600 Southgate Drive
Guelph ON Canada
N1G 4P6

Tel: +1.519.823.1311
Fax: +1.519.823.1316
E-mail: solutions@rwdi.com

September 21, 2021

Joe Boothe
City of Sarnia
255 Christina Street
Sarnia, ON N7T 7N2
E: Joe.Boothe@sarnia.ca

Re: Remedial Options Evaluation #3
G2 Area – Former Michigan Avenue Landfill, Sarnia, Ontario
RWDI Reference No. 1801685

BACKGROUND AND INTRODUCTION

The G2 Area within the Former Michigan Avenue Landfill (FMAL) located in Sarnia, Ontario, has been identified as requiring further investigation as it relates to concerns with subsurface light non-aqueous phase liquid (LNAPL) in proximity to the existing sheet piling barrier wall and potential impacts to subsurface utility corridors including the roadside municipal stormwater catch basin system along Michigan Avenue. The G2 Area sits to the south of a historical landfill (*see* **Figure 1**) near an area that 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 identified that the inferred limit of the LNAPL plume in the G2 Area was mostly limited to being upgradient of the sheet piling wall that was installed near the property boundary, north of Michigan Avenue, in 2000.

However, follow-up investigations conducted in 2020 using laser-induced fluorescence (LIF) technology indicated that the oily product plume front appeared to be present in the area east and north of the sheet-pile barrier wall limit, in an area where LNAPL had not previously been identified. The currently approved Trigger and Contingency Plan (T&C Plan, *Golder & Associates, 2015*) for the G2 Area of the FMAL designates the presence of sheen or floating oil confirmed to have originated from the FMAL in either of the two (2) stormwater catch basins (currently named 'East' and 'West') along Michigan Avenue would trigger the requirement to prepare a remedial action plan (RAP). The RAP would outline measures to prevent the floating oil of the FMAL from entering the municipal storm sewer.

Floating oil and/or sheen was not observed within the catch basins upstream and downstream of monitoring wells with known LNAPL detections in the G2 Area in 2020, and no sheen has been detected in either catch basin since July 2017. Moreover, the July 2017 occurrence of floating oil and sheen within the western catch basin appeared to have been a one-time event as observations prior to, and following, the 2017 event, did not confirm the presence of FMAL-generated floating oil or sheen. In addition, laboratory analytical testing for polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons (PHCs), as well as benzene, toluene, ethylbenzene, and xylenes (BTEX), completed for a sample collected from the west catch basin in 2017, indicated constituent concentrations that were below the laboratory reportable detection limits (RDLs). As such, the July 2017 floating oil and sheen was interpreted to have not originated from the FMAL and contingency measures were not required to be implemented.

In 2020, a LIF and subsurface soil characterization investigation determined a sub-area within the G2 Area related to the presence of LNAPL-impacted soil where LNAPL had not previously been observed. This occurrence was also noted by the MECP in a memorandum dated March 4, 2021, as a risk for potential future off-site LNAPL migration. The inferred LNAPL limit that was interpreted based on the 2020 investigations, indicates that the LNAPL plume is present in an area approximately 75 metres (m) east of the previously inferred limit (2011/2014) and places the current plume edge outside of the existing sheet pile barrier wall limit. It should be noted that, in 2020, floating product was observed in the newly installed monitoring well MW20174, however, it was absent in MW1431, MW1433, G4, and MW20170, which are in the vicinity of the 2020 inferred LNAPL limit. A historical report entitled: "*2014 Light Non-Aqueous Phase Liquid (LNAPL) Investigation - Remedial Action Plan – Addendum #2 Results - Lake Chipican and G2 Areas Former Michigan Avenue Landfill Sarnia, Ontario"*, dated April 2015, suggests that LIF boreholes where not advanced as far eastward and northward as the 2020 LIF in the G2 Area (*see* **Figure 2**) where the 2020 follow up was conducted. LNAPL impacts may have already been present in this area considering the slow rate of groundwater and LNAPL movement within the silty clay soil in this area of the FMAL.

The previously interpreted LNAPL plume limit was inferred to track north to south between monitoring well MW1402 and 606 on its western limit to the western edge of the existing sheet pile barrier wall, then following eastward along the length of the sheet pile barrier wall up to approximately monitoring well 804 before tracking northward again. 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). A component of a 1980 Report entitled: "*Industrial Waste Site Identification Study for Southwestern Region Ministry of the Environment*", prepared by Proctor & Redfern, denotes that "*Imperial Oil allegedly disposed of oil saturated clay in low flat areas along the railroad track and towards Kendall Street",* and that "*…the Ministry of the Environment has received complaints of illegal dumping of… oils… on property near Kendall Street*". This could be interpreted as the reason for oil-stained clayey soils identified within the G2 Area during recent drilling activities.

The existing containment/preventative controls and remedial measures in the G2 area include the above-mentioned sheet pile barrier wall, which was installed in 2000, along with two (2) recovery wells, namely RW1 and RW2, which were installed immediately north of the sheet pile barrier wall. In 2002 recovery well RW1A was installed at the eastern limit of the exiting sheet pile barrier wall. To remove oil, two (2) nominal 50 millimetre (mm) automatic top inlet, positive air displacement pumps were installed in the recovery wells of the G2 Area in 2003. In January 2017, new selective oil skimmer (SOS) pumps were installed in recovery wells RW1A and RW2 to replace the previous pumps. These pumps were installed as "skimmer pumps" to recover oil product floating on the groundwater table (i.e., they are not intended to depress the water table to collect floating oil). Since 2003, one (1) pump has been operating exclusively within recovery well RW2 while the second pump is typically installed and operating within RW1A. If required, or on an as-needed basis, recovery well RW1 may be commissioned for future oil recovery activities.

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 G2 Area lies greater than 120 m from Lake Chipican, review and approval of remedial measures by the SCRCA is not 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 G2 Area, including highly weathered fuels / mixtures, or heavy ended oil products, as interpreted from the LIF signal logs. The LIF investigation was not completed south of the sheet pile barrier wall due to the presence of an unlocatable utility.

Confirmatory subsurface soil sampling was conducted in the G2 Area following the LIF survey with sampling boreholes advanced at four (4) LIF borehole locations namely LIF20168 (becoming borehole BH20168), LIF 20170 (becoming monitoring well MW20170), LIF20174 (becoming monitoring well MW20174), and LIF20187 (becoming borehole BH20187). These boreholes and monitoring well locations were advanced/installed in proximity to the 2020 inferred limit of the LNAPL plume edge. Soil samples were analyzed for benzene, toluene, ethylbenzene, and xylene (BTEX), petroleum hydrocarbon (PHC) fraction F1, and polycyclic aromatic hydrocarbons (PAHs) to correlate soil quality with LNAPL presence or absence. The analytical results indicate that constituent concentrations within the soil at the tested locations were above their respective Table 3 criteria of the MECP Standards for PHC fractions F2 to F4, with a PHC F1 exceedance noted at BH20168. Ethylbenzene and total xylenes concentrations were also above their respective Table 3 criteria at the location of BH20168. A sheen was observed within the saturated zone of the soil core retrieved at the location of MW20174. Hydrocarbon staining and odours were noted within the soil at the locations of MW20170, MW20174, and BH20187. There were no staining, sheens, or hydrocarbon odours noted within the soil at the location of BH20168.

[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.

Historically, combustible gas monitoring has been conducted at the seven FMAL boundary locations, two (2) of which are in the G2 Area at subsurface combustible gas monitoring locations G4 and 602. These combustible gas monitoring locations are used to evaluate for the presence of potential combustible gases in the vadose zone that could pose a risk to nearby structures and enclosures. Quarterly field measurements up until 2016 and bi-annual field measurements thereafter for combustible gases have been below instrument detection at the monitoring locations since 2012.

In 2020, test pits were manually advanced in the Lake Chipican Area of the FMAL to visually assess the condition of the sheet pile barrier walls to evaluate whether the sheet pile joints were noticeably sealed with grout and, if not, whether these unsealed joints are allowing floating oily product to migrate through the sheet pile barrier wall. Soil conditions were also inspected for residual staining caused by oily product. The test pitting investigation indicated that the sheet pile barrier walls were not sealed at the joints. Moreover, evidence of oily product migrating through the sheet pile barrier wall joints was noted at one test pit location. The sheet pile barrier wall in the G2 Area was not investigated with manually advanced excavations based on the anticipated product and groundwater levels to be located approximately 1.7 to 2.2 m below ground surface (mBGS). As such, heavy equipment (i.e., vacuum truck) may be needed to excavate and expose the sheet pile barrier wall in the G2 Area. However, given the observations made in the Lake Chipican Area, and the timeline to which both sheet pile barriers walls were installed (early 2000's), the sheet pile barrier wall in the G2 Area is anticipated to have been installed in a similar configuration with unsealed joints.

Based on the 2020 and historical monitoring results for the monitoring wells located downgradient of the sheet pile barrier wall in the G2 Area, LNAPL migration through the potentially unsealed joints does not appear to be occurring at this time. Migration from the area of monitoring wells 801and 803, on the western side of the sheet pile barrier wall, toward Michigan Avenue also does not appear to be occurring based on the monitoring results for monitoring wells 202, 613, and 804, as there has not been LNAPL detections at these monitoring locations.

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 FMAL.

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.
- Removal of impacted soils beyond the inferred limit of the landfill footprint.

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. The ITRC framework provides a systematic approach in selecting appropriate remedial technologies for specific site concerns and remedial goals. The focus of this ROE is determining the effectiveness of the existing sheet piling barrier wall and preventing the off-site migration of floating oily product.

G2 Area Concerns

This ROE focuses on the G2 Area, which entails an area of approximately 0.65 hectares, interpreted to be impacted by subsurface LNAPL, located on the north side of Michigan Avenue and west of Front Street in the Village of Point Edward.

Concern 1: The existing sheet pile barrier wall in the G2 Area was installed around the same time as the sheet pile barrier wall in the Lake Chipican Area. A recent investigation of the Lake Chipicanj's early installation of a portion of the existing sheet pile barrier wall revealed that the joints between sheet pilings were not grouted at the time of installation and may be allowing LNAPL to move through. Given the observations made in the Lake Chipican Area, the sheet pile barrier wall in the G2 Area is anticipated to have been installed with unsealed joints as well, which presents a potential pathway for LNAPL to migrate towards the FMAL property boundary.

Concern 2: The 2020 LIF and subsurface characterization investigations indicated that the LNAPL plume front appeared to be present in the area east and north 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, MW20174, which sits in proximity to the recently inferred/updated plume front. As such, the MECP has raised concerns that the newly identified potential plume front beyond the existing engineering controls in the G2 Area represents a risk for potential future off-site migration.

G2 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 G2 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.

G2 Area Concern	LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Potential Performance Metric
Concern 1	- Investigate sheet pile barrier wall joints and, if necessary, prevent LNAPL movement through unsealed joints	- Contain LNAPL on up-gradient side of sheet piling in consideration of historical low and high groundwater levels	LNAPL mass control	- No leakage through barrier
Concern 2	- Prevent future LNAPL movement towards the southern property boundary along Michigan Avenue 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 the existing sheet pile barrier wall	LNAPL mass control	- No leakage through barrier
			LNAPL mass recovery	- No movement beyond point of recovery - Total system recovery rate vs. background LNAPL influx

G2 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 G2 Area of the FMAL and their respective remedial objectives/goals.

Concern 1: The existing sheet pile barrier wall in the G2 Area may have been installed without grouting/sealing the joints, which would present a potential pathway for LNAPL to migrate through the wall and towards the FMAL property boundary.

- **Objective:** Investigate sheet pile barrier wall joints and, if necessary, enhance the protective nature of the barrier to prevent LNAPL movement through unsealed joints.

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 of the existing steel sheet pile barrier wall to enhance the wall's impermeability. The sheet pile would require to be temporarily exposed to install the bentonite membrane.	- Lowers existing walls' permeability - Majority, if not entirety, of excavated material will be backfilled (little waste) if mechanical soil removal is selected	- Cost - Requires excavation to exposed portions of the sheet piling wall (in sections) - May require dewatering during installation - Management of liquid soils if excavation is completed using vacuum trucks

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 can 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. Given the observations made in the Lake Chipican Area and the timing of each of the Lake Chipician and G2 Area installations, the sheet pile barrier wall in the G2 Area is anticipated to have also been installed with unsealed joints, which presents a potential pathway for LNAPL to migrate towards the FMAL property boundary along Michigan Avenue. To address these potential joint seeps, a type of GCL could be affixed to either side 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 3.**

Concern 2: The LNAPL plume front appears to be present in the area east and north of the existing sheet-pile barrier wall limit, where LNAPL has not previously been noted. Floating product was also observed in a newly installed monitoring well, MW20174, which sits in proximity to the newly interpreted plume front. As such, the MECP has raised concerns that the newly identified potential plume front beyond the existing engineering controls in the G2 Area represents a risk for potential future off-site migration.

- **Objective:** Prevent future LNAPL movement towards the southern property boundary along Michigan Avenue 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 plume front within some specified distance to FMAL southern 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 (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)

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)**	Active LNAPL skimming	Install additional recovery wells east of the existing sheet pile barrier wall along interpreted LNAPL plume edge	- Could be connected to existing extraction infrastructure - Decreases mobility of LNAPL - Lower cost compared to other extraction technologies - "Visible action" towards site remediation	- 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)
	Phytoremediation (rhizodegradation, hydraulic control)	A variety of plant options can be evaluated for contaminant uptake, degradation, and hydraulic control	- Can remediate some contaminants at lower cost compared to other technologies - Plants which uptake large amounts of water can reduce the migration of contaminated groundwater - Disposal of "harvested" plant material is significantly less intensive than large scale excavations	- Does not show obvious "visible action" towards remediation - Presence of NAPL can decrease effectiveness of approach - Long time frames - Influenced by seasonality

On the eastern edge of the existing sheet pile barrier wall, floating oily product was observed at several locations beyond the current extent of the sheet pile barrier wall, including recovery well RW1A, and monitoring wells 803 and MW20174. 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 barrier wall in a sinuous (wavey) manner towards monitoring well MW20170. The MECP has identified this area as a concern for potential future off-site LNAPL migration. The implementation of each of the technologies listed in the table above could help prevent future off-site migration.

Use of Natural Source Zone Depletion Assessment on G2 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 G2 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 G2 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. In addition, 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 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 changes in groundwater indicator parameter geochemistry.

Given NSZDs potential contribution to LNAPL remediation, this strategy may be worth investigating as a long-term remedial option in the G2 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
Containment (Enhanced Containment Barrier (using GCL) and 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) - Fastening method of membrane to sheet pile barrier walls - Stability of membrane placement over time - Excavated waste soil/impacted soils (slurry wall)	- Integrity of barrier wall
Phytoremediation	- Soil type, structure, fertility, compaction, etc. - Plant growing zones - Depth of plume - Maximum plume concentrations - Proximity to sensitive utilities	- Root zone and penetration of selected plants - May require fertilization because of microbial competition - General landscaping maintenance and maintain aesthetic appeal of the Park	- Effectiveness of hydraulic barrier
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 G2 Area may be a combination of barrier wall retrofitting measures and wall extension to preclude the further migration of LNAPL towards the FMAL property boundary along Michigan Avenue and allowing the existing passive skimmers to continue to recover floating LNAPL over time. An additional dual-purpose monitoring and passive skimming sentry well may also be installed near the barrier wall extension such that the well could be outfitted with an additional passive skimmer based on monitoring findings.

The absence of floating product within several monitoring wells situated between the 2020 LNAPL inferred limit and Michigan Avenue, as well as the lack of floating oil and/or sheen in the monitoring catch basins along Michigan Avenue suggests that active migration towards the FMAL property boundary in the G2 area is not occurring.

However, as mentioned above, the sheet pile barrier wall within the G2 area may have been installed without sealing the joints and could therefore present a potential pathway for LNAPL migration towards the property boundary. As such, following the sheet pile investigation within the G2 area, depending on the findings, a GCL is proposed to be affixed to the landfill side 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 an enhanced hydraulic barrier toward LNAPL migration. This installation would involve the excavation of soils along the sheet pile barrier 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 by the GCL to laterally migrate. As such, dewatering efforts to be able to affix the GCLs below the groundwater table may be required.

To address the potential for future migration of LNAPL towards the FMAL boundary from the area where the recent LIF investigation identified the inferred LNAPL plume edge, a sheet pile barrier wall is proposed to be installed and connected to the existing sheet pile wall. 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 mBGS. Moreover, the sheet pile barrier walls will be sealed at the joints to further preclude the lateral movement of groundwater and LNAPL toward Michigan Avenue. The sheet pile barrier wall is proposed to be installed starting from the eastern edge of the existing sheet pile barrier wall and will then extend eastward for approximately 20 m and run parallel to Michigan Avenue. See **Figure 3** for layout details.

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.

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 G2 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 in the G2 Area. Given the above-noted estimates, an initial evaluation of costing is a ballpark estimate of **$105,600** with an estimated $7,700 annually required to monitor the natural attenuation capabilities of the native soils in the G2 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.

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
Sheet Pile Waterproofing (~3 days)	<u>Install GCL (assume only 1 side of sheet pile barrier wall)</u> $30,520 Approximately 30 m of wall to expose approximately 1.8 m below surface. Affix GCL to sheet pile Approximately 30 m of wall (*See* **Figure 3**), 3 m deep sheet piles, 2 m of GCL. Bentonite geotextile attached to plywood boards anchored to sheet pile wall. Backfill void between sheet piles and plywood, or similar method.	$9,780 (project supervision and support)	$40,300
NSZD (ongoing)	$14,600 (installation of estimated 3 new groundwater and vapour 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 presented herein is a ballpark estimate and may be adjusted based on further field investigative efforts to determine specific soil and LNAPL physical properties. Dewatering efforts, if required, could significantly inflate the overall costing of the remedial measures as this would require continuous pumping of liquids, temporary site storage, liquid characterization, and final disposal and management efforts.

FUTURE CONSIDERATIONS

The G2 Area consists of a larger expanse than the above-described sub-area near the existing and proposed extension of the sheet pile barrier wall. The remainder of the G2 Area does not currently require remedial measures based on the T&C Plan. However, the City understands that the LNAPL is present in the subsurface beyond the eastern extent of the sheet pile barrier wall where it has not been previously observed, representing a future potential for offsite migration. As such, the City proposes to plan for the future by exploring preventative measures that would safeguard the public and the environment at this location. 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 G2 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) beyond the beyond the eastern and northern extent of the existing and proposed extension of the sheet pile barrier wall extension.

G2 Area Concern	LNAPL Remedial Objective	LNAPL Remedial Goal	Technology Group	Potential Performance Metric
	- Recover LNAPL to "maximum extent practicable" (MEP) - Abate further LNAPL body migration by physical removal of mobile 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	- Remove/recover/naturally abate subsurface LNAPL to alleviate concerns around LNAPL movement towards FMAL southern property boundary (including vapour and dissolved phases where appropriate)	LNAPL mass recovery or phase change	- Cost per unit LNAPL recovered - LNAPL saturation profile - LIF signal < 5 % RE - Reduced LNAPL presence in monitoring wells and subsurface - Soil gas profiling - Sustained effective NSZD rates

Remedial and/or Preventative Measures Discussion

Within the G2 Area, the inferred LNAPL plume edge trends along the existing barrier wall and extends parallel to the wall and trends 20 m farther east, and then beyond this point, the inferred plume edge is situated approximately a minimum of 20 m closer (further north) to the FMAL waste footprint and farther away from Michigan Avenue (the FMAL property boundary). Additionally, beyond the western edge of the barrier wall the LNAPL has migrated from the FMAL waste footprint, but the plume edge is approximately 10 m to 15 m closer to the FMAL than the southern position of the sheet pile barrier wall.

The existing sheet pile barrier wall, and the extension of the wall earlier proposed in this ROE will serve to prevent the further southward migration of LNAPL in the sub-area of the G2 Area where the inferred LNAPL plume edge is in closest proximity to the FMAL property boundary. The inferred LNAPL extent in the G2 Area beyond the edge of the existing and proposed extension of the barrier wall could become a greater concern if continued plume migration occurs away from the FMAL waste to the southern position of the sheet pile barrier wall. As such, precluding LNAPL migration further southward may become necessary in the future, which could be achieved by the remedial technologies previously discussed herein.

If deemed necessary, based on future assessment findings, further extension of the above-discussed sheet pile barrier wall coupled with additional dual-purpose monitoring and passive skimming sentry wells would prevent the offsite migration of the LNAPL plume and could be incorporated into the existing remedial infrastructure of the G2 Area.

Excavation is the only method that could remove all LNAPL components, however it would generate a substantial amount of material for disposal with an estimated 15,000 to 18,000 metric tonnes of impacted soil, assuming an area of approximately 150 m x 60 m in area and approximately a 1 m vertical extent of impacted soil for disposal. Moreover, this estimate assumes the excavation area would extend northward from the inferred limit of the LNAPL plume towards the FMAL.

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 G2 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.

Preferred Approach

The G2 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 FMAL property boundary to the south. 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 (technologies) 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 G2 Area. The sheet pile barrier wall could be extended eastward approximately 80 m, as well as northwestward from the sheet pile barrier wall toward Front Street approximately 20 m. The proposed sheet pile barrier wall system installation is depicted in **Figure 3** for reference.

The 2020 LIF investigation identified the presence of LNAPL to the east and north of the existing sheet pile barrier wall in an area where it had not previously been identified. As such, 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. Part of this monitoring program would include a follow up LIF investigation in the G2 area approximately 3 years following the installation of engineering controls to evaluate the LNAPL plume front evolution.

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 G2 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 waterproofing of the existing sheet pile barrier wall is foremost, however, investigating the current condition of the sheet pile joints would precede this remedial measure.

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., G.I.T.
Scientist – Geoscience

Phil Janisse, B.Sc., P.Geo., QP_{ESA}
Senior Geoscience Specialist

Brent J. Langille, B.Sc., P.Geo., QP_{ESA}
Strategic Director | Principal

BJL/PEJ/DVSG

Attach.

REFERENCES

Newell, C. J., Acree, S. D., Ross, R. R., Huling, S. G. 1995. *Light nonaqueous phase liquids*. United States Environmental Protection Agency, Office of Research and Development,[and] Office of Solid Waste and Emergency Response.

Fisheries and Oceans Canada. 2020. *Historical Monthly Mean Water Levels from the Coordinated network for each of the Great Lakes.* https://waterlevels.gc.ca/C&A/historical-eng.html

ITRC (Interstate Technology & Regulatory Council). 2009. *Evaluating LNAPL Remedial Technologies for Achieving Project Goals*. LNAPL-2. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPLs Team. www.itrcweb.org.

ITRC (Interstate Technology & Regulatory Council). 2018. *LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies*. LNAPL-3. Washington, D.C.: Interstate Technology & Regulatory Council. LNAPL Update Team. https://lnapl-3.itrcweb.org.

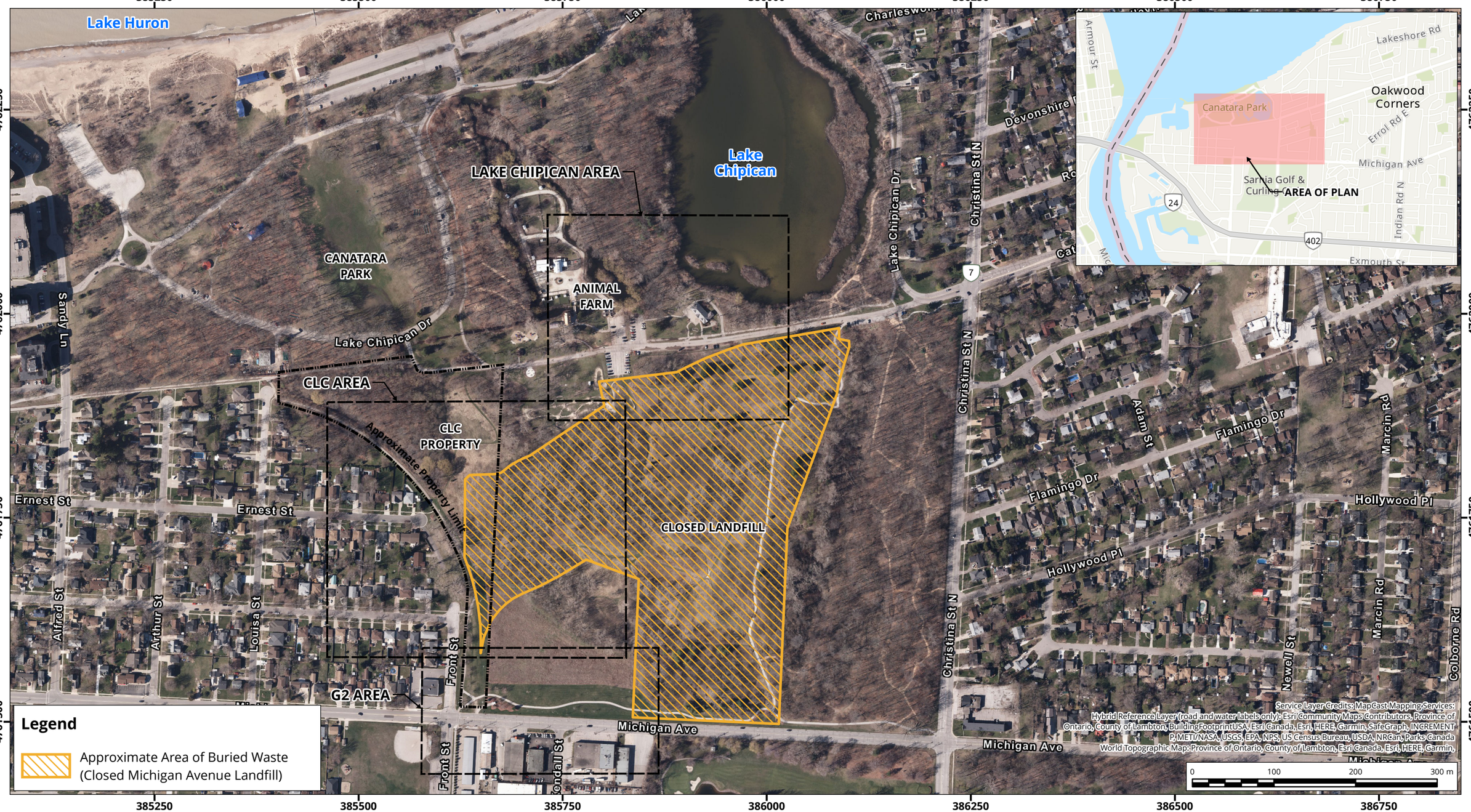
Some Additional Materials

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/

FIGURES



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

Area Location Plan

Former Michigan Avenue Landfill, Point Edward, Ontario

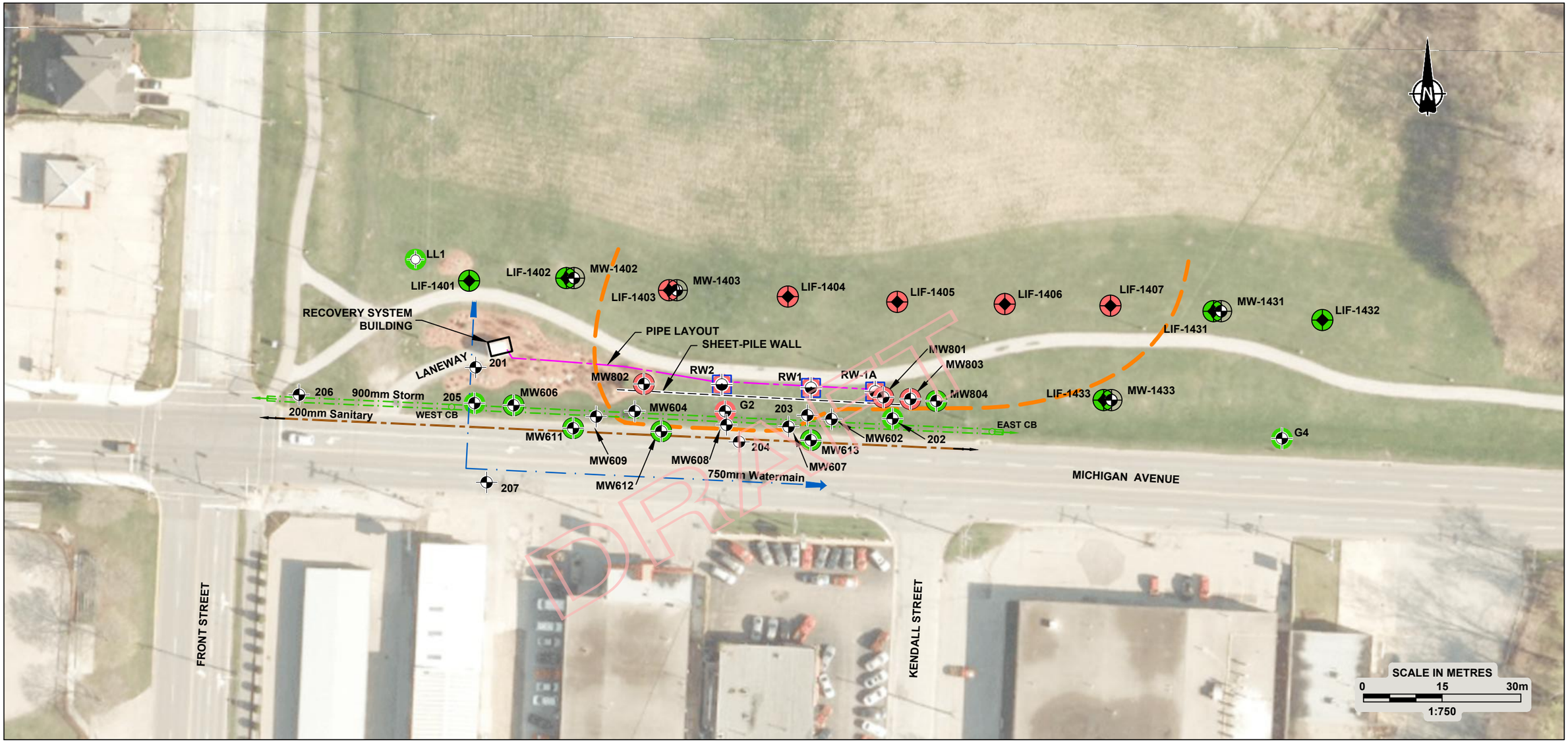
Map Projection:
City of Sarnia

Notes:
1. Drawing based on 2017 aerial image from First Base Solutions Web Mapping Service.
2. This drawing is schematic only and is to be read in conjunction with accompanying text.
3. All locations are approximate.

True North

Project #: 1801685

Drawn by:	DJH	Figure:	1
Approx. Scale:			1:4,500
Date Revised:			Sep 9, 2021



LEGEND

- 2014 LIF LOCATIONS
- 2014 MONITORING WELL
- MONITORING WELL
- MONITORING WELL (BY OTHERS)
- RECOVERY WELL
- WELL HEAD BOX
- NO LNAPL DETECTED (LIF OR MONITORING WELL DATA)
- LNAPL DETECTED (LIF, BOREHOLE OBSERVATIONS OR MONITORING WELL DATA)
- INFERRED LIMIT OF LNAPL (FEBRUARY 2015)
- 750mm WATERMAIN
- 900mm STORM SEWER
- 200mm SANITARY SEWER

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.

FOR LOCATION OF PLAN, REFER TO FIGURE 1.

PROJECT
2014 LIF INVESTIGATION
FORMER MICHIGAN AVENUE LANDFILL
SARNIA, ONTARIO

TITLE
LNAPL DELINEATION (G2 AREA)

Golder Associates
LONDON, ONTARIO

PROJECT No. 07-1135-029-0			FILE No. 0711350290-R09006
			SCALE AS SHOWN REV.
CADD	DCH/LMK	Mar. 31/15	
CHECK			

FIGURE 6

RWDI REFERENCE FIGURE 2

Drawing file: 0711350290-R09006.dwg Mar 31, 2015 - 11:00am

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:	3
Approx. Scale:			1:800
Date Revised:			Sep 9, 2021

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