Memo

SUBJECT
Summary of LNAPL Conditions at RACER Buick City Site

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DEPARTMENT
Environment

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Introduction

On behalf of RACER Trust, Arcadis of Michigan, LLC (Arcadis) has prepared this memo to present a summary of the current understanding of LNAPL conditions in the subsurface and the recommended path forward for areas where light non-aqueous phase liquid (LNAPL) remains at the Buick City Site (Site) in Flint, Michigan (**Figure 1**). The summary for each of the identified LNAPL areas relies on both historically and recently conducted investigations, presented within the context of industry best-practice guidance for LNAPL site management issued by the Interstate Technology and Regulatory Council (ITRC), as well as the recently published guidance released by the Michigan Department of Environment, Great Lakes, and Energy (EGLE) in 2023, titled *Non-Aqueous Phase Liquid – Petroleum Releases: Characterization, Remediation, and Management Guidance* (EGLE, 2023). The results of prior investigations related to the delineation of LNAPL and LNAPL recoverability, as well as the interim measures and remedial actions implemented in each of the LNAPL areas have been documented in a series of reports periodically submitted to EGLE. The results and conclusions presented in those reports, with a focus on those prepared since the submittal of the RACER Buick City Remedy Recommendation Report (RRR) (Arcadis, 2014 – updated 2016), were considered during preparation of this summary document. These include *Summary of LNAPL Recoverability Assessment Results* (February 14, 2023) (Arcadis, 2023a) and *LNAPL Pilot Recovery System Assessment Summary* (June 15, 2023) (Arcadis, 2023b).

The intent of this document is to provide a summary of the LNAPL Site activities for each identified areas to date, including the known estimated extent of LNAPL based on previous efforts to delineate both residual and mobile LNAPL mass, including a combination of information from soil borings (i.e. jar tests, staining), monitoring wells, and laser-induced fluorescence surveys[1] (**Attachment 1**). A summary of information on the potential recoverability of the remaining mobile portion of the LNAPL mass in the subsurface is also presented. Further, updates to concepts presented in the previously mentioned guidance documents related to LNAPL (e.g. residual, mobile, and migrating LNAPL, LNAPL fluctuations over time, and LNAPL recoverability) have also been included to provide insight into the decision-making process for recommended next steps and management approach, as well as to better understand any perceived changes in observed LNAPL behavior over time[2].

[1] See, summary memo with attached elevation table, entitled "Method to Determine Horizontal and Vertical Extent of Residual LNAPL Impacts (2/9/24)"

[2] For example, there are no known sources of continued LNAPL releases since about 2010. Consequently, given the intervening 14 years any LNAPL in the vadose zone would be considered "residual LNAPL". See, Non-*Aqueous Phase Liquid – Petroleum Releases: Characterization, Remediation, and Management Guidance* (EGLE, 2023)

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Current LNAPL Site Management and Conceptual Site Model Guidance

A comprehensive understanding of LNAPL in the subsurface uses multiple lines of evidence (MLE) to determine LNAPL mobility and the potential for LNAPL migration, as well as the potential for beneficial LNAPL recovery in areas where mobile LNAPL is present. Historically, the following MLE have been the primary datasets used to assess LNAPL mobility and recoverability at the Site:

- Soil boring installation and field characterization (e.g. jar tests, staining)
- Laser-induced fluorescence (LIF) investigation
- LNAPL observations in monitoring wells
- LNAPL transmissivity testing
- Active and manual LNAPL recovery efforts

These complimentary lines of evidence have an inherent logic used to determine whether or not LNAPL is immobile (in a residual state), mobile (capable of accumulating in a well), or migrating (expanding the known LNAPL footprint). The following sections describe the current EGLE regulatory and industry best-practice guidance for each of the primary lines of evidence used to assess LNAPL at the Site. A summary of the LNAPL conceptual Site model (CSM) for each area is provided in **Table 1**. Development of the LNAPL CSM for the Site is based on the guidance provided in **Attachment 2** – LNAPL Remedial Decision Tree – LNAPL Conceptual Site Model.

LNAPL Mobility Guidance

ITRC and EGLE identify three different conditions that characterize the potential for LNAPL movement in the subsurface (ITRC, 2009). EGLE definitions are presented below (EGLE, 2023):

- Residual LNAPL: occurs when the saturation is sufficiently low so that LNAPL occupies a fraction of pore spaces and is often discontinuous, resulting in the inability for the LNAPL to flow under the conditions during time of observation.
- Mobile LNAPL: when LNAPL is present and is at a high enough saturation to be hydraulically interconnected in the soil or aquifer pore spaces that it has the ability to flow. LNAPL that accumulates in a properly constructed well is considered mobile NAPL. The presence of LNAPL in a well, however, does not necessarily mean that the LNAPL body is migrating.
- Migrating LNAPL: LNAPL is considered to be migrating when the overall NAPL body footprint is expanding; in other words, NAPL is observed to spread or expand laterally (most common) or vertically. For the LNAPL to expand its footprint, two conditions must be present: 1) The LNAPL is of sufficient saturation that it is mobile, and 2) There is a driving force “pushing” the LNAPL body. Generally, once the release has stopped, the migration of LNAPL continues for a short duration and is a self-limiting process.

For the majority of the remaining LNAPL areas at the Site, a combination of both residual and mobile LNAPL is present. Previously conducted investigations have identified the extent of LNAPL in these areas through multiple lines of evidence, including field characterization, laboratory analysis or soil samples, and LIF investigation.

However, it is important to note that all detections of LNAPL are not indicative of potentially mobile or migrating LNAPL. The vertical distribution of LNAPL saturation over an impacted soil column varies with Site conditions, soil properties, LNAPL release history, and the LNAPL properties. In areas where shallow impacts have been noted in historically conducted investigations, the presence of mobile LNAPL is limited and most LNAPL is in a residual state.

LNAPL In-Well Thickness Fluctuations

EGLE guidance discusses fluctuations in LNAPL thickness and the mobile interval over which it is present, noting that observed variability can be the result of monitoring well screen placement and/or changes in the water table elevation (EGLE, 2023). The document also goes on to reference the ITRC, noting "…vertical re-distribution of NAPL with a rising or falling water table can result in the appearance of an increased (i.e., growing) or decreased (i.e., shrinking) footprint, or apparent lateral migration of NAPL that is not representative of actual conditions (ITRC, 2018)." Over time, a historical range in fluid elevations and corresponding LNAPL thickness is typically developed, which is representative of both high-water table conditions during times of increase precipitation or melting, and during times of drought or dry conditions when the groundwater elevation falls. Understanding these changing conditions helps explain the questions raised by EGLE in their November 3, 2023 *Response to EGLE Review of Infiltration Management and Generic LNAPL and PFAS Soil Management Plan* (see Item 18 of that letter) and Item 13 of EGLE's November 3, 2023 letter *Response to EGLE Review of "Draft Declaration of Restrictive Covenant and Supporting Exhibits".* The *Remedy Recommendations Report* (Arcadis, 2016) was prepared between 2014 and 2016 and represented conditions observed at the time. As noted above in the ITRC guidance document (ITRC, 2018), apparent changes in LNAPL conditions can occur over time due to fluctuating water tables, thus Site conditions from nearly 10 years ago would not necessarily be representative of current Site conditions. For, example as reported in Arcadis 2016 transmissivity testing conducted in 2011-2012 identified potentially recoverable LNAPL at five locations. Transmissivity testing conducted in 2022 identified only two locations with potentially recoverable LNAPL. Subsequent LNAPL removal efforts indicated essentially no success with LNAPL removal (Arcadis, 2023a and Arcadis, 2023b).

A comparison of corrected groundwater elevation and measured LNAPL thickness can be examined for trends in groundwater elevation and LNAPL thickness to determine if LNAPL is potentially migrating when temporal fluid level gauging indicates the following:

- Clear trend of increasing thickness of LNAPL in monitoring wells through time that is not attributable to seasonal water table fluctuations. No such trend in the data is apparent.
- Advancement of LNAPL across a portion of the monitoring well network previously lacking measurable LNAPL, suggesting that the LNAPL zone is expanding in that area.

While the measurable LNAPL thicknesses in wells has fluctuated over time with changes in groundwater elevation, the presence or absence of LNAPL in a well based on fluctuating groundwater elevations does not indicate migrating LNAPL (EGLE, 2023). LNAPL mobility at the pore-scale is dependent on the presence of a sufficient driving head and hydraulic gradient. Therefore, accumulation of LNAPL in monitoring wells is not a stand-alone indicator of LNAPL mobility. The stable, though fluctuating, LNAPL accumulation in historical monitoring wells within the footprint of the known extent of the existing plumes is a strong indication that the plumes are stable. To date, periodic monitoring of LNAPL plumes at the Site based on the presence or absence of LNAPL in monitoring wells indicates that none of the LNAPL plumes are migrating.

LNAPL Recoverability

The physical presence of LNAPL in the environment is not always a reliable predictor of potentially successful or practicable LNAPL recoverability. The recoverability of LNAPL is influenced by many factors, including LNAPL saturation in the impacted soil, soil permeability, and physical properties of the LNAPL. Testing of LNAPL transmissivity has been historically completed to assess the potential recoverability of the remaining mobile LNAPL at the Site. Transmissivity represents the volumetric rate of LNAPL flow through a unit width of porous media per unit time, under a unit hydraulic gradient. A direct mathematical relationship exists between LNAPL transmissivity and the rate of LNAPL flow into a well; therefore, it is an ideal parameter for assessing LNAPL recoverability. LNAPL transmissivity calculations inherently account for the combined effects of aquifer matrix permeability, LNAPL physical properties, and the relative proportion of pore space occupied by LNAPL within a specified vertical interval of aquifer material.

The 2023 EGLE LNAPL Guidance Document (EGLE, 2023) further describes LNAPL transmissivity testing and assessing potential recoverability in detail, within the context of reaching remedial or practicability endpoints. For example, the document references the ITRC (2018) document, which states that “Reaching a recoverability limit does not mean all NAPL is removed or that NAPL saturations are reduced to residual saturations (mobile NAPL will likely still exist), but it does typically represent an endpoint where the majority of remaining NAPL is of limited mobility”. Further, EGLE guidance also is clear in stating that “If there are no unacceptable risks associated with mobile NAPL, there are no statutory requirements for mobile NAPL recovery….” The language then goes on to say “…scientific studies, experience, and risk assessments have shown that there are cases where all NAPL cannot be recovered and there are instances where no recovery is necessary if all current and future risks are addressed or controlled.”

Given the history of investigation and remedial measures implemented at the Site, the risks associated with the remaining LNAPL in place in many of the LNAPL areas have been identified, and 1) No Further Action has been recommended or 2) the LNAPL plume has been mitigated through remedial actions/interim measures. These are summarized in **Table 1**. Based on LNAPL recoverability tests, LNAPL Areas 3 and 8 were determined to have potentially recoverable LNAPL. Accordingly, recoverability pilot tests were conducted at these two LNAPL areas (Arcadis, 2023b). The tests indicated that LNAPL was not practically recoverable in either area. These tests are discussed further below.

LNAPL Area Summaries

The following presents a brief summary of each of the identified 14 LNAPL areas at the Site. **Figure 2** shows the locations of the LNAPL areas on Site. Historical remedial activities related to each of the LNAPL areas are presented on **Table 1**. **Table 1** was developed based on information provided in the RRR (Arcadis, 2014 – updated 2016) and subsequent activities conducted in 2017, 2018, and 2022, to address the remaining risks associated with the remaining LNAPL in place. The areas have been the subject of extensive investigation and remedial activities over time, including but not limited to soil and LIF investigations, long term groundwater monitoring, fluid level gauging, LNAPL transmissivity testing, and natural source zone depletion (NSZD) assessment. In addition, remedy implementation of physical LNAPL removal (i.e. pumping and skimming, etc.), and bench scale testing of surfactant enhanced recovery, thermally enhanced recovery, and in-situ chemical oxidation have also been conducted (RRR, Arcadis, 2016) (Arcadis, 2023b). None of these potential remedies were pursued due to the lack of success in the bench scale testing. Managing LNAPL at each area was determined by understanding its CSM (**Attachment 2**).

LNAPL Area 1 – AOI Area 36-1/36-2

The RRR concluded that LNAPL in the northwestern portion of the LNAPL area was not practicably recoverable, and that recovery efforts would not result in a significant reduction in LNAPL mass or exposure risk. However, the LNAPL is mobile and at the time was infiltrating the Outfall 004 storm sewer. As a result, multiple interim measures were completed to address the LNAPL in the area. These included operation of an LNAPL recovery system (no longer operating), an LNAPL recovery trench, and additional manual recovery by General Motors. RACER eliminated the storm sewer pathway through bulkheading of the Outfall 002 storm sewer, and recovery trench monitoring. In addition, a pilot test for a multi-phase extraction system was completed but ultimately not recommended as a final remedy.

LNAPL Area 2 – AOI Area 36-5

The RRR concluded that LNAPL that had been managed as potentially recoverable, was to be transitioned to institutional controls following 20 years of recovery efforts, though multiple interim measures were completed to address the LNAPL in the area prior to institutional control implementation. These included years of LNAPL recovery from passive recovery trenches and recovery wells, and targeted excavation of impacted materials by General Motors. The Outfall 002 storm sewer was bulkheaded by RACER, thus eliminating the outfall pathway. Current LNAPL mobility conditions include both residual and mobile LNAPL within a stable LNAPL body.

LNAPL transmissivity testing was not performed in this area as LNAPL presence was insufficient to initiate a test. As a result, the current recommendation for the area is no further action at this time. The remaining LNAPL is to be managed in place with NSZD. Implementation of institutional controls for this area remains in progress.

LNAPL Area 3 – AOI Area 10-1/10-4

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL is mobile and at the time was infiltrating the Outfall 003 storm sewer and was also determined to be recoverable based on transmissivity testing results. To address the LNAPL, multiple interim measures were completed to address the LNAPL in the area. These included source area excavation LNAPL recovery from both a trench and manual efforts by General Motors, and the Outfall 003 storm sewer reroute, which eliminated the pathway, and surface cover maintenance.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 4.15 ft^2/day (20-FP8-4), exceeding the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. In response, follow-up skimming was conducted at well 20-FP8-4 in 2023 and the results were summarized in the June 15, 2023 *LNAPL Pilot Recovery System Assessment* (Arcadis, 2023). No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 4 – AOI Area 03-1

The RRR concluded that LNAPL was stable and not migrating and had been partially addressed through previously conducted remedial efforts by General Motors, which were focused in the suspected source area. As the recovery sump results were considered successful, no additional remedies were implemented.

LNAPL transmissivity testing performed most recently in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity value of 0.31 ft^2/day (03-03-R2), which is below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. As a result, no further action is recommended. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 5 and 6 – AOI Area 05-1/05-5

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL at the time was infiltrating the Outfall 004 storm sewer. Additionally, historic investigations and assessment suggested LNAPL was recoverable. As a result, General Motors completed multiple interim measures to address the LNAPL in the area. These included years of LNAPL recovery from passive recovery trenches and recovery wells, outfall pathway elimination, and targeted excavation of impacted materials.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 0.14 ft^2/day (TW-DH-RW-02-07), well below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. The current recommendation for the area is no further action at this time due to low LNAPL transmissivity results. Implementation of institutional controls for this area remains in progress.

LNAPL Area 7 – AOI Area 81-2

The RRR concluded that LNAPL was stable and not migrating. An LNAPL recovery system consisting of a recovery trench and well operated in this area by General Motors for 17 years prior to the issuance of the RRR has already been completed. Therefore, partial and effective LNAPL recovery

LNAPL transmissivity testing was performed most recently in 2022 to determine the potential recoverability of the remaining mass in place. The resulting transmissivity values ranged from 0.04 to 0.80 ft^2/day, which are below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. As a result, no further action is recommended. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 8 – AOI Area 86-1

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL is mobile and at the time was infiltrating the Outfall 004 storm sewer. As a result, multiple interim measures were completed to address the LNAPL in the area. These included bulkheading and rerouting the Outfall 004 storm sewer into the Outfall 013 storm sewer.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 1.42 ft^2/day (RFI-86-03), exceeding the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. In response, follow-up skimming was conducted at this well (Arcadis, 2023a). Skimming activities were performed in this well in 2023 and the results are summarized in the June 15, 2023 report *LNAPL Pilot Recovery System Assessment* (Arcadis, 2023b). No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 9 – AOI Area 83/84-4

The RRR concluded that LNAPL was stable and not migrating but was potentially recoverable LNAPL recoverability testing resulted in LNAPL transmissivity below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. LNAPL in this area exists in both the residual and mobile state but is not readily recoverable.

The current recommendation for the area is no further action at this time due to low LNAPL transmissivity result. The remaining LNAPL is to be managed in place with NSZD. Implementation of institutional controls for this area remains in progress.

LNAPL Area 10 – AOI Area 83/84-2 and 83/84-5

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL is mobile and was determined to be recoverable. Historical interim measures to address the LNAPL including a product recovery well installed by General Motors, LNAPL bailing and bulkheads installed by RACER in the Outfall 003 and 005 storm sewers to eliminate the storm sewer pathway, and surface cover maintenance.

LNAPL transmissivity testing performed most recently in 2022 to determine the potential recoverability of the remaining mass in place and resulted in transmissivity values ranging from 0.03 to 0.33 ft^2/day, which are below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. As a result, no further action is recommended. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 11 – AOI Area 83/84-1

Mobile LNAPL was originally identified on site prompting consideration of a passive recovery trench. Monitoring data identified LNAPL in Outfall 004 storm sewer which resulted in an interim measure to eliminate the storm sewer as a pathway. The RRR concluded that the remaining LNAPL was stable and not migrating. Furthermore, LNAPL transmissivity tests performed in 2013 indicated that the LNAPL was not readily recoverable.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 0.07 ft^2/day (MW-83/84-15R), well below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 12 – AOI Area 12-A, 12-B, 12-C

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL is mobile and in 2016 was infiltrating the Outfall 004 storm sewer. As a result, multiple interim measures were completed to address the LNAPL in the area. These include maintaining a surface cover, and outfall pathway elimination through the installation of bulkheads in the Outfall 004 storm sewer system.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 0.06 ft^2/day (RFI-12-23), which is well below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 13 – AOI Area 02-B

The RRR concluded that LNAPL was stable and not migrating. However, the LNAPL is mobile and at the time of the submittal of the RRR was infiltrating the Outfall 006 storm sewer. As a result, bulkheading was completed by General Motors to eliminate the pathway for LNAPL to the Flint River.

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 0.50 ft^2/day (RFI-02-19), which is below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

LNAPL Area 14 – AOI Area 40-A, 40-B, 16-C

The RRR concluded that LNAPL was stable, not migrating, and not infiltrating the Outfall 009 and 010 storm sewers. LNAPL transmissivity tests performed at this LNAPL for the RRR indicated showed results indicating both potential recoverable and non-recoverable LNAPL. Institutional controls were instituted. In addition, several technologies were evaluated for the RRR at bench scale and found to be potentially feasible; however, the results were limited to the former tunnel area within the LNAPL area...

LNAPL transmissivity testing performed in 2022 to determine the potential recoverability of the remaining mass in place resulted in a transmissivity of 0.08 ft^2/day (RFI-40-14R), which is well below the criteria of 0.8 ft^2/day above which LNAPL recovery is potentially feasible. No further action is recommended due to low recovery rates and limited accumulation of LNAPL. Instead, the remaining LNAPL is recommended for management via NSZD and institutional controls. Implementation of institutional controls for this area remains in progress.

Conclusions

LNAPL on the Site has been characterized extensively based on several years of investigation. In addition, multiple bench and pilot scale tests have been performed, along with full scale remedies to address LNAPL impacts. The significant conclusions to date are enumerated below:

- LNAPL on Site is not migrating.
- LNAPL impacts are present in both the residual and mobile phases in the soil, and the presence of mobile LNAPL in wells, can vary over time due to seasonal fluctuations in groundwater elevation.
- Changes in LNAPL thickness and/or the depth from ground surface to the LNAPL is not an indication of a significant change in Site conditions or that LNAPL is migrating beyond the known footprint. In general, the LNAPL conceptual Site model for each area is consistent with the current understand of LNAPL mass distribution and mobility.

- Interim measures and remedial actions completed to date have sufficiently addressed the recoverable portion of the remaining mass in the subsurface such that the recommended path forward for all, but two areas rely on natural processes and institutional controls for ongoing management.
- At the two areas where additional recovery efforts were determined to be warranted based on the results of the LNAPL transmissivity testing, LNAPL recovery limited, consequently further attempts at recovery are not warranted. As such, LNAPL at these two areas will be managed moving forward by relying on natural processes and institutional controls.

References

Arcadis, 2016. Final Draft – RACER Buick City Remedy Recommendations Report. August 14, 2014 (Revised February 15, 2016).

Arcadis, 2023a. Summary of LNAPL Recoverability Assessment Results - RACER Trust, Buick City, Flint, Michigan, February 14, 2023.

Arcadis 2023b. LNAPL Pilot Recovery System Assessment Summary - RACER Trust, Buick City, Flint, Michigan, June 15, 2023.

Michigan Department of Environment, Great Lakes, and Energy, 2023. Non-aqueous Phase Liquid – Petroleum Releases – Characterization, Remediation, and Management Guidance. June 29, 2023.

Enclosures

Table 1 – Summary of LNAPL Areas, Recent Data Collection, and Recommendations

Figure 1 – Site Redevelopment Map

Figure 2 –LNAPL Restrictive Covenant Areas

Attachment 1 – Method to Determine Horizontal and Vertical Extent of Residual LNAPL Impacts

Attachment 2 – LNAPL Remedial Decision Tree – LNAPL Conceptual Site Model Development

Tables

Table 1. Summary of LNAPL Areas, Recent Data Collection, and Recommendations
RACER Buick City Site
Flint, Michigan.

LNAPL Area	AOI Area	2016 RRR Conclusions	2016 RRR - Completed Interim Measures and Recommended Remedies	2017 LNAPL Summary Memo Conclusions	Previous Transmissivity Estimates (date) *highest result if multiple areas	Scope of Work Completed in 2022	2022 Transmissivity Results	Current Recommendations	LNAPL Decision Tree Status*
1	36-1/36-2	LNAPL in northwestern portion of LNAPL area indicated recovery not practical. LNAPL recovery will not result in beneficial reduction in overall LNAPL mass or exposure risk.	1 - Factory 36 LNAPL recovery system along CSX property boundery **(IM completed)** 2 - Outfall 001 and 002 infiltration pathway elimination **(IM completed)** 3 - 002 recovery trench monitoring **(IM completed)** 4 - Multi-phase extraction system **(Pilot test completed, MPE not recommended)** 5 - Surface cover **(IM completed)** 6 - Institutional controls **(In progress)**	LNAPL not recoverable	36-FP7 - 0.2 ft^2/day (4/25/2013)	Gauged wells 36-FP7, RFI-36-07R, MW-36-42, MW-36-6 Baildown test at well MW-36-42	MW-36-42 - 0.02 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
2	36-5	LNAPL recovery system operated at plume for ~20 years; partial and effective LNAPL recovery already been completed and transition to institutional controls appropriate	1 - Tank farm (source area) excavated **(IM completed)** 2 - Passive recovery trenches ~20 years of LNAPL recovery **(IM completed)** 3 - Outfall 002 storm sewer bulkhead **(IM completed)** 4 - 002 passive recovery trench monitoring **(IM completed)** 5 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	2014 RRR - Transmissivity testing has not been completed as there is insufficient LNAPL present to conduct	None	None	No further action at this time; area is interpreted to be low-risk and further assessment is not worthwhile given access/feasibility constraints. If conditions change, consider follow-up monitoring to update data set.	LNAPL is either immobile or mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
3	10-1/10-4	LNAPL found to not be migrating, but mobile and infiltrating Outfall 003 storm sewer. Transmissivity testing at 20-FP7 indicated LNAPL recoverable, but recovery system operated at this plume for ~13 years with declining rate of success.	1 - ~13 years of LNAPL removal **(IM completed)** 2 - Storm sewer laterals bulkhead to eliminate LNAPL migration pathway **(IM completed)** 3 - Outfall 003 pathway elimination **(IM completed)** 4 - 003 recovery trench monitoring 5 - Target excavation **(IM completed)** 6 - Maintain surface cover **(IM completed)** 7 - Institutional controls **(In progress)**	LNAPL may be recoverable in Southern area, but not recoverable in Northern area and TW-10-08	20-FP7 - 1.0 ft^2/day (4/25/2013)	Gauged wells 20-FP7, 20-FP8, MW-10-12 Baildown test at well 20-FP8, MW-10-12	20-FP8- 4.15 ft^2/d MW-10-12 - NA	Conduct follow-up skimming at well 20-FP8. Following skimming at 20-FP8, no further action is recommended due to low recovery rates and limited accumulation of LNAPL.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
4	AOI 03-1	Historic IM addressed partial and effective LNAPL removal already completed.	1 - A recovery sump addressed the suspected source area for this plume **(IM completed)** 2 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	2014 RRR - Transmissivity testing has not been completed as there is insufficient LNAPL present to conduct	Gauged wells 03-03-R2, TW-03-03-2, TW-03-03-3 Baildown test at well 03-03-R2	03-03-R2 - 0.31 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
5 and 6	05-1/05-5	LNAPL found to not be migrating, but mobile and infiltrating Outfall 003 storm sewer. Historic IM's indicate past LNAPL has been recoverable.	1 - 15 years of LNAPL removal from passive recovery trenches at AOI 05-1 **(IM completed)** 2 - ~5 years of LNAPL removal from recovery wells at AOI 05-5 **(IM completed)** 3 - Outfall 003 pathway elimination **(IM completed)** 4 - Targeted excavation **(IM completed)**[1] 5 - Institutional controls **(In progress)**	LNAPL may be recoverable in AOI 05-5, DH-RW-1, DH-RW-2, and DH-RW-3, but not recoverable at AOI 05-1, Western area, and 43-165	TW-DH-RW-01-01 - 0.74 ft^2/day (11/1/2016) TW-DH-RW-03-36 - 0.76 ft^2/day (2/23/2016)	Gauged wells TW-05-05-01, TW-05-05-02, TW-43-165-7, TW-DH-RW-01-01, TW-DH-RW-02-07 Baildown test at well TW-DH-RW-02-07	TW-DH-RW-02-07 - 0.14 ft^2/d	No further action at this time due to low transmissivity result. Manage in place with NSZD. Note Area 5 not assessed as part of this evaluation; area is interpreted to be low-risk and further assessment not warranted.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
7	81-2	LNAPL found to not be migrating or infiltrating Outfall 003. LNAPL recovery system with passive recovery trench and well operated for ~17 years.	1 - Passive recovery trench ~17 years of LNAPL removal **(IM completed)** 2 - Targeted excavation **(Partially completed, IM being re-evaluated due to the presence of PFAS)**[1] 3 - Institutional controls **(In progress)**	LNAPL may be recoverable in 70-101 area, but not recoverable in 70-103 and 70-107R areas	TW-70-101-02 - 1.5 ft^2/day (11/1/2016)	Gauged wells TW-70-101-2, TW-70-101-7, TW-70-103-11, TW-70-107R, TW-70-107R-9 Baildown test at well TW-70-101-2, TW-70-101-7, TW-70-103-11, TW-70-107R, TW-70-107R-9	TW-70-101-2 - 0.04 ft^2/d TW-70-101-7 - 0.06 ft^2/d TW-70-103-11 - NA TW-70-107R - 0.80 ft^2/d TW-70-107R-9 - 0.25 ft^2/d	No further action at this time due to low transmissivity results; 107R result is above 0.5 ft^2/d but removal is not anticipated to have a significant effect on potential risk or to be cost-effective. Manage in place with NSZD.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
8	86-1	LNAPL found to not be migrating, but mobile and infiltrating Outfall 004 storm sewer.	1 - Tank farm (source area) excavated **(IM completed)** 2 - Two recovery wells ~5 years of LNAPL removal **(IM completed)** 3 - LNAPL bailing and monitoring ~4 years **(IM completed)** 4 - Outfall 004 infiltration pathway elimination **(IM completed)** 5 - 004 recovery trench monitoring **(IM completed)** 6 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	2014 RRR - Transmissivity testing has not been completed as there is insufficient LNAPL present to conduct	Gauged wells RFI-86-02, RFI-86-03 Baildown test at well RFI-86-03	RFI-86-03 - 1.42 ft^2/d	Conduct follow-up skimming at well RFI-86-03. Following skimming at RFI-86-03, no further action is recommended due to low recovery rates and limited accumulation of LNAPL.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
9	83/84-4	LNAPL is not migrating or readily recoverable.	1 - Institutional controls **(In progress)**	LNAPL not recoverable	RFI-83/84-07 - 0.03 ft^2/day (4/24/2013)	Gauged wells RFI-83/84-07, RFI-83/84-45	NA	No further action at this time due to low transmissivity results; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is either immobile or mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
10	83/84-2 and 83/84-5	**83/84-2** LNAPL may be recoverable in southern portion of plume. Outfall 003 and 005 bulkheaded in this portion of site so no mobility concerns. **83/84-5** LNAPL may be readily recoverable in portion of LNAPL area.	**AOI 83/84-2** 1 - Building 32 recovery well **(IM completed)** 2 - Bulkheaded sections of outfall 003 and 005 to eliminate GSI pathway **(IM completed)** 3 - Maintain surface cover to address particulate soil inhalation and direct contact in soil concerns **(IM Completed)** 4 - Targeted excavation of PCB impacts **(IM re-evaluated, recommendation eliminated)**[1] 5 - Institutional controls **(In progress)** **AOI 83/84-5** 1 - Storm sewer lateral bulkhead to eliminate LNAPL migration pathway **(IM completed)** 2 - LNAPL recovery **(Evaluated in 2022, recovery not feasible)**[1] 3 - Institutional controls **(In progress)**	**83/84-2** and **83/84-5** LNAPL may be recoverable	RFI-83/84-53 - 4.1 ft^2/day (4/24/2013) MW-83/84-07 - 1.6 ft2/day (8/6/2013)	Gauged wells MW-83/84-22, RFI-83/84-49, RFI-83/84-53, MW-83/84-07, MW-83/84-12, MW-83/84-19, MW-83/84-34, MW-83/84-36, MW-83/84-38 Baildown test at well RFI-83/84-49, RFI-83/84-53, MW-83/84-07, MW-83/84-12, MW-83/84-19, MW-83/84-34, MW-83/84-36, MW-83/84-38	RFI-83/84-49 - 0.13 ft^2/d RFI-83/84-53 - NA MW-83/84-07 - 0.33 ft2/d MW-83/84-12 - NA MW-83/84-19 - 0.03 ft2/d MW-83/84-34 - 0.07 ft2/d MW-83/84-36 - 0.08 ft2/d MW-83/84-38 - 0.06 ft2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
11	83/84-1	LNAPL is not migrating, but is mobile and likely infiltrating Outfall 004. LNAPL may not be readily recoverable.	1 - Outfall 004 infiltration pathway elimination **(IM completed)** 2 - 004 passive recovery trench monitoring **(IM completed)** 3 - Institutional controls **(In progress)**	LNAPL may be recoverable	MW-83/84-15 - 0.71 ft^2/day (6/11/2015)	Gauged wells MW-83/84-15R Baildown test at well MW-83/84-15R	MW-83/84-15R - 0.07 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
12	12-A, 12-B, 12-C	LNAPL is mobile and infiltrating Outfall 004. LNAPL not readily recoverable.	1 - LNAPL recovery was attempted at two recovery wells (RFI-12-02/02R and RFI-12-11-D) for ~2 years; however, removal was not successful **(IM Completed)** 2 - Outfall 004 pathway elimination **(IM completed)** 3 - 004 recovery trench monitoring **(IM completed)** 4 - Maintain surface cover **(IM completed)** 5 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	RFI-12-23 - 0.4 ft^2/day (9/19/2012)	Gauged wells RFI-12-09R, RFI-12-22R, RFI-12-23, RFI-12-35, RFI-12-38 Baildown test at well RFI-12-23	RFI-12-23 - 0.06 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
13	02-B	LNAPL is not migrating and Outfall 006 that services area has been bulkheaded. LNAPL not readily recoverable.	1 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	2014 RRR - LNAPL too viscous to accurately measure	Gauged wells RFI-02-15, RFI-02-19 Baildown test at well RFI-02-19	RFI-02-19 - 0.50 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.
14	40-A, 40-B, 16-C	LNAPL is not migrating or infiltrating Outfall 009 or 010. Historical IM's include LNAPL bailing program.	1 -LNAPL bailing and recovery **(IM completed)** 2 - Outfall 009 and 010 bulkhead installation **(IM completed)** 3 - Institutional controls **(In progress)**	LNAPL area not included in evaluation	RFI-40-7R2 - 1.9 ft^2/day (6/12/2012)	Gauged wells RFI-40-14R, SB-40-23, RFI-16-08, RFI-16-10 Baildown test at well RFI-40-14R	RFI-40-14R - 0.08 ft^2/d	No further action at this time due to low LNAPL transmissivity; potential benefit of LNAPL recovery is not expected to outweigh costs. Manage in place with NSZD and controls.	LNAPL is mobile/flowable within a stable perimeter, but not readily recoverable. Manage via NSZD and controls.

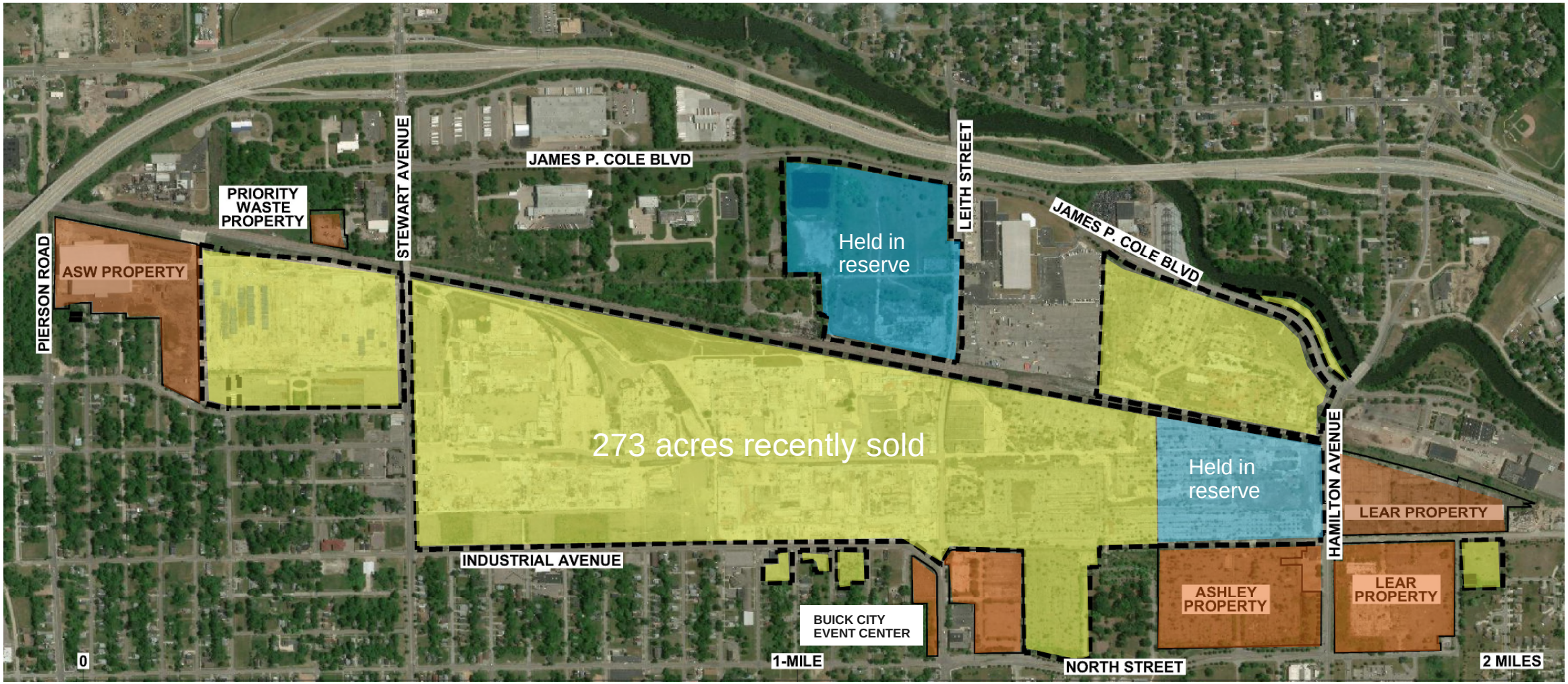
Footnotes:
1 - Select IMs proposed in the 2016 RRR were modified or eliminated following additional testing, investigation and/or evaluation of Site conditions.

Notes:
RRR: Remedy Recommendation Report
ft^2/d: square feet per day. A value of 0.5 ft^2/d or less is used by EGLE as an indication that recovery efforts have reached the extent practicable.
NSZD: Natural source zone depletion

Figures

Site Redevelopment

RACER property recently sold



Former RACER property

Portions reserved from sale pending remediation

NORTH END

SOUTH END

FLINT RIVER

LNAPL #1

LNAPL #2

LNAPL #3

LNAPL #4

LNAPL #5

LNAPL #6

LNAPL #7A

LNAPL #7B

LNAPL #8A

LNAPL #8B

LNAPL #9

LNAPL #10

LNAPL #11

LNAPL #12A

LNAPL #12B

LNAPL #12C

LNAPL #12D

LNAPL #13

LNAPL #14-A1

LNAPL #14-A2

LNAPL #14-B1

LNAPL #14-B2

LNAPL #14-B3

LEGEND:

- SOIL PILES
- RESERVED PROPERTIES
- LNAPL
- PROPERTY LINE

NOTES:

1. RACER PROPERTY BOUNDARY BASED ON 2023 ROWE SURVEY.
2. FORMER PROPERTY BOUNDARY BASED ON 2021 BMJ SURVEY.

0 400' 800'

APPROXIMATE SCALE IN FEET

RACER TRUST
BUICK CITY
FLINT, MICHIGAN

LNAPL RESTRICTIVE COVENANT AREAS

ARCADIS

FIGURE
2

Attachment 1

Method to Determine Horizontal and Vertical Extent of Residual LNAPL Impacts

Introduction

Establishing standard conditions for the delineation and management of LNAPL impacted soils is challenging because unlike many contaminants such as PCBs, lead, and VOCs there are no specific measurable soil delineation or remediation standards for LNAPL. LNAPL can be generally detected and reported on boring logs, it can be observed in monitoring wells, and LIF[1] studies can be used to generally identify areas of LNAPL impacted soils. EGLE LNAPL Guidance[2] assists with vertical delineation as described below.

Horizontal Extent

Based on discussions with EPA (2014 - 2016) and using guidance developed by ASTM[3] and ITRC[4] a comprehensive review of site information resulted in a series of recommendations submitted to EPA in 2016. For the purpose of this review the horizontal extent of LNAPL areas at the Site were defined using the following process. (The vertical extent has been estimated based on an assessment of residual LNAPL (in vadose zone) applying principles described in EGLE 2023 LNAPL Guidance– discussed below):

1. Groundwater/LNAPL gauging data were evaluated to identify where LNAPL had been measured at a thickness in a monitoring well of greater than 0.1 feet more than once since 2013 for inclusion in the LNAPL area. The use of 0.1 feet of LNAPL as the horizontal delineation was agreed to by the EPA during the RFI process. Furthermore, the 0.1 feet thickness is more conservative than the 0.2 feet used by EGLE in their 2014 *NAPL Characterization, Remediation, and Management for Petroleum* Releases guidance document for the minimum LNAPL thickness for which transmissivity testing is appropriate for determining LNAPL recoverability.
2. When evaluating data from monitoring wells that had been abandoned – the wells were included within the LNAPL area if LNAPL was measured at a thickness greater than 0.1 feet more than once, during the last three years it was monitored before abandonment.
3. The initial horizontal extent of LNAPL was established in 2016 halfway between a monitoring well where LNAPL is measurable (greater than 0.1 feet) and a monitoring well where LNAPL is less than 0.1 feet. The extents were further refined using multiple lines of evidence including information from soil boring logs (sheens, staining, etc.) and/or LIF logs completed in the area.

Vertical Extent

The EGLE LNAPL Guidance document (See, EGLE Guidance[5]) was referenced during the process of determining the elevation where residual LNAPL impacted soils may be first encountered at each LNAPL area. The EGLE Guidance states on page 16 of 42:

- In the unsaturated/vadose zone, generally once a release has stopped, any NAPL saturated soil will be drained by gravity to equilibrium and only residual NAPL will remain. Therefore, as long as there are not ongoing releases, NAPL in the vadose should be considered residual (ITRC, 2018)

[1] Laser Induced Fluorescence – Information obtained from LIF studies performed in 2010-2012 were used to assist in identifying LNAPL areas for further review as discussed in the Remedy Recommendation Report 2014 (Updated 2016)
[2] EGLE, 2023 NON-AQUEOUS PHASE LIQUID – PETROLEUM RELEASES Characterization, Remediation, and Management Guidance dated June 29, 2023
[3] ASTM, 2006 Standard Guide for Development of Conceptual Site Models and Remediation Standards for Light Nonaqueous-Phase Liquids Released to the Subsurface, E2531-06 ASTM
[4] Interstate Technology & Regulatory Council (ITRC), 2009, Evaluating LNAPL Remedial Technologies for Achieving Project Goals. www.itrcweb.org
[5] EGLE, 2023, NON-AQUEOUS PHASE LIQUID – PETROLEUM RELEASES Characterization, Remediation, and Management Guidance dated June 29, 2023

Given that no new releases of LNAPL have occurred at the site for at least 15 years it is fair to assume essentially all LNAPL in the vadose zone is residual. In those instances where a constituent has been identified above applicable criteria it is subject to its own independent restriction.

The initial LNAPL Restrictive Covenants (November 2023) have been modified to reflect the most current EGLE guidance and an updated assessment of the collection of multiple lines of LNAPL information at the site. The recommended LNAPL Restrictive Covenant text (February 2024) has been updated in part due to the EGLE Guidance and the recognition that the limits of the vadose zone are a more reliable vertical demarcation of potential residual LNAPL issues.

An example, of the modified text follows (for LNAPL Area #7A).

- Residual NAPL impacted soils (LNAPL generally consisting of cutting oil) may first be encountered at an approximate elevation of 742 amsl within the vadose zone with groundwater potentially encountered at an approximate elevation of 741 amsl. This area is covered with soil. Excavation in this area is prohibited below elevation 742 amsl unless the residual LNAPL impacted soils are managed in accordance with an EGLE approved Materials Management Plan. *If any liquid LNAPL is encountered it must be removed, placed in an appropriate container, and characterized for off-site disposal*. (emphasis added)

In addition, as noted in this text, to address essential remediation issues where liquid LNAPL (free flowing – not otherwise comingled in a soil matrix) is encountered it must be removed, characterized, and disposed of off-site.

Adjustments to Estimated Elevations where residual LNAPL may be First Encountered

The updated residual LNAPL elevations are based on multiple lines of evidence including a review of site boring logs, data from LIF logs as described below, and updated depth to groundwater measurements (corrected in appropriate locations for LNAPL thickness in wells).

Boring Log Review

Boring logs (2000 – 2013) from each LNAPL area were reviewed to identify where evidence of residual LNAPL was first encountered. The number of logs reviewed from each LNAPL area varied based on quality, quantity, and location of the boring logs available.

At LNAPL areas where there were 10 or fewer boring logs available, all of the logs were reviewed. However, at the larger LNAPL areas with numerous boring logs available a subset of logs was reviewed and summarized. Logs were selectively chosen throughout the larger LNAPL areas to incorporate representative variations of site conditions and to characterize the entire area.

Boring logs were reviewed for oil-in-soil (OIS) test results[6], presence of sheens and/or product and staining. The elevation of residual LNAPL was based primarily on the depth of positive OIS test results and notations of the presence of sheen or product in the logs. However, if a log with positive OIS, sheens and/or product also indicated staining at a shallower interval, then the depth of the staining was used to estimate the elevation where residual LNAPL impacted soils may be first encountered. (notes with respect to odor were deemed not reliable since they could be natural sources and are often subjective)

[6] OIS – Oil in Soils test were done by placing soil in a 4-ounce clear glass jar, adding an oleophilic dye and shaking the jar. The dye preferentially dissolves in and colors the oil rather than the water. If oil is present the dye will dissolve into the LNAPL and increase the visual contrast between the LNAPL and surrounding soil/water mixture. Test results are recorded on the boring log (positive or negative).

LIF Logs

LIF logs were used to supplement, and in some instances, combined with the soil boring logs to support multiple lines of evidence assessments of the vertical (and horizontal) extent of LNAPL. Note that during the LIF investigation, due to frequent below grade obstructions, a hand auger was used as part of utility clearance protocols. Consequently, the first 5 feet of the LIF logs do not provide information where subsurface residual LNAPL impacts may first be encountered.

Residual LNAPL Elevations

The residual LNAPL elevations, using the methodology described herein, for each LNAPL area are summarized in the attached table.

LNAPL Restrictive Covenant

Restricted Area	Residual LNAPL (LNAPL-Impacted Soils) Elevation (ft amsl)	GW elevation corrected for LNAPL * (ft amsl)
LNAPL Area #1	754	745.5
LNAPL Area #2	740.5	748
LNAPL Area #3	745.5	744
LNAPL Area #4	740.5	737.5
LNAPL Area #5	744.5	744.5
LNAPL Area #6	742.5	744.5
LNAPL Area #7A	742	741
LNAPL Area #7B	739.5	741
LNAPL Area #8A	733	735
LNAPL Area #8B	733	730
LNAPL Area #9	742	737.5
LNAPL Area #10	745	739
LNAPL Area #11	735.5	739.5
LNAPL Area #12A	734.5	735
LNAPL Area #12B	725.5	737.5
LNAPL Area #12C	736	734
LNAPL Area #12D	741.5	741
LNAPL Area #13	734	734.5
LNAPL Area #14A-1	728.5	730

* Groundwater elevations in wells containing LNAPL require correction for the depression of the LNAPL/water interface in the well to obtain total hydraulic head. The depression is caused by the weight of the hydrocarbon. The correction is accomplished by multiplying the apparent LNAPL thickness in the well by the specific gravity of the LNAPL. The result is then added to the elevation of the LNAPL/water interface to obtain the total hydraulic head (API, 1989; Hudak et al., 1993). The computed hydraulic head facilitates a more accurate assessment of hydraulic gradient which leads to better conclusions regarding potential contaminant sources, extent of free-product accumulation, and optimal areas for focusing remediation efforts (Hudak et al., 1993).

Attachment 2

LNAPL Remedial Decision Tree – LNAPL Conceptual Site Model Development

LNAPL Remedial Decision Tree - LNAPL Conceptual Site Model Development
RACER Buick City Template
Flint, Michigan

LNAPL CONCEPTUAL SITE MODEL (LCSM) DEVELOPMENT – MENU OF OPTIONS

	Potential Parameters/Considerations	Potential Evaluation Methods	Discussion
LNAPL Body Delineation/ Characterization	1. LNAPL body geometry: horizontal/ vertical extents, position relative to water table 2. Relative intensity of impacts (hot spots)	1. Installation of wells/borings, laser-induced flourescence (LIF), resistivity 2. Soil sampling (TPH, LNAPL saturations), groundwater sampling, LIF, resistivity	
Geology/ Hydrogeology	1. General Stratigraphy 2. Impacted Soil Types 3. Hydraulic Gradients 4. LNAPL Gradient 5. Hydraulic Conductivity	1,2. Field screening of soil borings, laboratory grain size analysis 3,4. Well gauging 5. Slug tests, pumping tests, laboratory testing	
LNAPL Physical/ Chemical Properties	1. LNAPL viscosity 2. LNAPL specific gravity 3. LNAPL type/age 4. LNAPL chemical composition	1,2. Laboratory physical property testing 3. Laboratory forensic testing/fingerprinting 4. Laboratory chemical analytical testing	
Dissolved and Vapor Phase Impacts	1. Groundwater concentrations of LNAPL constituents 2. Soil gas concentrations of LNAPL constituents 3. Soil gas explosivity	1. Groundwater sampling/laboratory testing 2. Soil gas sampling/laboratory testing 3. Field screening of well headspace and/or soil gas samples using handheld lower explosive limit (LEL) meter	1. Focus on wells without LNAPL. The potential benefit of sampling groundwater under LNAPL should be weighed against the risk of obtaining LNAPL-contaminated samples (LNAPL presence may not be readily apparent in a groundwater sample). 2. The need for soil gas sampling and the potential parameter list can be screened based on the volatility of the LNAPL and/or specific constituents (e.g., test for constituents with Henry's law constant > $1e^{-5}$ atm-m^3/mol and vapor pressure > 0.05 Torr)
LNAPL Mobility	1. Age of LNAPL body 2. Soil TPH concentrations 3. LNAPL saturations and residual saturations 4. LNAPL transmissivity 5. Recovery system performance 6. Dissolved phase trends *Typically involves a weight of evidence approach where multiple lines of evidence are considered (due to the complexity of multi-phase flow in the subsurface and the technical limitations of the potential evaluation methods).	2. Comparison against appropriate C_{res} value or conversion of TPH concentrations to saturations and comparison to typical residual saturation values (see ASTM E2531-06) 3. Soil core sampling and laboratory petrophysical testing (e.g., pore fluid saturation testing, water drive testing) 4. Field LNAPL baildown testing, pumping tests, field dye tracer testing (see ASTM E2856-11) 5. LNAPL recovery system cumulative recovery/ recovery rate plots, decline curve analysis 6. Groundwater concentration trends of LNAPL parameters	1. Older LNAPL is less likely to be mobile 2,3. LNAPL saturations exceeding residual levels provide a line of evidence of LNAPL mobility 4. LNAPL transmissivity > 0.5 ft^2/day provides a line of evidence of LNAPL mobility (see Swiger 2013) 5. Poor recovery system performance may provide strong evidence that remaining LNAPL is at residual levels/immobile (if the system has been effectively implemented and operated) 6. Dissolved phase trends provide an indication of the state of the LNAPL body (e.g., stable dissolved phase trends = stable LNAPL)
LNAPL Migration	1. LNAPL body expansion and migration *LNAPL migration differs from the LNAPL mobility consideration above in that is only considers the potential for LNAPL mobility around the perimeter of an LNAPL body (i.e., its ability to migrate or expand into areas that are not already impacted).	1. One or more LNAPL mobility lines of evidence indicates potential mobility along LNAPL body perimeter 2. LNAPL observations in sentry wells installed in clean soil 3. Estimate critical LNAPL head (pore entry displacement pressure) at LNAPL periphery	3. Critical LNAPL head (pore entry displacement pressure) exceeded at LNAPL periphery represents a potential for LNAPL body expansion/ migration
LNAPL Recoverability	1. Potential LNAPL recovery rates 2. Fraction of LNAPL body that may be recoverable *Most of the potential evaluation methods listed above for LNAPL mobility will also provide evidence relating to the potential recoverability of the LNAPL.	1. LNAPL recovery pilot results, LNAPL transmissivity estimation, full-scale LNAPL recovery system performance 2. Comparison of LNAPL saturations and residual saturations	1. LNAPL recovery may be considered technically practicable where LNAPL recovery rates exceed a minimum level and/or where LNAPL transmissivity > 0.5 ft^2/day (see Swiger 2013) 2. Regardless of the technical practicability of LNAPL recovery, any recovery activity will only have a significant effect on an LNAPL body where LNAPL saturations significantly exceed residual levels (i.e., significant recoverable fraction)
Potential Remedial Drivers	1. Risk (compositional concerns) 2. LNAPL mobility/migration (saturation concerns) 3. Non-risk (non-technical) factors such as aesthetic (e.g., visual, olfactory), regulatory or other considerations (e.g., property transaction condition)	1. Will vary from comparison of existing site data to generic criteria, to quantitative human health and ecological risk assessment (depending on complexity of site and magnitude of potential risks) 2. See LNAPL mobility and LNAPL migration lines of evidence and approaches above 3. Review applicable LNAPL regulations 3. Establish site goals	

NOTES/REFERENCES:

The “menu” provided above presents potential elements of an LCSM, potential evaluation methods and potential metrics (where applicable). The need to quantify specific items above should be based on a preliminary consideration of site-specific goals and site complexity. *It will not be necessary to quantify all items above at all sites.*

Table C-1 of ITRC’s Technical Regulatory Document entitled Evaluating LNAPL Remedial Technologies for Achieving Project Goals provides more detail on LCSM components and presents a three level tiered approach to LCSM development based on increasing levels of site complexity

Table X4.1 of ASTM Standard E2531-6 provides detailed information on LNAPL site data collection methods and their applicability.

Swiger, N., 2013. Nonaqueous Phase Liquids (NAPL) Management. Presentation at the American Institute of Professional Geologists (AIPG), Michigan Section, March 2013 Meeting.

LNAPL Remedial Decision Tree
RACER Buick City Template
Flint, Michigan

LNAPL Compositional Concerns (potential exposure/risk issues):
- Explosive hazards (vapor accumulation in confined spaces/ utilities, open excavations)
- Dissolved-phase concentrations (migration toward surface water bodies or groundwater supply wells)
- Vapor-phase concentrations (vapor intrusion/long-term exposure risk)
- Direct contact or ingestion

EVALUATE LNAPL CONCERNS FROM LCSM

LNAPL Concerns = Remedial Drivers

Compositional Concerns
Risk-based drivers such as unacceptable levels of dissolved or vapor-phase impacts

Saturation Concerns
Drivers relating to the mitigation of LNAPL migration and/or reduction of LNAPL mobility

LNAPL Saturation Concerns (mobility and migration issues)
- Potential for LNAPL to spread and create new or increased risk (migration toward surface water, property boundary, underground utilities)
- Aesthetic/Nuisance issues

1

Risk: Are unacceptable dissolved phase, vapor phase or direct contact exposures associated with the LNAPL under any use scenarios?

Yes → Do feasible options exist to mitigate unacceptable risk through compositional change? (9)

No → No Action Necessary

Yes → Can institutional/engineering controls provide effective risk mitigation? (10)

No → Implement treatment/removal action (6)

Yes → **Cost-Benefit** Is there potential benefit to partial treatment/removal that outweighs costs? (5)

Yes → Implement treatment/removal action (6)

No → Are controls required? (7)

Migration: Is LNAPL migrating or potentially migrating (i.e., mobile along perimeter)? (2)

No → **Mobility**: Is LNAPL potentially mobile within stable LNAPL perimeter? (3)

Yes → Do feasible options exist to mitigate migration through LNAPL recovery or mass control?

No → Are controls required? (7)

Yes → Implement LNAPL Recovery Remedy (6)

Yes → **Cost-Benefit** Will potential benefit of LNAPL recovery outweigh costs? (5)

No → **Recoverability**: Is LNAPL readily recoverable? (4)

No → Are controls required? (7)

Yes → Implement Controls

Implement Controls → Implement Long-Term Stewardship/ Monitoring Plan (**as required**) (8)

Are controls required? (7)

No → Implement Long-Term Stewardship/ Monitoring Plan (**as required**) (8)

Implement Long-Term Stewardship/ Monitoring Plan (**as required**) (8) → Corrective Action Complete

(#) NOTES

Note:
Template modified on June 20, 2014 from February 6, 2013 working draft.

LNAPL Remedial Decision Tree Notes
RACER Buick City Template
Flint, Michigan

1. The LCSM may identify both risk and mobility/migration issues at a given site. Consequently, compositional change techniques (to mitigate risk) and saturation reduction techniques (to mitigate mobility/migration concerns) may represent concurrent considerations that may require independent remedies.

2. Migration is only likely to be occurring where releases are active or shortly after cessation where a LNAPL gradient/head is present. Due to the complexity of multi-phase flow in porous media and the limitations of available assessment methods, LNAPL migration potential should be evaluated using multiple lines of evidence (see LCSM Menu – Page 1)

3. LNAPL Mobility – Is LNAPL present at saturations exceeding residual values? Example lines of evidence listed in LCSM Menu – Page 1.

4. The presence of readily recoverable LNAPL as defined by transmissivity > 0.5 ft^2/day does not necessarily indicate that a significant fraction of an LNAPL body would be beneficially affected through LNAPL recovery (Swiger 2013). An understanding of the fraction of the LNAPL body that may be recoverable is necessary in order to establish a realistic expectation of the actual benefit of any LNAPL recovery activity and a determination of whether the LNAPL body is “readily recoverable.” See Table 2 of the main report.

5. The potential benefit of LNAPL remediation should be weighed against the potential costs in terms of the associated expenditure of financial and natural resources, the risks involved in implementation, and the contamination potentially resulting from the remedial action (i.e., sustainability considerations). For situations where LNAPL bodies are stable with no associated risk, the net environmental benefit of active engineered LNAPL remedial systems should be scrutinized. See Table 8 of the main report.

6. Establish LNAPL recovery objectives and science-based achievable/measureable LNAPL recovery end-points prior to implementing LNAPL remediation (e.g., reduction of LNAPL transmissivity to less than 0.5 ft^2/day to meet a saturation objective).

7. Considering the significant technical limitations of LNAPL mass recovery or compositional change, engineering and/or institutional controls should be considered in conjunction with or in lieu of remedial action. See Tables 6, 7, and 10 of the main report.

8. Perform any necessary monitoring to confirm LNAPL remedial goals are/were met. See Table 8 of the main report.

9. LNAPL compositional change remediation is implemented to reduce the concentration or mole fraction of specific compounds in LNAPL that contribute to dissolved and or vapor phase concerns (i.e., air sparging and soil vapor extraction to reduce the mole fraction of benzene in LNAPL). Phase change technologies can be used to target immobile LNAPL, unlike conventional LNAPL mass recovery technologies such as LNAPL skimming. Examples of compositional change techniques may include air sparging, enhanced biodegradation, in situ thermal treatment, and in-situ chemical oxidation. Some phase change remedial technologies will accomplish both LNAPL mass recovery (saturation objective) and compositional change objectives simultaneously. See Table 7 of the main report.

10. Examples of potentially effective removal actions include excavation with off-site disposal, excavation with ex-situ thermal treatment and in-situ thermal treatment (e.g., electrical resistance heating with high vacuum extraction). See Table 7 of the main report.

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