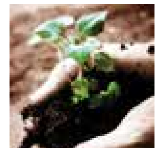
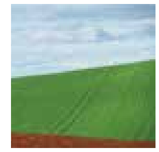
  

Treatment Train Approach Using RemOx® SR+ ISCO Reagent Cylinders at Former Dry Cleaner

SR (Sustained Release) ISCO Reagent

CASE STUDY

INTRODUCTION

Achieving remediation site closure can be challenging, time consuming, and costly. Treatment train approaches are often a practical means to address difficult remediation sites. The optimal approach to soil and groundwater clean-up often requires the use of multiple technologies either sequentially or concurrently to achieve the most cost-effective approach throughout the entire life cycle of cleanup at a project site.

RemOx® SR+ ISCO reagent (sustained release) cylinders have been specifically manufactured for environmental applications to meet a need for more passive treatment. The cylinders are 2.5 inches in diameter by 18 inches in length and are a solid paraffin wax matrix with ~38% RemOx® S ISCO reagent (potassium permanganate) and ~38% sodium persulfate. This product, often used as part of a combined remedy strategy, can be used to degrade a variety of contaminants, some of which are listed in Table 1.

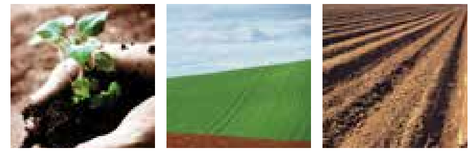
Chlorinated ethenes	BTEX (Benzene, Toluene, Ethylbenzene, Xylene)	Petroleum hydrocarbons
Chlorinated ethanes	MTBE (methyl tertiary butyl ether)	1,4-dioxane
Chlorinated methanes	PAH's (polyaromatic hydrocarbons)	Pesticides

Table 1: Common Contaminants of Concern (COC's) Degraded by RemOx® SR+ ISCO Reagent

RemOx® SR+ ISCO Reagent Cylinders and Packaging

SITE BACKGROUND

XCG Consulting Limited was hired by a property management firm to assist with remediation of a former dry-cleaning operation located in Mississauga, Canada. Dry-cleaning operations from 1981 to 2005 resulted in sub-surface releases of chlorinated solvents, including perchloroethylene (PCE) and its breakdown products, trichloroethylene (TCE), cis & trans-1,2-dichloroethylene (cis-1-2-DCE, trans-1,2-DCE), and vinyl chloride (VC). The bulk of the impacted area was beneath the building and adjacent to the foundation footings. The site was a fine-grained soil with low hydraulic conductivity. Due to the native soil characteristics, the contaminants tended to be retained in the soil matrix. Preferential groundwater flow patterns limited access of liquid amendments to the contaminated zones.



PROBLEM

Chlorinated solvents are persistent when present in the natural environment. The initial contaminant concentrations in groundwater were five to ten times higher than the standards for the commercial land use. Table 2 shows pre-remediation contaminant concentrations in groundwater.

	PCE	TCE	Cis-1,2-DCE	Trans-1,2-DCE	VC
Highest Concentration (µg/L)	260	57	220	40	1.2

Table 2: Pre-Remediation Contaminant Concentrations in Groundwater

The site presented several significant challenges including:

- High concentrations of contaminants with low remedial target concentrations;
- Space overlying the impacted area was an actively used commercial building;
- Subsurface utilities close to impacted areas;
- Potential air quality issues inside commercial building;
- Shallow water table (~1 meter (3.28 feet) below commercial building floor).

TREATMENT TRAIN APPROACH TIMELINE

SOURCE TREATMENT

In 2011, and as part of the overall remedial action plan developed for the site, a buried groundwater collection trench consisting of horizontal perforated pipe set in a bed of crushed stone about 3 meters (9.8 feet) below ground surface (BGS) was constructed to assist in providing some hydraulic control during remediation and as a means of source removal, as needed. Periodically impacted groundwater was extracted from the collection trench using a vacuum truck and an off-site industrial wastewater disposal service.

Following the initial groundwater extraction events, *in situ* chemical oxidation (ISCO) was implemented in 2012 through temporary injection points within the building and at exterior locations close to impacted areas. Prior to XCG's site involvement, solutions of activated persulfate were injected at low pressure through the injection points. Indoor air quality monitoring showed no detection of VC in the occupied building.

Direct injection was not successful in fully remediating impacted wells at exterior locations immediately adjacent to the building's foundation footings. Groundwater exceedances persisted. In order to access the footings and any residual contaminants remaining, a small scale remedial excavation using a mini excavator was the next treatment option. In June 2014, a narrow trench between the footings and an active natural-gas line was excavated and at the base, gravel bedding and dry RemOx® S ISCO reagent (potassium permanganate) crystals were placed. Former monitoring wells that were removed during the excavation were replaced in the trench prior to backfilling to allow for confirmatory water quality monitoring. Subsequent groundwater sampling in the exterior remediation area reported no detection of chlorinated solvents.

Figure 1 site map shows the groundwater collection trench, injection and monitoring wells, and the remedial trench excavation.

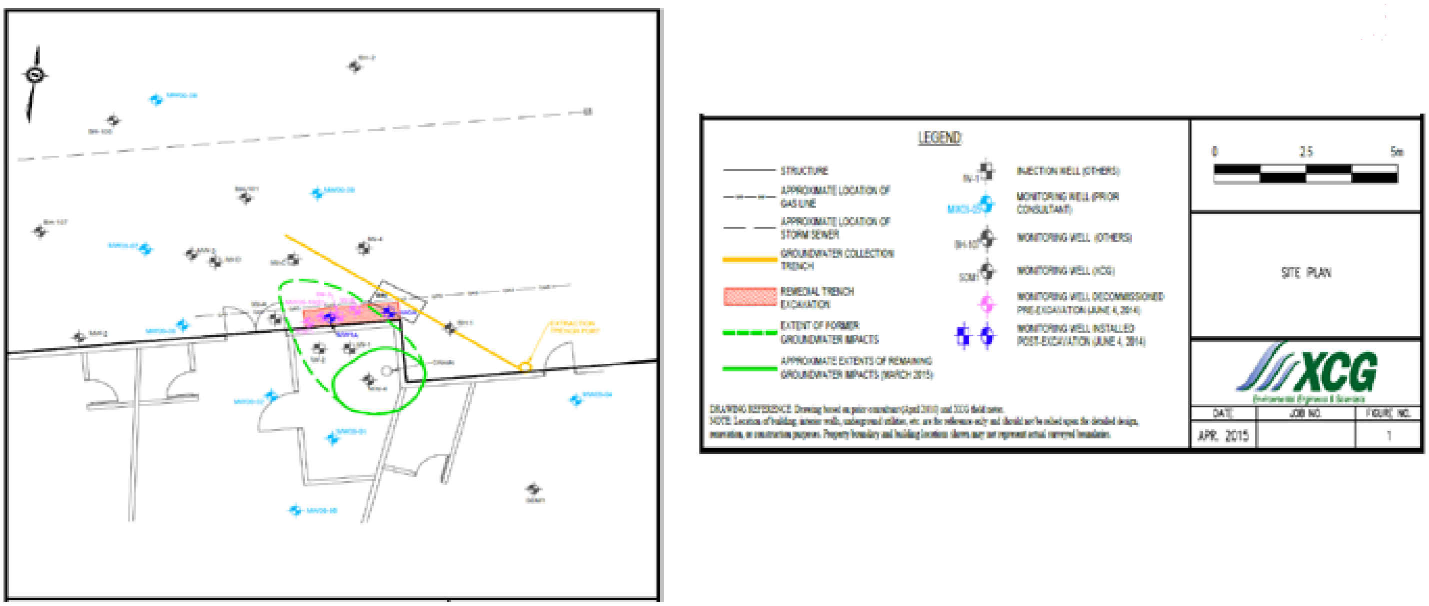


Figure 1: Site Map

Location of remedial trench excavation, groundwater collection trench, injection wells, and monitoring wells

RESULTS- SOURCE TREATMENT

The initial remedial activities were generally successful, with contaminant concentrations in groundwater being reduced by approximately 50-100%. However, residual groundwater impact persisted, due mainly to fine-grained soil conditions, unfavorable groundwater flow characteristics and possible contaminant re-introduction from below grade utilities and bedding. September 2015 groundwater monitoring results showed TCE and cis-1,2-DCE contaminant concentrations exceeded Ontario's Ministry of the Environment and Climate Change (MOECC) remedial targets as shown in Table 3. Figure 2 shows the trends of TCE and cis-1,2-DCE over time.

Parameter (µg/L)	MOECC Table 3 Standards	MW4												
		5-May-11	25-Oct-11	8-Feb-12	7-Jun-12	14-Sep-12	20-Dec-12	14-Mar-13	26-Jul-13	16-Sep-13	11-Dec-14	26-Mar-15	19-Jun-15	24-Sep-15
Vinyl Chloride	1.7	<0.17	0.58	<0.17	<0.17	<0.17	<0.17	<0.17	<0.17	<0.68	0.23	<0.20	<0.20	0.31
1,1-Dichloroethylene	17	0.42	1.1	0.47	<0.30	<0.30	0.92	0.53	<0.30	<1.20	0.52	0.31	0.54	0.64
trans-1,2-Dichloroethylene	17	8.5	**51**	6.4	9.3	9.1	**23**	12	1.6	3.6	9.1	4	8.1	11
cis-1,2-Dichloroethylene	17	**20**	**55**	9	15	**45**	**46**	17	7	17	**29**	16	**23**	**28**
Trichloroethylene	17	13	**47**	16	15	**27**	**39**	15	3	10	**32**	**19**	**31**	**37**
Tetrachloroethylene	17	8.4	4.6	2.2	4.6	5.8	4.9	3.3	2.3	4	5.8	3.8	5.4	6.3
Total Chlorinated VOCs (µg/L) :		**50**	**158**	**33**	**44**	**87**	**114**	**48**	**13**	**35**	**77**	**43**	**63**	**83**

Notes:

<=Less than RDL

NV= No Value

MOECC = Ministry of the Environment and Climate Change

MOECC Table 3 Standard = The Standards in the "Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the *Environmental Protection Act*," April 15, 2011,for full depth generic site condition standards for all types of property use in a non-potable groundwater condition, medium-fine grained soil texture

Bold Text and Highlight indicates concentration is greater than MOECC Table 3 Standard (medium-fine grained soil texture)

Table 3: Summary of MW4 Groundwater VOC's (May 2011- September 2015)

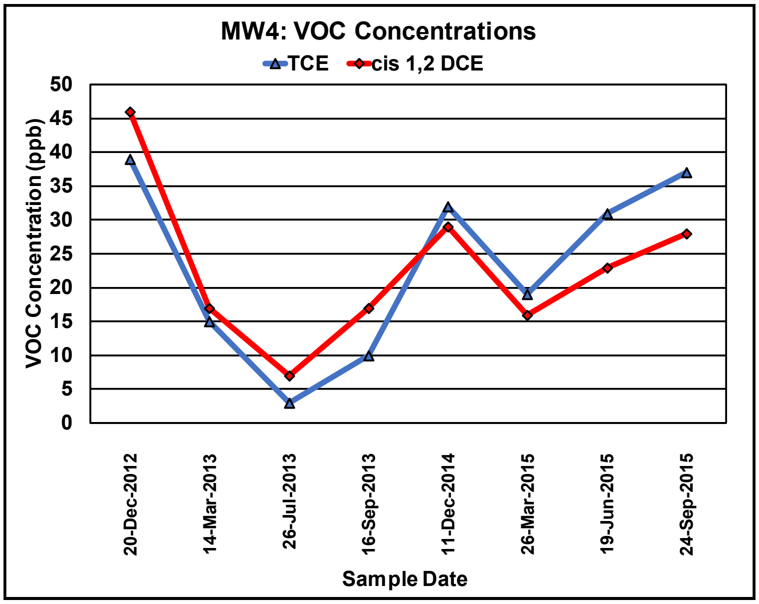


Figure 2: Summary of MW4 TCE and Cis-1,2-DCE (December 2012 - September 2015)

RESIDUAL TREATMENT

To address the remaining impacted areas with a passive technology, a program was implemented to advance boreholes through the concrete floor slab of the occupied building in September 2015. Within the saturated zone of each of the five boreholes, ten RemOx® SR+ ISCO reagent cylinders, two cylinders per borehole, shown in Figure 3, were applied with direct push technology (DPT).

The boreholes were backfilled with bentonite well sealant and new concrete placed to reinstate the coring holes advanced in the concrete floor. Extraction of groundwater from the collection trench continued to provide control of the groundwater flow and promote subsurface migration of groundwater flow around the cylinders. The extraction of groundwater further releases and dissolves the reactants inside the cylinders providing contact with the contaminants and increases the rate of treatment.

RemOx® SR+ ISCO Reagent Cylinder Deployment

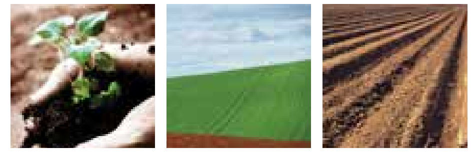


Figure 3: Site Map Location of Cylinder Deployment

RESULTS- RESIDUAL TREATMENT

Groundwater chemical parameters were completed to assess migration of RemOx® SR+ ISCO reagent in groundwater. Groundwater from monitoring well (MW4) located within 2 meters (6 to 7 feet) of the RemOx SR+ cylinders installation was monitored. The dissolution in groundwater of the permanganate compounds from the cylinders causes an increase in electrical conductivity and creates oxidizing conditions. Monitoring electrical conductivity and oxidation-reduction potential (ORP) in groundwater in the application area provides a means to cost effectively and instantly assess the extent and longevity of the treatment. The electrical conductivity was elevated approximately one order of magnitude (i.e. 10x) above historical 2011 levels shown in Table 4. The positive ORP readings indicate that the cylinders have created conditions favorable for continued degradation of VOC's.

Well ID: MW-4	3-May-11	23-Nov-15	23-Dec-15	16-Mar-16	20-Jun-16	2-Sep-16
pH	7.4	6.4	6.9	7.0	6.7	6.6
Temperature (°C)	13.1	16.8	15.7	13.7	17.6	20.9
Electrical Conductivity (mS/cm)	0.69	8.63	7.97	7.47	9.51	8.62
Oxidation Reduction Potential (mV)	132	177	199	228	66.4*	212

*Calibration error is suspected

Table 4: Summary of MW4 Groundwater Chemical Parameters

TCE and cis-1,2-DCE, September 2015 compared to September 2016 analytical results, decreased from 37 to 26 µg/L and 28 to 20 µg/L. However, these two VOC's remained in exceedance of MOECC shown in Table 5.

Parameter (µg/L)	MOECC Table 3 Standards	MW4				
		24-Sep-15	24-Dec-15	17-Mar-16	20-Jun-16	22-Sep-16
Vinyl Chloride	1.7	0.31	<0.20	<0.20	<0.20	<0.20
1,1-Dichloroethylene	17	0.64	0.37	0.39	0.43	0.4
trans-1,2-Dichloroethylene	17	11	6.2	5.9	8.5	7.2
cis-1,2-Dichloroethylene	17	**28**	17	17	**22**	**20**
Trichloroethylene	17	**37**	**22**	**19**	**27**	**26**
Tetrachloroethylene	17	6.3	6.4	3.1	4.5	5.3
Total Chlorinated VOCs (µg/L) :		**83**	**52**	**45**	**62**	**59**

Notes:
<=Less than RDL
NV= No Value
MOECC = Ministry of the Environment and Climate Change
MOECC Table 3 Standard = The Standards in the "Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act," April 15, 2011,for full depth generic site condition
Bold Text and Highlight indicates concentration is greater than MOECC Table 3 Standard (medium-fine grained soil texture)

Table 5: Summary of MW4 Groundwater VOC's (September 2015 - September 2016)

Prior to cylinder installation, remarkable decreases were seen each time amendments were added, but rebound occurred within six months. Once the cylinders were installed, the significant rebound seen previously within six months of treatment was not noted in post-installation monitoring results (Figure 4).

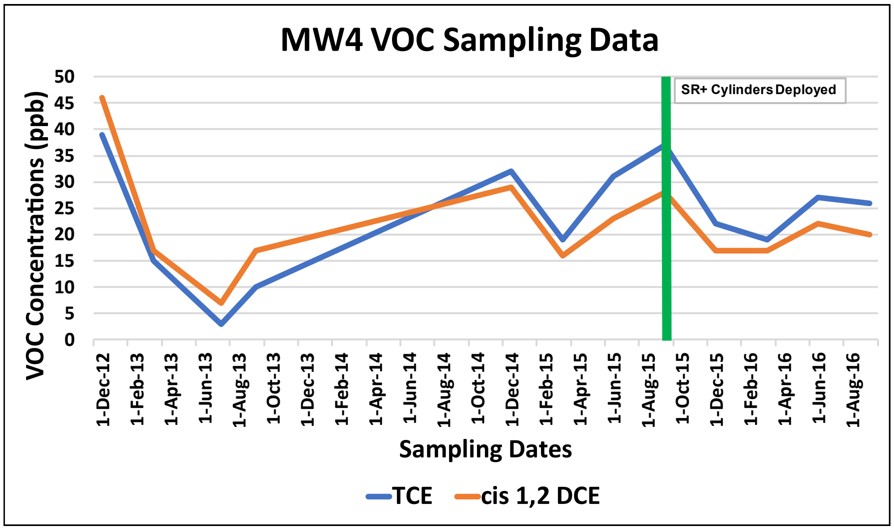


Figure 4: Summary of MW4 TCE and Cis-1,2-DCE Pre- and Post- RemOx® SR+ Cylinders Deployment

ADDITIONAL SOURCE TREATMENT

In 2016, a previously hidden source (floor drain and piping with bedding) was discovered below the floor in the area of MW4. Activities completed in an updated work plan included drilling access holes through the floor near MW4 and applying a RemOx® L ISCO reagent (liquid sodium permanganate) solution through each hole over a period of several days to effectively flood the area with oxidant (Figure 5). In January 2017, 20 injection holes were drilled through the concrete floor slab to a depth of approximately 0.6 meters (1.9 feet) BGS. A volume of 1,600 L (422 gallons) of 10% RemOx L ISCO solution was poured directly into the 20 injection holes. Monitoring continued post-injection monthly.

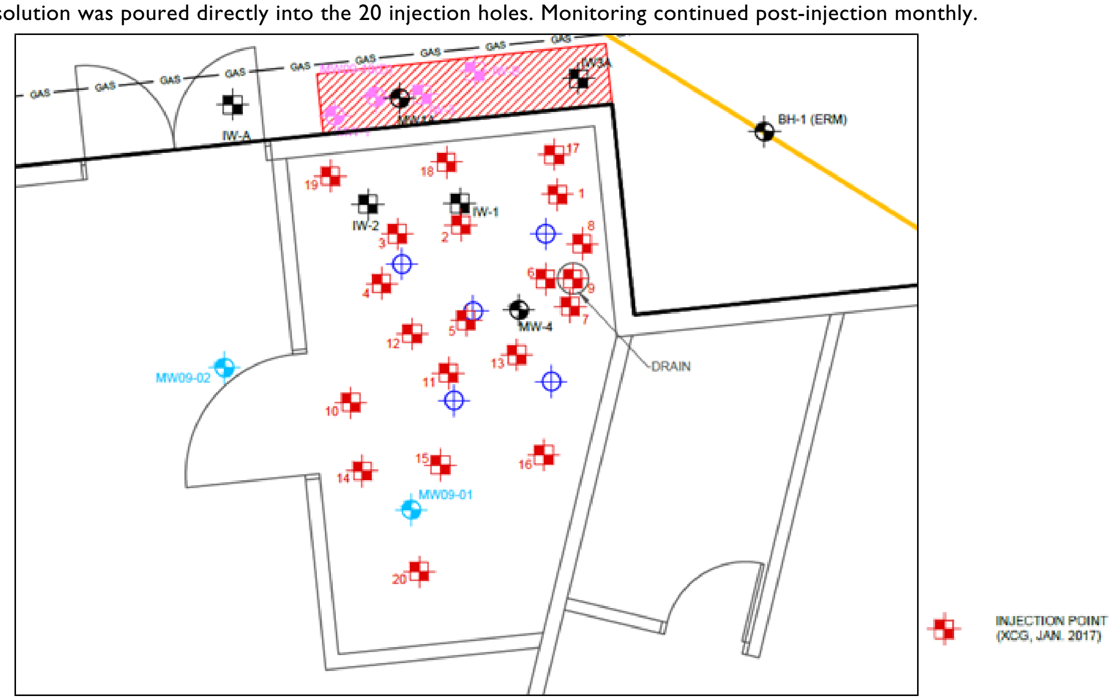
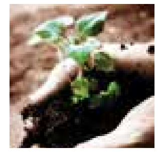
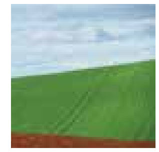


Figure 5: RemOx® L ISCO Reagent (10% Concentration) Injection Points

CARUS
REMEDIATION

RESULTS- ADDITIONAL SOURCE TREATMENT

After the January 2017 treatment event with 10% RemOx® L ISCO reagent (liquid sodium permanganate), monitoring results two months post-injection showed significant decreases in MW4. All contaminants of concern are below the MOECC standards (Table 6 and Figure 6).

Parameter (µg/L)	MOECC Table 3 Standards	MW-4									
		26-Mar-15	19-Jun-15	24-Sep-15	24-Dec-15	17-Mar-16	20-Jun-16	22-Sep-16	12-Jan-17	15-Feb-17	15-Mar-17
Vinyl Chloride	1.7	<0.20	<0.20	0.31	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20
1,1-Dichloroethylene	17	0.31	0.54	0.64	0.37	0.39	0.43	0.4	0.46	<0.20	<0.20
trans-1,2-Dichloroethylene	17	4	8.1	11	6.2	5.9	8.5	7.2	8.7	<0.50	<0.50
cis-1,2-Dichloroethylene	17	16	**23**	**28**	17	17	**22**	**20**	**18**	<0.50	<0.50
Trichloroethylene	17	**19**	**31**	**37**	**22**	**19**	**27**	**26**	**22**	<0.20	<0.20
Tetrachloroethylene	17	3.8	5.4	6.3	6.4	3.1	4.5	5.3	4	<0.20	<0.20
Total Chlorinated VOCs (µg/L) :		**43**	**63**	**83**	**52**	**45**	**62**	**59**	**53**	**0**	**0**
Notes:											
<=Less than RDL											
NV= No Value											
MOECC = Ministry of the Environment and Climate Change											
MOECC Table 3 Standard = The Standards in the "Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the *Environmental Protection Act*," April 15, 2011,for full depth generic site condition standards for all types of property use in a non-potable groundwater condition, medium-fine grained soil texture											
Bold Text and Highlight indicates concentration is greater than MOECC Table 3 Standard (medium-fine grained soil texture)											

Table 6: Summary of MW4 Groundwater VOC's (March 2015 - March 2017)

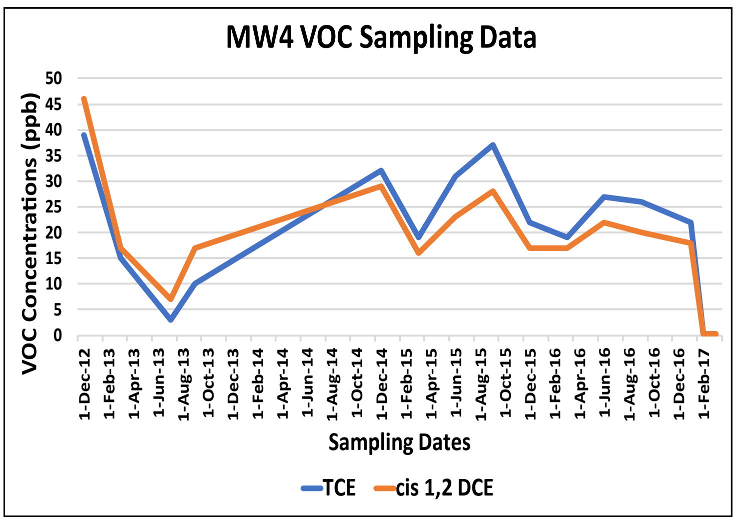


Figure 6: Summary of MW4 TCE and Cis-1,2-DCE

CONCLUSION

Combining a number of remedies has allowed the property owner to continue to lease the space during remediation with the end goal of meeting the applicable generic Standards for soil and groundwater, without requiring a risk assessment. Strategic activities and product use through the remediation process has enabled the remediation to be completed in small successful tasks. Varying the use of permanganate and persulfate products in solid and liquid forms has provided for source and residuals remediation. The site is now moving into the final closure phases with a series of 4 successive quarterly confirmatory analyses of groundwater to demonstrate the source removal and absence of rebound effects.

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