UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
CENTER FOR ENVIRONMENTAL SOLUTIONS AND EMERGENCY RESPONSE
TECHNICAL SUPPORT COORDINATION DIVISION
919 KERR RESEARCH DRIVE • ADA, OK 74820

September 14, 2022

OFFICE OF
RESEARCH AND DEVELOPMENT

MEMORANDUM

SUBJECT: Technical Review Comments for the Lot 46 Valley Gardens site, Des Moines, IA (22-R07-05)

FROM: Randall Ross, Director
Groundwater Technical Support Center

TO: Joe Davis, OSC
U.S. EPA Region 7

Per your request for continued technical support from the Groundwater Technical Support Center (GWTSC), the following comments are provided for the Lot 46 Valley Gardens TCE Site, Des Moines, Iowa. These comments are provided by ERG (Eastern Research Group), a STREAMS IV contractor that provides technical support to the GWTSC. If you have any questions or comments, please do not hesitate to contact me at your convenience (580-436-8611).

Introduction

ERG was tasked by EPA to conduct a technical review of and provide comments on documents and data associated with the Lot 46 Valley Gardens TCE Site. The Valley Gardens subdivision is south of downtown Des Moines and the Raccoon River in Polk County, Iowa. The area is loosely bounded north by George Flagg Parkway, east by Fleur Drive, south by Bell Avenue, and west by Southwest 30th Street. This area is referred to as Lot-46 in this review. ERG was supported on the review by team subcontractor, Dr. Thomas Boving.

Previous on-site investigations have documented a release of CVOCs including tetrachloroethene (PCE), TCE, and degradation products upgradient from the Des Moines Water Works (DWWW) facility at Fleur Drive. DWWW collects water from a 4.8 km (3 miles) long Gallery system, which runs parallel to the Raccoon River in Water Works Park from SW 46th Street to Fleur Drive. The Gallery water was tested in January 2021 and cDCE was detected at sample point VC-4 (1.2 µg/L), at the infiltration gallery intercept (IG Intercept at 1.2 µg/L), as well as IG North Shaft (1.0 µg/L). TCE was undetectable at the time of sampling. PCE was not reported in these samples. In early 2009, IDNR installed four sets of two nested monitoring wells on the DMWW property—deep (40 feet bgs) and shallow (23 feet bgs) wells (VGM-1 through VGM-4). Each well has 5 feet of slotted screen with solid riser to ground surface (STAR 2022). In April 2021, both TCE and 1,2-cDCE were detected in some of these wells. TCE concentrations ranged from non-detect (VGM-1D and VGM-4D) to up to 120 µg/L (VGM-3D). cDCE concentrations ranged from non-detect (VGM-1D) to up to 390 µg/L (VGM-3D). Apparently, none of the shallow monitoring wells were sampled at that time. In October 2012, nine

permanent monitoring wells (IMW-1 through IMW-9) south of the DWWW property. Well depths ranged from approximately 12.2 to 14.6 m (40 to 48 feet) bgs. Some of the highest cDCE and TCE groundwater concentrations at Lot 46 were associated with these wells in 2021.

The source of the CVOC in the Gallery water appears to the up-gradient CVOC plume that is moving towards the Raccoon River and the DWWW water intake structure (STAR 2022). Although the detected CVOC concentrations in the DWWW Gallery water are below the applicable water quality standards at the time of sampling, there is a concern that the approaching plume might eventually affect the water works operation. On this background, this report addresses the following three questions:

1. Can we use the existing data to develop a likely timeline of when the greatest impact to the water intake gallery will occur? If not, what additional data do we need to answer this question?

2. Can we use the existing data to support the identification of the likely responsible party (parties)? If not, what additional data do we need to answer this question?

3. Do we have enough data to development or review removal options?

Conceptual Site Model (CSM)

A CSM for the study area (Lot-46) was developed from geologic, hydrogeologic and water quality data from site reports (mainly STAR 2022 and Terracon 2019), the surficial geology map of the Des Moines Lobe (DNR 2003), as well as a USGS modeling study in the vicinity of the Lot-46 site (USGS 2021) and groundwater availability investigation of the lower Raccoon River aquifer (DNR 2013).

Lot-46 is within the floodplain of the Raccoon River at an elevation of approximately 245 m (800 to 810 ft) above mean sea level. The site geology is dominated by clays and unconsolidated sands and gravels of glacial and alluvial origin. Boring logs report lean to fat clays approximately 4.6 to 5.8 m (15 to 19 ft) thick underlain by approximately 6.1 to 10.7 m (20 to 35 ft) of fine to coarse sands. The bedrock (Shale) is encountered between 8.2 and 12.2 m (27 and 40 ft) below ground surface (bgs) in the study area. A generally 2 to 4 m thick layer of loess covers parts of the Lot-46 area (DNR 2003). Fill material may be present in some areas. Alluvial sediments (sand and gravel) are present in the immediate vicinity of the Raccoon River. The interface between bedrock and the unconsolidated sediments appears to be sculptured and may feature paleo channel like structures and ridges. Reported depth to groundwater is 4.6 to 6.1 m (15 to 20 ft) bgs. The groundwater flow direction is predominantly to the northwest.

The reported horizontal hydraulic conductivity of the bedrock is 0.09144 m/d (0.3 ft/d), that of the coarse-grained sediments between approximately 25 to 64 m/d (82 to 866 ft/d) and 13 to 26 m/d (43 to 85 ft/d) for the fine-grained deposits (USGS 2021). The effective porosity is about 25% (DNR 2013). The arithmetic mean transmissivity value is approximately 771 m^2/d (8,300 $feet^2$/d), based on aquifer testing along the lower Raccoon River (DNR 2013). The natural hydraulic gradient toward the river is approximately 0.007 (Terracon PPT, slide 18). The nearest United States Geological Survey (USGS) gaging station on the Raccoon River is near Van Meter, Iowa (~30 year record).

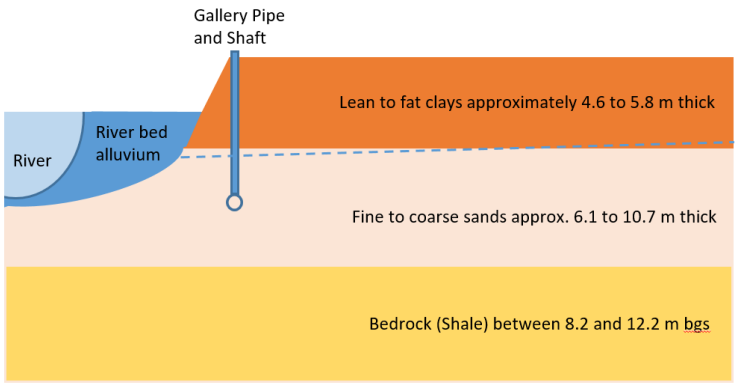


Figure 1: Conceptual site model (CSM) for the Lot-46 site.

The CSM consist of three main hydrogeologic units (Figure 1): bedrock of comparably low hydraulic conductivity at the base covered by coarse-grained unconsolidated sand and gravel deposits of high conductivity. Fine-grained unconsolidated deposits with medium to high hydraulic conductivity follow on top. The bed of the Raccoon River is hydraulically connected to the coarse-grained unconsolidated sand and gravel deposits. Groundwater is discharging to the Raccoon River. The natural hydraulic gradient toward the river is approximately 0.007 (Terracon PPT, slide 18). As indicated by the latest round of sampling (2021), there is no indication for CVOC groundwater pollution south or west of monitoring wells VGM-1D and IMW-9. However, cDCE (but no TCE) was detected in monitoring wells VGM-2D and VGM-4D, suggesting that the groundwater plume has reached the DWWW Gallery.

Q 1: Can we use the existing data to develop a likely timeline of when the greatest impact to the water intake gallery will occur? If not, what additional data do we need to answer this question?

Groundwater quality data examined herein was collected from Table B-1 of the STAR (2022) report and Tables 2 and 2A of the Terracon (2019) report. Periodic sampling of the groundwater for CVOC at the site began in 2009. Apparently, no samples were collected during 2020. The early 2021 CVOC sampling campaign of the groundwater is the latest data set available. The extent of the CVOC (cDCE and TCE) plume in early 2021 is shown in Figs. 2 and 3.

In case of the TCE plume (Fig.2), its leading edge has arrived at VGM-3D (120 µg/L TCE) but has not resulted in detectable TCE concentration in the water collected from the Gallery. Within the plume, the highest TCE concentrations were found at IMW-6 (3,200 µg/L). Well IMW-6 is approximately 417 m upgradient from VGM-2D, which is abutting the infiltration lakes immediately east of the Gallery. The VGM wells are nested with the deeper ones screened within 10.7 to 12.2 m (35 and 40 ft bgs; 34 to 39 ft in case of VGM-4D) i.e., at the base of the coarse sand aquifer. The shallower VGM wells are screened around 7.0 m (23 ft bgs) (STAR 2022) i.e., the upper part of the aquifer. Apparently, the shallower VGM wells were not sampled during the 2021 campaign.

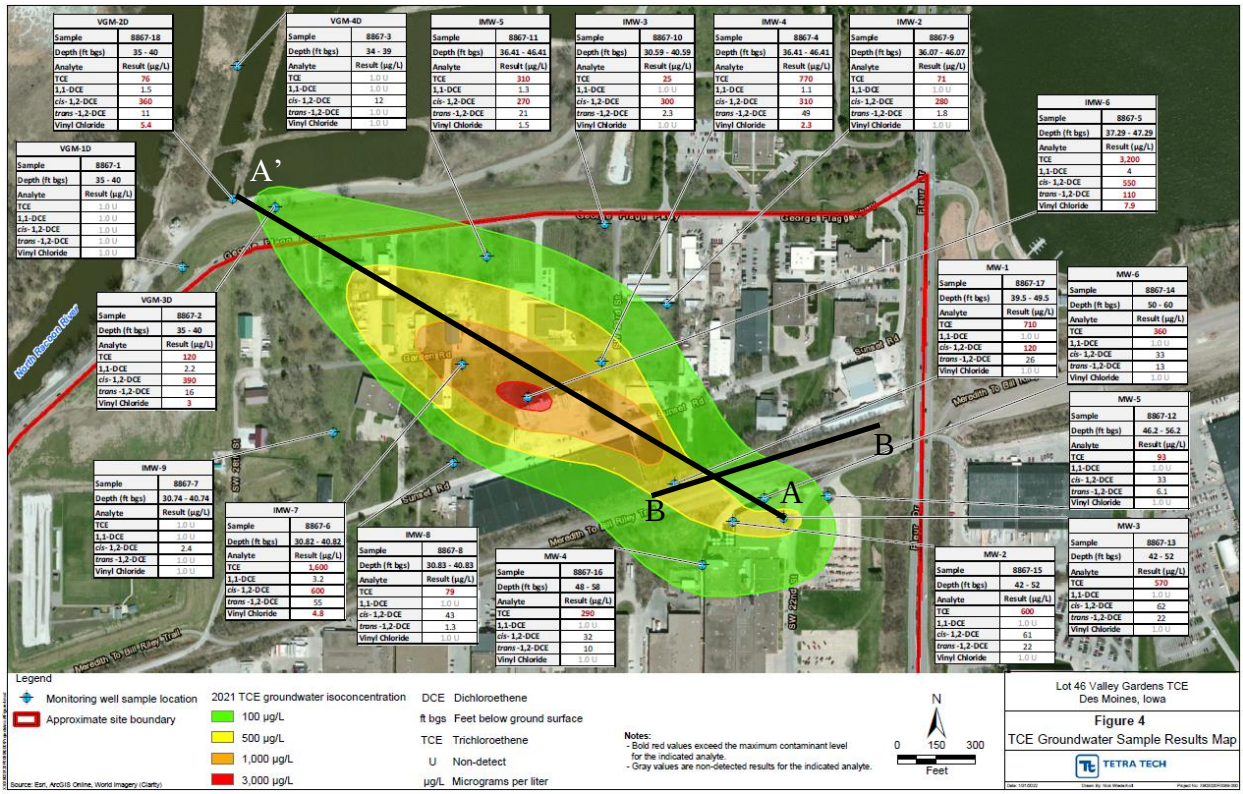


Figure 2: TCE groundwater concentrations in 2021. Lines: Transects A to A' and B to B'. Scale as shown. Source: STAR 2022.

Figure 3 depicts the cDCE plume. At the time of sampling, 1.2 µg/L were detected at monitoring well VGM-4D and 120 µg/L at VGM-2D. Also, cDCE was detected in the Gallery water at sample location VC-4 (1.2 µg/L), which is located at the NW corner of the infiltration lakes on the bank of the Raccoon River. Well VGM-4D is located close to the Gallery and is surrounded by the Raccoon River to the west the infiltration ponds to the east. Within the cDCE plume, the highest contaminant concentration was detected at IMW-7, which is about 320 m (1,050 ft) up-gradient from VGM-2D. Neither cDCE nor TCE were detected at VGM-1D. This monitoring well is located next to the Gallery, but about 97.5 m (320 ft) SW from VGM-2D. In addition, not CVOC was detected in the Gallery water at VC-5, located in close vicinity to VGM-1D.

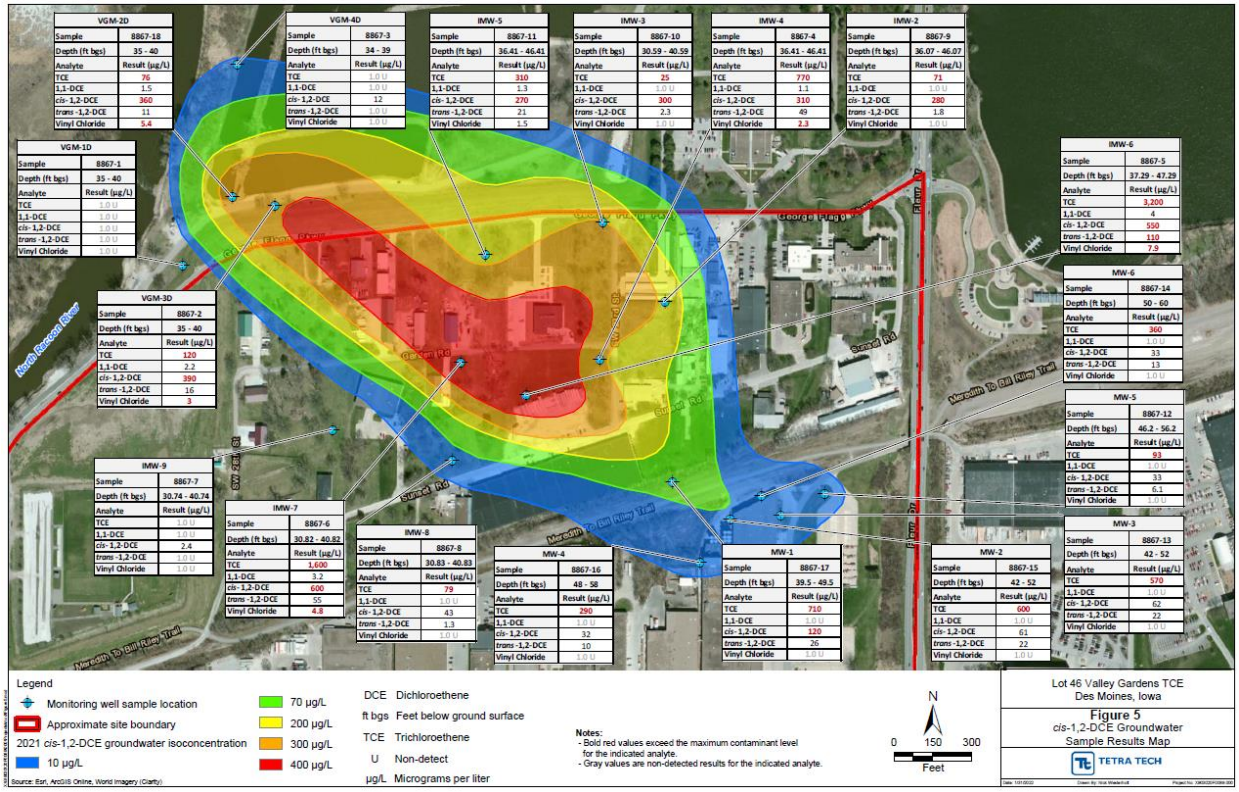


Figure 3: cDCE groundwater concentrations in 2021. Scale as shown. Source: STAR 2022.

Analysis of Plume Advancement

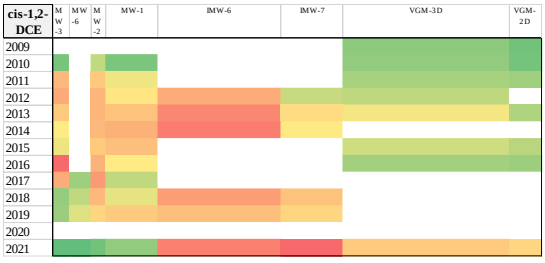
The approximate velocity by which the CVOC plume advances from the (undetermined) source zone towards the DWWW property to the northwest was estimated using the groundwater quality data summarized in Table B-1 of the STAR (2022) report. The report was provided in PDF format and data tables were converted to EXCEL format using Adobe Acrobat DC. Data from eight wells (Tab.1) along the A to A' transect (Fig. 2) were considered. This transect approximately marks the spine of the current CVOC plume. For this analysis, it was assumed that the origin of the CVOC contamination originated in the vicinity of MW-3.

For each well, the average annual concentration of cDCE and TCE was calculated in years when more than one data point was available (Tab. 1). The tabulated annualized cDCE and TCE concentrations were conditionally formatted in EXCEL i.e., low concentrations appear in shades of green whereas higher ones are in shades of yellow and red (highest). Conditional formatting is a semi-quantitative method to visualize values relative to each other. Figure 4a and 4b show the reported concentrations and the resulting conditional color patters for both cDCE and TCE. Other CVOC data were not evaluated. The purpose of this analysis was to obtain a visual impression of the plume hot spot location over time.

Well	Approx. Distance from MW-3 (meters)	Length of Record	Sample Frequency*
MW-3	0	Sept. 2010 – April 2021	Quarterly till 2017, Twice annually 2018-2019
MW-6	29	July 2017 – April 2021	Thrice annually 2017-2018 Twice annually 2019
MW-2	46	Sept.2010 – April 2021	Quarterly till 2017, Twice annually 2018-2019
MW-1	126	Sept.2010 – April 2021	Quarterly till 2017, Twice annually 2018-2019
IMW-6	326	Nov.2012 – April 2021 No data: 2015-2017	Once/twice annually
IMW-7	423	Nov.2012 – April 2021 No data: 2015-2017	Once/twice annually
VGM-3D	692	Jan. 2009 – April 2021 No data: 2014, 2017-2020	Twice annually 2009-2012, once annually thereafter
VGM-2D	743	Jan. 2009 – April 2021	

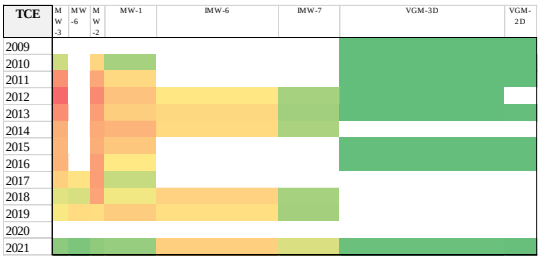
Table 1: Wells along the A to A' transect. *: No data was reported in 2020. Only one data set was reported in 2021 (April).

cis-1,2-DCE	MW-3	MW-6	MW-2	MW-1	IMW-6	IMW-7	VGM-3D	VGM-2D
2009							113	62
2010	101		**205**	80			120	69
2011	**415**		394	289			155	145
2012	436		433	330	**455**	216	200	
2013	389		436	406	**535**	352	298	172.2
2014	343		429	445	**558**	315		
2015	309		390	**413**			230	190
2016	**529**		439	317			150	140
2017	434	142	**493**	204				
2018	153	204	429	273	**486**	405		
2019	162	258	363	387	**412**	364		
2020								
2021	62	33	61	120	550	**600**	390	366



(a)

TCE	MW-3	MW-6	MW-2	MW-1	IMW-6	IMW-7	VGM-3D	VGM-2D
2009							2	2
2010	1430		**2940**	901			12	16
2011	**5588**		4725	2790			14	18
2012	**7108**		5893	3693	2260	907	20	
2013	**5741**		5110	3239	2840	834	25	39.2
2014	4387		**4608**	4228	2780	967		
2015	4170		**4448**	3480			40	36
2016	4215		**5050**	2168			38	36
2017	3188	2453	**5120**	1334				
2018	1690	1565	**4880**	1912	3090	908		
2019	2013	2680	2611	**3300**	2578	881		
2020								
2021	570	360	600	710	**3200**	1600	120	76



(b)

Figure 4: (a) Left: average annualized 1,2-cis DCE concentrations (µg/L); Right: Conditionally formatted data, (b) Left: average annualized TCE concentrations (µg/L); Right: Conditionally formatted data. Bold: highest reported concentration at any well in a given year. Color coding: shades of green mark low concentrations whereas higher ones are in shades of yellow and red (highest). White cells: no data. The column width reflects the approximate distance between wells, except for the transect's origin at MW-3, which has been horizontally exaggerated for illustration purposes.

Both, Figures 4a and 4b suggests that the center of mass (= plume core) has moved (as indicated by the shift of red colors away from MW-3 over time) in the direction of groundwater flow towards the DWWW facility. This is particularly well illustrated by the 2021 data set (bottom row), which indicates that the center of mass is near IMW-7 in case of cDCE and near IMW-6 for TCE. In addition, the relatively low concentrations of the tail end of the plume (shades of green) suggest that source of contamination might be losing strength. At the leading edge of the plume, the center of mass of the cDCE plume appears to advance faster than the TCE one. Overall, this analysis agrees with the plume delineation shown in Fig. 2 and 3.

(a)

cis-1,2-DCE	MW-3	MW-6	MW-2	MW-1	IMW-6	IMW-7	VGM-3D	VGM-2D
2009							1.6	0.9
2010	1.4		2.9	1.1			1.7	1.0
2011	5.9		5.6	4.1			2.2	2.1
2012	6.2		6.2	4.7	6.5	3.1	2.9	
2013	5.6		6.2	5.8	7.6	5.0	4.3	2.5
2014	4.9		6.1	6.4	8.0	4.5		
2015	4.4		5.6	5.9			3.3	2.7
2016	7.6		6.3	4.5			2.1	2.0
2017	6.2	2.0	7.0	2.9				
2018	2.2	2.9	6.1	3.9	6.9	5.8		
2019	2.3	3.7	5.2	5.5	5.9	5.2		
2020								
2021	0.9	0.5	0.9	1.7	7.9	8.6	5.6	5.2

(b)

TCE	MW-3	MW-6	MW-2	MW-1	IMW-6	IMW-7	VGM-3D	VGM-2D
2009							0.4	0.4
2010	286.0		588.0	180.2			2.4	3.2
2011	1117.6		945.0	558.0			2.8	3.6
2012	1421.6		1178.6	738.6	452.0	181.4	4.0	
2013	1148.2		1022.0	647.8	568.0	166.8	5.0	7.8
2014	877.4		921.6	845.6	556.0	193.4		
2015	834.0		889.6	696.0			8.0	7.2
2016	843.0		1010.0	433.6			7.6	7.2
2017	637.6	490.6	1024.0	266.8				
2018	338.0	313.0	976.0	382.4	618.0	181.6		
2019	402.6	536.0	522.2	660.0	515.6	176.2		
2020								
2021	114.0	72.0	120.0	142.0	640.0	320.0	24.0	15.2

Table 2a: Exceedance of the cDCE MCL (70 µg/L); (**b**) Exceedance of the TCE MCL (5 µg/L). Exceedance is defined as the multiple of the relevant MCL relative to the contaminant concentration measured at the sampling location.

Tables 2a and 2b show the factors by which the contaminant concentrations at each sampling point exceed the maximum contaminant levels (MCL) for cDCE (70 µg/L) and TCE (5 µg/L), respectively. During the most recent sampling round (2021), the MCL at the most polluted well was exceeded 8.6 times for cDCE (IMW-7) and 640 times (IMW-6) in case of TCE. It is noted that cDCE exceedance in 2021 is the highest over the entire observation period. This may suggest that cDCE is generated from the degradation TCE faster than it degrades itself. At the same time, cDCE was below its MCL concentration in the wells closest to the suspected source zone (MW2, MW-3 and MW-6).

To investigate the approximate travel velocity of the plume's center of mass, the distance of the well where the highest (= peak) TCE concentration was measured in 2021 (see bold highlights in Figs. 4a and 4b) was divided by 12 years, which is the extent of the data record. The distance of the wells relative to well MW-3 (origin of transect A-A') are provided in Table 1. This calculation assumes that a single spill occurred upgradient from MW-3. Based on the distance the center of mass has traveled by 2021 (as measured at well locations IMW-6 and -7), the resulting travel velocities are about 27 m/yr and 35 m/y for TCE and cDCE, respectively. A more refined assessment is based on the time when TCE concentrations peaked at MW-3 and the TCE peak location in 2021. At MW-3, TCE peaked in 2012 and in 2021, the peak is located at or around IMW-6. The two wells are 326 m apart. The resulting travel velocity is approximately 36 m/yr. The remaining distance between the position of the center of mass (IMW-6 for TCE and IMW-7 for cDCE) in 2021 and the Gallery is about 491 m (1,611 ft; IMW-6) and 406 m (1,332 ft; IMW-7) down-gradient. At the estimated velocities, the center of mass would overcome the distance in approximately 13 to 18 years (TCE) and about 12 years (cDCE), respectively. This analysis is based on the assumptions that the plume travels at constant velocity and that there are no changes in the flow direction compared to the historical record.

To investigate the past and future fate of the plume, the plume's center of mass i.e., the highest reported contaminant concentration for each year (see bold highlights in Figs. 4a and 4b) was plotted against distance (i.e., to the well location at which the concentration was observed; see Table 1 for distances between well locations). The resulting graphs for cDCE and TCE are shown in Figures 5a and 5b. Based on these data, a linear trend line for the period of 2012 to 2021 was calculated for each pollutant. The year 2012 was chosen because it coincides with some of the highest recorded contaminant concentrations (i.e., in the years prior to 2012 CVOC

concentrations were still rising before peaking in and around 2012). The trend lines suggest that TCE annual peak concentrations have been declining over time. For cDCE, the trend line is approximately flat or even slightly increasing, suggesting that cDCE concentrations are not declining over the observation period. If the historical trend data predict the future concentrations in the center of mass and assuming that it will take approximately 12 years for the center of mass to arrive at the Gallery, the approximate TCE concentration would be at or below detection limit at that time (~2033). The uncertainty in the future fate of cDCE is high because its concentration is linked to the currently unknown rate by which TCE degrades. Therefore, no estimate for the cDCE arrival concentration at the Gallery is provided.

(a) (b)

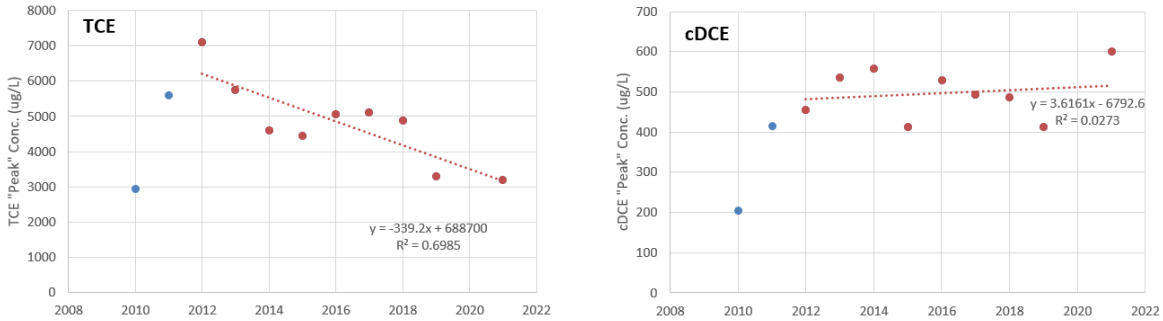


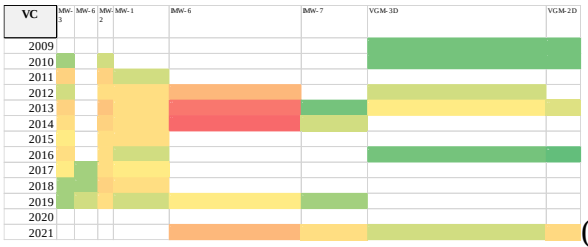
Figure 5(a) (Left): highest annual reported TCE concentration (µg/L) over time, (**b**) highest annual reported cDCE concentration (µg/L) over time. Red dots represent the period over which the linear trend line (red dotted line) was calculated.

Vinyl Chloride

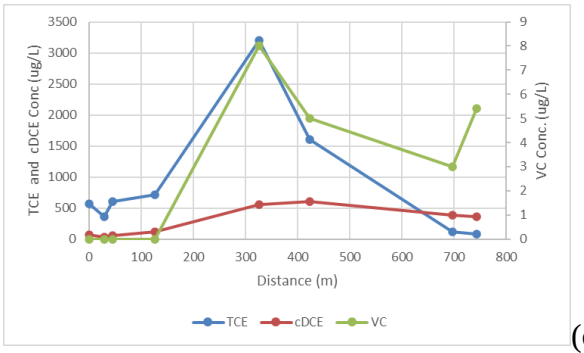
Vinyl Chloride (VC) is the degradation product of TCE and its daughter product DCE. Figure 6a an 6b show the reported VC concentration along transect A to A' and the conditionally formatted data. Figure 6c provides a picture of the VC concentration in relation to the TCE and cDCE concentrations along the transect during the most recent 2021 sampling campaign.

VC	MW-3	MW-6	MW-2	MW-1	IMW-6	IMW-7	VGM-3D	VGM-2D
2009							1	1
2010	2		3	mdl			1	1
2011	6		6	3			mdl	mdl
2012	3		5	5	8	mdl	3	
2013	6		7	5	13	1	4	3.3
2014	5		6	5	14	3		
2015	4		5	5			mdl	mdl
2016	5		5	3			1	0.6
2017	4	2	5	4				
2018	2	2	6	5	mdl	mdl		
2019	2	3	5	3	4	2		
2020								
2021	mdl	mdl	mdl	mdl	8	5	3	5.4

(a)



(b)



(c)

Figure 6: (a) Average annualized Vinyl Chloride (VC) concentrations (µg/L); (b) Conditionally formatted data, (c) VC, cDCE and TCE contaminant concentrations along A-A' in 2021. Color coding: shades of green mark low concentrations whereas higher ones are in shades of yellow and red (highest). White cells: no data. mdl: Method detection limit, varies over time. The column width reflects the approximate distance between wells, except for the transect's origin at MW-3, which has been horizontally exaggerated for illustration purposes.

From Figures 6a and 6b, the spatial and temporal distribution of the VC concentrations along the transect resembles that of cDCE (Fig. 4a) more closely than TCE (Fig. 4b), as expected by virtue of VC being the cDCE degradation product. The highest reported VC concentration was 14 µg/L and was measured at well IMW-6 in 2014 (Fig. 6c). Most recently, in 2021, the VC peak concentration was 8 µg/L and was measured still at or around IMW-6. The VC peak coincided with the TCE peak in 2021 (Figure 6c) and seemingly trails behind the cDCE peak (located at or around IMW-7). This suggests that the VC travel velocity is slower than cDCE and/or it is being generated at a rate slower than cDCE being produced from TCE dehalogenation, as expected. The concentration at the leading edge of the VC plume (at VGM-2D) was 5.4 µg/L in 2021, which exceeds the MCL for VC (2 µg/L). For comparison, the method detection limit was <1.0 µg/L during the 2021 analysis. Overall, the data indicates that a plume of VC contaminated groundwater has formed and is moving downgradient. The absolute VC concentrations have declined from their peak in 2014 but still exceeded the contaminant's MCL by 4 times in the center of plume in 2021 and about 2.6 times at the plume leading edge. However, more VC field data would be needed to predict the future fate of this compound.

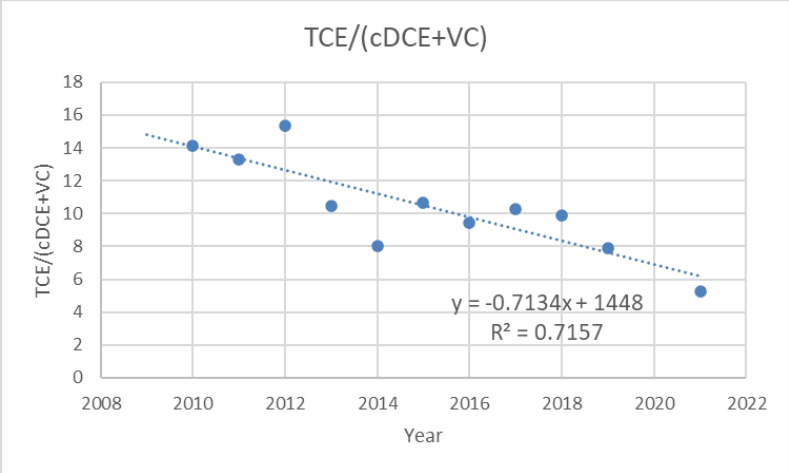


Figure 7: TCE degrades to DCE which degrades to VC. The data of the peak annual concentrations observed anywhere in the plume along transect A to A' indicate an enrichment in the degradation products over time.

Finally, as TCE degrades to DCE which degrades to VC, one should expect a relative accumulation of the daughter products which both degrade at rates typically slower than the TCE degradation rate (Fetter et al. 2017). As Figure 7 indicates, this is indeed the case at Lot-46 i.e., an enrichment in the degradation products can be observed over time when considering the peak concentrations for each compound as observed anywhere in the plume in a given year. By approximately 2030 and assuming the historical trend holds (see trendline in Fig. 7), the sum of the degradation products should be equal or greater than the TCE concentration. From Fig. 5a, the estimated peak TCE concentration will be approximately 124 µg/L in 2030. The current data is insufficient to estimate the corresponding absolute cDCE and VC concentrations and their ratios relative to each other at that time.

Analysis of DWWW Gallery and Fleur VOC Data Set

DWWW provided a data set of VOC concentrations in samples from the Gallery and the Fleur facility collected between 2010 and 2022. Six VOCs (VC, cDCE, TCE, trans-1,2-Dichloroethene, 1,1-Dichloroethene and Tetrachloroethylene) were tested for, but only TCE, cDCE and VC were detected at least once since the testing started. Of those three VOCs, cDCE was consistently detected over the entire monitoring period. All cDCE concentrations were <3 µg/L, except of one data point (9 µg/L in Gallery sample from 06/14/2012). VC was recorded in two Fleur samples in 2020 and 2021 (but not in Gallery water) and TCE was recorded in two Gallery samples (but not in Fleur water) in 2022. The detected VC and TCE were at or just above their respective method detection limits (0.5 µg/L for both).

Figure 8 shows the average annual cDCE concentrations for the Gallery and Fleur sampling locations. No clear trends are recognizable at the two sampling locations. It is plausible, however, that the impact of the polluted groundwater approaching the DWWW facility has not fully manifested itself yet (i.e., the potential impact of the advancing plume may still present itself in the future). Overall, the cDCE concentration averages (as well as their maximum reported concentrations within a given year) are well below the MCL for cDCE (70 µg/L).

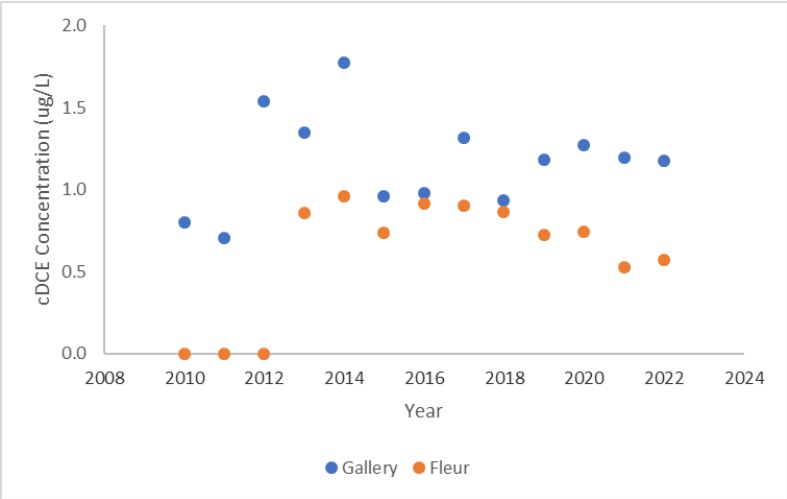


Figure 8: Average annual cDCE concentrations at sample locations Gallery and Fleur. Data from DWWW.

Estimation of the CVOC impact on the DWWW Gallery

In the previous section, reported concentrations along the CVOC plume have been used to estimate the evolution of CVOC plume over time. In this section, the focus is on the DWWW Gallery and the estimation of how much polluted groundwater has already affected the system or might affect it in the future.

DWWW collects water from a 4.8 km (3 miles) long Gallery system, which runs parallel to the Raccoon River in Water Works Park from SW 46th Street to Fleur Drive. The system collects naturally filtered water from sand and gravel of the river valley. The flow of water in the Gallery follows that of the river i.e., from the SW to NW in the direction of the DWWW facility. The Gallery includes a North Branch (NB: 1046 m or 0.65 mi) and a South Branch (SB: 3782 m or 2.35 mi). The two merge at the Intercept Shaft and the water is transferred to a tunnel for conveyance to the water treatment facility. The north shaft is closest to the water treatment plant (STAR 2022). Water flowing into the pipe consists of 86.56 percent surface water from the Raccoon River and 13.44 percent groundwater (STAR 2022). Based on sulfate and chloride concentrations in groundwater (represented by well VGM-3), the Raccoon River and the Gallery water (a mix of the former two waters), the fraction of groundwater ranges from approximately 3% to 8%. Radial collector wells consist of concrete rings 1.2 and 1.5 m (4 and 5 ft) in diameter and 0.6 m (2 ft) long and are held slightly apart so water can trickle into the pipe. The pipes are buried at approximate depth of 7.6 to 9.1 m (25-30 ft) bgs (STAR 2022). The DWWW infiltration gallery produces 121,003 m^3/d (11.7 bgy) (DNR 2013).

If both the North and South branch contribute proportional amounts of water to the Gallery, the amount coming from SB is 94,786 m^3/d and 16,263 m^3/d from NB, respectively. Further, assuming groundwater contributes proportionally to both branches, the daily inflow of groundwater to SB is 12,739 m^3/d and 3,524 m^3/d to NB, respectively.

The most current data indicate that Gallery water up-gradient from observation point VC-5 is unpolluted. However, at observation point VC-4 and the Intercept Shaft (i.e., closer to the DWWW facility), water contains 1.2 µg/L cDCE each. No TCE was detected at either location. Further, 1.0 µg/L cDCE was detected at NB but none was detected at observation point VC-3. Because VC-3 is located between NB and the Intercept Shaft, this part of the Gallery was assumed being relatively unaffected by the CVOC plume at this time. Given the amount of water collected along SB (94,786 m^3/d) and the cDCE concentration at the Intercept Shaft (1.2 µg/L), the daily flux of cDCE is approximately 114 g/d.

The distance between VC-4 and VC-5 is approximately 500 m (1,640 ft), which represents 13.2% of the southern branch of the Gallery. Based on 13.44 percent of groundwater contributing to the total Gallery flow, the amount of groundwater entering along this section is about 1,684m^3/d. Based on the lower estimates of groundwater contribution (3 to 8 percent), the amount of groundwater entering declines to 376 m^3/d and 1,003 m^3/d, respectively. The cDCE concentration at the leading edge of the groundwater plume is 12 µg/L at VGM-4D and 360 µg/L at VGM-2D further up-gradient. Assuming the polluted groundwater enters SB over the entire section between VC-4 and VC-5 at a concentration of 12 µg/L as measured at VGM-4D and assuming the percentage of groundwater contributing to the Gallery is at the high end of the spectrum (13.44 percent), there would not be sufficient cDCE mass entering the system to explain the 1.2 µg/L measured at VC-4 at this time (20 g/d). Conversely, if the plume reached the Gallery at 360 µg/L cDCE, a section about 94 m wide could explain the observed VC-4 pollution. Last, if the plume entered with the same concentration along the entire VC-4 and VC-5 section, 68 µg/L cDCE would suffice to cause the observed level of pollution in the SB water.

The most recently reported cDCE concentrations along SB are well below the MCL (70 µg/L). Therefore, what would be the minimum cDCE plume concentration to result in reaching the MCL at VC-4? It would require about 6.6 kg cDCE per day to enter via the groundwater flow. This translates to groundwater with a concentration of approximately 3,940 µg/L cDCE to enter over the entire VC-4 to VC-5 section. . In 2021, the highest reported cDCE concentration at the center of the plume is 600 µg/L (IMW-7).

Sensitivity Analysis

The estimates presented herein come with a degree of uncertainty because of data gaps, spatially variable hydraulic parameters and other factors that can influence the contaminant transport and fate in the subsurface and the breakthrough at the Gallery. Therefore, a sensitivity analysis was conducted to bracket these estimates to the degree possible.

DWWW Gallery		
Gallery Length	3	miles
Southern Branch	2.35	miles
Norther Branch	0.65	miles
Amount of water in Gallery	1.17E+04	gal/y
	121003	m^3/d
Percentage Southern Branch	78%	
Amount of water from S' Branch	94786	m^3/d
Percentage Northern Branch	22%	
Amount of water from N' Branch	26217	m^3/d
Percentage GW entering Gallery:	13.44%	
Amount of GW entering Gallery:	16263	m^3/d
Amount of GW entering via S' Branch	12739	m^3/d
Amount of GW entering via N' Branch	3524	m^3/d

Table 2: Parameters on which the flow of groundwater pollutants to the Gallery were estimated.

The parameters used to estimate the flow of groundwater pollutants to the Gallery are summarized in Table 2. The length of the Gallery, including its southern and northern branches, was considered insensitive (=constant). Also, the contaminant concentration is insensitive to the total amount of water produced from the Gallery as long as the mixing ratio between groundwater/surface water along the infiltration pipes remains unchanged and the hydraulic flow field does not change during times of higher withdrawal i.e., higher production rates do not steepen the hydraulic gradient towards the Gallery, thereby pulling-in more polluted groundwater. The following are considered parameters sensitive to changes:

- Fraction of groundwater entering the Gallery relative to river water
- Plume width, measured as the length of section through which contaminated groundwater enters the southern branch of the Gallery between VC-4 and VC-5 (Assumption: no polluted groundwater enters through the northern branch at this time)

- cDCE concentration measured at confluence of N' and S' branches (=entering DWWW plant)

The sensitivity analysis was performed over the ranges indicated in Table 3. The cDCE concentration at the leading edge of plume that would result in 1.2 µg/L observed at both VC-4 and the Confluence Point in 2021 was the principal measure of sensitivity. In the first scenario, it was investigated how low/high flow in the river might affect the water quality. In the second scenario, it was tested under what conditions the cDCE concentration would increase by one order of magnitude i.e., from 1.2 µg/L to 12 µg/L. This scenario also involved testing how the width of the plume (±25%) would affect the cDCE concentration. Finally, a worst-case scenario was tested wherein it was assumed that VC contaminated groundwater reached the Gallery.

Parameter	**Initial**	**Range analyzed**
Fraction of groundwater entering Gallery (Scenario 1)	13.44%	3% and 20%
cDCE concentration in DWWW influent (Scenario 2)	1.2 µg/L	Initial to 12 µg/L
Width of the plume: Length of section through which contaminated groundwater enter (Scenario 3)	500 m	±25%
Vinyl chloride MCL is exceed in DWWW plant influent (Scenario 3)	0 µg/L	N/A

Table 3: Parameters tested during sensitivity analysis.

Scenario 1: According to one estimate, groundwater accounts for 13.44 percent of the Gallery water. The remainder is from surface water (=river). A lower fraction of groundwater entering could be realized during high water flow in the river i.e., during a flood event when proportionally more surface than groundwater might enter the Gallery. Conversely, a higher fraction of groundwater inflow could be realized during low flow in the river i.e., under drought conditions. The analysis suggests that if the fraction of groundwater entering the Gallery decreased from 13.44% to 3%, the concentration of cDCE in the plume entering the system would have to rise from 68 µg/L to 303 µg/L to result in 1.2 µg/L pollution observed in 2021. At 20% groundwater inflow (=drought scenario), 45 µg/L would already be sufficient to result in 1.2 µg/L contamination level.

Scenario 2: A 10-fold increase in the cDCE concentration in the DWWW influent (from 1.2 µg/L to 12 µg/L) would result from polluted groundwater entering at 675 µg/L over the 500 m section between VC-4 and VC-5.

Scenario 3: Should the section through which the polluted groundwater enters the Gallery be reduced by 25% (i.e., from 500 m down to 375 m), the corresponding cDCE concentration would have to be higher (900 µg/L) to explain the most recent 1.2 µg/L measurement. Conversely, the effective groundwater concentration would be lower (540 µg/L) in case the section length increased by 25% (625 m).

Scenario 4: Under worst case conditions i.e., vinyl chloride contaminated groundwater has reached the Gallery, its concentration would have to rise to approximately 113 µg/L to reach the MCL (2 µg/L) of VC in the DWWW plant influent. During the 2021 sampling campaign, the highest recorded vinyl chloride concentration was about 8 µg/L in the center of the plume at IMW-6 and 5.4 µg/L at its leading edge (VGM-2D) (Figure 2).

In summary, the sensitivity analysis indicates that the water quality in the Gallery is largely resilient to major changes in operation patterns. However, even more extreme changes than analyzed are plausible in the future and it is possible that a combination of events could result in increasing the pollution levels in the DWWW water at that time.

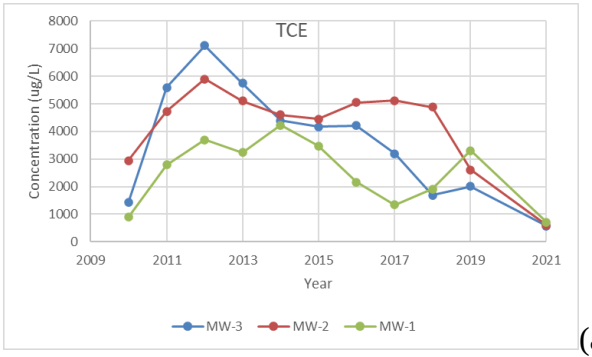
Disclaimer

The estimates presented herein are approximations only. Distances between observation points have been obtained from GoogleEarth. Estimates are based on a subset of reported data. Additional sampling campaigns would refine these estimates but would benefit from setting up a contaminant transport and fate simulation.

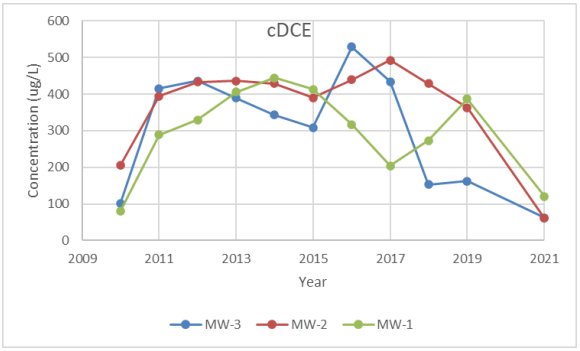
Q2: Can we use the existing data to support the identification of the likely responsible party (parties)? If not, what additional data do we need to answer this question?

The existing data set covers about 12 years and provides information about the spatial and temporal evolution of the groundwater contamination at Lot 46. From Figure 4b, TCE concentrations were the highest at and around wells MW-2 and MW-3 between 2010 and 2017. Well MW-2 is located about 28 m (~90 ft) from MW-3. More specifically (Figure 8), between 2010 and 2012, TCE concentrations increased at and around wells MW-2 and MW-3. Of note: the initial (2010) chloroethene concentrations were higher in well MW-2 than MW-3. TCE concentrations peaked at and around well MW-2 and MW-3 in 2012 (Fig. 8a). Of note: TCE concentrations were higher in MW-3 than MW-2 between 2011 and most of 2013. In the years following, TCE concentrations decreased in both wells, except of a temporary increase in MW-2 and MW-3 in 2016 and 2017, respectively. Afterward, TCE concentrations declined again. By 2021, the TCE concentrations at MW-2 and MW-3 had declined by approximately one order of magnitude relative to their peak concentrations recorded in 2012. In fact, the TCE concentrations were lower in 2021 than in 2010 when the contamination was detected initially.

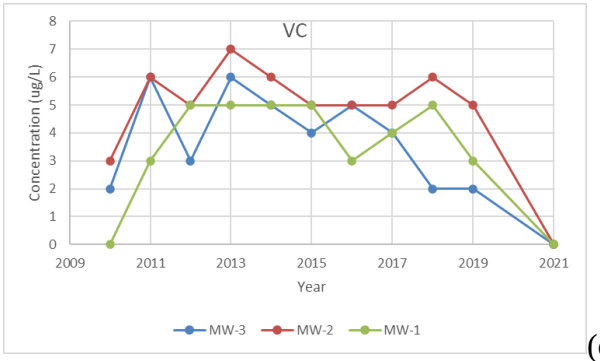
By 2014, the TCE center of mass had apparently arrived at MW-1. An apparent second peak followed in 2019. Together, the TCE data suggests that the source of the release might have been closer to MW-2 than MW-3 and that there were likely (at least) two separate incidents about five years apart.



(a)



(b)



(c)

Figure 9: Groundwater concentrations of (a) TCE, (b) cDCE and (c) VC between 2009 and 2021 wells MW-1 through MW-3. These wells are considered closest to the unknown source of the TCE release.

As shown in Figures 3 and 4a, the history for cDCE plume is more complex. That is, the center of mass appears to have oscillated between wells IMW-6 and MW-3 between 2010 and 2016. However, data gaps obscure the picture. Like TCE, the cDCE center of mass has traveled down gradient and left less polluted groundwater in its wake i.e., about 9 times lower concentrations at and around MW-3 compared to peaks during 2013 and 2016. From Figures 9(a) and (b), it appears that there were two TCE and cDCE peaks, respectively, at the wells located closest to the suspected source zone (MW-1 through MW-3). At MW-2 and MW-3, the first peaks occurred around 2012 and 2013 and the second one around 2016 and 2017. In case of MW-1, which is located downgradient for the other two wells, two peaks occurred about two years later i.e., around 2014 and 2019. Additionally, as for TCE, the highest initial cDCE concentrations were observed in well MW-2. Overall, the cDCE data also suggest that at least two separate spills occurred and that the source zone might have been close to MW-2 than MW-3.

The interpretation of the VC concentration data set is even more difficult than the cDCE data because the VC concentrations are fluctuating in a narrow range (Fig. 9c) and are near the method detection limit (1 ug/L). However, it appears that the highest initial VC concentrations were observed in well MW-2 and that there might be two peaks in 2013 and 2019. The delay of the VC peaks relative to cDCE should be expected by virtue of VC degrading from cDCE.

Terracon (April 5, 2019 report) measured CVOC groundwater concentrations in 10 shallow/deep wells (TB-100 S/D to TB 109 S/D) along the former railroad track separating the Packing Distribution Service from the Former Stone Container building (Figure 10). The path of the plume crosses the line of these wells (transect B-B'; Figs. 2 and 9) almost perpendicularly. The TCE and cDCE concentrations from the deeper wells (8.2 m or 27 ft) were plotted (Figure 11). Also included in this figure is the conditionally formatted concentration data set. The data show that cDCE and TCE concentrations are highest at and around wells TB-106D and TB-107D, respectively, i.e., in the middle of the transect. Further, at this location the contamination appears largely limited to the deeper section of the aquifer (8.2 m or 27 ft) i.e., shallow wells (7.0 m or 23 ft) CVOC concentrations were at or below the compound specific detection limit (data not shown). Assumed depth to bedrock varied from approximately 13.7 to 16.5 m (45 to 54 feet) across the transect.

In summary, the close examination of the plume history suggests that the groundwater pollution at Lot-46 *might* have been the result of at least two releases some five years apart. Also, the release location *might* have been closer to MW-2 than MW-3. However, the existing groundwater quality data is insufficient to pinpoint the exact release location(s) and timing of the release(s) with accuracy. To fill these data gaps, it would require, at minimum, additional groundwater sampling campaigns from existing wells, drilling of additional groundwater wells in the vicinity of MW-2 and MW-3 to determine the extent of the plume in this area. In addition, samples from new up-gradient wells, together with samples from existing wells, should be subjected to a compound-specific isotope analysis (CSIA) of TCE (Lojkasek-Lima et al. 2012). A CSIA might tell if more than one type of TCE solvent is present, which could indicate if more than one source contributed to the pollution problem. Also, it is recommended to confirm that TCE is being degraded by natural processes and to determine the respective degradation rates. Furthermore, a hydraulic model of the site together with a transport model would provide additional insights how the plume evolved, where it is heading, and what the TCE concentrations, including its degradations products, would be within the area the plume over time.

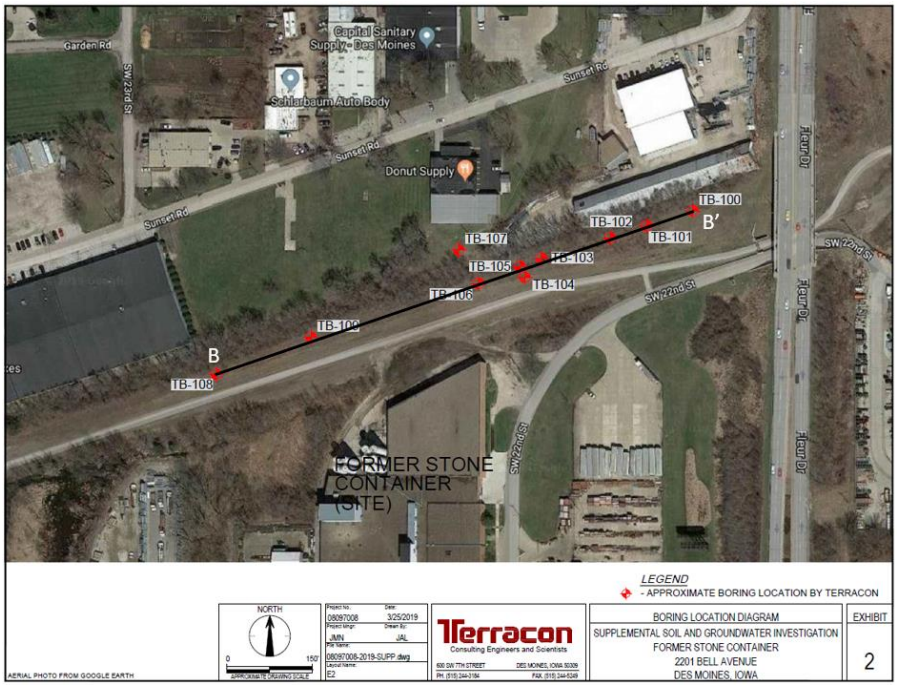
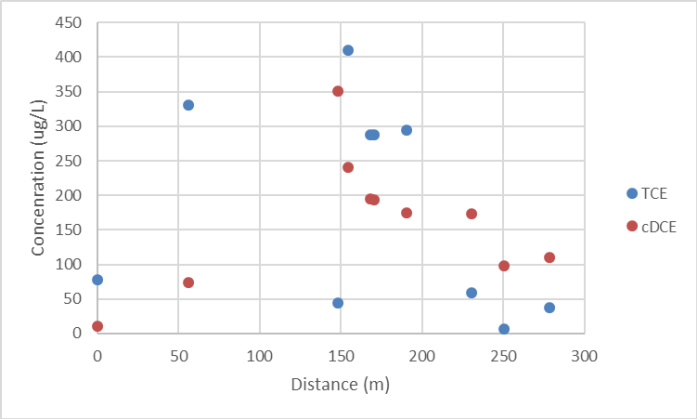


Figure 10: Approximate boring locations by Terracon along former railroad track. Black Line: Transect B-B'. Modified after: Terracon April 5, 2019.



B B'

	TB-108D	TB-109D	TB-107D	TB-10	TB-105D	TB-103D	TB-102D	TB-101D	TB-100D
Distance in meters	0	56	148	##	168	191	231	251	279
cis-1,2-Dichloroethene									
Trichloroethene									

Figure 11: Deep well CVOC data along transect B-B' plotted as concentration versus distance (above) and conditionally formatted (below). The column width reflects the approximate distance between wells, except for the transect's origin at TB-108, which has been horizontally exaggerated for illustration purposes.

Q 3: Do we have enough data to development or review removal options?

In general, the most appropriate remedial technology options should mitigate the CVOC mass flux from the source area characterized by groundwater TCE and cDCE concentrations on the order of hundreds of μg/L. The remediation goal should be to reduce total CVOC groundwater concentrations to less than the USEPA MCL of 5 μg/L and 70 μg/L, respectively. General response actions for CVOC-impacted groundwater include:

• Containment – actions resulting in CVOC-impacted groundwater being contained/controlled to limit or eliminate migration of CVOC and/or prevent direct exposure to CVOC.

• Recovery – actions resulting in the physical collection and removal of CVOC-impacted groundwater.

• Treatment – actions resulting in a reduction in the toxicity, mobility, and/or volume of CVOC contamination.

• Disposal – actions taken to dispose of or reuse treated or untreated groundwater.

There are numerous remedial technologies/process options available under these broad categories. However, only a subset of those technologies/process options may be technically implementable. Table 4 summarizes the technology process options that warrant further screening. The table provides an overview of potential remedial technologies, their working principles, effectiveness, implementability and, relative cost. Institutional controls (i.e., administrative, or legal controls that limit land or resource use) were not evaluated as a general response action herein as they use non-engineering methods and do not require engineering design.

At this time, the most promising technologies appear to be plume containment by pump-and-treat and the injection of reactive agents at the plume's edge. Anaerobic bioremediation may be another alternative but would require additional considerations. Note: treatment options for the source zone have not been evaluated but would likely require a different set of technologies. The ultimate technology selection for preventing polluted groundwater from impacting the DWWW facility requires further screening based on engineering judgment and current knowledge of site conditions, such as treatment timeline or preference of in-situ versus ex-site treatment (or a combination thereof). There are additional data needs, such as:

- Extraction flow rate/well specific capacity and achievable zone of hydraulic influence. This information may be obtained through aquifer testing.

- Extracted water quantity and quality (e.g., pH, alkalinity). This information may be obtained through aquifer testing and groundwater sampling.

- Key parameters for design of an amendment/reactive agent injection system including achievable reagent distribution, reagent dosing, reagent longevity, and potential for back-diffusion from less permeable portions of the primary (matrix) porosity or from matrix storage domains. This information may be obtained through field pilot testing.

- Refined understanding of the mechanisms for natural attenuation of CVOC in site groundwater. This information may be obtained through the collection of additional data to define the groundwater geochemistry and the activity of CVOC degrading microorganisms in groundwater and the associated aquifer solids.

Remedial Technology	Process Options	Description	Effectiveness	Implementability	Cost
In-Situ Treatment	Physical/Chemical – Permeable Reactive Barriers (PRB)	Solid reactive media (i.e., zero-valent iron, nano iron) are emplaced across the flow path of the contaminant plume to create a permeable treatment "barrier." As groundwater flows through this barrier, contaminants are passively removed in the treatment zones by physical and/or chemical processes. TCE and its reductive dehalogenation degradation products convert into water, chloride, and CO_2. Barriers may be installed using an array of boreholes, via fracturing/injection methods, dug trenches or by other means.	PRB is generally used for containment. Effective for achieving remediation goals downgradient of the PRB. Performance depends on continuity and integrity of the barrier. For PRBs installed using injection methods, remedial performance may be reduced due to lack of control over the thickness and uniformity of the treatment zone. Barriers are subject to clogging and reduced permeability over time (e.g., due to the oxidation of zero-valent iron).	Difficult to implement. Traditional trench installation methods may be practicable given site conditions (e.g., depth of impacted groundwater and lithology). Other construction methods such as fracturing or the use of closely spaced/overlapping boreholes are implementable but achieving the continuity required for effective passive treatment is challenging. Access for subsurface construction may be limited due to site infrastructure. Requires well-characterized hydrogeologic conditions.	High capital cost, low O&M cost.
	Emplacement of activated carbon (AC)	Fine (nano/colloidal) activated carbon suspensions are injected into the treatment zone using a number of injection wells. As contaminated groundwater flows through this zone, the contaminants are retarded due to adsorption. AC can be used in combination with reactive amendments, such as zero-valent iron, or with biostimulating agents. Sorption to the ACE increases the residence time of contaminants within the reactive zone and thereby increases contact with the reactive amendments, which has the potential to promote contaminant degradation.	Accepted technology for treating dissolved CVOCs. The design loading rate of AC products is typically determined by total mass of a contaminant in both high and low permeability zones. The design loading rate of colloidal AC-based products is based on the dissolved contaminant mass flux.	Moderate implementability. Vendors, equipment, and materials are anticipated to be available. Requires performance monitoring and possible additional injections once the sorption capacity and reactivity of the AC and its amendments is declining.	Moderate to high capital cost, moderate O&M cost.
	In-situ Chemical Oxidation (ISCO)	ISCO relies on the injection of chemical oxidants, such as permanganate or hydrogen peroxide, into the polluted plume. The oxidant chemically breaks up CVOCs into benign products.	Accepted technology for treating dissolved CVOCs. One or more injection wells are required to disperse the oxidant properly. The choice of oxidant depend on contaminant inventory. Is effective for treating source zone and dissolved CVOC.	Moderate implementability. Vendors, equipment, and materials are anticipated to be available. Requires well-characterized hydrogeologic conditions. May require several injection cycles if only plume is treated. Closeness to DWWW water intakes (Gallery) might be an obstacle and may require interceptor wells to prevent excess oxidant from reaching the Gallery.	Moderate to high capital cost, moderate O&M cost.
	Bioremediation - Anaerobic	Bioremediation treat contaminants in soil and/or groundwater with microorganisms or biomolecules generated by cells. Anaerobic biodegradation is particularly effective for TCE. Typically involves in-situ treatment via biostimulation using various carbon-based amendments to overcome the of lack sufficient organic carbon to promote anaerobic microbial respiration at most sites. Bioaugmentation, the injection of a microbial culture, may be required to provide the appropriate microbial community to promote complete degradation of the CVOC.	Bioremediation is widely applied for remediation of recalcitrant compounds present in soil and/or groundwater. Viable remediation approach for dissolved CVOC but limited effectiveness for source zone treatment i.e. potential presence of DNAPL in source zone may require much longer treatment times. Like with many in-situ technologies, bioremediation of low permeability zones may limit effectiveness.	Moderate to difficult implementability. Bioremediation effectiveness is highly site specific and requires treatability studies and well-characterized hydrogeologic conditions.	Moderate to high capital cost, moderate O&M cost.
	Monitored Natural Attenuation (MNA)	MNA relies on natural attenuation processes to achieve site-specific remediation objectives within a reasonable timeframe compared to more active approaches. MNA is often used as a remedy, or part of a remedy, where contaminants have been demonstrated to be degrading or sequestered in groundwater.	MNA requires characterization of the distribution of contamination at a site, characterization of the flow of groundwater, understanding of the processes that contribute to natural attenuation and using this information to build a conceptual model of the site.	Moderate implementability. Vendors, equipment, and materials are anticipated to be available.	Low capital cost. Low to medium O&M cost.
Ex-Situ Treatment	**Pump and Treat (PAT)** **(Plume Containment)**	Contaminated groundwater is pumped from one or more extraction wells placed in the path or periphery of a plume. The pumped water is treated via ex-situ technologies, such as granular activated carbon, air stripping or reverse osmosis (see below)	PAT is effective in controlling or capturing a plume. It can prevent polluted groundwater from further breaking through to the Gallery. PAT should not be used for treating the TCE source zone. If source zone remains untreated, long treatment times are likely.	Low implementability. Vendors and equipment are readily available. Requires well-characterized hydrogeologic conditions. Requires ex-situ treatment of the pumped water.	Low to medium capital cost. Low O&M cost.
	Granular Activated Carbon (GAC) Filtration	GAC removes dissolved CVOC by sorption to the carbon's large and active surface area.	Accepted/proven technology. High removal efficiencies possible but GAC filter have a finite live time, requiring periodic replacement.	Low implementability. Vendors and equipment are readily available. No pretreatment required. Requires regular monitoring to prevent CVOC breakthrough.	Moderate to high capital cost, moderate O&M cost.

	Air stripping	Air stripping transfers dissolved CVOC from the water to the air. The CVOC is removed from the air via filters, such as activated carbon.	Accepted/proven technology. High removal efficiencies possible. High iron/manganese concentration in the polluted water can cause clogging and result in high maintenance requirements.	Low implementability. Vendors and equipment are readily available. No pretreatment required. Requires regular monitoring to prevent CVOC breakthrough from air filter.	Low to moderate capital cost, low to moderate O&M cost.
	Reverse Osmosis (RO)	This method removes CVOCs by forcing water through extremely fine membranes, creating a water stream with very low CVOC concentrations and a concentrate stream with more concentrated CVOC levels. Management of the treated groundwater would be required.	Accepted/proven technology. Effective means to remove dissolved compounds from water. Very high removal efficiencies possible. Not generally impacted by influent water quality (i.e., individual constituents in the influent or variations in water quality conditions over time).	Low to moderate implementability. Vendors and equipment are anticipated to be available. Typically requires pre-treatment (e.g., pH adjustment/addition of scale inhibitors) to prevent scaling/fouling of the RO membranes and post-treatment. Produces a concentrated waste stream, which also requires additional processing prior to disposal. Produces a higher volume of waste (liquid rejectate) compared to other ex-situ treatment technologies. High energy use.	Moderate to high capital cost, high O&M cost.
	Bioreactor	Electron donor is added to a bioreactor (e.g., submerged packed bed reactor or hollow fiber membrane reactor) to facilitate microbially-mediated reduction of TCE to benign compounds. Potential electron donors include soluble organic compounds (acetate, glucose, ethanol) or hydrogen gas.	Proven technology. Presence of alternate electron acceptors (e.g., nitrate) will affect sizing of vessel and reagent demand.	Moderate implementability. Vendors, equipment, and materials are anticipated to be available. Biomass takes time to mature and can be upset. Requires management/disposal of solid waste.	Moderate to high capital cost, moderate O&M cost.
Containment/Isolation	Isolation	Isolation of a segment of the gallery intake pipe.	Apparently, this approach has been implemented at the DICO site to the north of Lot 46 in Des Moines.	Moderate to difficult implementability. Requires excavation near Raccoon River. Access for subsurface construction may be limited due to site infrastructure.	Moderate to high capital cost, low to moderate O&M cost.
Treated Groundwater Discharge	Publicly Owned Treatment Works (POTW)I	Extracted/pre-treated groundwater is discharged to a POTW.	Effective.	Readily implementable. Requires a discharge permit.	Low capital cost, low O&M cost.
	Injection	Extracted/treated groundwater is injected into onsite wells. If water quality standards are met, possible reintroduction into the water supply could be an option.	Effective. May be used to increase hydraulic gradients toward the extraction wells and increase groundwater flushing rate.	Moderate implementability. Installation would require standard construction techniques and equipment; and services and materials are anticipated to be available. Access for subsurface construction may be limited due to site infrastructure. Concerns about the public perception or reintroducing treated water back into the water supply.	Moderate capital cost, low to moderate O&M cost.

Table 4: List of potential remedial technologies. **Bold**: most promising technologies for preventing polluted groundwater from impacting the DWWW facility.

cc: Jessica Kidwell, Region 7
Lisa Messinger, Region 7
Randolph Brown, Region 7
Brad Roberts, Region 7
Robert Weber, Region 7 STL