Groundwater Review of Former Millbrook Jail Lands and Watershed

Includes:

Final Report

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Executive Summary

The property, once home for a maximum security correctional centre in Millbrook, Ontario, has remained vacant since facility closure in 2003. This building on the 105.8 acre property, owned by Infrastructure Ontario (IO), underwent demolition in 2012. Environmental Site Assessments (ESAs) were conducted in 2011 and 2012 to determine the environmental impacts as a result of potentially contaminating activities employed by the facility from 1957-2003. These assessments revealed over twenty areas of potential environmental concern (APECs), with subsequent soil and groundwater monitoring revealing locations of soil contamination. Such instances prompted the installation of shallow groundwater monitoring wells. Upon thorough testing, no contaminants of concern were identified in the groundwater at the time. IO continued their groundwater monitoring program, still in effect today, to further investigate the lateral and vertical extent of contamination on the property. The particular groundwater layer of interest is layer three - encountered at a minimum depth of approximately 25 meters below ground surface - as this is the aquifer that supplies drinking water to residents of Millbrook. The main contaminant of concern that has remained persistent over the years is perchloroethylene (PCE), also known as tetrachloroethylene or tetrachloroethene. The contaminant first appeared in 2014, at a maximum concentration of 5.6 µg/L in the upper interval of layer three on site, but has been steadily decreasing since then. The Site Condition Standard (SCS) for PCE in groundwater is 1.6 µg/L; although many sampling events appear above SCS, all groundwater samples obtained to date have exhibited PCE concentrations below the Ontario Drinking Water Quality Standard (ODWQS) of 10 µg/L. This collaborative research project with Baxter Creek Watershed Alliance (BCWA) aims to inform stakeholders about the history of contamination on the property and potential liabilities under future uses. Given its location within the environmentally sensitive Oak Ridges Moraine, where Baxter Creek's headwaters lie, understanding contamination impacts is crucial. Of particular concern are the Wellhead Protection Areas (WHPA) for Millbrook's municipal wells, with approximately 74% of the property falling within these vulnerable zones. Historical on-site activities, including hazardous waste disposal, raise apprehensions concerning off-site contamination.

While testing of municipal drinking water supply has shown no contamination above ODWQS since 2013, the extent of potential off-site contamination still requires further investigation.

Recommendations

- Off–site monitoring to assess vertical and lateral contamination spread, especially given the site's topography.
- Prior to considering residential development, review Official Plan policy sections 3.18, 3.4, and 4.5, specific to brownfields and contaminated sites [32].
- Explore low-impact educational or conservation uses to mitigate risks to groundwater and the Oak Ridges Moraine.

Introduction

Millbrook, Ontario, is a small village located 15 minutes southwest (SW) of Peterborough. This was the home for a maximum-security correctional centre, built in 1957 and in operation until 2003, when it closed, and demolition of the property commenced in 2012. The 105.8-acre site is owned by Infrastructure Ontario (IO) and has been vacant since site closure in 2003. Thus far, the property has been primarily used for recreational activities; however, trespassing on-site is strictly prohibited. Upon facility closure in 2003, since the property was no longer required for a correctional centre, and there was no immediate government need or interest in the property, the property was considered surplus in 2018. It was then circulated to other levels of government before circulation to eligible non-profit organizations, public colleges or universities, and eligible Indigenous communities. If anyone expresses interest, IO may facilitate a direct sale [1].

Phase I and II Environmental Site Assessments (ESA) were conducted on site in 2011 and 2012 to determine the impacts of on-site activities in the soil and groundwater. Instances of soil contamination were confirmed in these reports, available for full reference on the BCWA webpage [2,3]. Upon demolition in 2012, a consultation and documentation report (C&D report) was constructed as part of a regulatory process required in preparation for the demolition of a property [4]. Again, instances of soil contamination were confirmed and are detailed in the full document available [4]. Since 2011, IO has implemented a groundwater monitoring program to assess the impacts of contamination still being observed today. Testing events were occurring four times a year initially, although IO's most recent groundwater monitoring report recommends sampling events be reduced to semi-annual for the upcoming monitoring period [5]. The expected date for removal of groundwater monitoring wells and subsequent testing on site has not been determined.

This research project is in collaboration with Baxter Creek Watershed Alliance, an organization with a mission to "conserve and enhance the local watershed environment for future generations of humans and wildlife" [6]**.** BCWA supports those living and working in the Baxter Creek and Cavan-Monaghan areas and connecting watersheds across the Otonabee River basin. The purpose of this study is to conduct an independent third-party review to provide information about the history of the property in regards to contamination, to inform eligible non-profits including BCWA of the site conditions and liabilities under potential future uses, and to inform other eligible organizations who may be interested in the property or purchasing for future compatible uses. The property is well known in the community of Millbrook, therefore the purpose of this study is also to provide the residents with a comprehensive review of the contamination on site, and what impacts this may have on the local water supply.

Background

Significance

This project is extremely significant in terms of the location of the property in question, and its surrounding ecological features. A full map of the facility (since demolished) and property can be referenced in Appendix A, Figure 13. These qualities add weight to the reasons for documenting and confirming the current state of contamination, and for that status to be shared with the community and all stakeholders involved in future development of the property. There are significant "vulnerable areas" on and around the property, including wellhead protection areas (WHPA), significant groundwater recharge areas (SGRA), and highly vulnerable aquifers (HVA) [7]. The site lies within the Oak Ridges Moraine, an "environmentally sensitive geological landform" that supplies drinking water to many residents of Southern Ontario, covering approximately 470,000 acres [8]. In 2001, the *Oak Ridges Moraine Conservation Act*, was enacted, and it provided the authority to establish the Oak Ridges Moraine Conservation Plan in 2002. The aim of this plan is to provide land use and resource management planning direction to provincial ministers, ministries, and agencies, municipalities, municipal planning authorities, landowners and other stakeholders on how to protect the Moraine's ecological and hydrological features and functions [8]. Due to the site being located within the moraine area, it is subject to this Act. More specifically, the northern portion of the site is designated as an "Oak Ridges Moraine Linkage Area," further adding significance to the extent of contamination in these areas [4]. Downslope of the ravine on site, there is a tributary of Baxter Creek running along the northern edge of the property, therefore Baxter Creek's headwaters lie in the Oak Ridges Moraine. It is noteworthy that the largest threat to this watershed is significant residential development in the headwaters.

The site is located within the Source Water Protection Area for the Millbrook Municipal wells [4]. There are four wellhead protection areas of concern for this project: A, B, C, and D, as shown in Figure 1 below. WHPA-A is denoted as the location of the municipal wellhead - where Millbrook draws its drinking water from to supply to its residents - and encompasses the area within a 100 meter radius from the well. This is considered the most vulnerable area for groundwater supply intakes. WHPA-B is the area within a two-year time of travel to the well, which means that contaminants may reach the municipal well in two years or less if spilled or leaked in this area. WHPA-C is the area within five years of travel to the well. WHPA-D is the area within a 25-year time of travel to the well. These areas are deemed significant as about 74% of the property in question is within WHPA-B, and portions of WHPA-C and D occupy the north end of the property [9].

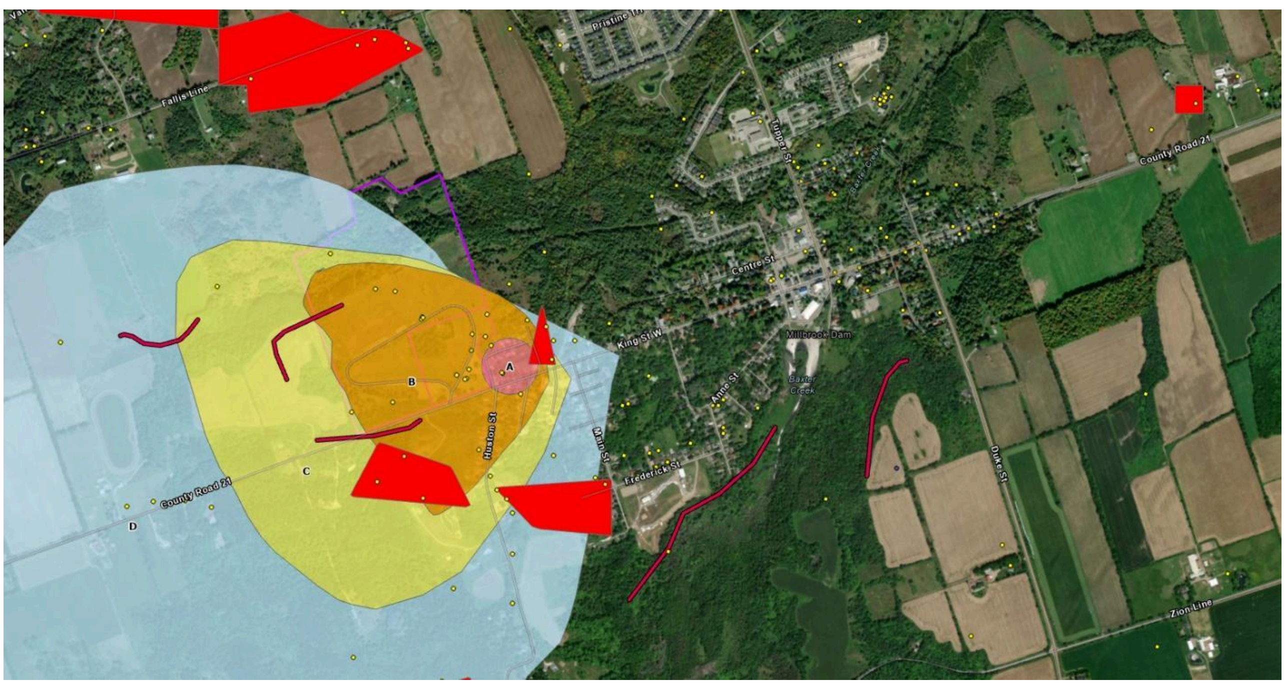

Figure 1. WHPA Zones; Pink = WHPA-A, Orange = WHPA-B, Yellow = WHPA-C, Blue = WHPA-D. Red - HVA. Site boundaries highlighted in purple.

Moreover, the property is primarily documented and mapped as a Significant Groundwater Recharge Area (SRGA) [9]. Groundwater recharge areas are important in replenishing underground aquifers, doing so by allowing water to infiltrate through its porous soil. Protecting these areas is essential in maintaining water quality and availability. The Oak Ridges Moraine serves as a significant groundwater recharge system and a primary water source for Ontario. Ecologically Significant Groundwater Recharge Areas (ESRGA) are regions that not only contribute to groundwater recharge, but also support sensitive ecological features like wetlands and streams [10]. Given the proximity of the SGRA to wetlands and coldwater streams such as the Baxter Creek tributary, it is likely to also be an ESRGA. A map of SGRAs on and surrounding the property is shown in Figure 2 below, labeled by their vulnerability; SGRAs of high vulnerability are assessed a score of 6, moderate areas are scored a 4, and low areas a 2.

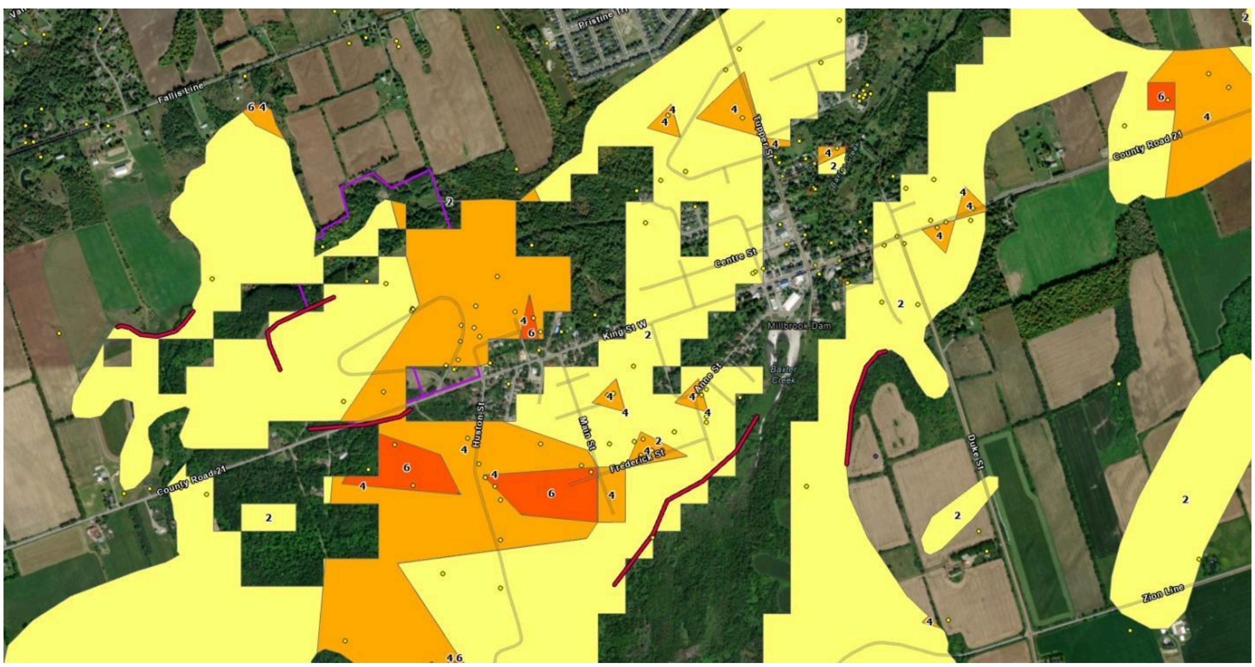

Figure 2. Significant groundwater recharge areas, labeled by their vulnerability (2 = yellow, 4 = orange, 6 = red.)

While there are no 'Highly Vulnerable Aquifers (HVAs) present on the site, the property drains directly to other HVA areas, highlighted in red in Figure 3 below. HVAs are underground geological formations that serve as sources of drinking water and are susceptible to contamination from pollutants released on the surface [11].

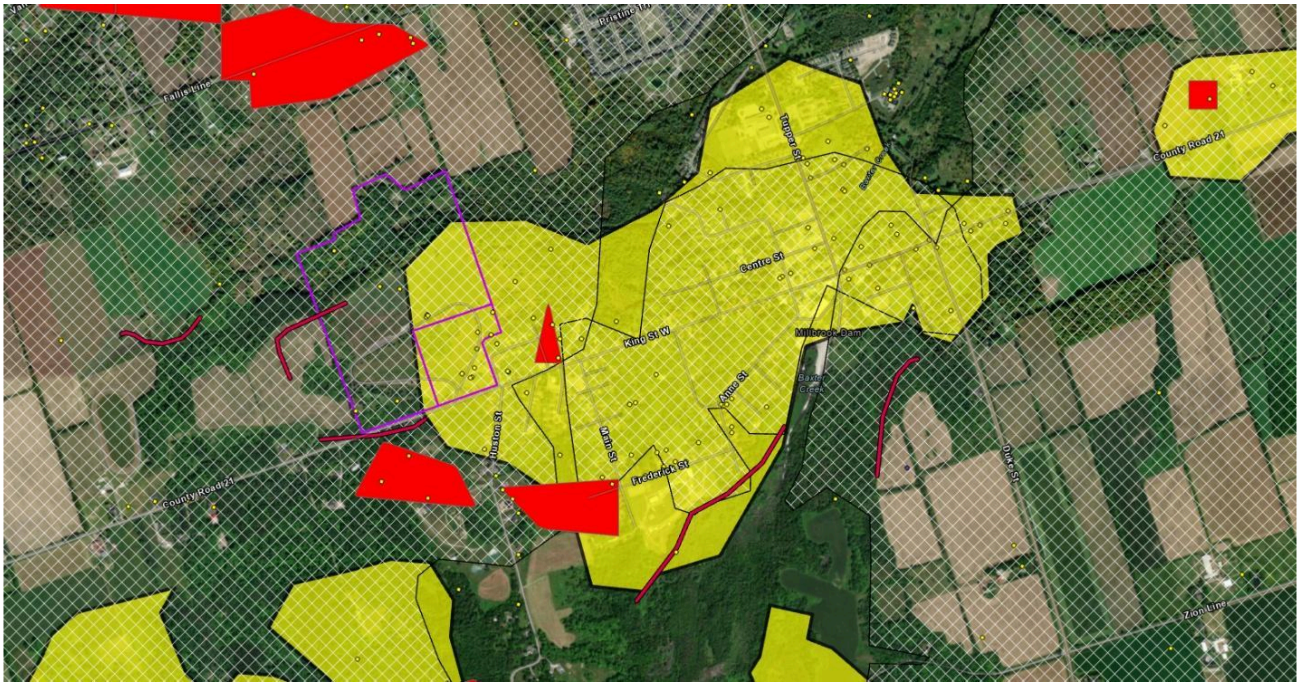

Figure 3. Highly vulnerable aquifers labeled in red. "Oak Ridges Moraine sediments aquifer" or Layer 3 shown in Yellow. Oak Ridges Moraine sediments aquifer shown in cross-hatch.

This property exhibits extreme potential for conservation, consisting of extensive wooded areas and natural landscapes that are still intact. Significant ecological features on the property include a tributary of Baxter Creek, mature woodlands with pine plantations, springs, seeps, open grasslands, and wild-flower-filled meadows. These areas present breeding habitats for grassland birds, some of which are at-risk species. Moreover, the coldwater tributary of Baxter Creek serves as a source of headwater and groundwater recharge area, where species like Brown Trout, Creek Chub, and Blacknose Dace have been observed [9].

Millbrook Municipal Wells

It is important to note for this project that prior to 1970, all residents in Millbrook obtained their drinking water supply from their own private wells. The first municipal well was installed in Millbrook in the early 1970s. The site is in close proximity to the municipal wells, as seen in Figure 1 above; the wellhead is in the center of the pink circle. To date, some residents still own and maintain a private well for drinking water, but most residents utilize the Millbrook municipal wells. As initial environmental assessments documented that contaminating activities were occurring at the correctional centre from the 1950s until closure in 2003, it raises concerns about contamination extending off-site into the municipal drinking water supply. Additionally, the contaminating activities were confirmed by independent recollection from former employees, interviewed throughout the research process. It wasn't until the 1980s that proper hazardous waste disposal methods were implemented at the facility. Prior to this, hazardous waste and garbage was being disposed of on site, with the potential for contaminants to leach into soil and subsequently sink within the water table to reach great depths within the groundwater layers on site. It wasn't possible to obtain drinking water monitoring records for the municipal wells in the 1970s, it wasn't until early 2010 that Millbrook implemented their drinking water monitoring program. Since 2013, there has been no contamination detected in the municipal drinking water supply. It is important to note that PCE, the main contaminant of concern, is actively being tested for in the municipal supply, listed as tetrachloroethylene in the township data records.

Brownfields and Regulatory Regimes

This property is termed a "brownfield," defined as vacant or underutilized areas where past activities may have left contamination in soil or groundwater [12]. When redeveloping a brownfield property for a new purpose, property owners and developers are required to meet set requirements through ESAs and filing a record of site condition (RSC). Filing an RSC can mitigate potential liabilities for property owners and other stakeholders [12]. There are specific cases such as low risk redevelopment situations, where filing an RSC is not required [12]. The requirements for RSCs and Phase I/II Environmental Site Assessments (ESA) are laid out in O. Reg 153/04. This regulation ensures brownfields are properly assessed to meet Site Condition Standards (SCS) set out by the MECP.

The implementation of environmental protection regulations in Ontario, particularly those relating to groundwater contamination, is rooted in the Safe Drinking Water Act, 2002, and the Clean Water Act, 2006. These legislative frameworks establish the foundation for ensuring the quality and safety of Ontario's water supply. The Safe Drinking Water Act (SDWA) is geared towards ensuring safe drinking water for Ontario residents, while the Clean Water Act (CWA) focuses on protecting certain areas from contamination through source protection areas [13,14]. Within the regulatory landscape of Ontario, the Ministry of the Environment, Conservation and Parks (MECP) plays a central role in overseeing the management and protection of groundwater resources. One of the key regulations in this regard is O.Reg. 511/09 under the Environmental Protection Act, 1990 (EPA), which outlines the standards and procedures for managing contaminated sites [15]. This regulation provides guidance on the assessment, remediation, and monitoring of contaminants to protect the environment. Regarding groundwater contamination, the Ontario Drinking Water Quality Standards (ODWQS) are crucial benchmarks established under the SDWA. These standards set maximum allowable concentrations for various contaminants in drinking water to ensure its safety for consumption. For instance, the ODWQS sets a maximum acceptable concentration (MAC) of 10 µg/L for PCE, the main contaminant of concern on this property, under O. Reg. 169/03 [16]. In assessing groundwater contamination, the Ministry of the Environment (MOE) provides comprehensive guidance through documents such as Table 1 Full Depth Background Site Condition Standards and Table 2 Full Depth Generic Site Condition Standards in a Potable Groundwater Condition [17]. This is essential data for comparison purposes to relate concentrations of contaminants found on-site to the acceptable levels provided by the Ontario government. Overall, these documents outline the standard levels of contaminants in groundwater and establish protocols for conducting assessments to determine compliance with regulatory standards.

The EPA is legislation designed to safeguard the environment from various sources of pollution, contamination, and degradation. Within its provisions, the EPA addresses a wide range of environmental concerns, including the remediation of brownfield properties. Brownfields have the potential to cause extensive environmental damage if left unattended, however there is potential for redevelopment of brownfields to meet environmental standards and allow for reuse of an area [12]. Under the EPA, brownfield redevelopment is encouraged with the aim to revitalize these areas while mitigating environmental risks. The assessment of environmental impacts on brownfield sites typically involves several steps. Firstly, a thorough site investigation is conducted to identify potential contaminants and assess their extent. Following this, risk assessments are performed to evaluate the potential harm posed by contaminants to human health and the environment, including wildlife. Subsequently, remediation plans are developed and implemented to address the identified risks, which may include containment, removal, or treatment of contaminants. Throughout this process, regulatory compliance and community engagement play integral roles in ensuring effective environmental protection and sustainable redevelopment of brownfield properties [18]. Altogether, the regulatory regime in Ontario, encompassing the EPA, CWA, SDWA, and associated regulations, provides a robust framework for mitigating groundwater contamination. By setting clear standards and procedures, monitoring contaminants of concern like PCE, TCE, and chloroform, and implementing remediation measures when necessary, Ontario strives to protect its groundwater resources and ensure the health and well-being of its residents, encompassing humans and wildlife.

Hydrogeology of Site

There are some important definitions surrounding groundwater and the watershed this site sits on that are necessary for understanding the scope of this research project. The layers of soil and groundwater below develop into aquifers and aquitards. An aquifer is a geological unit in the subsurface that acts as a large underground storage tank for large volumes of water. Typically composed of large rocks and gravel, the large pore size of this layer allows for the movement and flow of water. An aquitard is a geological unit made up of clay and silt, having small pore sizes to limit the movement of water. Aquitards act as effective barriers between aquifers, keeping the groundwater in each layer separate. Specific to the property where the Millbrook Correctional Centre was located, there are three main layers this project will focus on, shown in Figure 4 below. Layer one, the Recent Deposits and Oak Ridges Aquifer Complex overlays the underlying aquifer. Layer three is the aquifer Millbrook draws water from to supply residents with drinking water, known as the Inter-Newmarket Sediment Aquifer. The Upper Newmarket Till Aquitard creates layer two, acting as a hydraulic barrier between the two aquifers; however, there is some chemical evidence on site to suggest this layer is not functioning effectively, perhaps due to site disturbances during demolition [19].

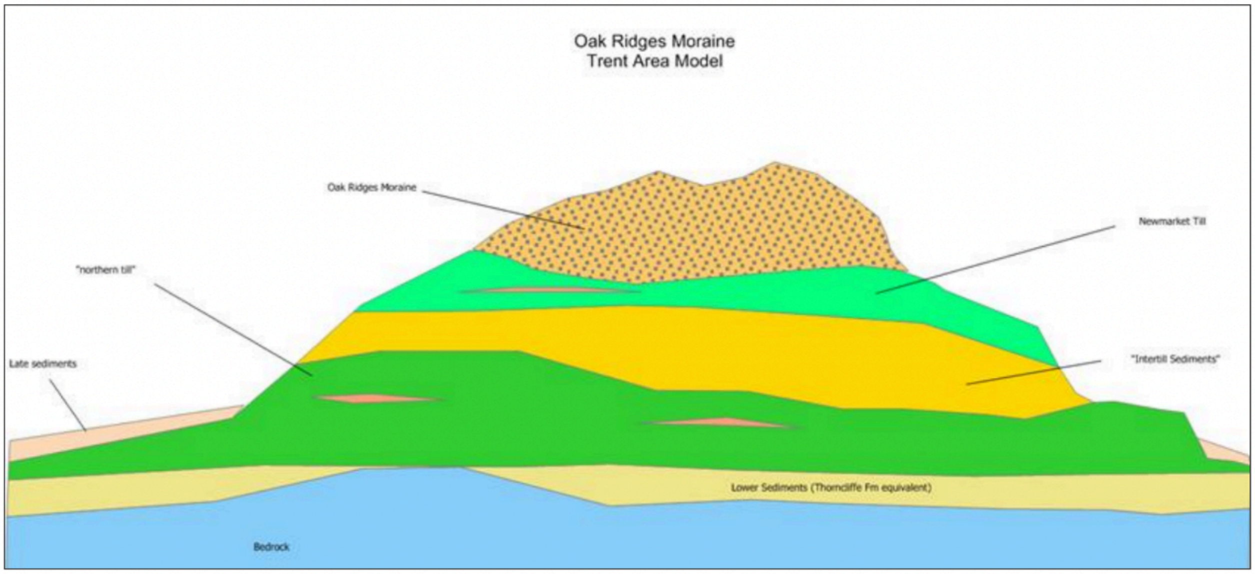

Figure 4. Groundwater layers of concern for this project.

The surface geology and topography of the land play crucial roles in determining the movement and distribution of contaminants such as DNAPLs within groundwater layers. Several factors can influence the behaviour of contaminants such as geological composition, slopes and elevation, hydrogeological features, and hydraulic conductivity. The geological composition of the land, including the presence of different rock types, soil formations, and geological structures, can affect the movement of contaminants in groundwater. Permeable geological formations such as sandstone or fractured limestone facilitate the rapid movement of contaminants, allowing them to infiltrate deeper into groundwater aquifers. In contrast, impermeable formations such as clay layers can act as a barrier, limiting the downward migration of contaminants and causing them to accumulate near the surface. This formation can be classified as an aquitard. Hydrogeological features such as aquifers and aquitards play a significant role in controlling the movement of groundwater and contaminants. Aquifers, which are permeable geological formations capable of storing and transmitting water, provide pathways for contaminants to migrate horizontally and vertically within groundwater layers. Conversely, aquitards act as barriers to groundwater flow, restricting the movement of contaminants between different hydrogeological units. The stratigraphy of the site is generally silty sand to sand, with bedrock for this area at approximately 100 m below ground surface (BGS). Site conditions consist of sandy soil covering an unconfined sand aquifer, positioned 25-30 m below ground level, as measured from the valley's highest point. These features are depicted in Figure 5 below.

At the rear of the property near the onion field and lagoon (reference map in Appendix A), the aquifer lies approximately 7 m below the creek, indicating "the creek is a losing stream at this location" [20]. A losing stream or disappearing stream is one that loses water as it flows downstream, as water permeates through the soil to recharge the local groundwater that underlies. The hydraulic conductivity of geological materials, which refers to their ability to transmit water, influences the rate at which contaminants can migrate through groundwater. Materials with high hydraulic conductivity, such as coarse-grained sand and gravels, facilitate rapid groundwater flow and the transport of contaminants over long distances. In contrast, materials with low hydraulic conductivity, such as clay and shale, impede groundwater flow and may cause contaminants to accumulate in localized areas. The hydraulic conductivity in layer one ranges between $2.4x10^{-3}$ cm/s and $2.7x10^{-3}$ cm/s; this is high and representative of an aquifer. The hydraulic conductivity in layer three ranges from $1.3x10^{-2}$ cm/s and $6.5x10^{-3}$ cm/s; again, high and representative of an aquifer [21]. These values, coupled with an assumed sand porosity value of 0.3, and a groundwater gradient of 0.017 m/m, allow for groundwater velocity to be calculated [20]. The groundwater velocity in layer one is approximately 45m/year, and 90m/year in layer three [21]. Factors such as slope and elevation of the property influence the direction and rate of groundwater flow. Direction of groundwater flow in different areas of the property is depicted by the light blue arrow in Figures 6 and 7 below. If contaminants are soluble in water, they will follow the natural gradient of groundwater flow, moving from higher to lower elevations. Contaminants such as dense non-aqueous phase liquids (DNAPL) tend to remain in a separate phase, failing to mix adequately with water, meaning they are more likely to follow the natural dips and paths of the underlying surface topography. Steep slopes, such as the ones located on this property, can accelerate the movement of contaminants downslope, increasing the risk of contamination spreading over a larger area. Conversely, flat or gently sloping terrain may result in slower groundwater flow rates, allowing contaminants to remain localized or pool within a dip in the land. This has likely occurred on this property due to the significant landscape features, leading to off-site contamination, although this has not been confirmed due to lack of off-site monitoring.

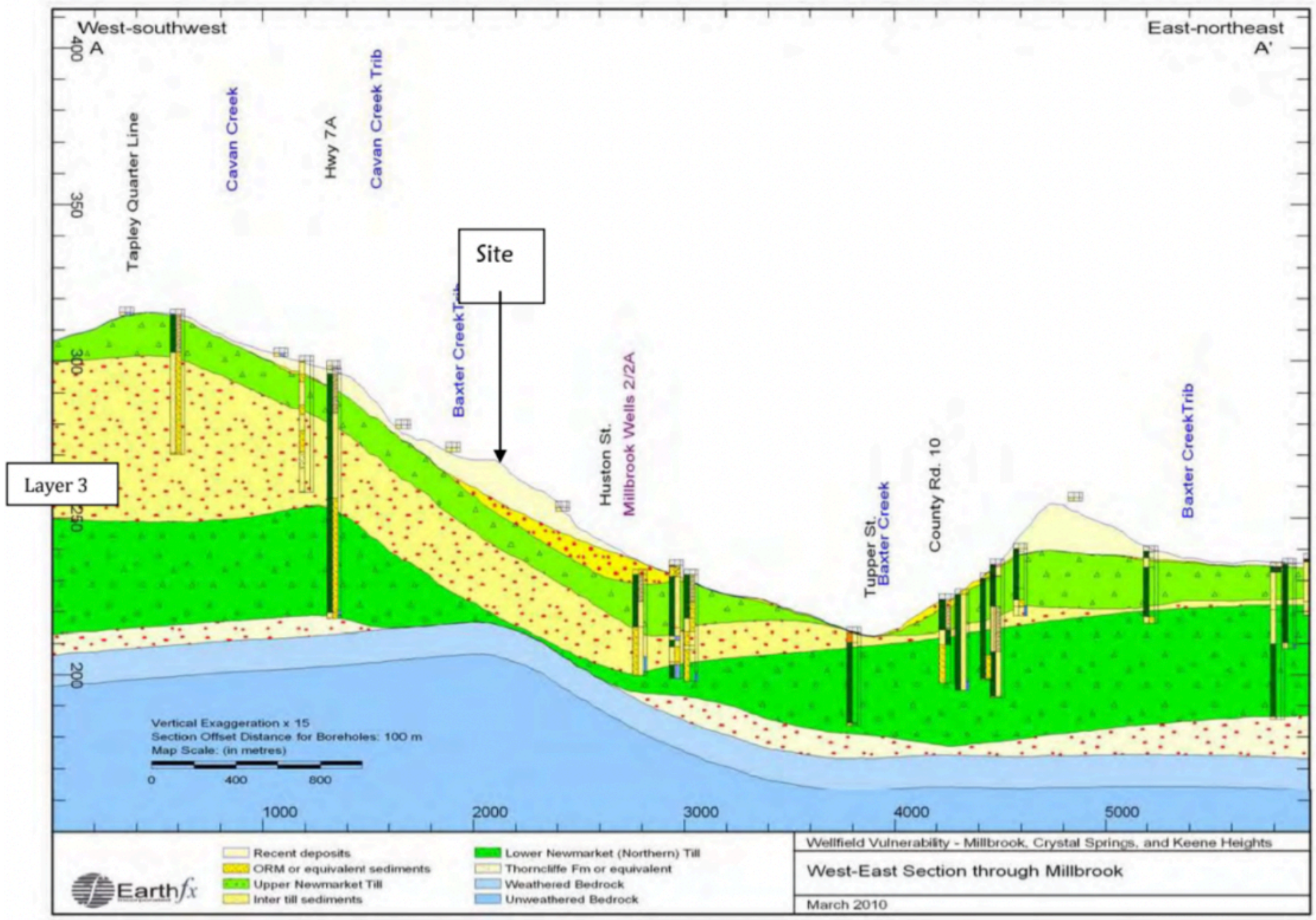

Figure 5. Specific site stratigraphy.

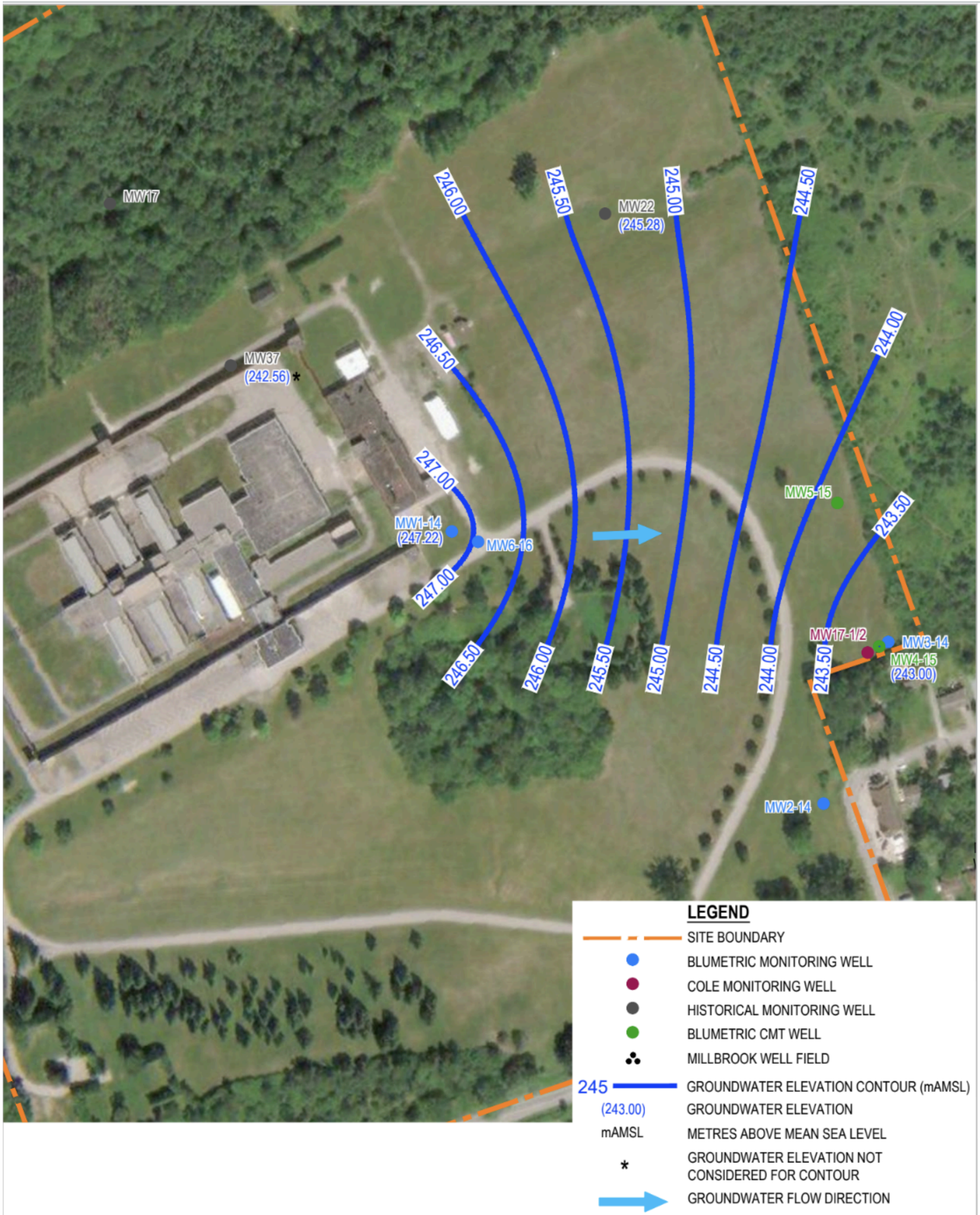

Figure 6. Groundwater flow direction indicated by a blue arrow.

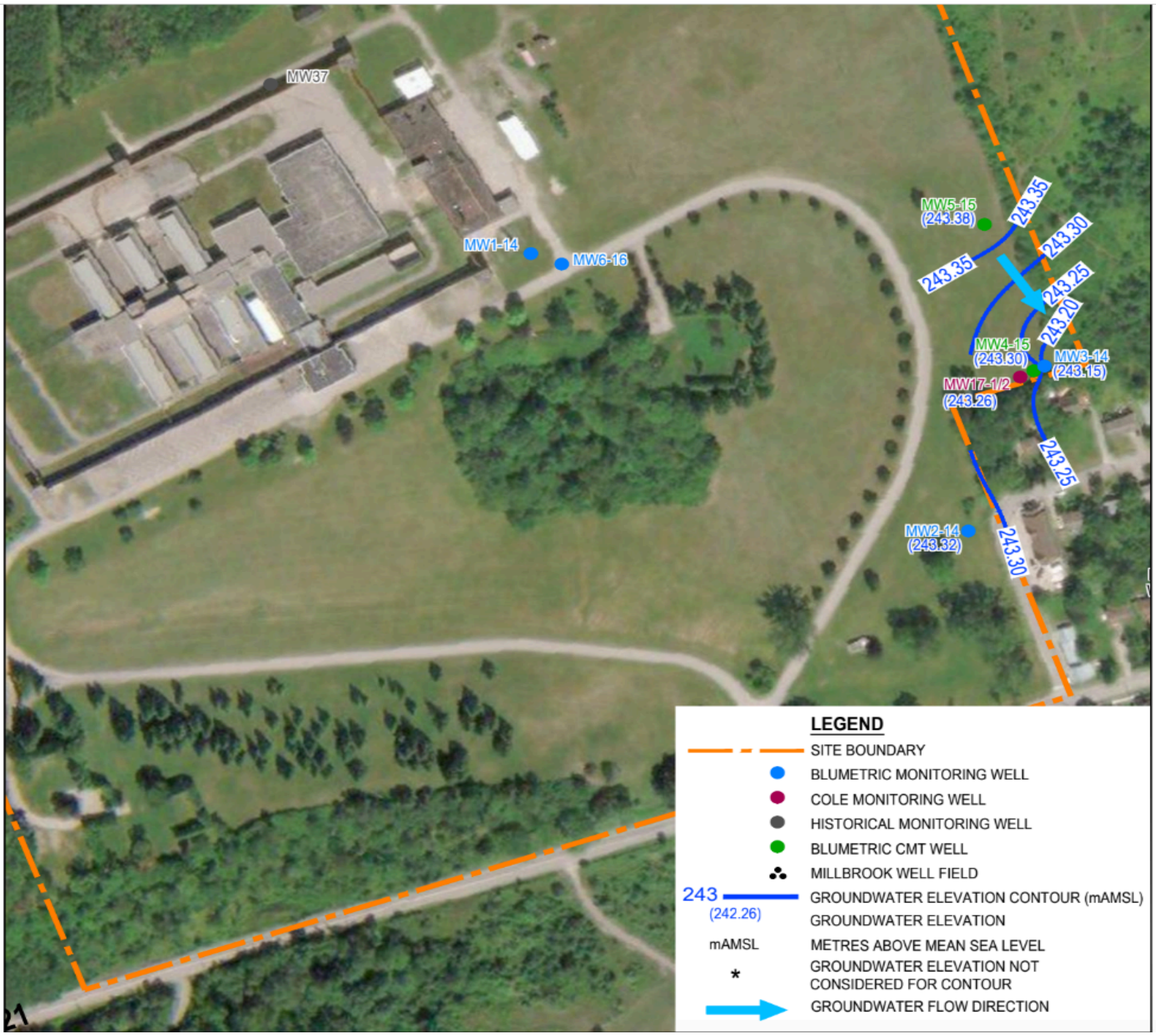

Figure 7. Groundwater flow direction indicated by a blue arrow.

Contaminants of Concern

The full list of contaminants of concern on the property is most accessible in the C&D Report (Part III, 2a, page 5) [4]. The full list of contaminants assessed in the groundwater samples is outlined in GHD's 2022-2023 monitoring report (Tables, Table 4A), along with their applicable SCS and concentrations of all sampling events [5]. It has been well-documented that historically on-site there were "potentially-contaminating activities," such as operations of a license plate manufacturing shop, tailor shop, laundry shop, and jobbing shop where metal items were made [2]. In these areas, heavy cleaning chemicals were used to clean clothing, and solvents would be used to maintain machinery and equipment. The main contaminant of concern, first observed in 2014, is perchloroethylene (PCE) also known as tetrachloroethylene. It is likely that the source of PCE originated from chemicals within the laundry shop and license plate manufacturing shop that operated within the facility. Other contaminants of concern noted in IO's 2022-2023 monitoring report are chloroform and trichloroethylene (TCE), which is a known breakdown product of PCE [5]. PCE is a popular solvent used in dry cleaning facilities to help dissolve grease or oil within the fabric without damaging the fabric itself. It is also commonly found in adhesives, wood cleaners, stain removers, and fabric finishers [22]. More specifically, this compound is defined as a chlorinated volatile organic compound (VOC), further classified as a dense non-aqueous phase liquid (DNAPL). VOCs are known to have high vapour pressure and low water solubility [22]. The contaminant of concern being a DNAPL is problematic because these compounds are denser than water, meaning they will sink within the aquifer until reaching the bottom (or the top of an effective aquitard), making them difficult to locate in a groundwater system, thus causing complex clean-up and remediation processes to ensure complete removal of contamination has occurred. Complete removal is also difficult due to PCE's resistance to degradation, however over time, PCE will decompose producing TCE and Vinyl Chloride. Despite this, there is evidence to suggest that biodegradability of PCE in environmental water is extremely low and concentrations may persist for months or years [22].

There is limited data regarding the half-life of PCE in groundwater, but sources state an average half-life of 1-2 years [23]. However, this time frame is highly variable, depending on factors such as topography, groundwater velocity, and amount of precipitation. The groundwater velocity in layer one is determined to be 40m/year, while the velocity in layer three is 90m/year [21]. These values are important to note; however, it is worth mentioning that PCE may not travel at the same velocity. Since it is a DNAPL, it is not readily dissolved in water, and it is denser than water, so it is expected to have a different velocity. The only way PCE would be seen moving at the same rate as the groundwater in each distinct layer is if some PCE is potentially dissolved. Although this is unknown and not confirmed, due to the properties of the contaminant, it is unlikely that any would readily dissolve in the groundwater; it will remain separate in its original state. Remaining separate, contaminants will follow the topography of the land rather than moving with groundwater flow, allowing them to settle in dips where they will continue to sink within the water table.

Turbidity

Turbidity in water refers to the cloudiness or haziness caused by suspended particles such as clay, silt, microorganisms, and other organic matter [24]. High turbidity levels in water can be concerning as it may indicate the presence of contaminants. To decrease turbidity in groundwater samples, several measures can be employed. Physical methods such as sedimentation and filtration can be utilized to remove suspended particles from water. Sedimentation involves allowing water to settle, allowing particles to settle to the bottom, while filtration passes water through porous materials to trap suspended solids. Chemical coagulants can also be added to water to facilitate the aggregation of particles, making them easier to remove through filtration. Additionally, implementing best management practices to prevent runoff into groundwater sources can help reduce the input of sediment and other particulate matter, thereby reducing turbidity levels in groundwater [24]. Regular monitoring of turbidity levels is essential to ensure compliance with regulatory standards set out for groundwater. In the most recent groundwater sampling events on the property, high turbidity values (1000 NTU+) were observed in various monitoring wells, with values significantly fluctuating between events [5]. A discussion of the turbidity results was not present within this report, although values are listed in Table 3 of the report [5]. Health Canada recommends water entering drinking water supply have turbidity levels of 1.0 NTU or less [24].

Methodology

Research Project Methodology

The methodology for this project involved several steps to comprehensively assess the extent and impact of contaminants in groundwater. Existing literature available on the public domain was supplied by BCWA to facilitate this research project. Included were technical documents and reports that had been developed by consulting groups hired by IO; the earliest documents accessed initially were the C&D Report filed in 2012 [4], and the BluMetric Monitoring Report from 2015 [25]. Since the facility closed in 2003, it was evident there were some environmental assessments missing prior to the C&D Report that was produced. Many gaps were observed within the literature due to missing sources. Documents such as Phase I and II ESAs were referenced in the C&D Report, but locating these files on the public domain was unsuccessful. The municipality was contacted in an attempt to gain access to these documents. After this being unsuccessful as well, an FOI (freedom of information) request was submitted to IO. While waiting for the request to process, four interviews were conducted with former Millbrook Correctional Centre employees with the aim of receiving firsthand information regarding chemical and hazardous waste activities and disposals on site. Valuable facts were derived from the interviews that aided in answering initial research questions. Prior to conducting interviews, an application was submitted to the Trent University Research Ethics Board for approval. Upon receiving approval, informed consent was required of the participants prior to participating. No personal information was collected throughout the interview process, and the identity of participants will remain confidential and anonymous. Throughout the research term, a comprehensive literature review was conducted to gather pertinent information that supports existing literature, to further assess and explain areas that were lacking. Google Scholar was the main search engine used to locate peer-reviewed articles that supported the gaps located within existing documents. Relevant information was pulled from articles to further explain limitations, and provide support for the hypotheses in this project.

In the final weeks of the research term, access to the documents requested from IO was granted; all five documents are available for reference on the BCWA webpage [2,3,20,26,31].

IO Methodology

Since the property was no longer required for use by the government, two Phase I Environmental Site Assessments (ESAs) were conducted, by two separate companies, to comment on the conditions of soil and groundwater and conclude whether or not the historical contaminating activities on site made an impact on the surrounding environment. SLR Consultants compiled the initial report in June 2010, utilizing interviews with three individuals to gather pertinent information about the facility during its time of operation [26]. Full details of the investigation can be found in the document available for reference on the BCWA webpage [26]. Later, Inspec-Sol was retained by Infrastructure Ontario (IO) to provide a Phase I ESA update in October 2011. The purpose of the update was to identify the “existence of any significant actual or potential environmental liabilities associated with the areas of the Site that were not covered within the SLR Phase One ESA" [3]. Inspec-Sol also carried out a Phase II ESA at the property, followed by a Delineation Phase II ESA in March 2012 [2,20]. The main purpose of Phase I ESAs is to provide an opinion on whether there are any significant environmental issues that may affect the future use of the property [26]. According to the first ESA in 2010, twenty areas of potential environmental concern (APEC) were located on site [26]. Of these, five areas in particular were locations where activity has impacted groundwater. Many of these areas were located near the dumping area, sand pit, license plate shop, and laundry shop. The Phase II ESA from Inspec-Sol identified six additional APECs; all 26 are shown on Figure 7 below [3]. Due to these findings, a Phase II ESA was recommended, as well as required, before a Record of Site Condition (RSC) could be filed. It is important to note that a RSC has still not yet been produced for this site. Conducting a Phase II ESA is essential in evaluating the potential soil or groundwater impacts resulting from the identified APECs on site [3].

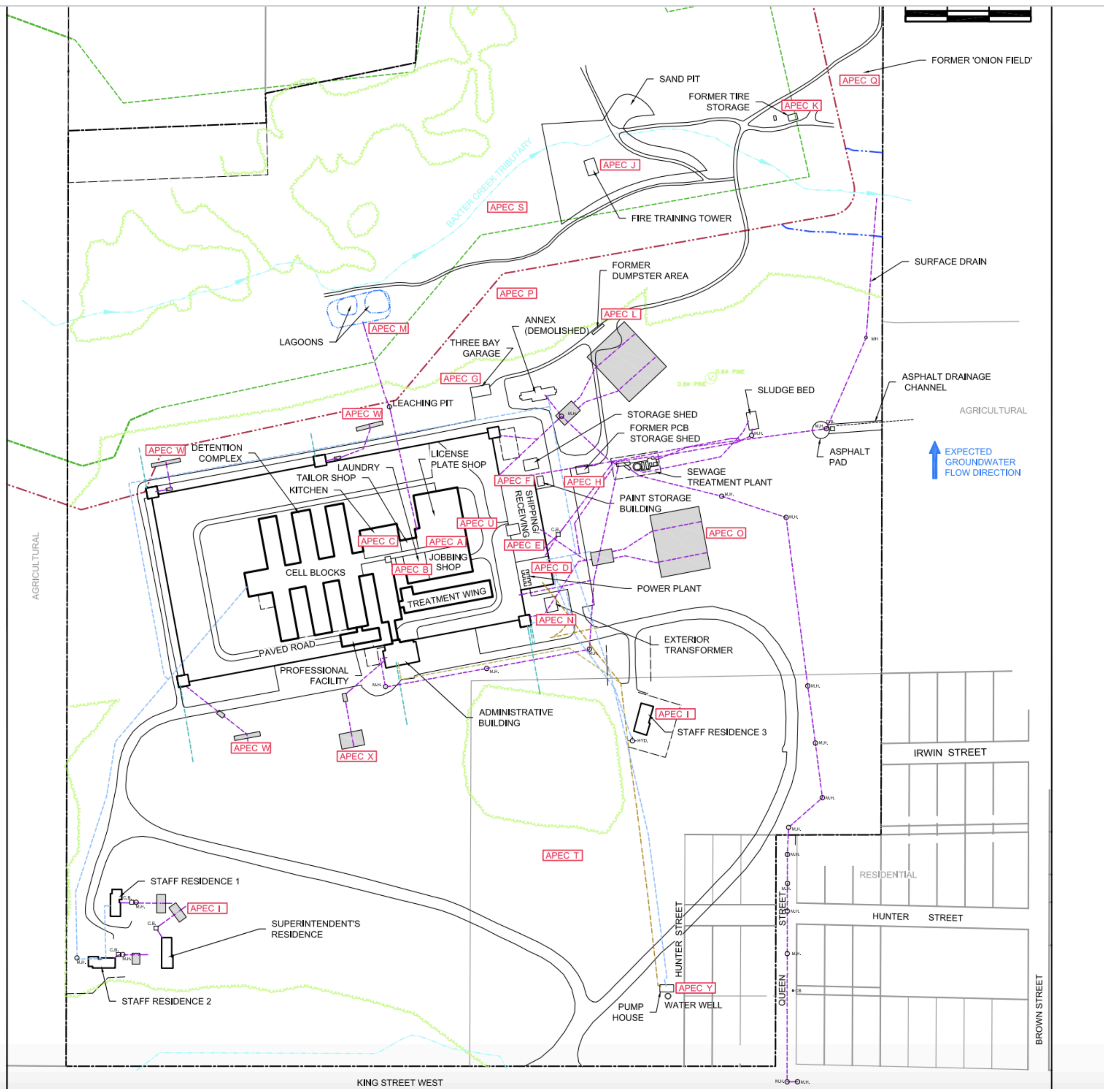

Figure 7. Map of former correctional centre (now demolished) highlighting the Areas of Potential Environmental Concern (APECs) with red boxes, n = 26.

The detailed methodology of each ESA investigation can be referenced in the respective reports that are available on the BCWA webpage [2,3,20,26]. Sampling and testing procedures were developed to further assess each APEC defined on the property. Initially, test pits and boreholes were installed for soil and shallow groundwater monitoring. Further, two boreholes were converted to monitoring wells in the Phase II ESA. The location and installation of these test wells was executed based upon confirmation of soil contamination discovered through sampling of test pits in the APECs. The two wells were drilled to depths of 15.24 m below ground surface (bgs) and 19.81 m bgs, respectively (MW17 in APEC M, MW22 in APEC O) [2]. These wells were installed within the unconfined sand aquifer of layer one. During the Delineation Phase II ESA, two additional monitoring wells (MW32 and MW37) were installed in APECs M & O, at depths of 25.1 m bgs and 27.5 m bgs, respectively. Upon thorough investigation, 63 soil samples and 6 groundwater samples were collected [20].

In 2012, the main facility and all outbuildings were demolished by Delsan Demolition. Upon demolition, a consultation and documentation report was filed (C&D Report), confirming instances and locations of contamination on the property [4]. It was stated that deconstruction was necessary “due to resultant liability concerns.” It has since been referenced in reports that IO wishes to “reduce their liability” [5]. Contaminated soil was removed from the lagoons, and all debris and garbage, including that in the former dumping area, was removed. All septic tanks and sludge beds were also removed at this time [4]. In order to facilitate removal of debris near the lagoons and former dumping area, tree removal was necessary and is detailed in Section IV of the C&D report (subsection 2 & 3) [4]. A permit was required before proceeding with any work in this area due to the Baxter Creek Tributary and it being part of the Oak Ridges Moraine and Natural Linkage Area [4].

Since demolition, the groundwater monitoring program has continued, with quarterly sampling events occurring every year. In total, four monitoring wells were installed in 2011, five in 2014, one in 2016, and one in 2017. Details of the monitoring wells and how they were installed, as well as sampling procedures and results, can be found in the corresponding documents available on the BCWA webpage [5,21,25]. The specific locations of all monitoring wells can be viewed in Figure 8 below. Note that perchloroethylene (PCE), the most prominent contaminant of concern for this project, was not initially detected or reported in the original C&D report produced in 2012. It wasn’t until November 2014 that PCE was detected in one of the wells installed for deeper groundwater monitoring within layer three. The persistence of this contaminant over the years has contributed to the extensive groundwater monitoring period, still going on today. The groundwater monitoring report produced by BluMetric, another consulting group retained by IO to investigate and report on contaminant concentrations observed on site mentions installation of two additional monitoring wells; MW4-15 and MW5-15. These wells were installed to depths of 46.9m bgs and 54.7m bgs, respectively, to determine contamination impacts in the underlying layer three aquifer. Full details of the wells can be found in the report referenced on the BCWA webpage however it is noteworthy that these wells encompassed different ports to conduct sampling in all three layers on site [25]. It was during this time that PCE started to consistently appear at concentrations above SCS in MW3-14; installed in 2014 at the southeast corner of the property, in the upper interval of the layer three aquifer. The most recent document filed for this property was GHD's 2022-2023 Groundwater Monitoring Report [5]. A record of site condition (RSC) has yet to be produced thus far.

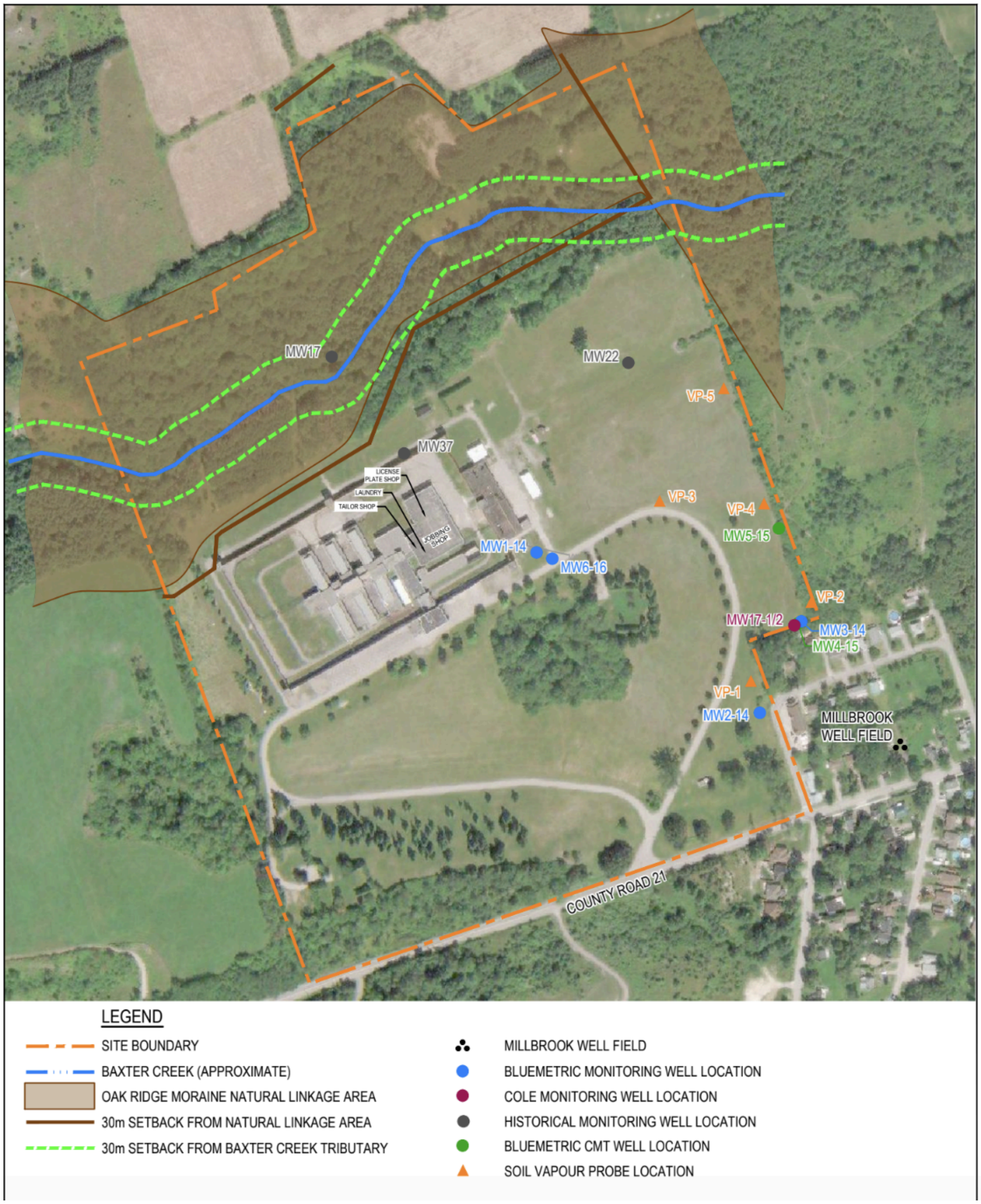

Figure 8. Locations of monitoring wells.

Results

Interviews

Significant information regarding waste disposal on site was obtained from the series of interviews conducted with former employees of the Millbrook Correctional Centre. Provided details aligned with the initial ESAs conducted on site, though this was confirmed after interviews were conducted and requested documents were analyzed. The interviewees were employed at the facility ranging from 1977 up until closure in 2003. The participants shared knowledge of specific locations where waste was being disposed of on site, while also providing detail regarding what types of chemicals may have been used within the facility, and were then being disposed of on site. According to the map of the property, there is a steep bank at the rear northern side of the property. It is denoted "former dumping area" on the site map in Appendix A (Figure 13). According to the interviewees, large garbage carts would be wheeled around the facility by the annex inmates, picking up garbage from every area of the correctional centre; "and this would include chairs, paint cans, ammonia bottles from the shops, cleaning detergents, and so on" (participant 2, personal communication, Jan 19, 2024). The annex was "a cottage style building that housed up to twelve inmates," (participant 4, personal communication, Mar 9, 2024) giving those in their last three months of their sentence a little more freedom; they were able to work outside in the onion field and other areas on the property to maintain its cleanliness. As stated, one main duty included garbage disposal, therefore they would "wheel the big garbage carts out to the dumping area, and all the waste was simply disposed of over that embankment," one interviewee revealed (participant 3, personal communication, Jan 19, 2024). There were many additional shops located in the facility where inmates would work. Some of these included the laundry shop, tailor shop, jobbing shop, and license plate shop. Strong cleaning chemicals were used in the laundry facility to remove tough grease and stains, while chemical solvents were used in the license plate facility and the jobbing shop to maintain the machines. Also, leaded paint was used on the license plates and the empty paint barrels would be picked up by the garbage carts. This was where all garbage on site was being disposed of, up until approximately 1980, as recalled by an interviewee. Around this time, there was a transitional period where the government introduced BFI waste bins, and a regular garbage collection was set up, with a garbage truck taking the waste to an off-site disposal area. The final interview revealed novel information regarding hazardous chemical waste disposal. It was mentioned that all hazardous chemicals and their containers would be sorted into a "containment area," where "a large disposal truck would come in twice a year" to pick up containers and transport them out to proper hazardous waste disposal facilities (participant 4, personal communication, Mar 9, 2024).

Phase 1 and Phase II ESAs

Throughout the Phase I and II ESAs conducted on the property, no contaminants of concern were confirmed in the groundwater. These assessments were carried out between 2011 and 2012. However, there was confirmation of contamination in soil samples obtained from certain APECs on site. Specifically, four underground fuel storage tanks were located beneath the power plant (reference map in Appendix A). Upon further investigation, soil samples collected from depths of 2.5 - 4.5m exceeded SCS for petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), and benzene [3]. Thus, 168 tonnes of impacted soil was excavated from this area, although the vertical and lateral extent of contamination was undetermined at the time. Potential impact from this was noticed when a water sample obtained from layer one of MW4-15 reported a benzene concentration of 6.91 μg/L, above the accepted SCS of 5.0 μg/L, in May 2021 [5]. Further investigation is recommended to confirm these results, although the May 2021 sampling event was the only instance of benzene contamination observed to date. Drain locations were identified on the property as potential migration pathways. Explained in greater detail within the Phase I and II ESAs is the location of the laundry drain, which was directed towards a leaching pit on the north side of the facility. Overflow discharged through a metal pipe to the crest of the slope at the rear of the property, where it was then conveyed through a half-culvert to a lagoon near the onion field (APEC M) [2,3,26]. Figures 12 and 13 in Appendix A depict the laundry drainage trench as well as the half-culvert leading to the onion field. Although this system was decommissioned in the 1970s, it was mentioned that contaminants had the potential to be released into the environment through any spillage or leaks along the half-culvert. Further, once grey water had reached the lagoon, there was the potential for overflow which would lead directly into the Baxter Creek tributary [3]. Extensive soil sampling was conducted in these areas to confirm, as well as shallow groundwater monitoring. Soil samples collected from APEC D, L, M, O, and S reported parameters above MOE standards for one or more of: PHC F1 to F3, naphthalene, chromium, mercury, lead, PCBs and Dichlorodiphenyltrichloroethane (DDT) [2]. These results required the need for further investigation. No contaminants of concern were detected in the groundwater samples during 2011-2012, however further investigation was recommended to confirm [2].

Phase II ESA Delineation

This investigation aimed to outline the extent of soil and groundwater contamination from the previously identified APECs, highlighted in the Phase II ESA , excluding the creek sediment (APEC S), which was to undergo a separate investigation [2,20]. A total of ten test pits, twenty-five boreholes, and two groundwater monitoring wells were installed to further define contamination extents. The collected samples were compared to the MOE applicable standards, with soil samples exceeding regulatory concentrations, particularly petroleum impacts in APEC D where the underground storage tanks were located [17]. Six groundwater samples were analyzed, all of which were below MOE standards, indicating no identified contaminants in the groundwater. APEC D required further investigation to accurately determine the potential lateral and vertical extent of contamination.

IO Monitoring

Full results of IO's groundwater monitoring events can be found in the respective reports available for full access on the BCWA webpage [5,21,25]. A summary of important results from various sampling events are displayed in the table below to provide context for this study. The SCS for PCE, TCE, and chloroform are 1.6 µg/L, 1.6 µg/L, and 2.4 µg/L, respectively.

Table 1. Relevant sampling events representing elevated concentrations of PCE, TCE, and Chloroform.

Contaminant of Concern	**Monitoring Well**	**Concentration (µg/L)**	**Sampling Event**
PCE	3-14	5.6	November, 2014
PCE	3-14	5.0	January/May, 2015
PCE	3-14	4.1	October, 2015
PCE	3-14	3.9	August, 2016
PCE	3-14	2.6	August, 2017

PCE	3-14	2.6	August/October, 2018
PCE	3-14	2.91	May, 2022
PCE	3-14	2.24	December, 2022
Benzene	4-15	6.91	May, 2021
TCE	1-14	1.66	August, 2022
Chloroform	4-15	2.8	July, 2015
Chloroform	5-15	5.4	August, 2015
Chloroform	17	28.1	September, 2020
Chloroform	17	15.9	October, 2020
Chloroform	17	10.0	January, 2021
Chloroform	17	3.8	February, 2022

Maximum Concentration of PCE

The maximum concentration of PCE was observed in a sample collected from layer three of monitoring well 3-14 in November, 2014. The concentration was 5.6 µg/L, which is well over the site condition standard (SCS) of 1.6 µg/L, however still falls below the Ontario Drinking Water Standard of 10 µg/L. This is also the first instance of PCE contamination being observed in the groundwater. MW3-14 is installed within the upper interval of layer three. PCE has also been consistently observed above SCS, most notably in the southern portion of the site, in MW1-14, 5-15, and 6-16. Figure 9 below depicts the depth within the groundwater layers at which this contamination is being observed.

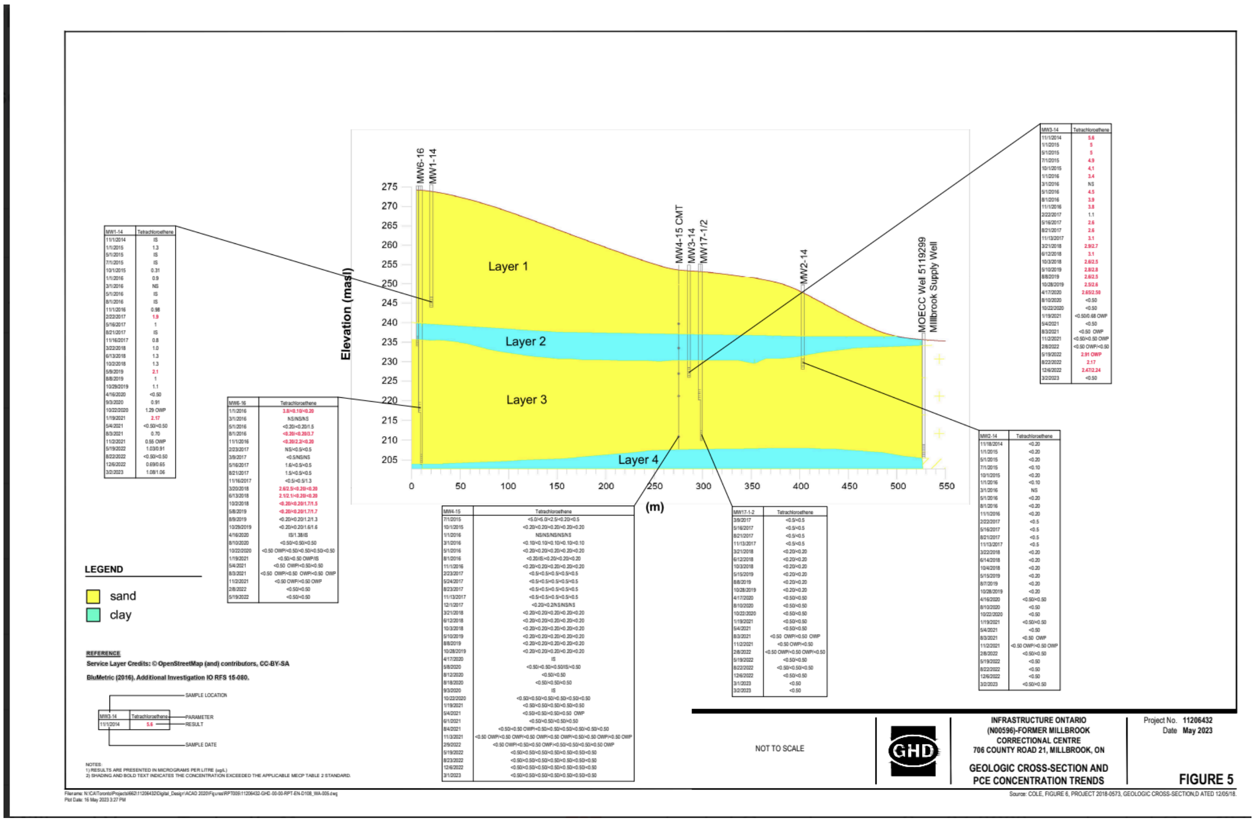

Figure 9. Showing where contamination is occurring in each layer, specifically for MW1-14, 6-16, 4-15, 17-1/2, 2-14, and 3-14 [5].

Maximum Concentration of TCE

The maximum concentration of TCE was observed in August 2022, in a sample obtained from layer one of monitoring well 1-14, that value being 1.66 µg/L. Again, the value is just above the SCS for TCE (1.6 µg/L), but falls below the ODWQS (5 µg/L). This is the same well the high concentrations of PCE were observed in, just in the layer one aquifer as opposed to the layer three aquifer.

Maximum Concentrations of Chloroform

The first instance of chloroform contamination was observed in 2015 in MW5-15, at a concentration of 5.4 µg/L [5]. No other exceedances have been noted to date in this monitoring well. In a sampling event from September 2020, chloroform was observed in MW17, layer one, at a concentration of 28.1µg/L. Conversely, in layer three during a sampling event one month later, the chloroform concentration was 9 µg/L, suggesting that contaminants are moving through the layer two aquitard and reaching the layer three aquifer. In the most recent sampling event conducted by GHD in 2022, chloroform exceedances were still detected in MW17, however at a much lower concentration of 3.8 µg/L. MW22 samples from September 2020 also exhibited chloroform exceedances at a maximum concentration of 18.9 µg/L in layer one. Again, this concentration has decreased according to the most recent sampling event [5]. Chloroform was not further discussed within GHD's 2022-2023 report as a potential contaminant. It is recommended that further testing be done to confirm the presence of chloroform and further monitor its concentration. The SCS for chloroform is 2.4 µg/L, although there is no ODWQS for chloroform.

Discussion

Points from the interviews directed the scope of the study to focus on the dumping area as that was the most likely source of contamination. It was concerning that currently, there are no groundwater monitoring wells in that area or in its vicinity. It was also derived from interviews that the laundry water would drain through a culvert down to a lagoon near the onion field. Upon obtaining access to the Phase I and II ESA's, it was discovered that the dumping area was in fact investigated and tested for contamination. The soil was tested and chromium exceedances were noted; likely due to the tin containers disposed of in this area in the past. No significant contamination was noted in this area, therefore it was concluded that there was no need for further or deeper testing. From the contamination we are seeing today, it can be hypothesized that at the time of the soil monitoring (20-30 years after we know disposal was occurring in this area), the contaminants of concern had already sunken within the water table and were present at depths below the two monitoring wells that did end up getting installed at this time. Since the monitoring wells were only installed to a maximum depth of 19.81 m, it is difficult to conclude whether or not contamination existed at a greater depth. It wasn't until 2014 when PCE, the main contaminant of concern, was observed at concentrations exceeding the site condition standard. Specifically, PCE was observed in MW3-14 at a maximum concentration of 5.6 µg/L. This well was installed at the southeast corner of the property to a depth of 27.4 m below ground surface, which is within the upper layer three interval. Figure 10 below shows the results of PCE concentrations obtained from groundwater sampling events from 2014-2022. It is clear that the concentration is on a decreasing trend over time in MW3-14. PCE was also observed multiple times at concentrations above SCS in MW6-16, which is installed to monitor between depths of

41.05 m and 72 m bgs. This is the maximum depth at which PCE has been observed at concentrations above 1.6 µg/L, graphed for reference in the figure below. Again, concentrations are on a statistically decreasing trend.

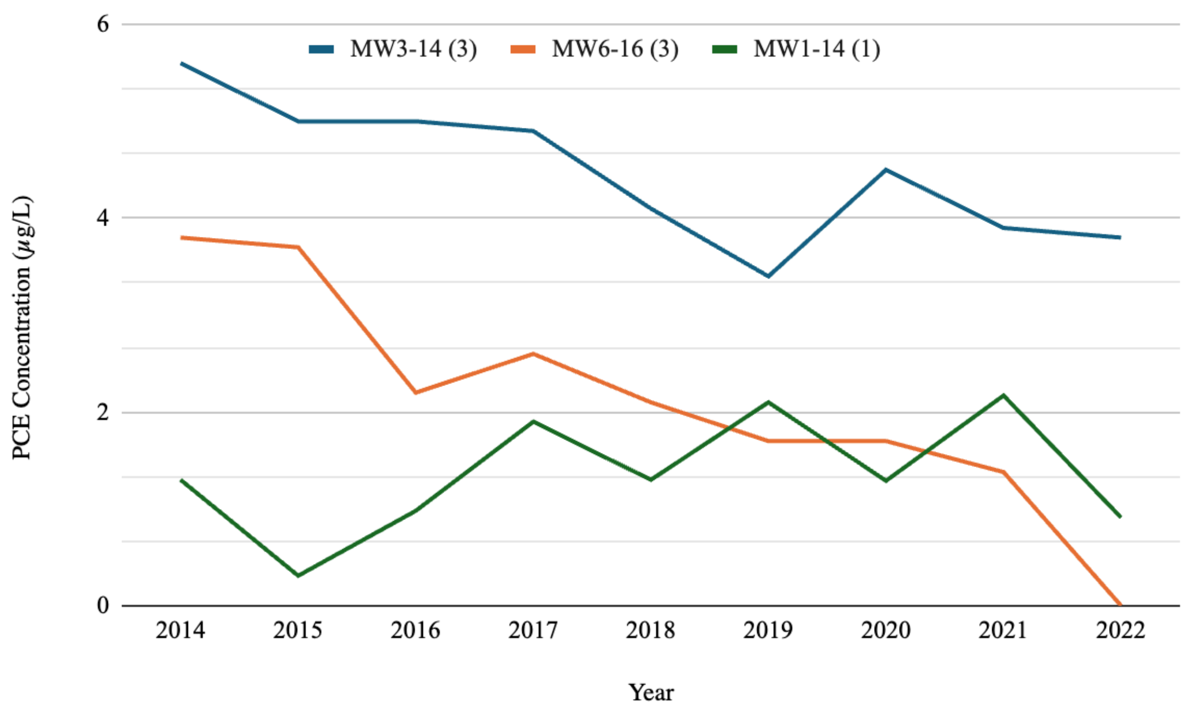

Figure 10. PCE concentrations over sampling events from 2014-2022, specifically in layer three of MW3-14 and 6-16, and layer one of MW1-14.

The reports produced fail to explain how PCE contamination appeared as deep as layer three on site. Directional drilling of monitoring wells has the potential to produce horizontal or vertical transport pathways, which can allow for cross contamination of aquifers [27]. Although not confirmed, it can be hypothesized that the wells drilled on site may have had the potential to introduce new transport pathways, resulting in a release of contaminants from layer one through to layer three. This would have been done inadvertently, and the effects of well drilling were not mentioned within the reports to date either. Further investigation would be required to determine the impacts of well drilling, or if contaminants were able to reach layer three due to the alleged ineffective layer two aquitard.

PCE is known to breakdown into TCE and Vinyl Chloride. Other chemicals are produced but these are the most commonly observed biodegradation products. This may explain why TCE contamination was observed in the most recent sampling events, however this is the first instance [5]. TCE was present at concentrations of 1.65 µg/L in MW1-14; slightly above SCS of 1.6 µg/L. This is evidence to support that the PCE on-site is going through its natural breakdown process, albeit much slower in groundwater conditions than anticipated. Further testing is required to confirm the extent of TCE contamination. Upon this discovery, Cambium (consulting group retained by township to peer-review IO reports) was not able to agree with GHD's plan to reduce sampling to semi-annual; it is recommended that sampling continue on a quarterly basis until TCE concentrations are confirmed and the extent is assessed [5, Cambium portion].

Liability

One of the main goals of this research project is to discover who is liable for the contamination on site, as well as the remediation and clean-up of said contamination. With IO listed as the current property owners, they are liable for contamination instances on site. Due diligence was done through Phase I and II ESAs, requirements for redeveloping brownfield properties for a new use [12]. The EPA establishes rules about who is responsible for clean-up and who is to pay for it. Although a record of site condition has not been produced for this property, new provisions have been included under the EPA to "reduce the potential liability from orders for property owners who have filed a record of site condition after assessing and cleaning up their property." These provisions also reduce potential liability for "municipalities, secured creditors, or others who are required to undertake investigative action." Specifically, these persons are protected from being a "person responsible" for contamination at a property not owned by them, if they choose to take action in regard to the property [28]. Thus, a Record of Site Condition (RSC) filed by IO would greatly reduce their liability, although failure of contaminants to meet Site Condition Standards (SCS) slows the process of filing such records. Mentioned provisions under the EPA serve to promote cleanup and redevelopment of brownfield sites by decreasing the uncertainty associated with liability [28].

Remediation and Clean-up

It is important to detail remediation and clean-up processes if these are deemed necessary upon completion of the groundwater monitoring program currently maintained by IO. Many different techniques have been analyzed and tested for remediation of contaminated groundwater sources; it will vary significantly depending on the type of contaminant and the composition of the groundwater layers. The processes used are very complex in nature and require extensive background knowledge to understand. Examples of remediation treatments for PCE-contaminated groundwater include air stripping/adsorption on activated carbon (also known as traditional pump-and-treat technology), UV-assisted oxidation processes, or de-chlorination by Hydrogen-Releasing Compound (HRC) [29]. Since PCE is environmentally persistent and highly resistant to aerobic degradation, dechlorination of the compound under anaerobic conditions is successful in degradation. A stepwise hydrogenolysis mechanism leads to degradation of the compound into less-chlorinated by-products, and eventually to ethylene which has no risk in groundwater [30]. With the depths of contamination observed on the property, remediation techniques would be difficult, time consuming, and costly. Invasive techniques can make the property and groundwater aquifers more vulnerable to contamination if not performed properly and comprehensively.

Recommendations/future for the site/future research direction

After review of the environmental assessments and ongoing monitoring conducted on the property, it is recommended that further testing be conducted; specifically off-site monitoring. At this time, there is no off-site monitoring of the contamination discovered on the property. Given the topography of the property and surrounding areas and the slope behind the ravine/creek, it is expected that contamination has extended off-site. Although it is confirmed that there is no contamination present in the municipal drinking water supply above ODWQS, the lateral and vertical extent of contamination off-site has never been thoroughly investigated. The red circle in the figure below highlights an area for potential soil monitoring and shallow groundwater monitoring. This area is concerning due to the presence of the highly vulnerable groundwater recharge area, represented by the dark orange triangle in the image below, as well as surrounding significant groundwater recharge areas. The former rail bed lines are shown in black in the zoomed in image below (Figure 12). Between the jail parcel and the rail bed is a recharge area; the rail line constrains the flow so that all of the water is moving south before it pinches and pushes its way across the rail bed. The entire area between the west and east lines of the rail bed, and specifically the V-shaped area to the top left corner of the dark orange triangle-shaped HVA, is an incredible seepage area with natural springs. It can be hypothesized that this area is a potential settlement area for contaminants as the area is saturated and the pressure pushes water in every direction. Saturation in this area is greater than surrounding areas, typically all year round, as a result of the elevation gradient that rises gradually from the HVA at the south end of the red ellipse to the top of the outline where the Baxter Creek stream crosses the railbed. Due to a significant portion of this area being a SGRA, there is a slow recharge of the groundwater and then it all flows south to the triangular HVA. The vast amount of seeps and springs in this area and the vulnerability of the groundwater leaves opportunity for shallow soil and groundwater monitoring.

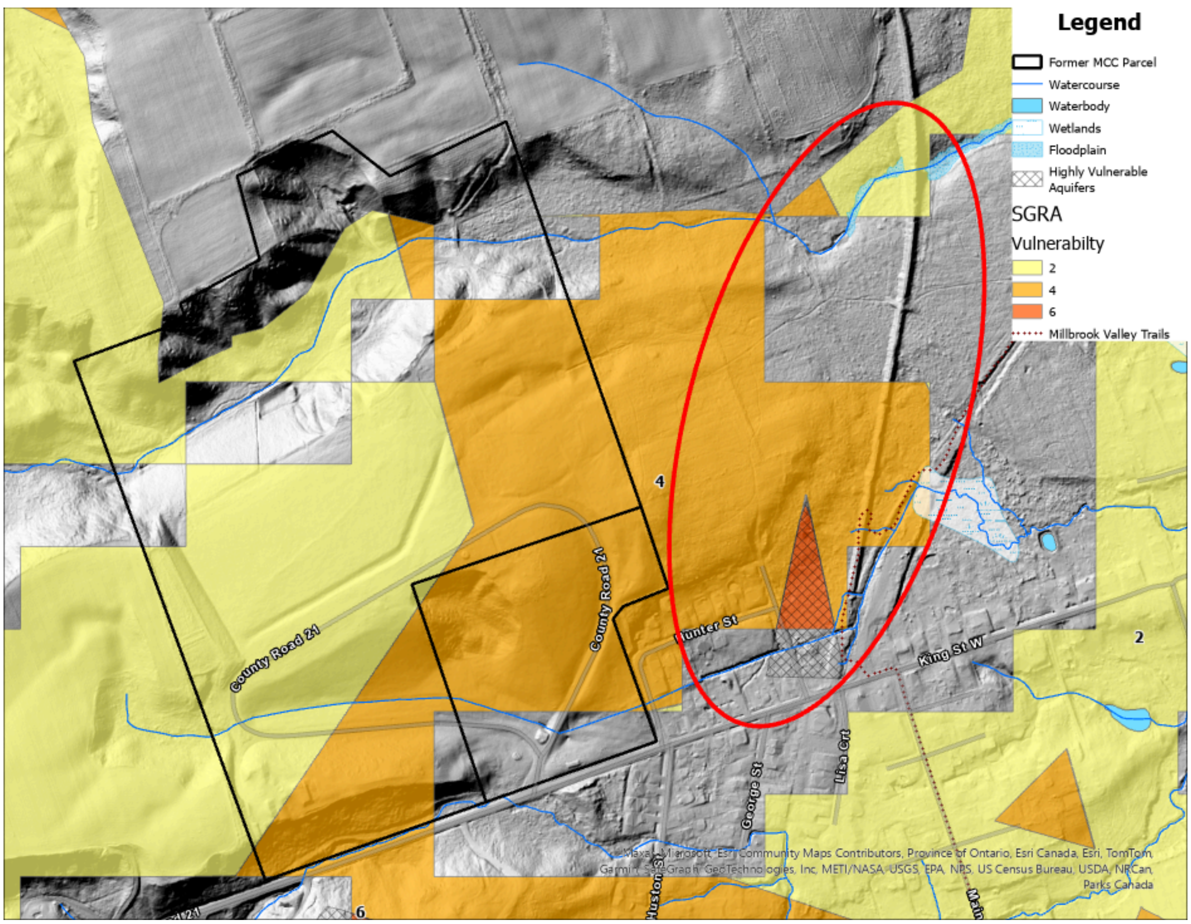

Figure 11. Area for potential off-site soil and shallow groundwater monitoring, highlighted by the red ellipse.

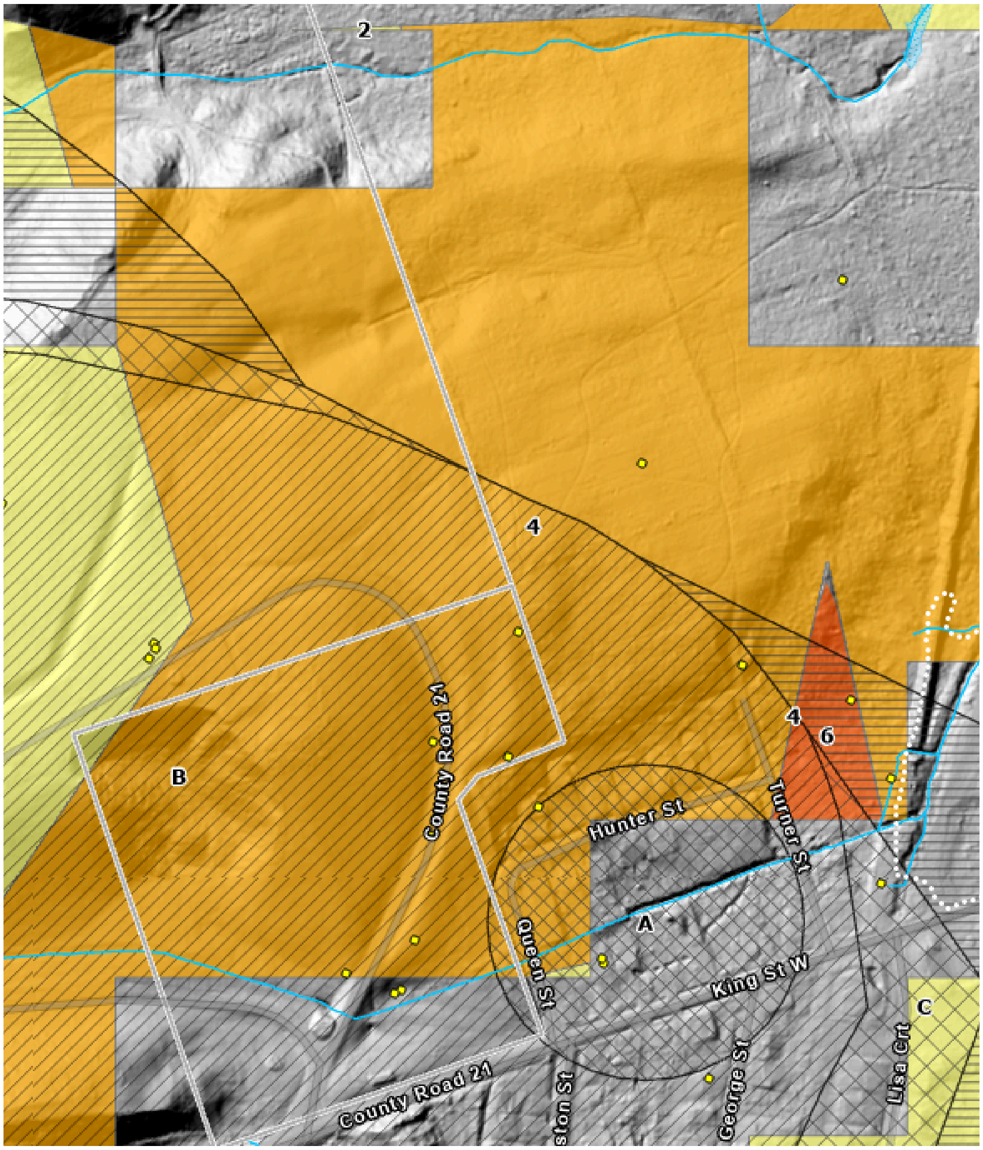

Figure 12. Zoomed in area for potential off-site monitoring, highlighting former rail beds with black lines.

Once SCS are met for the contaminants of concern on site, the question is what will be done with the property. Prior to residential development on site, it is recommended that Official Plan (OP) policies be reviewed, as this may be detrimental to the functionality of the Oak Ridges Moraine. Specifically, section 4.5 draws attention to the former correctional centre and the policies associated with future redevelopment of this area [32]. Moreover, this property should be considered under section 3.4 and 3.18 which speak to brownfields and contaminated sites

[32]. Only when these policies have been understood and followed should residential development occur.

Due to the consistent observations of contamination on site, and the expected extent off-site, this property is highly suitable for college or university teachings. The site could be the host of a research centre, allowing environmental focused students to carry out hands-on experiments and research, by further investigating the cause, extent, and clean-up of confirmed contamination. Many local residents of Millbrook would like to see the property preserved as a conservation area. The wooded areas and topography of the land provide excellent features for natural trails. Location alone is another significant aspect of the property, due to its ties with the Oak Ridges Moraine through the Baxter Creek tributary, the proximity to the municipal drinking water wells, and the surrounding significant groundwater recharge areas and highly vulnerable aquifers. These features add to the importance of conserving and protecting this area from significant development that would negatively impact the surrounding environment. Protecting this area would assist in preserving the natural linkage area near the Baxter Creek tributary, which is crucial for wildlife reproduction and protection. Further studies can focus on extensive mapping of the property, as well as assessing off-site contamination, if any is confirmed.

Limitations

Despite diligent efforts, this study encountered several limitations that impacted the comprehensiveness and depth of analysis. One significant downfall was the limited access to crucial assessments during initial stages of research, that had been filed by IO to assess the environmental risks on site. The lack of availability affected the ability to conduct a thorough analysis and assessment of contamination early on. Without access to crucial documents such as historical records obtained within the final weeks of the term, there was a shortfall in the background information necessary for an initial comprehensive evaluation of the environmental impact. The sheer volume and diversity of available information added challenges to the research process, requiring substantial scoping of information while still attempting to provide a complete review. A notable limitation within the groundwater monitoring reports is the absence of off-site monitoring. While the focus was primarily on on-site contamination, off-site monitoring could have provided valuable insights into potential migration pathways and broader impacts on the surrounding environment. Especially with the proximity of the property to the

Millbrook municipal wells, further off-site monitoring within the layer one and three aquifers is recommended. Moreover, inherent uncertainties associated with environmental assessments such as variability in sampling techniques, measurement errors, and natural fluctuations in environmental parameters, often made data interpretation difficult, thereby introducing limitations to the study's findings. Assessing encountered limitations is useful in providing future direction for further research projects regarding this property.

Conclusion

Historical contamination is present on the property in question, however no contaminants of concern are present at concentrations above Ontario Drinking Water Standards. A Record of Site Condition has not been produced yet due to failure of contaminants meeting applicable site condition standards. Continued groundwater monitoring is recommended for further analysis of contaminants being observed in the layer three aquifer. Remediation of this property remains a difficult task due to the depth and extent of contamination, and the steep costs and time associated with remediation processes. This property exhibits extreme potential for conservation purposes, as well as educational purposes, given the unique topography of the area and the significant ecological features that surround it. Limitations encountered throughout the study provide opportunities for further research, such as extensive in-depth mapping, access to more historical records, and potential for off-site monitoring and analysis.

Appendix A

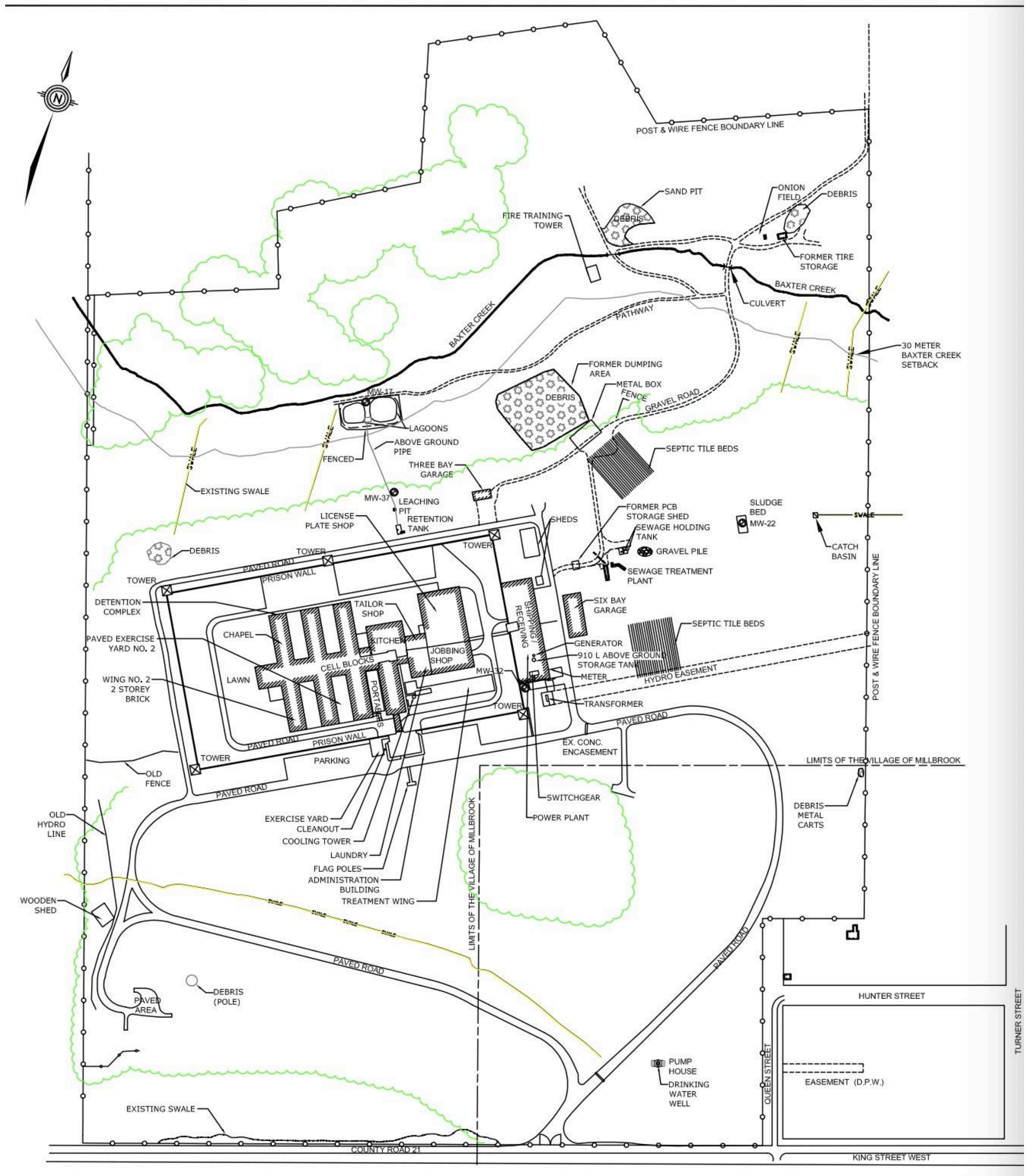

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Figure 13. Site map. Facility and all outbuildings were demolished in 2012.

Figure 14. View of drainage trench outlet from laundry. The drain leads to the ravine at the north side of the property; distressed vegetation was observed in this area [26].

Figure 15. Half-culvert where grey water from laundry would drain to the lagoon adjacent to the onion field, near the Baxter Creek tributary; notice the steep slope of the embankment behind.

Figure 16. Sand pit. Waste was allegedly disposed of or potentially buried in this area.

References

1. Disposition (Sales) Process. https://www.infrastructureontario.ca/en/what-we-do/real-estate-services/surplus-properties-sales-program-overview/disposition-sales-process/. Accessed 7 Jan 2024.
2. Chandoo S, Pasqualoni R. Phase II Environmental Site Assessment. Millbrook, ON: Inspec-Sol Engineering Solutions; 2011 Oct. Report No.: T040468e1-PII03.
3. Chandoo S, Pasqualoni R. Phase I Environmental Site Assessment Update. Millbrook, ON: Inspec-Sol Engineering Solutions; 2011 Oct. Report No.: T040468e1-PI02.
4. Slidders J, Taillefer G. Consultation and Documentation Report: Deconstruction of Millbrook Correctional Centre. DST Consulting Engineers Inc.; 2012 Aug. Project No.: 1007626.
5. Khandekar A, Guoth T. 2022-2023 Groundwater Monitoring Report, Millbrook, ON. GHD Consulting Inc.; 2023 May. Project No.: N-00596.
6. Baxter Creek Watershed Alliance. https://baxtercreekwatershed.org/. Accessed 2023 Sept.
7. Clean Water Act, 2006. https://www.ontario.ca/laws/statute/06c22
8. Oak Ridges Moraine Maps. https://www.ontario.ca/page/oak-ridges-moraine-maps#:~:text=As%20part%20of%20the%20Greenbelt,west%2C%20covering%20approximately%20470%2C000%20acres. Accessed 2023 Nov.
9. Baxter Creek Watershed Alliance. Conservation assessment of the lands of the former Millbrook Correctional Centre. 2023 July.
10. Groundwater Recharge. Lake Simcoe Region Conservation Authority. https://lsrca.on.ca/index.php/2020/11/30/groundwater-recharge/. Accessed 2024 Mar.
11. Highly Vulnerable Aquifers. Conservation Halton. https://www.protectingwater.ca/planning-process/vulnerable-areas/highly-vulnerable-aquifers/#:~:text=Highly%20Vulnerable%20Aquifers%20(HVAs),pollutants%20on%20the%20ground%20surface. Accessed 2024 Mar.
12. Brownfields Redevelopment. https://www.ontario.ca/page/brownfields-redevelopment. Accessed 20 Feb 2024.

13. Safe Drinking Water Act, 2002. https://www.ontario.ca/laws/statute/02s32. Accessed 2023 Dec.
14. Clean Water Act, 2006. https://www.ontario.ca/laws/statute/06c22. Accessed 2023 Dec.
15. O. Reg. 511/09. *Records of Site Condition*.https://www.ontario.ca/laws/regulation/r09511
16. O. Reg. 169/03. *Ontario Drinking Water Quality Standards.* https://www.ontario.ca/laws/regulation/030169. Accessed 2023 Nov.
17. Soil, ground water and sediment standards for use under Part XV.1 of the Environmental Protection Act. https://www.ontario.ca/page/soil-ground-water-and-sediment-standards-use-under-part-xv1-environmental-protection-act. Accessed 2023 Nov.
18. Environmental Protection Act. https://www.ontario.ca/laws/statute/90e19. Accessed 2024 Jan.
19. Taylor B, Bingham M, Bailey J. Former Millbrook correctional centre environmental review. Millbrook, ON: Cambium Inc.; 2016. Reference No.: 5327-001.
20. Chandoo S, Pasqualoni R. Delineation Phase II Environmental Site Assessment. Millbrook, ON: Inspec-Sol Engineering Solutions; 2012 Mar. Report No.: T040468e1-PII04.
21. Khandekar A, Guoth T. 2020-2021 Groundwater Monitoring Report, Millbrook, ON. GHD Consulting Inc.; 2021 Apr. Project No.: N-00596.
22. Nijhuis N, Loh M, Harrison P. Tetrachloroethylene. In: WHO Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organization; 2010. https://www.ncbi.nlm.nih.gov/books/NBK138706/. Accessed 2024 Dec.
23. Howard PH. Handbook of environmental degradation rates. CRC Press; 1991. p. 502.
24. Guidelines for Canadian Drinking Water Quality: Guideline Technical Document - Turbidity. Health Canada. https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-turbidity.html. Accessed Mar 2024.
25. Donaldson R. Millbrook deep aquifer investigation preliminary results, Millbrook, ON. BluMetric Environmental.; 2015 Sept. Project No.: W-B10392-00-03.
26. Sutter V, Hoyles K, Banderk L, Reynolds G. Phase I Environmental Site Assessment, Millbrook, ON: SLR Consulting Ltd.; 2010 June. Report No.: 209.05942.00.

27. Transport pathways. Source Water Protection Act. https://www.sourcewaterprotection.on.ca/wp-content/uploads/sp_plan3/SupDocs/TPDP/5%20Transport%20Pathways.pdf. Accessed 2024 Feb.
28. Guide: site assessment, cleanup of brownfields, filing of records of site condition. https://www.ontario.ca/page/guide-site-assessment-cleanup-brownfields-filing-records-site-condition. Accessed 2024 Mar.
29. Navarra W, Sacco O, Rescigno R, Daniel C, Vaiano V, Pisano D et al. Remediation of perchloroethylene contaminated groundwater using Fe0/ZnS21 embedded in a highly porous polymer: Experimental results on pilot-scale photoreactor and kinetic modeling analysis for industrial scale-up. Catal Commun. 2023;180:106699. doi: 0.1016/j.catcom.2023.106699.
30. Volpe A, Del Moro G, Rossetti S, Tandoi V, Lopez A. Remediation of PCE-contaminated groundwater from an industrial site in southern Italy: A laboratory-scale study. Process Biochem. 2007;42(11):1498-1505. doi: 10.1016/j.procbio.2007.07.017.
31. Cultural Heritage Assessment Report: Millbrook Correctional Centre. Millbrook, ON: Contentworks Inc.; 2006. Project No.: K80004.
32. Official Plan for Township of Cavan Monaghan. County of Peterborough. 2013 June 26. https://www.cavanmonaghan.net/en/build-and-invest/resources/Documents/Cavan-Monaghan-Official-Plan-Consolidated.pdf