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Re: Remedial Options Evaluation #2
Lake Chipican Area – 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. 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. Previous LNAPL delineation work completed in 2011 and 2014 identified an LNAPL finger plume extending towards the channel connecting the Duck Pond and Lake Chipican, northwest of the Pavilion. The existing sheet pile barrier wall originally constructed in 2000 as part of the Remediation Strategy along the southern shore of Lake Chipican was extended toward the southwest in two (2) stages: 1) in December 2011, and 2) in November 2012. These sheet pile barrier wall additions were installed across the finger plume to cut off further migration of the LNAPL finger. Two extraction wells were installed on the channel side of the sheet pile barrier wall within the finger plume to remove the mobile product. However, follow-up investigations conducted in 2020 using laser-induced fluorescence (LIF) technology indicated that LNAPL was still present within the subsurface, and in some areas the LIF profile showed LNAPL-impacted soil with thicknesses up to 0.9 m within the finger plume. 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 criteria based on 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.

The previously interpreted LNAPL limit to the northwest of the 2011/2012 sheet pile wall placed the leading edge of the inferred LNAPL finger plume near the channel which connects the Duck Pond to Lake Chipican. The 2020 LIF and subsurface characterization investigations revealed the primary finger plume may have somewhat receded from the channel, however, a new smaller finger was interpreted to be present to the northeast of the historical finger plume, north of monitoring well MW1111. 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 raised the mobile floating LNAPL and allowed it to flow over top of the existing sheet piling wall in some areas at the base of the historical finger plume. Additionally, 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, however, the existing containment/preventative controls in the Lake Chipican Area may not be adequate to prevent the further movement of LNAPL towards surface waters based on observations made of the condition of the sheet pile barrier walls in the Lake Chipican Area as part of an intrusive investigation completed in early spring 2021.

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,

[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.

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. Of the five (5) tested locations in proximity to the above-noted historical finger plume only two (2) sampled locations (BH20069 and BH20071) had constituent concentrations that were above their respective Table 3 criteria of the Ministry of Environment, Conservation and Parks' *Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act* (MECP Standards) for coarse-grained soil and residential/parkland/institutional (RPI) land use, for one or more petroleum hydrocarbons (PHCs). The corresponding borehole logs indicate the presence of a sheen at both locations. The soil sampled at location BH20080 satisfied the Table 3 criteria of the MECP Standards for the parameters analyzed, however, a sheen and noticeable free product were noted within the retrieved core.

Recent decreases in waste oil removal rates from the extraction wells installed within the historical finger plume (EW1 and EW2) were noted by the MECP as indicative of "the extraction well(s) … not operating at optimum capacity."

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 excavate, truck, 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.

- 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 Remedial Options Evaluation (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 historical LNAPL finger plume of the Lake Chipican Area of the FMAL.

Lake Chipican Area – Finger Plume Concerns

The primary LNAPL concerns in the Lake Chipican Area are listed below, however, not necessarily in order of priority for action.

Concern 1: LNAPL appears to have migrated overtop of the sheet piling barrier wall that is located near the base of the historical finger plume, potentially further allowing LNAPL to migrate beyond the sheet pile barrier wall and supplying more LNAPL to the historical finger observed in this area during high lake and groundwater levels.

Concern 2: A recent sheet piling investigation in the Lake Chipican Area revealed that the joints between sheet pilings were not grouted at the time of installation and may be allowing LNAPL to move through.

Based on concerns raised by the MECP in the Memorandum dated June 17, 2020, with respect to the extraction wells EW1 and EW2, the efficiency of these extraction wells may be decreasing, and alternative remedial options should be considered.

Though concerns were raised with respect to the efficiency of LNAPL recovery from the passive skimmers at extraction wells EW1 and EW2, it is plausible to interpret that their perceived inefficiency at recovering oil may be related to a higher than expected influx of LNAPL that is migrating beyond the sheet pile barrier walls and that the original design likely presumed a point source of LNAPL with finite volume. Thus, although the MECP has raised concerns with respect to the efficiency of LNAPL recovery from the existing passive skimmers, the City is proposing to first improve the impermeability of the existing sheet pile barrier walls then assess the effectiveness of passive skimming using existing monitoring infrastructures. Notwithstanding, this concern is addressed within this ROE, but is presented as a secondary option if following the sheet pile barrier wall enhancements that the existing passive skimming infrastructure proves inefficient at recovering subsurface LNAPL.

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 Lake Chipican Area and sub-areas. 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 LNAPL movement overtop of sheet piling barrier walls during high lake and groundwater levels	- Contain LNAPL on up-gradient side of sheet piling wall in consideration of historical low and high groundwater levels	LNAPL mass control	- No leakage over barrier
Concern 2	- Prevent LNAPL movement through unsealed sheet piling barrier wall joints	- Contain LNAPL on up-gradient side of sheet piling barrier wall in consideration of historical low and high groundwater levels	LNAPL mass control	- No leakage through barrier

LAKE CHIPICAN AREA 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 Lake Chipican Area of the FMAL and their respective remedial objectives/goals.

Concern 1: LNAPL appears to have moved over the sheet piling barrier wall near the base of the historical LNAPL finger plume, potentially contributing ongoing LNAPL to the finger sub-area of the Lake Chipican Area.

- **Objective:** Prevent LNAPL movement over sheet piling barrier walls during high lake and groundwater levels.

Goal	Technology Option	Description	Pros	Cons
- **Contain LNAPL on up-gradient side of sheet piling wall in consideration of available historical groundwater levels at nearby monitoring wells**	Raise existing sheet pile barrier wall OR Add additional wall skirt lengths and attached lengths using continuous welding methods.	Retain the services of an experienced sheet pile installer to either pull up sheet piling in the Lake Chipican Area, more specifically near the base of the historical LNAPL finger plume to be level with sheet piling along Lake Chipican shore and near grade level OR install supplemental sheet pilings above the existing piling and sealing the connection by welding the 2 sides together.	- Relatively inexpensive - Will prevent LNAPL from moving over the sheet pile barrier wall when considering historically elevated lake levels	- Does not address field-observed evidence of potential sheet pile joint leakage - Lifting sheet piles could physically damage existing piles, or sheet piles may subside after they have been lifted. - Welds could deteriorate over time and should be inspected intermittently over the years.

The sheet pile barrier walls installed in the Lake Chipican Area were installed in phases. The first phase was completed in 2000 and consisted of the northern portion of the sheet pile barrier wall, which extends eastward along the southern shore of Lake Chipican. The next phase was completed in 2011, which connected the northern portion to the west and extended the sheet pile barrier wall system southward along the fence line of the forested area and toward the animal farm. A recent investigation of the sheet pile barrier wall system in the Lake Chipican Area determined that the top of the 2011 sheet pile barrier wall was approximately 0.18 m lower in elevation than the 2000 sheet pile barrier wall, as observed at the connection point between the two barrier wall installation phases. This was interpreted to have allowed free-phase LNAPL to migrate over the 2011 sheet pile barrier wall in this location, further highlighting the need to raise and/or add more sheet piling to this section.

Concern 2: A recent sheet piling investigation in the Lake Chipican Area revealed that the joints between sheet pilings were not grouted at the time of installation and may be allowing LNAPL to migrate through.

- **Objective:** Prevent LNAPL movement through unsealed sheet piling barrier.

Goal	Technology Option	Description	Pros	Cons
- **Contain LNAPL on up-gradient side of sheet pile barrier wall in consideration of available historical groundwater levels at nearby monitoring wells**	Geosynthetic Clay Liner (GCL), or Bentonite sheet membrane (carpet)	A dual layered membrane containing bentonite granules would be draped over the landfill side (or both sides) of the existing steel sheet pile barrier wall to reduce the wall's permeability. This would be completed once the sheet pile barrier walls are lifted and/or enhanced as described previously. The sheet pile would require to be temporarily exposed to install the bentonite membrane.	- Lowers existing walls' permeability - No new wall needed to attach material to - Majority, if not entirety, of excavated material will be backfilled (little waste)	- Cost - Requires excavation to exposed portions of the sheet piling wall (in sections) - May require dewatering during installation

A recent investigation of the sheet pile barrier wall system in the Lake Chipican Area indicated soil staining on the downgradient side of the sheet pile barrier wall within the soil along the sheet pile joints. This formed the basis for the interpretation that the LNAPL is able to migrate through the sheet pile barrier wall in this area, but the migration is limited to the joint locations, which were not grouted or sealed at the time of installation. To address these potential joint seeps, a type of GCL could be affixed to either side (or both sides if needed) of the existing sheet piling, to preclude the movement of LNAPL through the sheet pile barrier wall joints. These GCLs are typically constructed with a layer of granular bentonite sandwiched between two synthetic layers (e.g., HDPE (high density polyethylene), woven or non-woven polypropylene, etc.). The swelling properties of bentonite clay and waterproof nature of the synthetic layers forms a strong hydraulic barrier. This remedial measure has the advantage of using the existing sheet piling wall as a structural support for the GCL, as opposed to installing a new barrier system. Excavation materials generated is anticipated to be reused as backfill in the same trench. Dewatering may be required depending on the targeted depth of installation for the bentonite sheet membrane, which could add significant cost to the project. The proposed linear length of sheet pile barrier wall for enhancement is depicted in **Figure 1.**

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

As described within the CLC 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 Area

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 gas probes G7 and G8, which are located within the interpreted LNAPL plume and typically do not show off-gassing of methane. Moreover, soil and sediment chemical results from samples collected at the edge of the historical finger plume did not indicate an immediate concern to surface water bodies based on low to non-detect concentrations of hydrocarbons and polycyclic aromatic hydrocarbons.

Data Required for Remedial Options

Technology	Site Specific Data Needed	Additional Considerations	Long term
Enhanced Containment Barrier (GCL)	- 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 - Fastening method of membrane to sheet pile barrier walls - Stability of membrane placement over time	- Integrity of barrier wall
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

Based on the evaluation of several remedial techniques, the most cost-effective approach to achieve the remedial goal presented herein for the Lake Chipican Area may be a combination of barrier wall adjustments and retrofitting measures to preclude the further migration of LNAPL towards Lake Chipican and nearby water features and allowing the existing passive skimmers to recover floating LNAPL over time.

Prior to the installation of the western section of the sheet pile barrier wall in 2011/2012, LNAPL in the Lake Chipican Area is interpreted to have migrated towards the Duck Pond channel, following the groundwater flow direction in the area. The sheet pile barrier wall was installed in this section to cut off this finger plume and extraction wells EW1 and EW2 were installed to remove the remaining LNAPL using passive skimmers. Since that time, LNAPL is interpreted to have continued to migrate in the direction of the Duck Pond and Channel in part due to high lake and groundwater levels which allowed the floating LNAPL product to flow over top of the 2011/2012 sheet pile barrier wall. Additionally, because the original sheet pile barrier wall was not grouted at the joints during installation, the LNAPL is also interpreted to have moved, albeit very slowly, through the unsealed joints of the sheet piles. Thus, the perception of the passive skimmers 'not performing as they should' may be simply due to the source LNAPL continuing to migrate northward at a rate that is greater than the LNAPL uptake of the passive skimmers.

To address the potential for further migration of LNAPL toward the Duck Pond and Channel in the Lake Chipican Area, adjustment and retrofitting measures of the existing sheet pile are being proposed. The top of the sheet piling installed in 2011/2012 which runs southwest to northeast was observed to be approximately 0.18 m lower in elevation than the adjoining 2000 sheet pile wall installed along the shore of Lake Chipican. The observation was made during a test pit investigation where a test pit was advanced at the location of the connection point between the sheet pile barrier wall installation phases. To address the potential for further migration of LNAPL over top of the sheet pile barrier wall system, the 2011/2012 sheet piles are proposed to either be raised to, or slightly above, surface grade, or retrofitted with extra lengths of sheet piling which would be welded together. The sheet piles in this area are reportedly 3 m (10 feet) in length and approximately 0.5 m (20 inches) in width. Thus, if the chosen method is to raise the sheet pile barrier wall, the sheet pile barrier wall is still expected to intersect and continue to preclude the movement of shallow groundwater, which in turn will act as a barrier to the floating LNAPL product.

A recent investigation of the sheet pile barrier wall system in the Lake Chipican Area indicated soil staining on the downgradient side of the sheet pile barrier wall within the soil along the sheet pile joints. Following the raising and/or the addition of a new welded section above the existing sheet pile barrier wall, a GCL is proposed to be affixed to the landfill side (or both sides) of the sheet pile barrier walls, to preclude the further migration of LNAPL through the unsealed joints and improve the impermeability of the existing sheet pile barrier wall system. These GCLs have very low hydraulic permeabilities ($< 5 \times 10^{-12}$ cm/s) and thus would provide a hydraulic barrier toward LNAPL migration through the sheet pile joints. This installation would involve the excavation of soils along the sheet pile wall in sections. The installation would consider historically low groundwater levels to determine the optimum installation depth below the groundwater table such that any LNAPL that is trapped within the soil beneath the groundwater table that can become mobile is precluded to laterally migrate by the GCL. As such, dewatering efforts to be able to affix the GCLs below the groundwater table may be required.

Following the sheet pile barrier wall enhancements, the effectiveness of the sheet pile barrier wall enhancements will be monitored using existing monitoring well infrastructure. In addition, the passive skimmers will continue to operate and the LNAPL recovery will be monitored closely. It should be noted that the passive skimming technique is inherently slower at recovering LNAPL compared to traditional active skimming or active drawdown techniques. However, the City is proposing to approach the remedial efforts in phases. Future considerations toward other remedial options are provided further into this report.

Based on the above, the City proposes to continue to monitor subsurface conditions using the existing monitoring well network and continue to utilize the passive skimmers at extraction wells EW1 and EW2 to evaluate their effectiveness over time following the sheet pile barrier wall enhancements. In theory, once the sheet pile barrier walls are enhanced as noted above, the source of the LNAPL should be cut off from laterally moving across the barrier system. Thus, the passive skimmers should be able to recover LNAPL more efficiently based on a limited volume available for recovery as the source is interpreted to be cut off. Continued monitoring will also help determine whether the passive skimmers were simply not effective enough to recover the influx of LNAPL to the finger plume.

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 Lake Chipican Area, modifications to the proposed approach may change based on consultation with the City of Sarnia and the MECP. Unknown field condition 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 Area of the FMAL.

Remedial Approach	Subcontractor Fees	Consultant Fees	Subtotals
Sheet Pile Barrier Wall Enhancements (~5 days)	Raise sheet piling to surface grade OR install additional vertical sheet piling to existing sheet piling *$35,400* Approximately 75 m of wall to raise/vertically increase height. A new channel cap will be seal welded to the top of the existing sheet pile to bring it up to surface grade.	$10,800 (project supervision and support)	$46,200

Remedial Approach	Subcontractor Fees	Consultant Fees	Subtotals
Sheet Pile Waterproofing (~5 days)	Install GCL (assume only 1 side of sheet pile barrier wall) $76,300 Approximately 75 m of wall to expose approximately 1.8 m below surface. Affix GCL to sheet pile Approximately 75 m of wall (*See* **Figure 1**), 10 feet deep sheet piles, 6 feet of GCL. Bentonite geotextile attached to plywood boards anchored to sheet pile wall. Backfill void between sheet piles and plywood, or similar method.	$16,300 (project supervision and support)	$92,600

Given the above-noted estimates (COVID cost fluctuation factors excluded), an initial evaluation of costing is a ballpark estimate of **$138,800**, which does not account for any supplemental monitoring that may be required to monitor the effectiveness of the existing passive skimmers following the sheet pile barrier wall enhancements (i.e. monitoring well observation and additional monitoring), and assumes that the existing well network is sufficient to observe the progress of passive skimming post-remedial measures.

FUTURE CONSIDERATIONS

The LNAPL finger extending towards monitoring well MW1201A within the Lake Chipican Area of Canatara Park 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. However, the continued presence of LNAPL beyond the installed sheet pile barrier wall continues to pose a more immediate concern to Lake Chipican.

DPLE with MPE and Bioremediation as Secondary Approach

If the existing passive skimmers demonstrate inefficiencies at capturing/recovering free-phase LNAPL following the enhancements to the sheet pile barrier walls, existing extraction wells EW1 and EW2 could be enhanced with a Total Liquid Extraction/Dual-Pump Liquid Extraction (DPLE) and Multiphase Extraction (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 the historical finger plume of the Lake Chipican Area 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.

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.). Most of the existing infrastructure for EW1 and EW2 can be utilized with this enhancement, which would reduce the cost of installing new equipment, conveyance lines, holding tanks, and wells.

Depending on the success of the DPLE and MPE enhanced wells, an enhanced in-situ bioremediation program may be implemented within the LNAPL finger area of approximately 500 m^2 on the downgradient side of the sheet pile barrier wall system. 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.

It should be noted that these remedial measures would only be implemented following the proposed sheet pile barrier wall enhancements and retrofitting measures, which is described previously in this report.

As the LNAPL contained within the plume finger is removed, provided that the sheet piling wall system adjustments and retrofitting measures prevent any further migration of LNAPL into this area, the performance of passive skimming should be monitored, along with the continued removal of oily product. Depending on the success of existing extraction wells EW1 and EW2, 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.

Concern: LNAPL finger extending towards the channel connected to Lake Chipican – interpreted as a result of decreased efficiency of current extraction wells.

- **Objective:** Prevent LNAPL movement towards and into Lake Chipican and its associated water features and increase efficiency of extraction wells within LNAPL historical "finger".

Goal	Technology Option	Description	Pros	Cons
- **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 (DPLE) + Multiphase Extraction (MPE)	Uses one pump to induce groundwater and subsequently the free-phase LNAPL towards an extraction well and another pump to capture the floating LNAPL. MPE enhancement increases remediation in vadose zone using high vacuum.	- Higher radius of influence (ROI) than passive skimming alone - Drawdown may expose and remobilize submerged LNAPL - 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	- Requires capture, treatment, and disposal of groundwater and LNAPL (plus vapours (if present) when using MEP) - 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)

CLOSING

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. In terms of priorities, the historical LNAPL finger extending towards the channel connecting Lake Chipican to the Duck Pond is foremost.

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

Yours truly,

RWDI

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FIGURE

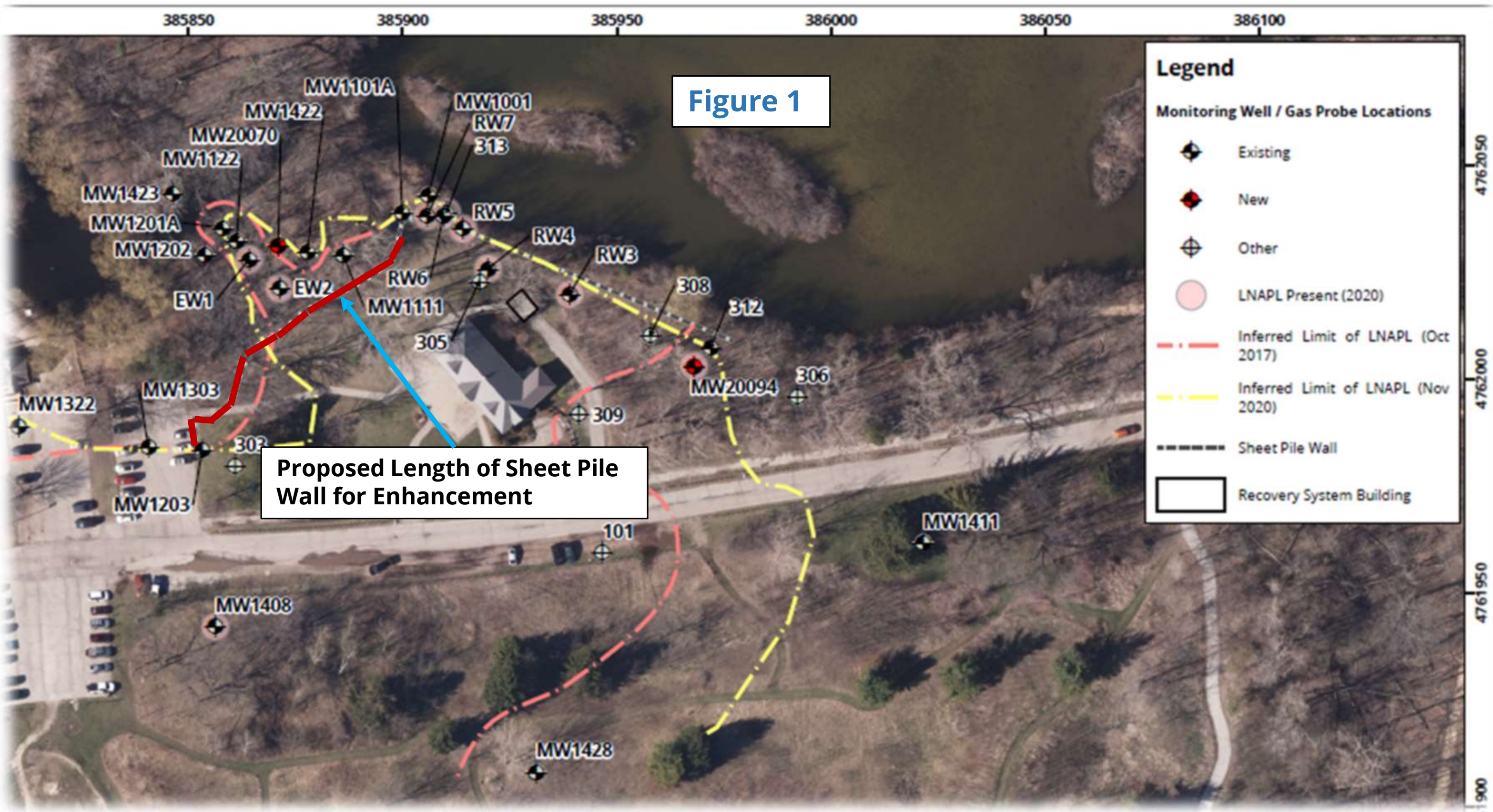

Figure 1
385850
385900
385950
386000
386050
386100
4762050
4762000
4761950
Legend
Monitoring Well / Gas Probe Locations
Existing
New
Other
LNAPL Present (2020)
Inferred Limit of LNAPL (Oct 2017)
Inferred Limit of LNAPL (Nov 2020)
Sheet Pile Wall
Recovery System Building
Proposed Length of Sheet Pile Wall for Enhancement
MW1101A
MW1422
MW20070
MW1122
MW1423
MW1201A
MW1202
EW1
EW2
MW1001
RW7
313
RW5
RW4
RW3
RW6
MW1111
305
308
312
MW20094
306
309
MW1303
MW1322
303
MW1203
101
MW1411
MW1408
MW1428