Technical Memorandum

TO: Bryan McCampbell, Precision Castparts, Inc.

FROM: Erin Waibel, RG and Clint Jacob, PE, LG

DATE: June 29, 2021

RE: **Cost-Benefit Evaluation**
Low-Temperature Thermal Enhancement of Source Treatment
PCC Structurals, Inc. SSBO Facility
Clackamas, Oregon
ESCI No 1617

This memorandum presents a cost-benefit evaluation for low-temperature thermal treatment as an enhancement for the trichloroethene (TCE) source zone treatment ongoing at the PCC Structurals, Inc. (PCC) Small Structurals Business Operation (SSBO) facility. The SSBO facility (Site) is located at 13340 Southeast 84th Avenue in Clackamas, Oregon. The interim remedial action measure (IRAM) activities are conducted under the Oregon Department of Environmental Quality (ODEQ) Voluntary Cleanup Program (VCP). The Site is identified by ODEQ as Environmental Cleanup Site Information (ECSI) File No. 1617.

Background

Chlorinated solvent contamination in groundwater was first discovered in June 2002 during a preliminary assessment at the former PCC Administrative Center, located west (hydraulically downgradient) of the PCC manufacturing building. A site-wide investigation determined that primary constituents of concern were the chlorinated volatile organic compound (cVOC) TCE and breakdown products cis-1,2-dichlorotethene (cDCE) and vinyl chloride (VC). These cVOCs in groundwater resulted from a historical release of TCE from a former vapor degreaser and/or its underground supply pipeline. Site characterization included analysis of soil, groundwater, soil vapor, indoor air, creek surface water, and creek pore water was documented in the remedial investigation (RI) report (LAI 2017, 2020c) approved by ODEQ in 2020 (Hoy 2020, ODEQ 2019). IRAMs for the groundwater source and indoor air have been conducted beginning in 2005 and 2009, respectively. The feasibility study (FS) for the Site (LAI 2020b) was approved by ODEQ in February 2021 and the record of decision (ROD) process was begun by ODEQ (Hoy 2021). The approved remedial action alternative from the FS consists of continuation of the groundwater source and indoor air IRAMs as cleanup actions, followed by monitored natural attenuation (MNA) to meet cleanup levels throughout the Site. The ODEQ ROD describing Site cleanup requirements based on the approved FS is anticipated in 2021 or early 2022.

The groundwater IRAM consists of injecting electron donor substrates (vegetable oil and lactate) and other amendments to the source zone around the former vapor degreaser. The groundwater IRAM has resulted in treatment of the downgradient plume and substantial mass reduction in the source zone (LAI 2020a). Six source zone injection events have been completed from 2005 to 2018. Each event involved injection of approximately 32,000 gallons to 53,000 gallons of electron donor and other substrates diluted in tap water. Based on favorable monitoring results, the interval between injection events has extended from 2 years for the first three events, to 4 years for the last three events. Various enhancements have been applied to source zone bioremediation, including:

1) Transition to the LactOil® electron donor substrate containing ethyl lactate to enhance dissolution/desorption of TCE mass (2014 and 2018 injections).
2) The addition of ferrous sulfate (2014 injection) to injection fluid for all source wells to stimulate *in situ* chemical reduction (ISCR) through reductive elimination of TCE and cDCE as a concurrent and complementary degradation mechanism to biological reductive dechlorination.
3) The addition of colloidal zero valent iron (ZVI; 2018 injection) to further enhance reductive elimination at the highest concentration wells present in the core of the source zone.

The indoor air IRAM consists of a soil vapor extraction (SVE) system operated beneath the building slab near the former vapor degreaser (TCE source zone) to mitigate indoor air concentrations of TCE within the SSBO facility. TCE volatilizes from groundwater into soil gas and can migrate through the floor slab into the building, a process known as vapor intrusion. Indoor air IRAM activities also included decommissioning the concrete pit that formerly held the vapor degreaser and sealing of floor slab penetrations. The SVE system has been operating continuously since March 2016 with limited shutdown periods. Effectiveness of the SVE system has been confirmed through pressure differential measurements and sampling of soil vapor and indoor air. In accordance with the approved remedial action alternative from the FS, the SVE system will continue to operate until groundwater cVOC concentrations in the source have decreased to levels protective of indoor air.

Potential Low-Temperature Thermal Enhancement

In keeping with LAI's ongoing efforts to enhance source zone treatment and shorten the remediation time frame, we have evaluated low-temperature thermal as a possible enhancement to bioremediation in the source zone. As described below, this low-temperature thermal is different from thermal remediation systems, which are operated at higher temperatures to volatilize contaminants and require vapor collection and treatment. Steam generation, which can be a health and safety concern for conducting higher temperature thermal beneath an active factory setting, does not occur with low-temperature thermal.

Low-temperature thermal involves heating the aquifer zone to approximately 35 degrees Celsius (°C), which is optimal for biological reductive dechlorination. In accordance with the Arrhenius equation, every 10°C increase in temperature results in an approximate doubling of chemical and biological reaction rates (i.e., source degradation rates). Increasing the aquifer temperature in the center of the SSBO source zone from approximately 15 to 20°C ambient temperature to 35°C would increase the degradation rates by approximately 3 to 4 times. The target temperature for low-temperature thermal of approximately 35°C is well below the boiling point of TCE (87°C), while the boiling point of VC is very low (-13°C) and below even the ambient aquifer temperature; therefore, the low-temperature heating would not substantially increase volatilization of these compounds. Regardless, the SSBO source zone SVE system will continue to operate as an ongoing measure to prevent vapor intrusion of these compounds to indoor air.

It has long been recognized that traditional high-temperature thermal treatment has beneficial effects on biotic and abiotic degradation during the heat-up and cool-down phases. Various studies indicate that temperatures up to 35°C, are ideal for growth of dechlorinating bacteria and enhanced reductive dechlorination. Dechlorinating bacteria are a subset of aquifer micro-organisms that are sensitive to elevated temperatures. Several species of bacteria can reduce TCE to cDCE (e.g., *Geobacter, Dehalobacter, Desulfitobacterium*), but further reduction from cDCE to VC can only be completed by bacteria of the species *Dehalococcoides* (DHC). Further reduction of VC to end products ethene and ethane can be achieved by DHC and other bacteria. Friis et al. (2005) showed that the maximum dechlorination rate for TCE reduction to cDCE occurred at around 30°C and transformation of cDCE and VC to ethene was maximized between 15°C and 30°C. Other studies have shown optimal temperatures for complete degradation of TCE to ethene to range from 22°C to 35°C (He et al. 2003, Holliger et al. 1993). Kengen et al. (1999) showed an optimal rate for the dechlorination step from TCE to cDCE to occur as high as 62°C. In another microcosm study with sediments from the Joint Base Lewis-McChord in Washington, Fletcher et al. (2007) demonstrated that no dechlorination occurred at 50°C, 70°C, or 95°C, and was repressed at 35°C. Friis et al. (2005) showed complete degradation of TCE to ethene with the mixed bacterial culture KB-1™ at temperatures between 10°C and 30°C, and only partial degradation of TCE to cDCE (no VC or ethene/ethane) occurring at 40°C. A field study at the Lewis-McChord site (Truex et al. 2007) showed evidence of enhanced biotic and abiotic dechlorination during heat up of the traditional thermal treatment system, including increased concentrations chloride, acetylene, and ethene. The studies cited above indicate that the dechlorination step from TCE to cDCE, which is mediated by several species of micro-organisms, can occur at nearly twice the temperature of cDCE dechlorination to VC, which is mediated specifically by DHC. Above-ambient temperatures will also increase the rate of abiotic degradation of TCE by iron sulfide or ZVI (reductive elimination), which increases by a factor of about 2.5 for every 10°C increase in temperature (Beyke and Fleming 2005).

Over the last decade or so, low-temperature thermal has been identified as a distinct technology (Horst et al. 2018, Suthersan et al. 2012,) with the primary objective to enhance *in situ* biotic and abiotic destruction of various organic contaminants instead of volatilization and vapor collection/treatment. Field testing of intentional low-temperature thermal for TCE treatment at the Lewis-McChord site showed an increase in biotic degradation rates of 2 to 4 times and an increase in abiotic degradation rates of 4 to 8 times (ESTCP 2012, 2015). Full-scale, low-temperature thermal has been conducted in TCE dense non-aqueous phase liquid (DNAPL) areas at the Well 12-A Superfund site in Tacoma, Washington (Welch et al. 2019) and is underway for petroleum constituents and non-chlorinated solvents in East Syracuse, New York (Jay and McCune 2021).

Low-temperature heating of the SSBO source would involve installation of conductive heater wells in the center of the source zone targeting the area where TCE in groundwater still exceeds 10,000 micrograms per liter (µg/L). Conductive heaters are essentially wells equipped with hot water heater elements. The 10,000 µg/L treatment zone includes the likely release area near the former vapor degreaser and wells where DNAPL TCE was periodically observed and removed through 2018. TerraTherm prepared a preliminary design and cost estimate for low-temperature thermal of the source, based on Site data (Attachment 1). This design utilizes eight thermal conduction heating (TCH) wells installed in the center of the source zone. TCH well locations and spacing accounts for Site access restrictions.

Cost Benefit

The cost for system installation and operation for 2 years are estimated as part of this evaluation. Costs include TerraTherm's estimated costs for design, construction, operation and maintenance (O&M), electrical usage, and system decommissioning (Attachment 1), as well as LAI's estimated costs for design, construction oversight, as-built report, and O&M support (Attachment 2). No additional monitoring, reporting, or project management costs are anticipated to result from this enhancement of source treatment. Combined TerraTherm and LAI costs through design, construction, and 2 years of operation, as presented in the attachments, are approximately $330,000. Low-temperature heating may continue for longer than 2 years based on monitoring results. The annual cost including O&M (TerraTherm and LAI) and electrical charges is approximately $50,000. Assuming up to 6 years of low-temperature heating, the estimated total cost would be approximately $530,000.

For comparison, the estimated remediation cost from the FS and a single injection event are summarized below:

- The recommended remedial alternative from the FS, which will be the basis for the ROD, consists of continued *in situ* bioremediation with complementary ISCR in the groundwater source, followed by MNA; SVE will continue to operate for protection of indoor air until groundwater concentrations protective of indoor air are achieved in the source zone. For costing purposes, the FS assumed three more injection events will be required over 8 years of active treatment; additional treatment may be needed based on monitoring results. Active bioremediation treatment is assumed to be followed by an additional 7 years of MNA to achieve Site-wide cleanup levels. The SVE system is assumed to continue operation for the 15-year period for protection of indoor air. The FS estimated cost for this treatment scenario is $2.3 million (range of $1.6 to $3.4 million).
- The cost of a single bioremediation injection, based on the last injection in 2018, is approximately $260,000. With generally increasing costs for substrates, equipment, and labor, the next injection event anticipated in 2022 may be closer to $300,000.

- The FS estimates the additional annual costs of groundwater monitoring, SVE system O&M, and reporting during the active treatment phase to be $103,000.

Conclusion

We recommend implementation of focused low-temperature thermal, as described in this memorandum. The increased biotic and abiotic degradation rates resulting from low-temperature thermal are expected to result in a significant reduction of the remediation time frame. The cost for design, construction, and 2 years of operation of the low-temperature thermal enhancement ($330,000) is less than the cost of one injection event ($260,000 to $300,000) plus the additional costs of a single year of monitoring, SVE system O&M, and reporting ($103,000). In short, the low-temperature thermal enhancement will pay for itself if it saves one injection event and 1 year of monitoring, O&M, and reporting expenses.

Use of This Technical Memorandum

This Technical Memorandum has been prepared for the exclusive use of PCC for specific application to the SSBO facility. No other party is entitled to rely on the information, conclusions, and recommendations included in this document without the express written consent of LAI. Further, the reuse of information, conclusions, and recommendations provided herein for extensions of the project or for any other project, without review and authorization by LAI, shall be at the user's sole risk. LAI warrants that within the limitations of scope, schedule, and budget, our services have been provided in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality under similar conditions as this project. We make no other warranty, either express or implied.

This document has been prepared under the supervision and direction of the following key staff.

LANDAU ASSOCIATES, INC.

E Waibel

Erin Waibel, RG
Senior Geologist

Clint Jacob

Clint Jacob, PE, LG
Principal

EMW/CLJ/ljl
[X:\PCC STRUCTURALS\2021-06_SSBO THERMAL\LAI PCC SSBO LOW TEMP HEAT COST-BENEFIT EVALUATION FINAL 062921.DOCX]

Attachments

Attachment 1. TerraTherm PCC SSBO Preliminary Site Evaluation
Attachment 2. LAI Estimated Costs

References

Beyke, G. and D. Fleming. 2005. "*In Situ* Thermal Remediation of DNAPL and LNAPL Using Electrical Resistance Heating." Remediation. Summer.

ESTCP. 2012. Final Report: Combining Low-Energy Electrical Resistance Heating with Biotic and Abiotic Reactions for Treatment of Chlorinated Solvent DNAPL Source Areas. Environmental Security Technology Certification Program, US Department of Defense. December.

ESTCP. 2015. Cost and Performance Report: Combining Low-Energy Electrical Resistance Heating with Biotic and Abiotic Reactions for Treatment of Chlorinated Solvent DNAPL Source Areas. Environmental Security Technology Certification Program, US Department of Defense. January.

Fletcher K.E., J. Costanza, N. Ramaswamy, K. Pennell, and F. Löffler. 2007. "The Effects of Thermal Treatment on Native and Introduced Dechlorinating Bacteria". *In Situ* and On-Site Bioremediation – 2007. Proceedings of the Ninth International In-Situ and On-Site Bioremediation Symposium. May 7-10, 2007, Baltimore Maryland. A.R. Gavaskar and C.F. Silver (Symposium Chairs).

Friis, A.K., A. Heimann, R. Jakobsen, H.-J., Albrechtsen, E. Cox, and P.L. Bjerg. 2005. "Temperature Dependence of Anaerobic TCE-dechlorination in a Highly Enriched Dehalococcoides-containing Culture." Water Research 41:355-364.

He, J., K.M. Ritalahti, M.R. Aiello, and F.E. Löffler. 2003. "Complete Detoxification of Vinyl Chloride by an Anaerobic Enrichment Culture and Identification of the Reductively Dechlorinating Population as a Dehalococcoides Species." Applied and Environmental Microbiology. 69:996-1003.

Holliger, C., G. Schraa, A.J.M. Stams, and A.J.B Zehnder. 1993. "A Highly Purified Enrichment Culture Couples the Reductive Dechlorination of Tetrachloroethene to Growth." Applied and Environmental Microbiology. 59:2991-2997.

Horst, J., C. Flanders, M. Klemmer, D.S. Randhawa, and D. Rosso. 2018. Low-Temperature Thermal Remediation: Gaining Traction as a Green Remedial Alternative. Groundwater Monitoring & Remediation. 38: 18-27. doi: 10.1111/gwmr.12295.

Hoy, R. 2020. Re: PCC SSBO RI/IRAM/RA Addendum. From Ray Hoy, Oregon Department of Environmental Quality, to Clint Jacob, Landau Associates, Inc. March 31.

Hoy, R. 2021. Re: File Transfer: PCC Structurals SSBO Facility Feasibility Study - 0883001 - PCC- Source Zone Treatment. From Ray Hoy, Oregon Department of Environmental Quality, to Erin Waibel, Landau Associates, Inc. February 5.

Jay, K. and W. McCune. 2021. Building 55 Area Interim Remedial Measure Work Plan, Site #C734138, BMS Syracuse North Campus, Restoration Area, 3551 Burnet Avenue, East Syracuse, New York. Arcadis of New York, Inc. Revised March.

Kengen, S.W.M., C.G. Breidenbach, A. Felske, A.J.M. Stams, G. Schraa, and W.M. de Vos. 1999. "Reductive dechlorination of tetrachloroethene to cis-1,2-dichloroethene by a thermophilic anaerobic enrichment culture." Applied and Environmental Microbiology. 65:2312-2316.

LAI. 2017. Report, Remedial Investigation, Interim Remedial Action Measures, and Risk Assessment, PCC Structurals, Inc. Small Structurals Business Operation (SSBO) Facility, Clackamas, Oregon, ECSI No. 1617. Landau Associates, Inc. November 15.

LAI. 2020a. 2019 Annual Report, Interim Remedial Action Measure and Supplemental Remedial Investigation, PCC Structurals, Inc. SSBO Facility, Clackamas, Oregon, ECSI No. 1617. Landau Associates, Inc. September 29.

LAI. 2020b. Feasibility Study, PCC Structurals, Inc. SSBO Facility, Clackamas, Oregon, ECSI No. 1617. Landau Associates, Inc. October 30.

LAI. 2020c. Report Addendum, Remedial Investigation, Interim Remedial Action Measure, and Risk Assessment, PCC Structurals, Inc., Small Structurals Business Operation (SSBO) Facility, ECSI No. 1617. Landau Associates, Inc. February 4.

ODEQ. 2019. Letter: Remedial Investigation Report, Precision Castparts - Small Parts Campus (ECSI #1617). From Ray Hoy, Oregon Department of Environmental Quality, to Bryan McCampbell, PCC Structurals, Inc. August 15.

Suthersan, S., J. Horst, M. Klemmer, and D. Malone. 2012. Temperature-activated Auto-decomposition Reactions: An Underutilized *In Situ* Remediation Solution. Groundwater Monitoring & Remediation. 32: 34-40.

Truex, M., T. Powell, and K. Lynch. 2007. *In Situ* Dechlorination of TCE During Aquifer Heating. Groundwater Monitoring & Remediation. 27: 96-105.

Welch, A., Z. Nquyen, T. Macbeth, D. Giaudrone, R. Chichakli, C. Cora, K. Lynch, and T. Powell. 2019. Implementation and Performance of Thermally-Enhanced Bioremediation for Targeted DNAPL Source Treatment. CDM Smith. October 3. https://nwremediation.com/wp-content/uploads/2A_Welch.pdf.

ATTACHMENT 1

TerraTherm PCC SSBO Preliminary Site Evaluation

Landau Associates
Precision Castparts SSBO Site

Clackamas, OR
Preliminary Site Evaluation
Revision 3

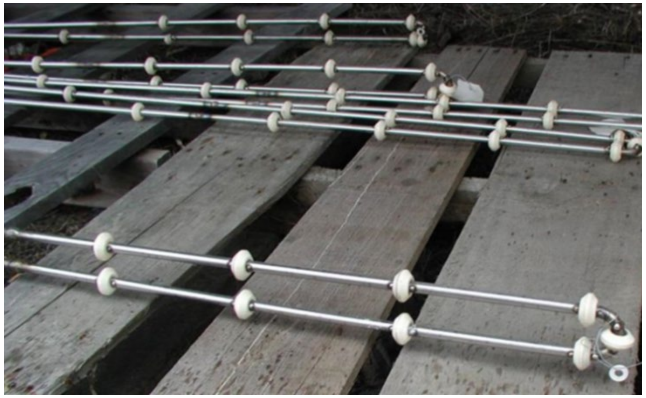
June 21, 2021

TERRATHERM
a Cascade Company
www.terratherm.com

About TerraTherm

- Based in MA and offering all major methods of subsurface heating
  - Thermal Conduction Heating (TCH)
  - Electric Resistance Heating (ERH)
  - Steam Enhanced Extraction (SEE)
- Over 20 years of experience implementing all three thermal technologies
- Our staff has played key roles in the technical development of TCH and ERH, and have an unparalleled knowledge about how to successfully deploy each technology
- TerraTherm has successfully completed more than:
  - 75 TCH projects
  - 55 ERH projects
  - 15 SEE projects
- 70 dedicated staff members with over 450 years of collective thermal experience
- Only thermal company in industry to gain UL electrical safety certification of heaters

Site Background



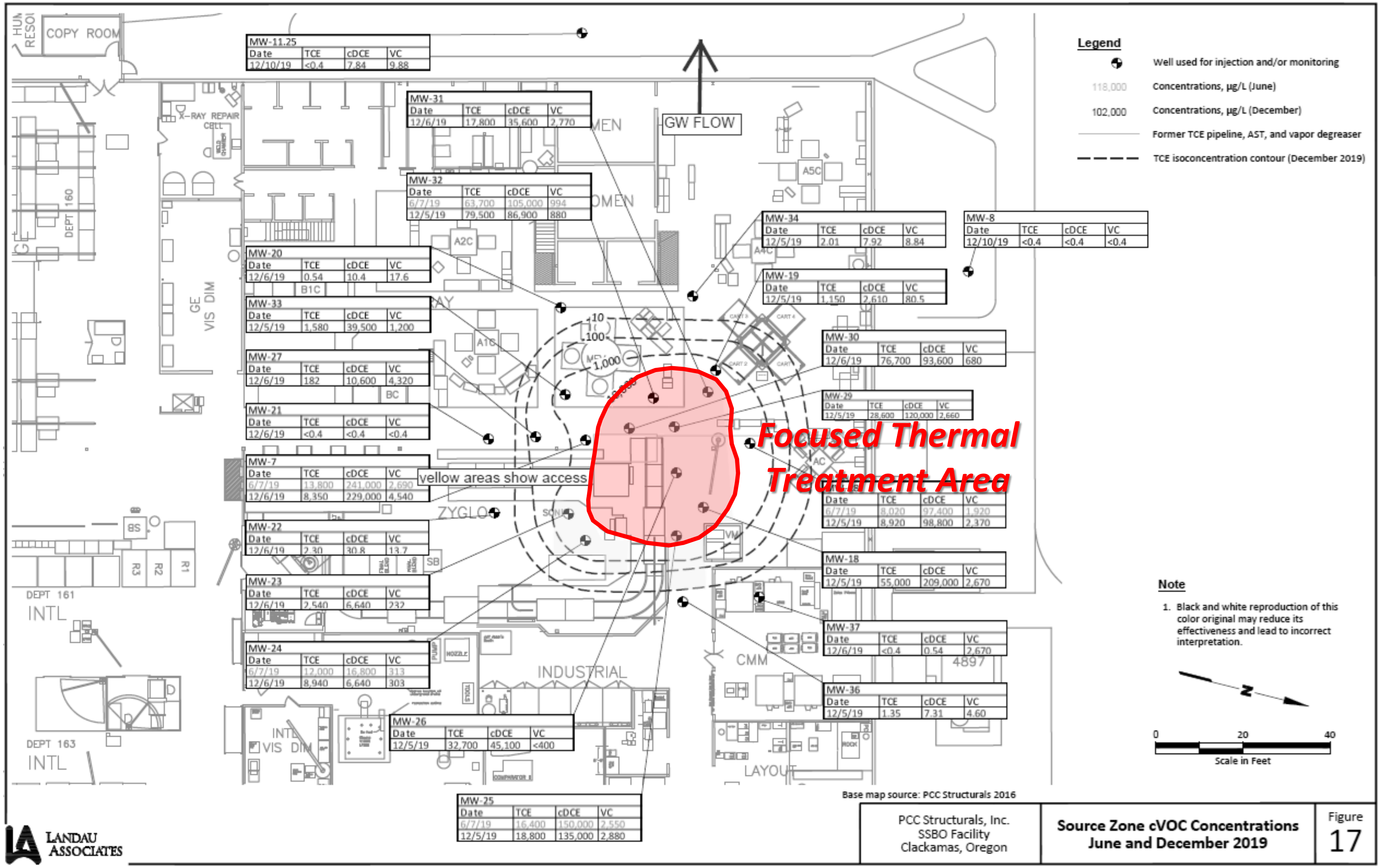
Site Name: Precision Castparts SSBO Site

Site Location: Clackamas, Oregon

Site/Environmental Consultant: Landau Associates

Objective: Obtain a conceptual cost to implement low temperature thermal to enhance ongoing bioremediation at the site.

Treatment Area Map



Focused Thermal Treatment Area

MW-11.25

Date	TCE	cDCE	VC
12/10/19	<0.4	7.84	9.88

MW-31

Date	TCE	cDCE	VC
12/6/19	17,800	35,600	2,770

MW-32

Date	TCE	cDCE	VC
6/7/19	63,700	105,000	994
12/5/19	79,500	86,900	880

MW-20

Date	TCE	cDCE	VC
12/6/19	0.54	10.4	17.6

MW-33

Date	TCE	cDCE	VC
12/5/19	1,580	39,500	1,200

MW-27

Date	TCE	cDCE	VC
12/6/19	182	10,600	4,320

MW-21

Date	TCE	cDCE	VC
12/6/19	<0.4	<0.4	<0.4

MW-7

Date	TCE	cDCE	VC
6/7/19	13,800	241,000	2,690
12/6/19	8,350	229,000	4,540

MW-22

Date	TCE	cDCE	VC
12/6/19	2.30	30.8	13.7

MW-23

Date	TCE	cDCE	VC
12/6/19	2,540	6,640	232

MW-24

Date	TCE	cDCE	VC
6/7/19	12,000	16,800	313
12/6/19	8,940	6,640	303

MW-26

Date	TCE	cDCE	VC
12/5/19	32,700	45,100	<400

MW-25

Date	TCE	cDCE	VC
6/7/19	16,400	150,000	2,550
12/5/19	18,800	135,000	2,880

MW-34

Date	TCE	cDCE	VC
12/5/19	2.01	7.92	8.84

MW-8

Date	TCE	cDCE	VC
12/10/19	<0.4	<0.4	<0.4

MW-19

Date	TCE	cDCE	VC
12/5/19	1,150	2,610	80.5

MW-30

Date	TCE	cDCE	VC
12/6/19	76,700	93,600	680

MW-29

Date	TCE	cDCE	VC
12/5/19	28,600	120,000	2,660

MW-[illegible]

Date	TCE	cDCE	VC
6/7/19	8,020	97,400	1,920
12/5/19	8,920	98,800	2,370

MW-18

Date	TCE	cDCE	VC
12/5/19	55,000	209,000	2,670

MW-37

Date	TCE	cDCE	VC
12/6/19	<0.4	0.54	2,670

MW-36

Date	TCE	cDCE	VC
12/5/19	1.35	7.31	4.60

Legend

⊕	Well used for injection and/or monitoring
118,000	Concentrations, µg/L (June)
102,000	Concentrations, µg/L (December)
──	Former TCE pipeline, AST, and vapor degreaser
— — — —	TCE isoconcentration contour (December 2019)

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Base map source: PCC Structurals 2016

LANDAU ASSOCIATES

PCC Structurals, Inc.
SSBO Facility
Clackamas, Oregon

Source Zone cVOC Concentrations June and December 2019

Figure
17

Geology and Hydrogeology

Geology:

- 0 to ~10 ft bgs: silt
- ~10 to ~30 ft bgs: sand and gravel with interbedded silty, clayey gravel
- Beyond ~30 ft bgs: silty, clayey gravel

Hydrogeology:

- Per the information provided, water surface elevation is found at 4 ft bgs and was used for this evaluation.
- A representative hydraulic conductivity value of 1.16×10^{-3} cm/sec (3.28 ft/day) was assumed and used for this evaluation.
- Per the information provided, a groundwater velocity ranging between 0.5 and 3.0 ft/day was considered for this evaluation.
- Groundwater flows in the westerly direction.

Hydraulic gradient:

- A representative hydraulic gradient value of 0.01 ft/ft was assumed and used for this evaluation.

Treatment Scenario

Treatment Scenario	Treatment Areas (ft^2)		Impacted Depth (ft bgs)	Treatment Depth (ft bgs)	Treatment Volume (CY)
Low temperature thermal not requiring soil vapor extraction (30 °C to 40 °C)	Treatment Area	1,100	10.0 – 30.0	0.0 – 30.0	1,222

Notes:

- Slab on grade
- Steel building
- Ceiling about 20 ft
- Current business: machining and metal finishing
- Installation to be done night shift and or weekend. Can install heater wells in the aisles but not where the equipment is shown, so access is limited to about 2/3 of the footprint within the 10,000 ug/L contour
- Existing SVE system operating above the source. Draws from base gravel layer below the slab.

COCs, Mass Estimate and Remediation Goals

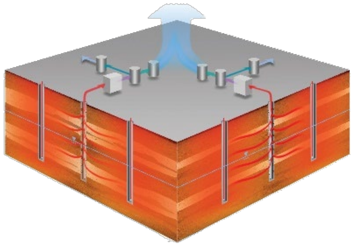
Contaminants of Concern (COC): TCE and VC

Remediation Goals: *"Add low temp heating to in situ biotic/abiotic treatment to shorten remediation time frame. Achieve GW level protective of indoor air (TCE RBC of 3,700 ug/L and VC RBC of 880 ug/L)."*

Chemical Name	Groundwater (mg/L)	
	Max Level Detected	Target Level
TCE	79.5	3.7
VC	4.5	0.88

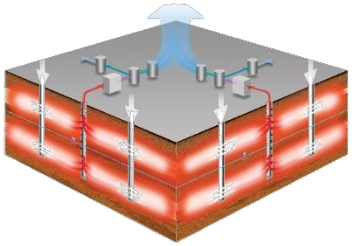
Thermal Technologies

Thermal Conduction Heating
(TCH / ISTD)



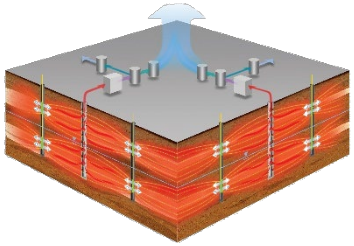
For all sites with low to moderate groundwater flow rates and either Volatile Organic Compounds (VOCs) or Semi-Volatile Organic Compounds (SVOCs).

Steam Enhanced Extraction
(SEE)

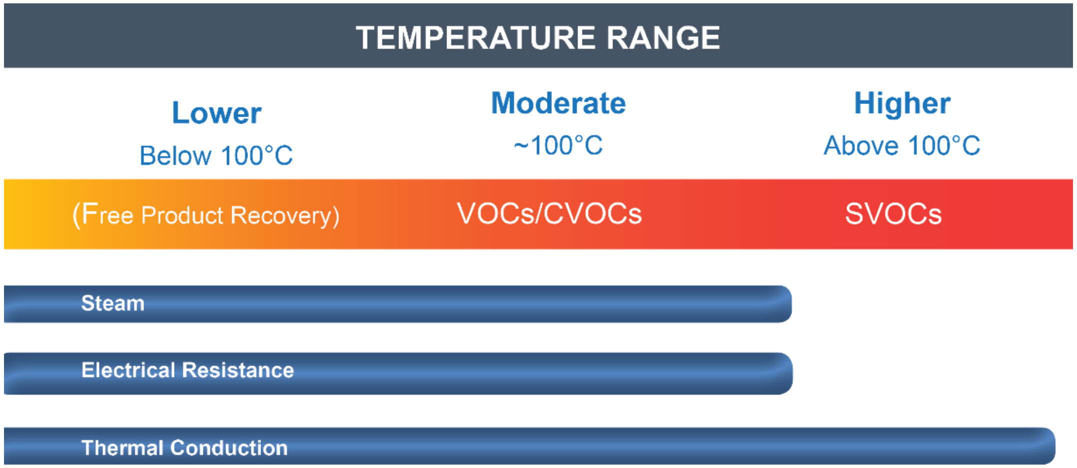


For permeable sites with significant groundwater flow rates and for sites with either volatile or moderately volatile contaminants.

Electrical Resistance Heating
(ERH)



For all sites with low to moderate groundwater flow rates and either volatile or moderately volatile contaminants.



TEMPERATURE RANGE

Lower
Below 100°C

Moderate
~100°C

Higher
Above 100°C

(Free Product Recovery)
VOCs/CVOCs
SVOCs

Steam
Electrical Resistance
Thermal Conduction

Thermal Technologies Evaluated

Characteristics	TCH	SEE	ERH
Heating Method	Conduction	Steam Injection, Convection	Electrical Resistance
Factors Governing Heating	• Thermal conductivity of the soil matrix. • Groundwater flow rate.	Injection rates and pressure are determined by the permeability of the soil matrix which can be too tight for SEE applications.	• Electrical resistivity of the soil matrix. • Groundwater flow rate. • Minimum electrode length is 10-feet
Maximum Temperature	• Low Temp TCH = 100°C (boiling point) • High Temp TCH = 325-400°C (once dewatered)	100°C (boiling point)	100°C (boiling point)
Sensitivity to Water Content and Flow	• Works in saturated and dry conditions. • High water flow can remove heat faster than it is added.	Not Sensitive	• Difficulty in dry Vadose Zone conditions. • High water flow can remove heat faster than it is added.
Sensitivity to Contrasts between Layers	Heating rates may be affected by differences in water content and flow rates between layers.	Aquitards not heated directly	Resistivity contrasts between layers require multi-element electrodes – long electrodes may be less efficient.
Sensitivity to Buried Objects	Not sensitive	Low-permeable layers may interfere with stream migration.	Metal debris and pipes may prevent uniform heating.
Heat Input Governed By	Soil thermal conductivity - which varies only by a factor of 1 to 3 between most common geologies.	Hydraulic conductivity of soil layers	Soil resistivity – which varies by large factors (over 200 X) between most common geologies.
Fluids Added to Ground	None	Steam	Water to keep electrodes saturated
General Safety Issues	High temperatures and steam	High temperatures and steam	• High temperatures and steam • Surface voltages

Low Temperature TCH selected for the application.

Conceptual Treatment Approach/Methodology

Conceptual Treatment Approach:

- Low temperature heating using a heater spacing of approximately 15 to 20 feet (accounting for access limitations) to target a temperature between 30 °C and 40 °C. Assumed base project duration is 2 years.

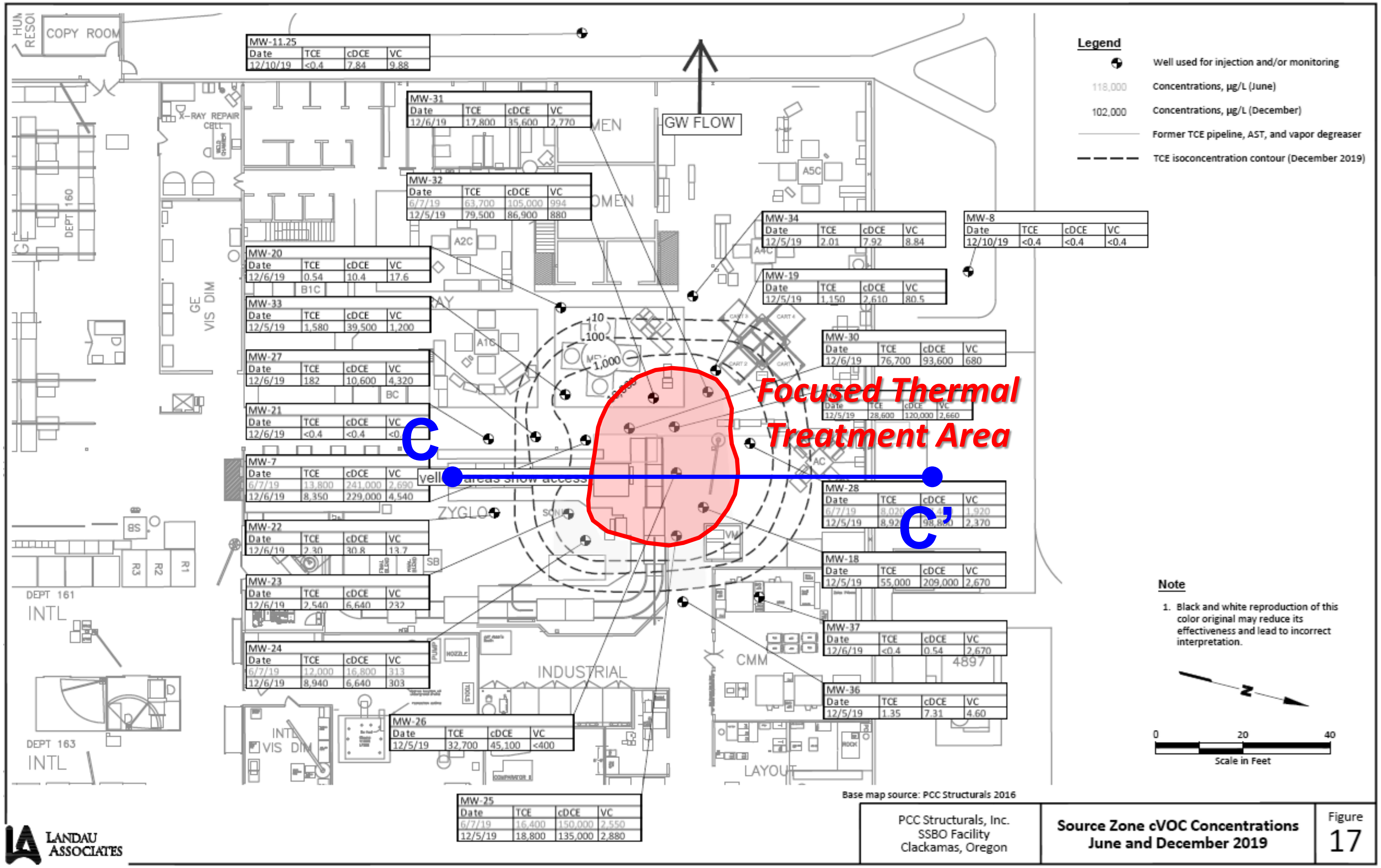
Vapor and Liquid Treatment Approach:

- No extractions system will be required for the thermal application. Existing SVE system will continue operation.

Monitoring:

- Temperature monitoring to track subsurface heating.

Treatment Area and Cross Section C-C’



MW-11.25

Date	TCE	cDCE	VC
12/10/19	<0.4	7.84	9.88

MW-31

Date	TCE	cDCE	VC
12/6/19	17,800	35,600	2,770

MW-32

Date	TCE	cDCE	VC
6/7/19	63,700	105,000	994
12/5/19	79,500	86,900	880

MW-20

Date	TCE	cDCE	VC
12/6/19	0.54	10.4	17.6

MW-33

Date	TCE	cDCE	VC
12/5/19	1,580	39,500	1,200

MW-27

Date	TCE	cDCE	VC
12/6/19	182	10,600	4,320

MW-21

Date	TCE	cDCE	VC
12/6/19	<0.4	<0.4	<0.

MW-7

Date	TCE	cDCE	VC
6/7/19	13,800	241,000	2,690
12/6/19	8,350	229,000	4,540

MW-22

Date	TCE	cDCE	VC
12/6/19	2.30	30.8	13.7

MW-23

Date	TCE	cDCE	VC
12/6/19	2,540	6,640	232

MW-24

Date	TCE	cDCE	VC
6/7/19	12,000	16,800	313
12/6/19	8,940	6,640	303

MW-26

Date	TCE	cDCE	VC
12/5/19	32,700	45,100	<400

MW-25

Date	TCE	cDCE	VC
6/7/19	16,400	150,000	2,550
12/5/19	18,800	135,000	2,880

MW-34

Date	TCE	cDCE	VC
12/5/19	2.01	7.92	8.84

MW-8

Date	TCE	cDCE	VC
12/10/19	<0.4	<0.4	<0.4

MW-19

Date	TCE	cDCE	VC
12/5/19	1,150	2,610	80.5

MW-30

Date	TCE	cDCE	VC
12/6/19	76,700	93,600	680

Date	TCE	cDCE	VC
12/5/19	28,600	120,000	2,660

MW-28

Date	TCE	cDCE	VC
6/7/19	8,020	[illegible]	1,920
12/5/19	8,92[illegible]	98,8[illegible]	2,370

MW-18

Date	TCE	cDCE	VC
12/5/19	55,000	209,000	2,670

MW-37

Date	TCE	cDCE	VC
12/6/19	<0.4	0.54	2,670

MW-36

Date	TCE	cDCE	VC
12/5/19	1.35	7.31	4.60

Legend

⊕	Well used for injection and/or monitoring
118,000	Concentrations, µg/L (June)
102,000	Concentrations, µg/L (December)
———	Former TCE pipeline, AST, and vapor degreaser
– – – –	TCE isoconcentration contour (December 2019)

Note

1. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

Base map source: PCC Structurals 2016

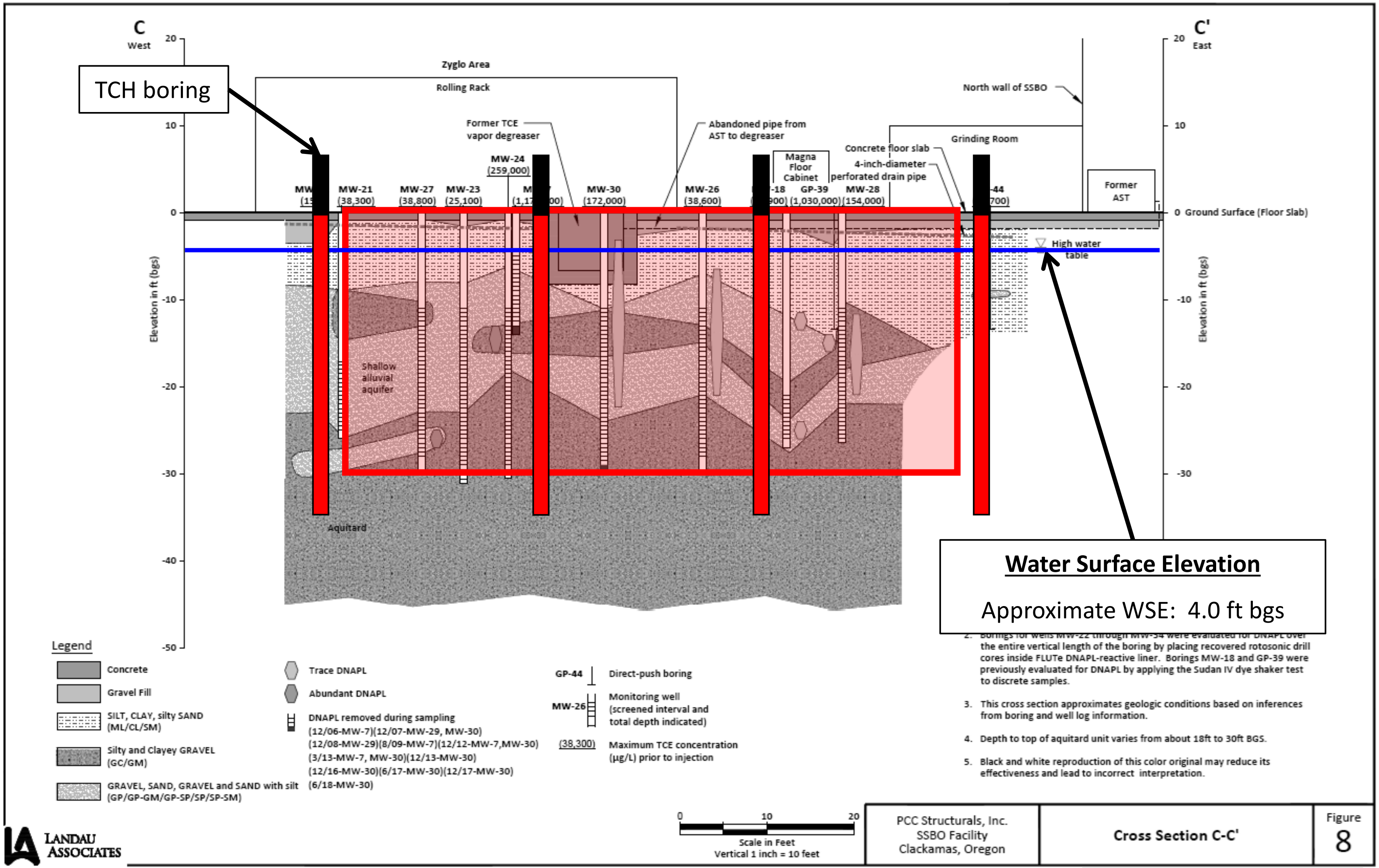
LANDAU ASSOCIATES

PCC Structurals, Inc.
SSBO Facility
Clackamas, Oregon

Source Zone cVOC Concentrations June and December 2019

Figure
17

Cross Section (C-C')



2. Borings for wells MW-22 through MW-34 were evaluated for DNAPL over the entire vertical length of the boring by placing recovered rotosonic drill cores inside FLUTe DNAPL-reactive liner. Borings MW-18 and GP-39 were previously evaluated for DNAPL by applying the Sudan IV dye shaker test to discrete samples.
3. This cross section approximates geologic conditions based on inferences from boring and well log information.
4. Depth to top of aquitard unit varies from about 18ft to 30ft BGS.
5. Black and white reproduction of this color original may reduce its effectiveness and lead to incorrect interpretation.

TCH boring

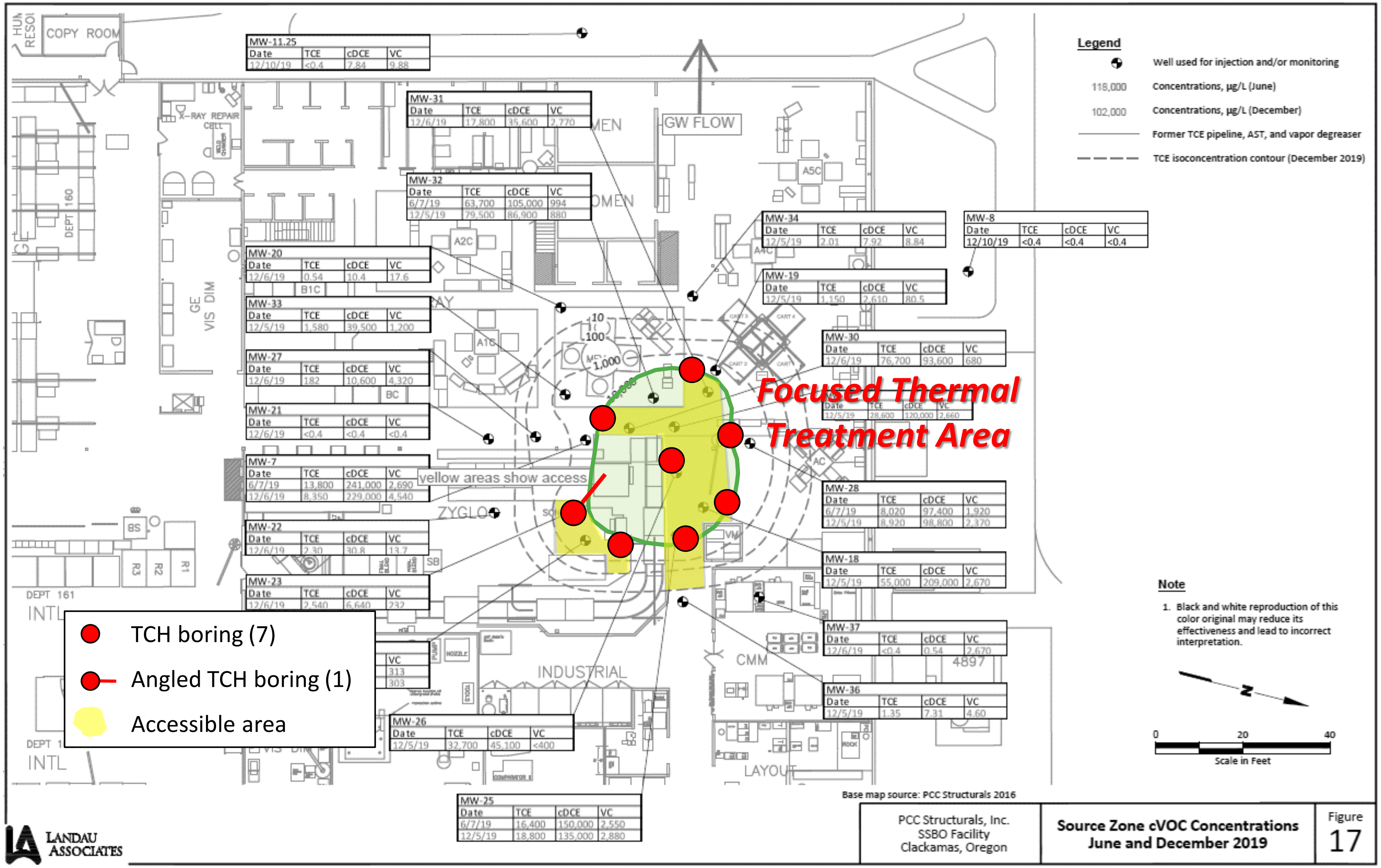
Water Surface Elevation

Approximate WSE: 4.0 ft bgs

** 5 ft heater stick down.*

NOT TO SCALE

Conceptual Wellfield Layout



TERRATHERM
a Cascade Company

Conceptual Design Parameters

Precision Castparts SSBO Site (Rev. 3)	**Landau Associates**	
Volume and heat capacity	***Treatment Area***	***Unit***
Treatment area	1,100	ft^2
Upper depth of treatment	0.0	ft bgs
Lower depth of treatment	30.0	ft bgs
Volume, TTZ	1,222	yd^3
Solids volume	794	yd^3
Porosity	0.35	-
Porosity volume	428	yd^3
Initial saturation	96	percent
Soil weight	3,547,439	lbs soil
Water weight	692,942	lbs water
Soil heat capacity	886,860	BTU/F
Water heat capacity	692,942	BTU/F
Total heat capacity, whole TTZ	1,579,802	BTU/F

Conceptual Design Parameters (Continued)

Precision Castparts SSBO Site (Rev. 3)		**Landau Associates**
Energy balance	***Treatment Area***	***Unit***
TCH power input rate	21	kW
Net energy flux into treatment volume	71,640	BTU/hr
Heating per day	1.1	F/day
Start temperature	15	C
Target temperature	40	C
Estimated heat loss, worst case	67	%
Operating time		
Heating to target temperature	83	days
Maintain temperature	647	days
Total operating time	730	days

Conceptual Design Parameters (Continued)

Precision Castparts SSBO Site (Rev. 3)	**Landau Associates**
Numbers of wells	***Treatment Area***
Heater borings (vertical and angled)	8
Temperature monitoring holes	2

Precision Castparts SSBO Site (Rev. 3)	**Landau Associates**	
Process equipment	***Value***	***Unit***
ISTD power supply	20	kW
Total power need to site	25	kW

Conceptual Utility Requirements & Budgetary Costs

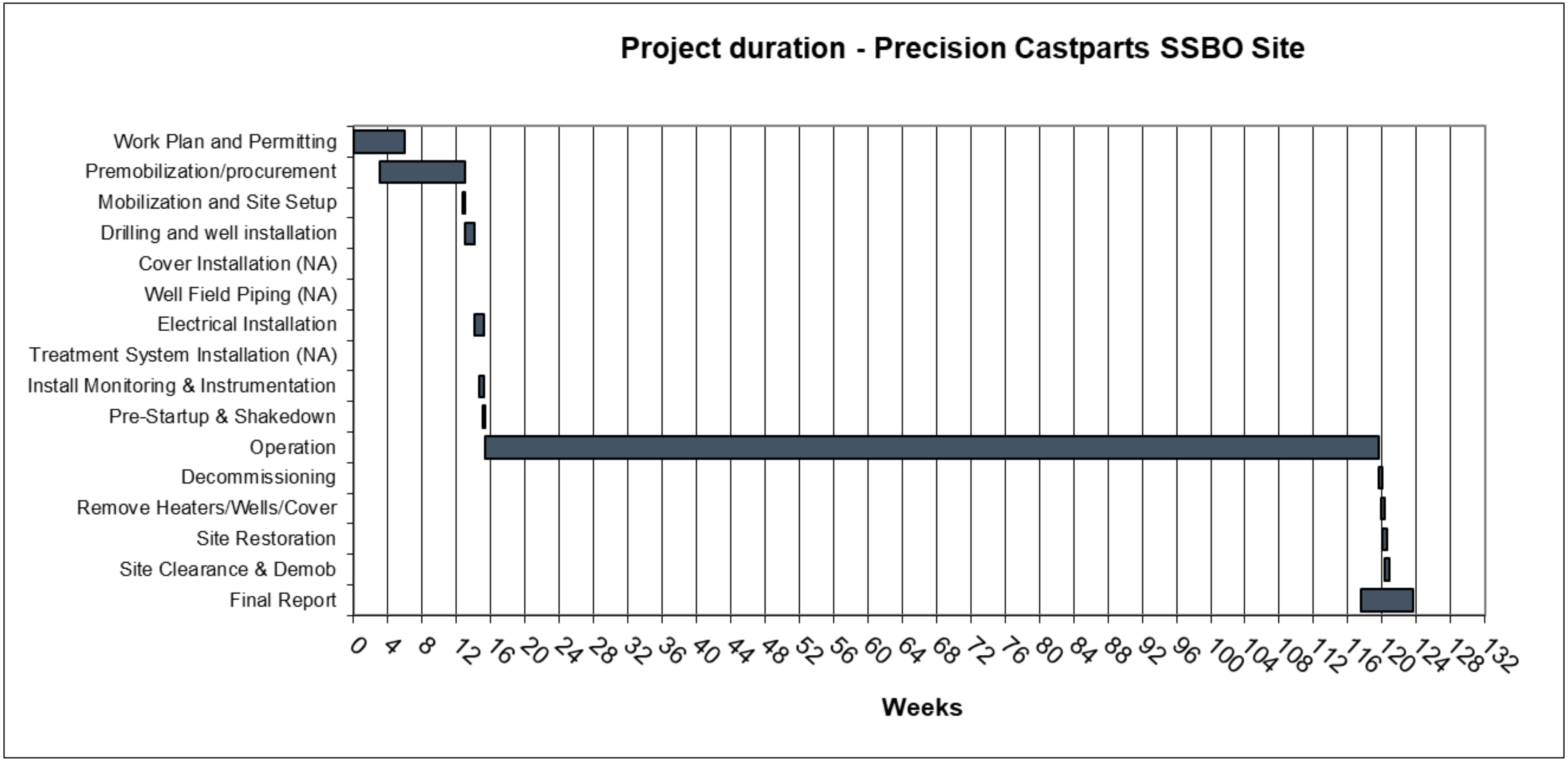
Precision Castparts SSBO Site (Rev. 3)	**Landau Associates**	
Utility estimates	***Value***	***Unit***
Power usage, in ground	107,000	kWh

Landau Associates **Precision Castparts SSBO Site (Rev. 3)**	
Design and procurement	$25,000
Construction	$123,000
Operation	$59,000
Demob and site restoration	$18,000
Subtotal	**$225,000**
Utilities	$9,000
Total with uilities	**$234,000**

Note:

- 2 years of operation of the heat enhanced system was assumed.
- Additional discussion is recommended to determine site accessibility within the treatment area and existing site operations.

Preliminary Schedule



Note: Preliminary schedule shown above is flexible and can be adjusted if required to meet project specific requirements.

Assumptions

Price:

- +/- 30% price accuracy based on current understanding of preliminary Conceptual Site Model (CSM) as stated in this treatment concept
- Unit power cost assumed: $0.09/kWh (Source: https://www.eia.gov/electricity/state/)
- Evaluation assumes: (a) full access to the site during construction and operation; (b) that all utilities will be protected at the boundary of the Treatment Area; and (c) that all electrical connections to be done below grade (where possible).
- It was assumed that the existing SVE treatment system can be modified by others to handle the expected slightly increased temperatures and moisture contents (may not be required).

Turn-Key services:

- Design/procurement/permitting (permitting managed by Landau Associates, TerraTherm supports the process)
- Construction
- Operations (site and office support)
- Demobilization
- Reporting

Construction:

- 80 ft/day drilling production assumed in the building
- Electrical connections below grade (where possible)

Operations

- Standard:
  - Field Crew (1 monthly site visit)
  - Office support: Project Management and Engineering. Remote heating operations monitoring.

Demobilization

  - Grouting up wells
  - Removal of all equipment
  - Overdrilling of wells is excluded

ATTACHMENT 2

LAI Estimated Costs

Attachment 2. Landau Associates Estimated Costs

Task	Estimated Cost
Work Plan and Thermal Treatment System Design	$ 15,000
Sub-Slab Vapor Pre-Investigation - Vapor Pin Installation, Sampling, and Laboratory Analysis - Data Evaluation	$ 6,000
Thermal Treatment System Installation/Decommission Oversight	$ 34,000
Thermal Treatment System O&M (2 years)	$ 24,000
Thermal Treatment System As-Built Report	$ 15,000
TOTAL	**$ 94,000**