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Re: Remedial Options Evaluation #4
Lake Chipican Sub-Areas – Former Michigan Avenue Landfill, Sarnia, Ontario
RWDI Reference No. 1801685

INTRODUCTION

The Lake Chipican Area within the Former Michigan Avenue Landfill (FMAL) located in Sarnia, Ontario, has been identified as requiring further immediate investigation as it relates to concerns with the migration of subsurface light non-aqueous phase liquid (LNAPL) in the vicinity of Lake Chipican and nearby water features, such as the Duck Pond and its associated channel. A Remedial Options Evaluation (ROE) report was prepared under separate cover for the City of Sarnia (City) on July 1, 2021, which described remedial approaches to address the immediate concerns in the Lake Chipican Area noted by the Ministry of Environment, Conservation and Parks (MECP).

This ROE is supplemental to the previous ROE submitted for the Lake Chipican Area, dated July 1, 2021, and includes emerging areas of potential LNAPL plume product migration south of the Animal Farm and east of the eastern extent of the existing sheet pile barrier wall (hereby referred to as Sub-Areas) of the Lake Chipican Area (*see* Figure 1).

The Lake Chipican Area is located north of a historical landfill that reportedly received oily waste between the 1920s and 1940s, and municipal waste from approximately 1930 to 1967. The existing sheet pile barrier wall in the Lake Chipican Area, constructed in multiple stages between 2000 and 2012, does not extend to the Animal Farm or east of the sheet pile barrier wall. In addition, there are no mitigative or preventative measures installed in these areas. Recent subsurface soil investigations conducted in 2020 using laser-induced fluorescence (LIF) technology indicated that LNAPL was present within the subsurface near the Animal Farm and east of the existing sheet pile barrier wall. However, within the above-mentioned sub-areas, floating LNAPL product was only identified within monitoring well MW20094, which is located near the eastern edge of the sheet pile barrier wall.

The currently approved Trigger and Contingency Plan (T&C Plan, Golder & Associates, 2015) for the Lake Chipican Area of the FMAL establishes as a trigger criterion, the presence of floating oil, thin oily film, or sheen in Lake Chipican and its associated water bodies, whereby this observation would trigger the requirement to implement contingency measures and/or remedial action as outlined in the T&C Plan.

A previous LIF investigation conducted in 2013, referenced within a January 2014 report entitled, *Light Non-Aqueous Phase Liquid (LNAPL) Delineation - Lake Chipican Area - Former Michigan Avenue Landfill Sarnia, Ontario*, (Golder & Associates, 2014), did not extend in the vicinity of the Animal Farm or beyond the eastern limit of the sheet pile barrier wall (*see* Figure 2). As such, the previously interpreted LNAPL limits in these areas may not have been representative of actual soil conditions even at the time of the previous investigation. The 2020 LIF and subsurface characterization investigations inferred the presence of a second finger plume formation extending from the Animal Farm parking area towards monitoring well MW1325, as well as the advancement of the plume edge toward the east-northeast. Of note, monitoring well MW1322, located within the newly identified finger plume, and MW1325, located beyond the leading northwestern edge of the inferred plume, have not indicated the presence of detectable LNAPL (i.e., floating product/oil) since monthly monitoring began in April 2013. In addition, soil samples submitted for analysis from BH20037 as part of the soil characterization efforts completed in 2020, which is also located within the finger plume, did exhibit a hydrocarbon sheen/staining and slight hydrocarbon odour. However, when comparing the analytical results to the Table 3 criteria of the MECP's *Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act* (MECP Standards) , the soil quality testing results satisfied the Table 3 criteria of the MECP Standards.

Record high lake levels in recent years (*Fisheries and Oceans Canada*, 2020) within nearby Lake Huron are expected to have raised the groundwater table in the area of the FMAL, which may have been one of the many possible contributors toward the subsurface movement of LNAPL free product (i.e., liquid phase of LNAPL). The elevated groundwater table may have remobilized previously immobile LNAPL that would have been trapped within the soil and perched above the groundwater table during previous lower groundwater table levels. Floating oil and/or sheen has not been observed in Lake Chipican or its associated water bodies since at least 2016. There are currently no containment/preventative control or other remedial measures in place near the Animal Farm or further eastward from the sheet pile barriers wall in the Lake Chipican Area.

It should be noted that although there are currently no remedial and/or preventative measures currently established in these 2 above-mentioned Sub-Areas of Lake Chipican, there are no indications of any immediate threats to nearby water bodies. As such, this supplemental ROE considers potential future remedial and/or preventative measures following the completion of remedial actions for the more immediate areas of concern in the Lake Chipican and CLC Areas of the FMAL.

St. Clair Region Conservation Authority

In 2019, the St. Clair Region Conservation Authority (SCRCA) established Lake Chipican as a Provincially significant wetland. Under Ontario Regulation 171/06 of the Ontario Conservation Authorities Act (OCAA), any construction activities, including select remedial measures, proposed to be completed at the FMAL within 120 m of Lake Chipican will require supplemental review and acknowledgement by the SCRCA prior to its implementation. As such, based on the proximity of the proposed remedial measures to be undertaking in the Lake Chipican Area, formal review and approval is required to be sought from the SCRCA.

Recent Data Collection

In 2020 a site wide LIF investigation was completed at the FMAL to refine and delineate the extent of subsurface LNAPL impacts and update the inferred limit of the LNAPL plume. The methodology and results of this investigation can be found in the January 22, 2021 report, *Update on Light Non-Aqueous Phase Liquid (LNAPL) Plume Delineation*. In brief, the report concluded that the LNAPL exists in the subsurface as continuous and discontinuous free phase products, and/or residual liquids trapped above and below the groundwater table. This "patchy" nature is likely due to subsurface soil heterogeneity and fluctuating groundwater levels, which can impact the apparent free phase LNAPL thickness measured in monitoring wells (Newell *et al*., 1995). The thickness of LNAPL in monitoring wells is commonly greater than the actual LNAPL-saturated thickness (free-phase) of the formation (American Petroleum Institute (API), 2003[1]). Moreover, the patchy nature of LNAPL within the soil results in LIF signals that depict a greater overall LNAPL profile thickness in comparison to the actual free-phase component of the LNAPL profile. The LIF survey also indicated the presence of multiple LNAPLs in the Lake Chipican Area, including highly weathered fuels / mixtures, or heavy ended oil products, as interpreted from the LIF signal logs.

Confirmatory subsurface soil sampling was conducted following the LIF survey with sampling boreholes installed adjacent to thirteen (13) LIF borehole locations in the Lake Chipican Area. Soil samples were analyzed for benzene, toluene, ethylbenzene, and xylene (BTEX), petroleum hydrocarbon (PHC) fraction F1, and polycyclic aromatic hydrocarbons (PAHs) to validate subsurface conditions interpreted by the LIF investigation.

Three (3) boreholes were advanced in the above-noted Sub-Areas with one of the boreholes instrumented with a groundwater monitoring well (MW20094) to evaluate for the presence of floating oil/product and/or LNAPL. East of the sheet pile barrier wall, the subsurface soil noted at borehole BH20095 and monitoring well MW20094 indicated constituent concentrations that were above their respective Table 3 criteria of the MECP Standards for PHCs with PHC concentrations typically greater at BH20095, which is closer to Lake Chipican. In addition, the concentration of PAH 1-methlynaphthalene was also noted to be above its Table 3 criteria of the MECP Standards at BH20095 (~1.9 meters below ground surface (mBGS)). The LIF results for both tested locations were slightly above 50 %RE with slight to strong hydrocarbon odours and staining noted during drilling. As previously stated, at the location of BH20037 the tested parameters within the soil satisfied the respective Table 3 criteria of the MECP standards for PHCs, PAHs, and BTEX. The LIF readout was over 116 %RE. The soil sample retrieved from the location of BH20037 exhibited a slight hydrocarbon odour and staining.

[1] American Petroleum Institute (API). 2003. *Answers to Frequently Asked Questions about Managing Risk at LNAPL Sites*. Soil and Groundwater Research Bulletin No. 18, May.

Oil-Impacted Material Removal and Disposal Estimates

One of the most efficient methods of remediating adversely impacted subsurface soils is to simply excavate and remove impacted soils for off-Site transportation to a facility that is licensed to receive the material. As a very high-level evaluation to determine a very ballpark estimate to excavate and remove oil-impacted soil and waste materials at the FMAL, assuming the material is determined to be non-hazardous, to be disposed at a non-hazardous solid waste landfill, a fee of approximately **$41.1M** could be incurred for trucking and disposal only. This value represents an estimated impacted area of 12 hectares (ha), including oil-impacted native soils located beyond the waste mound of the FMAL. This value also assumes an average oily-impacted material thickness of 2.5 m to be excavated and removed across the Site.

The above-identified dollar value to haul and dispose of non-hazardous solid waste to a licensed facility does not take into consideration several other costly factors that would pose important roles during excavation and disposal activities such as, but not necessarily limited to, the following considerations.

- Excavation equipment and operator(s) labour efforts.
- Dewatering requirements to be able to excavate oil-impacted soils and materials below the groundwater table, as well as management and treatment, if required, of the groundwater.
- Excavation vertical stabilization infrastructure.
- Truck traffic control measures, such as establishing dedicated truck routes, dust and mud control on residential/City streets, as well as air quality and noise control.
- Engineering planning and execution.
- Field coordination and excavation guidance.
- Management of potential materials deemed hazardous, which will be required to be landfilled at a hazardous landfilling facility at a much greater fee.
- Selection of another disposal site based on limited capacity of the selected nearby disposal site which would increase trucking fees and potentially disposal fees.
- Replacement of excavated soil with new clean soil/sand.

Given the above, the dollar value presented for the excavation and removal of oil-impacted materials could significantly inflate depending on field conditions encountered and engineering requirements to safeguard the public and construction workers during material removal.

EVALUATION OF LNAPL CONCERNS, REMEDIATION OBJECTIVES/GOALS

This supplemental ROE considered an LNAPL remediation options framework compiled by the Interstate Technology Regulatory Council (ITRC, 2009), with insight provided by components of the Canadian Council of Ministers of the Environment (CCME) *Guidance Manual for Environmental Site Characterization in Support of Environmental and Human Health Risk Assessment - Volume 1 Guidance Manual* (CCME, 2016), and the comments and suggestions put forth by the MECP in its memorandums

dated June 17, 2020, and March 4, 2021, toward the identification of LNAPL concerns, remedial objectives and goals, and remedial options screening. The ITRC framework provides a systematic approach in selecting appropriate remedial technologies for specific site concerns and remedial goals. The main focus of this ROE is the inferred newly identified finger plume extending towards the Animal Farm and the advancement of the LNAPL plume edge east of the sheet pile barrier wall in the Lake Chipican Area of the FMAL.

Lake Chipican Area – Sub-Area Concerns

This supplemental ROE focuses on two Sub-Areas located within the northwestern and northeastern components of the Lake Chipican Area at the FMAL. In the northeast, the plume front is inferred to have extended further eastward since the previous investigation in 2013 encompassing an extended area of approximately 500 square metres (m^2) and is near southern shore of Lake Chipican. The length of shoreline beyond which the LNAPL plume front is interpreted to have advanced eastward from the sheet pile barrier wall is approximately 20 m.

In the northwest, a newly identified finger plume extending northward from the previously interpreted plume front edge between the Animal Farm building and just east of monitoring well MW1325 consists of an area of approximately 500 m^2 and is near the Duck Ponds.

Concern 1: The 2020 LIF and subsurface characterization investigations indicated that the LNAPL plume front appeared to be present in the area east of the existing sheet pile barrier wall limit, where LNAPL had not previously been noted. Floating product was also observed in a newly installed monitoring well, MW20094, which is situated in proximity to the eastern limit of the existing sheet pile barrier wall near Lake Chipican.

Concern 2: The 2020 LIF and subsurface characterization investigations identified the presence of an LNAPL finger-like plume extending towards the Animal Farm and Duck Ponds in an area where there were no previous LIF investigations completed.

Lake Chipican Area Remediation Objectives/Goals

A remedial objective and its associated goals are set for each listed concern to select specifically targeted and appropriate remedial technologies for the Sub-Areas of Lake Chipican. The technology group indicates whether this goal will address the concern via LNAPL mass recovery (removal of free product), mass control (subsurface barriers), or phase changes (dissolution or volatilization of LNAPL). The listed performance metrics are suggestions for evaluating the effectiveness of these goals following the implementation of the eventual remedial technology.

Lake Chipican Area Concern	LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Potential Performance Metric
Concern 1	- Prevent future LNAPL movement towards Lake Chipican, beyond the limit of the existing sheet pile barrier wall (including vapour and dissolved phases, where appropriate)	- Contain existing LNAPL source within some specified distance from Lake Chipican	LNAPL mass control and recovery	- No leakage through or over barrier wall
Concern 2	- Monitor LNAPL finger plume evolution, and, - prevent migration towards Animal Farm and Duck Ponds (including vapour and dissolved phases, where appropriate, based on monitoring findings)	- Evaluate LNAPL mobility and, if necessary, contain existing LNAPL source to prevent seepage into nearby water features	LNAPL plume monitoring with potential for future mass recovery and/or migratory control	- Stability of LNAPL plume front and shape - No LNAPL seeps and sheen on nearby water features

LAKE CHIPICAN SUB-AREAS REMEDIAL TECHNOLOGY SCREENING

Selecting appropriate LNAPL remedial technologies depends on a variety of site-specific conditions such as, but not necessarily limited to, site access, geological conditions, contaminant location in saturated or unsaturated zones, regulatory limits and standards, remedial timeframes, public concern, and cost/benefit. This preliminary screening aims to identify technology options that address the previously stated concerns specific to the aforementioned Sub-Areas of the Lake Chipican Area in the FMAL and their respective remedial objectives/goals.

Concern 1: LNAPL free product found in newly installed monitoring well MW20094 and the interpreted advancement of LNAPL plume edge towards the east and beyond the limit of the existing sheet pile barrier wall.

- **Objective:** Prevent future LNAPL movement towards Lake Chipican, beyond the limit of the existing sheet pile barrier wall (including vapour and dissolved phases, where appropriate).

Goal	Technology Option	Description	Pros	Cons
- **Contain existing LNAPL source within some specified distance from Lake Chipican**	Extend the existing sheet pile barrier wall from the eastern limit towards the east along the shore of Lake Chipican, using sealed joint sheet pilings.	Hydraulic barrier contains groundwater by the installation of vertical steel strips into the soil, forming a "wall"	- Minimal waste disposal - Highly impermeable if sealed (grouting) - No excavation required - Rapid installation	- Can be more expensive than other "wall" barriers - Poor sealing will cause leakage - Corrosion can more rapidly occur in high O_2, low pH setting - Loud and intrusive installation - Vibration concerns during install
- **Recover LNAPL to "maximum extent practicable" (MEP)** - **Abate further LNAPL migration by physical removal of mobile LNAPL (i.e., liquid phase)**	Active LNAPL skimming	Install additional recovery wells east of the existing sheet pile barrier wall along interpreted LNAPL plume edge on the landfill side of the barrier wall	- Could be connected to existing extraction infrastructure - Decreases mobility of LNAPL - Lower cost compared to other extraction technologies	- Does not affect residual saturation - Long term operation - Well spacing is controlled by subsurface soil heterogeneity (i.e., need more wells in less uniform soils and in finer-grained soils)

On the eastern edge of the existing sheet pile barrier wall, floating oily product was observed in newly installed monitoring well MW20094. The inferred LNAPL plume edge based on the 2020 LIF investigation also indicates that the LNAPL impacted soil extends beyond the eastern edge of the sheet pile barrier wall towards the east. However, floating oily product was not observed in other monitoring wells in this sub-area in 2020. The MECP has identified this area as a secondary concern considering that the LNAPL plume edge may have the potential for future LNAPL migration towards Lake Chipican. The implementation of each of the technologies listed in the table above could help prevent LNAPL from migrating into Lake Chipican.

Concern 2: The 2020 LIF and subsurface characterization investigations identified the presence of an LNAPL finger-like plume extending towards the Animal Farm and Duck Ponds in an area that has not been previously investigated.

- **Objective:** Monitor LNAPL finger plume evolution and prevent migration towards Animal Farm and Duck Ponds (including vapour and dissolved phases, where appropriate), based on ongoing monitoring findings.

Goal	Technology Option	Description	Pros	Cons
- **Evaluate LNAPL mobility and, if necessary, contain existing LNAPL source to prevent seepage into nearby water features**	LNAPL monitoring well network with the potential to install passive skimmers if necessary.	Install additional monitoring/sentry wells that could be fitted with active skimming or dual pump systems at a future date if LNAPL migration towards the Animal Farm and Duck Pond becomes a concern	- Allows for ongoing evaluation of LNAPL migration risk prior to instilling further action - Could be connected to existing extraction infrastructure - Decreases mobility of LNAPL - Lower cost compared to other extraction technologies	- Does not affect residual saturation - Long term operation - Well spacing is controlled by subsurface soil heterogeneity (i.e., need more wells in less uniform soils and in finer-grained soils)

The LNAPL finger plume extending towards the Animal Farm and Duck Pond was identified as a concern by the MECP for potential future migration into nearby surface water bodies. The previous LIF investigation did not extend into this Sub-Area and floating LNAPL was not observed within existing nearby monitoring wells. As such, prior to the implementation of a large scale and potential very costly LNAPL mass recovery or preventative control programs (i.e.., skimmers or barriers walls), the mobility of the finger plume should be monitored. The additional monitoring wells proposed for installation in this Sub-Area would serve multiple purposes, including floating product sentry wells, gas monitoring wells, and potential recovery wells if deemed necessary in the future.

Use of Natural Source Zone Depletion Assessment on Lake Chipican Area Concerns and Remedial Objectives/Goals

As described within the Lake Chipican Area ROE, Natural Source Zone Depletion (NSZD) involves the natural mass loss of LNAPL products in the subsurface by the processes of sorption, dissolution, volatilization, and biodegradation (ITRC, 2018). When an LNAPL release occurs, natural degradation processes begin immediately, with more soluble constituents beginning to dissolve, volatiles beginning to off-gas (volatilization of LNAPL into the vadose zone), and soil microorganisms beginning to break down accessible components via reduction and oxidation (redox) reactions.

The three (3) major NSZD pathways of mass loss for LNAPL are vertical gas transport of volatilized and biodegraded constituents, lateral groundwater transport of dissolved and biodegraded constituents, and direct biodegradation of low solubility LNAPL components.

Mass loss via vertical gas transport is considered the dominant pathway toward the natural loss of LNAPL mass in the subsurface, where several subsurface reactions can occur as follows.

1. Diffusive, and/or to a lesser extent, advective flux (or movement) of volatilized LNAPL components (i.e., gaseous component), particularly in the early stages of spill. This process will decrease as the LNAPL ages and volatile components are diminished.
2. Aerobic biodegradation of LNAPL in near surface oxygenated zone, which consumes O_2 and produces CO_2.
3. Anaerobic methanogenesis of LNAPL in saturated zone, which produces methane (CH_4) and carbon dioxide (CO_2).
4. Aerobic oxidation of CH_4 in near surface, which consumes oxygen (O_2) and produces CO_2.

The lateral groundwater transport of dissolved LNAPL constituents and NSZD that follows also naturally contribute to the overall LNAPL plume mass loss, albeit to a lesser extent than vertical gas transport, at least initially in the early stages of the source spill or introduction to the subsurface. As the residual LNAPL mass migrates laterally within the subsurface, the biodegradation of dissolved LNAPL constituents occurs via redox reactions in order of decreasing redox potential (e.g., O_2, NO_3, Mn^{4+}, Fe^{3+}, SO_4^{2-}), where the LNAPL is oxidized and CO_2 is produced. Methanogenesis can also occur during this process, and gaseous products from the methanogenesis processes will undergo subsequent vertical gas transport, whereby CH_4 is consumed using O_2, which converts to CO_2.

More recently the direct biodegradation of LNAPL without an intermediate aqueous phase has been recognized as an important NSZD process. This process can impact even the low solubility LNAPL compounds, which is the most likely state of the current LNAPL source at the FMAL, and produces CH_4 off-gassing, which can then undergo subsequent oxidation in the near surface aerobic zone and convert CH_4 to CO_2.

Application of NSZD in the Lake Chipican Sub-Areas

NSZD can play an important role in LNAPL remedial strategies due to the mass loss of particularly the more volatile and soluble LNAPL components. In some cases, the transition from active remedial technologies to NSZD can be evaluated as a sufficient long-term remedial strategy, provided that the LNAPL composition and saturation are understood to be of no further concern. A median rate of LNAPL depletion of approximately 14,000 litres per hectare per year (L/ha-yr) (1,500 US gallons per acre per year) is reported by the ITRC (2018) for crude oil releases. Implementation of this strategy can require that the LNAPL source, including the vapour and aqueous phases, has stabilized, and that risks to surrounding stakeholders and infrastructure are abated, however, this varies by jurisdiction.

Within the Lake Chipican Area, where the risk of LNAPL movement towards potential receptors like buildings and enclosures is limited, NSZD depletion may provide an adequate remedial approach. This process will have been occurring within the FMAL since disposal of these waste oil contaminants, and as described above can contribute significant removal rates. Within areas where the potential for vapour phase intrusion within receptors like buildings and enclosures does exists, monitoring and evaluation for the potential of a vapour phase component to the LNAPL may alleviate potential concerns for vapour intrusion.

Measurement of site-specific NSZD rates can be conducted with various methods that involve the measurement of CO_2 and CH_4 soil gas fluxes, and subsurface heat gradients. Where NSZD is actively occurring groundwater concentrations downgradient and within LNAPL plumes are also expected to display an overall reduction in metals and total dissolved solids (TDS) concentrations.

Given NSZDs potential contribution to LNAPL remediation, this strategy may be worth investigating as a long-term remedial option in the Lake Chipican Area, provided that further movement towards Lake Chipican and nearby water features, is limited and that the residual LNAPL and its vapour and dissolved components do not pose a risk to nearby structures and are at concentrations that will allow natural processes to breakdown the LNAPL over time.

Of note, the low occurrence of combustible gases and soil vapours within this area, as well as the LIF results, which indicate the presence of highly weathered LNAPL products, point towards NSZD as an important process that occurred within this area and will likely continue to occur. This appears to be the case for the nearby gas probes G7 and G8, which are located directly south of the Animal Farm finger plume and typically do not show off-gassing of methane.

Data Required for Remedial Options

Technology	Site Specific Data Needed	Additional Considerations	Long Term
Containment (Barrier Wall Extension)	- Soil type and lithology - Subsurface hydraulic gradient and groundwater flow direction - Access to site - Location of buried utilities and infrastructure - Groundwater table depth - LNAPL zone depth and areal extent	- Barrier permeability - Vibration (metal pile driving)	- Integrity of barrier wall
Increased Monitoring Network	- Subsurface hydraulic gradient and groundwater flow direction - Access to site - Location of buried utilities and infrastructure - Groundwater table depth - LNAPL zone depth and areal extent	- Monitoring well diameter - Well screen depth, length, and slot size - Soil heterogeneity	- Radius of influence for potential LNAPL skimming and/or recovery
NSZD	- LNAPL characteristics - LNAPL zone depth and areal extent - Dissolved LNAPL concentrations - Electron acceptor/ biotransformation products - Soil vapour LNAPL concentrations - O_2/ CH_4 concentrations - Groundwater hydraulics	- Calculation of saturated and unsaturated zone LNAPL mass loss rate	- Remedial option transition metrics

PREFERRED APPROACH AND COST ESTIMATE

In both Sub-Areas, there are currently no remedial and/or preventative control measures in place. LNAPL is interpreted to have migrated in the direction of the Animal Farm (finger-like plume) and towards the east, in part due to high lake and groundwater levels in recent years. Based on the evaluation of several remedial techniques, the most cost-effective approach to achieve the remedial goal

presented herein for the eastern Sub-Area may be the extension of the existing sheet pile barrier wall including the installation of dual-purposed monitoring and sentry wells that could be retrofitted as passive recovery wells in the future. Near the Animal Farm Sub-Area, the installation of additional monitoring wells/sentry wells to supplement the existing monitoring well network would allow for the evaluation of the LNAPL mobility and NSZD effectiveness within the finger-like plume. These monitoring wells should also be installed with the intent of potentially retrofitting them with recovery pumping systems should monitoring findings indicate an imminent threat of LNAPL seepage into nearby surface water bodies.

Of note, monitoring well MW1322 (located within the Animal Farm finger plume) and MW1325 (located beyond the leading northwestern edge of the inferred plume) have not indicated the presence of detectable floating LNAPL since monthly monitoring began in April 2013. In addition, while soil submitted for analysis from borehole BH20037 (located within the Animal Farm finger plume) did exhibit a hydrocarbon sheen/staining and slight hydrocarbon odour, the soil analytical testing results satisfied the respective Table 3 criteria of the MECP Standards for PHCs, PAHs, and BTEX. As such, on-going monitoring is being proposed for this area and remedial measures are not being considered at this time for this specific area.

Within the eastern Sub-Area, the existing sheet pile barrier wall is proposed to be extended by approximately 20 m along the Lake Chipican shoreline following the same east-southeast direction of the existing barrier wall (*see* Figure 1). The installation is proposed to consist of advancing 4.6 m (15-foot) long sheet piles to near existing grade such that floating LNAPL can not migrate above the sheet piles when groundwater levels are at their historical peak elevation and can not migrate beneath the sheet piles based on historically low groundwater elevations observed within nearby monitoring wells. Moreover, the sheet pile barrier wall will be sealed at the piling joints to improve its impermeability and further preclude the lateral movement of groundwater and effectively, LNAPL, toward Lake Chipican. The sheet pile barrier wall is proposed to be installed starting from the eastern edge of the existing sheet pile barrier wall. An additional dual-purpose monitoring sentry well may also be installed near the barrier wall extension edge such that the well could be outfitted with an additional recovery system based on monitoring findings.

Following the installation of the sheet pile barrier wall, an assessment of the existing groundwater monitoring network will be undertaken such that existing monitoring wells may be utilized to assess the natural attenuation capacity of the native soils. Additional monitoring wells may be installed to enhance the existing well network and help determine the attenuation capacity of the native soils more accurately and across a larger area. Monitoring in this area may form part of the updated TC Plan for the FMAL.

The LIF investigation within the Animal Farm Sub-Area showed the presence of an LNAPL finger plume extending toward the Duck Pond which is situated directly south of the Animal Farm. It should be noted that floating oily product was not observed within the monitoring wells in this Sub-Area in 2020. As such,

the mobility of the LNAPL in this Sub-Area is poorly understood and proposed approach toward remedial efforts will be in phases. The scope of this approach would include the installation of additional dual-purpose monitoring wells and sentry wells within and adjacent to this finger plume as shown in **Figure 1**. These monitoring wells would be installed with well screens that intersect the groundwater table so they could function as gas monitoring wells. The well piping would be sized such that the well could be outfitted with recovery system based on monitoring findings. Future considerations toward other remedial options are provided further into this report.

Costing Estimate

The costing estimate is provided below for reference. It should be noted that although the preferred approach described above is being proposed for the Sub-Areas of the Lake Chipican Area, modifications to the proposed approach may change based on consultation with the City and the MECP. Unknown field conditions may also contribute to project modifications and budgetary adjustments. As such, the costing below represents best case scenario application of the proposed remedial approach to the Lake Chipican Sub-Areas of the FMAL.

Remedial Approach	Subcontractor Fees	Consultant Fees	Subtotals
Sheet Pile Installation (~2.5 days)	20 m of wall = $35,000 $1,750 per linear metre of 4.6 m long sheets, including sealed joints, all equipment, and labour fees	$5,900	$40,900
NSZD and Additional Finger Plume Monitoring (ongoing)	$24,350 (Installation of estimated 5 new Groundwater/gas monitoring locations, etc.)	$13,800 (Program setup, evaluation of existing monitoring infrastructure) $11,800 (Ongoing monitoring efforts including laboratory testing and field investigations (presumed to be semi-annually), reporting)	$39,250 - initially (+ $11,800 annually thereafter)

Given the above-noted estimates (COVID cost fluctuation factors excluded), an initial evaluation of costing is a ballpark estimate of **$80,150,** with an estimated $11,800 annually required to monitor the natural attenuation capabilities of the native soils in the Lake Chipican Sub-Areas following the installation of the sheet pile barrier wall and additional monitoring/sentry wells. The monitoring frequency is assumed to be semi-annually, but will be determined following consultation with the MECP, under the assumption that the evaluation for NSZD is an acceptable approach. The costing presented herein is a ballpark estimate and may be adjusted based on ongoing monitoring efforts and consultative efforts with the MECP.

FUTURE CONSIDERATIONS

The newly identified LNAPL finger extending towards monitoring well MW1325 near the Animal Farm presents a concern with regards to floating oil/sheen to Lake Chipican and its nearby water features. As described in the 2020 Annual Report dated May 31, 2021 (RWDI, 2021), floating oil/sheen has not been observed in this area in several years following weekly inspections of Lake Chipican, the Duck Pond and the connecting channel. The current preferred approach to address these newly identified finder plume includes an initial enhancement to the existing monitoring program, but with these monitoring wells constructed in a way that would allow future retrofitting as potential recovery wells should the presence of floating oily product occur within the newly installed wells, or, that NSZD becomes insufficient for product breakdown due to an increase in migration rate of the source product. In such a case, the presence of LNAPL may pose a more immediate threat for potential seepage into the Duck Pond and subsequently into Lake Chipican.

Concern: Migration of the LNAPL finger extending towards the Duck Pond in the Animal Farm Sub-Area with plume front at concentration that may be too elevated for NSZD to be sufficient and plume seepage may be imminent into the Duck Pond.

- **Objective:** Prevent LNAPL movement towards and into the Duck Pond and the associated water features.

Goal	Technology Option	Description	Pros	Cons
- **Contain existing LNAPL source within some specified distance from the Duck Pond**	Install seal jointed sheet pile barrier wall approximately 50 m in length tied into the western extent of the existing sheet pile barrier wall	Hydraulic barrier contains groundwater by the installation of vertical steel strips into the soil, forming a "wall"	- Minimal waste disposal - Highly impermeable if sealed (grouting) - No excavation required - Rapid installation	- More expensive than other "wall" barriers - Poor sealing will cause leakage - Corrosion can more rapidly occur in high O_2, low pH setting - Loud and intrusive installation - Vibration concerns during install - Utilities could impede on its final location and configuration affecting final cost
- **Recover LNAPL to "maximum extent practicable" (MEP)** - **Abate further LNAPL migration by physical removal of mobile LNAPL (i.e., liquid phase)**	Enhanced Bioremediation	Indigenous and/or introduced micro-organisms are supplied with electron donors or acceptors that enhance the biodegradation of LNAPL in situ.	- No waste generated or removed - Generally low cost (but may require long-term monitoring) - Low safety concerns for nutrient injections	- Variability in soil moisture and temperature will impact biodegradation effectiveness - Long time frames - Not effective in unsaturated zone - Requires injection and monitoring network
	Total Liquid Extraction/Dual-Pump Liquid Extraction	Uses one pump to induce groundwater and subsequently the free-phase LNAPL	- Higher radius of influence (ROI) than passive skimming alone - Drawdown may expose and remobilize submerged LNAPL	- Requires capture, treatment, and disposal of groundwater and LNAPL (plus vapours (if present) when using MEP)

Goal	Technology Option	Description	Pros	Cons
	(DPLE) + Multiphase Extraction (MPE)	towards an extraction well and another pump to capture the floating LNAPL. MPE enhancement increases remediation in vadose zone using high vacuum.	- Decreases mobility of LNAPL - Works for all LNAPL types - Limits LNAPL emulsification (i.e., intermixing with groundwater) - Vacuum enhances LNAPL recovery by volatilizing components trapped in drawdown cone - Medium term operation	- Only removes mobile LNAPL (residual or phreatic smear is left) - Vacuum system can generate noise (MPE) - Well spacing is controlled by subsurface soil heterogeneity (i.e., need more wells in less uniform soils and in finer-grained soils)

Sheet Pile Barrier Wall West Extension

If the enhanced monitoring within the Animal Farm finger plume identifies that the LNAPL contained therein is mobile and migrating toward the Duck Pond, a seal-jointed sheet pile barrier wall may be installed extending westward from the existing western edge of the sheet pile barrier wall, which would measure approximately 50 m in length. The sheet pile barrier wall could be installed to "cut-off" the finger plume from the main LNAPL body. This would allow for the implementation of enhanced extraction, similar to the historical finger plume north of the Pavilion in the Lake Chipican Area. The dual-purpose monitoring and sentry wells proposed in the main section of this ROE could at that time be retrofitted as passive skimmers or active recovery wells to capture the remaining LNAPL within the Animal Farm finger plume. If necessary additional sentry wells may be installed to monitor LNAPL plume movement in this area.

DPLE with MPE and Bioremediation

If passive skimming demonstrates inefficiencies at capturing/recovering free-phase LNAPL following the installation of the sheet pile barrier wall, the proposed dual-purpose monitoring and sentry wells could be enhanced with a DPLE and MPE pumping and treatment system. A DPLE and MPE enhancement to the existing extraction wells would be expected to remove the liquid phase of LNAPL more quickly and more rigorously by drawing groundwater and floating oil toward the screened interval of the extraction wells but is not expected to capture the entirety of the entrapped LNAPL. There is the potential for additional entrapped LNAPL that could remobilize by the physical action of drawdown. Thus, this system is typically robust in capturing floating LNAPL within a defined radius of influence (ROI) and in a relatively shorter time frame. Enhanced bioremediation may be implemented within this finger plume as LNAPL extraction rates begin to lower or plateau over time, such that the overall concentration of LNAPL in the soil and groundwater is manageable using microbial enhancement or such that NSZD may become more viable.

Moreover, nearby existing monitoring wells would continue to be utilized to monitor the progress of LNAPL removal through liquid level and LNAPL thickness measurements. Groundwater would require to be captured and treated separately from the free-phase LNAPL. The captured liquid phase LNAPL would be containerized and shipped off-site for disposal by a licensed liquid waste hauler. Groundwater quality testing may be completed to determine management options (i.e., municipal sanitary sewer discharge, recirculated into the waste mound, disposed off-site by a licensed liquid waste hauler, etc.). The existing infrastructure for EW1 and EW2 can be examined toward the feasibility of potentially connecting these extraction wells to the existing infrastructure, which could reduce the cost of installing new enclosures/sheds and holding tanks.

Depending on the success of the DPLE and MPE enhanced wells, an enhanced in-situ bioremediation program may be implemented within the cut-off portion of the LNAPL finger. This remedial technology involves the degradation of LNAPL by indigenous and/or introduced micro-organisms that are supplied with electron donors or acceptors to enhance the natural bioremediation capabilities of the native soils in the subsurface. The in-situ injection sites would be strategically placed within the existing monitoring well network and within and/or in the vicinity of, the finger plume. Additional monitoring wells may need to be installed to target areas identified by the LIF survey as containing particularly thick occurrences of LNAPL product or LNAPL impacted soil. Enhanced bioremediation relies on naturally occurring biological reactions in the groundwater, so is limited to remediating the LNAPL product that sits at or below the groundwater table. LNAPL trapped above the groundwater table is not expected to be mobile.

The Trap & Treat approach (Remediation Products Inc.) can also be utilized to essentially 'trap' the contaminants within an activated carbon (powder or solution) and then 'treated' by biological degradation by forming a permeable reactive barrier (PRB), which is essentially a virtual 'wall' that would preclude the movement of LNAPL in the subsurface.

It should be noted that these remedial measures would only be implemented following the installation of sheet pile barrier wall extension.

As the LNAPL contained within the plume finger is removed, provided that the sheet piling wall system measure prevents any further migration of LNAPL toward the Duck Pond, the performance of passive skimming, if installed, should be monitored, along with the continued removal of oily product. Depending on the success of the proposed extraction wells, an enhanced pumping system approach using DPLE with MPE, or enhanced bioremediation or a capture and remediate approach may be revisited as potential options to further remove LNAPL from the subsurface. If appropriate, a follow up LIF survey could be conducted in this area before no further action is recommended.

CLOSING

The supplemental Sub-Areas within the Lake Chipican Area in Canatara Park presents a complex assortment of LNAPL concerns, which may each require individual remediation measures or a hybrid of several approaches.

We trust the information provided in this Letter is satisfactory for your requirements. Please contact us should you have any questions.

Yours truly,

RWDI AIR Inc.

David Geuder, M.Sc.
Scientist – Geoscience

Phil Janisse, B.Sc., P.Geo., QP$_{ESA}$
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DVSG/PEJ/kta

Attach.

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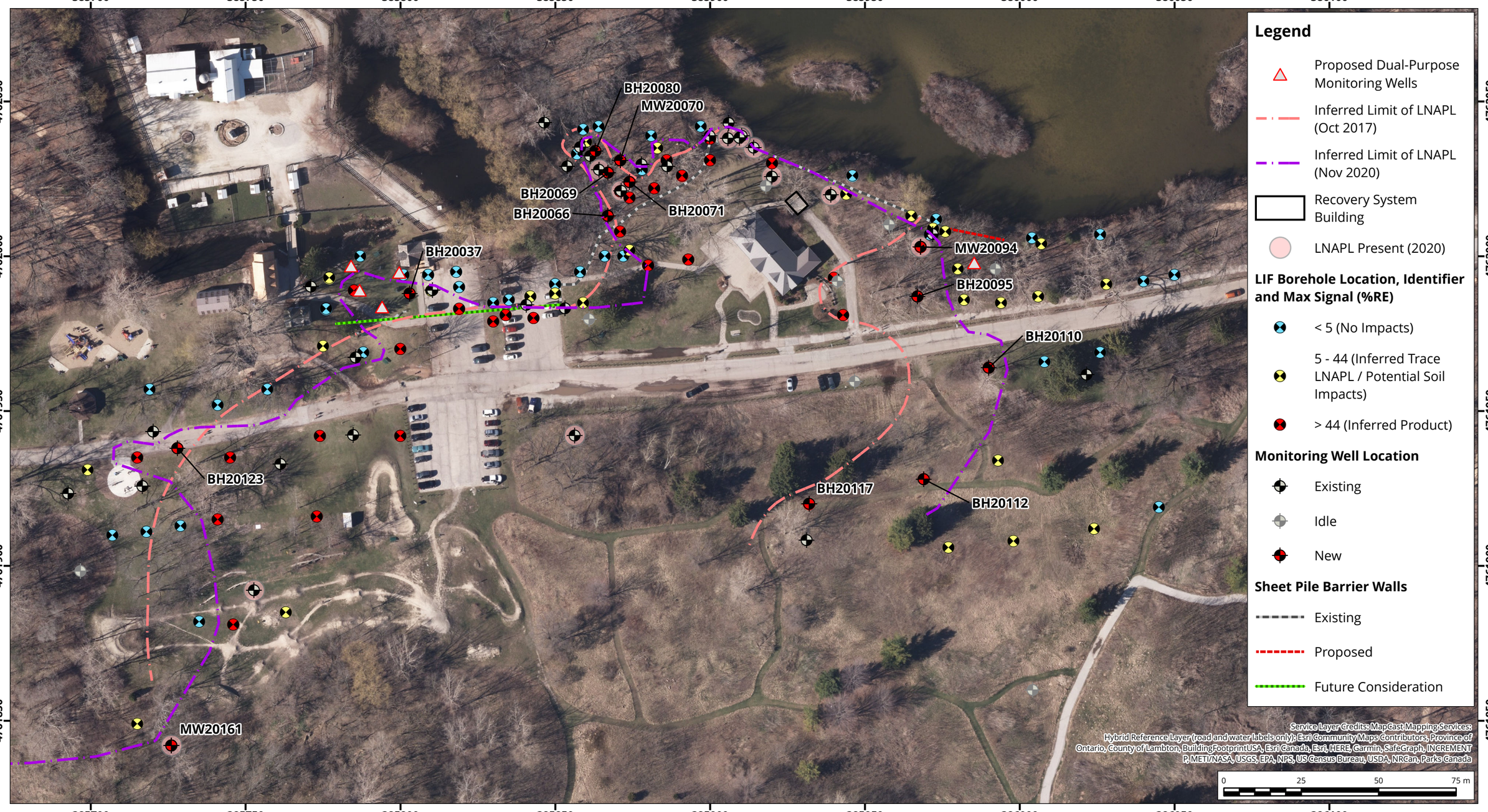
FIGURES



Proposed Remedial Options and Future Considerations Plan

Former Michigan Avenue Landfill, Point Edward, Ontario

Map Projection: NAD 1983 UTM Zone 17N

City of Sarnia

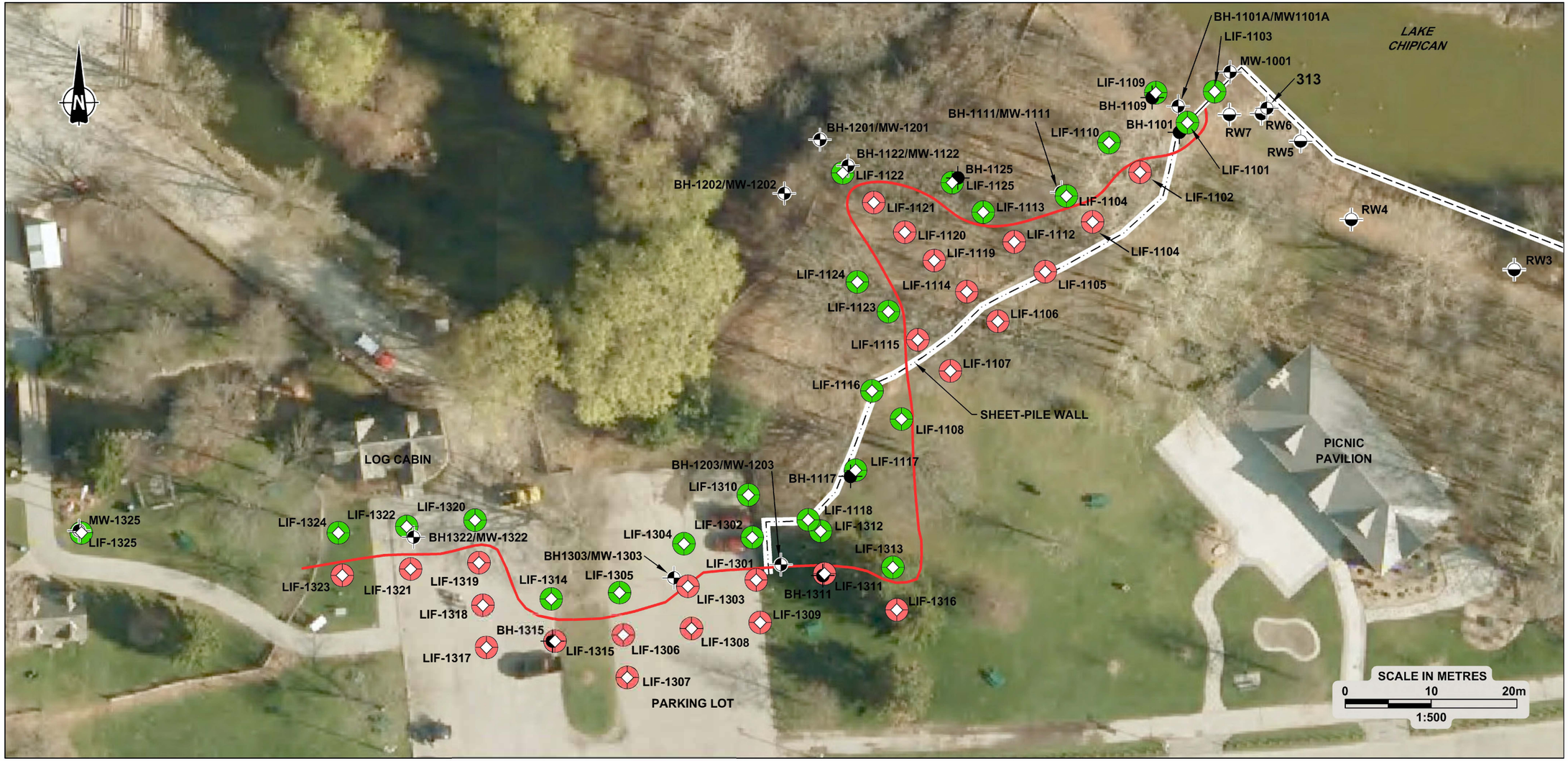
Notes:
1. Drawing based on 2017 aerial image from First Base Solutions Web Mapping Service.
2. Borehole locations measured using a handheld GPS unit with an accuracy of approximately 3 to 5 m.

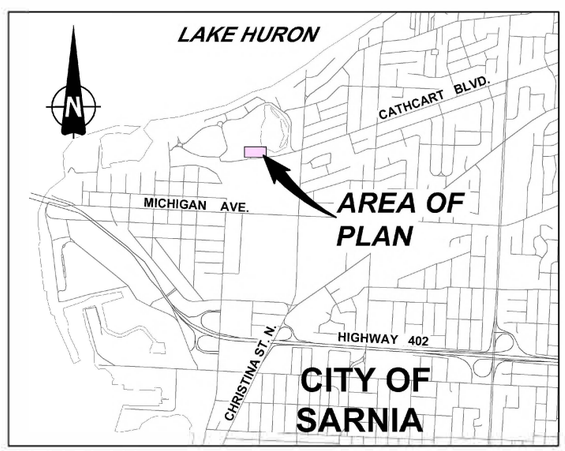
True North

Project #: 1801685

Drawn by: DJH	Figure: 1
Approx. Scale:	1:1,200
Date Revised:	Sep 23, 2021

Map Document: C:\GIS Temp - Copy\1801685\1801865_Sarnia_Landfill.aprx





KEY PLAN

LEGEND

- LIF HOLE
- BOREHOLE
- BHOREHOLE/MONITORING WELL
- RECOVERY WELL
- INFERRED NORTHWESTERN LIMIT OF LNAPL BASED ON LIF INVESTIGATIONS
- NO LNAPL DETECTED
- LNAPL DETECTED
- SHEET PILE WALL - 2000
- SHEET PILE WALL - 2011
- SHEET PILE WALL - 2012

REFERENCE

DRAWING BASED ON 2010 AERIAL IMAGE FROM THE COUNTY OF LAMBTON INTERACTIVE WEB MAPPING SITE, BY PERMISSION; AND CANMAP STREETFILES V2005.4.

NOTES

THIS DRAWING IS SCHEMATIC ONLY AND IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.

ALL LOCATIONS ARE APPROXIMATE.

PROJECT
LNAPL DELINEATION
LAKE CHIPICAN AREA, FORMER MICHIGAN AVENUE LANDFILL
SARNIA, ONTARIO

TITLE
LOCATION PLAN
RWDI Reference Figure #2

Golder Associates
LONDON, ONTARIO

PROJECT No. 07-1135-029-0			FILE No.	0711350290-R05001
			SCALE	AS SHOWN
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Figure 1

Drawing file: 0711350290-R05001.dwg Jan 17, 2014 - 4:15pm