MASSACHUSETTS DEPARTMENT OF ENVIRONMENTAL PROTECTION

FIELD ASSESSMENT AND SUPPORT TEAM (FAST)

Evaluation of Investigations, Remedial Activities, and the Potential for Vapor Intrusion at the Varian Site, Beverly MA

MassDEP RTN 3-00485

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Report Summary and Findings

The objective of this report is to: (1) evaluate the adequacy of site characterization efforts to date, including source and plume migration areas; (2) assess the efficacy of past and ongoing remedial activities; and (3) evaluate past and current data to determine if additional investigations are needed to assess the vapor intrusion pathway in downgradient commercial and residential buildings.

In order to achieve this objective, a considerable amount of time and effort was devoted to the review and evaluation of the voluminous detailed technical reports that have been submitted to MassDEP for this site over the last 30 years. Reasonable attempts were made to identify and assess all relevant information and data, but the sheer volume and age/condition of such materials may have led to omissions or misinterpretation of site conditions.

Within this context and with this limitation, our findings are summarized below:

- The assessment and remediation of chlorinated solvent sites of this nature is inherently complex and time consuming. While the amount of time that has passed since comprehensive cleanup actions commenced at this site is lengthy, it is not inconsistent with the rate of progress at other sites in Massachusetts with similar types and levels of contamination.

- At the present time, there is no evidence that workers in commercial buildings or residents in the surrounding neighborhood are being exposed to significant levels of contaminants that were released at the former Varian facility.

- Overall, a substantial degree of investigation and remedial activities have been undertaken to assess and clean up contamination at and emanating from the former Varian facility, including the installation of over 250 groundwater monitoring wells, and repeated application of ISCO and bioremediation remedial additives in numerous locations. However, we believe some data gaps do exist, and further investigative work and remedial refinements are warranted.

- DNAPL was present and is likely still present in multiple source areas on the former Varian property. Though the general source areas are known, the distribution of DNAPL and DNAPL ganglia has not been adequately delineated in key and problematic locations, especially beneath Building 3. While site constraints (most notably the buildings themselves) have impeded investigatory efforts, additional steps must be considered to more fully characterize source areas and refine, optimize and expedite remedial actions.

- The delineation and monitoring of the shallow VOC groundwater plume in the neighborhoods west of the Varian property are not adequate, and the presented plume maps fail to adequately define the western extent of VOC contamination. The installation of additional groundwater monitoring wells and continued monitoring of existing wells is necessary to eliminate data gaps in this regard.

- Additional monitoring and monitoring wells are also required south of the former Varian facility to more fully define the extent of VOC migration in this direction.

- Though VOCs continue to be present in the two streams that transit through the Varian site, the levels are not high enough to pose a significant health risk to neighborhood children wading or playing in the water or playing on impacted fields. The potential contamination of sediments in these streams, however, has not been adequately characterized and additional investigation and assessment are needed.

- The results of the comprehensive remedial response actions have been mixed. In some areas, such as Building 5, the actions appear successful (though incomplete). In other areas, particularly near Building 3, success in addressing DNAPL source areas has been limited. As such, MassDEP believes that efforts are needed to investigate the feasibility of enhanced and/or alternative investigatory and treatment technologies for these problem areas, to see if they could increase the rate and/or extent of VOC mass removal at the site.

- Past residential indoor air testing efforts in 2001 and 2002 correctly concluded that Volatile Organic Compounds were not posing a significant health risk to building occupants in all but one of the homes tested. TCE levels of concern were detected in one home on Sonning Road, though it is not clear whether those elevated levels were attributable to contaminants emanating from the Varian site, or use of a TCE-containing automotive product within the home and attached garage. Insufficient efforts were made to rule-out the presence of a vapor intrusion pathway at this and other homes assessed at this time.

- Testing of indoor air in 47 homes in December 2020 by MassDEP documented the lack of vapor intrusion pathways at the time of sampling in all homes. This included the home on Sonning Road with elevated concentrations of TCE in 2001 and 2002, which was found to have no detectable concentrations of TCE. This finding is consistent with our review of testing data obtained since 2002 that show levels of VOCs have significantly decreased in the groundwater in areas westerly of the former Varian facility. However, additional confirmatory testing of groundwater, indoor air and sub-slab soil vapor is required in a number of these homes to adequately assess site conditions and exposure potential.

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List of Acronyms

bgs: below ground surface
CVOC: Chlorinated Volatile Organic Compound
cis-1,2-DCE: Cis-1,2-Dichloroethylene
DCA: Dichloroethane
DCE: Dichloroethylene
DNAPL: Dense Non-aqueous Phase Liquid
ELCR: Excess Lifetime Cancer Risk
EPC: Exposure Point Concentration
HI: Hazard Index
ISB: In-situ Bioremediation
ISCO: In-Situ Chemical Oxidation
MassDEP: Massachusetts Department of Environmental Protection
mg/L: milligrams per liter
NAPL: Non-Aqueous Phase Liquid
PCE: Tetrachloroethylene
PPA: Potentially Productive Aquifer
PSL: Potential Source Location
RAM: Release Abatement Measure
ROS: Remedy Operation Status
RTN: Release Tracking Number
SSDS: Sub-slab Depressurization System
1,1,1-TCA: 1,1,1-Trichloroethane
TCE: Trichloroethylene
TVr: Threshold Value for Residence
SVE: Soil Vapor Extraction
VOC: Volatile Organic Compound

µg/L: micrograms per Liter
µg/m^3: micrograms per cubic meter

Site Background

The former Varian property is located at 150 Sohier Rd. in Beverly, MA. The 24-acre property is bounded by Rt. 128 to the north, Sohier Rd. to the east, Tozer Rd. and commercial properties to the west, and a storage facility to the south. The property currently houses an active manufacturing facility. A stream (Unnamed Stream) flows south along the eastern boundary of the property, then turns west in a channelized bed/stormwater drain, before flowing south along Tozer Rd. A second stream is located west of Tozer Rd (Stream A). The site location and major features are shown on Figure 1.

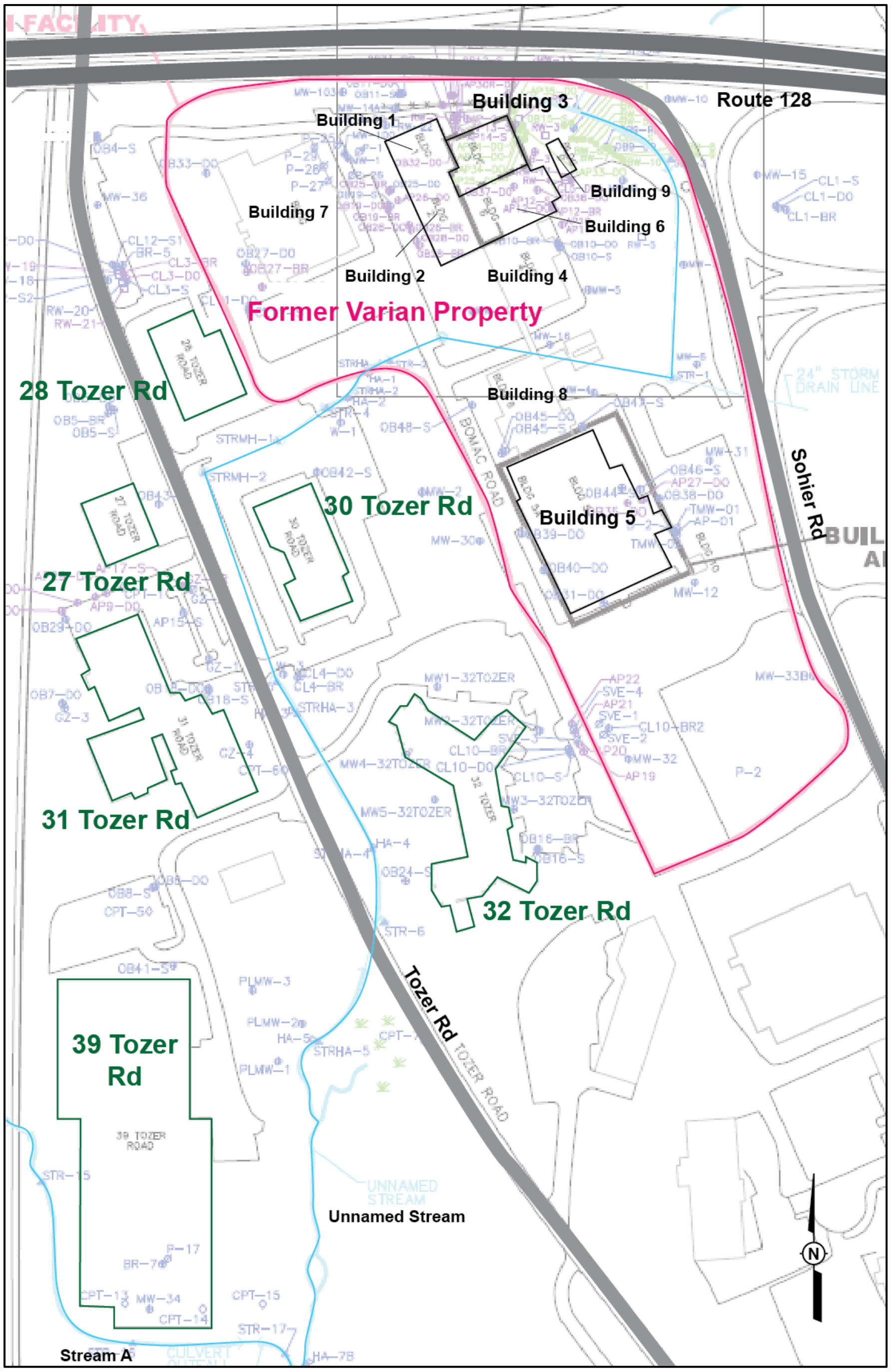

Figure 1. Map of the former Varian property, major features, and surrounding properties (basemap from CBI 2016a).

History and Operations

In 1950, the former Varian property was developed by Bomac Laboratories, which manufactured electronic equipment. In 1959, the property and operations were purchased by Varian, which operated at the property until 1995. From 1950–1995, electronic equipment, such as electron tubes, were manufactured onsite. Volatile organic compounds (VOCs) were likely used in cleaning and degreasing operations. Before 1972, waste was reportedly discharged to drywells and leaching fields. In 1972, Varian began operating a wastewater treatment system, which treated process wastewater before discharge to the municipal sewer system. This system was operational until the property sale in 1995 (IT 2000).

During Varian's tenure, the property housed eleven industrial buildings, two residential buildings, and paved areas; approximately 30% of the site was undeveloped. One of the buildings was located at 28 Tozer Rd., the remaining buildings were at 150 Sohier Rd. The site plan is shown in Figure 1 and the buildings are described below (IT 1994, 2000):

- Building 1 was constructed in 1950, and drawings indicate that discharges from production areas were directed to two sets of dry wells and/or septic systems (northeast corner and southeast corner of the building).
- Buildings 2, 3, 4, and 6 were constructed in 1951–1959. A chemical laboratory, machine shop, cleaning area, and plating shop were present in this cluster of buildings. A former 1,1,1-TCA tank was located on the north side of Building 4. A former septic tank was located beneath Building 3.
- Building 5 was constructed in 1957 and included a production area where solvents were used. Floor drains were present, though the discharge point is unknown. Possible receptors include the unnamed stream or a catch basin. Liquid waste was possibly discharged to the open field area south of Building 5.
- Building 7 contained a machine shop and an area for research and development. The machine shop had floor drains that discharged to sumps on the west side of the building; the ultimate discharge point is unknown.
- Building 9 housed the wastewater treatment system, which was operational beginning in 1972. Based on foundation plans from the 1940s–1950s, it also housed dry wells in the southeast corner, which were connected to a septic system/leach field. Production wastes were reportedly discharged to the dry wells.
- The building at 28 Tozer Rd. was leased to ST Olecktron, and operations included manufacturing of radar-based solid-state equivalents.

Several buildings had concrete-lined trenches, unlined sumps that received discharges, and floor drains (most with unknown discharge points). Liquid waste may have been discharged directly to the unknown stream and to the ground (IT 2000).

Geology and Hydrogeology

The site is underlain by two aquifers: one in the overburden and a deeper aquifer in the bedrock. The overburden aquifer is characterized by unconsolidated sediments and is 20–100 ft thick. The site is underlain by till, sand and gravel, and silt and clay deposits, the distribution of which are variable across the site. The bedrock is fractured granite (east) and gabbro (west), with a small basalt dike east of the site. Flow in the bedrock aquifer is in secondary porosity (fractures, faults, and geologic contacts) (IT 2000).

Depth to groundwater varies across the site. The former Varian property is located on a hill, where groundwater is about 30 feet below the ground surface. The residential neighborhood west of Tozer Rd is topographically lower, and groundwater in some locations is less than 5 ft below ground surface.

Both the overburden and bedrock aquifers follow the same general flow pattern: west from the former Varian property, then turning south, the presumed direction of regional flow. The overburden and bedrock aquifers are hydraulically connected, and vertical flow is generally down into the bedrock with some exceptions (e.g., near the streams south and west of the Varian property).

Of most interest is the movement of groundwater in the shallow overburden, as this defines the areas where contaminants at the water table interface could create a vapor intrusion pathway into overlying structures. As presented in Figure 2, groundwater flow in the shallow overburden is predominantly in a westerly direction from the former Varian property, slowly looping to the south in the Sonning/Longview Road neighborhood area, where the potentiometric surface is relatively flat. South of Lexington Drive, flow direction turns towards the southeast, then east, presumably induced by the localized discharge of overburden groundwater into Stream A.

Additional details on the shallow, deep, and bedrock flow regimes directly downgradient of the Varian property is provided in Figure 3–Figure 5. There are several differences between the aquifers of note in these figures:

- In the northeast corner of the former Varian property, there is localized radial overburden flow (Figure 3). This is particularly evident in the Building 3 area, where shallow groundwater flows east and south towards the Unnamed Stream, north towards Rt. 128, and west towards Tozer Rd. Groundwater that flows east and south towards the Unnamed Stream then turns west, following the stream channel.
- Shallow groundwater discharges to the streams, and thus it is expected that contaminants present in shallow groundwater would also be found in the surface water (IT 2000).
- North of the former Varian facility, the bedrock aquifer has a clear northwesterly flow (Figure 5). In contrast, the overburden aquifer has a westerly flow in this area.

Figure 2. October 1998 site-wide potentiometric surface map of the shallow overburden aquifer shows predominantly westerly/southwesterly flow from the former Varian facility towards Tozer Road, looping south and then easterly towards Stream A (IT 2000).

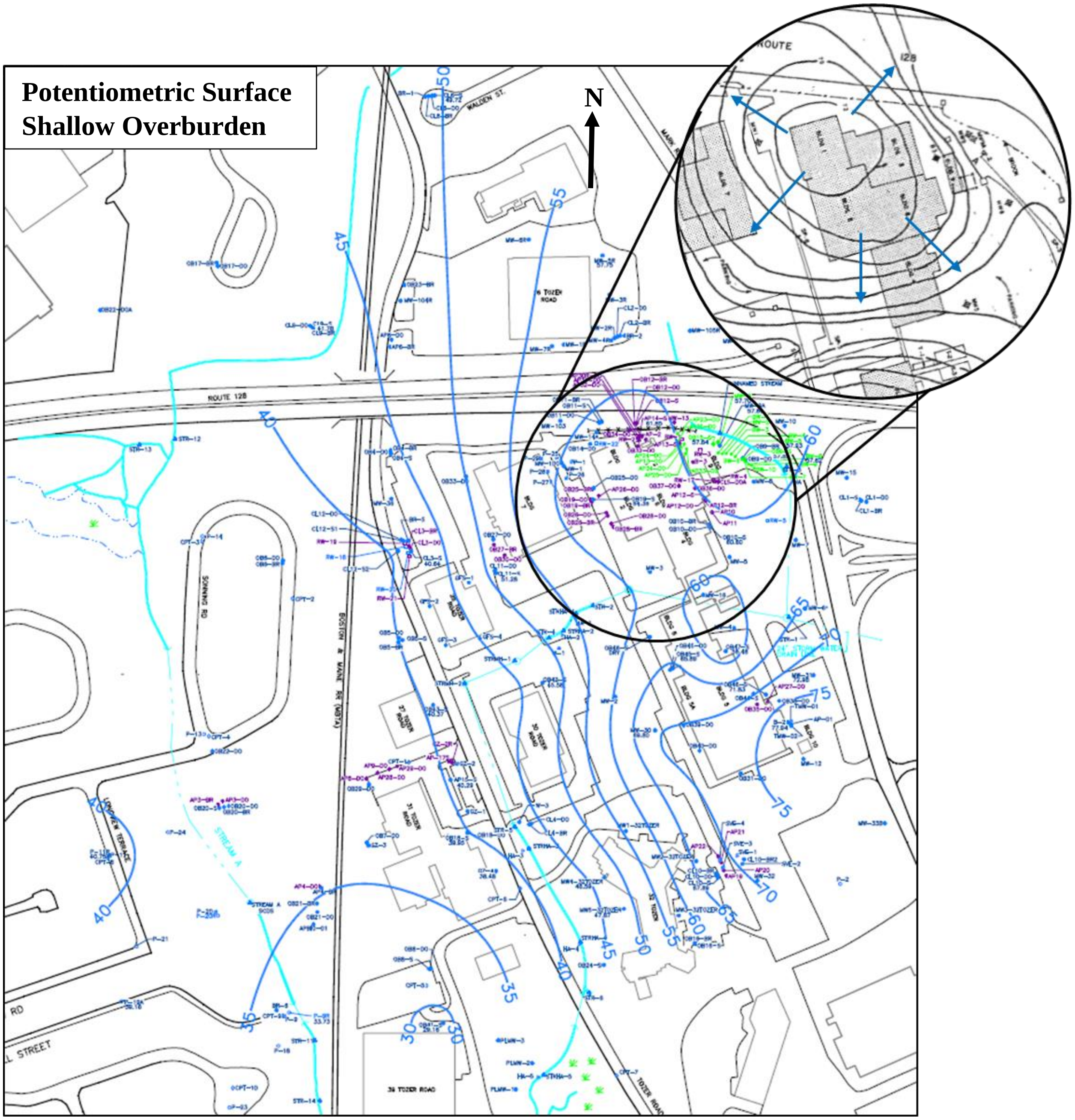

Figure 3. Potentiometric surface map of the shallow overburden aquifer shows predominantly westerly flow from the former Varian facility towards Tozer Road (CBI 2016b). A more detailed look shows radial flow in the overburden aquifer beneath the Building 3 area, with an easterly and southerly component toward the Unnamed Stream (CHIEE 1987).

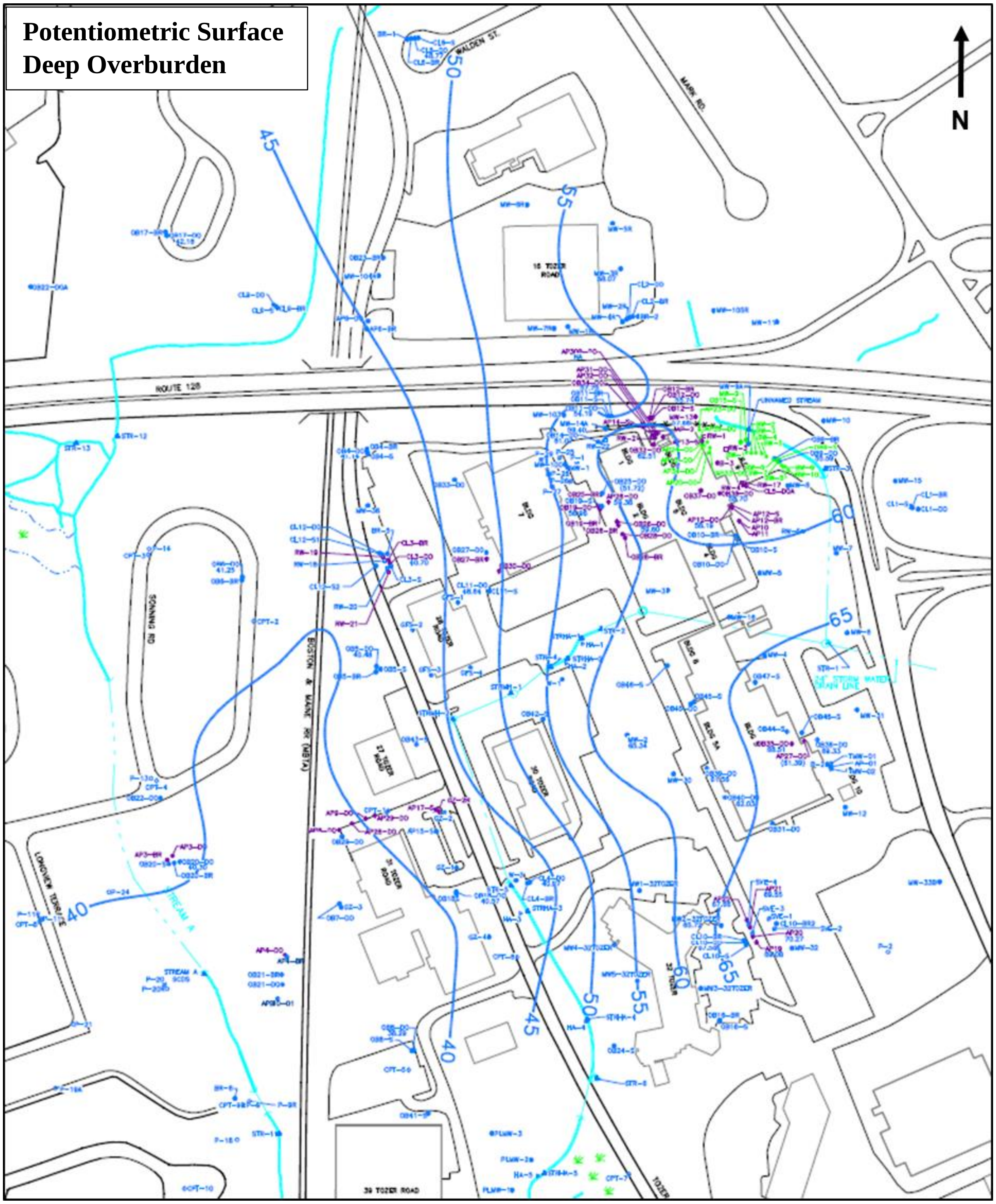

Figure 4. Potentiometric surface map of the deep overburden aquifer shows groundwater migrating west from the former Varian facility (CBI 2016b).

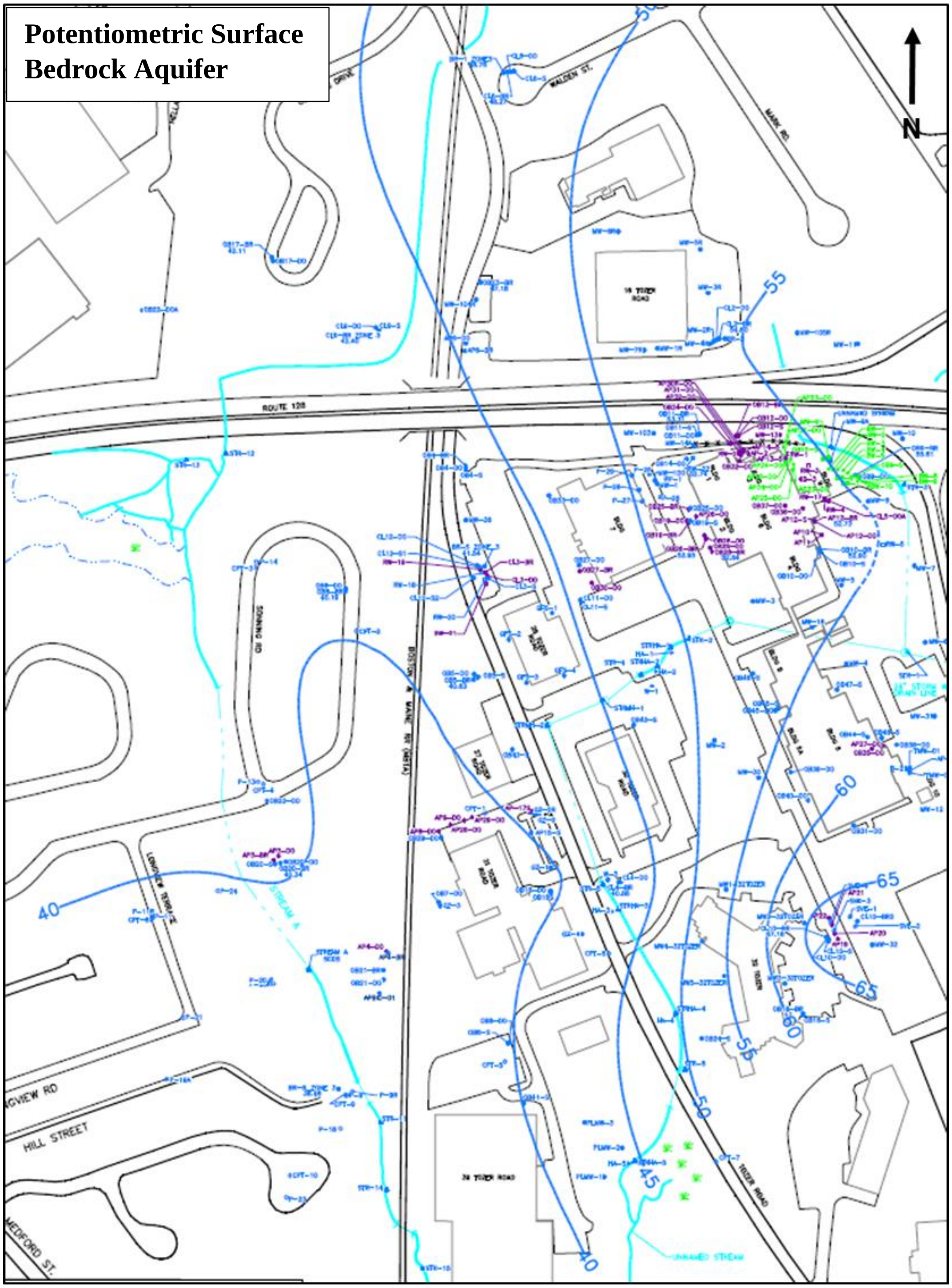

Figure 5. Potentiometric surface map of the bedrock aquifer shows groundwater flowing west from the former Varian facility.

Conceptual Site Model

Operations at the former Varian facility used VOCs, including the chlorinated solvents 1,1,1-TCA, PCE, and TCE, in electronic manufacturing operations. These materials were used in various buildings onsite, stored in tanks, and disposed of in floor drains, dry wells, septic systems, leaching fields, and may also have been discharged to the ground and the Unnamed Stream that bisects the property. Of greatest concern is the release of separate-phase solvents (as opposed to solvents dissolved in a wastewater).

Because they are denser than water, these chlorinated solvents are classified as dense nonaqueous phase liquids (DNAPL).

There are multiple source areas of DNAPL at the Varian property, which were determined based on historical operations and environmental data:

- **Building 3 Area:** Building 3 formerly hosted a laboratory, which may have discharged VOCs to the Unnamed Stream. Also, a former septic tank was located beneath Building 3 which may have received process waste. In 2019, possible residual DNAPL was found in soil beneath Building 3, with PCE concentrations up to 170,000 µg/kg. In 2020, APTIM (2020b) observed a break and an unknown connection in a drain line on the northern wall of Building 3. Drywells in Building 1 may also have received VOC-containing waste. In the 1990s, DNAPL containing equal parts PCE and TCE was recovered from the overburden aquifer north and east of Building 3. VOCs are also elevated west of the Building 3 Area, with possible DNAPL in the bedrock (up to 70 mg/L TCE in 2003, OB-19-BR).
- **Building 5 Area:** Building 5 also contained a laboratory, and waste was discharged to storm drains with an unknown final discharge point. Concentrations of TCE in groundwater on the eastern wall of Building 5 suggested the presence of DNAPL (up to 440 mg/L in 2005).
- **South of Building 5 near 32 Tozer Rd:** Detections of VOCs in the vadose zone soil, coupled with historical reports, suggest that liquid wastes were discharged to the ground in this area.

Spills or discharges of chlorinated solvents onto or into the ground will migrate vertically downward due to the force of gravity, typically in ganglia “fingers” along the pathways of least resistance. Because these solvents are denser than water, they can overcome pore entry pressures at the water table interface and continue to travel vertically downward through the saturated zone. If the volume of solvent releases is sufficiently large, separate phases of these solvents will continue migrating downward until they encounter confining layers and/or until they enter cracks and fissures in the underlying bedrock. The presence of DNAPL in bedrock fractures and fissures is especially problematic, given the difficulties in determining the route and extent of travel of undissolved and dissolved phases within the fracture network. Residual suspensions of the chlorinated solvent DNAPL in ganglia and on confining layers will slowly partition into pore water and diffuse into advective transport zones, where they can migrate as a dissolved-phase plume for hundreds or thousands of feet in downgradient directions.

Groundwater flow from the Varian property is mostly to the west, with a northwest component on the northern portion of the property and a southern component to the west of the property. Shallow groundwater discharges into the Unnamed Stream and into Stream A, which is located west and south of the former property. Both the overburden and bedrock aquifers contain VOCs.

Dissolved-phase VOCs from the Varian property would be expected to move westerly toward and under the railroad line, and toward and into the Sonning/Longview Road neighborhood. Plume movement would then gradually turn south. This area was reportedly the former location of a large marsh, initially filled in the 1860s for the construction of the still operational railroad track, with continued filling through the 1950s (Avidar 2013). As such, the movement of the shallow overburden plume in this area is likely influenced by the presence of such fills, and, considering the shallow depth of groundwater and relatively flat hydraulic gradient, potentially by subsurface drains and utilities and/or sump pumps in homes.

With continued subsurface migration, the dissolved contaminant plume at the water table interface can begin to dip, due to hydrodynamic forces created by infiltrating precipitation. This is unlikely to be the case in the Sonning/Longview Road area, nor in other areas of the plume proximate to Stream A, given the presumption of upward vertical gradients due to localized discharge to the stream and associated wetlands.

Shallow groundwater flow south of the Sonning/Longview area is influence by bedrock, which is reportedly about 3 feet below grade in a localized area at Hill Street, just west of the railroad track. The presence of VOC contaminated groundwater in the basement sump at a home formerly located at 28 Hill Street (DEP RTN 3-14661) was attributed primarily to flow in bedrock, and to a lesser extent, flow in the overburden (APTIM 2018).

Throughout areas of the plume, under reducing conditions, microbes present in the aquifer can slowly degrade the parent chlorinated solvents into daughter products with fewer chlorine atoms, including DCE, DCA, and vinyl chloride. The inclusion of trash and vegetation in fill materials in this area (Avidar 2013) may help promote these processes in the shallow groundwater, and would explain complaints of iron-fouling of the basement sump in at least one home on Sonning Road. It is also possible that the bedrock uplift near 28 Hill Street may result in upward hydraulic gradients in the deep overburden flow regime, transporting deeper groundwater under more reducing conditions to the water table, which may explain the predominance of cis-1,2-DCE (relative to PCE and TCE) in downgradient water table wells in this area.

Dissolved VOCs at the water-table interface can partition from the aqueous to vapor phase, and then enter overlying or surrounding buildings via diffusive and/or advective transport processes. The VOCs of most concern in areas downgradient of Varian property are PCE, TCE, and breakdown product cis-1,2-DCE (vinyl chloride is also a breakdown product, but it is less of a vapor intrusion concern because it is rapidly degraded by bacteria that are ubiquitous in the environment [Ma 2020]).

At a pure compound solubility of about 3500 mg/L, plumes of cis-1,2-DCE often travel faster and extend further than TCE (solubility of about 1000 mg/L) and PCE (solubility about 150 mg/L). Conversely, due to its more limited solubility, PCE has the highest Henry's Law constant of the three, followed by TCE and then cis-1,2-DCE, indicating that PCE has a greater propensity to partition out of groundwater, followed by TCE and cis-1,2-DCE. While this inverse relationship and many other site-specific fate and transport factors complicate the conceptualization of vapor intrusion pathways and potentials, the presence of cis-1,2-DCE within indoor air is a strong indicator that a pathway is present, given its lack of use in most household and consumer products.

Environmental Investigations

In 1985, assessment of an underground acetone tank resulted in acetone detections in surrounding soil. This finding precipitated additional investigations of other storage tanks and installation of groundwater monitoring wells, which revealed VOC impacts to property soil, groundwater, and surface water. VOCs were present in groundwater as deep as 50 ft below ground surface (bgs), and two separate plumes were identified (east of Building 3 and near Building 10). Studies identified 1,1,1-TCA, PCE, TCE, and degradation products as the primary chemicals of concern (Shaw 2002a).[1] Studies in the 1980s resulted in implementation of a "pump and treat" system (see below for details).

In 1993, the site received a Waiver under the Massachusetts Contingency Plan designating it as a non-priority site. In 1994, under the provisions of the Waiver, a Phase IIA investigation was conducted. The resulting report developed a conceptual hydrogeologic model of the site and identified 13 Potential Source Locations (PSLs) based on historical research, bedrock mapping, and environmental data. Six additional PSLs were identified in the following year (IT 2000). A second Phase II investigation report was issued in 2000 (IT 2000). The purpose of this investigation was to further define the nature and extent of VOC impacts at the Varian site, identify potential source areas, and characterize risk. Each of the 19 PSLs were investigated, and the report identified primary and low priority source areas.[2]

A Phase IV Remedy Implementation Plan was submitted for the site in December 2001, followed by a Phase IV As-Built and Final Inspection Report in October 2002. A Phase V Remedy Operation Status (ROS) was submitted for the site in December 2002. In accordance with 310 CMR 40.0893, ROS is available to sites that are conducting active operation and maintenance of remedial systems programs that will lead to a Permanent Solution.

Since 2002, semi-annual ROS reports have been issued by environmental consultants on behalf of Varian. These reports detail ongoing remedial efforts and include groundwater monitoring data. Groundwater data from 2002–2020 was compiled for this analysis, and is presented in Appendix A[3]

Remedial Actions

In 1992, a groundwater recovery and treatment system became operational at the Varian property. The system consisted of 6 extraction wells on the north and northwest portion of the site, screened in the overburden and bedrock (IT 2000), and incorporated an air-stripping system to remove VOCs.[4] In 1998, before the Waiver expired, Varian submitted a Tier 1B permit application stating that Varian would continue conducting response actions under a Release Abatement Measure (RAM) plan. The groundwater recovery and treatment system ceased operating in 2002 with the commencement of Comprehensive Response Actions (Shaw 2002a).

In 1996, as part of the Phase II investigations, VOCs were detected in the groundwater sump of a residence at 28 Hill Street. The detections prompted an Immediate Response Action plan and Imminent Hazard Evaluation that included a soil vapor survey in the surrounding neighborhood and installation of a groundwater and vapor recovery system at the residence, among other actions. Varian operated these systems until the property was purchased by Varian and the house was demolished in 2015.

Initially, the Comprehensive Response Actions were implemented with the goal of reducing groundwater concentrations below the GW-1 standard in the area north of Route 128, which was designated as a Potentially Productive Aquifer (PPA). The chosen remedial technology was *in situ* chemical oxidation (ISCO) using sodium permanganate injections. The construction report described 13 injection wells: 7 in the shallow overburden, 3 in the deep overburden, 2 in the bedrock aquifer, and 1

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[1] This report focuses on PCE, TCE, and their degradation products because 1,1,1-TCA is present at lower concentrations and forms a smaller plume than PCE and TCE.

[2] Low priority source areas were characterized as such due to a lack of evidence of VOC releases. Three PSLs were not designated as source areas (IT 2000).

[3] The data include 4,169 samples collected from 242 unique wells.

[4] Two overburden wells, RW-2 and RW-5, were screened across the overburden/bedrock interface (IT 1994).

that was used for pilot testing (Shaw 2002b). Two horizontal wells were installed under Building 3. In July 2002, permanganate injection began; in December of that year, Varian submitted a Remedy Operating Status (ROS) opinion.

In 2006, bioremediation was proposed and implemented to treat two VOC-impacted areas on the northeast corner of the site: shallow groundwater near the Unnamed Stream (to mitigate concerns of permanganate impacts to surface water) and deep overburden groundwater impacted with 1,1,1-TCA and acetone (APTIM 200b). Bioremediation treatment included injections of sodium lactate (food source) and a bioaugmentation culture. In 2007, the bioremediation program was expanded.

In 2008, permanganate was injected into two new areas: beneath Building 5 and on the southeastern portion of the property (open field area) (Shaw 2009). In 2009, an SVE system was installed in the Building 3 area to address risks from potential vapor intrusion.

In 2010, the remedial goals were revised to reflect the removal of the PPA designation for groundwater north of Rt. 128 (Shaw 2010). In 2012, a Phase III modification report addressed the Building 5 area, which was not originally included in the remedial plan. The modification was specifically to address VOCs in indoor air, and specified installation of a soil vapor extraction (SVE) system (Shaw 2012). The SVE system began operating in March 2013.

Remedial activities at the Varian site, including ISCO, bioremediation, and soil vapor extraction, continue today. In 2020, horizontal injection wells were installed beneath Building 3 to treat VOC contamination in soil using either bioremediation or ISCO (APTIM 2020b). A table showing wells that received treatments by date and treatment type is included as Appendix B.

Source Area and Plume Delineation

Source/DNAPL Areas

Building 3

The area north and east of Building 3 was first identified as a source area in the 1980s, and multiple lines of evidence indicate that separate phase DNAPL was present in the environment. In the 1990s, visible DNAPL was recovered from two wells screened in the overburden aquifer, one east and one north of Building 3.[5] This DNAPL was found to be about 50% TCE and 50% PCE (IT 2000). In 2000, IT Corporation stated “DNAPL that was released is now adsorbed in the overburden soil matrix and is no longer mobile as a NAPL” (IT 2000). As a point of clarification, though it is reasonable to assume that DNAPL mobility as a separate phase would cease or significantly decrease in the years following its discharge into the environment, it is presumed by MassDEP that most of the mass of the immobilized DNAPL at that time was trapped in pore spaces as a separate phase, and not adsorbed onto soil organic carbon.

The continued presence of separate and not sorbed-phase DNAPL was further suggested in post-2000 groundwater monitoring data. Specifically, groundwater concentrations can be used to assess the

[5] DNAPL was recovered from well RW-2 in 1993 and RW-4 in 1997. Well RW-2 is screened in both the deep overburden and the bedrock aquifer (IT 1994); RW-4 is screened in the deep overburden aquifer.

likelihood of DNAPL by using the 1% effective solubility rule of thumb.[6] The solubility of pure phase TCE is approximately 1000 mg/L, and PCE is 150 mg/L. Assuming the DNAPL was a mixture of equal parts TCE and PCE, the effective solubilities of each compound are approximately half their pure phase solubilities. The data that support the past and continuing presence of DNAPL are discussed below:

- In 2002, TCE was detected at concentrations up to 210 mg/L (OB-19-DO, 6/3/2002). The detected concentration is nearly half the presumed effective solubility, well above the 1% threshold. This well is located west of the Building 3 area.
- In 2010, TCE concentrations were even higher: up to 950 mg/L (AP-32-DO, 2/11/2010) north of Building 3.[7] This concentration approaches the solubility limit of pure TCE.
- In 2020, TCE concentrations remained elevated above the 1% effective solubility threshold, with concentrations up to 370 mg/L (AP-13-DO, 5/5/2020).[8] This well is located east of Building 3.
- The PCE data tell a similar story, with concentrations well above 1% of the solubility limit in 2002 (75 mg/L at CLO5-DOA) and 2020 (53 mg/L at AP-32-DO).

Based on the groundwater data, which indicate persistently elevated PCE and TCE concentrations, it is likely that DNAPL was and still is present in the overburden aquifer.

TCE has also been detected above the 1% effective solubility threshold in several bedrock wells located east and west of Building 3: AP-12-BR, OB-19-BR, and OB-25–28-BR. Given that the bedrock and overburden aquifers communicate locally and are not separated by a confining layer, it is possible that DNAPL could have entered fractures and fissures (secondary porosity) within the bedrock. A man-made preferential pathway between the overburden and bedrock is known to exist, as two recovery wells were screened across the overburden/bedrock interface (RW-2 and RW-3) (IT 1994). [9] Visible DNAPL was recovered from one of those wells (RW-2), and though it is unknown whether the DNAPL came from the overburden or bedrock, it appears to be clear that this well provided a conduit for possible downward migration of DNAPL into the bedrock.

It is important to note that detection of TCE and PCE above the 1% effective solubility does not provide information about the location of DNAPL, only the likelihood that DNAPL is present at the site. Thus, the TCE detections in the bedrock could indicate that DNAPL is present within bedrock fractures, but they could also result from downward migration of groundwater that was in contact with DNAPL in the overburden aquifer. Additional studies are needed to fully characterize the extent of DNAPL by depth.

Soil concentrations also support the presence of DNAPL. In 2019, potential residual DNAPL was discovered beneath Building 3, based on elevated PCE concentrations (up to 170 mg/kg at 12 ft bgs, AP-40-S). Slightly north of the building, PCE concentrations were found up to 260 mg/kg (OB-50-S). The maximum soil concentration in the absence of DNAPL was estimated following Kueper and Davies (2009) and found to be about 150 mg/kg. This value is sensitive to soil characteristics, which are variable at the site, and thus is not an exact value. However, it suggests that the measured PCE

[6] "Certain concentrations are now generally accepted by the research community as indicating a high likelihood of a subsurface source of DNAPL across a wide range of site types (i.e., 1% or more of a compound's solubility)" (EPA 1993).
[7] This well received injections beginning in 2012, so as of 2010, it was still in use as a monitoring well.
[8] This well has received injections since 2002, and thus may not represent the overall groundwater condition.
[9] These two wells are still in existence and have been used as treatment wells (2002–2004) and monitoring wells (2002–2020).

concentration is near or above the maximum possible soil concentration, which provides a line of evidence in support of residual DNAPL in the vadose zone beneath Building 3.

In the Building 3 source area, a delineation of DNAPL is difficult due to the ongoing operations inside the buildings. However, consideration should be given to the options available to better identify and map DNAPL around the building, such as horizontal borings and/or Membrane Interface Probes (MIPs), or a partitioning interwell tracer test. Data gaps also exist in the parking lot south of Building 7, as well as downgradient of the treatment area between the Building 3 Area and Building 7.

Building 5

Groundwater concentrations provide a line of evidence in support of DNAPL near Building 5. TCE was detected up to 440 mg/L (OB-35-DO, 5/3/2005), well above 1% of the solubility limit of pure TCE (though PCE was also detected, suggesting that DNAPL, if present, is a mix of PCE and TCE). Evaluation of post-2005 data is inconclusive because this well has received repeated injections of permanganate, most recently in 2017. However, the 2020 data suggests that PCE-containing NAPL may still be present (7.9 mg/L, > 1% of solubility).

Though DNAPL may be present beneath Building 5, the effects of ongoing treatment in the overburden suggest that the source area is being effectively treated by existing injection wells (see following section). For that reason, additional spatial delineation of DNAPL zones is not necessary at this time. However, little is known about the bedrock aquifer in this area, as there are no bedrock wells (for monitoring or treatment). Installation of bedrock wells beneath and downgradient of the source area on the eastern side of Building 5 would be needed in order to determine if DNAPL has migrated down into the bedrock aquifer.

South Property

In 2002, groundwater in this portion of the site contained TCE and PCE concentrations suggestive of DNAPL (e.g., 56 mg/L TCE and 4 mg/L PCE at AP-21). Evaluation of more recent data in this well is difficult because it was used for permanganate injection as recently as 2019; however, there is evidence of VOC rebound after application of treatment. The rebound indicates that untreated VOCs are still present in the area, which may be part of a separate phase (DNAPL) or adsorbed to organic carbon in the soil matrix. Sampling in the next few years will determine if the most recent treatment was effective, or if additional treatment is needed. Whether or not additional treatment is needed, the source area is well-delineated in the overburden with upgradient and downgradient wells containing notably lower groundwater concentrations. Concentrations in bedrock wells east and west of the source area are also lower, which suggests that there is no source material/DNAPL in the bedrock.

Dissolved-Phase Plume

The Phase II Report (IT 2000) included plume maps depicting PCE, TCE, 1,1,1-TCA, and their degradation products in the shallow overburden, deep overburden, and bedrock aquifers. These maps were generated based on groundwater data collected in 1999. We evaluated the maps to determine if the plumes were well-delineated at the time. In particular, we looked for wells in which VOCs were not detected; a ring of non-detects surrounding the known extent of the plume (taking into account groundwater flow direction) is desirable to have increased confidence in the plume location. We performed a similar exercise using newly created (2020) VOC plume maps provided to DEP by APTIM.

In general, we found sufficient wells to delineate the plume in the 1999 data, with the exception of the Sonning Road area, where there were no shallow (water table) monitoring wells on the eastern loop of this circular roadway, despite the installation of two deep wells (OB-6-DO and CPT-2) and one bedrock well (OB-6-BR). Moreover, we disagree with the statement that the source of TCE detected in the Longview Terrace/Hill Street area "is uncertain" and "probably not related to historical sources on the 150 Sohier Road property" (IT 2000, p. 144). We believe that the evidence then and now strongly connects the TCE in this area to releases on the Varian property.

In addition to the lack of water table wells in the eastern loop of Sonning Road, we also believe that monitoring of installed wells in the western neighborhood areas was prematurely curtailed, which has created data gaps in our understanding of plume conditions in this sensitive location, and that a lack of data has resulted in what appears to be anomalous plume boundaries. Details are presented in the following sections.

Shallow Overburden

In 1998–1999, the VOC plume originating at the Varian facility stretched west past Longview Terrace, south to 39 Tozer Rd., and north of Rt 128 (Figure 6).[10] Two other areas of elevated PCE are located west of the site and appear to be associated with dry cleaners (though neither of these sites appear to be impacting the neighborhood downgradient of the Varian site, nor comingling with the Varian plume).

At the time, the outer extremities of the plume were relatively well understood, with multiple wells containing no detectable VOCs located between the Varian plume and the plumes to the west. As previously mentioned, however, the existence of a water table plume could not be ascertained in the easterly loop of Sonning Road, due to the lack of an adequate number of shallow wells.

VOCs were also not detected south of the site, at wells located near the confluence of Stream A and the Unnamed Stream. Fewer wells were sampled on the eastern side of the plume tail. The northeastern plume (north of Rt 128) is not well defined, which is apparent in the TCE and cis-1,2-DCE maps that show an abrupt edge to the plume near Mark Street.

The most recent depiction of shallow overburden contaminant contours (Figure 7) shows a plume of similar size to the 1999 maps. However, fewer wells were sampled in 2020 than 1999, and nearly every well had at least one contaminant of interest detected (one exception is P-11A, located west of the plume along Longview Terrace). The lack of data points to the west of the 100 µg/L (0.100 mg/L) isocontour line on the western edge of the plume is problematic and needs to be addressed. And the westerly (foot-shaped) lobe now appears even more anomalous and in need of an explanation; while it is possibly due to the bedrock peak in this area, it may also be the continuation of a water table plume at and west of the railroad track—areas without groundwater monitoring data. In fact, the existence of a water-table plume in areas west of the railroad tracks—and in the Sonning Road neighborhood—appears highly likely, given the monitoring data from Stream A at station "SCDS", located east of 3 Longview Terrace, which has consistently contained 20 to 30 µg/L of VOCs since monitoring began in 2008. Given dilution in this stream from surface water runoff, the concentrations of VOCs in shallow groundwater in this area would be presumably some multiple of the levels in the stream itself.

[10] The apparently detached TCE plume is the result of incomplete sampling. In 1999, more wells were sampled, which resulted in a continuous plume as seen with PCE and cis-1,2-DCE.

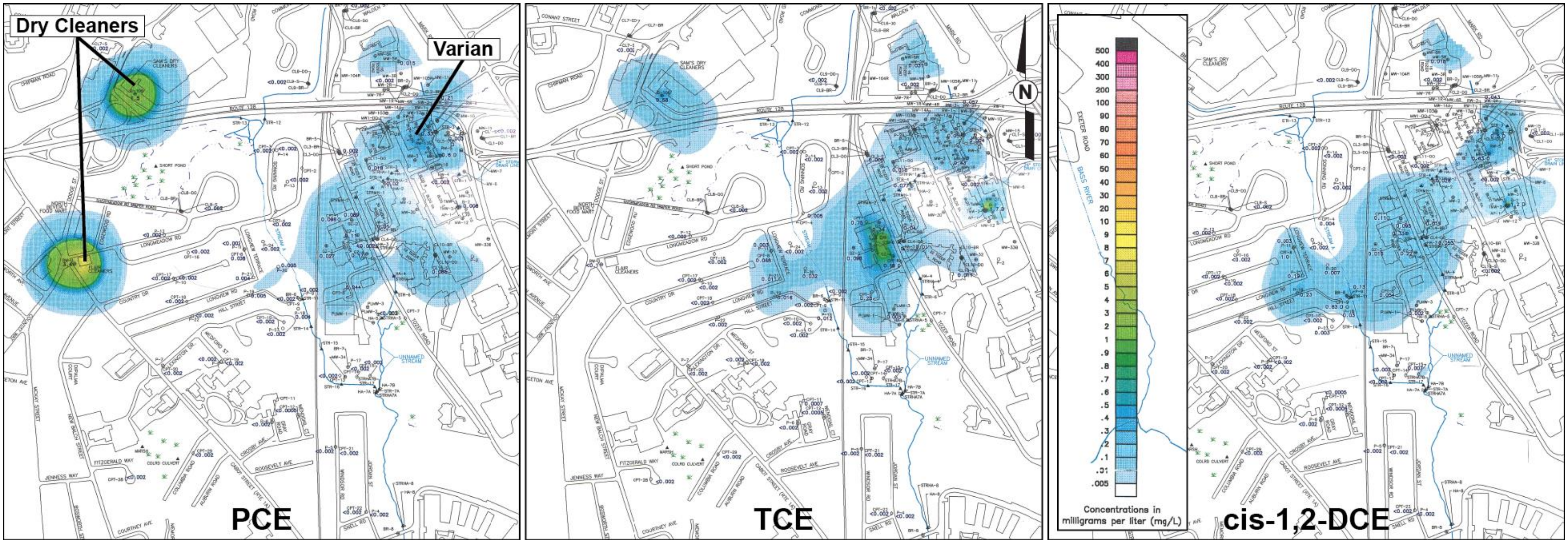

Figure 6. Shallow overburden plumes of PCE, TCE, and cis-1,2-DCE presented in the Phase II report (IT 2000).

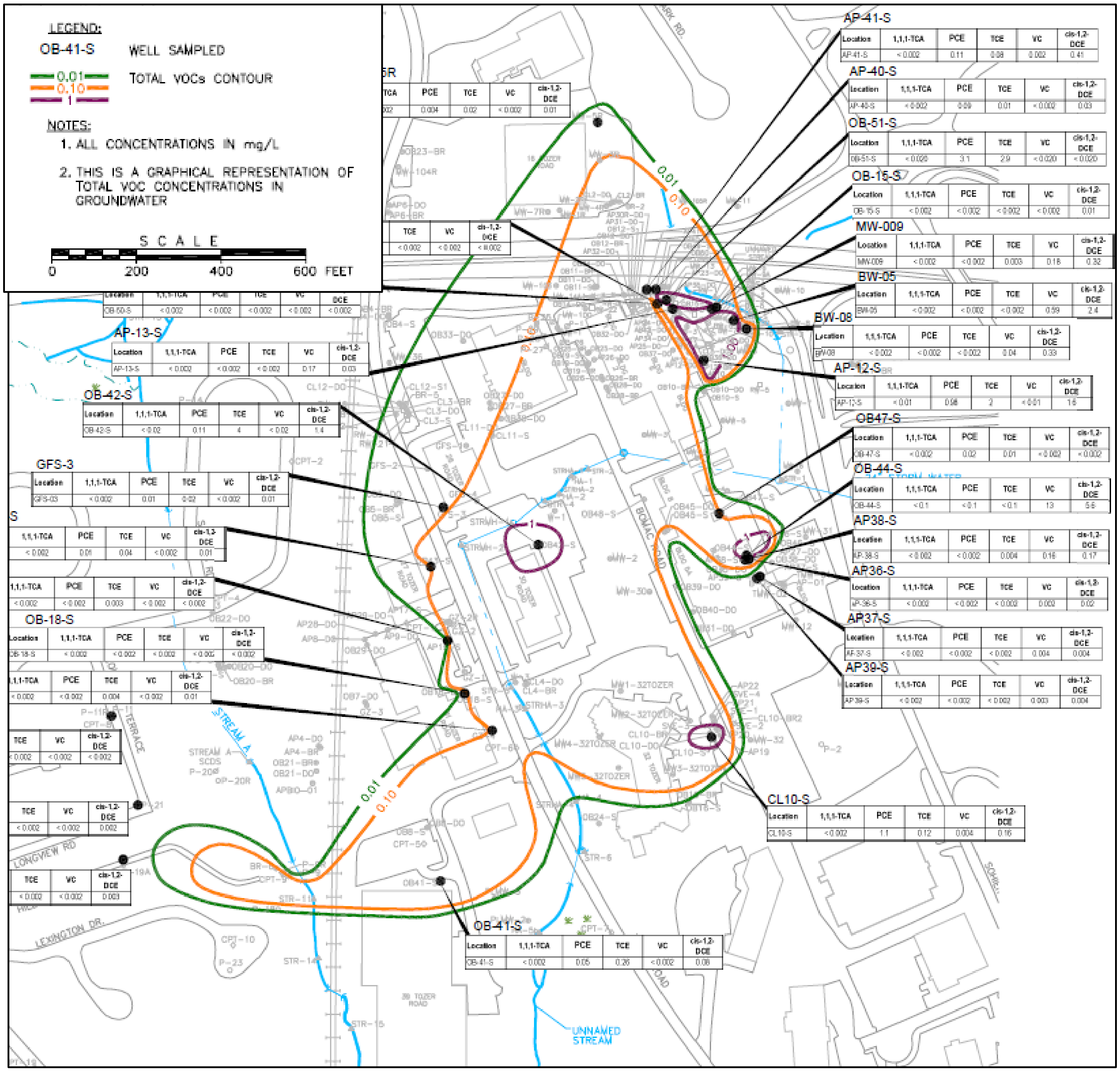

Figure 7. VOC plume in shallow overburden aquifer, based on data from May 2020.

It is noted that in December 2020, as part of an effort to evaluate the vapor intrusion pathway in residential neighborhoods, APTIM collected additional water samples from five wells near the western lobe. No VOCs were detected in P-09R (Hill St.), P-11R (Longview Terrace), or P-23 (Lexington Dr.). In two wells, cis-1,2-DCE was detected below the GW-2 standard (P-19A [Hill St.] and P-21 [Longview Ter./Longview Dr.]). TCE was also detected in P-21 below the GW-2 standard. Based on these recent results, VOC contamination in groundwater extends west of the plume shown in Figure 7, particularly along Hill Street and to at least the intersection of Longview Terrace. and Longview Drive. These data affirm the need for additional sampling in the areas north of the lobe.

In addition to the western edge of the shallow overburden plume, there are also data gaps in the southerly direction. For example, there are no wells located south of OB-41S, which contained PCE, TCE, and DCE. Without data south of that well (direction of groundwater migration), it is not possible to determine the southern extent of the plume.

Deep Overburden

In 1999, the extent of VOC contamination in the deep overburden was more extensive than the shallow overburden, with DCE present as far west as Cabot St. and as far south as Tudor Rd. (Figure 8). Two purported detached DCE plumes are presented: one east of 32 Tozer Rd. and one near the intersection of Cabot St. and Russel St (south). While a possible occurrence, detached plumes are an unusual phenomenon, generally occurring only in highly transmissive aquifer systems following the rapid depletion of source area residual NAPL (API 2007). More typically, reports of such detachments are due to a lack of a sufficient network of data points between the source area/plume and purported discrete downgradient plume. That appears to be the case here, given the limited well network in this area, and absence of other likely source areas.

More recent plume depictions (Figure 9) correctly infer the continuous nature of the source area plumes east of 32 Tozer Road, but fail to adequately follow up on the southerly detections of cis-1,2-DCE, inferring the dissipation of site contaminants in this area. In the depiction of 2020 conditions in Figure 9, well MW-034, located beneath the building at 39 Tozer Rd., was the southernmost well sampled. This well contained cis-1,2-DCE at 2000 µg/L; TCE and vinyl chloride were detected at lower concentrations.[11] Since 2002, no samples have been collected from the deep overburden wells south of 39 Tozer Rd. Therefore, we have no recent information about the purported detached plume area shown in the Phase II report (IT 2000). Additional sampling of the deep overburden in this area is needed to fully delineate the VOC plume.

There are discrepancies between the most recent piezometric surface map and the deep overburden plume. Specifically, the piezometric surface map does not show southerly groundwater flow, whereas the plume extends south between Stream A and the Unnamed Stream. The inconsistency is likely with the piezometric surface map, which does not include data south of OB-8-DO (north of the building at 39 Tozer Rd.). In addition to the sampling of VOCs discussed above, further water level gauging is needed in order to understand plume migration and predict future movement.

The 2020 results also do not adequately represent the deep overburden VOC plume in the residential neighborhood west of the railroad tracks. In 1999, cis-1,2-DCE was detected beneath Lexington Dr. and Medford St, as well as along Sonning Rd and Country Dr. Since 2002, the deep overburden wells in this area have not been sampled (with the exception of CL08-DO on Longmeadow Rd., which contained no detectable VOCs in 2020). Therefore, the current status of VOCs in the deep overburden in this area is mostly unknown, and additional sampling is needed to delineate the western edge of the deep overburden VOC plume.

[11] TCE concentrations at this well have been steadily decreasing since 2006. The observed increase is cis-1,2-DCE is further evidence of ongoing degradation via reductive dechlorination.

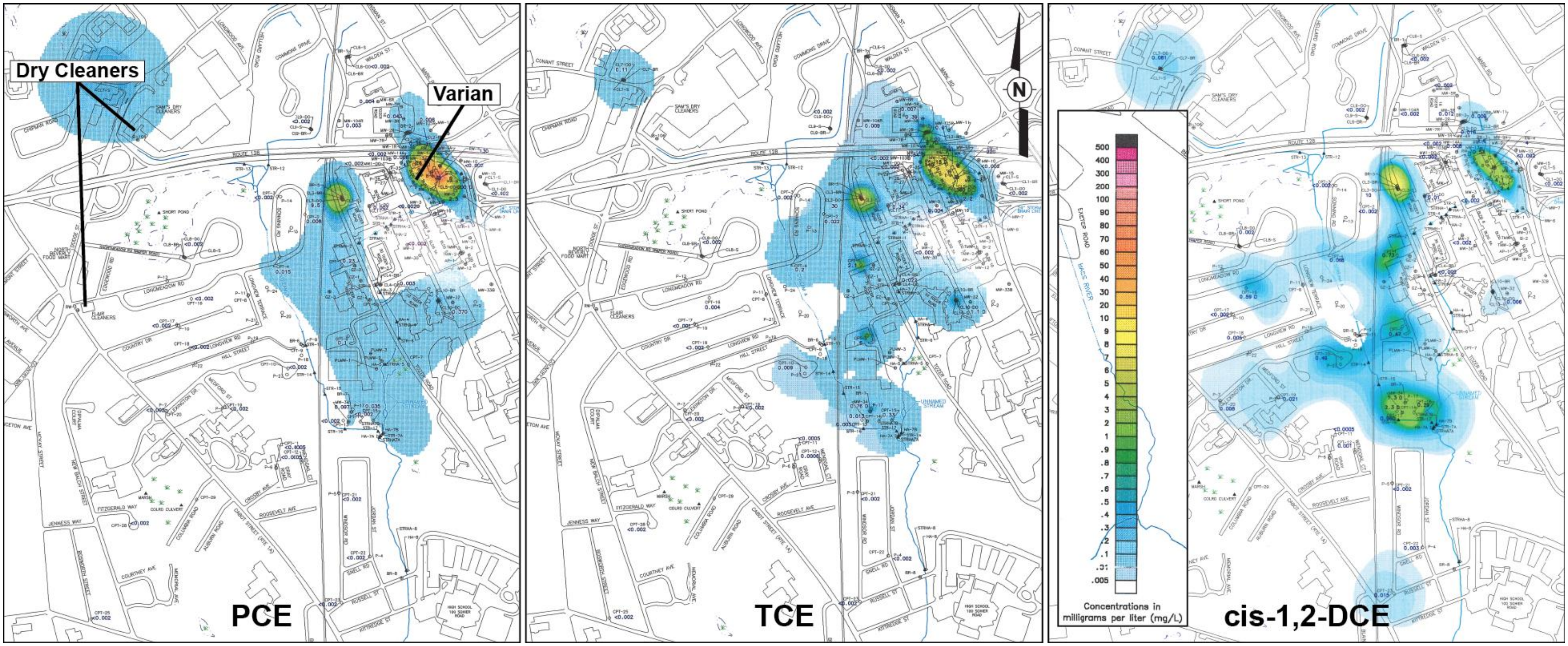

Figure 8. Deep overburden plumes of PCE, TCE, and cis-1,2-DCE presented in the Phase II report (IT 2000).

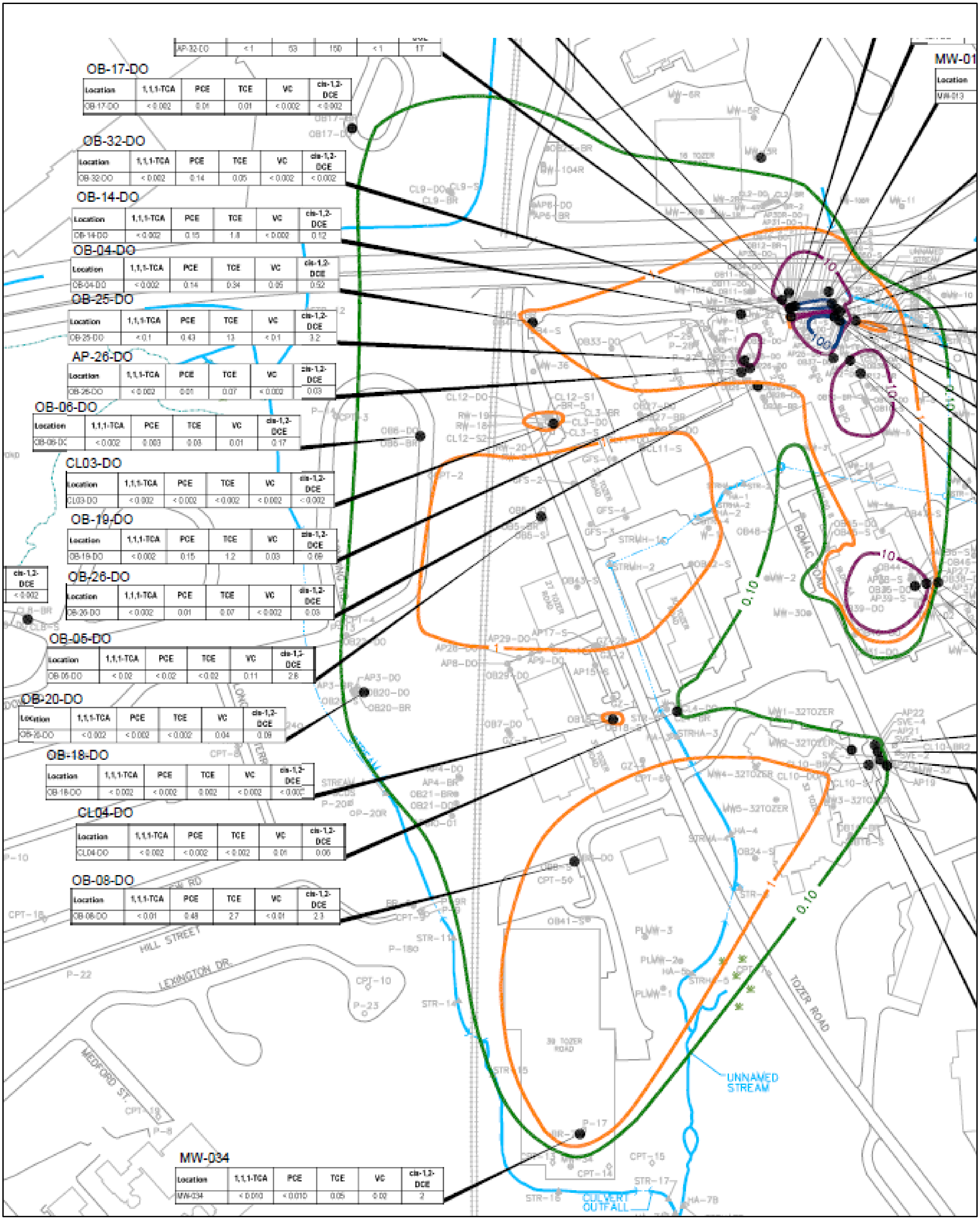

Figure 9. VOC plume in the deep overburden aquifer, based on data from May 2020.

Bedrock

In 1999, the VOC plume in the bedrock aquifer extended south of the confluence of Stream A and the Unnamed Stream, west beneath the residential neighborhood (Hill Street area), and north to Commons Dr. and Walden St. (Figure 10). Fewer bedrock wells resulted in more uncertainty regarding the extent of the plume. For example, no bedrock wells were placed along Lexington Dr., where the deep overburden plume extended to Cabot St., so it's unknown if the bedrock plume had a similar extent. Data gaps such as this existed west, south, and north of the plume.

By 2020, the presented bedrock plume had reduced in size with a number of wells with low (or non-detectable) concentrations of VOCs (Figure 11). More specifically, the well beneath 39 Tozer Rd contained VOCs below the detection limit, and two wells west of Stream A contained low or non-detectable VOC concentrations. Three wells north of the plume were sampled and VOCs were not detected.

In 2020, the bedrock plume had a smaller extent than the deep overburden plume. Given the likelihood of ongoing migration from the overburden to the bedrock, it is important to continue monitoring bedrock wells where VOCs are present in the deep overburden.

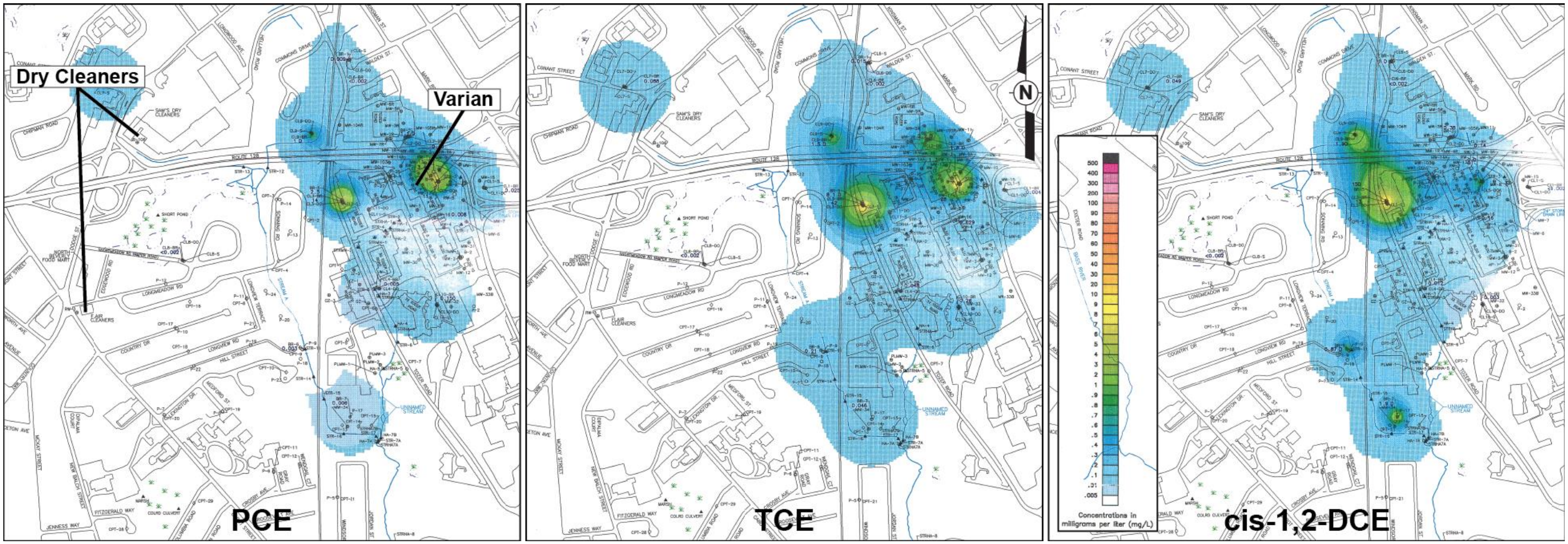

Figure 10. Bedrock plumes of PCE, TCE, and cis-1,2-DCE presented in the Phase II Report (IT 2000).

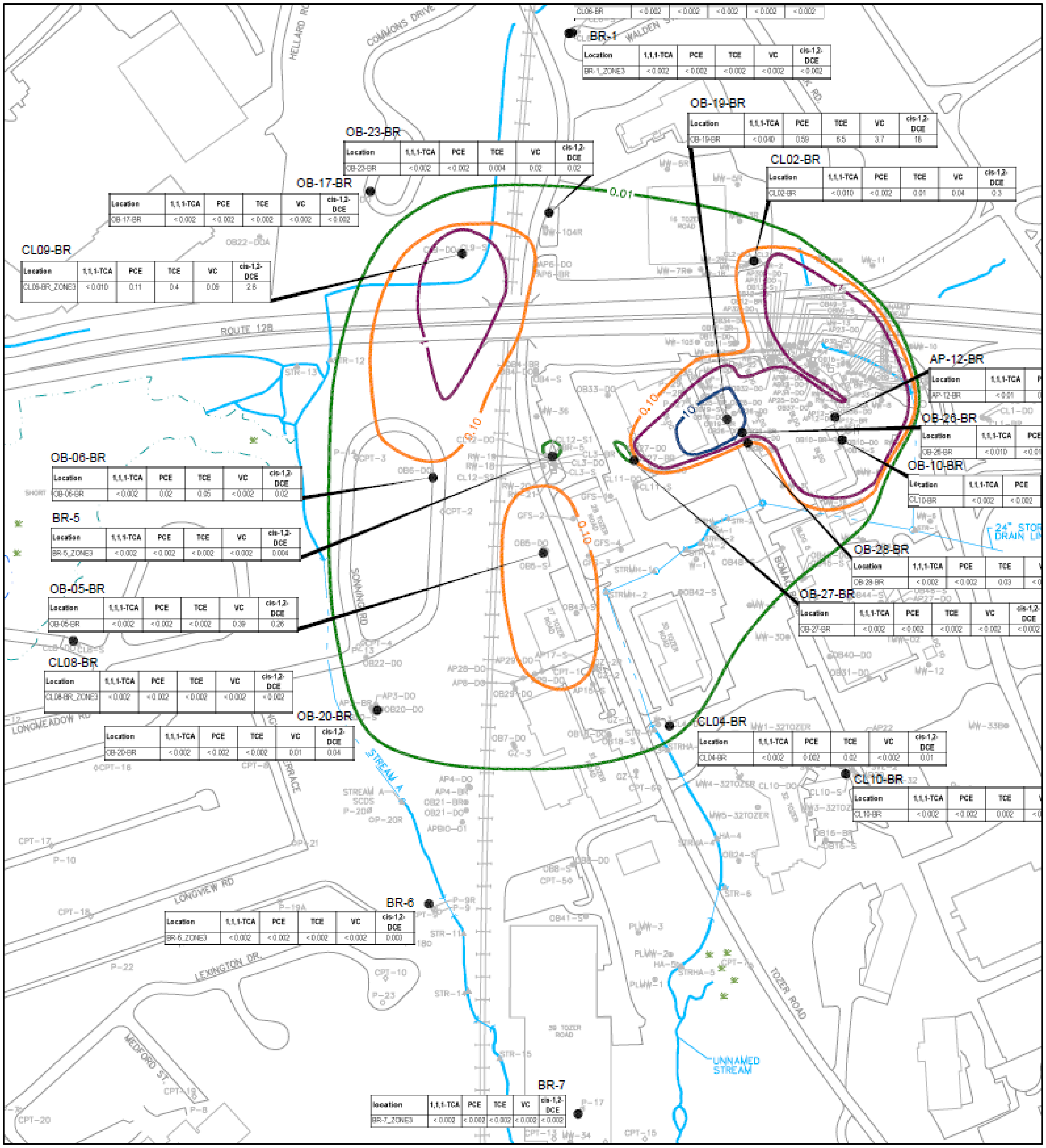

Figure 11. VOC plume in the bedrock aquifer, based on data from May 2020.

Plume condition in Sonning/Longview/Hill Neighborhood

Given its location immediately downgradient of the Varian site, the residential neighborhood on Sonning Road, Longview Terrace, and Hill Street is of special interest. Its location in a filled groundwater discharge zone (Stream A and associated wetlands), combined with a shallow water table, raises concerns over past, present, and potential future vapor intrusion pathways.

Though there was and is no evidence of highly elevated VOC concentrations in the Sonning Road area, the lack of shallow monitoring wells on the easterly loop of this roadway prevents a conclusive determination in this regard. It is highly likely that a water table plume existed and continues to exist in the Patton Park area, with elevated VOC concentrations present beneath Longview Terrace pre-2000. The most contaminated location—the former home at 28 Hill Street—is due to the presence of a localized bedrock peak.

There is, however, evidence that water-table VOC concentrations in this area have significantly decreased over time, due in part to the remedial measures that have been ongoing in source areas and previous remedial measures in this area. Declining concentrations are demonstrated in Figure 12.[12] Ongoing monitoring of these and other wells in this area will be needed to ensure that these contaminant reductions continue over time.

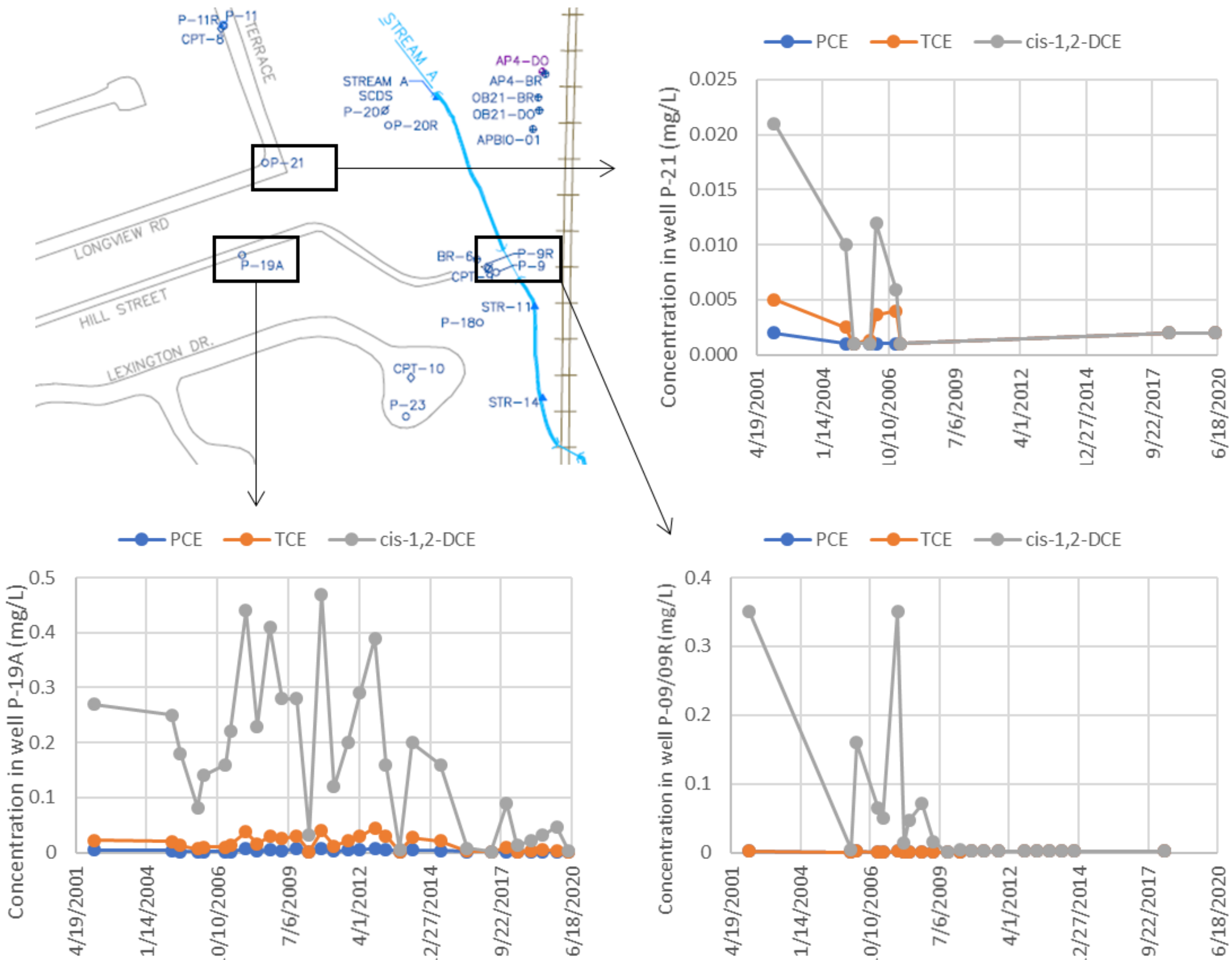

Figure 12. VOCs in water table wells located in the residential neighborhood near Hill Street have declined since 2002.

Stream Contamination

Two streams exist at the site. The "Unnamed Stream" flows south along the eastern boundary of the former Varian property before turning west (in an underground culvert) and then south again along Tozer Road. This stream historically received VOC discharges from Varian operations. The second stream, identified as "Stream A," also flows south, but is located on the western portion of the site and did not receive direct waste discharges from Varian operations. It is located to the west of the Sonning Rd. loop, flows south beneath Patton Park, and crosses under the railroad tracks onto the property at 39

[12] Wells in the residential area with no VOC detections in the past 20 years or no recent data were excluded from the figure.

Tozer Rd. The confluence of the streams is located south of the building at 39 Tozer Rd. Figure 13 shows the stream locations.

In addition to providing a means to evaluate risks to potentially exposed populations, an evaluation of surface water contamination data can also be a valuable line of evidence in understanding the nature and extent of groundwater contamination. This relationship, along with an evaluation of potential risks, are discussed in the following sections.

Nexus with Groundwater Plume

Both streams are in hydraulic communication with groundwater and receive some discharge from shallow overburden groundwater. This is especially true for Stream A, located in a topographically low/wetland area functioning as a localized groundwater discharge point, and is further reinforced by the increasing flow downstream compared to upstream. As such, both streams continue to receive mass inputs of VOCs that are present in shallow groundwater in the areas that they traverse.

VOC concentrations in both streams have been monitored by APTIM for about 25 years. Figure 13 shows the stream sampling locations, VOC data from the past 18 years (PCE, TCE, and cis-1,2-DCE), and the shallow groundwater plume mapped by APTIM, based on data from May 2020.

In 2020, concentrations in surface water were highest in the Unnamed Stream on the former Varian property. Shallow groundwater, which contains VOCs > 5 mg/L near Building 3, enters the Unnamed Stream, resulting in VOC concentrations of a similar order of magnitude. Large fluctuations in VOC concentrations are likely due to the precipitation events/surface water runoff and periodic groundwater treatments. Concentrations in the Unnamed Stream decrease with increasing distance from this area. At the confluence with Stream A, VOC concentrations are about 100 times lower than measured at the former property. The reduction in concentration with distance is likely due to dilution with unimpacted groundwater and surface water runoff, as well as volatilization.

Conversely, VOC concentrations in Stream A do not decrease with distance in the direction of flow. Samples collected upstream, in Patton Park, contain a similar concentration to downstream samples (collected near the confluence with the Unnamed Stream). In December 2020, APTIM collected a stream sample at 57 Sonning Road, which is farther upstream than Patton Park, and no VOCs were detected. The increasing VOC concentration with distance in Stream A indicates that groundwater infiltration is the source of VOCs in this waterbody, and that the shallow groundwater plume is likely larger than depicted on the map.[13]

The Culvert Outfall, which drains surface water and groundwater from 39 and 31 Tozer Rd. (IT 2000), contains the second highest concentrations of VOCs in local surface water. Again, this suggests that the groundwater plume extends farther south than shown on the map. There are no known surface soil VOC impacts at these properties, so the likely source of VOCs to the culvert outfall is shallow groundwater. To account for the VOC concentrations measured at the outfall (0.109 mg/L in May 2020), one would expect the shallow groundwater plume to extend beneath a larger portion of the two properties.

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[13] The sample location STRM A SCDS contained detectable concentrations of TCE and cis-1,2-DCE in May 2020, indicating that impacted shallow groundwater was likely present in the stream. In November 2019, the VOC concentration at this location was greater than 0.05 mg/L. This sample location is located upstream of the plume edge as depicted on the map. To account for the presence of VOCs in the stream at this location, the plume likely extends north to at least Patton Park.

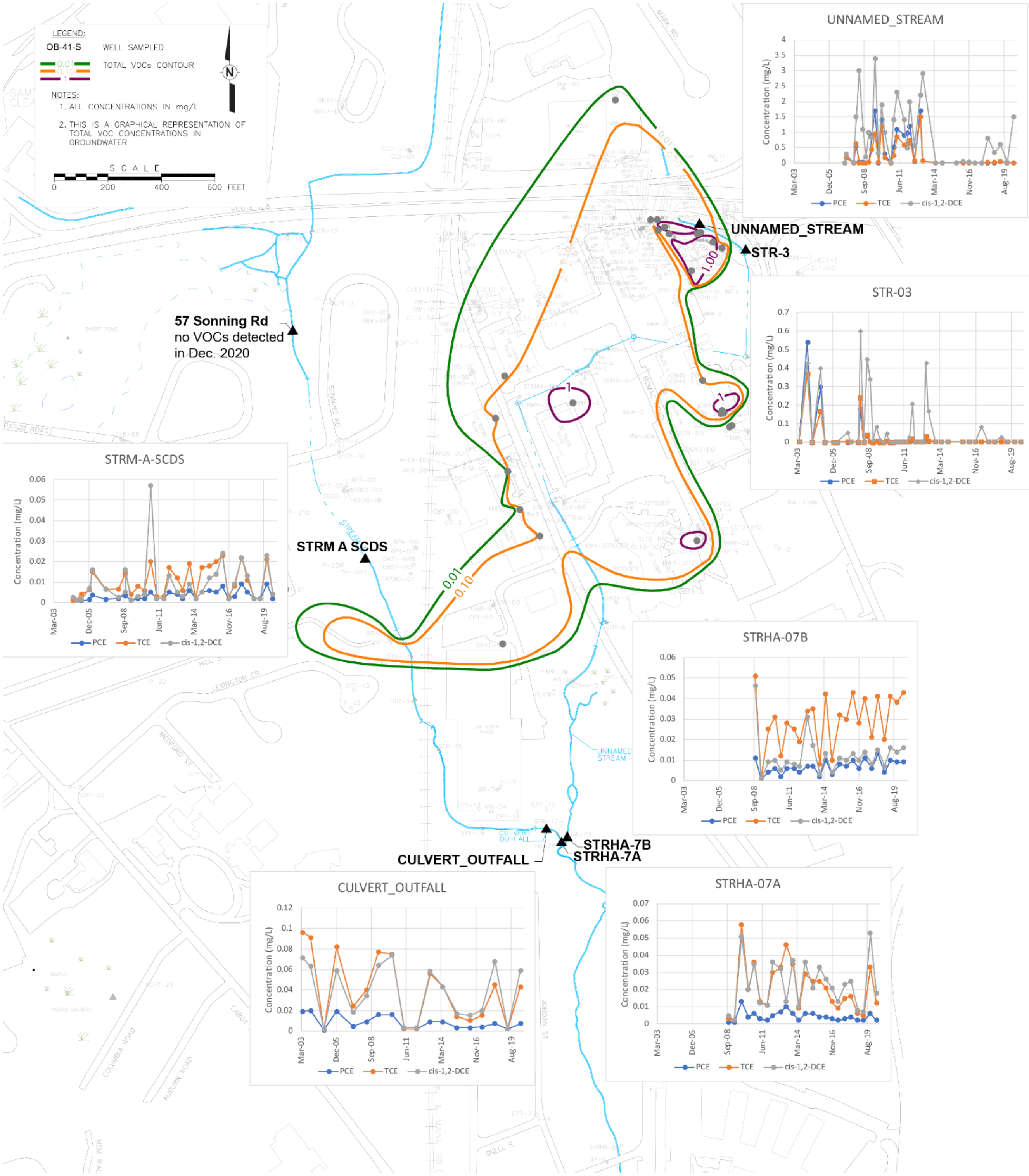

Figure 13. VOCs, including PCE, TCE, and cis-1,2-DCE, have been detected in the Unnamed Stream and Stream A for over 2 decades. VOCs are present outside the shallow groundwater plume as depicted by APTIM.

Risks Posed to Neighborhood

As part of the Phase II environmental assessment, IT (2000) evaluated the human health risk posed to children wading along the edges of Stream A and the Unnamed Stream. Given the shallow nature of the streams (4–6”), swimming, and thus ingestion of water, was not considered a likely exposure pathway.

Thus, the risk assessment evaluated the potential for dermal contact with surface water. The evaluation assumed 2 hours of exposure per day for 76 days per year, and to be conservative, assumed that all exposure was to surface water with the highest measured concentrations.

Based upon the collection and analysis of 124 surface water samples, the highest levels of contamination were determined to be in the Unnamed Stream west and south of the former Varian property. The temporal average concentrations (1997–1998) of contaminants in five sampling stations along this reach of the stream were used to calculate the Exposure Point Concentration (EPC) values in the risk assessment: TCE at 40.6 µg/L, PCE at 6.9 µg/L, and cis 1,2-DCE at 10.2 µg/L (IT 2000). Using these values and exposure assumptions, the risks from exposures to chemicals with threshold health effects was determined to be a Hazard Index (HI) of 0.2, which was below the allowable limit of 1; the risks from exposures to chemicals with non-threshold (cancer) effects was an Excess Lifetime Cancer Risk (ELCR) value of 1×10^{-6}, which was below the allowable limit of 1×10^{-5}. As such, the assessment concluded that non-carcinogenic health hazards and carcinogenic risks are not significant, and thus exposure to the stream water was "unlikely to result in adverse health effects" (IT 2000).

Under the MCP, an HI value of less than 1 means that an exposed person would be unlikely to experience a non-cancer health effect (e.g., organ damage) even over a lifetime of exposure. With respect to cancer, an ELCR limit of less than 1×10^{-5} means that a person exposed to carcinogenic chemicals (like TCE and PCE) have an increased risk of developing cancer of less than 1 extra chance in 100,000 chances (for comparison, about 1 in 3 Americans will develop cancer in their lifetime, i.e., each American has a 1 in 3 chance of developing cancer).

As specified in Section 7.3.3.9 of MassDEP Guidance for Disposal Site Risk Characterization (MassDEP 1995), "exposure point concentrations used to evaluate swimming and wading exposures should represent conservative estimates of the arithmetic mean concentration." The EPC values calculated in the Phase 2 report do not appear to comport with this directive. As depicted in Figure 14 the concentration of TCE measured in this reach of the stream (from station STR-05 to station STRHA-05) were anomalously low during three of the four 1997 samples—perhaps because of dilution from significant rainfall events preceding the sampling events. The results for PCE and cis-1,2-DCE were similarly low.

As the mechanism of stream contamination is via the discharge of contaminated groundwater, the EPCs should reflect "base flow" conditions, which are presumably more representative of day-to-day conditions. As such, a suitably conservative EPC value for TCE would be 60 µg/L, with PCE at 11 µg/L. Using these values, and correcting a mathematical mistake in the original risk assessment, the revised Hazard Index would be 0.71 and the revised ELCR would be 2.6×10^{-6}, which are still below the allowable limits.

In the 20 years since this risk assessment was conducted, scientific studies have shown that some chemicals are less toxic than once believed, while other chemicals are more toxic. Of relevance to this site was the change to the toxicity values for TCE, which is now considered to be more toxic than once believed. If these new toxicity and EPC values were used to re-calculate risk in the 2000 Phase II report, the resultant HI and ELCR values would be 0.98 and 4.7 x 10-6, which would have still been below the allowable limits.

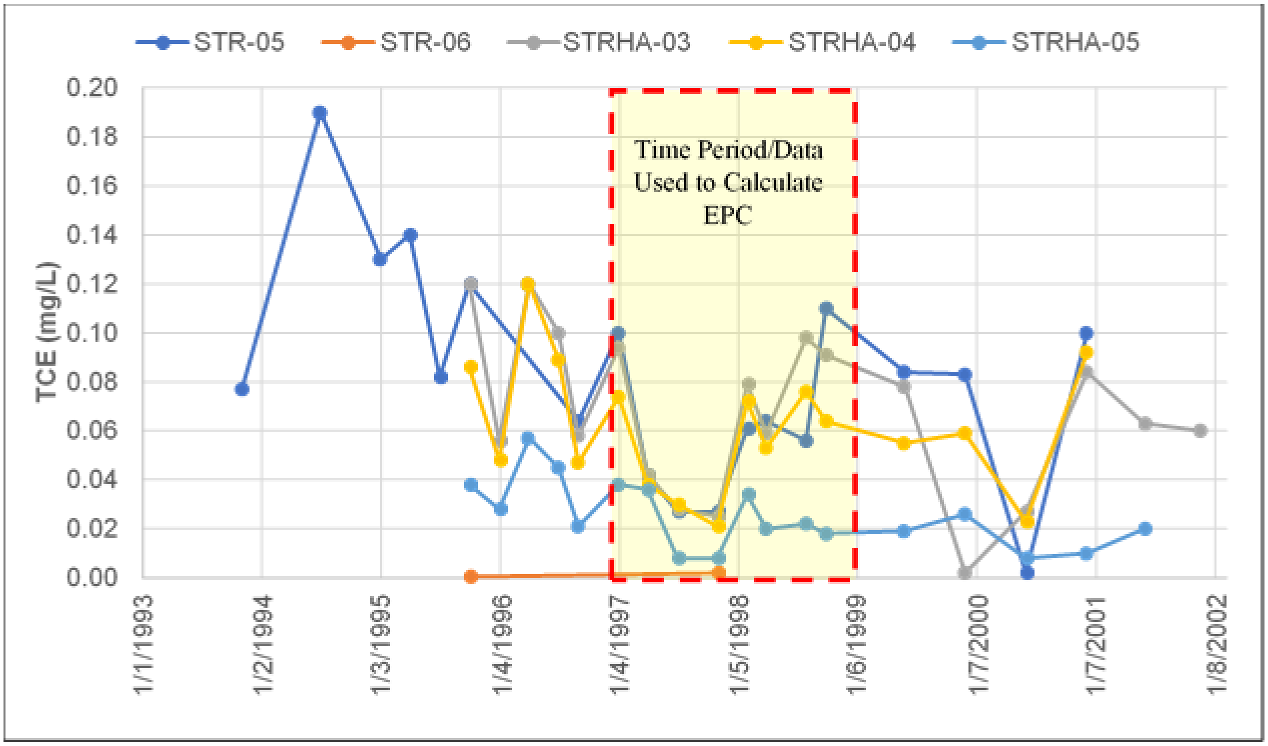

Figure 14. TCE concentrations at specified sampling points in Unnamed Stream used to calculate Exposure Point Concentrations for Phase II risk assessment.

Notably, the concentrations of site contaminants in Stream A and the Unnamed Stream have decreased over the years, though remain elevated. We have reviewed the last 4-years of available data for both streams and have determine that the maximum concentration of TCE was 43 µg/L, with maximum values of PCE and cis-1,2-DCE of 13 µg/L and 53 µg/L, respectively. Using these maximum values, we have calculated an HI value of 0.7, and an ELCR value of 3.8 x 10^{-6}. Even at these maximum values, the level of risk does not exceed allowable limits.

Many stream sample locations, however, including some of those with the highest historical VOC concentrations, have not been sampled since 2001. Additional sampling of the Unnamed Stream in areas that historically had the largest VOC concentrations should be done in order to confirm the continued condition of no significant risk.

In addition to dermal exposures to contaminants in the stream water, another concern would be dermal exposures to contaminants in the stream sediments, or to soils near the streams that may have been impacted by flooding events.

According to the 2000 Phase II comprehensive site assessment report, only three sediment samples were taken at this site—all in the Unnamed Stream, in the northern end of the property. There were no samples taken in the Unnamed Stream as it flows south of the former facility, in the reach up to and beyond the confluence point with Stream A. This is problematic because of the concern that DNAPL wastes may have been disposed directly into this stream in the past. In fact, the existence of a source area at 31 Tozer Road is likely due to the flow of DNAPL to this location via the Unnamed Stream. In addition to possible exposure concerns, residually contaminated sediments can continue to function as a source of dissolved-phase contamination to the Streams. This data gap needs to be corrected.

Lastly, if the streams were to flood, soil could become contaminated with VOCs. Although this pathway was not addressed in the Phase II report, we calculated the maximum concentration of PCE, TCE, and cis-1,2-DCE that could result from flooding of either stream, including in the area of Patton Park. Using the maximum VOC concentrations from the last 4-years, as previously delineated, we estimated a maximum soil concentration value of less than 0.3 mg/kg each for TCE, PCE, and cis-1,2-DCE, via equilibrium partitioning calculations with an assumed fraction of organic carbon (foc) value of 0.05, consistent with an organic topsoil. These values are well below allowable limits for playground exposures.

Efficacy of Remedial Activities

In 2002, Comprehensive Response Actions began at the site. In the subsequent 18 years, there have been 81 wells in 6 separate areas that received Remedial Additives (e.g., sodium permanganate, sodium lactate). Three remedial technologies have been applied across the site: *in situ* chemical oxidation (ISCO), bioremediation, and soil vapor extraction (SVE). The remedial areas are shown on Figure 15.

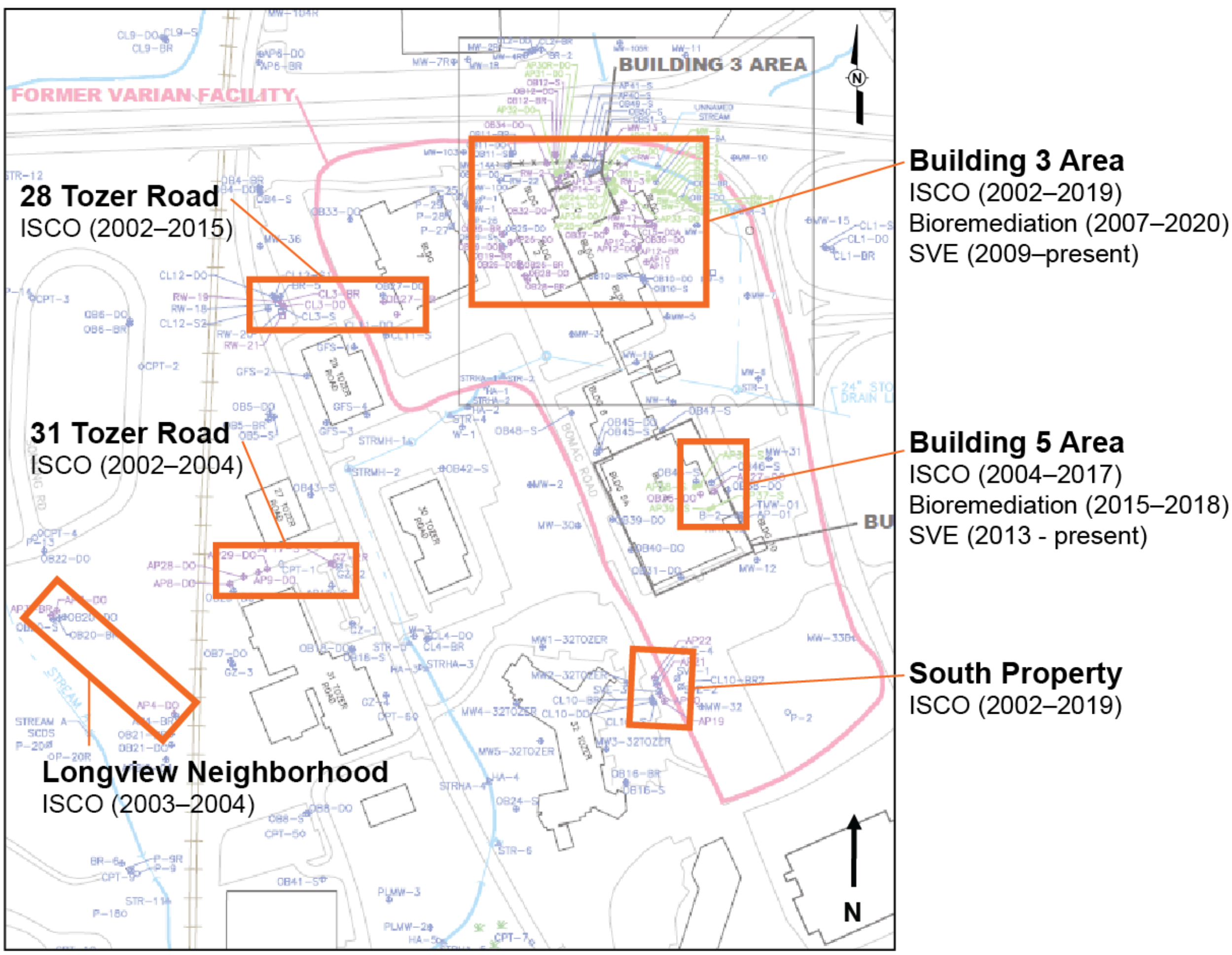

Figure 15. Remedial areas, technologies, and application dates at the Varian site.

In evaluating the efficacy of the remedial actions conducted to date, we examined several factors:

- Composition of VOCs: ISCO oxidizes PCE, TCE, and their degradation products to form carbon dioxide and chloride ions. Biodegradation occurs via reductive dechlorination; PCE is transformed to TCE, which is then reduced to DCE, vinyl chloride, and finally ethene. Thus, shifts in the VOC composition from predominantly PCE/TCE to DCE is indicative of biodegradation.
- Concentration of VOCs: If successful, remedial activities should reduce the overall concentration of VOCs in both source area and downgradient wells. VOC "rebound" occurs when treatment temporarily reduces the concentrations, but VOC concentrations subsequently rise. Rebound can be caused by new material entering the well from upgradient, untreated material desorbing from soil, or untreated material dissolving into groundwater from a separate phase (DNAPL).
- Temporal trends: To evaluate the changes in composition and concentration, we examined the concentration of VOCs over time in selected wells.
- Spatial trends: To evaluate the efficacy of the remedial actions in reducing plume size, we examined wells located both near to and far from source areas.

Downgradient/Plume Treatments

28 Tozer Road

Beginning in 2002, at least six wells have received ISCO treatments along Tozer Road, north and northeast of the building at 28 Tozer Road (APTIM 2020b, IT 2001). Multiple treatments were applied, with the most recent ISCO injection in 2015.[14] Both bedrock and deep overburden wells were treated. Two downgradient well clusters were designated as monitoring wells for this treatment area: OB-05-DO/BR and OB-06-S/DO/BR (Figure 16A).

Results after the initial injection were largely positive. In 2002–2005, VOC concentrations in the bedrock monitoring wells decreased by up to 99% (OB-05-BR, Figure 16B). Similarly, VOC concentrations in the deep overburden decreased during the same period, with OB-05-DO showing a more significant decrease than OB-06-DO (Figure 16C). Beginning in 2009, VOC concentrations rebounded in both deep overburden wells, but have been steadily declining since about 2013. Though multiple permanganate injections occurred between 2006 and 2013, the changing composition of VOCs suggests that upgradient biotreatment, i.e., in the Building 3 area, is responsible for the reductions observed in the past 5–7 years. Specifically, the rise of cis-1,2-DCE coupled with decreasing concentrations of TCE and PCE is indicative of biodegradation rather than *in situ* oxidation (Figure 16D).

[14] For example, well OB-27-DO received ISCO treatments in 2006, 2007, 2012, and 2015.

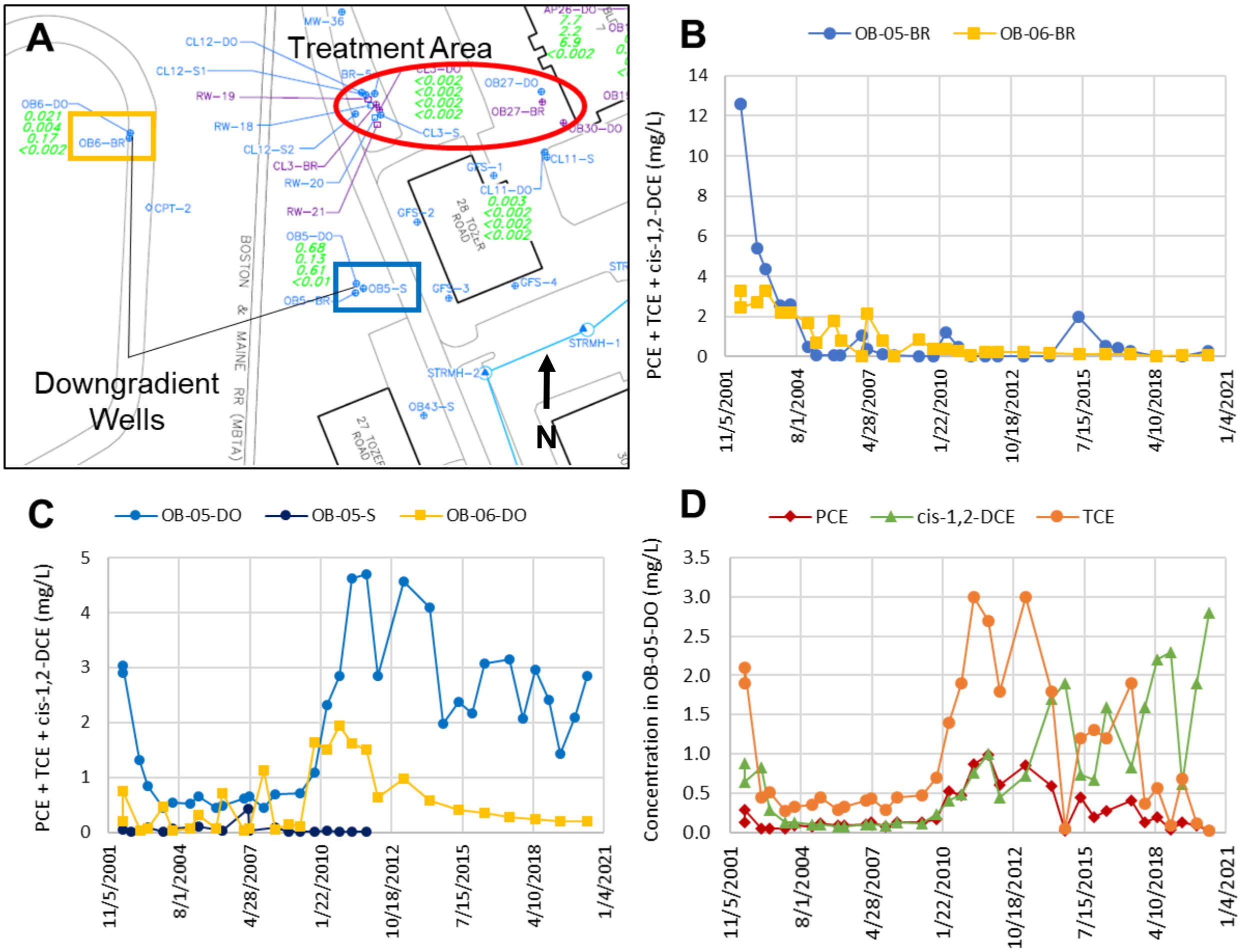

*Figure 16. Two clusters of monitoring wells are located downgradient from the treatment area at 28 Tozer Rd (**A**, base map from APTIM 2019). VOCs in downgradient bedrock wells decreased in response to treatment (**B**). In deep overburden wells, VOC concentrations initially decreased with a strong rebound in 2009–2010 (**C**). Starting around 2014, evidence of biodegradation (increasing cis-1,2-DCE) is present in the deep overburden aquifer, possibly the result of treatments applied to the source area (**D**).*

31 Tozer Road

In 2002–2003 and 2004, chemical oxidants were injected into multiple wells on the property of 31 Tozer Rd. (Figure 17). Shallow overburden wells were treated in 2002–2003; the deep overburden was treated in 2004. Three downgradient deep overburden observation wells were monitored to determine the extent of remedial impact: OB-07-DO, OB-18-DO, and OB-08-DO (IT 2001). Of the three downgradient deep overburden wells, only one (OB-18-DO) shows clear changes in TCE concentration related to treatment (Figure 17).

- OB-18-DO (250 ft downgradient of treatment area): In this well, TCE declined between 2002 and 2010. In 2010, TCE concentrations rebounded, which was followed by a second period of decreasing TCE concentration. Since 2014, the concentration has averaged less than 10 µg/L.
- OB-07-DO (200 ft downgradient of treatment area): There may have been an initial TCE decrease in 2003, but a lack of recent data makes it difficult to make conclusions. The TCE concentration was unchanged from 2004–2009, and the well has not been sampled since 2009.
- OB-08-DO (500 ft downgradient of treatment area): Has not shown any change in TCE concentration since 2002.

Based on the wells evaluated above, the groundwater plume treatment at 31 Tozer Rd has been effective only in a relatively small area of deep overburden groundwater.

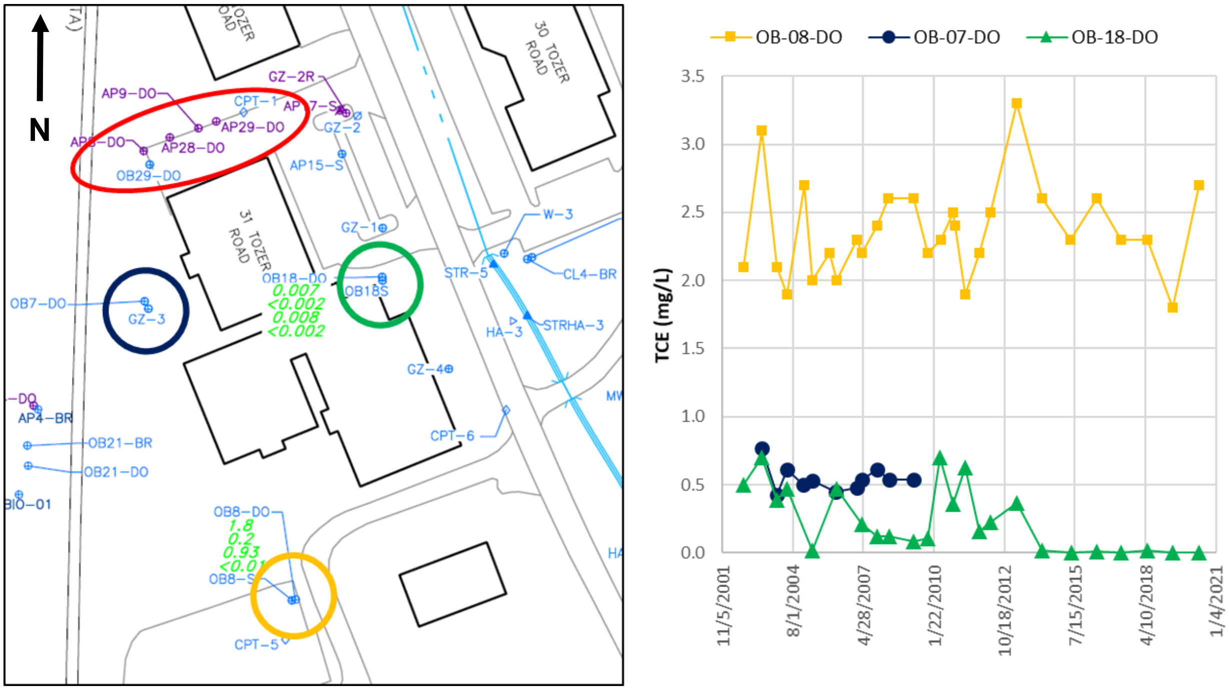

Figure 17. Groundwater at 31 Tozer Rd was treated by permanganate injections in 2002-2004. Downgradient deep overburden monitoring wells show that the impacts of treatment were spatially limited. (Map shows deep overburden groundwater results and is from APTIM 2019.)

The results in shallow monitoring wells show a similar pattern: in the monitoring well closest to the treatment area (AP15-S), TCE concentrations decreased during the period 2002–2004 (Figure 18). There was an apparent rebound in 2007, followed by a second period of decline. The two wells farther downgradient (OB-08-S and OB-18-S) did not show decreases in TCE in response to the treatments applied in 2002–2004; TCE in OB-08-S (500 ft downgradient) increased during the monitoring period (2002–2013) and TCE in OB-18-S has been consistently low with a few exceptions (temporary spikes of TCE that are roughly correlated in time with the treatments). PCE and cis-1,2-DCE show similar trends in all three wells. Thus, downgradient/plume treatment appears to effectively reduce the VOC concentrations in a spatially limited way, and nearly 20 years after treatment was applied, there is no evidence of VOC reductions 500 ft downgradient.

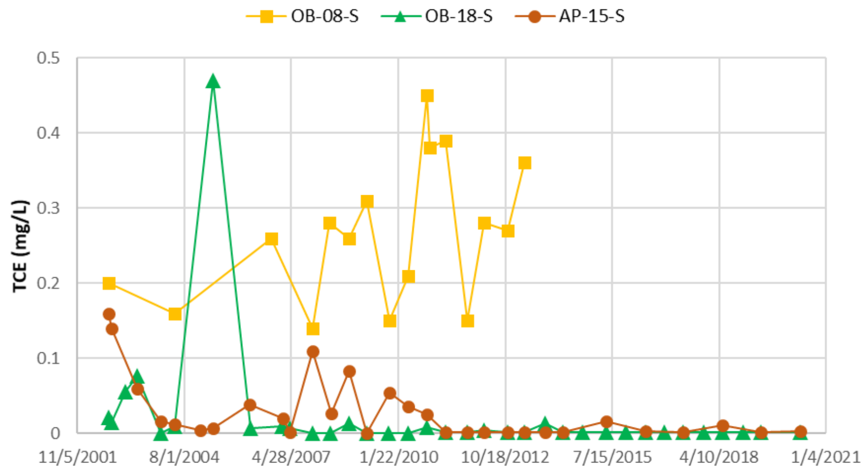

Figure 18. TCE in the shallow well closest to the treatment area (AP-15-S) decreased after ISCO treatments were applied. Two other shallow wells in the vicinity either show no evidence of treatment (OB-O8-S) or showed brief increases in TCE possibly associated with permanganate injections (OB-18-S).

Longview Residential Neighborhood

In 2004 and 2005, ISCO was applied to deep overburden and bedrock wells located west of the railroad tracks: AP3-DO, AP-4-DO, and AP-3-BR (Shaw 2009) (Figure 19). Downgradient monitoring wells include shallow wells in the residential neighborhood (P-9, P-11, P-18, P-19A, P-20, P-21, P-24)[15] and observation wells (APBIO-01 (DO), OB-20-DO [too close to injection wells], and OB-21-DO).

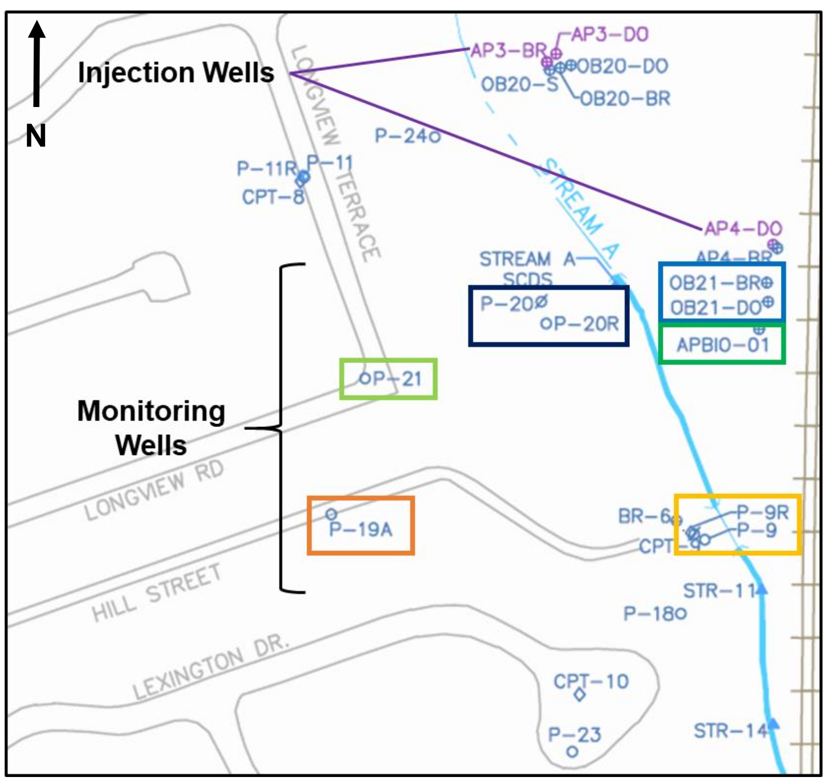

Figure 19. Longview neighborhood injection and monitoring wells (basemap from APTIM 2020b).

[15] P-18 was sampled in 2002 only and thus cannot be used to evaluate the efficacy of groundwater treatment in this area.

South of the treatment area (OB-21-DO/BR, APBIO-01, and P-9/9R), there is limited evidence for groundwater quality improvement following the ISCO injections in 2004–2005 (Figure 20A).

Additionally, there does not appear to be a correlation between groundwater quality and distance from the treatment area. For example, the wells OB-21-DO/BR are located closest to the treatment area, about 70 ft south of AP-04. In both wells, VOCs did not decline after 2004 (or a possible decline was masked by a rebound in early 2005). Well APBIO-01 is located slightly farther south (100 ft from AP-04), and shows a similar pattern to the OB-21 wells with time delay of 6–12 months. In all three wells, there are no samples available from before the ISCO injections, so it's not possible to determine if the injections resulted in a drop in VOC concentration. However, if concentrations did drop following ISCO injections, they rebounded within one year. The data appear to show VOC reductions in 2009, followed by a rebound, and again in 2012–2013, also followed by a rebound.[16] The well farthest to the south (P-9/9R) is located about 350 ft from AP-04. There was a decrease in VOC concentrations between 2002 and 2006, but a lack of data points between 2001 and 2006 makes it impossible to determine precisely when that drop occurred. VOC concentrations have been < 0.1 mg/L since 2009.

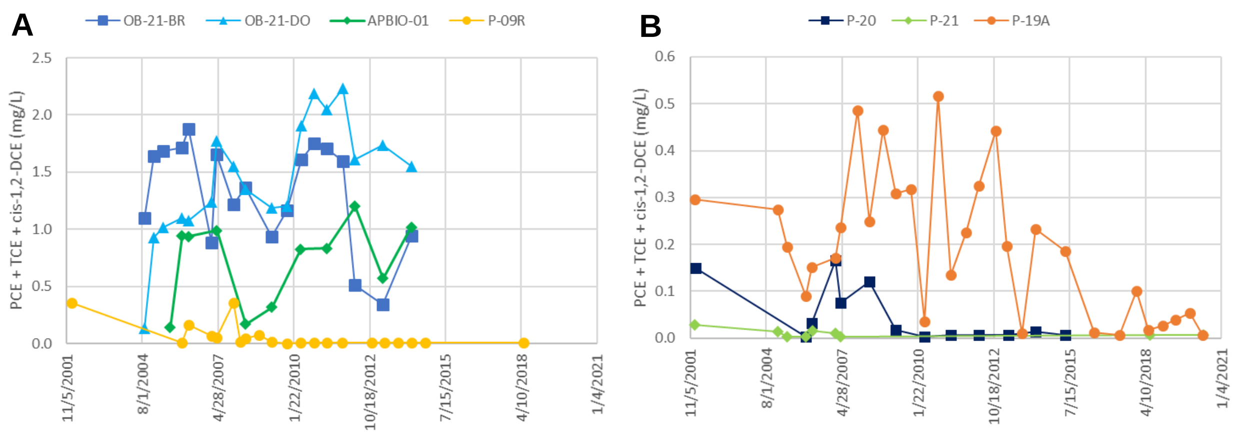

*Figure 20. Groundwater downgradient (south [**A**] and west [**B**]) of the Longview treatment area was minimally impacted by ISCO injections in 2003–2004. However, concentrations in shallow groundwater have since declined.*

West of the treatment area, there are several shallow observation wells (though a bedrock high in this area means that the overburden aquifer is thinner than other areas of the site). Of the wells in this area, some have never had VOC detections (P-24 and P-11/11R). In well P-21, the VOC concentrations decreased between 2002 and 2005, possibly due to local ISCO treatments, and have remained below or near detection limits since then (Figure 20B). Well P-20 showed a similar decline between 2002 and 2006, followed by a VOC rebound and a second period of decline. PCE, TCE, and cis-1,2-DCE concentrations remained below 0.01 mg/L from 2010–2015 (when sampling ceased). The last well in this area contains the highest concentrations of VOCs (P-19A). VOCs in this well appeared to respond to ISCO treatment with a decline between 2005 and 2006. However, in 2007 concentrations rebounded and remained elevated (with fluctuations) until about 2016. Individual VOC compounds have all been below GW-2 standards since 2018.

Based on the data in downgradient monitoring wells, there is no evidence that ISCO treatments in the Longview neighborhood reduced VOC concentrations in the deep overburden and bedrock aquifers. There is some evidence that ISCO treatments reduced VOC concentrations in the shallow overburden,

[16] The cause of these period of VOC decline are unknown, but may be related to treatment activities at other areas of the site.

though the reductions were temporally limited and followed by rebound events that resulted in equal or higher VOC concentrations. Concentrations have been declining for the past 8-10 years, however, and by 2018, all shallow wells had met the regulatory standard (GW-2). Monitoring is needed to ensure continued compliance.

Source Area Treatments

The primary challenge associated with evaluating source area treatments is the lack of monitoring wells downgradient from the treatment area that have not been used as injection wells. This is particularly true at the Building 3 area, where most wells have been used for permanganate injections and/or biotreatment (see Figure 21a; purple and green wells have received injections and blue wells are strictly monitoring wells). According to the New Jersey Department of Environmental Protection, "injections into monitoring wells are not recommend…in the event that injections are needed directly into or in close proximity to existing monitoring wells, these wells may no longer be suitable for compliance monitoring because ground water samples…are typically no longer representative of overall groundwater quality" (NJDEP 2017). ITRC (2005) agrees, stating, "it is ideal if monitoring wells are not used for injection purposes to ensure they are monitoring general subsurface conditions and are not directly affected by the injection" (ITRC 2005).

Building 3 Area

The Building 3 area has received ISCO treatments since 2002 and bioremediation treatments since 2007. Permanganate and bioremediation injections have occurred at numerous wells in the Building 3 Area (Figure 21); many wells have received multiple treatments. Additionally, in 2009, an SVE system was installed at Building 3. All three remedial actions are ongoing.

Evaluation of the efficacy of treatment in the Building 3 area is difficult because most wells have been used for treatment at some point in the past 20 years, making them unsuitable as monitoring wells. Thus, few wells are available for evaluation, and even wells that have not received treatment are often located very close to injection wells, making the data difficult to interpret.

Groundwater flow in the deep overburden and bedrock aquifers is generally to the west from Building 3. However, there is evidence of radial flow, so we included wells from the north, west, and south in our evaluation. We focused on deep overburden and bedrock wells because (1) most treatments have been applied at depth and (2) that is where concentrations were highest when Comprehensive Response Actions began in 2002.

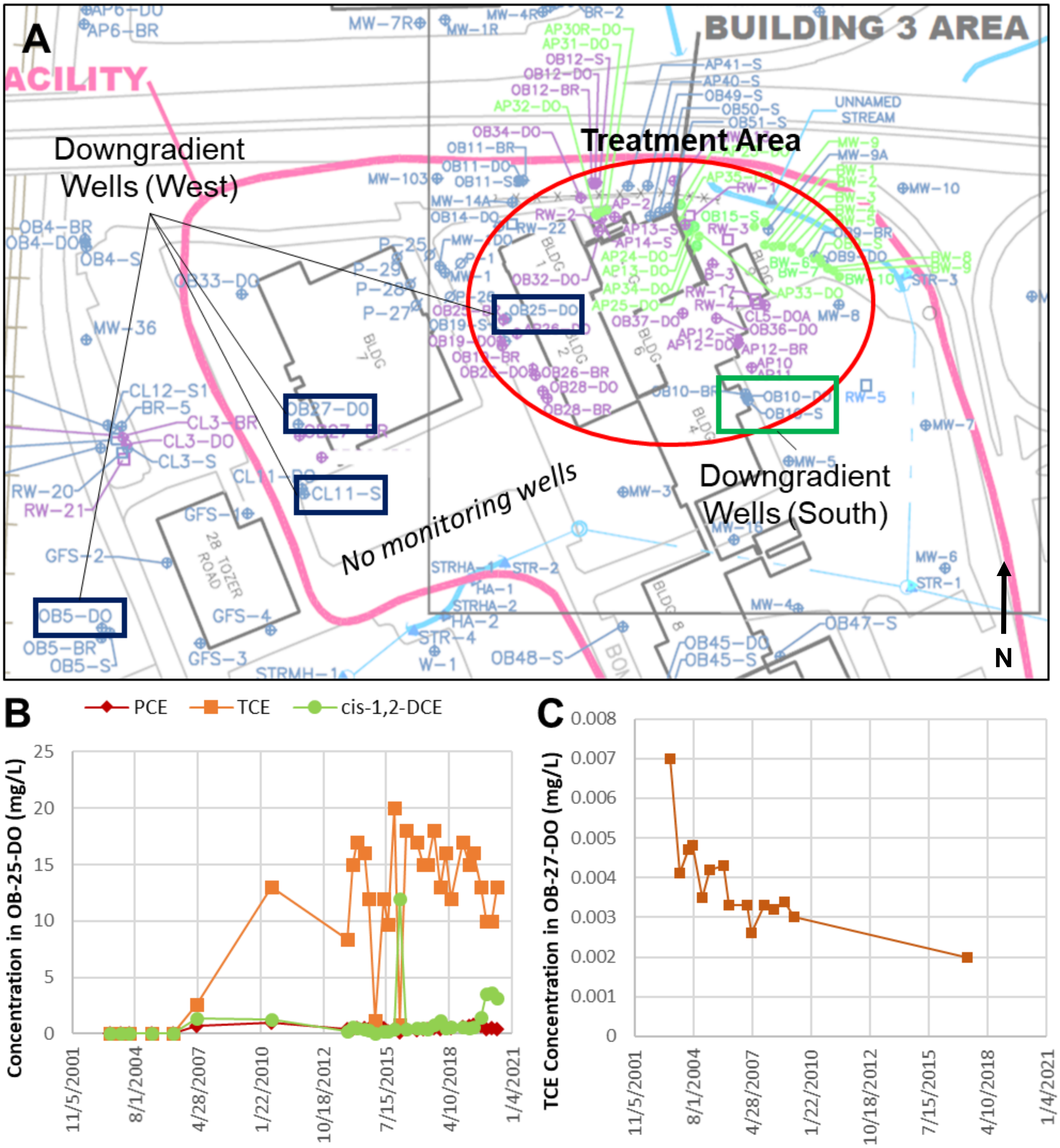

*Figure 21. Many wells have been used for ISCO (purple) and bioremediation (green) treatment (**A**). VOCs in well OB-25 increased after initiation of the Comprehensive Response Actions, and effects of treatment have been limited (**B**). Farther downgradient, OB-27-DO shows a steady decline in TCE concentrations (**C**).*

West of the Building 3 area, we evaluated three wells/well clusters, listed in order of distance from Building 3: OB-25-DO (closest/source area), OB-27-DO,[17] and OB-5-DO/BR (farthest).

- OB-25-DO: From 2003–2006, VOCs were not detected in this well. Beginning in 2006, VOC concentrations, particularly of TCE, increased sharply, and remained elevated through 2020. It is possible that remedial injections in 2002–2006 displaced either source material or VOC-

[17] OB-25-BR and OB-27-BR were not evaluated as monitoring wells because both have received ISCO treatments.

containing groundwater, which resulted in contamination of this well. There is evidence of successful treatment, though the results were temporally limited. In January 2015 a decrease of TCE occurred, and may have been the result of ISCO treatment in the bedrock well the prior year.[18] In 2016, TCE again decreased, though this time with a corresponding increase in cis-1,2-DCE, indicating biodegradation. This may be the result of bioremediation efforts in wells east of Building 3, which occurred in 2015. Similarly, an increase of cis-1,2-DCE from 2019 to the present time is an indicator of ongoing biodegradation/reductive dechlorination of TCE. Overall, the impact of remedial activity has been negative, as it the concentrations have increased since 2002, and any observed VOC reductions have been temporally limited. Also, the proximity of this well to treatment wells means it may be within the radius of influence, and thus may not represent overall groundwater quality.

- OB-27-DO: This building is located west of Building 7 and is farther from the Building 3 source area/treatment area than OB-25. Concentrations in this well have always been lower than OB-25-DO. The predominant VOC is TCE, and concentrations have decreased steadily over time, suggesting successful remediation in this area. CL11-DO, located slightly south of OB-27-DO, shows a similar pattern of decreasing TCE. Combined, these wells suggest that the line of injection wells along the western edge of Building 2 are reducing the VOC concentrations downgradient.
- OB-05-DO: This well was discussed previously, as it is downgradient of the treatment area at 28 Tozer Rd. In that discussion, we identified a biodegradation/reductive dechlorination signature in post-2012 data (Figure 16C–D). Bioremediation has not occurred at the 28 Tozer Rd. treatment area, so we attribute the biodegradation signature to bioremediation treatments applied in the Building 3 area. The decrease of TCE and rise of DCE indicates that reductive dechlorination is occurring, but additional treatment is needed to push the reaction to completion.

Based on the three monitoring wells discussed above, bioremediation (and possibly ISCO) treatment at Building 3 has resulted in decreasing TCE concentrations downgradient. For example, wells near Building 7 have historically lower VOC concentrations, and they show a steady decline. However, the numerous ISCO treatments have *not* had a long-term effect on the well with highest VOC concentrations (and located closest to the source area); instead, the effects are temporally limited on the order of months. We suspect that DNAPL is present in the source area and is causing the observed rebound events.

We noted an absence of monitoring wells in the parking lot south of Building 7 (west of Buildings 2 and 4). We suggest installation of at least one monitoring well cluster in this area, which would allow for monitoring of the Building 3 treatment area efficacy. Nearly all the wells directly west of Building 2 have been used for treatment, making them unsuitable monitoring wells.

The well cluster OB-10-S/DO/BR is located south of the Building 3 treatment area. The bedrock well contains higher concentrations of VOCs relative to the overburden wells, and concentrations have increased since 2002. Before 2006, the composition indicated a degraded product (i.e., more cis-1,2-DCE than TCE or PCE) (Figure 22). Beginning in 2006, the ratio flipped, which suggests a fresher material was entering the well. The change in signature coupled with increasing concentration suggests that relatively undegraded VOCs were entering the well—it's possible that remedial activities flushed

[18] The observed TCE decline may also be the result of ISCO treatment in upgradient well AP-26-DO, which occurred in 2012.

high concentration groundwater into this area. There are several, short-lived periods where the TCE/DCE ratio indicated (bio)degraded material (e.g., April 2010, 2016–2017), but most often, there has been more TCE than DCE present. Thus, this well is further evidence for temporally limited effects from remedial efforts. As of July 2020, relatively undegraded material was present in the bedrock well.

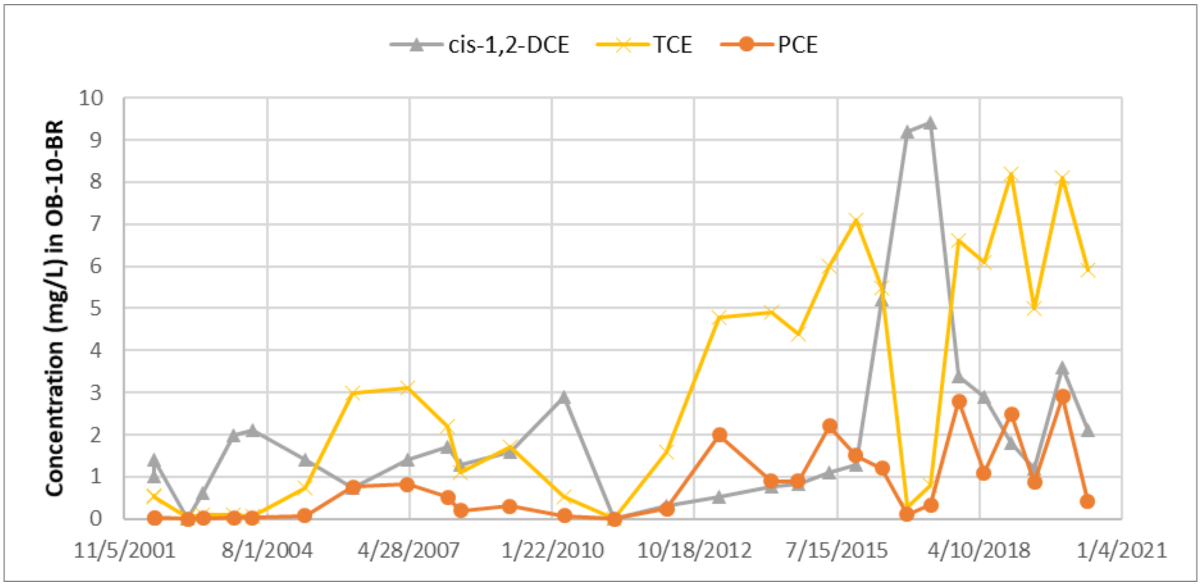

Figure 22. VOC concentrations in well OB-10-BR, south of the Building 3 Treatment Area, have increased since 2002.

The deep overburden well at this location has a similar pattern, though lower concentrations (TCE up to 1.2 mg/L). With a few exceptions, TCE has been the dominant compound (compared to PCE and DCE); the pattern continues into 2020. The total VOC concentration has increased by about 20% since 2002. Little VOC contamination is present in the shallow well at this location.

In summary, the well cluster at OB-10 is not supportive of an effective remedy. The bedrock and deep overburden wells at this location contain higher VOC concentrations than they did in 2002, and effects of remedial action, while visible in the data, are short-lived. In fact, there is evidence that the remedial injections caused the VOC plume to spread in a southerly direction into well OB-10-BR (Figure 22).

Several wells north of the Building 3 area (OB-14-DO, OB-11-DO/BR) were examined to evaluate treatment efficacy in this area. Concentrations were lower than those found west of the treatment area; TCE was detected up to 1.2 mg/L in OB-14-DO. None of these wells showed evidence of treatment; concentrations have been consistent over the past 20 years.

Building 5

In 2004, remediation began in the Building 5 area with permanganate injections in well AP-27. Concentrations in the area were as high as 440 mg/L (TCE in OB-35-DO, May 2005). Permanganate injections were also conducted in 2005, 2006, and 2007 (AP-27-DO and/or OB-35-DO) (Shaw 2007). Additional permanganate injections occurred in 2008, 2011-2012, and 2014–2017. Biotreatment was applied to shallow wells between 2015–2018 (APTIM 2019, CBI 2015b). An SVE system has been operational since 2013. Well locations are shown in Figure 23a.

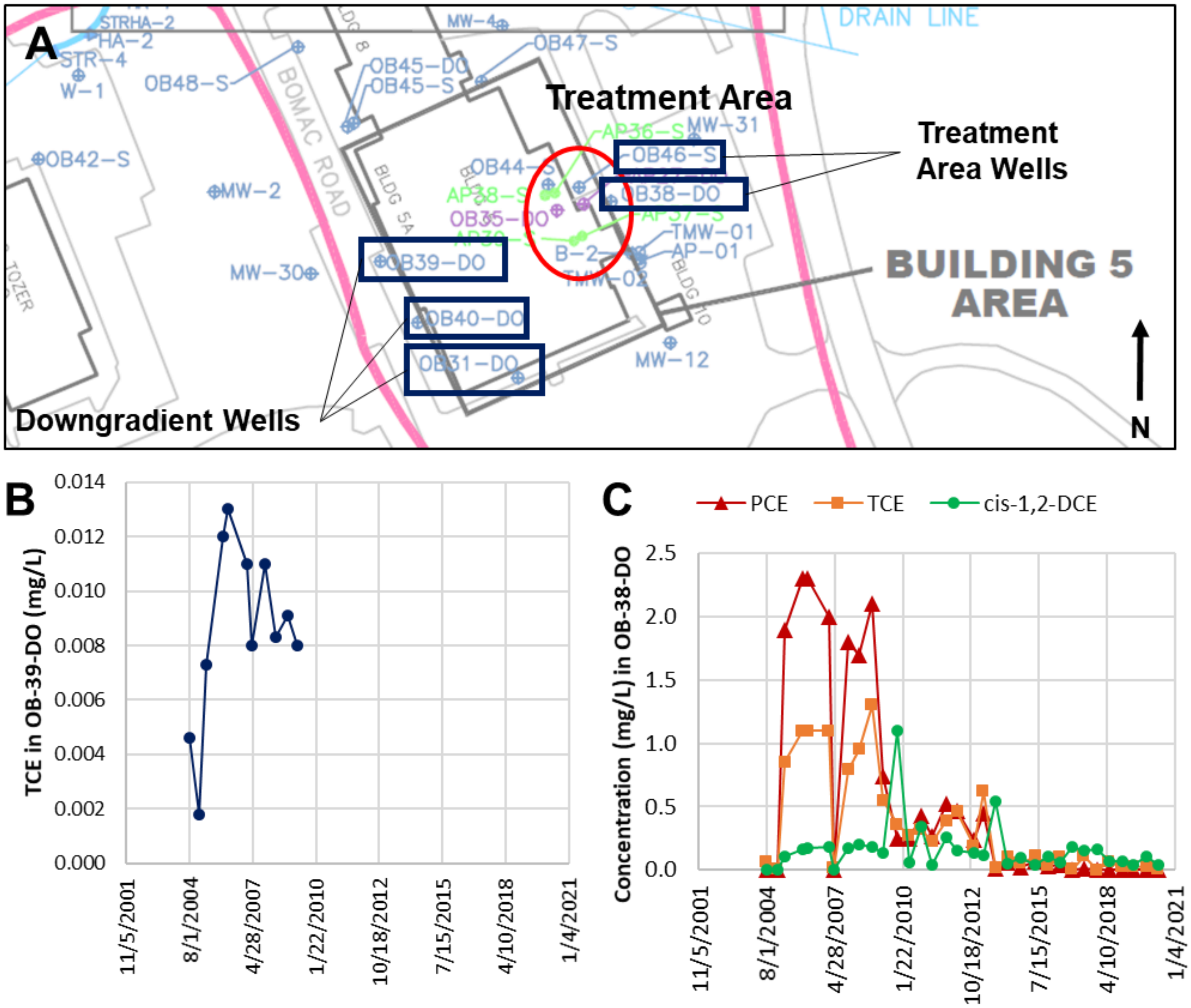

*Figure 23. The Building 5 treatment area consists of several permanganate injection and bioremediation wells (**A**). Downgradient well OB-39-DO shows decreasing TCE between 2006 and 2009 (**B**). Source area well OB-38-DO also shows decreasing and degrading VOCs, with significant fluctuations caused by repeated ISCO treatments followed by VOC rebound events (**C**).*

Downgradient monitoring wells west of Building 5 include OB-39-DO, OB-40-DO, and MW-30 (shallow overburden).[19] Monitoring in the deep overburden wells began in July 2004. In OB-40, all VOCs of interest have been below detection limits for nearly all sampling events. Thus, this well was unimpacted by VOCs beneath Building 5. Similarly, MW-30 contained very low or undetectable concentrations of VOCs during each monitoring event (2004–2009). Conversely, OB-39 has contained detectable concentrations of TCE since 2004 (Figure 23b). TCE concentrations rose after response actions began (2004–2006) reaching a maximum concentration of 0.012 mg/L. This indicates that the initial injections may have released VOCs, which traveled downgradient to OB-39. However, the maximum detected concentration was low relative to the concentrations under Building 5, and TCE has declined since 2006.

In summary, VOC concentrations beneath Building 5 were elevated before the initiation of Comprehensive Response Actions in 2004, but there are no significant downgradient impacts in the deep or shallow overburden west of Building 5.

[19] Well OB-31-DO will not be discussed due to limited available data.

Monitoring wells located within the source area include OB-38-DO, OB-44-S, and OB-46-S. None of these wells received injections, but they are clustered with wells that did receive injections. In OB-38-DO, the data show an initial input of fresh VOCs (PCE>TCE>cis-1,2-DCE), possibly caused by remedial injections (Figure 23c). Concentrations fluctuated widely from 2005–2014, likely due to annual (or nearly annual) permanganate injections in nearby OB-35-DO. However, the rebound that occurs after each injection has decreased over time, and recent (post-2017) data show a 95%+ reduction relative to the maximum VOC concentrations in 2006. Also, the post-2017 data show a degraded mix of VOCs, with PCE below laboratory detection limits.

Shallow groundwater in the source area shows decreasing concentrations of VOCs after the initiation of biotreatment applications in 2015. For example, in well OB-46-S, PCE dropped from 1.8 mg/L to below detection limits between 2015 and 2016. A contemporaneous spike in cis-1,2-DCE confirmed that reductive dechlorination was occurring. No apparent rebound has occurred since the last treatment in 2018.

Based on the downgradient and source area wells, the treatments in the Building 5 area appear to be effective, though incomplete. Downgradient wells have not been negatively impacted by injections, and concentrations in these wells are decreasing. Concentrations in source area wells are also declining, though ongoing rebound may necessitate additional treatment(s) in the future, especially in the deep overburden. No bedrock wells in the area make it impossible to assess the presence or absence of VOCs in the bedrock aquifer.

Field on southern portion of Varian Property

The open field located south of Building 5 and adjacent to 32 Tozer Rd (PSL 10) may have historically received waste solvent disposal from the laboratories inside Building 5 (IT 2000). The Phase II investigation identified VOCs in soil (PCE up to 1.8 mg/kg) and considered this area to be a source of VOCs to groundwater. For those reasons, this area was included in the Comprehensive Response Actions.

From 2002–2019, numerous permanganate injections were applied in this area to four different wells screened at 15–30 ft (CBI 2015b, APTIM 2019).[20] Downgradient monitoring wells include the well cluster CL10-S/DO/BR. Well locations are shown on Figure 24a.

Before treatment, the downgradient wells contained relatively low concentrations of VOCs. The initial permanganate injections appeared to cause an increase in VOC concentrations, particularly in the deep overburden aquifer (CL10-DO, 16 mg/L TCE in May 2003). Concentration fluctuations, caused by treatment followed by rebound, occurred from 2003–2005 (Figure 24b). Since 2005, VOC concentrations in both the deep overburden and bedrock wells have been near or below laboratory detection limits. However, there is some evidence the PCE concentrations are rising in CL10-DO (0.39 mg/L in May 2020). Additional data points are needed to evaluate the possibility of rebound in this well.

[20] Permanganate injections occurred in 2002–2004, 2006–2008, 2011, 2014, 2017, and 2019 (CBI 2015b, APTIM 2019, 2020a).

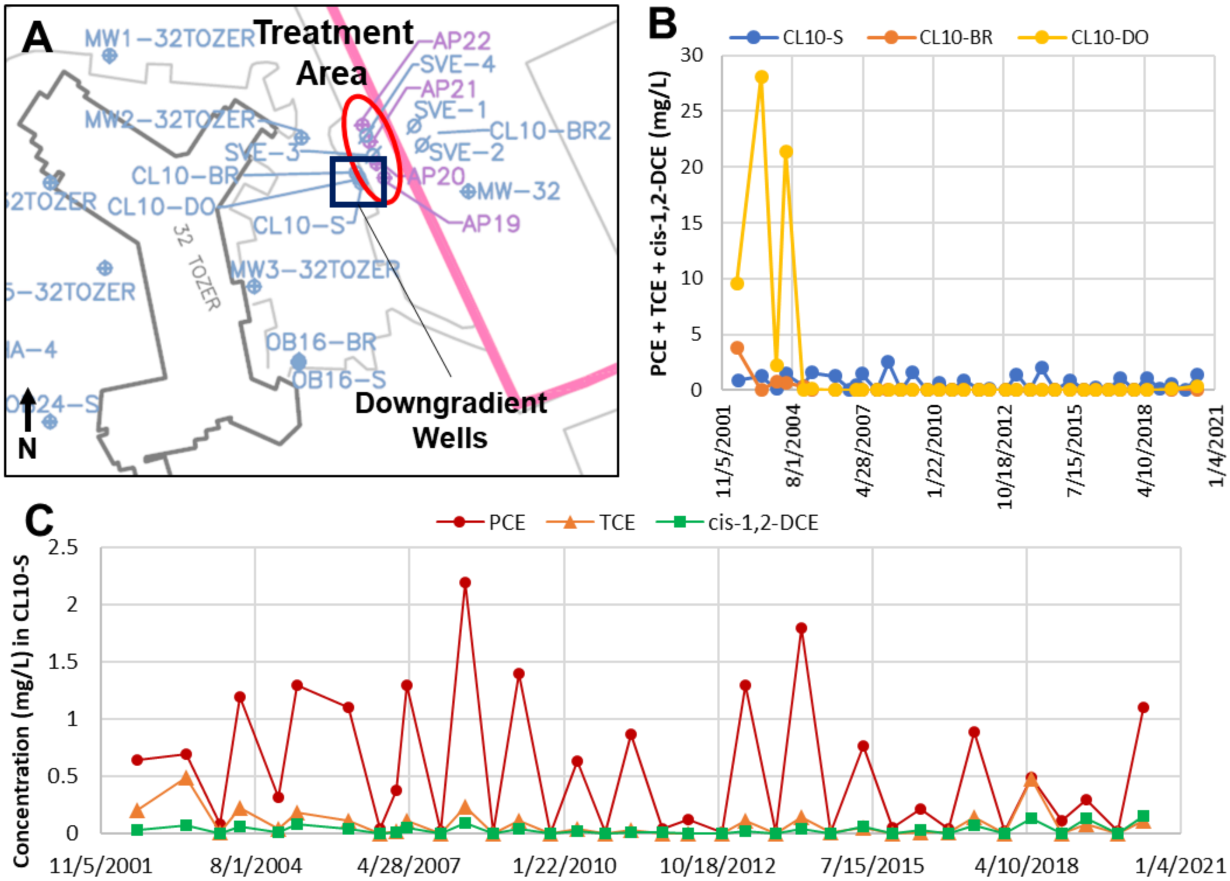

*Figure 24. The treatment area on the southern portion of the former Varian property (near 32 Tozer Rd.) consists of four injection wells and one downgradient monitoring well cluster (**A**). VOC concentrations in the deep overburden rose after initiation of treatment in 2002, but have remained at or near detection limits since 2005 (**B**). In the shallow overburden, concentrations have fluctuated with no long-term reduction; PCE is the dominant compound (**C**).*

The data from CL10-S are difficult to interpret because of what appears to be very large seasonal variations (Figure 24c). For example, in April 2008, the PCE concentration was 2.2 mg/L; in November 2007 and October 2008, the PCE concentration was 2 orders of magnitude lower. In general, concentrations in the spring/summer sampling events are 1–2 orders of magnitude higher than in the fall sampling events. The cause of the concentration fluctuations is unclear, but it is clear that the VOCs present in spring/summer are relatively fresh/undegraded, with PCE concentrations exceeding those of TCE and cis-1,2-DCE. Given that the shallow groundwater concentrations show no long-term reduction, and the presence of an occupied commercial building downgradient, additional treatment and monitoring in this area is needed.

Alternative Remedial Technologies

Over the past 20 years, permanganate and bioremediation have been only partially effective in treating DNAPL in certain areas of the site, most notably the source area near Building 3. This is evident from well data near Building 3, where there is still evidence of DNAPL and in some downgradient wells, where dissolved VOC concentrations remain elevated. It is understood that there are significant technical challenges to addressing the deep contamination in this area due to inherent challenges with remediation of DNAPL, compounded by current site uses. However, after almost 20 years of employing a limited set of technologies, with only limited success, it would be prudent to evaluate other tools in the remedial toolbox.

The primary treatment technology at the Varian site has been ISCO, specifically injection of sodium permanganate solutions. Permanganate reacts with chlorinated alkenes via a direct electron transfer rather than the free radical process that characterizes other ISCO additives (e.g., persulfate). Advantages of permanganate as an oxidant include stability, persistence, and efficacy over a wide range of pH and alkalinity ranges. However, it is more reactive with natural organic matter than other oxidants, which results in non-productive loss of oxidant. Also, manganese dioxide (MnO_2) is a solid byproduct that precipitates in the subsurface, reducing permeability and possibly forming a protective coating on DNAPL (ITRC 2005). The mass of MnO_2 produced is significant: degradation of 1 gram of vinyl chloride produces 4.64 grams of MnO_2.

There are several ways to improve the efficacy of ISCO with permanganate. Efficacy of permanganate delivery to the subsurface can be improved with the use of additives; for example, sodium hexametaphosphate can be used to control MnO_2 precipitation, and polymers improve the sweep efficiency and reduce preferential flow paths (Crimi et al., 2013). Injecting permanganate as a slurry, particularly into bedrock, has been shown to increase the oxidant residence time and allow for more destruction of VOCs (EPA 2011).

Other oxidants are also widely used to treat chlorinated VOCs and may be useful at the Varian site. For example, ozone is delivered as a gas (rather than an aqueous solution), and thus is effective in the vadose zone. Ozone may be appropriate for treating residual DNAPL located above the water table. Persulfate reacts with natural organic matter to a lesser extent than permanganate, resulting in less non-productive loss of oxidant. It is less persistent than permanganate, but more persistent than other oxidants (ozone and peroxide) (ITRC 2005). Ozone, persulfate, and peroxide oxidize VOCs via a free-radical process.

Sequencing of different remedial technologies is another way to improve overall remedy efficacy. Sequencing may involve the use of different oxidants or combining ISCO with *in situ* bioremediation (ISB) (ESTCP 2010, ITRC 2005). When properly sequenced, ISCO is first used to address high concentrations in soil, groundwater, and/or NAPL.[21] Once the NAPL has been addressed and concentrations decreased, bioremediation, specifically bioaugmentation, is an effective and cost-efficient way to further reduce contaminant mass. Permanganate has an adverse effect on microbial activity, and may change the composition of the microbial community, particularly affecting the species that dechlorinates PCE and TCE. The oxidizing conditions caused by ISCO are also temporary, because oxidant is consumed by the contaminants, aerobic bacteria, and natural organic matter; resumption of reducing conditions occurs rapidly after cessation of ISCO injections (ITRC 2005).

Finally, alternatives other than ISCO and ISB should be considered, such as thermal treatment (with a vapor recovery system) and surfactant/co-solvent flushing coupled with extraction and above-ground treatment (EPA 2004).

Additional evaluation of the treatment efficacy, along with proposed changes to the treatment regime, is needed for the Building 3 area. For example, several treatment wells at the Varian site have been used for ISCO followed by ISB, though it’s not clear why this change was made. Possible modifications

[21] ISCO can enhance bioactivity by reducing contaminant concentrations below toxicity thresholds (ITRC 2005).

include the use of additives with permanganate injections, use of a different oxidant, or more wide-spread implementation of ISB.

Summary

Downgradient treatments, specifically ISCO injections at and near 28 Tozer Rd., 31 Tozer Rd., and the Longview residential neighborhood, reduced VOC concentrations in a limited way. As one might expect, groundwater has continued transporting VOCs from the source areas, and thus any observable effects from downgradient plume treatment were temporary. Also, the area of influence is on the order of a few hundred feet; evidence of ISCO treatments was not observed in wells farther afield. Based on the limited effects of downgradient treatment, it appears that this has not been an effective way to reduce the mass of VOCs in the environment. However, targeted downgradient actions may be effective at temporarily protecting sensitive receptors.

Results have been mixed in the source areas. The Building 5 area demonstrates the most evidence of successful remediation, with reductions in VOC concentrations in the source area and little to no downgradient impacts. The treatment area south of Building 5 (near 32 Tozer Rd) has effectively reduced the VOC concentrations in the bedrock and deep overburden aquifers, though possible rebound of PCE concentrations is ongoing. Shallow groundwater shows no long-term decline, and could pose a risk to downgradient receptors, so additional treatment is likely necessary. Finally, treatment in the Building 3 area has resulted in VOC concentration reductions in some downgradient wells, and evidence of partial bioremediation/reductive dechlorination is apparent. However, initial injections may have spread VOC contamination, introducing it to wells that were previously clean, and these wells contained elevated VOCs as recently as May 2020. Evaluation of alternative remedial measures is warranted given the persistence of DNAPL-suggestive concentrations of PCE and TCE.

Downgradient Properties Vapor Intrusion Evaluation

Sonning/Longview Neighborhood: Residential Properties

Indoor air samples were collected from the residential neighborhood in the summer of 2001 (36 homes), and winter 2002 (29 homes) (IT 2002a). To our knowledge, no residential indoor air samples were collected between 2002 and December 2020, when MassDEP collected and analyzed indoor grab samples from a number of homes in this neighborhood.

IT Corporation concluded that there were no observed impacts from the Varian site in either study (IT 2002a), including in a home in which TCE had been identified in indoor air at 97 $\mu g/m^3$ (2001) and 25 $\mu g/m^3$ (2002), based on the assertion that the home in question was not within an area where shallow groundwater contained VOCs emanating from the Varian site. Given the geographic scope of the indoor air sampling effort (i.e., as far west as the intersection of Longmeadow Road at Sonning Road), such an assertion was plausible. However, the testing results for the specific addresses of the homes sampled during these studies were never provided to MassDEP.

The rationale for this lack of disclosure was provided in the report on the summer sampling effort (IT 2001):

> *"In order to protect each homeowner's privacy, Varian agreed that the sampling results for each home would be treated as confidential and not disclosed publicly unless reporting under the*

MCP was required. No such reporting was required. Although all the technical data are presented in this report, this report does not include specific addresses of the homes that were sampled, or the names of the residents that participated in the sampling….The decision whether to make public the sampling results from a specific home is up to the resident of that home."

MassDEP did not obtain the specific addresses associated with the data reports for the 2001 and 2002 indoor air investigations until December 2020, as part of its in-depth review of actions undertaken at the Varian site. As far as we know, none of the owners of the sampled homes ever elected to provide MassDEP with their testing results.

Summer 2001 and Winter 2002 Indoor Air Sampling

The summer 2001 investigation included 36 homes. Based upon the shallow overburden plume maps that had been constructed by IT, only 16 of these homes were deemed to be overlying contaminated groundwater. The winter 2002 investigation included 29 homes, of which only 14 were deemed to be overlying contaminated groundwater. However, as previously discussed, it appears that the footprint of water table contamination may have been more extensive than depicted on the plume maps, particularly in the Sonning Road area.

The investigation detected VOCs within indoor air but did not associate those detections with elevated risk and/or the Varian site. For example, in the winter study, TCE was detected in 83% of the samples at concentrations from 0.18–25 µg/m^3. The house with the highest concentration was reportedly not located above the shallow groundwater plume, and therefore was eliminated from further vapor intrusion pathway consideration.

Houses reportedly located above the plume had a higher rate of TCE detections than houses reportedly not above the plume, but concentrations were below the MassDEP background concentration at the time (4.5 µg/m^3 in 2002).[22] Similarly, in the winter study, PCE and 1,1,1-TCA were detected in 97% of samples at concentrations ranging from 0.28–9.7 µg/m^3 (PCE) and 0.18–12 µg/m^3 (TCA), below the background concentrations of 11 µg/m^3 (PCE) and 30 µg/m^3 (TCA) (IT 2002a). In this context, "background" was assumed to be the levels of chlorinated hydrocarbons that could be present in any home, due to the use of products and cleaners that contained these compounds (this terminology is no longer used by MassDEP, as the actual "background" level of contaminants within indoor air is generally unknown; the current metrics of comparison in this regard are "Typical Indoor Air Concentration" and "Threshold Values").

The VOC concentrations in all homes tested with one exception were below the background values that had been provided by MassDEP at the time of the study (for compounds with established background concentrations). The exception was the home with 25 µg/m^3 TCE in the winter sampling round (which was 97 µg/m^3 during the summer sampling effort); a home that was deemed to be outside the footprint of water-table contamination emanating from the Varian site, and which reportedly contained an automotive cleaning product that was 100% TCE.

Based on these results, and the reported observation of VOC-containing household products at residences, the reports determined that the VOC concentrations found in all homes were the result of

[22] In 2016 the Department set a Residential Threshold Value of 0.4 µg/m^3 and an Imminent Hazard trigger concentration of 6 µg/m^3. Based on the updated TCE thresholds, additional investigation and analysis would be required if the same results were obtained today.

releases from household chemicals, not the Varian site, and that "no further actions are required by Varian or any of the homeowners" (IT 2002a).

The reports also stated that the vapor intrusion investigations and evaluations were conducted "in accordance with the MADEP draft 'Indoor Air Sampling and Evaluation Guide,' dated September 2001 (MADEP, 2001)." However, there were two significant issues in this regard:

1. **Soil Gas Probes**

   Consistent with evolving scientific practices, the 2001 MassDEP guidance document recommended obtaining soil gas data in conjunction with indoor air data, to help determine whether a vapor intrusion pathway may be present. The guidance specifically recommended the installation of "at least one or two soil gas sampling probes beneath the structure of concern (e.g., through the concrete slab of a basement floor)" and commented on the potential negative bias of soil gas probes located outside of a structure, due to the displacement of soil gas vapors from the infiltration of precipitation. The placement of soil vapor probes outside the building was a less desirable second choice, if "probes cannot be installed within the footprint of the structure."

   For the summer 2001 investigation, a single soil vapor probe was driven into the ground outside each home, to a depth of only 3 feet below grade. Site contaminants TCE, PCE and cis-1,2-DCE were only detected in a few of the 36 probes installed at low levels.

   In a conversation with site LSP Tim Kemper on January 3, 2002, Stephen Johnson of MassDEP relayed his concerns over the collection of soil gas via shallow external probes during the summer 2001 study. Mr. Johnson specifically reiterated the agency's preference that soil gas samples be collected from beneath buildings, and that other approaches should only be implemented if permission cannot be obtained for sub-slab collection.

   During the winter investigation, the method employed to obtain soil gas samples, "in order of preference", was to (i) install a single probe through an earthen bottom of a (dry) basement sump [13 homes], (ii) in a paved driveway [7 homes], (iii) outside and adjacent to the building foundation [6 homes]. Only low levels of site contaminants were identified in a small percentage these probes: PCE in 4 of 29 probes; TCE in 6 of 29 probes, and cis-1,2-DCE in 4 of 29 probes.

   The "order of preference" articulated by IT did not include installation through the basement slab. There was no explanation provided why probes were not placed in the preferred location (i.e., through basement slabs), nor any discussion on possible negative biases that may exist with data obtained from these less-than-optimal locations. This is particularly problematic because of the reports' reliance on the need for a "complete pathway" to be present to link VOCs within indoor air to the Varian groundwater plume.

2. **Background Concentrations**

   The report correctly referenced (now outdated) MassDEP indoor air "background" values for specific VOCs of interest. However, IT (2002, p. 12) incorrectly placed too much weight on this specific line of evidence, by making it a bright line: "If VOCs were detected in indoor air at or below "background" concentrations, further evaluation was not necessary, as there is no significant risk to residents, as defined by MADEP."

This bright line is contrary to the cited MassDEP guidance. Section 8.7 of this guidance document is titled "Comparison of Data with Chemical Background Concentration Distribution," and contains the following admonition:

> *It should be noted that literature background used under the MCP represents higher percentile values, generally in the 75th-95th percentile range. It is a generous estimate of background which should encompass the range of concentrations of the vast majority of structures. However, as stated above, literature background should not form the sole basis for determining site impact and other compelling evidence of contamination from a site should not be ignored in making this determination.*

Though the background values provided by MassDEP in 2001 were based upon the best available science at that time, the agency's understanding of "background" has continued to evolve, with respect to specific concentration values, and the actions they would trigger. In 2016, MassDEP released new Vapor Intrusion guidance with updated sampling protocols, and updated "background" values rebranded as "threshold values" (TV) (MassDEP 2016). Updated toxicity information, particularly for TCE, resulted in lower comparison metrics for TCE and PCE and new metrics for additional VOCs, including cis-1,2-DCE.

Though it was appropriate to cite the existing MassDEP background values in the 2001 and 2002 indoor air evaluation reports, applying today's residential threshold values (TVr) to the data from 2002 would lead to a different set of conclusions and recommendations on needed actions:

- In 2002, cis-1,2-DCE did not have a background concentration defined by MassDEP. Today, the TVr is 0.8 $\mu g/m^3$; 5 homes in the investigation had higher concentrations of cis-1,2-DCE than the TVr. Four of those five homes were located over groundwater known to be impacted by cis-1,2-DCE from the Varian site. Given the lack of other known sources of cis-1,2-DCE,[23] it's likely that the fifth home was also impacted by vapor intrusion from shallow groundwater (possibly via preferential pathways in the subsurface).
- In 2016, MassDEP defined the TVr for TCE to be 0.4 $\mu g/m^3$, an order of magnitude below the background threshold used in the 2001/2002 IT Indoor Air reports. Accordingly, at least 16 homes exceeded the 2016 TVr. Most (11 of 16) homes were located in the eastern portion of the neighborhood, between Sonning Road and Lexington Avenue, where TCE was present in shallow groundwater in 1999 (see Figure 6). Of the remaining 5 homes, two were located where TCE may have been present (unknown due to lack of water table wells in the area). Of the three remaining homes, one contained cis-1,2-DCE, which is not generally found in consumer products. Thus, it's reasonable to assume that vapor intrusion may have been causing or contributing to the elevated TCE in at least 14 of the homes with TCE concentrations greater than the 2016 TVr, and additional work would have been required to provide other lines of evidence against the vapor intrusion pathway.
- Fourteen homes contained PCE at concentrations above the 2016 PCE TVr (1.4 $\mu g/m^3$). PCE is found in many homes with no vapor intrusion pathway because of its presence in common products (such as dry-cleaned clothes). For that reason, it is a less compelling line of evidence for or against vapor intrusion, but still warrants an evaluation. Many of these fourteen homes also contained TCE

[23] Cis-1,2-DCE is a breakdown product of PCE and TCE, and is not manufactured as a stand-alone product. Trace amounts may be found in trans-1,2-DCE, which is manufactured for use as a metal and electronics cleaning agent.

and/or cis-1,2-DCE above the 2016 TVrs, and thus are already accounted for in the above discussion. Of the remaining four homes:

- One had cis-1,2-DCE and TCE detected in soil vapor and TCE detected (below the 2016 standard) in indoor air. This home may have been located above the shallow groundwater plume, but the data are inconclusive. The presence of VOCs in soil vapor, coupled with PCE and TCE detections in indoor air, suggests that vapor intrusion may have caused the measured PCE in 2002.
- One home had TCE detected in indoor air below the 2016 standard. This home was located near other homes with possible vapor intrusion impacts, and the shallow groundwater plume was (and still is) not fully delineated in this area.
- The remaining two homes did not have other TCE or cis-1,2-DCE present above laboratory detection limits, and have no other evidence of a vapor intrusion pathway.

Since the indoor air study was conducted in 2002, concentrations of TCE have declined in shallow groundwater beneath the residential neighborhood (Figure 25). Concentrations declined after 2005, likely due to ISCO injections applied in 2004–2005. TCE rebounded after conclusion of treatment in the Longview neighborhood, but has been steadily declining since 2015. The more recent decline may be due to successful biotreatment upgradient (e.g., at Building 3). Given that concentrations have been largely below the GW-2 threshold over the past 4 years, it's unlikely that vapor intrusion is a concern today.

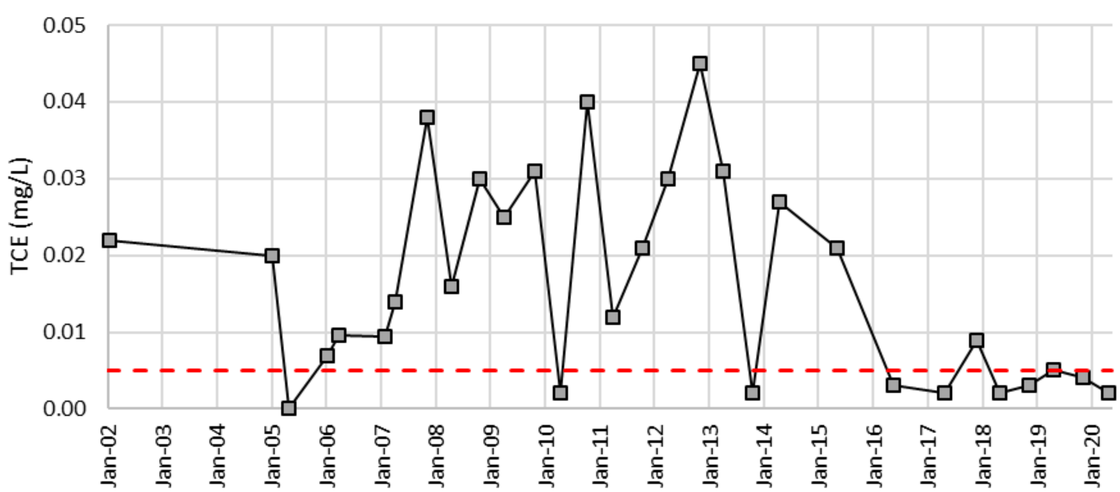

Figure 25. Since 2015, TCE concentrations have decreased in shallow groundwater beneath Hill Street (generally below the GW-2 threshold, red dashed line) (well P-19A, data from APTIM 2020b and Shaw 2009).

In summary, the application of the 2016 TVrs to the 2002 data results in multiple homes that would have required additional investigation and lines of evidence to rule out vapor intrusion as the source of PCE, TCE, and/or cis-1,2-DCE. Regardless of whether a vapor intrusion pathway was present, it is important to stress that, except for one home, none of the reported levels of VOCs represented an immediate health risk, even by today's standards, and in most cases, were below current residential standards for lifetime exposures.

The home in which elevated levels of TCE were detected (up to 97 µg/m^3) warrants further discussion.

In December 2020, MassDEP was made aware for the first time that this home was 34 Sonning Road. While a conclusion was made by IT in 2002 that this home was not within the footprint of water-table contamination, as discussed previously in this report, the lack of a water-table well on the easterly loop of Sonning Road is a significant data gap that limits the confidence in such a statement.[24]

An evaluation of the other lines of evidence for the likelihood of the presence of a vapor intrusion pathway at this home is inconclusive:

- Shallow wells on the Varian property (600 feet) upgradient from Sonning Road (e.g., CL-3-S) contain relatively low levels of TCE, and two water table wells on the western loop of Sonning Road (wells P-13 and P-14) are free of VOCs. Conversely, other shallow wells east of Sonning Road (e.g., OB-5-S) had higher concentrations of TCE, and there are very high concentrations of TCE in deeper upgradient wells (e.g., CL-03-DO), that could conceivably be transported toward the water table on Sonning Road due to hydrodynamic forces and/or the use of basement sumps.
- There is some evidence of a vapor intrusion pathway at the contiguous home at 32 Sonning Road (e.g., elevated PCE and TCE), though TCE levels are substantially lower.
- No VOCs were detected in the soil vapor probe installed at 34 Sonning Road, though the probe was not installed in the most protective manner, which is preferred and recommended by MassDEP (i.e., it was not installed through the basement slab, reportedly because of objections by the homeowner).
- In general, vapor intrusion conditions are worse during winter months, though the highest levels of TCE in this home (97 $\mu g/m^3$) were identified under summer conditions, compared to 25 $\mu g/m^3$ during winter conditions. However, there are factors that could explain this discrepancy.
- In general, if a vapor intrusion pathway is present, the highest levels of contamination will be observed in the basement, with lower values on the first and second floors. This was the case during the summer investigation, but not the winter investigation. However, the possible presence of a forced-hot-air heating system could explain this dichotomy.
- Reportedly, a can of "Carbo-Sol"—an automotive product comprised solely of TCE—was present in this home. It was reportedly present in the basement during the summer 2001 sampling, and in an attached first-floor garage during the winter 2002 sampling. This would be consistent with the TCE concentration gradient throughout the floors of the home during the two sampling events. However, there is uncertainty on the extent to which this product was used and/or would impact indoor air in this home.
- The breakdown product cis-1,2-DCE was not identified in the indoor air, which would be a strong indicator of a vapor intrusion pathway. However, this chemical has less of a propensity to partition out of groundwater (due to its Henry's Law Constant).

It is plausible that the high concentrations of TCE within the indoor air of this home could be due to the use of one or more products within the home that contained this chemical, as asserted by IT. However, given the high levels of TCE—a known site contaminant—more work should have been done to more definitively rule out the presence of a vapor intrusion pathway, including the installation of water-table wells on the eastern loop of Sonning Road, and the installation and sampling of at least 2 sub-slab soil vapor points through the basement slab. This data gap needs to be corrected.

[24] With regard to the home at 34 Sonning Road, the report stated, "that home was not located over impacted shallow groundwater containing the VOCs detected in indoor air, demonstrating that the level detected was not associated with contaminated groundwater" (IT 2002).

December 2020 Indoor Air Sampling

During the week of December 7th, 2020, MassDEP collected "grab" indoor air samples at 47 residential homes in neighborhoods west and south of the Varian site (MassDEP 2020). Included in this investigation was 34 Sonning Road, which contained elevated levels of TCE in 2001 and 2002. Importantly, TCE and cis-1,2-DCE were not identified in any of the sampled homes. PCE was detected at low levels in a majority of the homes, with levels in 6 homes above the TVr value of 1.4 $\mu g/m^3$ and a maximum concentration of 3.2 $\mu g/m^3$. Because of the lack of other site contaminants (i.e., TCE and cis-1,2-DCE), the random distribution of detections within expected typical indoor air distribution (i.e., the 90th percentile value for PCE is 4.1 $\mu g/m^3$), and detection of PCE in the air sampling bags used during the effort, a determination was made that there was no indication of a vapor intrusion pathway in any of the evaluated homes at the time of sampling.

Though MassDEP has high confidence in the data and conclusions generated as a result of this air sampling effort, the vapor intrusion pathway is temporally variable and episodic, and a single sample represents a "snapshot in time." Additional air sampling is necessary, together with additional lines of evidence, including adequate data on water table VOC concentrations and VOC measurements in sub-slab soil vapor points.

Tozer Road Commercial/Industrial Properties

Six commercial and industrial properties are located west of and downgradient from the former Varian property (Figure 1). The following sections evaluate the available data for each of the six properties to determine if additional investigations are warranted at this time.

27 Tozer Road

The property at 27 Tozer Rd. is located on the west side of Tozer Rd., west of and downgradient from the former Varian property. The property is occupied by Arro Engineering Corporation, which operates a machine shop. Since 2011, shallow groundwater at the property has been monitored in well OB-43S (APTIM 2020b). Before 2015, TCE concentrations were generally below the GW-2 standard; in 2017, a sharp increase in TCE concentrations was observed (Figure 26). During this same period, PCE and cis-1,2-DCE concentrations also increased.

The increase in groundwater TCE concentrations motivated a soil gas study, which was conducted in February 2019 (APTIM 2019). Soil vapor was collected from two sub-slab sampling points. PCE was detected in both samples below screening values; TCE was not detected. Indoor air samples were not collected. Given the lack of indoor air sampling and spike in groundwater concentrations, additional sampling and evaluation is necessary for this building.

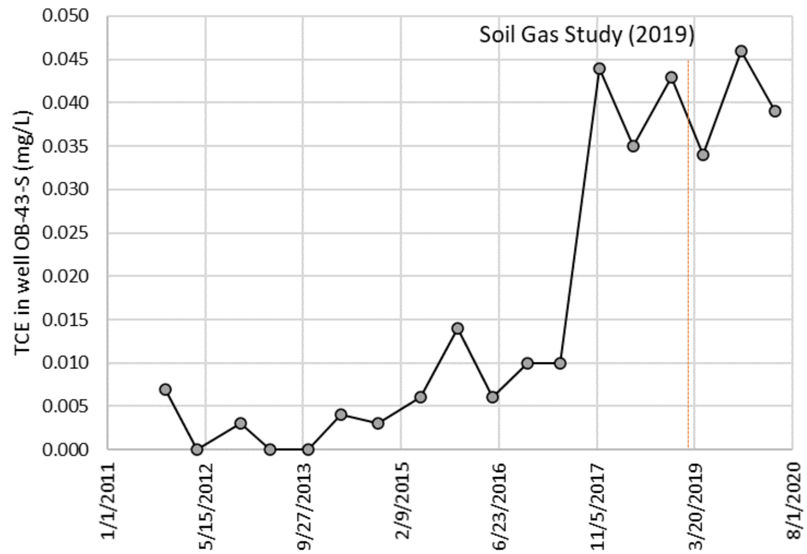

Figure 26. TCE concentrations in shallow groundwater at 27 Tozer Rd. have increased over time.

28 Tozer Road

The property at 28 Tozer Rd is located west of and downgradient from the former Varian property, along Tozer Rd (east side). Currently, the property houses the Hopeful Journeys Educational Center, a school for children with developmental disabilities. From 2002–2015, there were periodic permanganate injections on and near the property (see previous section for efficacy evaluation).

A sub-slab depressurization system (SSDS) was reportedly installed at this building by Geological Field Services (GFS) about 5 years ago, during an extensive building rehabilitation project. Two indoor-air grab samples obtained and analyzed by MassDEP in December 2020 did not show evidence of a vapor intrusion pathway.

On property groundwater monitoring wells in the shallow overburden include CL11-S, CL03-S, and GFS-1–GFS-4. From 2002–2020, groundwater samples from at least one well have been collected; the results are described below and shown in Figure 27.

- Well CL03-S is located directly above the treatment area (ISCO was conducted in the deep overburden and bedrock aquifers), 100 ft north of the building. From 2002–2011, the TCE concentration was consistent, remaining below the GW-2 threshold (5 µg/L).[25] Beginning after 2011, the concentration rose to 20 µg/L, above the GW-2 standard. The TCE concentrations suggest that vapor intrusion is a potential concern. Similarly, well GFS-3 contains TCE at concentrations greater than the GW-2 standard, and is located at the southwest corner of the building.
- Well GFS-4 (south of the building) and CL11-S (east of building) contain lower concentrations of TCE. There are no samples from either well collected in the last 2 years.

It appears that the SSDS installed in this building is effectively cutting off vapor intrusion pathways that may otherwise exist at this location.

[25] In 2013, and ISCO treatment was applied to the deep overburden (CL03-DO), which did not have an apparent impact on TCE in the shallow overburden (CL03-S).

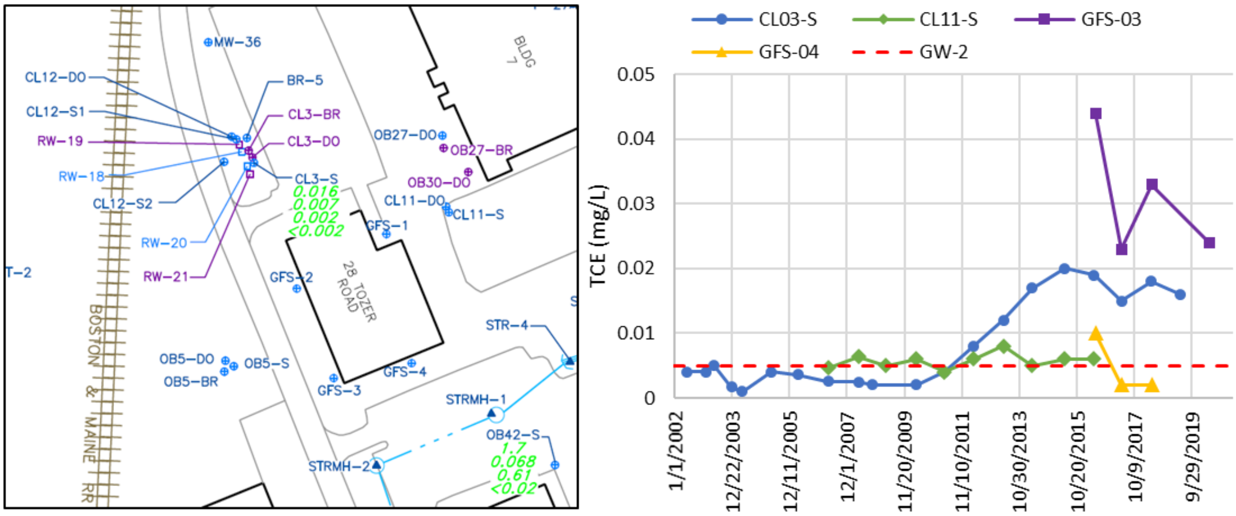

Figure 27. TCE concentrations in shallow wells at 28 Tozer Rd. have risen since 2011 and are currently above the residential/educational GW-2 threshold in two wells.

30 Tozer Road

The property at 30 Tozer Rd is located west of and downgradient from the former Varian property. Currently, the property is comprised of a single building (the Ayres D'Souza Medical Building), which houses a pediatrics practice. In January 2016, extensive renovations were completed at the building, including installation of an SSDS. Data from shallow groundwater, soil vapor, and indoor air samples are shown in Figure 28.

In January 2012, a soil vapor sample collected at 30 Tozer Rd, outside the building footprint, indicated additional vapor investigation was needed. In May 2012, a sub-slab soil vapor sample from inside the building exceeded MassDEP screening levels, triggering additional investigation. In November 2012, three indoor air samples and two sub-slab soil gas samples were collected (CBI 2013). Sub-slab and indoor air samples exceeded their respective screening values, so a risk evaluation was conducted that resulted in excess lifetime cancer and non-cancer risks below the MassDEP limits. Thus, CBI (2013) concluded that a condition of No Significant Risk was present at this property. Notwithstanding this finding, the owners of the building elected to contract with GFS to install an SSDS.

In January 2016, several weeks after initiation of the SSDS, a second indoor air and sub slab soil vapor investigation was conducted (CBI 2016a). Samples were collected when the sub-slab depressurization system was active. Again, sub-slab and indoor air TCE concentrations exceeded their respective screening values, and a risk evaluation concluded that a condition of No Significant Risk applied to the property.

From 2011 to present, shallow groundwater has been monitored at well OB42-S (APTIM 2020b). For much of that time, TCE concentrations have fluctuated between 1.3 and 3.5 mg/L. The most recent sample, collected in May 2020, contained the highest TCE measured to date, and is nearly double the concentration measured in 2016 (the last time indoor air was sampled). A single indoor-air grab sample obtained and analyzed by MassDEP in December 2020 reported the presence of 1.1 µg/m^3 of TCE. Given the recent uptick in TCE concentrations, and the fact that groundwater contains TCE an order of magnitude above the GW-2 screening threshold (5 µg/L), additional air sampling and/or evaluation of the SSDS is needed to ensure that conditions in all occupied areas of the building are at a condition of No Significant Risk.

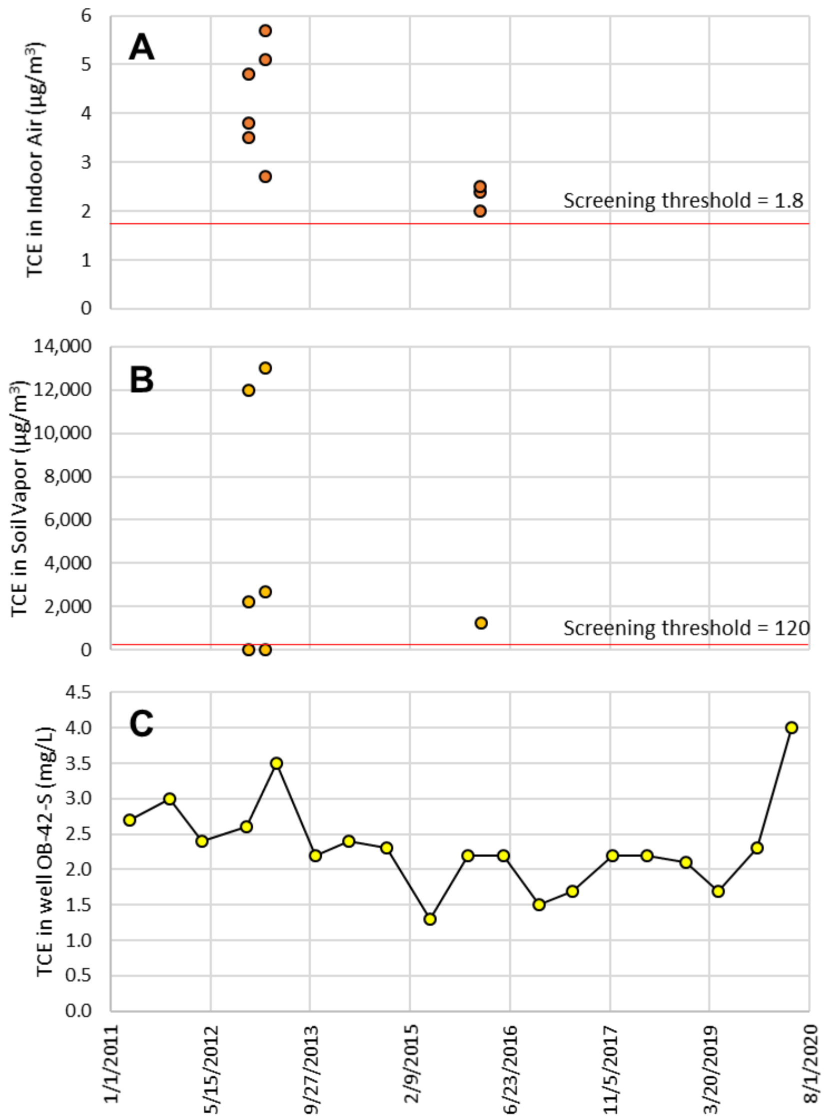

*Figure 28. TCE in indoor air (**A**), sub slab soil vapor (**B**), and groundwater (**C**) at 30 Tozer Rd.*

31 Tozer Road

Impacts in shallow overburden may be from a former stream, which historically flowed along Tozer Road. Discharges to the Unnamed Stream would have flowed downhill and settled as it flowed through a vegetated area near 31 Tozer Rd (IT 2000). TCE concentrations in groundwater at this location have fluctuated greatly over the past decade, ranging from 1.6 mg/L to below detection limits (Figure 29).

In August 1995, two indoor air and one ambient air sample**s** were collected at 31 Tozer Road. Although VOCs were identified in all 3 samples, it was concluded that none were related to the contaminants emanating from the Varian site. Given the fluctuating levels of TCE, lack of recent indoor air samples, and proximity to source areas, additional investigation is necessary.

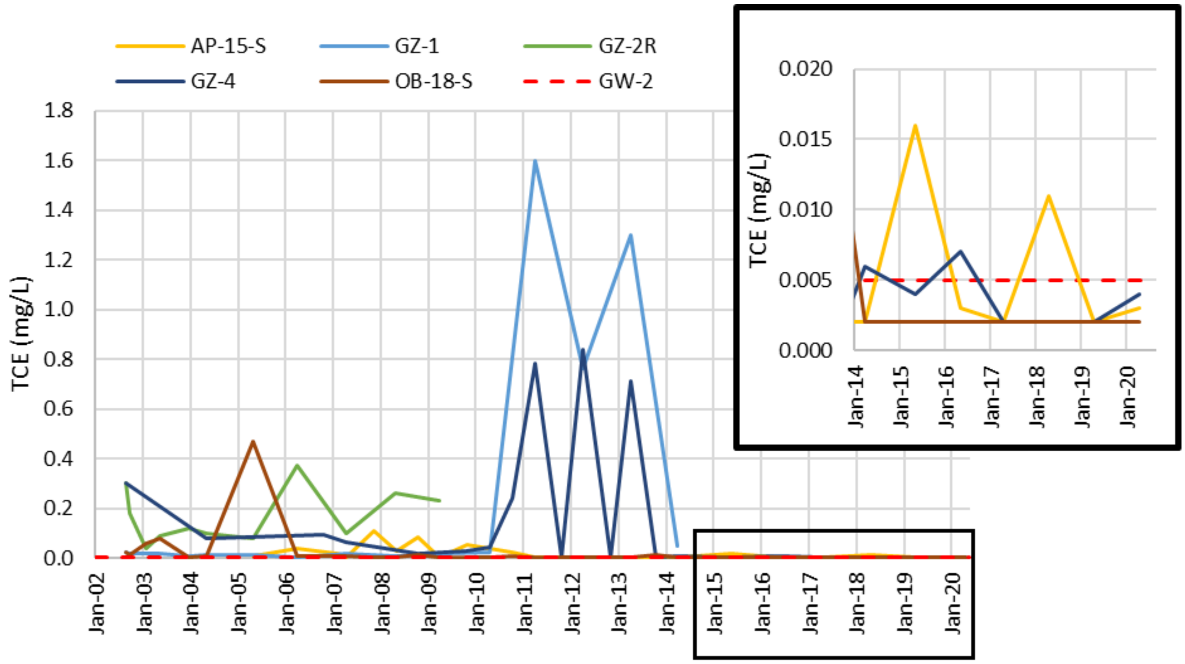

Figure 29: Since January 2015, TCE concentrations in shallow groundwater have been near or below the GW-2 threshold. Before 2015, TCE concentrations exceeded the (current) GW-2 standard in multiple wells at 31 Tozer Rd.

32 Tozer Road

The property at 32 Tozer Rd. is located on the east side of Tozer Rd. and borders the former Varian property (Figure 1). The 32 Tozer Rd. property contains a single building, which houses a biotechnology company (Cell Signaling Technology, Inc.). The building underwent extensive renovations, which were completed in May 2013.

In March 2011, the property owner collected soil, groundwater, sub-slab vapor, and indoor air samples as part of a pre-construction assessment (Shaw 2011). PCE, TCE, and cis-1,2-DCE were detected in soil, groundwater, sub-slab vapor, and indoor air samples; PCE exceeded the commercial/industrial indoor air screening value (Figure 30). Indoor air in the northern portion of the building contained higher CVOC concentrations than the southern portion. The assessment concluded that a pathway exists between VOC contamination in the subsurface and indoor air and recommends that this pathway be addressed during construction activities.

Shallow groundwater has been monitored since 2009 at well CL10-S (Figure 30). CVOC concentrations show a strong seasonal influence, with spring (April and May) samples containing higher concentrations than fall (October and November) samples. No long-term trends are apparent. PCE, TCE, and cis-1,2-DCE have all been detected, with generally higher concentrations of PCE than TCE and degradation products, indicating that the CVOCs are relatively undegraded.[26] Though the concentration of cis-1,2-DCE has doubled between 2017 and 2018, indicating some ongoing degradation of PCE and TCE, in July 2020 the cis-1,2-DCE concentration was nearly ten times lower than the PCE concentration.

After completion of renovation activities, several rounds of indoor air and sub-slab soil vapor samples were collected: May 2013, October 2013, February 2014, and April 2014 (CBI 2014b). During each of

[26] One exception was May 2018, when the concentrations of PCE and TCE were 0.49 and 0.48 mg/L, respectively.

the four sampling rounds, three indoor air and three sub-slab samples were collected. PCE, TCE, and cis-12-DCE were detected in indoor air; PCE and TCE exceeded their respective commercial/industrial screening values. A risk assessment was conducted, and CBI (2014b) concluded that a condition of No Significant Risk existed on the property.

APTIM (2020b) concluded that a condition of No Significant Risk related to indoor air continues to exist at 32 Tozer Rd, based on a decline in CVOC concentrations in well MW-2-32. Concentrations in well CL-10-S have not declined, but are consistent with conditions present when indoor air and sub-slab vapor investigations were last conducted. Thus, we agree that additional indoor air investigations are not warranted at this time.

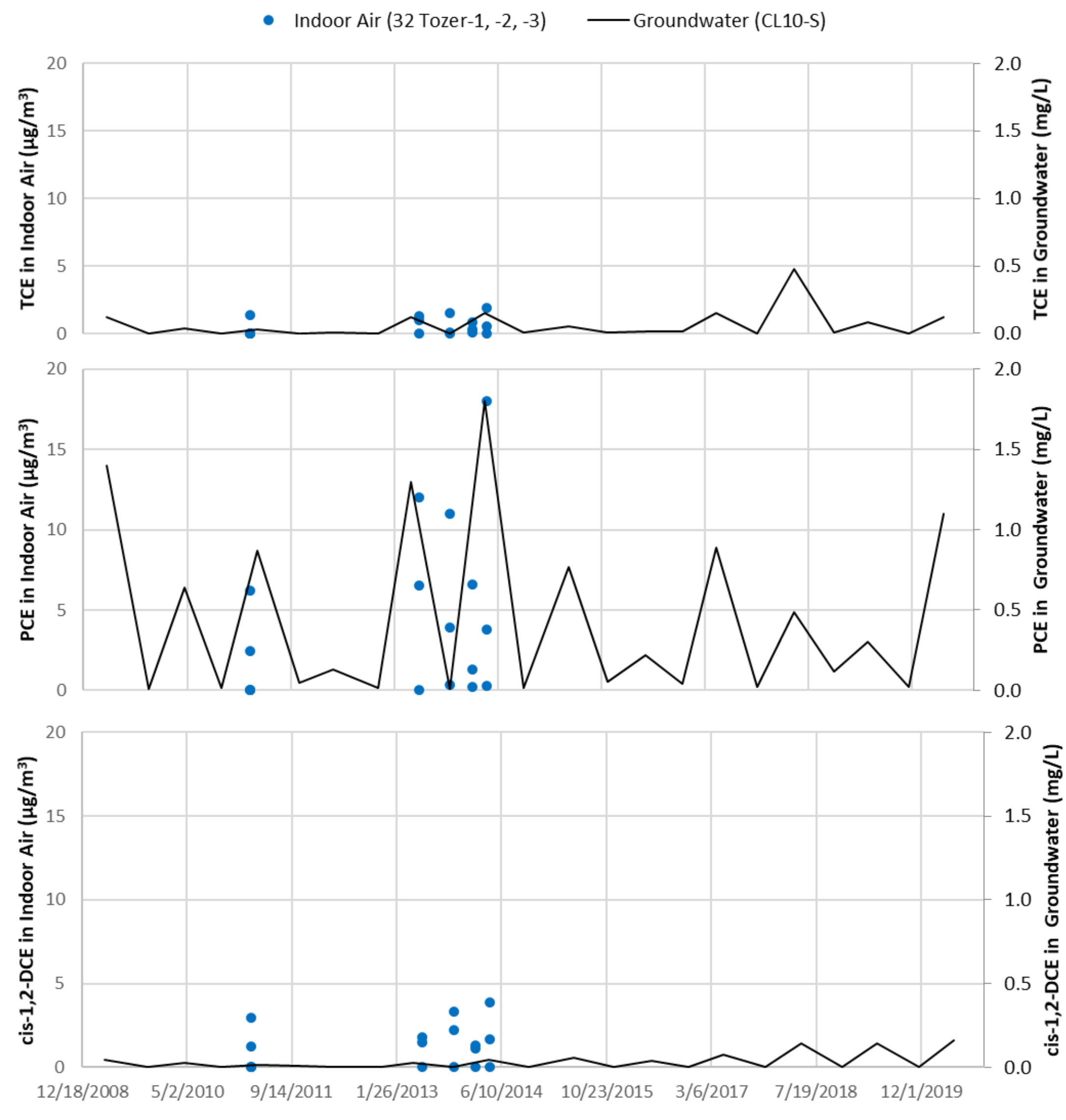

Figure 30. PCE and TCE concentrations show strong seasonal influences, and the prevalence of PCE relative to TCE and cis-1,2-DCE indicates that the material is relatively undegraded. Indoor air samples were collected in 2013 and 2014; groundwater conditions have not changed since that time.

39 Tozer Road

The property at 39 Tozer Road is located on the west side of Tozer Road, and hosts two commercial facilities: a moving/storage company and an industrial packaging production facility. The building is located between the Unnamed Stream (to the east) and Stream A (to the west). From at least 1999–2020, VOCs have been present in shallow groundwater at the property (Figure 6, Figure 31).

In January 2013, Varian performed a soil vapor and indoor air evaluation at 39 Tozer Road, which concluded that a condition of No Significant Risk was present at 39 Tozer Rd. The evaluation consisted of one soil vapor monitoring point installed through the building floor (northeastern corner of the building) and one indoor air sample collected concurrently. In soil vapor, PCE, TCE, cis-1,2-DCE, and vinyl chloride were detected above MassDEP screening values.[27] In indoor air, PCE, TCE, and cis-1,2-DCE were also detected, though only TCE exceeded the residential/commercial threshold value (at the time).[28] A risk assessment was conducted to evaluate the potential risk to workers exposed to VOCs in indoor air at the property, which found estimated lifetime cancer risk and cumulative non-cancer hazards below MassDEP limits.

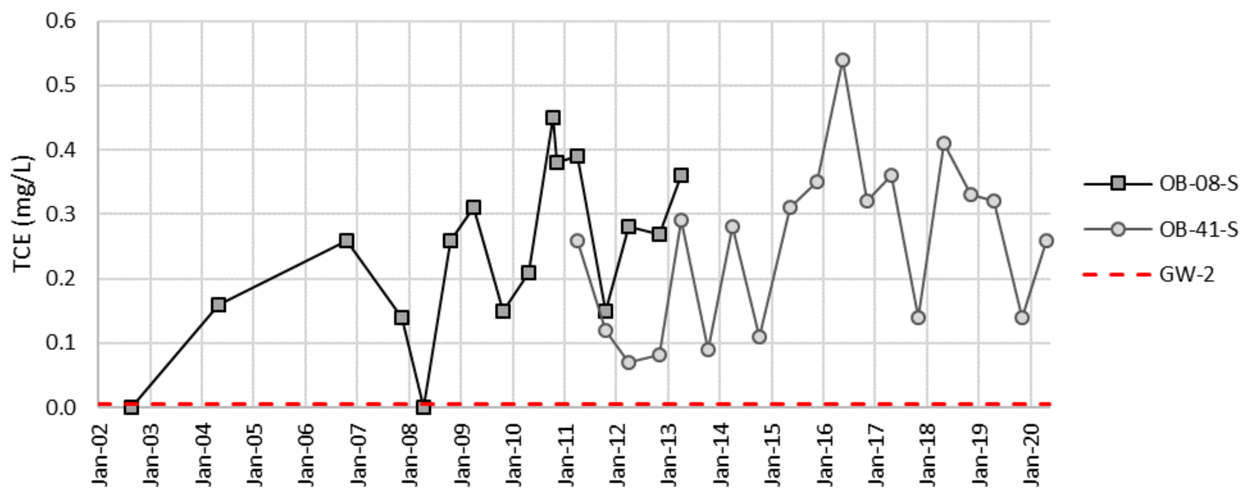

Figure 31. With one exception, shallow groundwater at 39 Tozer Rd. has been consistently above the 2016 GW-2 standard (Data from APTIM 2020b).

At this time, MassDEP recommends additional indoor air sampling at this facility. The 2013 indoor air evaluation was based on a single indoor air sample collected over a 4-hour period, and represents a snapshot in time that may or may not represent typical conditions. Though variable, groundwater concentrations have not trended down since the study was conducted in 2013.

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[27] In soil vapor, PCE was detected at 420 μg/m^3, TCE at 2,200 μg/m^3, cis-1,2-DCE at 2,100 μg/m^3, and VC at 29 μg/m^3.

[28] In indoor air, PCE was detected at 2.1 μg/m^3, TCE at 2.1 μg/m^3, and cis-1,2-DCE at 2 μg/m^3.

Specific Actions Required to Address Data Gaps

In our review of the available data, MassDEP has identified a number of data gaps and information needs that must be addressed. These gaps, along with required actions, are detailed in the sections below.

Groundwater Plume Delineation

- At least 2 new water-table wells are required on the eastern loop of Sonning Road; one at the OB6 deep/bedrock well cluster near 45 Sonning Road, and one further south near 35 Sonning Road. Existing wells on the western loop of Sonning Road must be inspected and repaired or replaced if no longer functional.
- At least one new water table well is required on the northern side of Tudor Rd. Existing shallow wells on Windsor Road and Jordan Road must be inspected and repaired or replaced if no longer functional.
- The existing shallow well on Walden Street must be inspected and repaired or replaced if no longer functional.
- Several monitoring wells are required in the parking lot of Building 7 in order to adequately monitor remedial operations, replacing wells in which remedial additives have been injected.
- Several bedrock wells are needed beneath and downgradient of the source area outside of Building 5, in order to determine if DNAPL has migrated down into the bedrock aquifer.
- Subsequent to the installation of these new wells and/or repair or replacement of existing wells, additional testing must be conducted to better define the extent of the VOC plume westerly and southerly of the former Varian property, and better define conditions at and near treatment areas.

Surface Waters and Sediments

- Additional sampling of the Unnamed Stream is necessary in areas that historically had the highest concentrations of VOCs but have not been sampled in over 20 years. This includes STR-02, STR-05 or STRHA-03, STRHA-04, and STRMH-01 or STRMH-02. Also, additional stream sampling downstream of the site at STRHA-8 is necessary.
- Sediment sampling is required in at least two locations in the Unnamed Stream; one along Tozer Road upstream of culvert, and at least one downstream of the Tozer Road culvert and before the confluence with Stream A. At least two more sediment samples are needed downstream of the confluence with Stream A, one prior to Russell Street, and one between Kittredge Street and Herrick Street, westerly of the playing fields at the high school. All samples should be composite samples from quiescent (deposition) areas, and analyzed for all site contaminants, including VOCs.
- Sampling of the recently identified groundwater discharge point ("spring") near 28 Hill Street is required to determine if it is a point source of VOCs to Stream A, and a stream sample collected downstream of the spring shall also be analyzed. Based on these results, a risk assessment shall be conducted, and remedial actions shall be considered to address risk from the spring and downstream surface water. Identification, sampling, and assessment of other potential VOC point sources to Stream A are also necessary; these actions include:
    - A survey to identify other discrete groundwater discharge points;
    - Collection of spring and downstream surface water samples from each identified discharge point;

- Analysis of water samples for all site contaminants;
- Assessment of risk associated with dermal contact to spring water for children playing in the stream; and
- Consideration of remedial actions, if needed, to reduce the risk to acceptable levels.

Evaluation of Vapor Intrusion Pathways

Residential Homes

A multiple lines-of-evidence investigation of the potential existence of a vapor intrusion pathway must be conducted on a representative number of residential homes westerly and southwesterly of the Varian site during January or February of 2021. This must include the installation and sampling of at least two sub-slab vapor and 24-hour indoor air sampling in basement and first-floor area. At a minimum, and subject to obtaining access, this must include those homes in neighborhoods closest to the Varian site where a (current) TVr value was exceeded in the 2001/2002 sampling effort and/or in the 2020 MassDEP sampling effort, as delineated below:

- 26 Jordan Street
- 26 Lexington Drive
- 28 Lexington Drive
- 32 Lexington Drive
- 33 Lexington Drive
- 34 Lexington Drive
- 36 Lexington Drive
- 38 Lexington Drive
- 40 Lexington Drive
- 1 Longview Terrace
- 5 Longview Terrace
- 29 Longview Drive
- 30 Longview Drive
- 33 Longview Drive
- 31 Sonning Road
- 32 Sonning Road
- 34 Sonning Road
- 40 Sonning Road
- 43 or 45 Sonning Road
- 35 or 37 Sonning Road
- 61 Sonning Road
- 63 Sonning Road

Commercial Buildings

- 27 Tozer Road - A synoptic sub-slab soil vapor and indoor air sampling effort is required. Depending on the results of this testing, a continuing sampling program and/or installation of an SSD system may be necessary.

- 30 Tozer Road - A synoptic sub-slab soil vapor and indoor air sampling effort is required. Depending on the results of this testing, a continuing sampling program and/or modification of the existing SSD system may be necessary.
- 31 Tozer Road - A synoptic sub-slab soil vapor and indoor air sampling effort is required. Depending on the results of this testing, a continuing sampling program and/or installation of an SSD system may be necessary.
- 39 Tozer Road – A synoptic sub-slab soil vapor and indoor air sampling effort is required. Depending on the results of this testing, a continuing sample program and/or installation of as SSD system may be necessary.

Source Delineation

It is unclear whether DNAPL source areas beneath Buildings 3 and 5 have been adequately defined, which is needed to ensure optimal remedial operations. In order to address this concern, a report needs to be prepared and submitted by Varian that includes the following specific elements:

- A succinct summary of investigatory activities that have been undertaken to date to identify the specific locations of DNAPL in the vadose zone, overburden saturated zone, and bedrock;
- An evaluation of the need for and cost/benefit of angle boring membrane interface probe (MIP) characterization of the sub-building overburden; and
- An evaluation of the need for and cost/benefit of performing a partitioning interwell tracer test (PITT) to detect and quantify DNAPL.

Remediation

ISCO

It is unclear whether ongoing ISCO operations are optimal and/or whether refinements could be made to improve mass removal and expedite site cleanup. While studies and considerations in this regard have been outlined in various submittals by APTIM over the years, an up-to-date dedicated report on this subject is necessary, including the following specific elements:

- A plan detailing the location of ISCO injections at Building 3 and at Building 5, including relevant details on specific piping networks.
- An evaluation of whether the multi-year injections of permanganate oxidants at the site has created excessive quantities of manganese oxide precipitates that has reduced soil permeability in a manner and/or to an extent that is impeding the timely remediation of source areas. This evaluation shall include information on any observed reductions in application rates that would suggest decreases in soil permeability or mass removal. If such a condition is shown or suspected to exist, the report shall include and recommend options to address the problem.
- An evaluation of whether alternative oxidants, such as Persulfates, could improve mass removal rates.
- An evaluation of whether alternative technologies, such as in situ thermal treatment, could improve mass removal rates.

SVE

It appears that existing SVE systems were initially installed to cut-off vapor intrusion pathways into overlying buildings, and it is not clear if they were designed and/or operated in a manner to optimize mass removal of VOCs and DNAPL from the vadose zone. While it is acknowledged that details in this regard have been provided in various APTIM submittals, a succinct summary report is necessary in the evaluation of this matter. This report should include the following specific elements:

- A plan detailing the piping and treatment network for the SVE systems in Buildings 3 and 5, indicating pipe diameter and blower CFMs, and the mode of operation (e.g., continuous or cycling).
- Details on the radius of influence, including how it has been established and monitored.
- Information, data, and/or graphs showing mass removal rates over time.

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