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Re: Remedial Options Evaluation #1
CLC Area – Former Michigan Avenue Landfill, Sarnia, Ontario
RWDI Reference No. 1801685

BACKGROUND AND INTRODUCTION

The CLC 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 associated with subsurface light non-aqueous phase liquid (LNAPL) in proximity to residential buildings along Ernest Street within the neighbouring municipality of the Village of Point Edward, ON. The CLC Area sits within a historical landfill and was reportedly subject to disposal of oily clayey soil waste between the 1920s and 1940s along a former rail spur that ran along the southwestern edge of the FMAL. Previous LNAPL delineation work completed in 2011 and 2014 did not confirm the presence of LNAPL within the specified limit of nearby residential buildings. However, follow-up investigations conducted in 2020 using LIF technology indicated the presence of subsurface LNAPL approximately 6.5 m of a neighbouring residence located at 720 Ernest St., in Point Edward, ON. The currently approved Trigger and Contingency Plan (T&C Plan, *Golder & Associates, 2015*) for the CLC Area of the FMAL designates a 5 metre (m) buffer distance from the western property boundary, whereby the presence of *floating product* in this buffer area would trigger the requirement to implement contingency measures and/or remedial action within a 12-month period.

The 2020 LIF and subsurface characterization investigations determined a specific sub-area of concern within the CLC Area related to the presence of subsurface LNAPL near the residence at 720 Ernest Street. The inferred LNAPL limit indicates that this plume finger moved approximately 25 m westward compared to its interpreted position in 2014 and places the current plume edge approximately 6.5 m of the FMAL's western property boundary. South-southeast of this plume finger, over a length of approximately 150 m following the curvature of the former rail spur and current walking path, the LNAPL plume edge moved towards the west in sporadic finger extensions measuring between 5 to 10 m on average from its previously interpreted 2014 limit.

The previously interpreted LNAPL limit was inferred to be along the eastern side of the historical rail spur, now a walking trail. 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 many possible contributors toward the subsurface movement of LNAPL free-product (i.e. liquid phase of LNAPL). These elevated groundwater levels may have introduced the mobile floating LNAPL components to the high porosity and permeability of the track ballast beneath the walking path which would provide a preferential flow path along and across the ballast in the direction of the above-noted residences in Point Edward. There are currently no containment/preventative control or remedial measures in place in the CLC Area.

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 the CLC Area lies greater than 120 m from Lake Chipican, review and approval of remedial measures by the SCRCA should not be required.

Recent Data Collection

In 2020 a site-wide LIF survey was conducted at the FMAL to refine, delineate, and update the extent of the LNAPL plume. The methodology and results of this survey 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 also impacts 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 thickness in comparison to the free-phase component of the LNAPL LIF borehole profile. The LIF survey also indicated the presence of multiple LNAPLs in the CLC Area, including diesel or weathered gasoline, highly weathered fuels / mixtures, and heavy ended oil products, as interpreted from the LIF signal logs.

Confirmatory subsurface soil sampling was conducted in the CLC Area following the LIF survey with sampling boreholes installed adjacent to nine LIF borehole locations. Soil samples were analyzed for benzene, toluene, ethylbenzene, and xylene (BTEX), petroleum hydrocarbon (PHC) fraction F1, and

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[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.

polycyclic aromatic hydrocarbons (PAHs) to correlate soil quality with LNAPL presence or absence. Additional soil samples were collected and analyzed following the installation of two gas probes (GP20149 and GP20150) in the CLC Area. At one of the soil sampling locations, the soil displayed a distinct sheen and hydrocarbon odour, but laboratory analytical results indicated negligible hydrocarbon concentrations. This was interpreted to potentially be due to the highly weathered nature of the LNAPL products.

Historically, combustible gas monitoring has been conducted at the seven FMAL boundary locations. Two supplementary soil gas monitoring probes were installed within the CLC Area near the interpreted leading edge of the inferred LNAPL plume as recommended by the Ministry of Environment, Conservation and Parks (MECP) in its Memorandum dated May 21, 2020. These combustible gas monitoring locations are used to evaluate for the presence of potential combustible gases and volatile organic compound (VOC) vapours in the vadose zone that could pose a risk to nearby residences and enclosures. Weekly field measurements for combustible gases and soil VOC vapour concentrations Since July 2020 have been below instrument detection at the new probe locations. The absence of VOC vapour readings within locations which have shown visual indications of oily product impacts was interpreted to indicate that the LNAPL present in the area does not readily volatilize.

A door-to-door groundwater supply and/or residential sand point well survey is being completed for residences within a 250 m buffer distance from the FMAL, in order to evaluate whether potential offsite pumping is drawing the LNAPL plume towards the nearby residences.

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), 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.

CLC Area – Sub-Area Concerns

This ROE focuses on a sub-area of the CLC Area, which entails a small area of approximately 60 square metres (m^2) interpreted to be impacted by subsurface LNAPL and is near the residence along Ernest Street, in the Village of Point Edward.

Concern 1: LNAPL free-product (plus potential vapour and dissolved phases) in close proximity to FMAL property boundary and off-site residential home (720 Ernest Street).

Concern 2: Continued movement of plume towards the western FMAL property boundary and residence located at 720 Ernest Street.

CLC Area – Sub-Area Remediation Objectives/Goals

A remedial objective and their associated goals are set for each listed concern to select specifically targeted and appropriate remedial technologies for the sub-area of the CLC Area. 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 the remedial technology.

CLC Area Sub-Area Concern	LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Potential Performance Metric
Concern 1	- Remediate area of concern to alleviate concerns around LNAPL movement towards FMAL property line (including vapour and dissolved phases where appropriate), with emphasis on the sub-area of detected subsurface LNAPL within 6.5 m of the residential property located at 720 Ernest Street.	- Soil, water, vapour emissions within regulatory/TC Plan limits, within some specified distance to FMAL western property boundary.	LNAPL mass recovery	- LNAPL saturation profile - LIF signal < 5 % RE - Cost per unit LNAPL recovered
Concern 2	- Prevent further LNAPL movement towards FMAL western property boundary (including vapour and dissolved phases where appropriate)	- Contain existing LNAPL source within some specified distance to FMAL western property boundary	LNAPL mass control	- No leakage through barrier
			LNAPL mass recovery	- No movement beyond point of recovery - Total system recovery rate vs. background LNAPL influx

CLC 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 CLC Area of the FMAL and their respective remedial objectives/goals.

Concern 1: LNAPL free-product (plus potential vapour and dissolved phases) in close proximity to FMAL western property boundary and residential home (720 Ernest Street).

- **Objective:** Remediate sub-area of concern near the residence on Ernest Street to alleviate concerns around LNAPL movement approaching the FMAL's western property boundary (including vapour and dissolved phases where appropriate)

Goal	Technology Option	Description	Pros	Cons
- **Soil, water, vapour emissions within regulatory/TC Plan limits, within some specified distance to FMAL's western property boundary**	Excavation (Following the installation of the sheet pile barrier wall)	LNAPL is removed from subsurface by total material removal	- Only option that can remove 100% of LNAPL - Applicable in all soil types/geology - Applicable in saturated and unsaturated zone - Very-short time frame	- Substantial construction activity (noise, public concern) - Large amount of contaminated material generated (disposal) - Can require dewatering (disposal) - Potential sudden increase in volatilized compounds when disturbing the subsurface (regulatory exceedances, safety)

The identified subsurface LNAPL finger that is interpreted to be extending towards the residence at 720 Ernest Street represents the most pressing concern in the CLC Area. Excavation is the only remediation technology evaluated that can remove 100% of the LNAPL contaminants, including the vapour and dissolved phases. If 100% removal of subsurface LNAPL is not the goal for this sub-area of the CLC Area, other technologies could be considered.

Some additional considerations for the use of this technology/technique are the following:

- The cost of the program is related to the size of the proposed excavation area
- Excavation could be limited to LNAPL finger only (approximately 60 square metre (m^2) area) – *See* **Figure 1** for details.
- Excavation and replacement of contaminated soil from this location prior to addressing upgradient contaminants could be redundant as new soil fill may become contaminated before further remediation measures are in place. As such, temporary barriers may be installed at the excavation limits.
- A residential garden shed is currently built over the property line which may impede excavation.
- Dewatering may be required to access immobile LNAPL-impacted soil beneath the groundwater table.

Concern 2: Continued movement of LNAPL towards the property boundary and residence at 720 Ernest Street.

- **Objective:** Prevent further LNAPL movement towards the FMAL's western property boundary (including vapour and dissolved phases where appropriate) near the residence located at 720 Ernest Street.

Goal	Technology Option	Description	Pros	Cons
- **Contain existing LNAPL plume within some specified distance to FMAL property boundary**	Sheet Piling Barrier	Hydraulic barrier contains groundwater by the installation of vertical steel strips into the soil, forming a "wall"	- Minimal waste disposal - Highly impermeable if sealed well (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
	Slurry Cut-off Wall	Installation of subsurface "wall" made of cement, bentonite, soil mixtures	- Can be installed quickly and to significant depths - Additives like plastics, ash, furnace slag, and clay can be incorporated to significantly reduce wall degradation - Inexpensive and accessible	- Installation produces substantial waste material - Wetting/drying and freeze/thaw can lead to cracking and leakage - Can be difficult to achieve sufficiently low permeability (cement bentonite mix)
	In Situ Soil Mixing	Subsurface barrier is mixed in-place by mechanical methods and heavy equipment	- Minimal to no waste disposal - Safer installation than traditional slurry walls	- Difficult to ensure continuity - Contaminated soil is incorporated into wall (potential leaching)

Goal	Technology Option	Description	Pros	Cons
	Composite Cut-off Walls	Installation of geomembrane liner into slurry trench	- Highly impermeable (more than traditional slurry wall) - Greater resistance to chemical attack - Not susceptible to wetting/drying or freeze/thaw - Can incorporate free product collection system (drainage trench) - Long term stability of geomembrane materials	- Can be very expensive - Installation depth is limited - Very slow installation

Following excavation and soil replacement activities, a limited monitoring program may be established to monitor the effectiveness of remedial measures near the excavation area. Existing monitoring wells may be utilized to evaluate liquid level and groundwater quality data. This monitoring effort will consider aspects of evaluating the natural source zone depletion (NSZD) capabilities of the native soils as detailed in the following section.

Each technology listed above could provide the means to inhibit LNAPL migration towards the west in the CLC Area, so selecting the remedial technology must consider the installation location. For example, the granular bedding material of former rail spur ballast represents an additional complication to the remedial approach as it likely facilitates a more rapid means for LNAPL transport across and along the former rail spur and now walking trail than the native soil.

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

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 CLC 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.

The CLC Area within the FMAL contains several LNAPL impacted areas of concern where NSZD may provide some understanding of the contaminant's evolution since the disposal of oily waste between the 1920s and 1940s. In particular, 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 which occurred within this area and will likely continue to occur. Measurement of site-specific NSZD rates can be conducted using various field and analytical 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 CLC Area, provided that further movement towards the property boundary is limited and that the residual LNAPL and its vapour and dissolved components do not pose a risk to nearby structures and human health.

Data Required for Proposed Remedial Options

Technology	Site Specific Data Needed	Additional Considerations	Long term
Excavation	- Access to site - Location of buried utilities and infrastructure - Groundwater table depth - LNAPL zone depth, thickness, and extent	- Soil type - Excavation volume - Hazardous vs non-hazardous contaminated soil characterization for disposal options (i.e. toxicity characteristic leachate procedure (TCLP)) - Soil quality verification at extent of excavation - Installation of impermeable barrier at excavation boundaries - Dust control for trucking routes	- Recovery vs cost
Containment (Sheet Pile Barrier, Slurry Cut-off Wall, Composite Cut-off Wall)	- 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 - Noise attenuation (metal pile driving) - Vibration (metal pile driving) - Excavated waste soil/impacted soils (slurry wall)	- Recovery vs cost
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 CLC Area may be a combination of a barrier wall to preclude the further migration of the LNAPL source in waste mound, followed by excavation of LNAPL-impacted soils to alleviate the immediate concern with the approaching LNAPL finger plume near the residential property located at 720 Ernest Street, and establishing a monitoring program that will monitor the natural attenuation capability of the native soils (i.e. NSZD). LNAPL in the CLC Area is interpreted to have migrated westward partly due to rising groundwater levels in the waste mound. The rising shallow groundwater table may have driven the LNAPL plume vertically upward to an elevation that is near the buried rail ballast stone layer of the former rail spur (that is currently a paved walking trail), which, due to its expectedly more permeable nature than the native silty sand, may have facilitated an increase in lateral migration rate westward toward the property boundary.

To address the potential for further migration of LNAPL toward the residence located at 720 Ernest Street, a sheet pile barrier wall is proposed to be installed on the non-landfill side of the existing walking trail. The installation is proposed to consist of advancing 4.6 m (15-foot) long sheet pile walls to near existing grade such that floating LNAPL can not migrate above the sheet pile walls when groundwater levels are at their historical peak elevation and can not migrate beneath the sheet pile walls based on historically low groundwater elevations observed within nearby monitoring wells, which are typically less than 3 m below grade. Moreover, the sheet pile barrier walls will be sealed at the joints to further preclude the lateral movement of groundwater and LNAPL toward the west. The sheet pile barrier wall is proposed to be installed starting from approximately 6 m NE of the NE corner of the north-most garden shed of the residence located at 720 Ernest Street. The sheet pile barrier wall will then extend southeastward for approximately 20 m and follow along the curvature of the former rail spur.

Following the installation of the sheet pile barrier wall, an excavation remediation program will be undertaken near the residence located at 720 Ernest Street. The proposed excavation will extend eastward from the inferred western extent of the LNAPL finger plume up to the sheet pile barrier wall. The excavation will continue northward and southward until there is no longer any evidence of LNAPL in the subsurface based initially on visual and olfactory field observations, as well as sporadically selected areas for soil quality verification laboratory testing. Dewatering efforts may be necessary to achieve full removal of LNAPL-impacted soils that may be trapped in the soil below the groundwater table. Dewatering efforts may require special permitting depending on field observations and an assessment of disposal options for excavation waters. A falling head test may be required to determine the anticipated dewatering requirements during excavation activities based on the calculated range of the soil permeability.

Prior to initiating excavation activities, a soil characterization laboratory assessment will be required for the LNAPL-impacted soil, such as the TCLP, to determine final disposal options.

Following the completion of the excavation activities near the resident located at 720 Ernest Street, 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.

Costing Estimate

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
Excavation and Removal (~3 days)	$22,400 Excavate and remove approximately 60 m^3 or approximately 120 metric tonnes of LNAPL-impacted soils. Soil laboratory testing for disposal options and soil quality verification sampling of excavation sidewalls and floor Backfill with imported material	$9,950	$32,350

NSZD (ongoing)	$14,600 (installation of estimated 3 new groundwater and gas monitoring locations, etc.)	$9,800 (program setup, evaluation of existing monitoring infrastructure) $7,700 (Ongoing monitoring efforts including laboratory testing and field investigations (presumed to be semi-annually), reporting)	$24,400 - initially (+ $7,700 annually thereafter)

The costing estimate is provided below for reference. It should be noted that although the preferred approach described above is being proposed for the CLC Area, modifications to the proposed approach may change based on consultation with the City of Sarnia and the MECP. Unknown field conditions may warrant project modifications and budgetary adjustments. As such, the costing below represents best case scenario application of the proposed remedial approach to the CLC Area's sub-area near the residence located at 720 Ernest Street.

Given the above-noted estimates, an initial evaluation of costing is a ballpark estimate of **$97,650** with an estimated $7,700 annually required to monitor the natural attenuation capabilities of the native soils in the CLC Area following the installation of the sheet pile barrier wall. 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 further field investigative efforts to determine specific soil and LNAPL physical properties.

FUTURE CONSIDERATIONS

The CLC Area consists of a much larger expanse than the above-described sub-area near the residence located at 720 Ernest Street. The remainder of the CLC Area does not currently require remedial measures based on the T&C Plan. However, the City understands that the LNAPL has migrated further westward and appears to be approaching the residential development adjacent to the FMAL. As such, the City proposes to plan for the future by exploring preventative measures that would safeguard the public and the environment. As such and similar to above, this section will focus on potential future remedial and/or preventative measures that are currently being considered for the remainder of the CLC

Area. These future remedial measures would be implemented in consideration of MECP and City consultation prior to implementation.

Concern: LNAPL free-product (plus potential vapour and dissolved phases) on western side of the former rail spur.

CLC Area Concern	LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Potential Performance Metric
- **Remove/recover/ naturally abate subsurface LNAPL to alleviate concerns around LNAPL movement towards FMAL western property boundary (including vapour and dissolved phases where appropriate).**	- Recover LNAPL to "maximum extent practicable" (MEP) - Abate further LNAPL body migration by physical removal of <u>mobile</u> LNAPL - If needed, further remediate phreatic smear and residual LNAPL Assess the natural attenuation capability of the native soils and monitor changes of LNAPL concentrations over time	LNAPL mass recovery or phase change	- LNAPL saturation profile - LIF signal < 5 % RE - Reduced LNAPL presence in monitoring wells and subsurface - Soil gas profiling - Sustained effective NSZD rates - Cost per unit LNAPL recovered	- Remove/recover/ naturally abate subsurface LNAPL to alleviate concerns around LNAPL movement towards FMAL western property boundary (including vapour and dissolved phases where appropriate).

Remedial and/or Preventative Measures Discussion

The inferred LNAPL plume edge on the western side of the former rail spur, excluding the extended inferred plume edge near the residence located at 720 Ernest Street, appears to be generally greater than 20 m from any residential dwellings. The inferred LNAPL western extend in the CLC Area could become a greater concern if continued plume migration occurs in the direction of these residences. As such, precluding LNAPL migration further westward is necessary, which could be achieved by the remedial technologies previously discussed herein. Except for complete site excavation, the other remedial options rely on reducing the mobility of LNAPL, either by physical removal or phase change and subsequent removal, to prevent further migration. These latter options then will necessarily leave some component of LNAPL in the soil, in the form of residual saturation (non-mobile product), and dissolved phases.

Excavation is the only method that could remove all LNAPL components, however it would generate substantial waste material with an estimated 3,000 metric tonnes of impacted soil, assuming an area of approximately 15 m x 200 m in area and approximately a 1 m vertical extent of impacted soil for disposal and may be better suited to remove localized areas of contamination that exceed regulatory limits near residential dwellings. Moreover, this estimate assumes the excavation area would extend eastward from the inferred limit of the LNAPL plume up to the western edge of the existing former rail spur trail.

A dual pump liquid extraction and multi-phase extraction (DPLE + MPE) system would require the installation of extraction wells along the length of the LNAPL plume in the CLC Area, with spacing and ROI dictated by subsurface geological conditions. The MPE enhancement is not necessary for mitigating plume migration, as DPLE will reduce the LNAPL saturation and limit plume mobility on its own, but the vacuum removal of the volatilized components can further reduce LNAPL saturation and vapour phases.

Air sparging and soil vapour extraction (AS/SVE) when used in combination can remove LNAPL from above and below the groundwater table. Both processes function by volatilizing LNAPL and enabling remediation without pumping any water. The additional of oxygen in the injected air can further enhance aerobic biodegradation in the subsurface. The injection of gas into the subsurface may require additional permitting, however the necessity of high-pressure pipe systems may cause the most concern for residents in this park environment.

In addition to these more practical approaches, several other injection and capture technologies where evaluated as part of this ROE, such as, but not necessarily limited to the following.

- Heated Water Flooding, which involves the injection of hot water into the subsurface to decrease the viscosity and interfacial tension of the LNAPL to increase capture
- Surfactant Enhanced Subsurface Remediation (SESR), which uses a surfactant to increase the solubility of LNAPL and increase capture
- Cosolvent Flushing, which involves the injection of solvents like alcohols to solubilize and mobilize LNAPL to increase capture
- Enhanced biodegradation whereby subsurface conditions are enhanced through the insertion of electron acceptors such as oxygen, nitrate, or sulfate, that would increase the rate of natural biodegradation
- In-situ combustion/smoldering uses the energy inherent to the contaminant (in this case LNAPL) to fuel the process once the contaminant is ignited. The process is sustained by the addition of air through a well to the target treatment zone.

The above-noted technologies require the installation of networks of injection and capture wells in the direction of groundwater flow to function properly. Since the LNAPL plume is substantially longer than it is wider these technologies did not appear to provide significant added benefits over DPLE.

Other potential technologies and/or remedial approaches that could be considered may include, but not necessarily be limited to, the following.

- **Phytotechnology**: Using plants/trees to contain and breakdown contaminants within the subsurface via the root zone. Some trees such as ash, alder, willow, and poplar can be utilized toward the phytoremediation of subsurface LNAPL.
- **In-situ Soil Mixing**: Mechanical mixing of soils with low-permeability materials such as clays, reactive media such as chemical oxidants or electron acceptors, or stabilizing media such as Portland cement.

Preferred Approach

The CLC Area may continue to be subject to LNAPL migration from the FMAL for the foreseeable future due to the inferred extent of the contaminated material disposed in the waste mound. Due to the interpreted large quantity of LNAPL contaminants, the proposed solution is to cut-off any further migration towards the residential dwellings and properties to the west. Several technologies are outlined herein, which serve this goal by the installation of a physical barrier, however, each of these solutions will have an impact on the local shallow groundwater flow regime. Thus, care must be taken such that the selected technology needs to consider the installation location characteristics.

Any potential future need for extending the sheet pile barrier wall system would be to connect to the sheet pile barrier wall length (20 m) proposed to be installed in the sub-area of the CLC Area. The sheet pile barrier wall could be extended southward up to approximately the intersection of Front Street and Victoria Street, as well as northward from the sub-area sheet pile barrier wall toward the northeast, across the walking trail and approximately 30 m east of the walking path.

As the LNAPL migration appears to be limited within the CLC Area south of the residence located at 720 Ernest Street, a monitoring program would be recommended to be implemented to monitor the effectiveness of the sheet pile barrier wall system and evaluate the NSZD capacity of the native soils on the residual LNAPL. The proposed sheet pile barrier wall system installation is depicted in **Figure 1** for reference.

Costing efforts to extend the sheet pile barrier wall system and implement enhancements to the current monitoring program would be presented to the City separately.

CLOSING

The CLC Area of the FMAL presents a complex assortment of LNAPL concerns, which may each require individual remediation measures or a hybrid approach of several methods. In terms of priorities, the inferred plume edge near the residential property located at 720 Ernest Street is foremost, however remediating this area prior to cutting-off the source of LNAPL from the landfill may cause repeated contamination if the groundwater table is high again this year.

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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Some Additional Materials

Geo-solutions. *Composite Systems*. https://www.geo-solutions.com/services/bio-polymer-trenches/composite-systems/

Vertex Environmental Inc. *Multiphase Extraction*. https://vertexenvironmental.ca/project/multiphase-extraction/

Waterloo Barrier Inc. *Waterloo Barrier Groundwater Containment Wall*. http://www.waterloo-barrier.com/

FIGURE

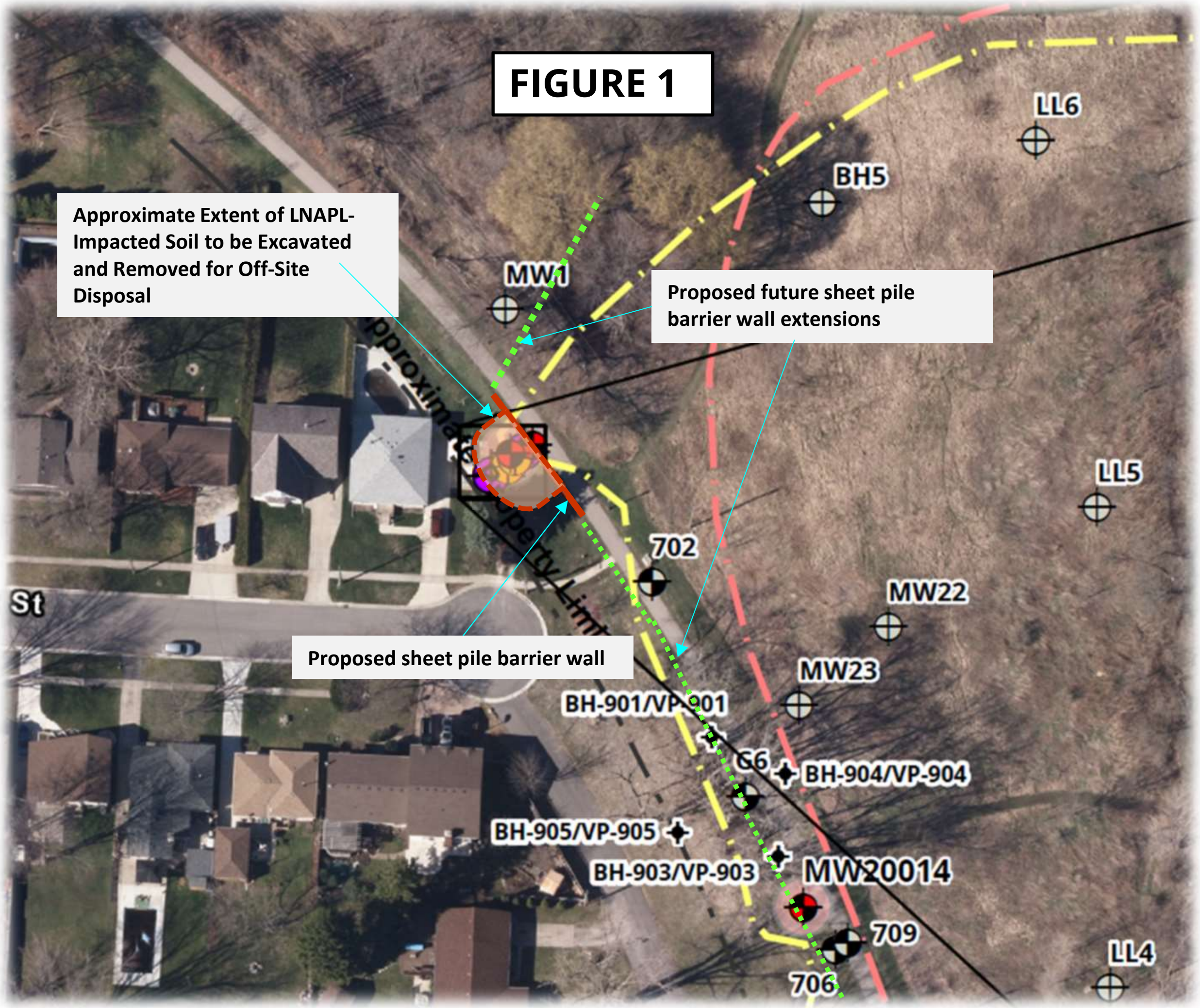
FIGURE 1
Approximate Extent of LNAPL-Impacted Soil to be Excavated and Removed for Off-Site Disposal
Proposed future sheet pile barrier wall extensions
Proposed sheet pile barrier wall
LL6
BH5
MW1
LL5
702
MW22
MW23
BH-901/VP-901
G6
BH-904/VP-904
BH-905/VP-905
BH-903/VP-903
MW20014
709
706
LL4
St