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Arcadis Project No.: 30006870

Subject: Plant 2 LNAPL Area - Natural Source Zone Depletion Summary
RACER Trust, Plant 2, Lansing, Michigan

Arcadis, on behalf of the Recovering Automotive Communities Environmental Response (RACER) Trust, has completed an evaluation of light non-aqueous phase liquid (LNAPL) natural source zone depletion (NSZD) at the Plant 2 Site located in Lansing Township, Michigan (Site). The Plant 2 LNAPL area is shown on **Figure 1**. The extent of LNAPL impact at Plant 2 covers approximately 1.2 acres with impacts occurring in 2 primary zones, shallow and deeper, as shown in the cross-section on **Figure 2**. Within the 1.2 acres and the shallow and deeper zones, areas of both residual and mobile LNAPL are present, and LNAPL has been previously removed via recovery efforts. Details regarding the distribution of LNAPL at Plant 2 are included as part of the RFI Phase 2 Summary Report (Arcadis 2013), the Summary of LNAPL Transmissivity Results Memorandum (Arcadis 2015a), the LNAPL Removal Work Plan (Arcadis 2015b), Annual Groundwater Monitoring Reports, as well as other submittals.

The goal of the NSZD evaluation was to identify and quantify light non-aqueous phase liquid (LNAPL) depletion processes occurring at the Site. Based on LNAPL transmissivity values observed at the Site (Arcadis 2015), which are two to three orders of magnitude below Michigan Department of Environment, Great Lakes, and Energy (EGLE) reference values for cost effective and efficient LNAPL recovery, active LNAPL recovery is not expected to significantly affect the overall mass of LNAPL at the Site. In contrast,

NSZD processes could potentially lead to substantial LNAPL mass reduction in future years; the objective of this assessment is to quantify degradation NSZD rates to an order-of-magnitude level and support future comparison of NSZD rates to active recovery rates.

NATURAL SOURCE ZONE DEPLETION BACKGROUND

NSZD is a combination of processes, including dissolution, volatilization, and biodegradation, that reduce the mass of LNAPL in subsurface systems. NSZD occurs when processes act to physically redistribute LNAPL components to the aqueous phase via dissolution or to the gaseous phase via volatilization. In turn, dissolved or volatilized LNAPL constituents can be biologically degraded by microbial and/or enzymatic activity. Biodegradation can also occur directly on the LNAPL phase, without a need for dissolution or volatilization. Collectively, these biodegradation reactions result in the production of carbon dioxide (CO₂), and under the strongly reducing conditions typically observed in LNAPL source zones, methane (CH₄). Due to the limited solubility of carbon dioxide and methane, these byproducts partition into the gas phase and migrate toward the ground surface by diffusive and advective gas transport. Typically, as soil gas migrates upward through the soil column and comes into contact with higher concentrations of atmospheric oxygen (O₂), methane is oxidized to carbon dioxide, and carbon transfer processes are dominated by the flux of carbon dioxide from the subsurface to the atmosphere (Molins et al. 2010). However, in some locations, it is possible that methane is not fully oxidized and may still be present at the surface. The evaluation completed at the Site incorporates methods qualitatively evaluate the presence or absence of NSZD (soil vapor screening) and methods that are better able to quantify the rate of NSZD (temperature profiles and flux measurements). These methods and underlying mechanisms are discussed separately in the following sections.

Qualitative NSZD Assessment via Soil Gas Composition

Hydrocarbon volatilization and methanogenesis within LNAPL bodies are often significant contributors to NSZD processes. Conditions within an LNAPL-impacted area are typically strongly anaerobic; as petroleum hydrocarbons moving upward in soil vapor encounter oxygen (O₂), they are aerobically degraded and converted to carbon dioxide. Similarly, methane generated through anaerobic processes is mineralized to carbon dioxide in the vadose zone under aerobic conditions (Sihota et al., 2011).

The presence of methane and/or carbon dioxide in soil gas is a significant indication NSZD processes are active (ITRC, 2009 and 2018). While nested soil gas sampling ports can be used for a rigorous quantitative evaluation of NSZD rates, soil gas samples can also be collected from existing monitoring wells with screened intervals intersecting the vadose zone for NSZD screening. The observation of elevated methane or carbon dioxide, and depleted O₂, in these samples indicates that NSZD processes are depleting LNAPL mass.

Quantitative NSZD Assessment via Temperature Profiles

The biologically-mediated NSZD processes that destroy hydrocarbons also release heat and create subsurface temperature anomalies above the natural soil temperature profile. Recent research has focused on measuring temperature in and around LNAPL-affected areas and characterizing thermal anomalies (areas of warmer temperature) associated with methane oxidation from NAPL depletion (Sweeney and Ririe, 2014). The studies concluded that temperature evaluation can provide useful information to evaluate biodegradation of hydrocarbons in soil.

Quantitative NSZD Assessment via Carbon Dioxide and Methane Flux

As discussed above, the biodegradation reactions that occur as part of NSZD processes result in the production of CO₂, and under the strongly reducing conditions typically observed in LNAPL source zones, methane. Due to the limited solubility of carbon dioxide and methane, these products partition into the gas phase and migrate toward the ground surface by diffusive and advective gas transport processes (Amos et al., 2005). Typically, as soil gas migrates upward through the soil column and comes into contact with higher concentrations of atmospheric oxygen, the methane is oxidized to CO₂, and the carbon transfer is dominated by the flux of CO₂ from the subsurface to atmosphere (Sihota et al., 2011). However, some methane may not be fully oxidized and may be present at the ground surface. Based on this understanding of NSZD processes, NSZD rates can be measured by quantifying the amount of CO₂ and CH₄ discharging from the subsurface to the atmosphere in a defined area.

NSZD Measurements and Variability

Current methods for quantitative NSZD assessment are generally understood to be accurate to within an order of magnitude (Garg et al. 2017, ITRC 2018). Measurements also entail substantial variability, both spatially and temporally, due to two factors. First, actual changes in NSZD rates can occur due to changes in subsurface temperature, soil moisture, and other environmental factors that affect biological activity and biochemical kinetics. Second, even if the actual NSZD rate is constant, changes in the subsurface and surface environment can affect the degree to which indicators of NSZD are visible to current measurement methods (for example, a heavy rainfall which saturates shallow surface soil, or infiltrates unevenly based on surface cover, could temporarily block the upward flux of CO₂ to the atmosphere). For these reasons, longer-term NSZD measurements were favored in this assessment, and spatial variability between measurement locations was considered acceptable relative to the overall goal of estimating area-wide LNAPL loss rates due to NSZD on an order-of-magnitude basis.

DATA COLLECTION

NSZD data were collected at the Site to support assessment via each of the above-described methods (soil gas screening, temperature profiling, and soil gas efflux measurements). Data collection was conducted from August 2018 through June 2019.

Soil Gas Composition Screening

Soil gas readings were taken at monitoring points with screened intervals extending into the vadose zone and at two soil vapor monitoring points installed above the LNAPL footprint for the purpose of NSZD assessment (SVMP-Shallow and SVMP-Deep). These data were collected to provide qualitative evidence of NSZD processes. Evidence that NSZD is occurring includes the presence of volatile organic compounds in soil vapor, the presence of methane and/or carbon dioxide at concentrations greater than atmospheric conditions, and/or the presence of oxygen at concentrations less than atmospheric conditions. These indicators of NSZD can be observed in the vadose zone, but reflect activity occurring both above and below the water table.

The soil gas composition data were collected at five locations in August 2018: LMW-12-05, PMW-01, PMW-03, SVMP-Shallow, and SVMP-Deep. Concentrations of volatile organic compounds, methane, carbon dioxide, and oxygen were monitored in the field using an RKI Eagle landfill gas meter. Measurements could not be collected at one proposed location, LMW-12-03D, due to the presence of shallow LNAPL in the well above the screened interval.

Temperature Profiling Measurements

Vertical temperature profiles were collected in August 2018. Each profile consists of multiple temperature measurements at discrete vertical intervals within existing monitoring wells, using a handheld thermometer and thermocouple probe to measure temperatures at 1- to 2-foot intervals. The thermocouple was allowed to equilibrate at each depth interval prior to recording readings.

Temperature readings were collected from within the air-filled casing of existing monitoring wells; while there may be some variation between the temperature of air within the casing and the temperature of the surrounding soil, the in-casing temperatures are considered sufficiently representative for the screening-level purpose of this evaluation. The methods used were consistent with the process described by Sweeney and Ririe (2014), who noted that the lower heat capacity of air within the casing, relative to that of surrounding soil, causes the in-well temperature to be similar to the formation temperature at adjacent depths.

Following the August 2018 measurements, a total of 25 temperature probes were placed in five monitoring wells (MW-14-54, LMW-12-06, LMW-15-16D, P2-SB-37, and LMW-12-07) for longer-term monitoring. Five temperature probes were placed at discrete depths within each well, and recorded data from October 2018 to June 2019. Data were retrieved from the dataloggers in June 2019 and analyzed as described below.

Dynamic Closed Chamber Flux Measurements

CO₂ flux and CH₄ flux were measured at 20 locations in August 2018 with an automated dynamic closed chamber (DCC) and gas analyzer equipment manufactured by LI-COR Biosciences (model LI-8100A) and Gasmeter (model DX4040). The locations are shown on **Figure 2**. The automated analyzers measure the change in carbon dioxide and methane concentration in the dynamic closed chamber system over short periods of time using an automated sampling process (the LI-COR unit measures CO₂ and the Gasmeter unit measures CH₄).

At each soil gas flux measurement location, a soil collar, consisting of a 3- to 4-inch long section of 8-inch-diameter plastic pipe, was installed at the ground surface. The soil collar isolates an area of the ground surface and provides a base for the seating of the DCC assembly. The soil collars used in this assessment were installed either by (1) driving the soil collar directly into surface soils, or (2) loosening shallow surface soils by hand-digging and placing the collar downward into surface materials, then re-compacting surface soil within and around the collar as closely as possible to pre-installation conditions.

The measurement process consists of the DCC closing on a soil collar, creating a closed system in which the gases emanating from the ground surface can accumulate. CO₂ and CH₄ concentrations in the chamber are then measured at short (e.g., 1-second) intervals by the analyzers to evaluate the rate at which concentrations within the chamber are increasing. For typical soil gas flux values, effective equilibrium with surrounding air pressure and subsurface pressure is maintained by the chamber design, which controls for negative pressures that may be created through ambient wind or similar factors.

The DCC measurements quantify total CO₂ and CH₄ flux only, and do not directly measure the proportion of soil gas flux related to naturally occurring or background conditions such as shallow soil respiration. While approximate background corrections can be conducted by subtracting gas flux values observed at known unimpacted areas from those measured in impacted areas, some variability and uncertainty are inherent in this approach; therefore, the DCC approach was used in this assessment as a screening tool to identify areas of anomalously high or low soil gas flux as well as to quantify an approximate typical range of fluxes for the site.

CO₂ Trap Flux Measurements

As a follow-up to the DCC measurements, CO₂ traps were used to measure upward CO₂ flux from the ground surface at the Site (as shown on **Figure 3**). CO₂ traps were provided by E-Flux, LLC of Fort Collins, Colorado (E-Flux) and were deployed at 8 locations across the Site. Five of the traps were placed in unpaved portions of the Site and were deployed by installing a four-inch-diameter receiver pipe with a specially designed sorbent canister directly into the ground surface. The three remaining traps were placed in paved portions of the Site; at these locations well vaults were installed into the underlying soil and the trap was placed in the well vault. The sorbent canister captures CO₂ gas moving upward from the soil within and beneath the receiver pipe and provides a time-averaged measurement of carbon dioxide flux over the deployment period. The CO₂ traps were deployed between October 24 and November 7, 2018.

At the end of the deployment period, the CO₂ traps were retrieved and sent to E-Flux for analysis of total carbon dioxide as well as a measurement of carbon-14 (¹⁴C) content within the captured CO₂. This ¹⁴C measurement is used to evaluate the portion of CO₂ flux associated with petroleum degradation as opposed to naturally-occurring shallow soil respiration. Laboratory analytical reports are included as **Attachment 1**. Soil gas flux is reported in micromoles per square meter per second ($\mu\text{mol}/\text{m}^2/\text{sec}$); these values are converted to equivalent LNAPL loss rates using a conversion rate of 1 $\mu\text{mol}/\text{m}^2/\text{sec}$ to 625 gallon per acre per year (gal/acre/yr). The derivation of this conversion factor is also presented in the laboratory reports in **Attachment 1**.

RESULTS

Soil Gas Composition Screening Results

The results of the soil vapor screening are included in **Table 1**. The results indicated that NSZD is actively occurring at the Site; elevated CO₂ concentrations and depleted O₂ concentrations relative to background values were observed at several locations.

Temperature Profiling Results

The temperature profiles collected during the initial data collection (using a handheld thermometer at existing monitoring wells) are presented in **Attachment 2**. These profiles were compared to the background data measured at MW-14-59 and to background temperature profiles generated using a model based on Van Wijk and de Vries (1963) and Sweeney and Ririe (2014). That model output is included as **Attachment 3**. Relative to background values, the temperature profiles from the wells within the LNAPL body indicate thermal signatures consistent with methane oxidation and therefore NSZD. The approximate NSZD rate indicated by these temperature data ranges from 1,300 gal/acre/yr to 3,500 gal/acre/yr.

Temperature profiling data were collected using dataloggers in five wells for a period from October 2018 through June 2019. Multiple measurement dates were used at each well to construct profiles using the same model as discussed above to account for seasonal changes. The estimated NSZD rate based on this data ranges from 200 gal/acre/yr to 2,000 gal/acre/yr and the average was approximately 500 gal/acre/yr.

Soil Gas Flux Results

Flux measurements collected using the DCC and infrared gas analyzers indicate that most of the methane being produced is being converted to CO₂ prior to reaching the ground surface. The average CO₂ flux across the plume in August 2018 was 2.57 μmol/m²/sec (**Table 2**). The equivalent average LNAPL loss rate for this flux would be 1,200 gal/acre/yr; however, that estimate would be biased high because it does not account for (i.e., subtract) the contribution of naturally occurring CO₂ within the reported total flux. A more direct and robust background correction was completed using the ¹⁴C analysis as part of the CO₂ trap data collection.

The CO₂ trap results indicated petroleum-related CO₂ fluxes from near-zero to 1.45 μmol/m²/sec, corresponding to equivalent LNAPL loss rates up to 900 gal/acre/yr. In addition to incorporating a robust correction for naturally occurring CO₂, and also provides a longer-term time-averaged result relative to the DCC measurements (approximately two weeks rather than five to ten minutes). Therefore, the CO₂ trap data are considered to provide a more representative rate than the DCC measurements, although they do not capture seasonal variation that would occur over a longer timeframe.

Results from the DCC and CO₂ trap measurements are included in **Table 2** and **Attachment 1**, respectively.

CONCLUSIONS

Each line of evidence evaluated (soil gas screening, subsurface temperature profiling, and soil gas flux measurement) indicates that NSZD is active and ongoing at the Site. The longer-term monitoring methods capable of evaluating NSZD indications at timeframes on the scale of weeks to months (i.e., CO₂ trap measurements and datalogger measurements of subsurface temperature) indicate LNAPL degradation rates ranging from approximately 30 to 1,000 gal/acre/yr at individual locations.

Using the average NSZD rate calculated from these measurements, the Plant 2 LNAPL area NSZD rate is estimated at 570 gallons of LNAPL depleted per year over an approximate LNAPL footprint of 1.2 acres. This equivalent loss rate would be expected to vary based on seasonal and environmental factors, and to decrease over time as LNAPL mass is depleted. The estimated loss rate is substantially larger than current LNAPL removal rates achieved via manual LNAPL bailing and would surpass any automated recovery system that could be installed at the Site that are is to the same limiting factors. NSZD is therefore the dominant contributor to current LNAPL mass reductions.

NEXT STEPS

Based on the results of the NSZD evaluation, RACER proposes to discontinue the manual LNAPL bailing activities. The current removal rates via manual bailing typically vary between 30 and 50 gallons per year. Overall, mass removal due to manual bailing is insignificant relative to NSZD. Changes to the LNAPL removal activities has been proposed as part of the revised Interim Groundwater Monitoring Plan.

Following the submittal of this report, RACER will prepare a Plant 2 LNAPL Conceptual Site Model report that incorporates the findings of the LNAPL characterization to date. As part of the submittal, RACER will update the LNAPL Decision Tree, which was developed in collaboration with the MDEQ Technical Assistance Program Support team.

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- Van Wijk, W.R, and D.A. de Vries. 1963. Periodic Temperature Variations in Homogeneous Soil. *Physics of Soil Environment*. North Holland Publishing Company, Amsterdam.

Enclosures:

Tables

- 1 Soil Vapor Screening Results
- 2 Dynamic Closed Chamber Results

Figures

- 1 Plant 2 LNAPL Extent and Monitoring Well Locations
- 2 Plant 2 LNAPL Area Cross-Section
- 3 Plant 2 Dynamic Closed Chamber Locations
- 4 LNAPL Depletion Rates

Attachment

- 1 E-Flux Laboratory Analytical Report
- 2 Initial Temperature Data
- 3 Temperature Profiles

TABLES



Table 1
Soil Vapor Screening Results
RACER Lansing
Lansing, Michigan

Location	O ₂ (% by volume)	CO ₂ (% by volume)	CH ₄ (% by volume)	VOCs (ppm)
SVMP-Shallow	17	3.53	2.04	0
SVMP-Deep	12.2	3.86	2.26	1.1
LMW-12-05	3.5	2.02	25	0.5
PMW-01	19.1	0.0	0.22	35.4
PMW-03	2.5	3.4	0.0	0.0
Typical Atmospheric	20.95	0.036	0.0005	0.0

Notes:

- O₂ - oxygen
- CO₂ - carbon dioxide
- CH₄ - methane
- ppm - parts per million

Table 2
Dynamic Closed Chamber Results
RACER Lansing
Lansing, Michigan

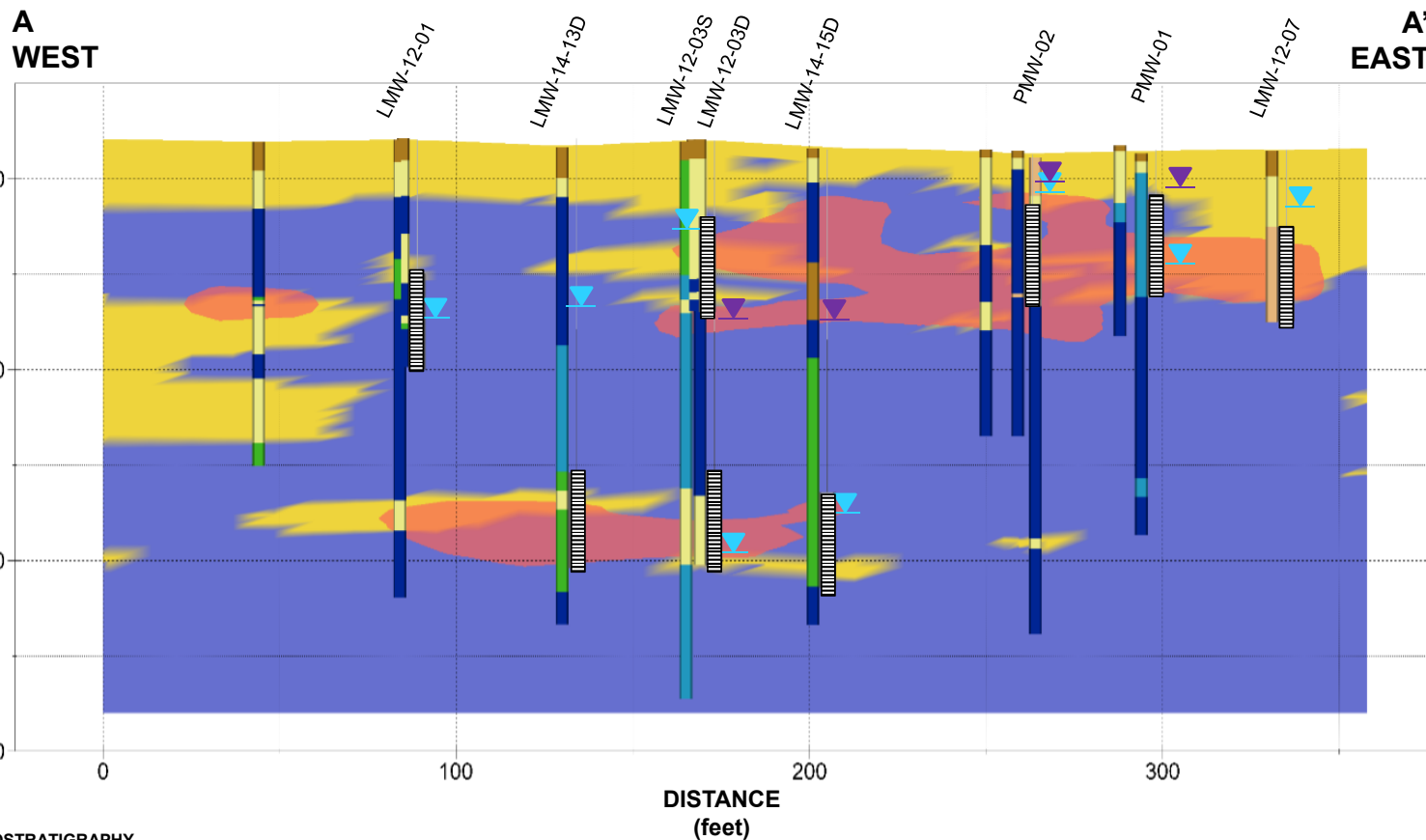
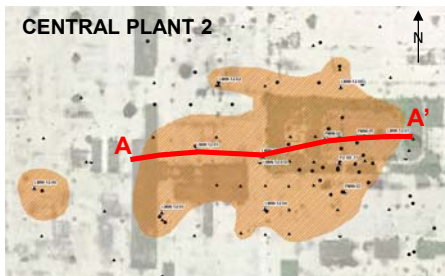
Sample ID	CO ₂ Flux (μM/m ² /sec)	CH ₄ Flux (μM/m ² /sec)	NAPL Loss Rate (gallons/acre/year)
C1	1.25	9.05E-05	778
C2	1.66	4.42E-04	1038
C3	0.72	-2.68E-03	447
C4	0.67	-2.92E-03	419
C5	0.45	-1.03E-17	281
C6	1.61	9.53E-04	1003
C7	1.01	3.44E-04	628
C8	2.89	1.22E-04	1806
C9	17.20	-4.59E-05	--
C10	2.47	-4.93E-04	1547
C11	1.33	1.76E-04	831
C12	2.43	4.61E-04	1519
C13	1.50	1.31E-04	938
C14	1.67	-3.44E-04	1041
C15	2.05	5.91E-03	1281
C16	2.15	4.48E-03	1344
C17	4.61	1.93E-04	2884
C18	2.69	-2.70E-04	1681
C19	1.64	-1.28E-04	1025
C20	1.48	-5.01E-06	925
Plume Average	2.57		1189

Notes:

- μM/m²/sec - micromoles per square meter per second
- NAPL loss rate calculated by converting the carbon dioxide flux to gallons per acre per year using a flux equivalence of 1 μM/m²/sec to 625 gal/acre/yr.
- NAPL loss rate not calculated; flux is artificially high due to location of reading.

FIGURES



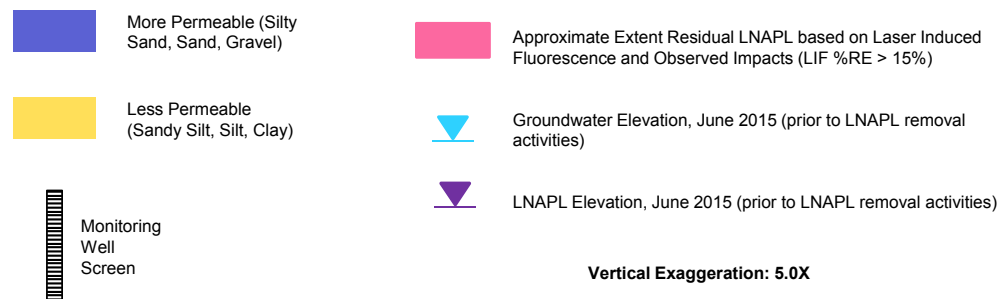


LEGEND

BOREHOLE STRATIGRAPHY



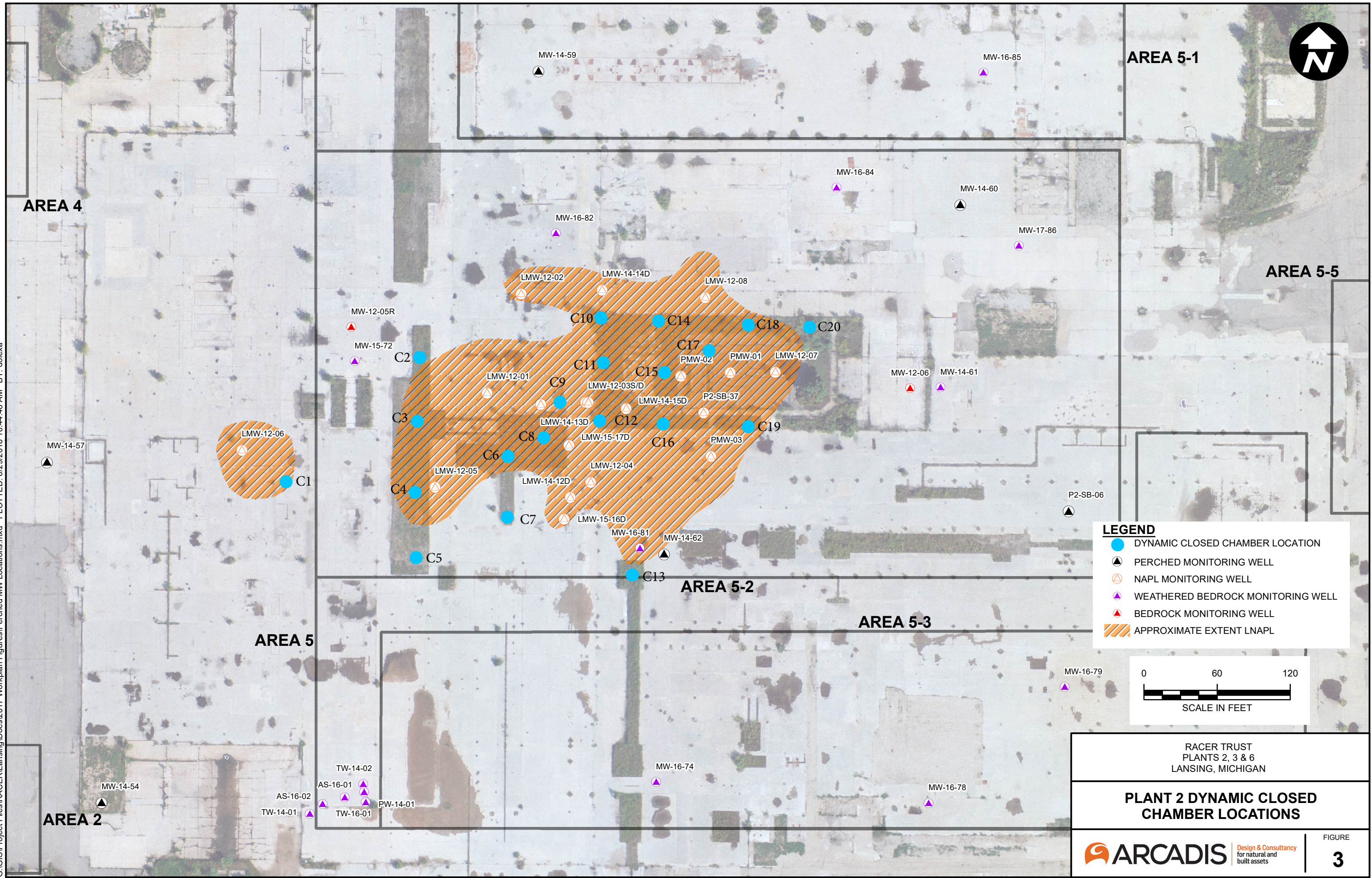
HYDROSTRATIGRAPHY

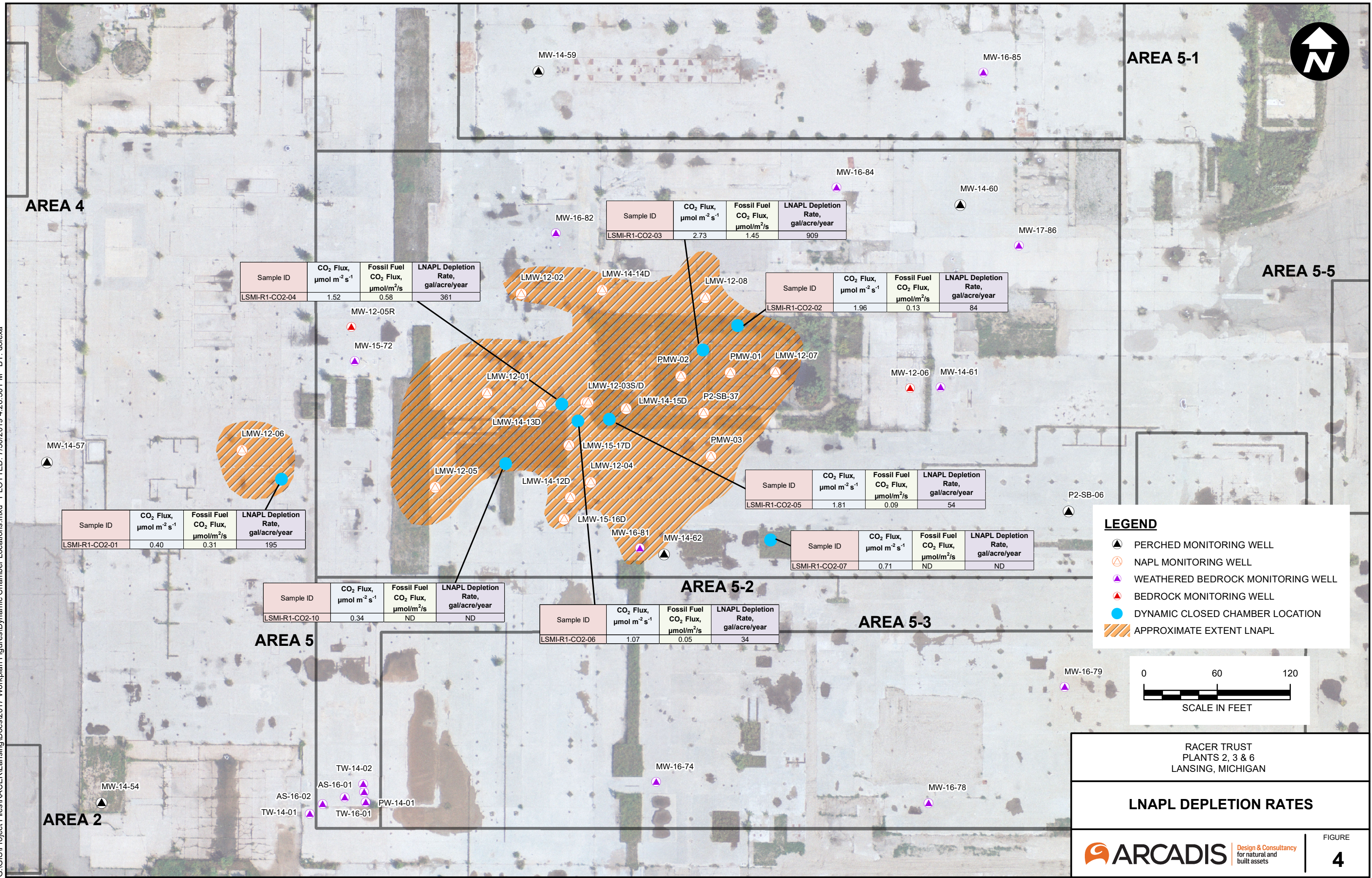


Vertical Exaggeration: 5.0X

RACER TRUST PLANTS 2, 3 & 6 LANSING, MICHIGAN	
PLANT 2 LNAPL AREA CROSS-SECTION	
	<small>Design & Consultancy for natural and built assets</small>
<small>FIGURE</small>	2

CITY: Novi DIV: ENV DB: TRY PIC: PM: TM: TR: PROJECT NUMBER: COORDINATE SYSTEM: NAD 1983 StatePlane Michigan South FIPS 2113 Feet Intl G:\GIS\Project Files\RACER\Lansing\Docs\2017 Workplan Figures\Perched MW Locations.mxd PLOTTED: 6/29/2018 10:44:48 AM BY: dolixa





AREA 4

AREA 5-1

AREA 5-5

AREA 5-2

AREA 5-3

AREA 5

AREA 2

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-03	2.73	1.45	909

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-04	1.52	0.58	361

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-02	1.96	0.13	84

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-01	0.40	0.31	195

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-05	1.81	0.09	54

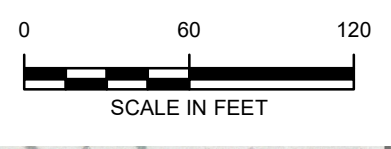
Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-07	0.71	ND	ND

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-10	0.34	ND	ND

Sample ID	CO ₂ Flux, $\mu\text{mol m}^{-2} \text{s}^{-1}$	Fossil Fuel CO ₂ Flux, $\mu\text{mol/m}^2/\text{s}$	LNAPL Depletion Rate, gal/acre/year
LSMI-R1-CO2-06	1.07	0.05	34

LEGEND

- PERCHED MONITORING WELL
- NAPL MONITORING WELL
- WEATHERED BEDROCK MONITORING WELL
- BEDROCK MONITORING WELL
- DYNAMIC CLOSED CHAMBER LOCATION
- APPROXIMATE EXTENT LNAPL



RACER TRUST
PLANTS 2, 3 & 6
LANSING, MICHIGAN

LNAPL DEPLETION RATES

ARCADIS Design & Consultancy
for natural and built assets

FIGURE
4

ATTACHMENT 1

E-Flux Laboratory Analytical Report





Confidential Report
CO₂ Flux and NSZD Rate Results

ANDY PENNINGTON
ANDREW LORENZ
ARCADIS
PROJECT: LANSING, MI
SAMPLING DATES:
10/24/2018-11/7/2018

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The purpose of this document is to provide sample calculations for the reported results, and to explain the method for differentiating petroleum hydrocarbon-derived CO₂ from that produced from natural soil respiration processes. The value of the ¹⁴C analysis, site-specific study results and applicable notes, calculation explanations, and references are included.

The Value of the ¹⁴C Analysis

How to differentiate between petroleum hydrocarbon-derived CO₂ and natural process-derived CO₂ using CO₂ flux traps:

Unimpacted soils naturally produce CO₂ fluxes due to microbial root zone activity and/or the degradation of natural organic matter (NOM). Thus, the total measured CO₂ flux at an impacted location is the sum of both natural soil respiration processes and those related to LNAPL degradation (Sihota and Mayer, 2012). The CO₂ flux caused by LNAPL degradation can be estimated by subtracting measured CO₂ fluxes at unimpacted locations from the total measured CO₂ fluxes at LNAPL impacted locations (Sihota and Mayer, 2012). This process is a spatial “background correction,” and assumes that the rates of natural soil respiration (i.e., present-day, bio-based CO₂ fluxes) are similar for both impacted and unimpacted locations. This approach is complicated to implement, given that at many industrial facilities it is difficult to find unimpacted areas, and that vegetation is different between impacted and unimpacted locations. Alternatively, carbon isotope analysis can be used as a location-specific correction for total measured carbon CO₂ fluxes, and effectively overcomes the limitations of the background correction.

Carbon Isotope Analysis Methodology:

Isotopic analysis has been previously used to differentiate between anthropogenic (due to fossil fuel-burning) and natural sources of atmospheric CO, CO₂, and methane (for example, Klouda and Connolly, 1995; Levin et al., 1995; Avery et al., 2006). These findings form the basis of ASTM Method D6866-18, “Determining the Biobased Content in Solids, Liquids and Gases Using Radiocarbon Analysis” (ASTM, 2018). This technique relies on the analysis of ¹⁴C, an unstable carbon isotope with an absolute half-life of 5,730 years, which is generated by cosmic rays in the atmosphere. Thus, living and bio-based organic carbon is ¹⁴C-rich, while fossil fuel carbon is completely ¹⁴C-depleted. Furthermore, bio-based organic carbon and atmospheric samples have the same characteristic amount of ¹⁴C. Despite the use of highly sensitive accelerator mass spectrometry (AMS), the short isotopic half-life of ¹⁴C only allows for dating of samples younger than 60,000 years, while older samples (such as fossil fuels) contain non-detectable amounts of ¹⁴C and thus cannot be dated using this method (Stuiver and Polach, 1977).

For samples that contain both contemporary and fossil fuel carbon, such as E-Flux’s fossil fuel traps, measurement of ¹⁴C enables quantitation of *both* source contributions. The fossil fuel-derived fraction of the sample (ff_{sample}) and the remaining non-fossil fuel fraction ($1-ff_{sample}$) are related by the following two-component mass balance (modified from Avery, Jr. et al., 2006):

$$Fm_{sample} = (ff_{sample})(Fm_{ff}) + (1 - ff_{sample})(Fm_{atm})$$

Here, Fm_{sub} represents the fraction of modern, a measure of how close the present ¹⁴C/¹²C ratio of the sample is to the ratio from 1950, which is derived from a pre-industrial era standard. Fm_{sample} is the total measured fraction of modern of the sample, which takes all ¹⁴C from the sample into account. Fm_{ff} is the fraction of modern of only the fossil fuel portion of the sample; this number is 0, as there is no ¹⁴C in fossil fuel-derived

CO₂. $F_{m_{atm}}$ is the fraction of modern of the part of the sample derived from living material and natural soil respiration processes; this value has been experimentally determined and is considered a fixed value at each point in time, and is currently equal to 1.02 (Cerling et al., 2016, Larsen et al., 2018). By convention, the results of carbon isotope analysis are reported based on a 1950 NBS oxalic acid standard, and so $F_{m_{sample}}$ is reported as if the analysis was done in 1950. However, current ¹⁴C atmospheric levels are now higher than in 1950 due to nuclear testing, meaning that $F_{m_{atm}}$ is counter-intuitively larger than 1 (as the ¹⁴C/¹²C sample ratio is higher now than it would have been in 1950).

Expected Results and Recommendations:

Recent work suggest that the ¹⁴C-based technique offers a built-in, location-specific correction as an alternative to a background correction, as is often done for contaminated sites. Earlier work on a limited amount of samples suggests that ¹⁴C-corrected results are equivalent to background-corrected results (McCoy et al., 2015; Sihota and Mayer, 2012). However, a recent compilation of 4 sites comparing results from the background correction to the ¹⁴C correction suggests that measured carbon fluxes are highly variable and can differ by up to five times among different locations within the same site (Zimbron and Kasyon, 2015). Depending on the location, the resulting difference between background-corrected and ¹⁴C-corrected estimates can be up to one order of magnitude.


This suggests that the assumption implied by the background correction (that the non-fossil fuel carbon flux is constant for an entire site) might introduce large errors in the background correction of petroleum biodegradation-derived CO₂ fluxes. Contrary to the background correction, the ¹⁴C correction is co-located with the measurement, and thus is spatially unbiased by uncertainties related to differences with respect to the background location(s) (i.e., different vegetation and lithology, unknown impacts, different gas transport regimes, high sensitivity to soil moisture, etc).

The fossil-fuel carbon content of unexposed CO₂ sorbent as used in the traps is non-zero (typically around 30%). This might be the result of processing of the chemical or mineral sources, or of material handling (e.g., exposure to fossil fuel fumes). Although this fossil fuel CO₂ mass is very small, its effects on the results are removed by carrying out a travel blank correction: the mass of fossil fuel CO₂ from an unexposed trap (a travel blank) is subtracted from the masses of fossil fuel CO₂ from field-deployed traps. The ¹⁴C analysis is then performed on CO₂ sorbent sub-samples after homogenization of the entire bottom layer of sorbent, which follows sampling and sample analysis procedures from McCoy et al. (2015).

Study Results

The reported results below are based on proprietary technology used to measure soil gas efflux. All information contained in this report is strictly confidential to the customer. The chemical analysis is based on methods ASTM 4373-14 (Rapid Determination of Carbonate Content of Soils; ASTM, 2014) and ASTM D6866-18 (Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis; ASTM, 2018).

The site-specific results and interpretation are as follows:

	Project: Lansing, MI	Customer: Arcadis	Customer Contact: Dan Stockard	Report Date: 4-Dec-18													
<i>Easy set-up. Expert results.</i>																	
Sample ID	Deployment Dates			Raw Results (not blank-corrected)				Blank-corrected Results ^a		Blank-corrected ¹⁴ C Analysis Results (Fossil Fuel) ^b							
	Deployed	Retrieved	Days	Moisture content, %	Dry Sorbent Mass, g	Avg. CO ₂ ^c , %	CV CO ₂ ^d , %	Carbon Content ^e		CO ₂ Flux, μmol m ⁻² s ⁻¹	Fraction of Modern Carbon, As Reported ^f	Std. Dev., 1σ	Contemporary CO ₂ Flux ^g , μmol m ⁻² s ⁻¹	Adjusted Fossil Fuel Carbon ^h	Grams Of Fossil Fuel CO ₂ , g	Fossil Fuel CO ₂ Flux, μmol m ⁻² s ⁻¹	Equivalent Fossil Fuel-Based NAPL Loss Rate, gal. acre ⁻¹ yr ⁻¹
								%	g								
LSMI-R1-CO2-TB	NA	NA	14.00	19.2%	43.150	1.01%	4.21%	-	-	-	74.55%	0.27%	-	26.9%	-	-	-
LSMI-R1-CO2-01	10/24/18 9:30	11/7/18 12:35	14.13	36.3%	45.900	1.39%	1.81%	0.38%	0.18	0.40	60.34%	0.35%	0.09	40.8%	0.14	0.31	195
LSMI-R1-CO2-02	10/24/18 11:25	11/7/18 11:55	14.02	20.9%	43.740	2.94%	4.94%	1.94%	0.85	1.96	87.99%	0.33%	1.82	13.7%	0.06	0.13	84
LSMI-R1-CO2-03	10/24/18 11:15	11/7/18 12:10	14.04	27.0%	44.310	3.68%	0.25%	2.67%	1.18	2.73	55.08%	0.27%	1.28	46.0%	0.63	1.45	909
LSMI-R1-CO2-04	10/24/18 10:50	11/7/18 11:30	14.03	31.0%	44.150	2.50%	2.57%	1.49%	0.66	1.52	67.85%	0.32%	0.95	33.5%	0.25	0.58	361
LSMI-R1-CO2-05	10/24/18 11:30	11/7/18 11:40	14.01	26.8%	43.990	2.78%	0.17%	1.77%	0.78	1.81	88.95%	0.35%	1.72	12.8%	0.04	0.09	54
LSMI-R1-CO2-06	10/24/18 12:00	11/7/18 12:25	14.02	20.6%	45.510	2.02%	0.78%	1.01%	0.46	1.07	85.71%	0.31%	1.01	16.0%	0.02	0.05	34
LSMI-R1-CO2-07	10/24/18 11:55	11/7/18 11:20	13.98	24.6%	42.680	1.72%	4.56%	0.71%	0.31	0.71	86.09%	0.23%	0.71	15.6%	ND	ND	ND
LSMI-R1-CO2-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LSMI-R1-CO2-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
LSMI-R1-CO2-10	10/24/18 11:45	11/7/18 11:00	13.97	21.6%	45.460	1.33%	1.71%	0.33%	0.15	0.34	83.80%	0.35%	0.38	17.8%	ND	ND	ND

This report contains Confidential Information and is to be delivered only to the Customer indicated above.

See following page for assumptions, project specific quality assurance/quality control information, and notes.

General notes:

- Trap cross sectional area is $8.11 \times 10^{-3} \text{ m}^2$ (i.e., equivalent to a **4-inch** receiver pipe).
- The flux equivalence is $1 \mu\text{mol m}^{-2} \text{ s}^{-1}$ equals **625.2** gallons acre⁻¹ yr⁻¹. This assumes a representative hydrocarbon density of 0.77 g mL^{-1} with the formula C_8H_{18} .
- Carbon analysis of each trap/sample is conducted in duplicate if the coefficient of variation (CV) of the duplicates is $\leq 5\%$. If $\text{CV} > 5\%$, duplicate analyses are repeated until $\text{CV} \leq 5\%$.
- NA = Not Applicable
- ND = Not Detectable

Results Report Notes:

- Results are travel blank-corrected and are not yet ¹⁴C-corrected. Blank Corrected Results = Raw Results - Travel Blank
- Results have been both travel blank- and ¹⁴C-corrected.
- "Avg. CO₂" refers to the measured (not blank corrected) % CO₂ of the dry sorbent mass.
- CV is the coefficient of variation, the ratio of the standard deviation of the % CO₂ to the average % CO₂.
- If the travel blank contains more carbon than a trap, carbon content results (expressed as CO₂, not pure carbon) are reported as ND.
- "As reported" refers to the total measured fraction of modern ($F_{m_{\text{sample}}}$) as it would have been at the time when ¹⁴C testing was developed (1950). This number is reported as pMC (percent of modern carbon) and is converted into F_m for our calculations using the relation $100.0 \text{ pMC} = 1.0 F_m = 100\% F_m$. This value has not been corrected to account for present-day ¹⁴C atmospheric levels.
- "Contemporary" indicates a correction has been applied which accounts for the difference between 1950's and present-day ¹⁴C levels (Stenström et al., 2011). This value is the portion of the total carbon flux derived from present-day (non-fossil fuel) sources.
- "Adjusted fossil fuel carbon" refers to the percentage of carbon in a sample that is derived from fossil fuel CO₂ according to ambient levels of ¹⁴C at the time of sampling. This number is adjusted to account for the increase in atmospheric ¹⁴C levels since 1950.

Quality Assurance / Quality Control Notes:

- The Travel Blank (TB) concentration is **1.01%**; typical TB concentration is $< 2\%$.
- Trap tops are not saturated with CO₂ (sorbent saturation is 30%). The maximum measured (not blank-corrected) top concentration is **1.83%** (sample **LSMI-R1-CO2-02.1**).
- Contemporary carbon fluxes represent the CO₂ contributions from natural soil respiration processes (bio-based CO₂ production) to the total carbon flux; the ¹⁴C analysis corrects for this contribution. Average contemporary CO₂ flux is $1.00 \mu\text{mol m}^{-2} \text{ s}^{-1}$, and the coefficient of variation is **61%**. The range of contemporary CO₂ fluxes is between **0.09** and **1.82** $\mu\text{mol m}^{-2} \text{ s}^{-1}$. If this interference was not removed using the results of the radiocarbon analysis, the error in the NSZD rate estimate would be between **57** and **1141** gallons acre⁻¹ yr⁻¹.
- **Samples LSMI-R1-CO2-07 and LSMI-R1-CO2-10** show non-detectable (ND) fossil fuel CO₂ flux. The entire CO₂ flux for these samples is likely derived from non-fossil fuel sources.
- ASTM 4373-14 QA/QC criteria does not provide acceptable variability (CV) standards. Similar methods (e.g., ASTM D513-16, Total and Dissolved Carbon Dioxide in Water) allow typical errors of $\leq 20\%$. E-Flux practice is that a $\text{CV} \leq 5\%$ for duplicate analyses is acceptable.

Calculation Explanations

Conversion of grams CO₂ to CO₂ Flux:

Calculating the CO₂ flux from grams of CO₂ involves the cross-sectional area of the trap (8.11×10^{-3} m² for a 4-inch receiver), the number of days that the trap was deployed in the field, and the molecular weight of CO₂ (44 g mol⁻¹). Grams of CO₂ is converted to CO₂ flux according to the following equation:

$$\frac{\text{g CO}_2 \cdot \frac{1 \text{ mol CO}_2}{44 \text{ g CO}_2} \cdot \frac{1,000,000 \text{ } \mu\text{mol CO}_2}{\text{mol CO}_2}}{\text{days in the field} \cdot \frac{24 \text{ hr}}{\text{day}} \cdot \frac{3600 \text{ s}}{\text{hr}} \cdot (8.11 \times 10^{-3} \text{ m}^2)} = \frac{\mu\text{mol CO}_2}{\text{m}^2 \cdot \text{s}}$$

Conversion of Fraction of Modern Carbon to Fossil Fuel Carbon:

Fraction of modern (Fm_{sample} , from ¹⁴C analysis) is reported by convention based on ¹⁴C levels from 1950. Because of atomic testing, current environmental ¹⁴C levels are approximately 5% higher than they were in 1950 (Hua et al., 2013). Thus, the equation for calculating the fraction of fossil fuel carbon (ff_{sample}) is derived from the following mass balance:

$$Fm_{\text{sample}} = (ff_{\text{sample}})(Fm_{\text{ff}}) + (1 - ff_{\text{sample}})(Fm_{\text{atm}})$$

Solving for ff_{sample} yields:

$$ff_{\text{sample}} = 1 - \frac{Fm_{\text{sample}}}{Fm_{\text{atm}}}$$

As Fm_{atm} is equal to 1.05, this equation becomes:

$$ff_{\text{sample}} = 1 - \frac{Fm_{\text{sample}}}{1.05}$$

The fraction of contemporary carbon (cc_{sample}) can then be calculated using the relation:

$$cc_{\text{sample}} = 1 - ff_{\text{sample}} = 1 - \left(1 - \frac{Fm_{\text{sample}}}{1.05}\right) = \frac{Fm_{\text{sample}}}{1.05}$$

Calculating Grams of Fossil Fuel CO₂:

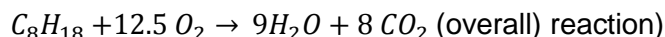
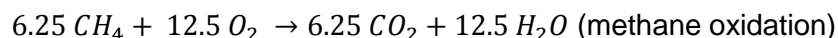
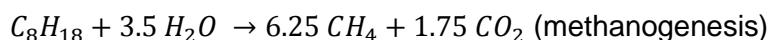
Grams of fossil fuel CO₂ (g CO_{2(ff)}) is calculated by subtracting the total fossil fuel CO₂ in the travel blank (TB) from the total fossil fuel CO₂ in the sample:

$$\text{g CO}_{2(\text{ff})} = \text{g}_{\text{sorbent}} \cdot [((\% \text{CO}_2)_{\text{sample}}(ff_{\text{sample}})) - ((\% \text{CO}_2)_{\text{TB}}(ff_{\text{TB}}))]]$$

Here, $\text{g}_{\text{sorbent}}$ is the mass of sorbent used in the bottom layer of a trap, $(\% \text{CO}_2)_{\text{sample}}$ is the average weight percent of CO₂ in the sample, ff_{sample} is the percent of carbon in the sample derived from fossil fuels, $(\% \text{CO}_2)_{\text{TB}}$ is the average weight percent of CO₂ in the travel blank, and ff_{TB} is the percent of carbon in the travel blank derived from fossil fuels.

Converting Carbon Flux to Equivalent LNAPL Loss Rate:

The intermediate reactions for LNAPL mineralization include methanogenesis (production of methane and CO₂) and the subsequent aerobic oxidation of methane (into CO₂):



Assuming a conservative LNAPL density of 0.77 g/mL (upper range of gasoline) and using the molecular weight of C₈H₁₈ (octane, 114.23 g/mole), μmol m⁻² s⁻¹ of CO₂ can then be converted into gal. acre⁻¹ yr⁻¹:

$$1 \frac{\mu\text{mol CO}_2}{\text{m}^2 \text{ s}} \cdot \left(\frac{1 \mu\text{mol C}_8\text{H}_{18}}{8 \mu\text{mol CO}_2} \right) \left(\frac{\text{mol}}{1 \times 10^6 \mu\text{mol}} \right) \left(\frac{4,046 \text{ m}^2}{1 \text{ acre}} \right) \left(\frac{3600 \text{ s}}{1 \text{ h}} \right) \left(\frac{24 \text{ h}}{1 \text{ d}} \right) \left(\frac{365 \text{ d}}{1 \text{ yr}} \right) \cdot$$

$$\left(\frac{114 \text{ g C}_8\text{H}_{18}}{1 \text{ Mole C}_8\text{H}_{18}} \right) \left(\frac{1 \text{ mL C}_8\text{H}_{18}}{0.77 \text{ g C}_8\text{H}_{18}} \right) \left(\frac{1 \text{ L}}{1000 \text{ mL}} \right) \left(\frac{1 \text{ gal.}}{3.785 \text{ L}} \right) = 625 \frac{\text{gal. C}_8\text{H}_{18}}{\text{acre} \cdot \text{yr}}$$

Note that both the LNAPL formula and its density are assumed, and thus this conversion is subject to uncertainty; however, site specific data can be used if available. Using alternative representative hydrocarbon formulas and densities generally results in conversion factors that are within 10-15% of 625.2 gal acre⁻¹ yr⁻¹. Therefore, the uncertainty associated with these values does not preclude an acceptable estimate.

References

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ATTACHMENT 2

Initial Temperature Data



Temperature Profile Data Sheet
RACER Lansing

LMW-12-01

DTP: NA
 DTW: 12.45
 TD: 14.78
 Date/Time 8/24/2018 16:05
 Surface Elevation 861.14
 TOC Elevation 864.91
 Ambient Temp. 23.4

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
14.78	850.13	850	18.7
13.78	851.13	851	19.3
12.78	852.13	852	20.0
11.78	853.13	853	20.5
10.78	854.13	854	21.1
9.78	855.13	855	21.4
8.78	856.13	856	21.6
7.78	857.13	857	21.8
6.78	858.13	858	22.3
5.78	859.13	859	22.4
4.78	860.13	860	22.7
3.78	861.13	861	23.4
2.78	862.13	862	23.7

Collect readings at 2-foot vertical intervals below 15 feet bTOC,
 and at 1 foot intervals 3-15 ft bTOC
 Stabilization time: 1 minute below the water table, 3 minutes above the water table

Temperature Profile Data Sheet
RACER Lansing

LMW-12-04

DTP: NA
 DTW: 12.38
 TD: 24.9
 Date/Time 8/24/2018 14:25
 Surface Elevation 862.12
 TOC Elevation 864.94
 Ambient Temp. 23.4

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
24.90	840.04	840	15.2
22.90	842.04	842	15.1
20.90	844.04	844	15.5
18.90	846.04	846	16.2
16.90	848.04	848	17.2
15.90	849.04	849	17.7
14.90	850.04	850	18.4
13.90	851.04	851	19.0
12.90	852.04	852	19.6
11.90	853.04	853	19.9
10.90	854.04	854	20.1
9.90	855.04	855	20.3
8.90	856.04	856	20.5
7.90	857.04	857	20.6
6.90	858.04	858	20.8
5.90	859.04	859	21.1
4.90	860.04	860	21.3
3.90	861.04	861	21.5
2.90	862.04	862	21.8

Temperature Profile Data Sheet
RACER Lansing

LMW-12-08

DTP: 9.24
 DTW: 10.68
 TD: 15.49
 Date/Time 8/24/2018 14:55
 Surface Elevation 861.56
 TOC Elevation 864.40
 Ambient Temp. 23.6

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
15.49	848.91	849	18.7
14.49	849.91	850	18.8
13.49	850.91	851	19.4
12.49	851.91	852	20.4
11.49	852.91	853	21.1
10.49	853.91	854	21.9
9.49	854.91	855	22.0
8.49	855.91	856	22.0
7.49	856.91	857	22.1
6.49	857.91	858	22.4
5.49	858.91	859	22.8
4.49	859.91	860	22.9
3.49	860.91	861	23.2

Temperature Profile Data Sheet
RACER Lansing

LMW-14-14D

DTP: NA
 DTW: 14.02
 TD: 24.9
 Date/Time 8/24/2018 15:30
 Surface Elevation 861.90
 TOC Elevation 864.89
 Ambient Temp. 24.9

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
24.90	839.99	840	14.5
22.90	841.99	842	14.5
20.90	843.99	844	15.2
18.90	845.99	846	16.1
16.90	847.99	848	17.3
14.90	849.99	850	18.4
13.90	850.99	851	18.5
12.90	851.99	852	18.8
11.90	852.99	853	19.0
10.90	853.99	854	19.3
9.90	854.99	855	19.7
8.90	855.99	856	20.0
7.90	856.99	857	20.3
6.90	857.99	858	20.5
5.90	858.99	859	20.9
4.90	859.99	860	21.5
3.90	860.99	861	22.0
2.90	861.99	862	22.3

Temperature Profile Data Sheet
RACER Lansing

LMW-15-17D

DTP: NA
 DTW: 12.73
 TD: 27.31
 Date/Time 8/24/2018 14:00
 Surface Elevation 862.2
 TOC Elevation 865.21
 Ambient Temp. 23.6

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
27.31	837.90	838	14.3
25.31	839.90	840	13.7
23.31	841.90	842	14.0
21.31	843.90	844	14.4
19.31	845.90	846	15.1
17.31	847.90	848	16.0
15.31	849.90	850	16.8
14.31	850.90	851	17.5
13.31	851.90	852	18.0
12.31	852.90	853	18.1
11.31	853.90	854	18.1
10.31	854.90	855	18.2
9.31	855.90	856	18.4
8.31	856.90	857	18.9
7.31	857.90	858	19.7
6.31	858.90	859	19.6
5.31	859.90	860	19.8
4.31	860.90	861	20.9
3.31	861.90	862	22.3

Temperature Profile Data Sheet
RACER Lansing

LMW-12-07

DTP: NA
 DTW: 7.38
 TD: 11.96
 Surface Elevation 861.50
 Date/Time 8/24/2018 10:00
 TOC Elevation 864.13
 Ambient Temp.

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
11.96	852.17	852	20.5
10.96	853.17	853	21.2
9.96	854.17	854	22.0
8.96	855.17	855	22.8
7.96	856.17	856	23.5
6.96	857.17	857	23.8
5.96	858.17	858	24.1
4.96	859.17	859	24.2
3.96	860.17	860	24.3
2.96	861.17	861	23.5

Temperature Profile Data Sheet
RACER Lansing

LMW-14-12D

DTP: 11.15
 DTW: 24.88
 TD: 25.05
 Date/Time 8/23/2018 10:09
 Surface Elevation 861.11
 TOC Elevation 864.59
 Ambient Temp. 22.5

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
25.05	839.54	840	15.3
23.05	841.54	842	15.4
21.05	843.54	844	15.7
19.05	845.54	846	16.2
17.05	847.54	848	16.7
15.05	849.54	850	17.4
14.05	850.54	851	17.9
13.05	851.54	852	18.3
12.05	852.54	853	18.8
11.05	853.54	854	19.0
10.05	854.54	855	19.4
9.05	855.54	856	19.8
8.05	856.54	857	20.4
7.05	857.54	858	21.1
6.05	858.54	859	21.9
5.05	859.54	860	22.3
4.05	860.54	861	22.5
3.05	861.54	862	22.4

Temperature Profile Data Sheet
RACER Lansing

LMW-14-15D

DTP: 11.89
 DTW: 22.67
 TD: 22.7
 Date/Time 8/24/2018 12:55
 Surface Elevation 861.66
 TOC Elevation 865.11
 Ambient Temp. 23.4

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
22.70	842.41	842	14.0
20.70	844.41	844	14.3
18.70	846.41	846	14.5
16.70	848.41	848	15.2
14.70	850.41	850	15.9
13.70	851.41	851	16.5
12.70	852.41	852	17.0
11.70	853.41	853	16.9
10.70	854.41	854	17.1
9.70	855.41	855	17.2
8.70	856.41	856	17.4
7.70	857.41	857	17.6
6.70	858.41	858	17.8
5.70	859.41	859	17.9
4.70	860.41	860	18.0
3.70	861.41	861	18.3
2.70	862.41	862	19.2

Temperature Profile Data Sheet
RACER Lansing

LMW-12-03D

DTP: 12.59
 DTW: 12.94
 TD: 25.19
 Date/Time 8/24/2018 12:20
 Surface Elevation 862.08
 TOC Elevation 864.99
 Ambient Temp. 22.8

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
25.19	839.8	840	13.5
24.19	840.8	841	13.8
22.19	842.8	843	14.2
20.19	844.8	845	14.9
18.19	846.8	847	15.7
16.19	848.8	849	16.8
14.19	850.8	851	17.4
13.19	851.8	852	18.2
12.19	852.8	853	17.8
11.19	853.8	854	18.0
10.19	854.8	855	18.3
9.19	855.8	856	18.6
8.19	856.8	857	18.7
7.19	857.8	858	19.1
6.19	858.8	859	19.6
5.19	859.8	860	20.3
4.19	860.8	861	20.5
3.19	861.8	862	20.7

Temperature Profile Data Sheet
RACER Lansing

LMW-14-13D

DTP: NA
 DTW: 12.4
 TD: 24.35
 Date/Time 8/23/2018 11:31
 Surface Elevation 862.06
 TOC Elevation 865.03
 Ambient Temp.

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
24.35	840.68	841	14.1
22.35	842.68	843	14.5
20.35	844.68	845	15.2
18.35	846.68	847	16.1
16.35	848.68	849	17.1
14.35	850.68	851	18.5
13.35	851.68	852	19.3
12.35	852.68	853	19.6
11.35	853.68	854	19.9
10.35	854.68	855	20.6
9.35	855.68	856	21.0
8.35	856.68	857	21.3
7.35	857.68	858	21.9
6.35	858.68	859	22.2
5.35	859.68	860	22.8
4.35	860.68	861	23.0
3.35	861.68	862	23.3

Temperature Profile Data Sheet
RACER Lansing

LMW-15-16D

DTP: 14.74
 DTW: 17.74
 TD: 27.12
 Date/Time 8/23/2018 9:00
 Surface Elevation 862.2
 TOC Elevation 865.2
 Ambient Temp. 22.5

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl) rounded	Temperature
27.12	838.08	838	14.4
24.12	841.08	841	14.8
21.12	844.08	844	15.3
18.12	847.08	847	16.2
15.12	850.08	850	17.2
14.12	851.08	851	17.4
13.12	852.08	852	17.9
12.12	853.08	853	18.3
11.12	854.08	854	18.8
10.12	855.08	855	19.6
9.12	856.08	856	20.5
8.12	857.08	857	21.6
7.12	858.08	858	22.1
6.12	859.08	859	22.9
5.12	860.08	860	23.3
4.12	861.08	861	23.3
3.12	862.08	862	22.9

Temperature Profile Data Sheet
RACER Lansing

MW-14-54

DTP: NA
 DTW: 15.3
 TD: 19
 Date/Time 8/24/2018 16:55
 Surface Elevation 862.21
 TOC Elevation 865.21
 Ambient Temp. 22.6

Depth (ft bTOC)	Elevation (ft amsl)	Elevation (ft amsl rounded)	Temperature
19.00	846.21	846	15.7
18.00	847.21	847	16.0
17.00	848.21	848	16.6
16.00	849.21	849	17.0
15.00	850.21	850	17.4
14.00	851.21	851	17.6
13.00	852.21	852	17.9
12.00	853.21	853	18.2
11.00	854.21	854	18.6
10.00	855.21	855	18.8
9.00	856.21	856	19.4
8.00	857.21	857	19.6
7.00	858.21	858	19.8
6.00	859.21	859	20.0
5.00	860.21	860	20.2
4.00	861.21	861	20.9
3.00	862.21	862	21.3

ATTACHMENT 3

Temperature Profiles



