ALASKA DEPARTMENT OF ENVIRONMENTAL CONSERVATION

DIVISION OF SPILL PREVENTION AND RESPONSE
CONTAMINATED SITES PROGRAM

River Terrace RV Park (RTRVP)

Fourth 5 Year Review of the Record of Decision

December 2021

Executive Summary

The Alaska Department of Environmental Conservation (DEC) issued its Record of Decision (ROD) for the River Terrace RV Park (RTRVP) in August 2000 and in September 2000 entered a Consent Decree with the RTRVP property owners. Since September 2000, DEC has implemented the cleanup approach dictated by the ROD, using Hydrogen Release Compound (HRC™) to promote biodegradation of tetrachloroethene (PCE) and its degradation products, to treat contaminated groundwater prior to it migrating off RTRVP property. Monitoring data have shown that use of HRC™ has successfully enhanced the biodegradation of chlorinated ethenes at much of the site. In some locations, PCE has degraded to below established cleanup levels. In other locations, PCE remains above cleanup levels primarily in a deeper area of the semi-confined water-bearing zone of the Lower contaminant plume where remaining Dense Nonaqueous Phase Liquids (DNAPL) likely exists. Several degradation products, primarily vinyl chloride (VC), remain above cleanup levels in both the Upper and Lower plumes. Most recent sampling from 2019 and 2020 indicate that PCE maybe rebounding in portions of the Upper and Lower plumes.

During the cleanup process, DEC has continually evaluated monitoring data and modifies its plans to best treat/monitor the site to protect the adjacent Kenai River and its ecological receptors. Because past sampling demonstrates that the HRC™ method has indeed enhanced reductive dechlorination of PCE and its degradation products to treat groundwater, and the total mass of chlorinated ethenes has decreased, DEC at this time has no intent to depart from this treatment/monitoring strategy as described in the ROD.

This is the fourth "five-year review" of the selected remedy. In the previous five-year reviews, DEC concluded that the selected remedy was both appropriate and sufficiently protective. That conclusion still applies during this fourth five-year review, but some remedial action is necessary to maintain the remedy and protection of receptors.

Purpose

In accordance with the August 2000 ROD issued by DEC for the RTRVP site, DEC is required to review its cleanup decision every five years until all cleanup levels are achieved. The five-year review requires an evaluation of all relevant data to determine whether the implemented cleanup alternative continues to be both appropriate and sufficiently protective. Required components of the five-year review are listed below:

1. An evaluation of all relevant data to determine whether the implemented cleanup alternative continues to be both appropriate and sufficiently protective;

2. Consideration of any new toxicological data pertinent to the contaminants of concern;

3. A discussion of any discernable trends in contamination concentrations;

4. Concerns of the public; and

5. Any other relevant information.

It should be noted that, while this analysis includes a detailed review and presentation of the five criteria above, DEC and its contractors, Ahtna Engineering (and previously ERM/OASIS/ERM Environmental, Inc), in consultation with the RTRVP site owners or their consultants, have since 2000 continually evaluated the effectiveness of the site remediation and groundwater monitoring and provided recommendations for additional studies when necessary, to meet DEC's obligations in the ROD and the 2000 Consent Decree.

The seven sections of this five-year review document are listed below, along with a brief description of their contents.

I. Summary of RTRVP Site Information

a. Background (contamination history, hydrogeology, 2000 ROD and Consent Decree, and cleanup levels)

b. Activities to meet objectives (lists the cleanup actions, studies, and monitoring activities from 2000 through 2020)

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II. Multiple Lines of Evidence approach to monitor contaminants and assess remedial approach

a. Upper Plume

b. Lower Semi-confined (water-bearing) Plume and Deep Source Zone

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ii. Total chlorinated ethenes

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IV Consideration of new toxicological data pertinent to contaminants of concern.

V Concerns of the Public

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VII Conclusions

The primary conclusion of the 20-year review is that the selected remedy continues to be both appropriate and sufficiently protective, but additional action (treatment and monitoring) is warranted to sustain and maintain the effectiveness of the remedial approach.

I. <u>Summary of RTRVP Site Information</u>.

A. Background

RTRVP is a former dry cleaner located on approximately 10 acres adjacent to the Kenai River in Soldotna, Alaska. The dry cleaning solvent, PCE, and its degradation compounds, trichloroethene (TCE); trans-1,2-dichloroethene (trans-DCE); cis-1,2-dichloroethene (cis-DCE); 1,1-dichloroethene (1,1-DCE), and VC, have been documented in RTRVP soil and groundwater. In 1997, approximately 2,700 yards of contaminated soil were excavated from the site and transported out-of-state for treatment and disposal. The excavation was extended to a maximum depth of 35 feet below ground surface (bgs); however, some contamination remained below the base of the excavation. Figure 1 shows the layout of the RTRVP site.

Figure 1. River Terrace RV Park and location of former dry cleaner

The RTRVP hydrogeology is complex. There is a shallow water table aquifer overlying a silty till confining layer, which overlies a confined deeper aquifer. Depth to water in the shallow water table aquifer varies from less than 2 feet bgs in monitoring wells near the Kenai River to approximately 18 feet bgs near the former dry cleaner building. The till unit, which is encountered at depths between about 10 and 25 feet bgs across RTRVP, rises above the shallow water table across the middle of the site, thus acting as a groundwater divide. The till unit also contains thin layers of sand that are capable of producing small amounts of water; they are referred to as "semi-confined water-bearing zones." The confined (artesian) aquifer underlying the till unit (at approximately 85 to 95 feet bgs) is used as a drinking water source for residents in the Soldotna area, including for the two community water system wells (formerly referred to as Class A wells) on RTRVP property that service the RTRVP occupants. Contamination has not been detected in the confined aquifer as measured in the RTRVP community water well by the former dry cleaner building.

Three groundwater contaminant plumes have been identified in the underlying complex aquifer:

- The "<u>Upper Plume</u>" is the contaminant plume located near the former dry cleaner building, which typically migrates west toward the Sterling Highway, and
- The "<u>Lower Unconfined Plume</u>" is shallow contaminant plume located south of the former dry cleaners building, which migrates south toward the Kenai River. This is also the area where shallow near-river wells are located for compliance monitoring. Where the plume enters the river, pore water sampling locations are established, and surface water sampling locations are accessed.
- The "<u>Lower Semi-confined Plume"</u> is the contaminant plume includes a water-bearing zone within the remaining source area that underlies the "Lower Unconfined Plume" in the till. This area has been also been referred to as the "deep (till) source area," or "semi-confined water-bearing zone." This remaining source area is in the vicinity of the deepest portion of the excavation (between MW-44 and MW-48) and was somewhat defined by Hart Crowser during 1998 and OASIS/ERM during 2002. The source area was better defined by additional assessment activities performed by OASIS/ERM/ERM during 2005, as described below. Upward vertical groundwater movement into the overlaying shallow aquifer has been documented from this semi-confined water-bearing zone.

The 2000 Consent Decree requires DEC to perform cleanup and monitoring work as specified in the August 2000 ROD, and allows the State and its contractor's site access to perform needed work. The remedial method established in the ROD was bioremediation using Hydrogen Release Compound (HRC™) to enhance biological treatment of the groundwater prior to it migrating off site to the adjacent Kenai River and Sterling Highway area. HRC™ is a lactate-based product that provides a fermentable growth substrate for microorganisms in the subsurface (HRC PRIMER™ is a less viscous formulation of HRC that more easily migrates in tight soils). One of the byproducts of fermentation is hydrogen; the increased availability of hydrogen ultimately enhances a biological process known as reductive dechlorination, in which PCE degrades sequentially to TCE, then to cis- and/or trans-DCE, then to VC, and finally to a nontoxic endpoint (ethene). During each step, a chlorine atom is removed from the contaminant molecule and replaced with hydrogen, by microbes that utilize the molecule as an electron acceptor during metabolic respiration. Thus, the HRC™ substrate injections assist in driving the aquifer conditions anaerobic, i.e., more highly reducing, by encouraging fermentation. As the fermentative and acetogenic (producing acetate) microbes utilize the HRC™ material (as a carbon or food source) and the available dissolved oxygen in the groundwater (as an electron acceptor), the geochemical conditions transition with a successive decrease in oxygen availability in the groundwater, to more reducing conditions. As fermentation proceeds, the availability of hydrogen increases (as do simpler carbon sources), which in turn is the energy source (or electron donor) for many subsurface microbes. Hydrogen can be consumed by many metabolic types of bacteria, including denitrifiers, iron-reducers, sulfate-reducers, methanogens, and dechlorinating microorganisms. One in particular is *Dehalcoccoides mccartyi* (Dhc), a chloro-respiring microorganism whose sole energy source is hydrogen, with chlorinated contaminants being the electron acceptors utilized during microbial respiration. The contaminants are consequently reduced to lesser chlorinated compounds as respiration proceeds. Of particular importance for this to occur are sustained growth conditions in the subsurface for chloro-respiring microbes, such as sufficient carbon and hydrogen availability to overcome interspecies competition and the maintenance of highly reduced geochemical conditions, and the possession of the proper genes and functional enzymes by the microbes themselves. Genetic biomarkers for these genes can be monitored to assess the progression of this remedial approach over time and have been periodically utilized at RTRVP since implementation of the ROD. These biomarkers include so-called identity genes (known as 16s rRNA gene used to identify microbes), as well as functional reductive dehalogenase genes that encode for trichloroethene reductase *(tceA)* and vinyl chloride reductase *(vcrA, bvcA)*. These reductases are the enzymatic agents that transform the contaminants.

Portions of the uncontaminated groundwater conditions at the RTRVP site tend to be more oxygen-rich and intermediately reducing (e.g., iron-reducing geochemistry), which is reportedly not tolerated by Dhc, a strict anaerobe. Contaminant degradation can also proceed under these conditions, but by different oxidative respiratory pathways by different microorganisms (i.e., co-metabolic and direct oxidative respiration, both aerobically and anaerobically). Genetic biomarkers are now available to monitor the oxidative contaminant biodegradation processes for 16s rRNA genes of *Polaromonas, Pseudomonas and Rhodferax* spp., microorganisms responsible for dechlorination of cis-DCE or VC under aerobic respiratory conditions, and for the oxidative epoxyalkane: coenzyme M transferase (etn C & E), a functional gene of ethenotrophic microorganisms (also signifying aerobic catabolism of chlorinated ethenes may be occurring). Degradation under these conditions may occur in more oxygenated environments that are present in the Upper contaminant plume area, and possibly in the Kenai River sediments. Anaerobic oxidation of chlorinated ethenes is known to result in carbon dioxide (CO2). Although direct measurement of CO_2 is possible in the field, discerning CO_2 from other sources (e.g., decomposition of organics, etc.) is challenging. It is likely that some level of anaerobic oxidation of chlorinated ethenes occurs at the RTRVP site, but the predominant anaerobic biodegradative pathway that is encouraged through remedial action is reductive dechlorination.

Many additional microorganisms can partially degrade chlorinated ethenes under anaerobic groundwater conditions (e.g., *Geobacter, Desulfuromonas, Dehalobacter*, spp., etc.), some doing so in less-reduced geochemical and possibly microaerophilic conditions, such as manganese and iron-reducing groundwater conditions common to the RTRVP site. Strains of another microbe, *Dehalogenomonas* spp., have been shown to be capable of reductive dechlorination of trans-DCE and VC. But Dhc is the only microbe known to have the full genetic compliment necessary for complete reductive dechlorination of PCE to TCE, DCE isomers, VC and eventually ethene. This microorganism is an obligate anaerobe, requiring highly reduced subsurface conditions for survival, and simple carbohydrates, such as acetate as carbon source. They can outcompete other microorganisms that may also utilize hydrogen as an energy source under high concentrations of chlorinated ethenes. Additionally, Dhc does not exist in isolation; it forms syntrophic relationships (or microbial cross-feeding) with other fermenting and dehalo-respiring microbes that may aide in supplying growth factors (e.g., cobalamins or vitamin B_{12}) favorable for Dhc, as well providing hydrogen and acetate. Thus, Dhc (whether naturally occurring or as part of an introduced consortia of fermenting and dehalo-respiring microbes) is the chosen agent to focus on during reductive dechlorination approaches to remediation of groundwater contaminated with chlorinated ethenes.

Bioaugmentation with commercial microbial consortia containing Dhc was piloted in the Lower Unconfined Plume at the RTRVP during October 2002. Although Dhc is naturally occurring and likely ubiquitous worldwide, it typically exists in low abundance, and can sometimes be undetectable in the subsurface, particularly in geochemical conditions that favor the activity of competing microorganisms (e.g., methanogenic archea and hydrogen-utilizing homoacetogens). Strains of Dhc may also lack some functional genes, such as particular vinyl chloride reductase genes. Bioaugmentation with Dhc consortia culture with known genetic make-up and chlorinated ethene degradative abilities likely shortens time to achieve complete reductive dechlorination of contaminants, over biostimulation with fermentable substrate alone (i.e., HRC™ injections). Researchers have suggested that an abundance of Dhc of 1 x 10^6 cells/ml as a screening criterion to identify sites where biological reductive dechlorination is predicted to proceed at “generally useful” rates (Lebron et. al 2015). Combined bioaugmentation and biostimulation has the potential to increase Dhc abundance by orders of magnitude (e.g., ~1x10^8 cells/ml or more). Dhc abundance at RTRVP has been observed to be as high as 2x10^9 cells/ml during 2018, six years after substrate injection.

In addition to bioremediation as the remedial method, the ROD also established cleanup levels for soil and groundwater on and off RTRVP property; compliance points to meet cleanup levels including for surface water at sentry wells; action levels for active treatment; scheduled groundwater monitoring and other DEC-selected monitoring as determined; and provides for a mechanism by which to change the remedial method, if necessary. Table 1 below depicts the groundwater cleanup levels (GCLs) and alternate cleanup levels (ACLs) established for groundwater both on and off the site.

Table 1. Groundwater Cleanup Levels and Alternate Cleanup Levels for RTRVP

Compound	Current GCL (µg/L)	ROD ACLs (µg/L) On-Property Shallow Unconfined Aquifer	ROD ACLs (µg/L) Off-Property Shallow Unconfined Aquifer	ROD ACLs (µg/L) On-Property Deep Confined Aquifer
	18 AAC 75 (October 2018)	1997 DEC Risk Evaluation and Letter	"ten times rule" 18 AAC 75 (January 1999)	18 AAC 90 MCL (October 1999)
PCE	41	840	50	5
TCE	2.8	21,900	50	5
cis-DCE	36	11,600	700	70
trans-DCE	360	11,600	1,000	100
1,1-DCE	280	7	70	7
VC	0.19	2	20	2
Benzene	4.6	50	50	5

ACL = Alternative Cleanup Level
GCL = Groundwater Cleanup Level
MCL = Maximum Contaminant Level
PCE = tetrachloroethene
TCE = trichloroethene
cis-DCE = cis-1,2-dichloroethene
trans-DCE = trans-1,2-dichloroethene
1,1-DCE = 1,1-dichloroethene
ROD = Record of Decision
µg/L = micrograms per liter

In addition to establishing site cleanup levels, the ROD also established modelled water quality impact levels, as well as ecological action (Eco-action) levels, where contaminant concentrations in Lower Unconfined Plume and near-river wells, and in sediment and pore water, may indicate a pending exceedance of water quality standards, or anticipated impacts to ecological receptors, respectively. Table 2 below depicts both modelled water quality and eco-action levels for the RTRVP site.

Table 2. Modelled Water Quality and Eco-action Levels for RTRVP Groundwater in the Lower Unconfined Plume (in µg/L)

COC	PCE	TCE	cis-DCE	trans-DCE	1,1-DCE	VC	Benzene
Modelled Level for Water Quality	15	15	210	300	21	6	Not established
Eco-action Level	120	350	210	300	21	6	Not established

Although the ROD does not estimate the time to meet established cleanup levels, the cleanup timeframe (i.e., 20 years so far) has exceeded estimates provided in the 2000 Remedial Investigation/Feasibility Study (RI/FS). The RI/FS provided an estimated timeframe of 5 years after initial treatment in the Lower Plumes areas and 10 years after initial treatment in the Upper Plume area, assuming that no additional source areas remained, and that site conditions were readily conducive to bioremediation of the PCE. However, since the completion of the RI/FS in 2000, subsequent field work has determined that the 1997 excavation did not remove all of the highly-contaminated soil, as discussed below. Additionally, site biodegradation rates may have been slower than originally anticipated, potentially due to cold sub-arctic groundwater temperatures, site groundwater geochemistry (i.e., initially oxidizing redox conditions in the Upper Plume), and low abundance of the appropriate microbes (e.g., Dhc).

A limited risk analysis was performed at the site in 1997 to support the development of ACLs, and an updated risk evaluation was included in the 1999-2000 RI/FS. The RI/FS concluded that the primary risks from site contamination included: (1) potential human health risk due to vapor inhalation in the former dry cleaner building and (2) potentially deleterious ecological effects due to contamination of the Kenai River sediments and surface water adjacent to RTRVP. In addition, since the groundwater is hydrologically connected to the Kenai River, the RI/FS concluded that cleanup must be performed to ensure that there is no violation of surface water criteria. If there are surface water violations to 18 AAC 70 without remedial action showing an effort to reduce the contaminant levels to meet applicable water quality standards (WQSs), the possibility exists that a portion of the Kenai River (adjacent to RTRVP) could be placed on the "impaired" waterbody list.

Concern regarding the indoor vapor was conveyed to the property owners and their consultant during preparation for Phase I HRC™ injection in 2000. Although the property owner's consultant purchased the air monitoring equipment, the indoor air monitoring was never performed. DEC later measure sub-slab, indoor and outdoor air in 2010. Although contaminants were below DEC indoor air targets, they exceeded target levels in sub-slab soil gas. Together the results indicated a potential for a complete exposure pathway, and the need for periodic assessment.

B. Summary of Activities to Meet Objectives

The following tasks have been performed since 2015 to meet the obligations in the ROD and Consent Decree:

- While no substrate injections have occurred at the site since October 2012, details about the previous HRC/HRC PRIMER injections are provided in Section I-C, which follows this section.

- Performed groundwater monitoring of select monitoring wells during 2016, 2018, 2019, and 2020. Thirteen pore water samples, and three surface water samples are collected concurrently with the 2020 groundwater monitoring event. Details about the groundwater and surface water monitoring are provided in Section I-D.

- Monitored pore water (but not sediment) of the Kenai River in the spring of 2020. Details about the pore water monitoring are provided below (Section II).

- Evaluated the groundwater treatment system on an ongoing basis.
- Consistently informed the property owners and/or their consultants of the assessment/cleanup findings and involved them in planning cleanup work.
- Communicated with interested members of the community to inform them of the status of the cleanup and address their concerns.
- Reviewed toxicological data of PCE and its degradation products to determine whether any recent such changes may impact the imposed cleanup strategy.

C. Cleanup Actions To-Date

For the first five years of remediation under the ROD, DEC's management of the site was focused on meeting site cleanup objectives by treating groundwater prior to it migrating off RTRVP property. HRC™ was injected into selected locations in the Upper and Lower contaminant plumes to enhance biodegradation (HRC™ treatment phases I through III). Between 2005 and 2015, the treatment of groundwater prior to migration off-property has been augmented by hot-spot treatment of the remaining source area (HRC™ treatment phases IV through VI, and HRC PRIMER treatment in 2011 and 2012). The HRC/HRC PRIMER™ treatment to-date is summarized below. There have not been any HRC™ substrate injection at the site since 2012. As described below, additional injections may be planned in the future.

- <u>In October 2000</u>, the first injection of HRC™ occurred (Phase I). Permanent (i.e., re-injectable) injection points were installed as biotreatment barrier walls across both the Lower and Upper contaminant plumes. HRC™ was injected into all of the Phase I permanent injection points, i.e., 41 permanent injection points across the Lower plume (L1 through L41) and 15 injection points across the Upper Plume (U1 through U15).
- <u>In June 2001 (Phase II)</u>, additional injection points were installed to expand the Phase I treatment areas. The Phase II injection points are summarized below:
    - 10 injection points (L42 through L51) were installed 15 feet upgradient of the Phase I wells across the Lower Plume to lengthen the treatment zone.
    - 7 injection points (L52 through L58) were installed between MW-4A and the Kenai riverbank in the Lower Plume to intercept potential plume migration towards the Alaska Department of Transportation (ADOT) right-of-way.
    - 8 injection points (L59 through L66) were clustered around MW-4A in the Lower Plume.
    - 13 injection points (U22 through U34) were installed 25 feet downgradient of the Phase I wells across the Upper Plume to provide coverage downgradient of the primary source area.
    - 5 injection points (U35 through U39) were installed parallel to the NE side of the former dry cleaning facility to treat groundwater in the vicinity of MW-42.

- 5 injection points (U40 through U45) were installed parallel to the NW side of the former dry cleaning building to treat groundwater in the vicinity of MW-36.

- 3 injection points were installed to replace Phase I points U2, U16, and U19, which were dry.

HRC™ was injected into all of the non-dry Phase I and Phase II injection points (total number of non-dry Phase I and II injection points in the Upper Plume is 38 and in the Lower Plumes is 66).

- In October 2002, a pilot bioaugmentation project was initiated in the Lower Unconfined Plume around MW-9 to test whether this technique would break down the cis-DCE at the site. In the pilot test, a consortium of microorganisms known to degrade cis-DCE (KB-1) was injected into 5 injection points upgradient of MW-9.

  Also in 2002, a monitoring well (MW-44) was installed into the till in the Lower Semi-confined Plume to a depth of 35 feet bgs and completed across semi-confined water-bearing zones (from 25 feet bgs to 35 feet bgs) to investigate a suspected deep source area on the periphery of the large 1997 excavation (near MW-39 and MW-9 and here-in-after referred to as the "source area"). High PCE levels (up to 31,300 µg/L) detected in MW-44 groundwater suggested the presence of a source area.

- In November 2003 (Phase III), HRC™ was injected into 43 of the 66 Phase I and Phase II Lower Plume injection points after data showed that HRC™ was or soon would be depleted. Two additional deep monitoring wells (MW-45 and MW-46) installed to the southeast and southwest of MW-44 showed no contamination.

- Also in 2003, DEC entered a cooperative agreement with USGS to evaluate how to best accelerate bioremediation at the site. The principal findings of the USGS/DEC study were that the addition of HRC™ (or a similar substrate) was necessary for reductive dechlorination to occur at RTRVP, and, interestingly, a different degradation mechanism (e.g., aerobic and/or anaerobic oxidation to nontoxic carbon dioxide, instead of reductive dechlorination to nontoxic ethene) may be degrading cis-DCE and VC in portions of the aquifer sediments and in the Kenai River sediments.

- In August 2005 (Phase IV), HRC™ was injected into most of the Phase I and Phase II injection points after data showed that HRC™ was becoming depleted. HRC™ was injected into all 38 of the Upper Plume injection points and the following Lower Plume injection points: L42 through L51 north of MW-39/44; L2, L4, and L6 south of MW-39/44, L24 through L28 south of MW-19, and L52 through L58 near MW-10. The injection points near MW-4A could not be injected during Phase IV, because of ADOT construction activities (upgrading the adjacent Kenai River Bridge and Sterling Highway) which resulted in a number of injection points and several monitoring wells in/near the right-of-way and river to be temporarily covered with several feet of building material/gravel.

  Phase IV also marked the first phase of HRC™ treatment of the deep source area in the till. To guide the source area treatment, seven exploratory soil borings (L67 through

L73) were driven into the till near MW-44 and assessed for chlorinated ethenes using a Membrane Interface Probe (MIP) using direct push technology. Based on the MIP responses, HRC™ was injected into six deep (direct push or temporary) Phase IV injection points near MW-44 (L67D-HRC, L68D-HRC, L70D-HRC, L71D-HRC, L72D-HRC-E, and L72-HRC-W).

- In October 2006 (Phase V), HRC™ was injected into fourteen existing Phase I and II Lower Plume injection points where monitoring data indicated that HRC™ was nearly depleted (L7 through L16, L30, L32, L33, and L35). Additional source area assessment activities were also performed to guide further source area treatment, including four exploratory soil borings (L74 through L77) into the till for MIP and soil sample analysis and one new deep monitoring well (MW-47). This effort identified the greatest concentration of PCE in soil (144 mg/kg in L74, 22 to 25 feet bgs), exceeding the maximum value of 20 mg/kg reported in the 2000 ROD. PCE was also detected at 139,000 µg/L in L76, and is the greatest concentration ever reported for groundwater collected at the site. As a result of this characterization effort, HRC™ was also injected into four new deep permanent injection points (L78 to L81) and ten deep temporary injection points (L82 to L91) to treat the deep source area soil contamination.

- In August 2009 (Phase VI), HRC™ was injected into five Phase II Lower Plume injection points (L42 to L46). Additional source area assessment activities were also performed to guide further source area treatment, including five exploratory soil borings (L92 through L96) into the till for MIP and soil sample analysis and three new deep monitoring wells (MW-48, MW-49, and MW-50). PCE was also reported at 120,000 µg/L in monitoring well MW-48 during this sampling event. HRC was injected into five new permanent deep plume injection points (L97 to L101) and three deep temporary injection points (L102, L105, L107), while HRC PRIMER™ was injected into five temporary deep injection points (L-103,L-104,L-106,L-108,L-109) to treat the deep source area soil contamination. HRC PRIMER™ was used due to its ability to migrate in tight soils more easily.

- In June 2010, HRC was injected into 6 Upper Plume pre-existing injection points and 2 Deep Lower Plume pre-existing points. An additional 2 pre-existing Deep Lower Plume points were injected with HRC PRIMER™. Again, HRC PRIMER™ was used due to its ability to migrate in tight soils more easily.

- In October 2010, four soil borings (L112 to L115) and three new monitoring wells MW-6A as a replacement for MW-6, MW-51, and MW-52 were installed.

- In September 2011, 600 pounds of HRC PRIMER™ was injected into four of the deep Lower Plume injection points (L79, L99, L100, and L101). HRC PRIMER™ was used due to its ability to migrate in tight soils more easily.

- In October 2012, three additional HRC injection points (L80, L102, and L103) were installed in the vicinity of monitoring wells MW-50, MW-51, and MW-48 respectively. 300 pounds of HRC PRIMER™ was injected into 5 injection points in the Upper Plume area and 1,200 pounds of HRC PRIMER™ was injected into 7 injection points in the deeper Lower Plume area. HRC PRIMER™ was used due to its ability to migrate in tight soils more easily.

- Also in 2016, epoxyalkane:co-coenzyme –M transferase (EaCoMT; encoded by the gene designated *etnE* in some organisms) was reported by University of Iowa researchers (Liu and Mattes, 2016), from groundwater sampled collected from MW-6 and MW-40 during 2008-9, implying VC-assimilating microorganism are present in the Lower unconfined plume, and in near-river sentry wells.

II. Multiple Lines of Evidence Approach to Monitor Contaminants and Assess Remedial Approach

Because the selected remedy results in sequential dechlorination of PCE to TCE, to DCE (cis-DCE primarily), to VC, and finally ethene, there are anticipated relationships between contaminants that can be monitored over time to assess remedial progress. PCE is expected to decrease, while daughter products of its degradation will temporarily increase and then eventually decline. Additional multiple lines of evidence are also considered to understand the factors that support and sustain the remedial approach. Together, these lines of evidence are summarized below:

a. Contaminant concentrations are monitored over time to assess the degree to which the PCE has degraded and to compare current concentrations to cleanup levels. This can be reported as concentration of individual chlorinated ethenes in each well, and as molar percentage of chlorinated ethane in a given well. Percentage of individual ethenes can be monitored over time (e.g., decrease of PCE to an eventual increase in VC and ethene),

b. The distribution and the degree to which the total chlorinated ethene concentrations (total chlorinated ethenes = PCE + TCE + cis-DCE + vinyl chloride as molar concentration) have decreased is assessed with each monitoring event. Ethene concentrations (although not strictly a contaminant, but rather the terminal product of reductive dechlorination) is also monitored in groundwater.

c. Statistical analyses of contaminant trends are evaluated to understand the likelihood that contaminant concentrations are either decreasing or increasing, or remaining stable over time.

d. Geochemical information is monitored to understand if subsurface conditions remain favorable to the chosen remedial approach. This includes field measurements for dissolved oxygen, oxidation-reduction potential (ORP), pH, temperature, and conductivity, and laboratory measurements for dissolved iron and manganese, and total organic carbon;

e. The generation of metabolic volatile fatty acids from the fermentation of lactate esters (or other injected substrates) is monitored with laboratory analyses, to indicate the extent of subsurface fermentation and if suitable carbon (acetate) and energy (hydrogen) sources for reductive dechlorination are expected to be sufficiently available.

f. Biomarker's analysis involving both identity (16s rRNA) and functional genes (tceA, vcrA, bvc1) of the microbial community is periodically monitored to determine the abundance, genetic compliment, and activity of dechlorinators (particularly Dhc).

Additional notes:

a. Contaminant Concentration summary, 2015-2020

Every year between 2000 and 2020, the monitoring well sampling has been reviewed and modified, if appropriate, to meet the goals of this project. As the remediation has progressed and understanding of site conditions has increased, the number of unconfined aquifer monitoring wells to be sampled has been decreased and the sampling frequency reduced.

The current status of RTRVP monitoring wells, and the sampling efforts since the previous 2015 five-year review are summarized in **Table 3** below. In addition to the monitoring wells shown in **Table 3**, samples are sometimes collected from one or more of the deep HRC™ injection points (i.e., L-78 through L-81 and L-97 through L-101). Groundwater samples are collected for compliance purposes (i.e., comparison with established cleanup levels), as well as to evaluate the performance of the bioremediation effort, using the multiple lines of evidence described above.

Table 3: River Terrace Monitoring Well Sampling Summary 2015 - 2020

	Number sampled in 2020	Number sampled in 2019	Number sampled in 2018	Number sampled in 2016
Upper Plume	0	6	5	8
Lower Unconfined Plume (includes near-river compliance wells)	4	0	7	17
Lower Semi-confined Plume with water-bearing zone in the till	0	0	10	10

b. Total Chlorinated ethenes

To determine the total chlorinated ethene concentrations, the contaminant concentrations measured during sampling events (which are measured in units of mass per volume (µg/L) are converted into molar concentrations (µmol/L) and then summed to determine the total molar concentration of chlorinated ethenes in samples. Likewise, percent molar concentration of chlorinated ethenes is calculated by converting to molar concentration (µmol/L) and determining the percentage of individual chlorinated ethenes in the sample.

c. Mann-Kendall and Linear Regression Statistical Trend Analysis

Two statistical approaches are used to evaluate contaminant trends over time at the RTRVP site. Total molar concentrations of chlorinated ethenes for select monitoring wells over the duration of sampling (September 2000 to May 2020), as well as during the past 5 sampling events are used in the analyses.

The Mann-Kendall (M-K) analysis is a nonparametric test that is commonly used to evaluate trends in groundwater monitoring results. In the Mann-Kendall analysis, the results are tabulated in the order collected over time, and then each result is compared to all of the previous results. The sign of the differences (i.e., positive or negative) is recorded, and the signs for each monitoring event are summed to determine the M-K statistic, S. The S-statistic is compared to a 90% confidence level chart provided in AFCEE, 2000. If the S-Statistic is less than the confidence criteria (i.e., coefficient of variance) then no upward or downward trend is indicated, which denotes stable conditions. A negative S statistic reflects a negative (downward) trend at a 90% confidence level, and a positive S reflects a positive (upward) trend at a 90% confidence level. The coefficient of variation (CV) for each data set is also computed to provide a measure of scatter, or fluctuation in the data from year to year, and is defined as the sample standard deviation divided by the sample mean. The CV is useful in classifying data as "stable" vs. "no discernable trend" when the null hypothesis holds. The closer the CV is to zero, the less variation in concentrations between sampling events, and the more stable the concentration is in the well. Generally, if no trend is present at the specified level of significance, but the CV is small (e.g., < 1), it can be concluded that plume concentrations remain "stable" over time. A benchmark CV value of 1 based on Table 3.2 in (AFCEE, 2000) is used with RTRVP data. For a negative S-value with a confidence level of $< 90\%$, a CV less than one ($CV < 1$) indicates that the concentration at that location is stable, and $CV > 1$ indicates no trend could be discerned. "No discernable trend" indicates that no statistical increase or decrease is present at the specified level of significance, and the data fluctuates too dramatically from one event to another to be considered "stable."

Since 2018, a linear regression analysis was also performed on the data as a parametric alternative to the M-K test. The analysis is a linear approach to modelling the relationship between a dependent and independent variable and involves assessing the linear slope by computing the R^2 value of the least-squares regression on the sample mean. The R^2 value indicates the fit of the data, or distance of data points from the regression line. Higher R^2 values (> 0.8) indicate a close fit of the data and a strong relationship, suggesting that there is a trend. Values of R^2 between 0.5 and 0.8 suggest some association in the data and the possibility of a trend. Linear regression is based on the assumption that the data approximately follow a normal distribution and can confidently be used with eight or more data points. With fewer than eight data points it is difficult to determine if the normality assumption has been met and the linear regression has low power, or a lower probability of correctly detecting a trend when a trend exists. Linear regressions are provided as a qualitative assessment of trend and should be used for decision-making with caution since the normal distribution assumption of the data has not been determined, and the number of data points has not been considered. However, the 2000 ROD (DEC 2000) stated that linear regression trend analysis of the five most recent quarterly sampling event results will be used to determine whether concentrations of COCs are decreasing. Quarterly monitoring has not been performed at the RTRVP since 2008-2009; therefore, the latest five monitoring results were analyzed, which included data from the previous (2015) 5-year review.

Up until 2016, a series of select wells were evaluated with M-K analyses in the Upper, Lower (semi-confined) and Lower unconfined Plumes, in 2018, 2019, and 2020, both Mann-Kendall and Linear Regression were used to analyze total molar concentrations in all the wells sampled during the particular sampling event. During 2020, thirteen pore water samples were also included in the analysis. The M-K analysis spreadsheets are contained in the individual 2016, 2018, 2019, and 2020 Groundwater Monitoring reports, and are not presented here. Rather, a summary of the results is presented here.

Upper Plume monitoring synopsis since 2015

<u>Contaminant concentrations</u>

Select Upper Plume wells were sampled during 2016, 2018, and again in 2019 for volatile organic carbon (VOC) contaminants, and results are summarized below:

- PCE was detected in all samples collected from Upper Plume wells sampled during 2016-19. Concentrations ranged from 1.07 to 280 µg/L Monitoring well MW-25, located proximal to the northwestern boundary of the property (within 10 feet) contained PCE at a concentration that increased from 16.7 to 89.5 and again to 280 µg/L, during 2016, 2018, and 2019 respectively. This information suggests the Upper Plume aquifer may be experiencing recent contaminant (PCE) rebound, likely from upward vertical groundwater movement originating from the deeper source and semi-confined water-bearing zone (Lower semi-confined Plume), where elevated PCE concentrations remain.

- TCE was detected in all but one Upper Plume wells sampled during 2016-2019. TCE increased in concentrations in most wells sampled, but most notably in MW-25, where concentrations rose from 16.7 µg/L during 2016 to 44.3, and then 101 µg/L during 2018 and 2019, respectively. Some wells (MW-38 and MW-42) had TCE concentrations that decreased between 2018 and 2019. Increased TCE concentrations in some wells is indicative of PCE degradation, but decreased concentrations in other wells, and observations of increased PCE, suggest degradation may be starting to become limited in some Upper Plume locations.

- Cis-DCE was detected in all but one Upper Plume wells sampled during 2016-2019. Cis-DCE concentrations increased between 2018 and 2019 in MW-16 and MW-25 (from an estimated 7.45 and 67.1 µg/L to 23.1 and 180 µg/L, respectively). However, cis-DCE decreased in MW-38 from 281 to 231 µg/L, from 2018 to 2019.

- Trans-DCE was detected in samples from three of the Upper Plume wells sampled during 2016-2019. Concentrations ranged from an estimated 0.32 µg/L to 3.04 µg/L.

- 1,1-DCE was not detected at, or above, the limit of detection in samples from any of the Upper Plume wells during 2016-2019.

- VC was detected in samples from four of the Upper Plume wells sampled during 2016-2019. Concentrations ranged from 0.899 µg/L to 45.1 µg/L. From 2018 to 2019, VC in MW-38, located off the property, decreased from 45.1 to 32.3 µg/L, but exceeded the off-RTRVP property ACL of 20 µg/L during both years. VC also decreased in MW-25 from 1.4 to 0.899 µg/L between 2018 and 2019. However, VC increased in MW-16 from 5.16 to 15.9 µg/L between 2018 and 2019. Increased VC concentrations in some wells is indicative of DCE degradation, but decreased concentrations in other wells, and observations of increased PCE, suggest degradation via reductive dechlorination may be starting to become limited in some Upper Plume locations.

- Ethene was detected in only one Upper Plume well (MW-38), at a concentration of 15 µg/L, indicating reductive dechlorination was occurring or had recently occurred in the past.

- Benzene was detected in samples from two of the Upper Plume wells; concentrations ranged from an estimated 0.25 µg/L to 0.4 µg/L. Petroleum constituents likely serve as low-level additional carbon sources for dechlorinating microbes and may be expected to attenuate.

<u>Groundwater Geochemistry</u>

Geochemical data (field parameters) were collected from Upper Plume wells during the 2016, 2018, and 2019 sampling events, and are summarized below:

- The pH ranged from 6.33 to 7.27, which is within the optimal range (5 to 9) for reductive dechlorination (AFCEE, NFESC, and ESTCP 2004).
- During 2016-2019, the groundwater temperature ranged from 6.02°C to 10.84°C, which is below 20°C a level associated with more temperate zone subsurface microbial processes and where accelerated biodegradative processes may occur (however, psychrotolerant microbes may be adapted to metabolize at these RTRVP groundwater temperatures).
- Dissolved oxygen data collected in 2016 was considered to be outside the range of normal results, perhaps the result of a faulty probe, and all the data were rejected, The

dissolved oxygen collected in 2018 and 2019 together ranged from 0.0 mg/L to 8.08 mg/L. Groundwater at three of the wells (MW-21, MW-25, and MW-42) had dissolved oxygen concentrations above the recommended 1.0 mg/L threshold level (AFCEE, NFESC, and ESTCP 2004) indicating the reductive dechlorination pathway may not be optimal at these two locations. Dhc is an obligate anaerobe, and exposure to oxygen is known to inhibit robust dechlorination. Elevated dissolved oxygen in Upper Plume wells may suggest aerobic degradation of DCE and VC occurs there, but PCE would not undergo such transformations. Elevated dissolved oxygen also suggests fermentation of organic acids may be minimal.

- The ORP measured during 2016 was largely negative in all wells. However, positive ORP readings were measured during 2018 in all but one Upper Plume well. During 2019 each Upper Plume sampled well had positive ORP readings, ranging from 47.5 millivolts (mV) to 218 mV. All of the wells have groundwater with ORP above the recommended threshold level of -100 (AFCEE, NFESC, and ESTCP 2004) to sustain reductive dechlorination.
- The dissolved iron concentrations in Upper Plume samples ranged from 0.007 mg/L to 0.813 mg/L during 2018, which may be interpreted as being relatively low. Groundwater samples collected in 2019 were not analyzed for dissolved iron. Detectable concentrations of dissolved iron are indicative of anaerobic iron reduction processes in groundwater, some which may be involved in partial chlorinated ethene biodegradation. Elevated dissolved iron greater than previous analytical results is indicative of previous substrate injections to favor more highly reduced geochemical conditions. Dissolved iron can also indicate a competing terminal electron accepting process (TEAP) that may compete with reductive dechlorination processes for hydrogen.
- Total organic carbon (TOC) concentrations in Upper Plume wells ranged from 2 mg/L to 4 mg/L during 2018, which is below the minimum threshold level of 20 mg/L (AFCEE, NFESC, and ESTCP 2004). This concentration range suggests the carbon (carbon and electron donor) source at these locations is not sufficient to maintain long-term reductive dechlorination in the Upper Plume.
- Methane concentrations ranged from 0.027 mg/L to 2.83 mg/L. The methane concentration of 2.83 mg/L at MW-38 is greater than the 1.0 mg/L recommended threshold level (AFCEE, NFESC, and ESTCP 2004) and is indicative of reducing conditions favorable for reductive dechlorination at this particular location.

  Upper Plume groundwater samples were not analyzed for TOC or methane during 2016, nor during 2019.

Together these geochemical results suggest many Upper Plume wells have only mildly reducing geochemical conditions, and additional substrate injection may be warranted in the Upper Plume to continue reductive dechlorination.

Metabolic Volatile Fatty Acids

Volatile fatty acids (VFAs) were not detected in Upper Plume wells MW-38, MW-25, or MW-42 sampled during 2018, which indicates an inadequate fermentable substrate (carbon sources) at those locations. VFAs were not measured during 2019 Upper Plume sampling event.

Dehalorepsiring microorganisms

The abundance of Dhc and the functional genes tceA, vcrA, and bvcA was measured during 2018 in samples collected from the RTRVP site. Upper Plume wells (MW-25, -38, and -42) had detections of Dhc and VC reductase genes ranging from 3x10^3 to 1x10^6, suggesting Dhc and its functional genes are present, and some moderate level reductive dechlorination was occurring, or has previously occurred.

Discernable trends in contaminant concentrations

Mann-Kendall and Linear Regression

During 2016, The M-K trend analysis results for the two Upper Plume monitoring wells evaluated (MW-16, and MW-25) indicate that the total chlorinated ethene molar concentrations all exhibited a decreasing trend.

During 2018, the M-K and linear regression trend analyses using results from all past sampling events for two Upper Plume monitoring wells (MW-16 and MW-25) exhibited a decreasing trend in total chlorinated ethene molar concentrations. MW-16 and MW-25 are both near-property-boundary wells. Results from two additional Upper Plume wells were also analyzed during 2018. MW-38 exhibited a decreasing trend via M-K analysis, but no trend via linear regression. MW-42 did not exhibit a trend using either analysis for all past sampling events' results. None of the four Upper-plume wells exhibited a trend using M-K analysis on results from the last five sampling events. Analysis of MW-25 results from 2019 sampling activities indicated increasing or stable concentrations using M-K analysis, and possibly increasing total chlorinated ethene molar concentrations using linear regression analysis in MW-25. Both MW-38 and MW-43 showed possibly increasing linear regression trends for results from the last five sampling events, while the M-K analysis of these two wells indicates there is likely no trend, but conditions are stable. An additional three Upper Plume wells did not exhibit a trend using either analysis for the last five sampling events.

Taken with contaminant concentrations, it appears Upper Plume wells are beginning to show a reversal of historical decreasing contaminant concentration trends.

Graphical Analysis of Total Chlorinated Ethenes

The total molar sum of chlorinated ethenes in Upper Plume in wells sampled during 2016 and again in 2018 increased from 1.89 to 7.55 µMol/L (although additional Upper Plume wells were sampled in 2018). In 2019, the total molar sum increased to 9.3 µMol/L (again, an additional well was included in 2019 sampling activities that was not sampled during 2018).

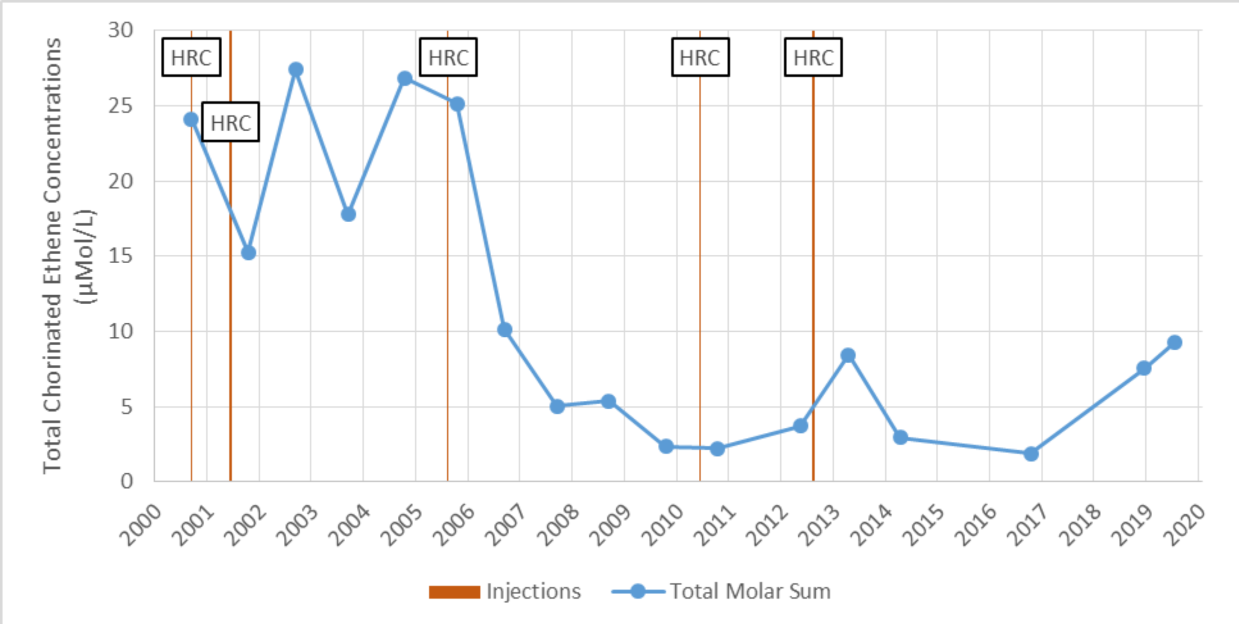

Figure 2. Total molar sum (µMol/L) of chlorinated ethenes in Upper Plume Wells

When the total molar sum of chlorinated ethenes in Upper Plume wells is examined using only the same wells sampled each year, the total increased from 2.9 µMol/L during 2014 to 7.6 µMol/L during 2018 (Figure 3), again illustrating a recent increase in chlorinated ethenes in Upper Plume wells.

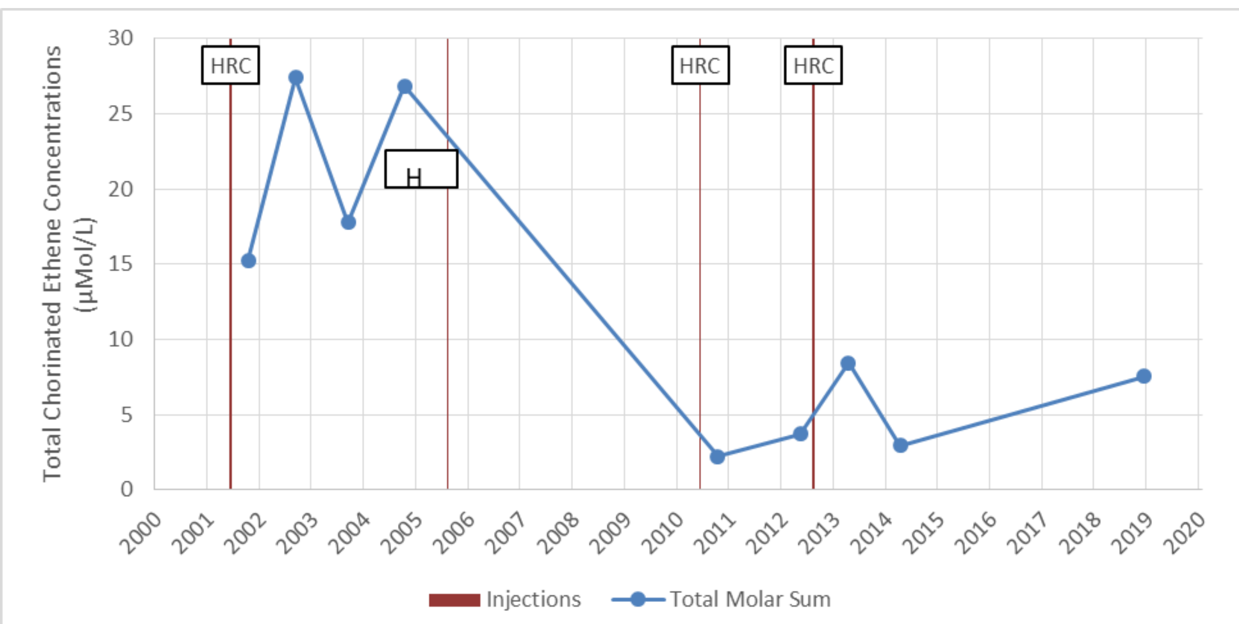

Figure 3. Total Sum of Chlorinated Ethenes in Upper Plume Wells (sum of all wells excluding years not all wells sampled)

Figure 4 depicts individual chlorinated ethenes graphically; the percent PCE molar mass in samples during 2018 and 2019 has increased since 2016 from 7% PCE to 25% PCE. This observation supports other lines of evidence reported above that PCE may be rebounding in Upper Plume
well

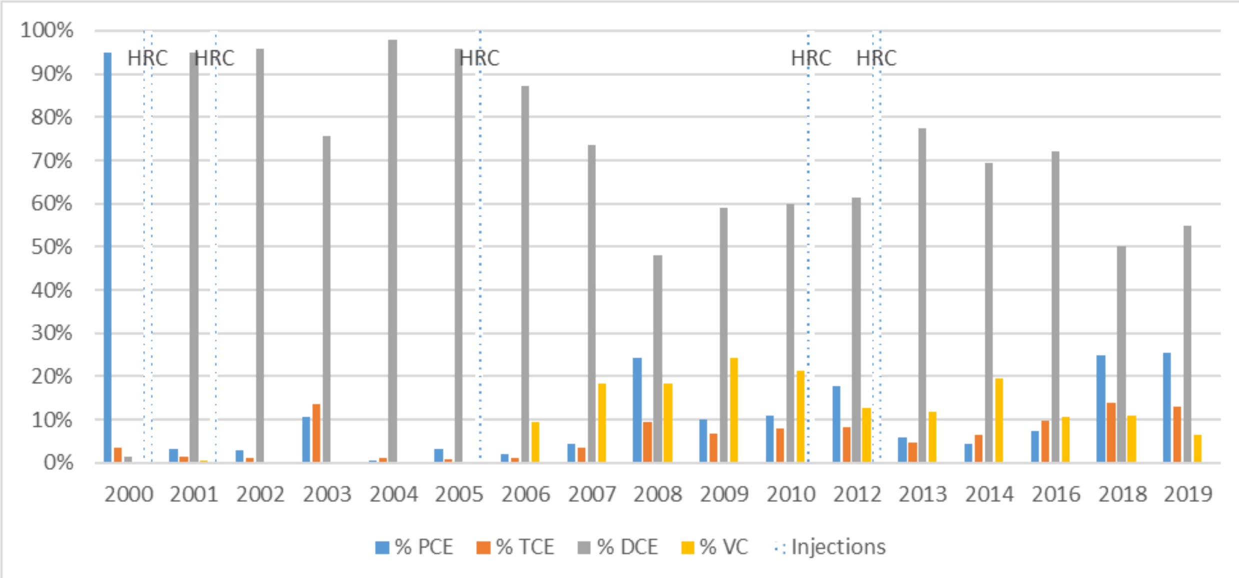

Figure 4. Percent molar mass of chlorinated ethenes in Upper Plume wells; notice increase in percent molar mass of PCE during 2018 and 2019.

Lower Semi-confined Plume and water-bearing till zone synopsis since 2015

Contaminant concentrations

- During 2018, PCE was detected in nine of ten wells sampled in the Lower semi-confined (deep source area) plume. One notable observation is that the concentration of PCE during 2018 in the deeper till well L80A was 104,000 µg/L (compared to a PCE concentration of 139,000 µg/L in nearby deeper till well L76 during 2006). This suggests sufficient mass of PCE (as DNAPL) may remain on the RTRVP in the deeper source (till) area to promote contaminant rebound in groundwater. This elevated concentration during 2018 contrasts sharply with concentrations of PCE reported during 2016 in Lower Semi-confined Plume wells where no wells exceeded the 840 µg/L ACL, and higher concertation was reported as <31 µg/L.

- TCE was detected in nine of ten wells sampled and ranged from an estimated 0.34 µg/L to an estimated 19,300 µg/L in the semi-confined water-bearing zone. TCE concentrations during 2018 were orders of magnitude higher than they were in 2016.

- Cis-DCE was detected in all ten wells sampled in the Lower Semi-confined Plume, deep source
zone, and concentrations ranged from 20.1 µg/L to 167,000 µg/L. While many of the wells had elevated concentrations of cis-DCE (indicating PCE degradation), at least one

well also contained cis-DCE orders of magnitude lower in concentration than during 2016. In contrast, cis-DCE increased in concentration in MW-50 from 47,000 μg/L during 2016 to 167,000 μg/L during 2018. This is supporting evidence that significant mass of PCE remains in the semi-confined water-bearing till zone.

- trans-DCE was detected in all samples collected from the ten lower plume semi-confined zone wells, and concentrations ranged from 1.99 μg/L to 548 μg/L.

- 1,1-DCE was detected in samples collected from six of the ten Lower Semi-confined Plume zone wells, and concentrations ranged from 0.32 μg/L to an estimated 197 μg/L.

- VC was detected in all samples collected from the ten Lower Semi-confined Plume zone wells sampled, and concentrations ranged from 30.7 μg/L to 34,500 μg/L. As with cis-DCE concentrations, some well samples had VC concentrations lower in 2018 than during 2016. However, there were increases in VC in many more wells between 2016 and 2018, suggesting reductive dechlorination is robust in this portion of the RTRVP site, and is still ongoing from significant PCE mass located in the semi-confined water-bearing zone.

- Ethene was detected in all seven Lower semi-confined Plume wells sampled in 2018, and concentrations ranged from 0.032 mg/L to 2.610 mg/L. This concentration range indicates reductive dechlorination was occurring at these sampling locations.

- Benzene detected in three wells during 2018 in the semi-confined water-bearing zone, with L-103 having an elevated estimated concentration of 45 μg/L.

Groundwater Geochemistry

Geochemical data (field parameters) was collected from the Lower semi-confined Plume (source zone) wells during the 2016 and 2018 sampling events, and are summarized below:

- The groundwater pH during 2016 and 2018 in the Lower semi-confined plume ranged from 5.46 to 8.89, which is within the desirable range for reductive dechlorination.
- The groundwater temperature during 2016 and 2018 sampling activities in the Lower semi-confined plume ranged from 3.54°C to 7.4°C, which is below 20°C, a level associated with more temperate zone subsurface microbial processes and where accelerated biodegradative processes may occur (however, psychrotolerant microbes may be adapted to metabolize at these RTRVP groundwater temperatures).
- The dissolved oxygen collected during 2016 was rejected; while the 2018 values ranged from 0.22 mg/L to 4.75 mg/L. Four of the Lower semi-confined plume wells (MW-39, MW-44, MW-47, and L-103) had dissolved oxygen concentrations below the 0.5 mg/L recommended threshold level supportive of reductive dechlorination pathway at these two locations.
- The ORP in the Lower semi-confined plume wells during 2016 ranged from -56.5 mV to -96.2 mV, while during 2018 ORP ranged from 47.7 mV to -310.8 mV. Four of the wells (MW-44, MW-52, L-78, and L-80A) had ORP values less than -100 mV, while four wells (MW-47, MW-48, MW-50, and L-103 had ORP values between -50 mV and -100 mV, indicating reduced geochemical conditions at those locations.

- Dissolved iron concentrations during 2018 ranged from 4.3 mg/L to 2,940 mg/L. Detectable concentrations of dissolved iron are indicative of anaerobic iron reduction processes, some which may be involved in partial chlorinated ethane biodegradation. Elevated dissolved iron elevated well above expected background concentrations in the aquifer (e.g., 2,940 mg/L in monitoring well L-103) may be indicative of previous substrate injections promoting more reduced geochemical conditions.
- Total organic carbon concentrations ranged from 31 mg/L to 157,000 mg/L, which are above a minimum recommended threshold level of 20 mg/L (AFCEE, NFESC, and ESTCP 2004). This concentration range suggests the carbon sources at these locations is likely sufficient to drive dechlorination processes.
- Methane concentrations ranged from 1.85 mg/L to 19.8 mg/L, which is greater than the 1.0 mg/L recommended threshold level (AFCEE, NFESC, and ESTCP 2004) and is indicative of reducing conditions favorable for reductive dechlorination.

Volatile Fatty Acids

VFAs were detected in samples from six of the seven Lower semi-confined Plume wells sampled in 2018 (MW-47, MW-48, MW-49, MW-50, MW-51, L-78, and L-103). The concentrations of VFAs ranged from 76.8 mg/L to 22,960 mg/L, above the 10 – 20 mg/L desirable concentration for a remedial treatment zone (AFCEE, NFESC, and ESTCP 2004). This indicates there is likely continued carbon supply at these locations; VFAs in samples from five of the wells were predominantly acetate, indicating the primary substrate in HRC™ injections have been fermented to simpler forms of carbon substrates. This is likely promoting continued reductive dechlorination, when considered with the prevalence of TCE, cis-DCE and VC.

Dehalorepsiring microorganisms

Dhc and its VC reductase genes (vcrA and bvcA) were particularly abundant in the Lower semi-confined deep source aquifer wells during 2018. For example, MW-50 contained 8x10^8 cells/L Dhc, and MW-48 contained 2x10^9 cells/L Dhc, which is well above the recommended minimum 1x10^6 cells/L Dhc for sustained and robust reductive dechlorination (AFCEE, NFESC, and ESTCP 2004, and ITRC, 2013). These same wells also contained very high concentrations of VC reductase genes; in MW-50, vcrA was reported at 1x10^9 gene copies/L, while bvcA was reported at 2x10^7 gene copies/L. Similarly, in MW-48 vcrA was reported at 5x10^9 gene copies/L, while bvcA was reported at 9x10^6 gene copies/L. Most other wells sampled in this location of the plume also had Dhc cells and VC reductase genes near or above the recommended 1x10^6 level.

Discernable trends in contaminant concentrations

Mann-Kendall and Linear Regression

During 2016, the M-K trend analysis results for the six Lower semi-confined Plume monitoring wells indicated that the total chlorinated ethene molar concentrations exhibit no trend at five locations: MW-48, MW-49, MW-50, MW-51, and MW-52. Only results from monitoring well MW-44 exhibited a decreasing trend.

During 2018, both M-K and linear regression trend analyses were conducted. Two of the eight Lower semi-confined Plume monitoring wells (MW-44 and MW-51) exhibited decreasing total chlorinated ethene molar concentration trends for both M-K and linear regression analyses, when data from 2000 to 2018 were analyzed. Five of the eight wells (WM-47, MW-48, MW-49, MW-50, and L-78) showed no trends by either M-K or linear regression. One of the eight wells (L-80A) showed a possibly increasing linear regression trend, but no M-K trend. However, this location has only been sampled four times.

MW-50 in the Lower Semi-confined Plume showed increasing total chlorinated ethene molar concentrations during the last five sampling events, as analyzed by M-K and linear regression, while well L-80A showed a possibly increasing trend via linear regression, but no trend via M-K analysis (four years of data). The remaining six wells in the Lower Semi-confined Plume (MW-44, MW-47, MW-48, MW-49, MW-51, and L-78) did not display total chlorinated ethene molar concentration trends during the last five sampling events.

These analyses are conducted with total molar concentrations of chlorinated ethenes, and do not take into account changes in individual chlorinated ethene molar concentrations.

Total Chlorinated Ethenes

The total chlorinated ethene concentration in the semiconfined monitoring well MW-44 indicates an overall decline through time (i.e., 206 µmol during 2002 to 4 µmol during 2018). However, the total chlorinated ethene concentration in the other semi-confined monitoring wells (MW-47 and MW-50) appears to be showing an increasing trend during the last couple of monitoring events. This is supported by the increase in chlorinated ethene concentrations observed in these same wells during 2018, as well as the percent molar concentrations of individual chlorinated ethenes.

Lower Unconfined Plume and near-river monitoring synopsis since 2015

<u>Contaminant concentrations</u>

Monitoring wells in the Lower Unconfined Plume, and sentinel wells located closer to the Kenai River, were sampled during 2018 and 2020.

- During 2018, PCE was detected in all samples collected from the four near-river wells, and concentrations ranged from 1.46 µg/L to 16.9 µg/L. It is important to note that the PCE concentration in the sample collected from MW-7 exceeded the modeled action level of 15 µg/L for surface water impacts. During 2020, PCE was detected in all samples collected from the four near-river wells, and concentrations ranged from 3.85 µg/L to 46.1 µg/L. PCE in monitoring well MW-7 was 46.1 µg/L during 2020, greater than the concentration observed in this same well during 2018 (16.9 µg/L). PCE MW-5 (17.8 µg/L) also exceeded the modeled action level of 15 µg/L for surface water impacts

- During 2018, TCE was detected in samples from three of the four near-river wells, with concentrations ranging from 1.55 µg/L to 5.36 µg/L. TCE was also detected in all samples from the four near-river wells during 2020, and concentrations ranged from 1.07 µg/L to 2.57 µg/L.

- Both cis-DCE and trans-DCE were detected in samples from the four near-river wells during 2018. Concentrations ranged from 4.3 µg/L to 24.9 µg/L cis-DCE and from 0.8 µg/L to 4.47 µg/L trans-DCE. Similarly, cis-DCE was detected in samples from all four near-river wells during 2020, and concentrations ranged from 1.03 µg/L to 24.9 µg/L. Trans-DCE was detected in only one near-river well (MW-6A) at an estimated concentration of 0.625 µg/L.

- 1,1-DCE was not detected in any of the near-river wells sampled during 2018, nor in any samples from the four near-river wells during 2020.

- During 2018, VC was detected in all samples collected from the four near-river wells, at concentrations ranging from 0.24 µg/L to 8.02 µg/L. The VC from monitoring well MW-6A (at 8.02 µg/L) exceeded the modeled action level for potential water quality impacts, as well as the eco-action level for potential adverse effects to aquatic organisms. VC was detected in samples from three of the four near-river wells during 2020, and concentrations ranged from 0.247 µg/L to 3.8 µg/L. Concentrations of VC in MW-6A and MW-7 during 2020 were lower than during 2018 in the same wells.

- During 2020, ethene was detected in two wells sampled (MW-6A and MW-7) and concentrations were 0.0013 mg/L and 0.002 mg/L, respectively. These ethene concentrations suggest complete reductive dechlorination is likely not occurring at these locations. (Ethene was not measured during 2018 from near-river wells).

- During 2018, Benzene was detected in samples from two of the four near-river wells, with concentrations ranging from 0.69 µg/L to 0.81 µg/L. However, benzene was not detected any of the four near-river monitoring wells during 2020.

Overall, these observations of VOC concentrations in the different groundwater plumes indicate continued contaminant migration and transport from a remaining source area in the deeper semi-confined water-bearing till, an open contaminant exposure pathway to the Kenai River, and that contaminant transformations are occurring, but likely slowing over time.

Discernable Trends in Contamination Concentrations

Mann-Kendall and Linear Regression Statistical Trend Analysis

During 2016, M-K analyses of Lower Unconfined Plume wells MW-6A, MW-9, and MW-39 indicated that the total chlorinated ethene molar concentrations all exhibited decreasing trend in the three Lower Unconfined Plume monitoring wells sampled.

During 2018, total chlorinated ethene molar concentrations in monitoring wells MW-9, MW-39, and MW-40 showed decreasing contaminant concentration trends when the historical sampling results were analyzed by M-K or linear regression. When the past five years of data were analyzed, only MW-39 exhibited decreasing contaminant concentrations via M-K or linear regression, while five year data from the remaining two wells did not display a trend.

Total contaminant molar concentrations were analyzed during 2018 from near-river wells MW-6, MW-7, MW-12, and MW-35. All historical data analyzed from the four wells exhibited decreasing concentration trends via M-K analysis, but data from three wells (MW-6, MW-7, and MW-12) also exhibited decreasing trends via linear regression, while data from MW-35 did not display a trend via linear regression.

When data from the last five sampling events were analyzed, total chlorinated ethene molar concentrations in MW-35 showed a decreasing trend using both M-K and linear regression analyses. Data from MW-12 showed only a possibly decreasing linear regression trend. Data from MW-6 and MW-7 did not exhibit trends using either M-K or linear regression analyses.

A different set of near-river wells was sampled during 2020, and contaminant concentration data were analyzed as described above (from all sampling events, and from the past five sampling events). All past sampling events data (total chlorinated molar ethane concentration) from MW-5 exhibited a decreasing trend, and no trend, for Mann-Kendall and linear regression trends, respectively, Data from an additional three wells (MW-6A, MW-7, and MW-8) displayed a decreasing M-K trend, and a possibly decreasing linear regression trend.

When data from the past five sampling events was analyzed, data from monitoring well MW-5 exhibited an increasing or stable trend via M-K analysis, and a likely increasing trend from linear regression. Data from wells MW-6A and MW-7 showed likely no trend or stable via M-K analysis, and no trend via linear regression. Data from monitoring well MW-8 indicated a decreasing or stable trend via M-K analysis, and a possibly decreasing trend via linear regression.

Graphical Analysis

Overall, the total chlorinated ethane molar concentrations have decreased in the near-river sentry wells since 2000. However, sampling conducted during 2018 and 2020 suggests the total molar concentration of chlorinated ethenes is beginning to increase. After initial HRC treatments began in 2000 DCE isomers have been the predominant chlorinated ethene on a molar percentage basis in groundwater in the near-river sentry wells. However, PCE (and TCE, to a lesser extent) appears to have recently rebounded in these wells since the last HRC™ injection in 2012; the greatest percent molar mass of PCE in samples since 2001 was observed in 2020. During 2020 the percent molar mass of TCE in samples from near-river wells was nearly at the same level as during 2012 (before treatment), after having been at the lowest levels observed at the site since 2001. TCE was also most recently observed above 18 AAC 75 Table C GCLs in near-river sentry wells. The percent molar mass of VC has remained roughly between 10-20% during the past 10 years.

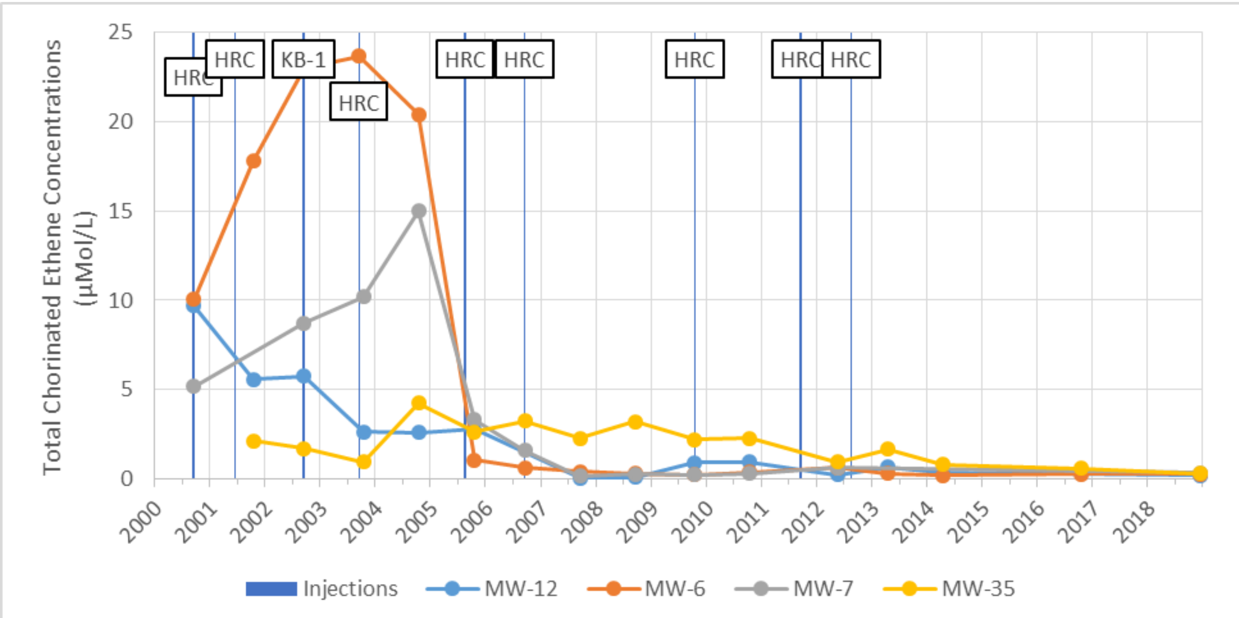

Figure 5 Total Molar Concentration of Chlorinated Ethenes in Near-river Sentry Wells

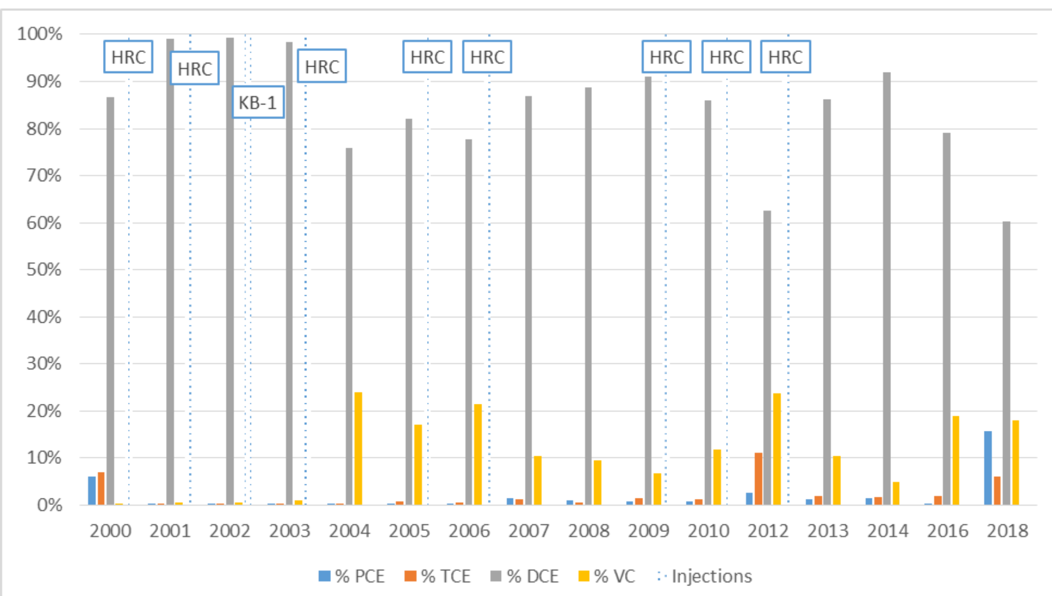

Figure 6 Percent Molar Mass of Chlorinated Ethenes in Near-river Sentry Wells

Groundwater Geochemistry

Only limited, field-derived geochemical data were collected from five groundwater wells in the Lower Unconfined Plume during 2016, and from seven Lower Unconfined Plume wells (which included four near-river wells) during 2018. During 2020, field-derived groundwater geochemistry data was collected from four near-river monitoring wells, but additional geochemical data was collected from only two near-river wells (MW-6A and MW-7).

During 2016, the following geochemical observations were recorded from Lower unconfined plume wells:

- pH ranged from 6.5 pH to 7.7
- Temperature ranged from 5.5°C to 8.7°C
- Dissolved oxygen data were rejected because concentrations were considered to be outside the range normally observed for these monitoring wells
- ORP of -189 mV measured in Lower Unconfined Plume well MW-35 was also interpreted to be an anomaly since these locations were outside the areas of past HRC™ treatments.

During 2018, geochemical data included the following observations:

- pH ranged from 5.81 to 7.52
- Temperature ranged from 4.15 °C to 7.41 °C
- ORP ranged from -48.3 mV to 166.9 mV
- Dissolved oxygen ranged from 0.30 mg/L to 2.04 mg/L

During 2020, geochemical data included the following observations:

- pH ranged from 5.37 to 5.83, which is within the desirable range for reductive dechlorination
- Temperature ranged from 5.13°C to 7.95°C, which is below 20°C, a level associated with more temperate zone subsurface microbial processes and where accelerated biodegradative processes may occur (however, psychrotolerant microbes may be adapted to metabolize at these RTRVP groundwater temperatures).
- ORP ranged from 145.2 mV to 210.18 mV, above the recommended threshold level of -100 (AFCEE, NFESC, and ESTCP 2004) to sustain reductive dechlorination,
- Dissolved oxygen ranged from 0.42 mg/L to 1.23 mg/L. Two of the wells (MW-7 and MW-8) had dissolved oxygen concentrations below the 0.5 mg/L recommended threshold level supportive of reductive dechlorination pathway at these two locations
- Total organic carbon concentrations from MW-6A and MW-7 ranged from 0.00673 mg/L to 0.00684 mg/L, well below the minimum recommended threshold level of 20 mg/L (AFCEE, NFESC, and ESTCP 2004). This concentration range suggests the carbon sources at these locations are likely not sufficient to sustain reductive dechlorination processes.

- Methane concentrations ranged from 0.18 mg/L to 0.252 mg/L, lower than the 1.0 mg/L recommended threshold level (AFCEE, NFESC, and ESTCP 2004) that would be favorable for reductive dechlorination.

Volatile Fatty Acids

Volatile fatty acids were not analyzed from Lower unconfined Plume groundwater samples collected during 2016, 2018, nor 2020.

Dehalorespiring microorganisms

The abundance of Dhc and functional gene biomarkers were not analyzed from Lower unconfined Plume groundwater samples collected during 2016, 2018, nor 2020.

Kenai River surface water /sediment/pore water monitoring synopsis since 2015

Surface water column sampling (at upstream, midstream, and downstream RTRVP locations) has been periodically conducted concurrently with groundwater monitoring. PCE and/or its degradation products have not been detected in any surface water column samples collected between 1999 and 2008. In October 2009, and again in May 2020, PCE was detected in surface water samples, but at concentrations below water quality criteria protective of human health and the environment. However, contaminant detections in surface water do signify contaminant transport and a complete exposure pathway to ecological and human receptors. The presence of PCE may also indicate a reduction of contaminant biodegradation in groundwater located hydrologically upgradient.

Sediment/pore water sampling has also been periodically performed to assess the effects of site treatment activities on the Kenai River and its receptors. The most recent sampling event of 2020 involved pore water sampling only (without sediment collection). Each sediment/pore water monitoring event utilizes the same sampling locations, to the extent possible, as the previous investigations and the same sampling methodologies are followed. These sampling locations are generally between MW-8 and MW-35, are below the mean high water line at the groundwater interface and extend about 10 feet into the Kenai River, approximately one foot below the sediment/surface water interface. The sediment and pore water sampling events are typically performed early in the spring when the Kenai River is near its lowest river stage, to ensure the river under a gaining stream scenario, and to allow for access to the sample locations.

During May 2020, PCE and its degradation products were detected in 13 pore water sampling locations, often exceeding the groundwater cleanup level or water quality standard (depending on location and contaminant.

Results and conclusions from the 2020 sediment and pore water sampling event are summarized below:

Contaminant concentrations

Surface water

- PCE was detected in all three samples collected from the Kenai River, and concentrations ranged from an estimated 0.315 J µg/L to 1.72 µg/L, but were below all cleanup levels. The remaining chemicals of concern were not detected in surface water samples.

Pore water

- PCE was detected in all 13 pore water samples collected, and concentrations ranged from 6.13 µg/L to 33.5 µg/L. The maximum PCE concentration was at SD-010.
- TCE was detected in all 13 pore water samples, and concentrations ranged from 0.486 µg/L to 4.72 µg/L.
- Cis-DCE was detected in all 13 pore water samples, and concentrations ranged from 0.542 µg/L to 9.17 µg/L. The maximum concentration was at SD-043.
- Trans-DCE was detected in eight of the 13 pore water samples, and concentrations ranged from an estimated 0.311 µg/L to an estimated 0.923 µg/L. The maximum concentration was at SD-033.
- 1,1-DCE was not detected in any samples.
- VC was detected in samples from 11 of the 13 pore water sample locations, and concentrations ranged from 0.109 µg/L to 2.37 µg/L.
- Benzene was not detected in any samples.

Discernable Trends in Contamination Concentrations

Mann-Kendall and Linear Regression Statistical Trend Analysis

M-K analyses and linear regression were not conducted with pore water nor surface water data collected during 2020.

Graphical analysis

Historical pore water collection has shown that DCE isomers have been the predominant chlorinated ethane in pore water, until 2020, when PCE became the predominant chlorinated ethene (figure 7). The total chlorinated ethene concentrations visually appear to decrease over time in the pore water since 2004, although the concentration has increased since 2013 (figure 8). The increase in PCE in pore water likely indicates that degradation has slowed or stopped in portions of the Lower unconfined groundwater Plume.

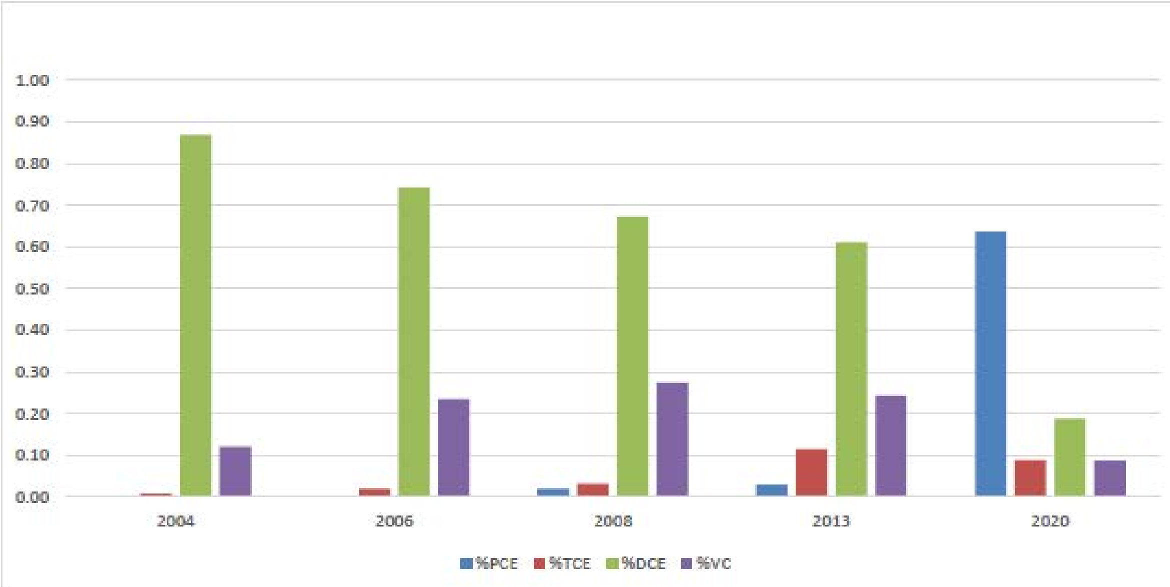

Figure 7. Percent Molar Mass of Chlorinated Ethenes in Pore Water Samples

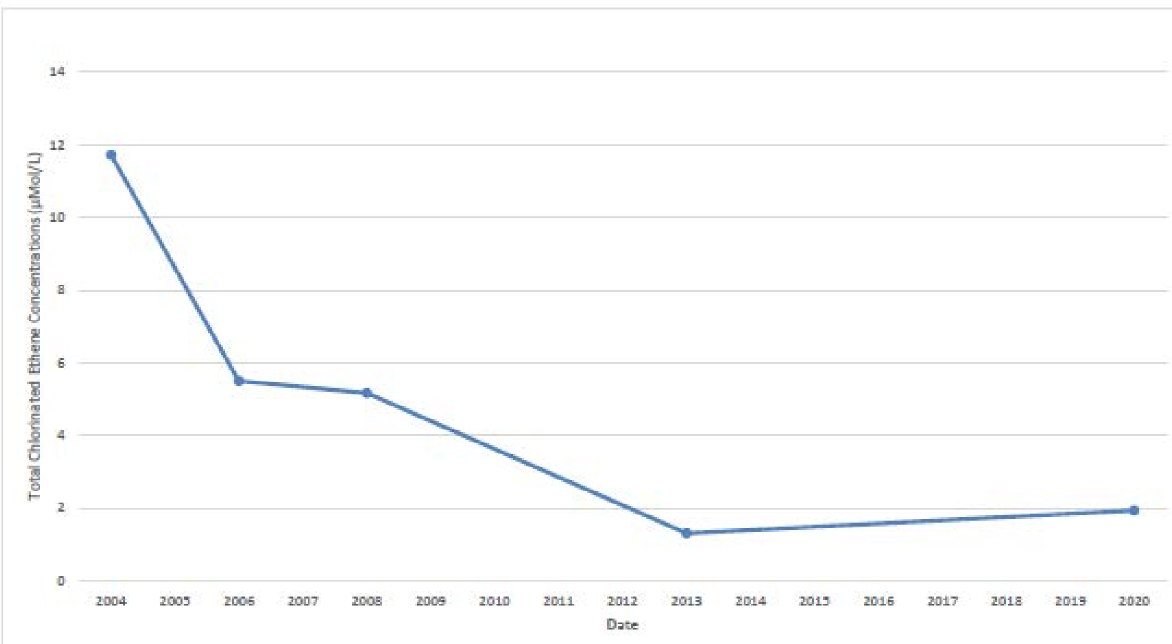

Figure 8. Total Molar Sum of Chlorinated Ethenes in Pore Water Samples

Groundwater Geochemistry

Surface water

During 2020, geochemical data collected from surface water data included the following observations:

- pH ranged from 5.96 to 6.14
- Temperature ranged from 8.89°C to 8.98°C
- Dissolved oxygen ranged from 11.9 mg/L to 12.42 mg/L
- ORP ranged from 188.7 mV to 190.3 mV.

Pore water

During 2020, geochemical data collected from surface water data included the following observations:

- pH ranged from 4.88 to 5.82
- Temperature ranged from 5.58°C to 9.55°C
- Dissolved oxygen ranged from 0.65 mg/L to 2.70 mg/L. All of the locations had DO concentrations above the 0.5 mg/L threshold level indicating the reductive dechlorination pathway is minimal or likely not occurring at these locations;
- ORP ranged from 151.9 mV to 260.7 mV. ORP values greater than -50 mV indicate the reductive dechlorination pathway is likely minimal or not occurring in pore water (AFCEE, NFESC, and ESTCP 2004).

Pore water samples collected from eight of the 13 sampling locations (SD-006, SD-007, SD-009, SD-033, SD-035, SD-040, SD-041, and SD-042), were analyzed for additional geochemical parameters:

- Total organic carbon concentrations ranged from 5.39 mg/L to 7.02 mg/L, which are below the threshold level of 20 mg/L. This concentration range suggests that carbon and electron donor sources at these locations is not likely sufficient to sustain reductive dechlorination (AFCEE, NFESC, and ESTCP 2004).
- Methane concentrations ranged from 0.152 mg/L to 0.783 mg/L. Only one location SD-033 was above the 0.5 mg/L threshold level indicative of reducing conditions favorable for reductive dechlorination
- Ethene was detected in all five locations, and concentrations ranged from 0.00048 mg/L to 0.007 mg/L. This concentration range is less than the threshold level of 0.01 mg/L and also indicates the reductive dechlorination pathway is not likely at these sampling locations (AFCEE, NFESC, and ESTCP 2004). The presence of ethene may be originating from other natural sources in the pore water environment.

Volatile Fatty Acids

Volatile fatty acids were not analyzed in any pore water nor surface water samples collected during 2020.

Dehalorepsiring microorganisms

The abundance of Dhc and its functional genes were not analyzed in any pore water nor surface water samples collected during 2020.

Detections of the primary site contaminant (PCE) in pore water and surface water demonstrates continued contaminant transport from upgradient site locations and likely lowered contaminant transformations since pore water and surface water were last sampled during 2013.

III. Compliance with ACLs and Current GCLs

Upper Plume (2016-2019)

- PCE was detected in all samples collected from Upper Plume wells sampled during 2016-2019, but was below the 840 µg/L on-RTRVP property ACL. PCE concentrations in MW-25 (within 10-feet of property boundary) during both 2018 and 2019 exceed both the applicable off-RTRVP property ACL of 50 µg/L and the current GCL of 41 µg/L. PCE in MW-21 also exceeded the GCL. Additionally, MW-42 contained PCE concentrations at 178 and 147 µg/L, respectively, which exceeded the current GCL (but not the ACL).

- TCE was detected in all but one Upper Plume wells sampled during 2016-19, and exceeded the GCL in all wells sampled during 2018 and 2019. The 2019 TCE concentration in MW-25, as well as that in MW-38 during 2018, exceeded the off-property ACL (50 µg/L), but were below the 21,900 µg/L on-RTRVP property ACL.

- Cis-DCE was detected in all but one Upper Plume wells sampled during 2016-19, with many exceeding the GCL of 36 µg/L during 2018 and 2019, but not on-site or off-site ACLs.

- Trans-DCE was detected in samples from three of the Upper Plume wells sampled during 2016-2019, but was below all applicable cleanup levels.

- VC exceeded the 2 µg/L on-RTRVP property ACL in samples from two of the wells (MW-16 and MW-38), as well as the current GCL of 0.19 µg/L, during both 2018 and 2019. From 2018 to 2019, VC in MW-38, located off the property, also exceeded the off-RTRVP property ACL of 20 µg/L during both years.

- Benzene was detected in samples from two of the Upper Plume wells, but concentrations were below all applicable cleanup levels.

Lower semi-confined Plume (2018)

- During 2018, four wells (MW-47, MW-50, L-80A, and L-103) contained PCE concentrations above the ACL of 840 μg/L (as well as the current GCL of 41 μg/L).

- TCE concentrations were detected above the 2.8 μg/L GCL four of the Lower semi-confined plume wells in the water-bearing zone (MW-47, MW-50, L-80A, and L-103).
- Cis-DCE was detected in all ten wells sampled in the Lower semi-confined plume, deep source
zone, and samples from five of the wells (MW-47, MW-50, L-78, L-80A, and L-103) exceeded the 11,600 μg/L on-RTRVP property ACL, while samples from nine wells exceeded the current GCL of 36 μg/L.

- Trans-DCE was detected in all samples collected from the ten Lower semi-confined plume wells. It was below the 11,600 μg/L on-RTRVP property ACL in each well, but two of the wells (MW-47 and MW-50) contained trans-DCE above the current GCL of 360 μg/L.

- 1,1-DCE was detected in samples collected from six of the ten Lower semi-confined plume wells, and samples from three wells (MW-47, MW-50, and L-80A) exceeded the 7 μg/L on-RTRVP property ACL, but did not exceed the current GCL of 280 μg/L.

- VC was detected in all samples collected from the ten Lower semi-confined plume wells sampled, and all results in the Lower Semi-confined Plume water-bearing zone wells exceeded the 2 μg/L on-RTRVP property ACL and the current 0.19 μg/L GCL.

- Benzene concentrations were detected above the 4.6 μg/L GCL at two wells (MW-47 and L-103) in the semi-confined water-bearing zone. However, the limits of detection for samples from three of the wells (MW-48, L-78, and L-80A) in the Lower Semi-confined Plume were greater than the GCL Benzene was detected at a concentration above the 50 μg/L on-RTRVP property ACL at one well (MW-47) in the semi-confined water-bearing zone.

Lower unconfined Plume (2018)

- During 2018, PCE was detected in all samples collected from the four near-river wells, and concentrations below both the current GCL and the 840 μg/L on-RTRVP property ACL. However, the PCE concentration in the sample collected from MW-7 exceeded the modeled action level of 15 μg/L for surface water impacts.

- TCE was detected in samples from three of the four near-river wells during 2018, below the 21,900 μg/L on-RTRVP property AC). TCE in monitoring well MW-7 exceeded the current GCL of 2.8 μg/L.

- Both cis-DCE and trans-DCE were detected in samples from the four near-river wells and both compounds were below applicable cleanup levels.

- 1,1-DCE was not detected in any of the near-river wells sampled.

- VC was detected in all samples collected from the four near-river wells, and two wells (MW-6A and MW-7) contained VC above the 2 µg/L on-RTRVP property ACL. Additionally, the VC from monitoring well MW-6A (at 8.02 µg/L) exceeded the modelled action level for potential water quality impacts, as well as the eco-action level for potential adverse effects to aquatic organisms. All VC concentrations in all four wells sampled during 2018 exceeded the current GCL of 0.19 µg/L.
- Benzene was detected in samples from two of the four near-river wells, but were below applicable cleanup levels.

Lower unconfined Plume (2020)

- During 2020, PCE was detected in all samples collected from the four near-river wells, but was below the 840 µg/L on-RTRVP property ACL. PCE in monitoring well MW-7 exceeded the applicable modeled action level of 15 µg/L for potential water quality impacts, as well as the current GCL of 41 µg/L. PCE MW-5 (17.8 µg/L) also exceeded the modelled action level for water quality.

- TCE was also detected in all samples from the four near-river wells during 2020, but concentrations did not exceed any ACLs, GCLs nor action levels.

- Cis-DCE was detected in samples from all four near-river wells during 2020, while tDCE was detected in only one near-river well (MW-6A). Both DCE isomers were below all applicable cleanup levels and the current GCL.

- VC was detected in samples from three of the four near-river wells during 2020, and concentrations in MW-8 (3.8 µg/L) and exceeded the 2 µg/L on-RTRVP property ACL. All detected VC concentrations in wells (MW-6A, MW-7, and MW-8) exceeded the current GCL of 0.19 µg/L.

- Benzene was not detected any of the four near-river monitoring wells.

Surface water

- PCE was detected in all three samples collected from the Kenai River, but were below all cleanup levels, and did not exceed water quality standard of 18 AAC 70 (5 µg/L).

Pore water

- PCE was detected in all 13 pore water samples collected and all were above the 18 AAC 70 water quality standard of 5 µg/L, but were below the current GCL of 41 µg/L.

- TCE was detected in all 13 pore water samples but were below the 18 AAC 70 water quality standard of 5 µg/L. Concentrations at two locations (4.72 µg/L at SD-037 and 3.15 µg/L at SD-044) were above the GCL of 2.8 µg/L.

- VC was detected in samples from 11 of the 13 pore water sample locations, and concentrations at nine locations were above the GCL of 0.19 µg/L. One location (SD-043) exceeded the 18 AAC 70 water quality standard of 2 µg/L.

IV. New Toxicological Data Pertinent to the Contaminants of Concern.

During the twenty years since the signing of the ROD, DEC has continued to review toxicological data for PCE and its degradation products to evaluate whether the cleanup plans should be adjusted to ensure the Kenai River and its ecological receptors are protected. Most recently, DEC revised its 18 AAC 75.341 Method Two soil cleanup levels and 18 AAC 75.345 Table C groundwater cleanup levels during October 2008. Additional updates soil and groundwater cleanup levels occurred during 2016 when DEC used risk-based approach to calculating all cleanup levels, where "the risk from hazardous substances does not exceed a cumulative carcinogenic risk standard of 1 in 100,000 across all exposure pathways and does not exceed a cumulative noncarcinogenic risk standard at a hazard index of one, reported to one significant figure, across all exposure pathways." This was followed by additional updates for some contaminants during October 2018. Significantly, a single human health cleanup value was established for soil and groundwater, with a migration to groundwater cleanup level remaining for soil. For the RTRVP contaminants of concern, this resulted in increased in soil and groundwater cleanup levels for some contaminants, but decreased levels for others.; The most recent (2018) 18 AAC 75.341 soil cleanup levels for the RTRVP contaminants of concern are shown below in Table 2, along with the site-specific soil cleanup levels established in the ROD.

During 2015, DEC reviewed the decrease in these cleanup levels (e.g., PCE from 80 mg/Kg to 10 mg/Kg for the outdoor air inhalation pathway) and concluded that the site ROD's cleanup levels coupled with the findings of contaminant concentrations and locations at the site, (e.g., high concentrations of PCE remaining at approximately 20 to 35 ft. bgs near wells L74, L76, and MW-47) remain protective of the receptors at the RTRVP site.

DEC does not anticipate a need to change ROD based on changes in soil cleanup values, because exposure risks are managed and cleanup approach continues.

Table 4: Comparison of 2008 and 2018 Soil Cleanup Levels with ROD Cleanup Levels (in mg/Kg)
(18 AAC 75.341 Table B1, Method 2, under 40-inch precipitation zone)

	Direct Contact (2008)	Outdoor Air Inhalation (2008)	**Human Health (2018)**	Mig. to GW (2008)	**Mig. to GW (2018)**	*ROD Cleanup Levels (on-RTRVP/off-RTRVP)*
PCE	15	10	**68 (95)***	0.024	**0.19**	*11.5/0.3*
TCE	21	0.57	**4.9**	0.02	**0.011**	*300/0.27*
1,1-DCE	14	0.85	**330**	0.03	**1.2**	*7.1/0.3*
cis-1,2-DCE	1000	130	**200**	0.24	**0.12**	*72.1/2*
trans-1,2-DCE	2000	160	**960 (2000)***	0.37	**1.3**	*87.3/4*
VC	5.5	4.3	**0.65**	0.0085	**0.00080**	*2.1/0.09*

** This level is based on a soil saturation concentration (Csat) using the equations set out in Procedures for Calculating Cleanup Levels, adopted by reference in 18 AAC 75.340. The Csat value is listed first, followed by the human health risk-based cleanup level in parentheses. The human health risk-based cleanup level assumptions do not take free product into consideration. In accordance with 18 AAC 75.325(f), free product must be recovered to the maximum extent practicable. Contaminant concentrations above the Csat value trigger the need to assess the practicability of product recovery; if the department determines product recovery is impracticable, the risk-based cleanup level may be applied as long as the cumulative risk standards are met.*

Changes to the Table C groundwater cleanup levels for the RTRVP contaminants of concern have also occurred since the last 5-Year Review of 2015, and the "ten times rule" (which was used to establish off-RTRVP property groundwater cleanup levels in the ROD) has been removed from regulation (18 AAC 75.345). The 18 AAC 75.345 groundwater cleanup levels for the RTRVP contaminants of concern are shown below in Table 3, along with the site-specific groundwater cleanup levels established in the ROD.

**Table 5: Comparison of Current DEC Groundwater Cleanup Levels with ROD Cleanup Levels (in mg/L)
(18 AAC 75.345 Table C)**

	Table C Cleanup Level (2018)	RTRVP On-Property Cleanup Level	RTRVP Off-Property Cleanup Level
PCE	0.041	0.84	0.05
TCE	0.0028	21.9	0.05
1,1-DCE	0.280		
cis-DCE	0.036	11.6	0.7
trans-DCE	0.360	11.6	1.0
VC	0.00019	0.002	0.02

Although the groundwater cleanup levels have changed since the last 5-Year review, and contaminants still remain above the ACLs outlined in the ROD, implementation of the remedy has sustained the overall reduction of the contaminants and remains the protective of receptors. As discussed below, however, recent data indicates additional action is necessary to maintain the effectiveness of the remedy.

The 2000 ROD implemented Institutional Controls for the RTRVP site to ensure protection of human health, safety, and welfare. These included a prohibition of drinking water well installations in the shallow unconfined aquifer (and landowner concurrence to record this land use restriction on the property deed). Soil excavations, or other activities that could interfere with site cleanup, operation, and maintenance, or monitoring also requires Departmental approval. A 2011 amended Consent Decree re-established the “site” as approximately 1.5 acres of property on the bank of the Kenai River consisting of Kenai Peninsula Borough Tax Parcel 060-260-01 and Tax Parcel 060-260-02. Institutional controls were established for the properties impacted by chlorinated solvent releases in the form of equitable servitudes (which run with the land in perpetuity). These equitable servitudes prohibit water wells in the shallow aquifer lying beneath Tax Parcel 060-261-99, and provide for testing for vapor intrusion before construction of new buildings on Tax Parcel 060-261-99, or alternatively for installation of vapor intrusion mitigation systems on new building constructed on Tax Parcel 060-261 -99.

Together, these institutional controls ensure that receptors to the drinking water, vapor intrusion, and soil contact or ingestion pathways remain protected from contamination that remains on the properties.

V. Concerns of the Public

As a prefatory note, prior to and since the Consent Decree was signed, DEC has been active in communicating with interested members of the community. DEC has maintained close communication with the interested public by copying stakeholders with reports, informing them of events, and updating the Kenai River Special Management Area (KRSMA) board during their public meetings. DEC provides published reports to the Kenai River Center in Soldotna, which acts as a repository for RTRVP documents that are available to the public. DEC has also worked closely with the RTRVP owners' environmental consultant in the planning phase of work proposed for the site and discussed the findings with the consultant. DEC has also worked closely with DOT representatives regarding contamination at the site that may have impacted planned upgrade work. DEC duly considers input from the public, the RTRVP owner(s) and their consultant(s), and DOT while developing plans to perform further assessment/monitoring/cleanup activities. DEC continues to consider such comments by stakeholders and the public at large during this five-year review. DEC posts copies of its consultants' reports on the DEC web page at http://dec.alaska.gov/spar/csp/sites/riverterrace.htm .

VI. Other Relevant Information – Vapor Intrusion

In 2009, DEC sampled the treated soil landspread in 2003 to determine whether a risk via indoor vapor intrusion may be possible. Low levels of PCE were detected in one out of seven samples.

Between January and June 2010, DEC conducted a vapor intrusion assessment at the site focusing around the former dry cleaner building. The assessment included the following work scope:

- Installation and sampling of thirty two soil gas monitoring points.
- Performance of a building assessment at the former dry cleaner building and three nearby trailer homes.
- Collection of indoor air, outdoor air, and sub-slab samples at the former dry cleaner building.
- Collection of indoor air, outdoor air, and soil gas or crawl space air samples at each of the trailer home locations.

January and April results indicated that PCE, the main contaminant of concern, was present in soil gas and sub-slab air samples at concentrations exceeding DEC target soil gas levels; and indoor air samples at one of these locations also exceeded DEC indoor air residential target levels for PCE, TCE, and benzene.

Vapor intrusion monitoring performed in April 2010 and June 2010 showed indoor air samples above DEC target concentrations only in the basement of the former dry cleaner building. The target concentrations are based on a continuous use (i.e., residential use) of that area of the building. Due to the limited use of the basement area vapor intrusion did not appear to be a risk at that time.

Because PCE appears to be rebounding in some locations Upper Plume locations, and the former dry cleaning building is located in the Upper Plume, DEC suggests the vapor intrusion pathway be re-evaluated at the building (i.e., monitor sub-slab and indoor air concentrations).

VII. Conclusions

Generally, there are four characteristic stages of contaminant distributions and concentrations during the remedial approach:

- Pre-treatment (PCE prevalent)
- Cis-DCE stall is site conditions and subsurface microbial composition do not support further reductive dechlorination (i.e., PCE and TCE degrade to cis-DCE but not further)
- Cis-DCE decline (i.e., cis-DCE is being reduced to vinyl chloride), and
- Ongoing treatment (i.e., the molar percentage of VC + Ethene tends to be the dominant form of chlorinated ethene fractions)

The first 5-year review (2005) focused on the first component, i.e., the degree to which PCE has degraded to its daughter products. At that time, there was little or no significant decrease in total chlorinated ethene concentrations. However, this 20-year review focuses on the subsequent components, i.e., the degree to which the total chlorinated ethene concentrations have transformed and decreased, as well as anticipated contaminant changes. During the period between 2015 and 2020, the total chlorinated ethene (molar) concentrations have continued to remain stable, relative to the total chlorinated ethane concentrations observed in 2000. However, recent increased contaminant concentrations and distributions in the Upper and both Lower plumes suggest contaminant rebound (likely from remaining DNAPL) and transport. This is particularly evident for PCE, as the percent molar mass of PCE is greater in many locations during 2020 than in previous years, indicating that biodegradation is decreasing in some areas of the Upper and both Lower plumes, and the need for additional treatment. Table 6 below illustrates the percentage of COCs in select wells of the various contaminant plumes, by the remedial status anticipated during treatment.

Table 6: Remediation Status Summary, based on percentage of COCs present.

Treatment Stage	Dates	% PCE + TCE	% cis-DCE	% VC + ethene
Upper Plume: MW-16				
Pre-Treatment	Through 9/2000	95 – 100%	0 – 5%	0%
cis-DCE Stall	3/01 – 10/05	0 – 5%	95 – 100%	0%
cis-DCE Decline: 5/06 – 5/07				
Ongoing Treatment	9/07 – 4/14	0 -- 25%	12 – 88%	8 – 78%
	10/2016 to present	13 - 20%	34 - 76%	1 - 44%
Lower Unconfined Plume: MW-9				
Pre-Treatment	Through 9/2000	15 – 60%	40 – 85%	0%
cis-DCE Stall	11/00 – 3/03	0 – 15%	85 – 100%	0 -- 5%
cis-DCE Decline: 6/03 – 10/04				
Ongoing Treatment	5/05 –4/14	0 – 5%	7 – 60%	35 – 89%
	10/2016 to present	2 -33%	32 - 73%	12 - 18%
Lower Unconfined Plume (Sentry Well): MW-6				
Pre-Treatment	Through 9/2000	10 – 30%	70 – 90%	0%
cis-DCE Stall	11/00 – 9/03	0%	95 – 100%	0 – 5%
cis-DCE Decline: 1/04 – 10/04				
Ongoing Treatment	5/05 – 4/14	0 – 5%	5 – 35%	52 – 95%
	10/2016 to present	0 -52%	13- 33%	32 - 48%
Lower Semi-confined Plume Deep Source Area: MW-44				
Pre-Treatment	Through 6/2005	85 -- 100%	0 – 15%	0%
cis-DCE Stall	10/05 – 9/06	Gradual decline from 85% to 0%	Gradual increase from 15% to 100%	0 – 5 %
cis-DCE Decline	5/07 – 5/09	0 – 5%	Gradual decline from 65% to 5%	Gradual increase from 25% to 95%
Ongoing Treatment	5/09 – 4/14	0%	< 16%	> 84%

	10/2016 to present	0 - 1%	16 - 51%	47 - 83%
Lower Semi-confined Plume Deep Source Area: MW-47				
Pre-Treatment	Sep-06	37%	62%	1%
cis-DCE Stall	5/07 – 4/14	0% - 25%	> 71%	< 8%
	10/2016 to present	18%	78%	2%
cis-DCE Decline: Not yet reached				
Ongoing Treatment*: Not yet reached*				

Upon evaluation of all relevant data presented in this current five-year review, DEC concludes that the selected remedy continues to be both appropriate and sufficiently protective. However, multiple lines of evidence a collected during the past five years (VOC concentrations, groundwater geochemistry, and trend analysis) from the different groundwater plumes indicate:

- continued contaminant migration and transport (to both the Upper and Lower unconfined plumes) from a remaining source area in the deeper semi-confined water-bearing till,
- contaminant rebound in some locations, (namely, PCE),
- potential for vapor intrusion risks in the former dry cleaning building,
- contaminant transformations are occurring, but likely slowing over time, and
- an open contaminant exposure pathway to the Kenai River,

Table 7 provides a summary of conclusions regarding the contaminant degradation in the Upper Plume, Lower (unconfined) plume, and Lower (confined) plume source area within the till. Conclusions from the 2005 five year review are presented along with current conclusions to illustrate the progress of remediation at the site over the past 15 years.

Table 7: Comparison of Conclusions from the 2005 Five-Year Review and the 2020 Twenty-Year Review

Topic	2005 Conclusion (1st Five Year Review)	2020 Conclusion
Upper Plume		
Degradation of PCE to cis-DCE	Although somewhat slower than in the Lower Plumes, the HRC injections were successful at rapidly degrading PCE to TCE to cis-DCE within about 12 months.	Recent 2018 and 2019 data show a significant rebound of PCE in groundwater in the Upper Plume.
Degradation of cis-DCE to vinyl chloride and	Only low levels of vinyl chloride are occasionally detected in Upper Plume monitoring wells, suggesting that only minor reductive	Recent groundwater data from the Upper Plume shows some meaningful concentrations of

ethene	dechlorination of cis-DCE is occurring. Similar to the Lower Plumes outside of the bioaugmentation pilot test area, contaminant concentrations are generally stable, although they have declined from levels detected prior to 2002.	cDCE, VC and ethane to suggest some moderate level of reductive dechlorination. Most recent monitoring data indicates an increase in total chlorinated ethene concentrations in the Upper Plume. Geochemical and remedial progress data indicate only mildly reducing subsurface conditions, and a lack of detectable carbon substrates for fermentation and sustained reductive dechlorination. A moderate abundance of Dhc and functional genes were detected during 2018, indicating low level reductive dechlorination may was occurring, or has occurred in the past.
Lower Unconfined Plume		
Degradation of PCE to cis-DCE	The HRC injections initiated during 2000 were successful at rapidly degrading PCE to TCE to cis-DCE in the Lower Unconfined Plume within a few months. Data collected after subsequent substrate injections showed continued biodegradation.	HRC/HRC PRIMER injections remain successful at degrading PCE to cis-DCE in portions of the plume. However, the percent molar concentration on PCE has increased during the past few years of monitoring, signaling contaminant rebound and continued groundwater transport.
Bioaugmentation Pilot Test (October 2002)	The bioaugmentation pilot test in the Lower unconfined groundwater plume successfully mediated degradation of the cis-DCE to vinyl chloride and ethene. Within the bioaugmentation pilot test area, the three 2005 monitoring events suggested a decrease in total chlorinated ethene concentrations, as the vinyl chloride is degraded to ethene.	Monitoring data between 2005 and 2015 suggest significant vinyl chloride and ethene production throughout and downgradient of the bioaugmentation pilot test. Most recent monitoring data demonstrates a sustained overall decrease in total sum of chlorinated ethene concentrations since 2002, but recent increases in chlorinated ethane concentrations, particularly PCE, in some Lower Unconfined Plume locations suggest contaminant rebound. Recent Geochemical and remedial progress data suggest a

		lack of fermentable carbon substrates to supply hydrogen and carbon for robust reductive dechlorination. There is a lack of data for Dhc and functional gene abundance in this portion of the site.
Plume Near-River Sentry Wells		During 2018, VC in monitoring well MW-6A (at 8.02 µg/L) exceeded the modeled action level for potential water quality impacts, as well as the eco-action level for potential adverse effects to aquatic organisms. During 2020, PCE concentration (16.9 µg/L) in MW-7 exceeded the modeled action level of 15 µg/L for surface water impacts.
Kenai River sediments and pore water	Near the Kenai River, the aquifer sediments appear to have a significant capacity for oxidizing cis-DCE and vinyl chloride directly to carbon dioxide, thereby contributing further to the cleanup of contaminants from RTRVP.	Sediment and pore water sampling show general decreasing contaminant concentrations between 2004 and 2014. But pore water sampling conducted during 2020 showed increase in contaminant concentrations, with PCE becoming the predominant chlorinated ethane in pore water. PCE in pore water exceeded groundwater cleanup and surface water quality standards during 2020. No sediment sampling has been conducted during 2015-2020.
Kenai River surface water	The RTRVP site remedy does not appear to have adversely impacted the Kenai River. Although contamination was detected in the Kenai River surface water column prior to implementation of the bioremediation remedy, no contamination was detected in the Kenai River surface water column samples collected since the remedy was implemented in 2000 and through 2005. Sediment sampling results from 2002 and 2004 indicated less widespread contamination than sediment sampling results prior to 2000.	PCE was detected in all three surface water column samples collected during May 2020, but concentrations were below the surface water quality standard. PCE presence in Kenai River surface water demonstrates an open contaminant transport and exposure pathway.
Lower Semi-confined Plume Source Area in the Till		
Source area in till	The contaminated soil source area in the till around MW-44 is providing a continuing source of dissolved PCE contamination to the unconfined	Additional monitoring during 2005-6 at MW-47, MW-48, MW-49, and MW-50, as well as soil

	aquifer. The HRC in the unconfined aquifer is effectively dechlorinating the PCE before offsite migration. It is too early to evaluate the effectiveness of the August 2005 HRC treatment of the till in the MW-44 source area.	samples and MIP logs, have further delineated the deep source area (currently interpreted as an area roughly 35 feet long [i.e., from L100 to MW-49) by 20 feet wide [i.e., from MW-49 to L101], with a narrow "tail" extending towards MW-44 approximately 15 feet long by 12 feet wide), and between about 20 and 40 feet below ground surface. Six different injection events involving HRC or HRC PRIMER the deep till have been performed (See section Ic above). During 2018, PCE concentration in deeper till well L80A was 104,000 µg/L (compared to a PCE concentration of 139,000 µg/L in nearby deeper till well L76 during 2006). This suggests sufficient mass of PCE (as DNAPL) remains on the RTRVP in the deeper source (till) area. Other wells in the confined plume till area show a prevalence of cDCE and VC, indicating some sustained reductive dechlorination. But there is also likely continued PCE transport via groundwater movement to both the Upper and Lower Unconfined plumes The till in this area is very dense, and the water-bearing layers show little connectivity (based on different geochemistry and vertical gradients). These conditions inhibit the lateral spreading of the HRC material in the till and slow remediation efforts. Recent data (2018) on Dhc and functional gene abundance suggest robust populations of Dhc persist in the Lower confined plume source area. Geochemical and remedial progress data indicate additional substrate injections may be warranted in this source area to sustain

		reductive dechlorination and reduce transport of PCE to other locations across the site.

DEC and its contractors recommend additional targeted treatment (i.e., substrate injection) of groundwater in the semi-confined water-bearing zone area, as well as in the Upper Plume. Additionally, complimentary forms of remedial action (such as implementation of phytoremediation technologies) should be considered for the Lower Unconfined plume and closer to the Kenai River. This may be an economical aide in preventing contaminant transport offsite and into the river.

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