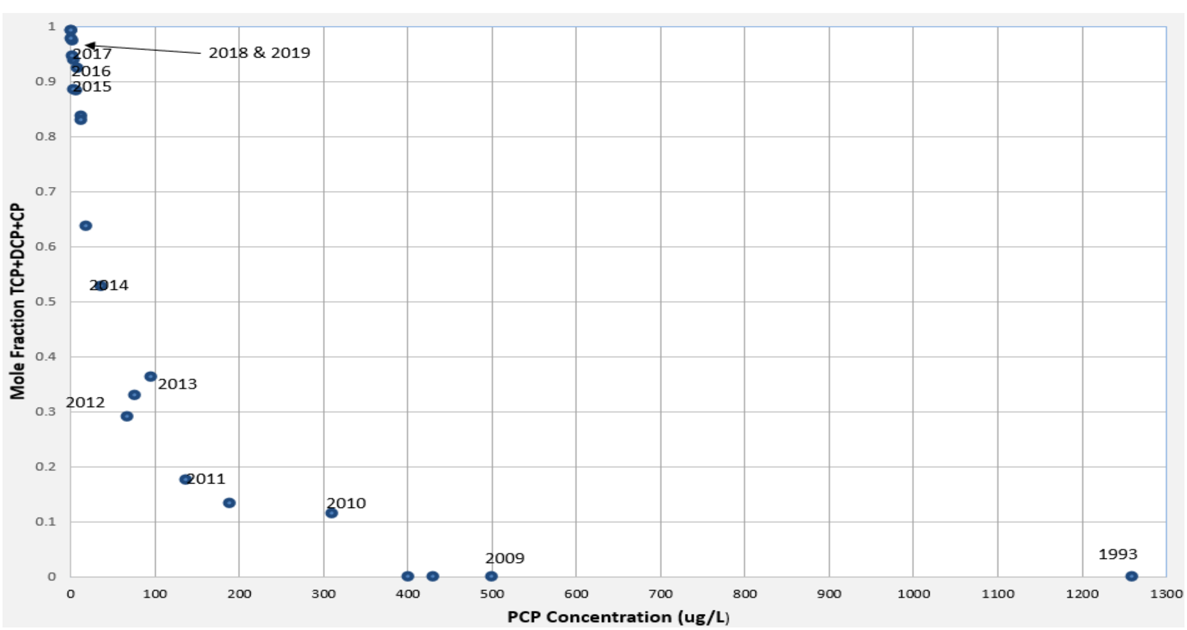

FIGURE 11
PCP CONCENTRATIONS 2009-2015

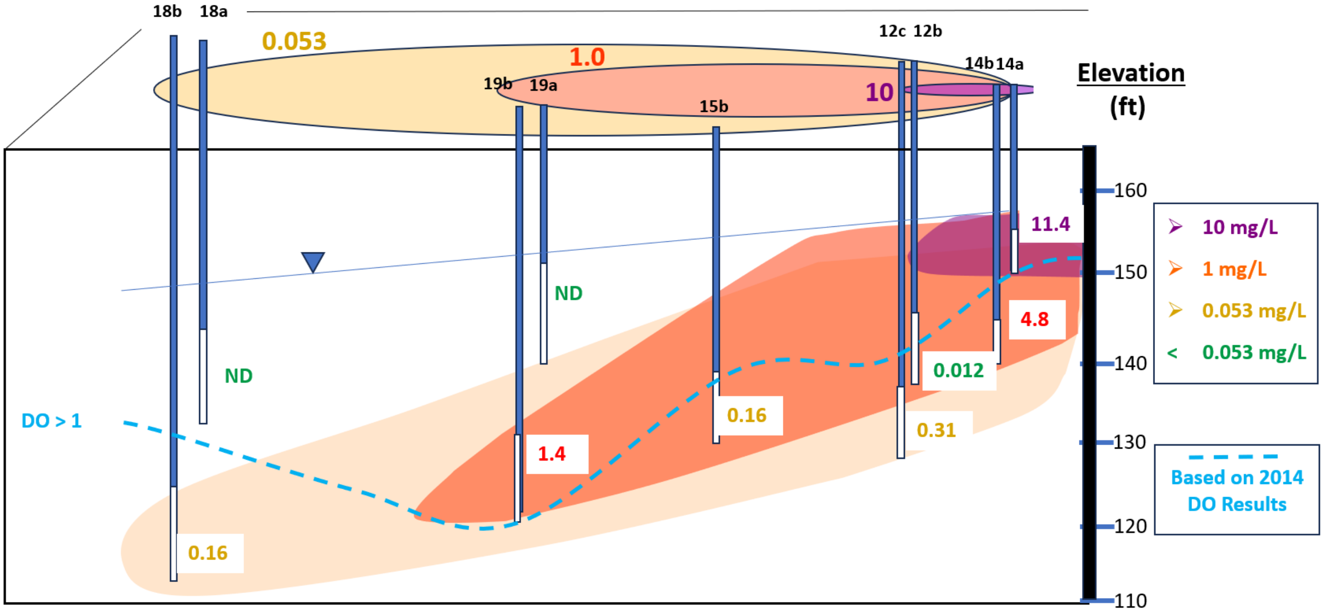

FIGURE 12
PCP CONCENTRATIONS IN 2022-2023