Natural Source Zone Depletion

July 2022 Assessment

Southern Terminals Group

21 February 2023

→ **The Power of Commitment**

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1. Introduction

On behalf of the Southern Terminals Group (STG); GHD Services Inc. (GHD) is submitting this Natural Source Zone Depletion (NSZD) Report for the Southern Terminals Group (STG) and Cold Springs Terminal (CST), New York State Department of Environmental Conservation (NYSDEC) Spill No. 89-04923, located at 7437 Hillside Road in Lysander, Onondaga County, New York (the 'Site', Figure 1).

1.1 Purpose of this Report

NSZD processes have been shown to account for significant mass losses over time at other sites, and preliminary data gathered from the CST indicated that these processes likely are occurring at the CST as well. The purpose of this report is to summarize a comprehensive NSZD assessment completed at the CST during July 2022 to confirm and quantify the natural, on-going light non-aqueous phase liquid (LNAPL) depletion processes occurring at the CST. The assessment included locations throughout the formerly-developed portions of the CST.

The intent of the assessment was to determine the viability of NSZD (after LNAPL has been recovered to the extent practicable) in accordance with the decision logic diagrams provided in the Revised Remedial Action Work Plan (RAWP, GHD, September 2021, Revised: May 2022). As such, information gathered from the NSZD evaluation event will be used to assist in determining when active recovery of LNAPL is no longer providing an increased benefit over natural processes alone.

1.2 Scope and Limitations

This report has been prepared by GHD for Southern Terminals Group and may only be used and relied on by Southern Terminals Group for the purpose agreed between GHD and Southern Terminals Group as set out in this report.

GHD otherwise disclaims responsibility to any person other than Southern Terminals Group arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions, and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions, and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

The opinions, conclusions, and any recommendations in this report are based on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the Site may be different from the Site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular Site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant Site features and conditions may have been identified in this report.

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2. Site Background

The CST is comprised of three former Petroleum Bulk Storage (PBS) facilities occupying a total of approximately 6 acres of land. The Northern Terminal (NT) is north of Hillside Road. The Southern Terminal (ST) is south of Hillside Road and is subdivided into the southeastern terminal and the southwestern terminal, as shown in Figure 2.

Aboveground storage tanks (ASTs) and portions of their associated aboveground piping were previously removed from the ST by the property owners and/or their contractors circa 2017. As a result, the ST currently consists of deteriorated asphalt pavement, dilapidated office buildings (one on the western end and two on the eastern end), and three petroleum transport truck loading racks along Hillside Road. South of these features and north of the Seneca River, the ST currently consists of two containment areas: the southeastern terminal, and the southwestern terminal, which are in disrepair, overgrown with vegetation, and contain some wet/standing water areas. The entire ST is fenced and is located in an area with residences to the east and west, a cemetery and the NT adjoining to the north, and the Seneca River adjoining to the south.

During their operational histories, the facilities handled gasoline, Jet A fuel, kerosene, diesel, and fuel oil. NYSDEC-mandated environmental activities were initiated following a 1989 spill of an unknown volume of gasoline; however, other spills have been documented. Multiple investigations have occurred at the CST and historical remedial actions at the CST have included manual and automated LNAPL recovery and soil vapor extraction (SVE). These activities were performed adjacent to Hillside Road, beneath the southernmost portion of the NT, and in northernmost portion of the ST. Reportedly, over an 18-year period between 1990 and 2008 (prior to the involvement of these Respondents in the remedial activities), an estimated 12,800 gallons of LNAPL was removed from the CST as liquid and soil vapor (GES, 2015).

The LNAPL area shown on Figures 3 and 4 is based on December 2019 in-well LNAPL observations. Locations and wells used for the NSZD assessment are categorized as being “within”, “adjacent to”, or “outside” this LNAPL area. It should be noted that the areal extent of residual and/or immobile LNAPL will likely be larger than this area where LNAPL is observed in wells, and NSZD would therefore be expected to be active both within and outside what is referred to in this report as the “LNAPL area.” As a result, for this assessment, locations were chosen throughout both the NT and ST to assist in understanding natural biodegradation processes and rates across both areas, as well as providing locations outside current and historically known LNAPL areas in an attempt to establish background reference locations for use in calculations.

3. NSZD Background

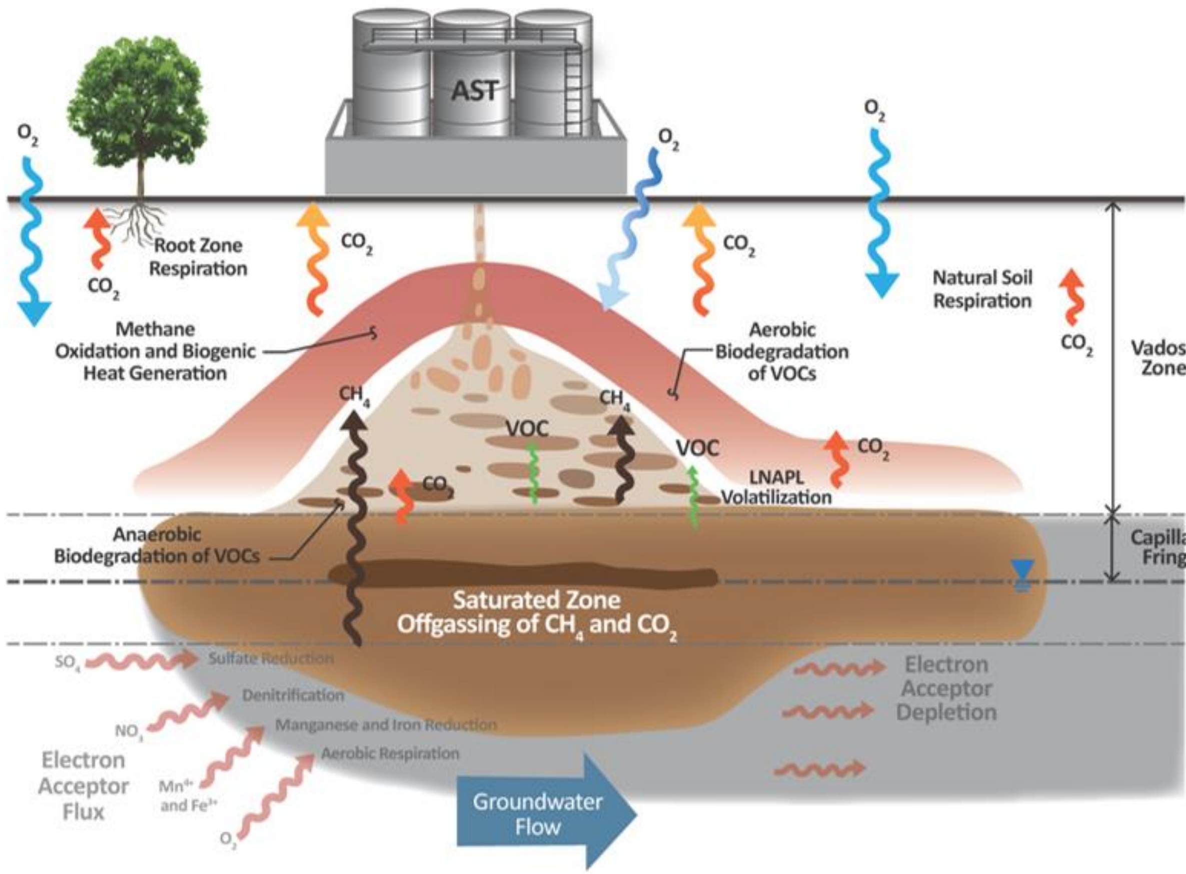
3.1 NSZD

NSZD refers to the degradation of an LNAPL body or LNAPL source zone via a combination of physical, chemical, and biological processes. NSZD of petroleum hydrocarbons, once released to the subsurface, can be universally assumed to be occurring via various mechanisms including dissolution, volatilization, biodegradation of both dissolved and volatilized constituents, and direct biodegradation of the LNAPL itself.

NSZD processes reduce LNAPL mass, saturation, and mobility. The rate of LNAPL biodegradation (NSZD) depends on many factors, including the availability and type of electron acceptors present in the soils and groundwater to enable microbial and/or enzymatic activity[1]. The degradation of LNAPL will generally proceed anaerobically via

[1] Interstate Technology & Regulatory Council (ITRC). *Evaluating Natural Source Zone Depletion at Sites with LNAPL*. LNAPL-1. Washington, D.C.: Interstate Technology & Regulatory Council, LNAPL Teams. April 2009.

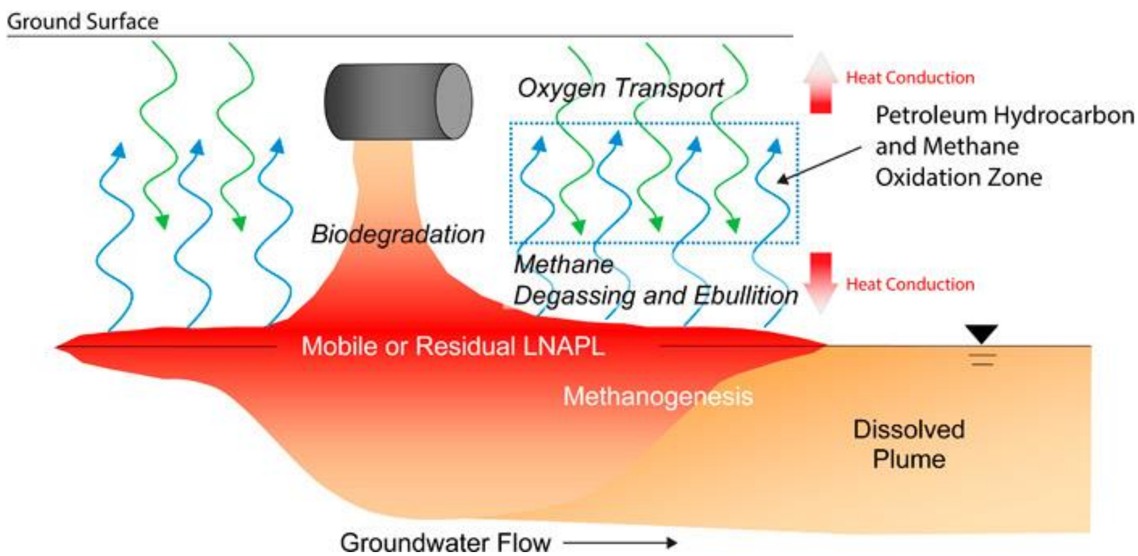
methanogenesis, producing methane (CH_4) and carbon dioxide (CO_2), with CH_4 subsequently oxidized to CO_2 via an exothermic process in the vadose zone. A conceptual depiction of these processes follows:[2].



Since gaseous CO_2 will be the ultimate by-product of LNAPL mineralization, one typical method for screening for vadose zone NSZD processes is to perform a survey of surficial CO_2 efflux within the petroleum-impacted area as compared with background locations. Subsurface soil gas gradient monitoring is a complementary technique involving multi-level gas measurements (CH_4, CO_2, O_2) in existing wells using a handheld multigas analyzer. In general, the observation of O_2 depletion with simultaneous CH_4 and/or CO_2 production in the vadose zone provides confirmation of methanogenic conditions and NSZD activity.

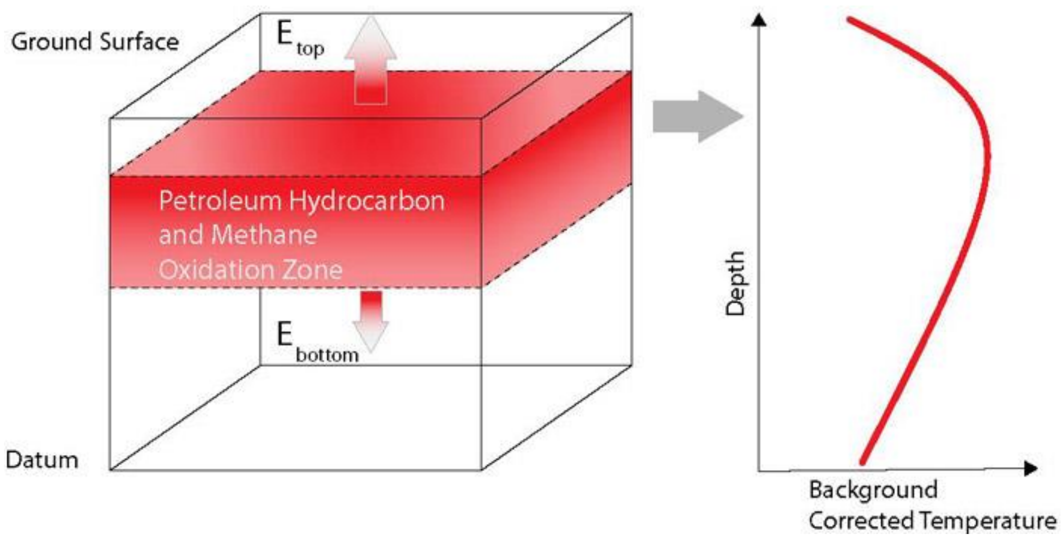
Additionally, the exothermic CH_4 oxidation reaction in the vadose zone presents another potential line of evidence of NSZD. Temperature anomalies within an LNAPL-impacted area compared with areas where LNAPL is not present can provide evidence that NSZD is active, particularly when correlated with other data such as soil gas monitoring results. Vertical subsurface temperature profiling at locations both in and outside of LNAPL-impacted areas can be used to approximate NSZD rates by relating estimates of heat flux above background levels to the heats of reaction for the NSZD processes. The following figure provides a conceptualization of the methane oxidation related to LNAPL degradation and the associated heat conduction from the exothermic reaction.

[2] NSZD conceptualization from American Petroleum Institute (API) Publication #4784 *Qualification of Vapor Phase-related Natural Source Zone Depletion Processes, First Edition.*



Source: ITRC LNAPL-3

As seen below, the heat released during the exothermic methane oxidation reaction can be conceptualized as two-dimensional heat transfer upward toward ground surface and downward toward the water table. This heat transfer can result in temperature anomalies/gradients that reflect this two-dimensional (horizontal and vertical) process when compared to background locations away from the contamination, resulting in a characteristic temperature profile that peaks in the heart of the methane oxidation zone.



Source: ITRC LNAPL-3

These temperature gradients (i.e., temperature change over vertical distance or $\Delta T/\Delta z$) and the summation of the associated heat fluxes form one basis to estimate the rate of NSZD.

And finally, natural attenuation processes play a critical role in the long-term stability of both LNAPL and associated dissolved plumes. It is well established that natural attenuation processes in groundwater dictate the extent and stability of dissolved petroleum hydrocarbon plumes, which is the basis for the application of monitored natural attenuation (MNA) as a groundwater remedy. Similarly, it has been demonstrated that NSZD processes can result in

LNAPL mass loss rates that equal or exceed those associated with active remedial measures that are sufficient to balance residual LNAPL gradients, thereby stabilizing the LNAPL body/footprint.[3]

The NSZD assessment at the CST took a multiple-lines-of-evidence approach to confirming that the LNAPL is actively degrading through direct microbial biodegradation using the following methods:

- **Surficial CO_2 efflux via dynamic closed chamber (DCC)** - A technique that provides initial screening/estimation of NSZD rates via background corrected CO_2 efflux dynamic closed chamber (DCC) measurements. This technique obtains readings over the course of several minutes at a given location, therefore allowing the determination of short term NSZD rates.
- **Surface CO_2 Traps (passive)** - Subsequent CO_2 efflux measurements collected via deployment of passive CO_2 traps at locations based on DCC results. Traps remain in place for one week or more and are submitted for laboratory analysis to isolate the portion of the measured CO_2 efflux that is associated with LNAPL degradation (using radiocarbon dating). Traps provide a more definitive estimation on NSZD rates due to longer collection times and built-in, location-specific background measurements.
- **Subsurface Gradient/Soil Gas Monitoring** - A technique to screen for vadose zone NSZD processes involving multi-level gas measurements (CH_4, CO_2, O_2) in existing CST wells using a handheld multigas analyzer. In-well gas screening measurements are completed at the top and bottom of the vadose zone at select wells to approximate vertical gradients of the target gases. The vertical gas profiles are then used to develop screening-level NSZD estimates.
- **Biogenic Heat Method** - The biogenic heat method involves subsurface vertical temperature profiling at existing wells to screen for evidence of biogenic heat production and provide a supporting line of evidence of NSZD. This method involves measuring temperatures throughout the vadose zone to the top of saturated zone to develop screening-level NSZD estimates.

The ultimate goal of quantifying natural attenuation rates of LNAPL is to assess the applicability of NSZD as a stand-alone, long-term management strategy and/or practical endpoint where the remaining LNAPL predominantly exists in a residual state that is hydraulically immobile and recovery from the subsurface is technically impracticable.

4. NSZD Methodology

The application of each of the NSZD monitoring techniques implemented at the CST is described below. All NSZD methods were performed consistent with the principles and general methodology described by American Petroleum Institute (API), Interstate Technology & Regulatory Council (ITRC), and Cooperative Research Centre for Contaminated Site Assessment and Remediation (CRC CARE).[3,4,5]

4.1 Surficial CO_2 Efflux

The surficial CO_2 efflux rates were measured, background corrected, and then converted to NSZD rates using stoichiometry that indicates that a sustained rate of 1 micromole (µmol) per square meter (m^2) per second of corrected CO_2 efflux corresponds with approximately 625 US gallons LNAPL naturally degraded per acre per year (US gal LNAPL $acre^{-1}$ yr^{-1}) as shown in the derivation below.

The procedure assumes that the average molecular weight of an LNAPL source is appropriately represented by octane (C_8H_{18}). The following stoichiometry describes the process:

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[3] Mahler et al, 2012, *A Mass Balance Approach to Resolving LNAPL Stability*, Groundwater, Volume 50, Number 6, doi: 10.1111/j.1745-6584.2012.00949.x

[4] American Petroleum Institute (API) Publication #4784: *Quantification of Vapor Phase-Related Natural Source Zone Depletion Processes* (May 2017).

[5] Cooperative Research Centre for Contaminated Site Assessment and Remediation (CRC CARE) Technical Report 44: *Technical measurement guidance for LNAPL natural source zone depletion* (August 2018)

Anaerobic Reaction in Vadose Zone (immediately above source)

$C_8H_{18} + 3.5\ H_2O \rightarrow 1.75\ CO_2 + 6.25\ CH_4$

Aerobic Reaction in Vadose Zone (above anaerobic halo)

$6.25\ CH_4 + 12.5\ O_2 \rightarrow 6.25\ CO_2 + 12.5\ H_2O$

Overall Reaction (summation of both reactions)

$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2 + 9\ H_2O$

The molecular weight of octane (C_8H_{18}) is 114.23 g/g·mole[6]. Assuming an LNAPL specific gravity of 0.77 (upper range for gasoline), the conversion of CO_2 efflux to LNAPL loss (NSZD) rate involves the conversion of the CO_2 efflux in units of micromoles per square meter per second to a volumetric rate as follows:

$$1\,\frac{\mu\text{Mole CO}_2}{\text{m}^2\text{ s}} =$$

$$\frac{\mu\text{Mole CO}_2}{\text{m}^2\text{ s}} \times \frac{1\ \mu\text{Mole C}_8\text{H}_{18}}{8\ \mu\text{Mole CO}_2} \times \frac{\text{Mole}}{1 \times 10^6\ \mu\text{Mole}} \times \frac{4{,}046\ \text{m}^2}{1\ \text{acre}} \times \frac{3{,}600\ \text{s}}{1\ \text{h}} \times \frac{24\ \text{h}}{1\ \text{d}}$$

$$\times \frac{365\ \text{d}}{1\ \text{yr}} \times \frac{114.23\ \text{g C}_8\text{H}_{18}}{1\ \text{Mole C}_8\text{H}_{18}} \times \frac{1\ \text{mL C}_8\text{H}_{18}}{0.77\ \text{g C}_8\text{H}_{18}} \times \frac{1\ \text{L}}{1{,}000\ \text{mL}} \times \frac{1\ \text{US gallon}}{3.75\ \text{L}}$$

$$= 625\ \frac{\text{US gallons C}_8\text{H}_{18}}{\text{acre}\cdot\text{yr}}$$

As previously mentioned, CO_2 efflux monitoring and the development of NSZD rate estimates (i.e., estimates of the volume of LNAPL degrading per unit area per year) were completed using CO_2 efflux via dynamic closed chamber (DCC) and passive CO_2 traps.

4.1.1 Dynamic Closed Chamber (DCC)

The DCC is an active sampling device that generates CO_2 efflux estimates over the course of several minutes at a given location. These CO_2 efflux estimates are then used to develop a snapshot of very short term NSZD rates, primarily as a screening tool for follow-up CO_2 trap placement. In order to isolate the portion of the measured CO_2 that is petrogenic from the total CO_2 that will include contributions from modern sources such as plant respiration, a correction is necessary to account for background modern CO_2. Accordingly, the measured CO_2 efflux in the LNAPL-impacted area is typically corrected by subtracting the lowest measured CO_2 efflux obtained from a location(s) with comparable surface cover. The lack of unimpacted areas away from LNAPL and the variability in surface cover at many sites can add considerable complexity in siting suitable background locations. As with most sites, the CST site does exhibit variability in surface cover; however, background locations away from LNAPL were available to consider in correcting CO_2 efflux data,

Soil surface CO_2 efflux was measured at the CST using a LI-COR LI-8100A CO_2 flux monitoring system. The DCC PVC collars were driven into the ground surface with minimal disturbance, allowing for a minimum depth penetration of 2 inches. Prior to placing the DCC on the collar, details of the ground surface soil type and vegetation surface cover (percentage) were recorded. At the CST, all locations were chosen to have as similar as possible surface cover to allow the same background correction at all locations. The ground surface within the sample collar was not disturbed prior to DCC readings; therefore, a lengthy stabilization time was not required prior to measurements being obtained with the DCC. When placed atop the collar, the DCC created an airtight seal over the PVC collar to prevent interference of atmospheric ambient air conditions that can impact the soil gas flux measured within the collar. Duplicate sequential CO_2 flux measurements were collected at each location. The raw data was processed using the manufacturer-supplied software to determine the CO_2 flux rates in units of micromole of CO_2 per square meter per second (μmol CO_2 m^{-2} s^{-1}).

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[6] This is the specific gravity for octane; the standard of practice is to assume octane as the LNAPL surrogate for NSZD calculations.

The background correction methodology introduces some uncertainty in the calculation of NSZD rates. This is due to inevitable variability in surface cover and associated background CO_2 efflux levels notwithstanding efforts to only use locations with visibly consistent surface cover. However, it is thought the use of the lowest rate(s) represents a conservative approach for this method, since non-vegetated background correction would have most likely resulted in a lesser correction and, consequently, a higher corrected NSZD estimate. For the CST, the average of the two lowest CO_2 efflux locations was used as the correction factor. As a comparison, an additional background correction was completed using backgrounds from the CO_2 trap method (see below) once analytical results were obtained. The average of all of the location-specific CO_2 trap bio-based efflux rates (backgrounds) was used, since the bio-based efflux is likely a more reliable measure of non-petroleum-based CO_2. Detailed calculations can be found in Appendix A.

4.1.2 Passive CO_2 Trap

The CO_2 trap is a passive sampling device that contains a solid-state sorbent material. The sorbent is strongly basic, converting the CO_2 that passes through to stable carbonates that are retained in the trap. Traps typically remain in place for a timeframe of one week or more, which provides some level of normalization of the temporally variable CO_2 efflux measurements.

Following the sampling period, traps are analyzed for total CO_2 and petrogenic CO_2 via unstable isotope analysis (^{14}C radiocarbon dating). The unstable isotope ^{14}C is present in modern carbon sources, but due to a half-life of 5,600 years, is not present in fossil fuel carbon sources. Consequently, CO_2 trap analysis involves a 'built-in' location-specific background correction based on analytical data that results in much more reliable petrogenic CO_2 efflux estimation than can reasonably be accomplished via the DCC method alone. Detailed calculations can be found in Appendix B.

4.2 Gradient/Soil Gas

This procedure again assumes that the average molecular weight of an LNAPL source is appropriately represented by octane (C_8H_{18}), with the same stoichiometric reactions as presented above in Section 4.1 for the CO_2 efflux method. The overall reaction is reiterated here:

Overall Reaction

$$C_8H_{18} + 12.5\ O_2 \rightarrow 8\ CO_2\ (g) + 9\ H_2O$$

For the gradient method, the ratio of O_2 to C_8H_{18} is used to determine NSZD rate. The overall reaction indicates 2 moles of C_8H_{18} react with 25 moles of O_2. The molecular weight of C_8H_{18} is 114.23 g/mole and the molecular weight of O_2 is 32g/mole, giving a stoichiometric conversion ratio of $C_8H_{18}:O_2$ = 0.285.

This conversion can be used to determine the amount of octane consumed based on the amount of O_2 depleted. Again, assuming an LNAPL specific gravity of 0.77 (upper range for gasoline), an LNAPL loss rate (NSZD rate) can then be determined by converting the O_2 depleted as follows:

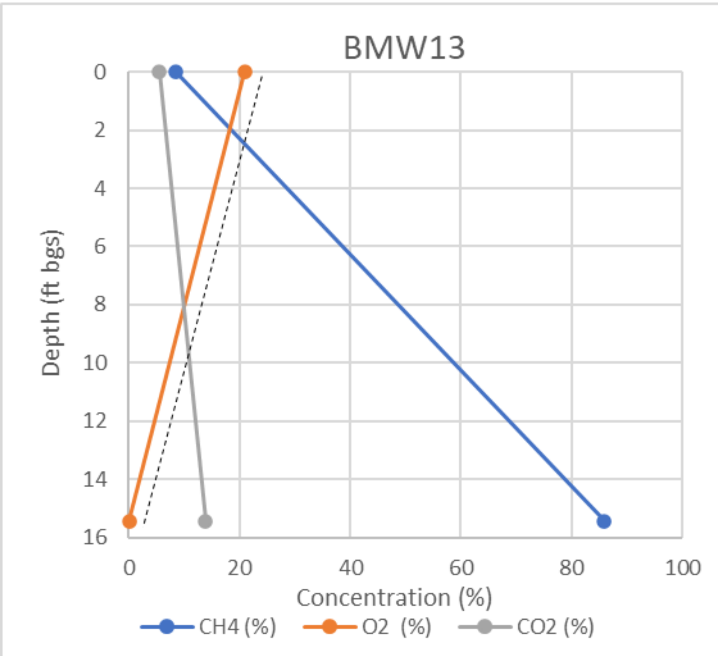
$$1\ \frac{g\ O_2}{m^2\ d} \times 0.285 \frac{g\ C_8H_{18}}{g\ O_2} \times \frac{1}{770 \frac{g\ HC}{L}} \times \frac{1\ \text{U.S. gal}}{3.785\ L} \times \frac{4{,}047\ m^2}{1\ \text{acre}} \times \frac{365\ d}{1\ yr}$$

$$= 139.0\ \frac{\text{US gallon}\ C_8H_{18}}{\text{acre} \cdot \text{yr}}$$

Therefore, approximately 139 US gallons of LNAPL are degraded per acre per year given a sustained O_2 depletion rate of one gram per square meter per day.

Developing this line of evidence involved the assessment of a 2-point gradient for O_2 in soil gas in existing wells. For each well, the atmospheric level of O_2 (20.9%) was assumed to represent ambient conditions at surface, with O_2 concentration measured at depth in the vadose zone for the second point approximately 1 foot above the air/liquid interface (i.e., near LNAPL where well screen is open to the subsurface) using a handheld multigas analyzer. An example of these target gas gradients is shown below in Graph 1, with the dotted black line indicating the decreasing O_2 concentration (O_2 gradient) used in determining NSZD rates.

Additionally, a qualitative assessment of NSZD activity can be evaluated through relative patterns of increasing and decreasing CH_4, CO_2, and O_2 gas concentrations with depth. When NSZD is occurring, increases in CH_4 and CO_2 levels will be observed at depth, while decreases in O_2 levels are observed moving down through the vadose zone. Examples of this can also be seen below in Graph 1. Observation of these concentration trends provides an additional line of evidence supporting the presence of NSZD activity.



Graph 1 Example soil vapor gradients

The O_2 soil gas gradient from BMW13 was used for background correction of the other locations in order to isolate the oxygen consumption associated with NSZD activity. Parameters used in converting soil gas gradients into NSZD rates, such as the effective vapor diffusion coefficient for O_2, are based on site-specific conditions or guidance such as the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) Technical Report 44 and are included with calculation details in Appendix C.

4.3 Biogenic Heat

The biogenic heat method uses temperature gradients within an LNAPL-contaminated zone along with known heats of reaction and stoichiometry to estimate NSZD rates based on the heat released during the oxidation of petrogenic methane in the vadose zone. The method was first described by Sweeney & Ririe[7], and has been further elaborated on by Warren & Bekins[8], ITRC, API, and CRC CARE since.[4,5,6]

Background-corrected temperature gradients are used as the basis for the estimates. The temperature gradients are converted to heat fluxes according to the following equation: [4,8]

[7] Sweeney, R.E., and G.T. Ririe. 2014. *Temperature as a Tool to Evaluate Aerobic Biodegradation in Hydrocarbon Contaminated Soil*. Groundwater Monitoring & Remediation (doi:10.1111/gwmr.12064).

[8] Warren, E., and B.A. Bekins. 2015. *Relating subsurface temperature changes to microbial activity at a crude oil-contaminated site*. Journal of Contaminant Hydrology (doi: 10.1016/j.jconhyd.2015.09.007).

$q_h = -K_T(\Delta T/\Delta z)$,

where: q_h = heat flux ($J/m^2/s$)

$-K_T$ = thermal conductivity of the soil/rock (J/s/m/˚C)

$\Delta T/\Delta z$ = temperature gradient (˚C/m)

Thermal conductivities are typically derived from reference material on the thermal properties of soil/rock. The total heat flux, q_T, is then represented by the summation of the heat fluxes upwards and downwards as follows:[4,8]

$q_T = -K_T(\Delta T/\Delta z)_{upward} - K_T(\Delta T/\Delta z)_{downward}$

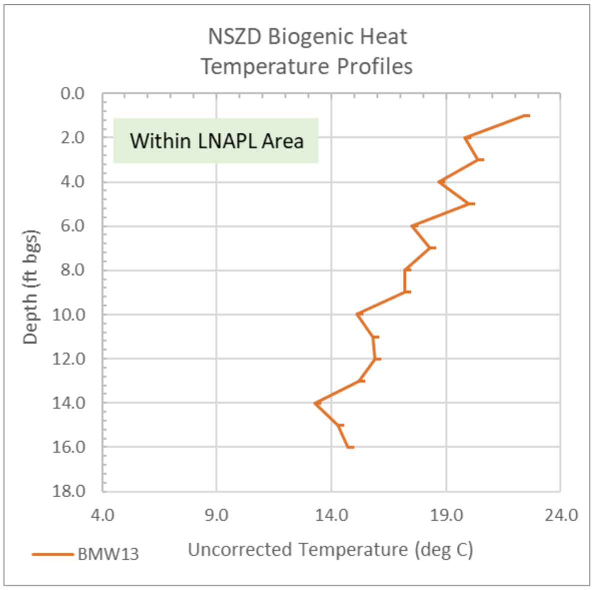
The ultimate estimation of the NSZD rate is facilitated by dividing the total heat flux, q_T, by the heat of reaction for the methane oxidation reaction as shown below:

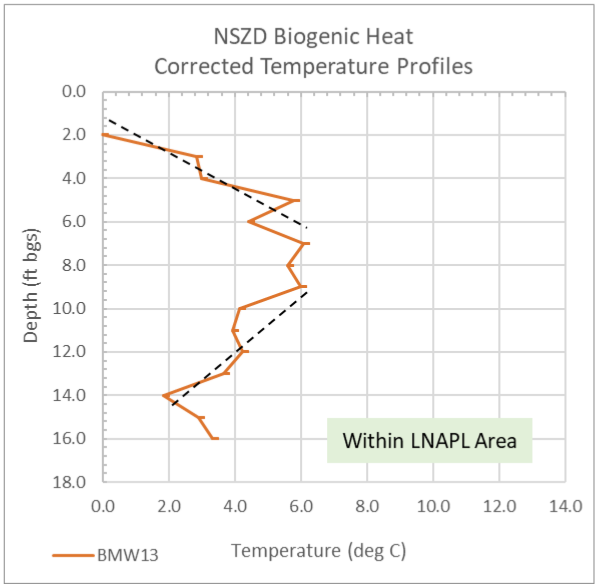
$R_{NSZD} = q_T/\Delta H_{rxn}$,

where: R_{NSZD} = NSZD rate (g hydrocarbon degraded/m^2/s)

ΔH_{rxn} = heat of reaction (J/g)

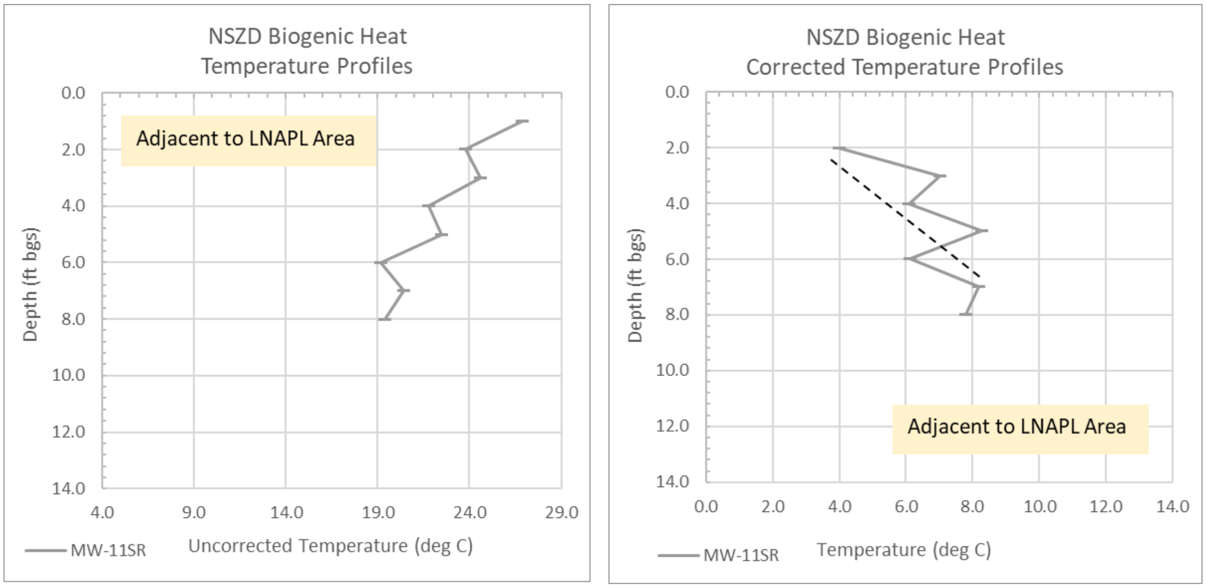
Instantaneous or "snapshot" temperature profiles were mapped with a handheld temperature meter and multi-level thermocouple string. Temperature profiles in each well start near ground surface and terminate below the water table, with measurements spaced at 1-foot intervals. Near-surface measurements are disregarded for NSZD rate determination due to potential surface effects. The background correction for biogenic heat calculations was performed using a modeled subsurface background temperature profile rather than wells proposed as outside the LNAPL area (see Section 4.4 for further discussion on the modelling of subsurface temperature profiles). The temperature profiles from the model aligned well with the profiles from the proposed background wells. However, the background wells were too shallow to allow a background correction in all wells used for the assessment, so the modeled profile was used. An example of uncorrected (as measured) and corrected (background temperatures subtracted) subsurface temperature profiles are provided below in Graph 2. A typical temperature anomaly can be seen in the corrected temperature profile on the right. The slopes used for the up and down temperature gradient calculations are denoted by dashed black lines.





Graph 2 Site example of uncorrected temperature profile (left) and corrected temperature profile (right) with upward and downward gradients

For the CST, some of the temperature anomalies are dominated by the upward temperature gradient. An example from the CST can be seen below in Graph 3. The slope used for NSZD rate calculation associated with the upward gradient is indicated with the dashed black line.



Graph 3 ***Site example of uncorrected temperature profile (left) and corrected temperature profile (right) with only upward gradient***

Some assumptions were used during the calculation of NSZD rates based on the biogenic heat method, as is typical with these types of estimates. Summarizing the CST geology into a single geologic profile and representing this soil profile with a single value for thermal conductivity were necessary simplifications, in part due a lack of site-specific information regarding such parameters. However, the assumptions and values used were based on site-specific materials and information to the degree possible. Parameters used in the biogenic heat rate calculations are included with calculation details in Appendix D.

4.4 Modeling of Background Subsurface Temperature Profiles

Where background soil temperature monitoring locations are not available (e.g., no locations that are well away from current or historical LNAPL, offsite in areas without legal access permission), then estimated background soil temperatures can be determined through mathematical means. The sinusoidal Van Wijk & de Vries[9] (1963) function provides an analytical solution to estimate subsurface temperatures based on ambient temperature variation, key soil properties, and curve fitting constants as discussed in literature such as Sweeney & Ririe (2014) and CRC CARE Technical Report no. 44. The Van Wijk & de Vries (1963) function is shown below:

$T(z,t) = To + Ao * (e^{-z/D} * \sin(wt - z/D + \psi))$,

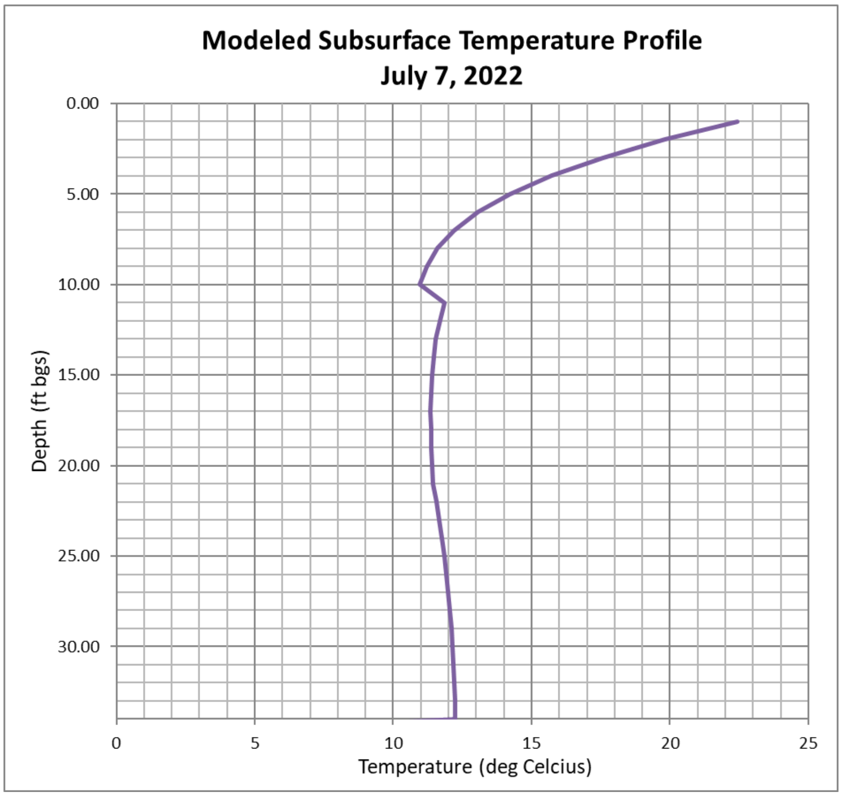
where T(z,t) is the soil temperature (°K) at depth z (m) and time t (s), T_o is the mean annual ambient temperature (°K), A_o is the amplitude of the sinusoidal curve (°K), w is the angular frequency (s^{-1}) equal to $2\pi/P$ where P is the period of the sinusoidal curve (s) typically set to 365 days, D is equal to $2*\alpha^{0.5}/w$ where α is thermal diffusivity of the soil (m^2/s), and Ψ is a phase shift curve fit parameter (s).

[9] Van Wijk, WR & de Vries, DA 1963, 'Periodic temperature variations in a homogeneous soil', in WR Van Wijk (ed) Physics of Plant Environment, North-Holland Publishing Company, Amsterdam.

Daily average temperature meteorological data were downloaded from a nearby weather station, Syracuse Hancock International Airport station, for approximately one and a half years prior to the field event (1/1/2020 through 7/8/2022). The data were tabulated in an Excel worksheet, and a sinusoidal curve was fit to the data. The curve fit equation (the Van Wijk & de Vries function for Z = 0 m) becomes $T = To + A_0 \sin(\omega t + \psi)$. The mean ambient temperature T_0 and mean amplitude A_0 were determined from the meteorological data set, with P assigned the standard value of 365 days. To determine the phase-shift necessary for the model to lineup with actual temperatures, the curve fit sinusoidal wave is overlaid on the plot of historical surface temperatures.

The background soil temperatures were then estimated using the Van Wijk and de Vries function and determined parameters (T_0, A_0, and Ψ) the background soil temperatures were estimated and tabulated for each measurement depth.

For the CST, estimated subsurface background temperatures for July 7, 2022 were used for biogenic heat background corrections, which were then used in soil gas gradient calculations. The modelled background surface temperature profile is shown below in Graph 4.



Graph 4 ***Modelled subsurface temperature profile for CST for date of biogenic heat assessments***

5. NSZD Results

5.1 Surficial CO_2 Efflux - DCC

The DCC field screening event was performed over four days in July 2022 (14th, 15th, 19th, and 20th), and included 55 locations spread over the NT and ST, within, adjacent to, and outside the LNAPL area, as shown in Figure 3. Surface cover type, which is important for determining background correction, was recorded for each location. At the CST, all locations were chosen to have as similar as possible surface cover to support consistent background correction at all locations. The mean of the two locations with the lowest CO_2 efflux (CS-DCC-01 and CS-DCC-03) was used for background correction. These two locations were located in the ST outside the LNAPL area. DCC field data and detailed calculations are included in Appendix A.

The results of the DCC CO_2 efflux screening indicated that NSZD activity is occurring in the NT and ST, at locations within, adjacent to, and outside the current LNAPL area, with no obvious distinction between these areas. Estimated NSZD rates ranged from 998 to 11,413 gal LNAPL acre^{-1} yr^{-1}, and the average NSZD rate was 3,417 gal LNAPL acre^{-1} yr^{-1}. This average rate is of a 'typical' magnitude based on GHD's experience in quantifying LNAPL NSZD rates at numerous/varied sites, along with what others have reported in the literature. For context, an NSZD/LNAPL loss rate of 1,000 gal acre^{-1} yr^{-1} is approximately equivalent to a loss of 1 mm of LNAPL thickness per year. DCC results are reported below in Table 5.1.

As noted on the table, there was a measurement error in some of the data. This error was not evident in the field but was observed in post-processing of the raw data files. It is believed this error was due to a hose that apparently disconnected during the last day of testing and went unnoticed. It is believed that this error had little impact on the integrity of the DCC evaluation since the DCC results were used at a screening level, effected locations were all in the NT outside the current LNAPL area, and multiple other NSZD monitoring techniques were used as part of this overall effort.

The DCC results were used as screening level to direct further NSZD CO_2 efflux assessment using CO_2 traps (discussed in Section 5.2). Since determining an appropriate background location for the DCC method produces some uncertainty, even from locations that can appear similarly vegetated (see method Section 4.1.1), the DCC results were also corrected using the CO_2 trap bio-based efflux for background correction since this is a more reliable measure of non-petroleum-based CO_2. The CO_2 efflux from the DCC survey used for background correction was 1.23 µmol m^{-2} s^{-1}. The bio-based (background) CO_2 efflux measured by the traps ranged from 3.14 to 10.55 µmol m^{-2} s^{-1}. The average efflux of 6.51 µmol m^{-2} s^{-1} was used for the additional DCC background correction. Based on the bio-based background correction, the DCC NSZD rates were either non-detect or fell in the range from 93 to 8,115 gal LNAPL acre^{-1} yr^{-1}, with an average of 985 gal LNAPL acre^{-1} yr^{-1}. The results from both background correction methods are summarized below on Table 5.1.

Table 5.1 NSZD rates - DCC CO_2 Efflux

DCC Location ID	NSZD Estimate (gallons LNAPL degraded per acre per year)		Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
	Background Corrected with DCC Background Locations	Background Corrected with Average of Bio-Based CO_2 Efflux from CO_2 Traps	
CS-DCC-01	Background correction location	0	ST; Outside
CS-DCC-02	2,516	0	ST; Outside
CS-DCC-03	Background correction location	0	ST; Outside
CS-DCC-04	2,174	0	ST; Outside
CS-DCC-05	11,413	8,115	ST; Outside
CS-DCC-06	4,517	1,218	ST; Outside
CS-DCC-07	1,500	0	ST; Outside
CS-DCC-08	5,206	1,907	ST; Outside
CS-DCC-09	1,552	0	ST; Adjacent
CS-DCC-10	4,679	1,381	ST; Within
CS-DCC-11	4,572	1,274	ST; Within
CS-DCC-12	1,514	0	ST; Within
CS-DCC-13	3,254	0	ST; Adjacent
CS-DCC-14	2,616	0	ST; Outside
CS-DCC-15	4,082	783	ST; Within

DCC Location ID	NSZD Estimate (gallons LNAPL degraded per acre per year)		Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
	Background Corrected with DCC Background Locations	Background Corrected with Average of Bio-Based CO_2 Efflux from CO_2 Traps	
CS-DCC-16	2,265	0	ST; Within
CS-DCC-17	2,404	0	ST; Within
CS-DCC-18	998	0	ST; Within
CS-DCC-19	1,628	0	ST; Within
CS-DCC-20	3,273	0	ST; Within
CS-DCC-21	3,394	0	ST; Within
CS-DCC-22	3,185	96	ST; Within
CS-DCC-23	3,392	0	ST; Adjacent
CS-DCC-24	4,386	93	ST; Within
CS-DCC-25	3,003	1,087	ST; Within
CS-DCC-26	2,449	0	ST; Within
CS-DCC-27	1,744	0	ST; Outside
CS-DCC-28	1,369	0	ST; Within
CS-DCC-29	7,242	0	ST; Within
CS-DCC-30	2,634	3,944	ST; Within
CS-DCC-31	2,747	0	ST; Within
CS-DCC-32	2,053	0	ST; Within
CS-DCC-33	2,769	0	ST; Within
CS-DCC-34	5,129	0	ST; Outside
CS-DCC-35	5,437	1,831	NT; Outside
CS-DCC-36	5,094	2,139	NT; Outside
CS-DCC-37	5,623	1,796	NT; Outside
CS-DCC-38	5,399	2,324	NT; Within
CS-DCC-39	6,823	2,101	NT; Adjacent
CS-DCC-40	9,389	3,525	NT; Outside
CS-DCC-41	6,391	6,091	NT; Outside
CS-DCC-42	3,096	3,092	NT; Outside
CS-DCC-43	2,166	0	NT; Outside
CS-DCC-44	4,527	0	NT; Outside
CS-DCC-45	measurement error	measurement error	NT; Outside
CS-DCC-46	measurement error	measurement error	NT; Outside
CS-DCC-47	measurement error	measurement error	NT; Outside
CS-DCC-48	measurement error	measurement error	NT; Outside
CS-DCC-49	4,578	1,280	NT; Outside
CS-DCC-50	measurement error	measurement error	NT; Outside
CS-DCC-51	measurement error	measurement error	NT; Outside

DCC Location ID	NSZD Estimate (gallons LNAPL degraded per acre per year)		Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
	Background Corrected with DCC Background Locations	Background Corrected with Average of Bio-Based CO_2 Efflux from CO_2 Traps	
CS-DCC-52	measurement error	measurement error	NT; Outside
CS-DCC-53	measurement error	measurement error	NT; Outside
CS-DCC-54	measurement error	measurement error	NT; Outside
CS-DCC-55	measurement error	measurement error	NT; Outside
Average	**3,417**	**985**	

5.2 Surficial CO_2 Efflux – Passive CO_2 Traps

Ten (10) CO_2 traps, supplied by E-Flux of Fort Collins, Colorado, were deployed at the CST on August 11, 2022, following E-Flux standard operating procedures. Sampling locations are shown in Figure 3 and were selected based on the NSZD estimates obtained from the DCC sampling with the following considerations:

1. Geographic coverage of the NSZD assessment area
2. Apparent CO_2 efflux anomaly from DCC testing or lack thereof (for verification of low/zero NSZD rates)
3. NSZD activity observed using other assessment methods

Once deployed, the traps remained in place and undisturbed until retrieval. The ten sample traps were collected on August 22, 2022 and shipped to E-Flux along with one un-deployed trap (trip blank) for laboratory analysis.

Eight of the ten deployed CO_2 traps confirmed the occurrence of NSZD, indicating the LNAPL body is actively biodegrading at the CST. The NSZD rates from this method ranged from 26 to 4,800 gal LNAPL $acre^{-1}$ yr^{-1}, with NSZD processes observed in both the NT and the ST at an average rate of 1,230 gal LNAPL $acre^{-1}$ yr^{-1}. The three lowest results (two non-detects and a single location with a very low NSZD rate of 26 gal LNAPL $acre^{-1}$ yr^{-1}) were in the NT outside the current LNAPL area. The two highest results were in the ST both within and outside the current LNAPL area. The laboratory CO_2 trap results are summarized below in Table 5.2.

Although CO_2 traps provide a longer-term average than the DCC method, which reduces effects from barometric pressure changes and have a “built-in” background at each location, soil moisture can reduce the CO_2 efflux signal reaching the surface and the CO_2 traps, thus biasing results low. A heavy rain event occurred after 10 days of CO_2 trap deployment and heavy precipitation was forecast to continue for several more days. As a result, it was decided best to retrieve the traps since additional collection of CO_2 by the traps was unlikely and the chance of the traps becoming saturated with water was elevated. Therefore, the traps were removed after 11 days of deployment, which is within the recommended deployment timeframe. Due to the large amount of precipitation that fell in the 24-hour period prior to retrieval, GHD had discussions with E-Flux and it was determined that the calculations should be based on a shortened period of a 10-day deployment timeframe. This timeframe reflects the time period that soil gas was able to freely flow into and through the traps prior to the saturation of shallow soil from precipitation. This change is shown in the revised COC included with the E-Flux analytical report in Appendix B. Nonetheless, the results could be biased low due to precipitation saturating shallow soil to some extent, thereby limiting the free flow of soil gas into the CO_2 traps.

Table 5.2 NSZD Rates - CO_2 Traps

Location ID	NSZD Estimate (gallons LNAPL degraded per acre per year)	Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
CO2-1	192	NT; outside
CO2-2	26	NT; outside
CO2-3	Non-detect	NT; outside
CO2-4	Non-detect	NT; outside
CO2-5	721	NT; within
CO2-6	573	NT; within
CO2-7	435	ST; within
CO2-8	2,749	ST; within
CO2-9	347	ST; within
CO2-10	4,800	ST; outside
Average	**1,230**	
Notes: ***Average does not include non-detect locations.**		

5.3 Gradient/Soil Gas

Gas screening measurements were completed in 21 existing wells located in the NT and ST on July 11, 12, and 13, 2022. Well locations included within, adjacent to, and outside the current LNAPL areas and are shown in Figure 3. In-well measurements were collected in the vadose zone near the surface and at a depth approximately 1 foot above the air/liquid interface in each well.

Soil gas profiles provided two methods to confirm the occurrence of NSZD at the CST. The first method allowed the determination of NSZD rates based on vertical profiles of O_2 concentration and stoichiometry. The second method provided a qualitative confirmation of NSZD based on observation of the expected trends in soil gas levels that correspond to NSZD processes.

The results of the stoichiometric method indicated that NSZD activity is occurring in the NT and ST at locations within, adjacent to, and outside the current LNAPL area based on the O_2 gas profiles with no obvious distinction between these areas. Estimated NSZD rates ranged from 832 to 3,833 gal LNAPL acre^{-1} yr^{-1}, and the average NSZD rate was 2,256gal LNAPL acre^{-1} yr^{-1}.

The second method confirmed these results are associated with NSZD processes as evidenced by the expected trends in soil gas concentrations. More specifically, the presence/profile of methane in the multigas measurements along with an increase in CO_2 levels and a simultaneous decrease in O_2 levels as depth in wells increased are typical observations where NSZD processes are active. This method confirmed LNAPL degradation (NSZD) in 19 of the 21 wells. Minimal trends were observed in well BMW6, which was determined to provide the best profile background correction for the stoichiometric method. The results for well MW-205 were inconclusive, as the fluid elevation was high in this well, resulting in a shallow vadose zone which limited measurements to the top 2 feet of the well. A summary of NSZD rate estimates and confirmation trends is provided in Table 5.3 below, with detailed calculations and trend plots in Appendix C.

Table 5.3 NSZD rates – gradient method

Soil Gas Location ID	NSZD Estimate – Stoichiometric Analysis (gallons LNAPL degraded per acre per year)	NSZD Confirmation – Trend Analysis (CH_4 ↑, CO_2 ↑, O_2 ↓)	Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
RW-1	3,413	CH_4, CO_2 & O_2	ST; within
RW-2	3,096	CH_4, CO_2 & O_2	ST; within
RW-3	3,833	CH_4, CO_2 & O_2	ST; within
RW-5	3,128	CH_4, CO_2 & O_2	ST; within
MW-5SR	3,564	CH_4, CO_2 & O_2	ST; within
A10	3,559	CH_4, CO_2 & O_2	ST; within
BMW5	1,069	CH_4, CO_2 & O_2	NT; within
BMW13	1,832	CH_4, CO_2 & O_2	NT; within
MW-11SR	2,808	CO_2 & O_2	ST; adjacent
MW-12S	1,299	CO_2 & O_2	ST; adjacent
AMW7	1,501	CO_2 & O_2	ST; adjacent
A9	2,069	CH_4, CO_2 & O_2	ST; adjacent
MW-8S	2,310	CH_4, CO_2 & O_2	ST; adjacent
MW-10S	2,897	CO_2 & O_2	ST; adjacent
BMW14R	1,328	CO_2 & O_2	NT; adjacent
BMW6	Background reference	minimal changes	NT; adjacent
MW-205	Inconclusive – shallow vadose zone	-	NT; outside
MW-208	1,257	CH_4, CO_2 & O_2	NT; outside
MW-211	832	CO_2 & O_2	NT; outside
AMW4	917	CO_2 & O_2	ST; outside
MW-204	2,152	CO_2 & O_2	NT; outside
Average	**2,256***		

Notes:
*Average does not include background reference or inconclusive results.

5.4 Biogenic Heat

Instantaneous or “snapshot” temperature profiles were collected on July 7, 2022, with a handheld temperature meter and multi-level thermocouple string in the same CST wells used for the gradient assessment, as shown in Figure 3. Vertical temperature measurements were spaced at 1-foot intervals starting near ground surface and ending with the last measurement below the water table in each location. A modeled subsurface temperature profile was used for background correction due to a lack of an appropriate profile for background correction from wells as discussed in Section 4.3. Calculations and the full collection of temperature profiles including all uncorrected (including water table) and corrected profiles (vadose zone only) are provided in Appendix D.

Temperature anomalies corresponding to NSZD activity were observed in 17 of the 21 wells used in the analysis, confirming the presence of an active methane oxidation zone. Four of the wells were determined to be inconclusive, as their temperature profiles did not exhibit a clear or obvious temperature anomaly. Well MW-205 had a shallow vadose zone. Overall, observed maximum temperature anomalies ranged from 0.5-7.5˚C at monitoring locations compared with the modeled background. The associated NSZD rate estimates ranged from 1,104 to 11,414 gal LNAPL $acre^{-1}$ yr^{-1}, and the average NSZD rate was 4,012 gal LNAPL $acre^{-1}$ yr^{-1}. Results are summarized on Table 5.4 below, with calculations provided in Appendix D.

Table 5.4 NSZD rates - biogenic heat method

Biogenic Heat Well ID	NSZD Estimate (gallons LNAPL degraded per acre per year)	Location: Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
RW-1	inconclusive	ST; within
RW-2	inconclusive	ST; within
RW-3	inconclusive	ST; within
RW-5	10,346	ST; within
MW-5SR	8,710	ST; within
A10	2,763	ST; within
BMW5	2,414	NT; within
BMW13	2,438	NT; within
MW-11SR	1,142	ST; adjacent
MW-12S	11,414	ST; adjacent
AMW7	5,336	ST; adjacent
A9	4,146	ST; adjacent
MW-8S	2,308	ST; adjacent
MW-10S	2,808	ST; adjacent
BMW14R	2,788	NT; adjacent
BMW6	1,999	NT; adjacent
MW-205	inconclusive – shallow vadose zone	NT; outside
MW-208	1,104	NT; outside
MW-211	1,281	NT; outside
AMW4	4,200	ST; outside
MW-204	3,012	NT; outside
Average	**4,012***	

Notes:
*Average does not include inconclusive results.

It is noted that corrected temperature profiles were dominated by the upward gradient in wells RW-5, MW-5SR, A10, MW-11SR, MW-8S, and MW-10S. The lack of a downward gradient is most likely due to a shallower vadose zone. This limitation is expected to underestimate NSZD rates for the biogenic heat method in these wells.

In general, the biogenic heat-based estimates are comparable to the CO_2 efflux-based estimates, indicating a similar magnitude of NSZD activity. These results constitute independent lines of evidence that LNAPL at the CST is actively biodegrading.

6. Discussion

This evaluation demonstrated that NSZD is occurring throughout the survey area at the CST in locations within, adjacent to, and outside the LNAPL area. These active NSZD areas occur on both the NT and the ST and are indicated on Figure 4. Based on the results, calculated LNAPL biodegradation rates for the NSZD methods employed range from 26 up to 11,414 gal LNAPL $acre^{-1}$ yr^{-1}. Due to differences in approach (i.e., specific NSZD process targeted) and necessary assumptions described above for each method, these results should be considered order of magnitude estimates. The range of rates are summarized below in Table 6.1 by method.

Table 6.1 Summary of NSZD degradation rates from July/August 2022 assessment

NSZD Method	NSZD Rate Estimates (U.S. gallons LNAPL per acre per year)	Notes:
CO_2 Efflux - DCC	998 - 11,413	45 locations with results 10 measurement errors
CO_2 Efflux – DCC (using bio-based background)	93 - 8,115	19 locations with results 26 non-detect 10 measurement errors
CO_2 Efflux - CO_2 Traps	26 - 4,800	8 locations with results 2 non-detects
Gradient / Soil Gas	832 – 3,833	19 locations with results 1 background location 1 inconclusive result
Biogenic Heat	1,104 - 11,414	17 locations with results 4 inconclusive results

A location-specific comparison of NSZD rate estimates from the various NSZD assessment methods used in 2022 are summarized in Table 6.2 below. This comparison was limited to the locations used for the CO_2 trap measurements that also provided representative data from independent lines of evidence employed during the 2022 assessment.

Table 6.2 Location-specific NSZD rate comparisons

CO_2 Traps		Nearest DCC			Nearest NSZD Well			Site Location
CO_2 Trap ID	NSZD Estimate	DCC ID	NSZD Estimate Corrected with lowest DCC bkgr	NSZD Estimate Corrected with mean CO_2 trap bkgr	Well ID	NSZD Estimate Gradient method	NSZD Estimate Biogenic heat method	Terminal (NT or ST) & Current LNAPL Area (within, adjacent to, outside)
CO2-2	26	DCC-44	4,578	1,229	MW-208	629	1,104	NT; outside
CO2-4	no detect	DCC-41	6,391	3,092	MW-211	416	1,281	NT; outside
CO2-5	721	DCC-38	5,399	2,101	BMW13	916	2,438	NT; within
CO2-6	573	DCC-35	5,437	2,139	BMW5	534	2,414	NT; within
CO2-7	435	DCC-29 DCC-30 DCC-31 DCC-32	7,242 2,634 2,747 2,053	3,944 0 0 0	RW-1	1,707	inconclusive	ST; within
CO2-8	2,749	DCC-21 DCC-22 DCC-24	3,394 3,185 4,386	96 0 1,087	RW-2, RW-3	1,548 1,916	inconclusive, inconclusive	ST; within
CO2-9	347	DCC-16a DCC-16b	2,836 2,265	0 0	RW-5	1,564	10,346	ST; within
Average NSZD rate		**2,128**	**gal/acre/yr**					

Notes:
All NSZD rate units in gal LNAPL per acre per year
NT = North Terminal
ST = South Terminal

The CST-wide average NSZD rate based on the results in Table 6.1 is on the order of 2,000 gal LNAPL acre^{-1} yr^{-1}, which is comparable to the typical site-wide average LNAPL depletion rates that have been observed by GHD and documented in the literature (e.g., see, Garg et al 2017 and CRC CARE Technical Reports 46 and 47).

The ultimate goal of assessing the occurrence of LNAPL natural attenuation via NSZD is to evaluate its potential use as a long-term LNAPL management strategy. In order to do this, the evaluation results must support that a transition from active LNAPL recovery to a nature-based solution is appropriate. This transition is considered technically appropriate when a practical endpoint to mechanical LNAPL recovery has been reached, where the remaining LNAPL predominantly exists in a state of residual saturation that is hydraulically immobile and unrecoverable, and natural biological attenuation rates are comparable to or exceed mechanical LNAPL recovery performance.

LNAPL transmissivity (T_n) testing previously performed at the CST was reported in the *Supplemental Investigation Summary – Southern Terminals* report dated April 3, 2020. Baildown tests were performed in the LNAPL zone at wells A13, S3, RW-1, and RW-5, resulting in LNAPL T_n values ranging from 0.01-0.4 square foot per day (ft^2/day). This is within the commonly accepted de minimis LNAPL recoverability range of 0.1-0.8 ft^2/day identified by ITRC, which is widely used to evaluate the practicability of mechanical LNAPL recovery. The observed de minimis LNAPL transmissivity values indicate that mechanical LNAPL recovery would not be technically specified/supported and, therefore, would not provide a meaningful improvement in site conditions.

The operation of solar skimmers in wells on the ST between April 8, 2021 and August 22, 2022 has independently confirmed the LNAPL transmissivity measurements and supports the finding that de minimis quantities of LNAPL are recoverable from the Site. Early on in this time period, several wells that had appreciable apparent LNAPL thicknesses when skimming commenced were quickly evacuated of LNAPL with little or no observed LNAPL recharge (i.e., little or no LNAPL thickness accumulation since). Over this period of skimmer operation, an approximate total of 250 gallons of LNAPL has been recovered from the CST. During the more recent portion of this operational period (April to August 2022), a total of only 51 gallons of LNAPL was recovered from the CST through skimmer and manual recovery which equates to a CST-wide total of approximately 2.6 gallons per week or 0.4 gallons per day. Given there are approximately 15 wells at which regular LNAPL recovery is being performed, this averages to approximately 0.02 gallons per day per well. As a comparison, the State of Minnesota considers an LNAPL recovery rate of 1 gallon per day per well to represent a de minimis condition at which LNAPL recovery is unlikely to provide an ongoing benefit and is not/no longer needed to reduce LNAPL mobility to below a level of concern (see Minnesota Pollution Control Agency Document #c-prp2-02). Therefore, in addition to the T_n line of evidence discussed above, looking at LNAPL recovery performance (or the need for ongoing LNAPL recovery) in terms of LNAPL recovery rates indicates that what is being realized at the CST is already orders of magnitude below what other jurisdictions consider a de minimis level of LNAPL mobility/recoverability.

A comparison of LNAPL degradation rates to current skimmer system and manual recovery performance data demonstrates that LNAPL is naturally degrading at a rate that is larger than the rate achievable through mechanical recovery (see, calculations in Appendix E). The CST-wide average NSZD rate is two orders of magnitude higher than the LNAPL recovery performance. More specifically, the average NSZD rate of approximately 2,300 gal LNAPL acre^{-1} yr^{-1} translates into approximately 250 gal LNAPL wk^{-1}, whereas the average LNAPL recovery rate based on recent recovery data (April to August 2022) is approximately 2.6 gal LNAPL wk^{-1}. It is also noted that NSZD is active over a much wider area of the CST that contains both LNAPL in wells and LNAPL at low enough saturations that it would not be seen in wells, whereas the mechanical LNAPL recovery activities are limited to areas where LNAPL is observed in wells (and can be recovered). While there is/will be both spatial and temporal variability in NSZD rates, the results presented herein indicate that much more of the remaining LNAPL is now being depleted naturally via NSZD than is recoverable through ongoing mechanical LNAPL recovery efforts.

The NSZD assessment has confirmed the occurrence of intrinsic biological degradation of LNAPL at the Site. Multiple independent lines of evidence (e.g., baildown testing and LNAPL recovery efforts) have demonstrated that LNAPL recovery rates are de minimis and that the remaining LNAPL is immobile and hydraulically unrecoverable. In addition, the calculated rates of LNAPL depletion via NSZD activity exceed the amount of LNAPL being recovered via skimming and bailing recovery, and NSZD will continue to deplete residual LNAPL and aqueous-phase contamination over time that would be inaccessible to LNAPL skimming.

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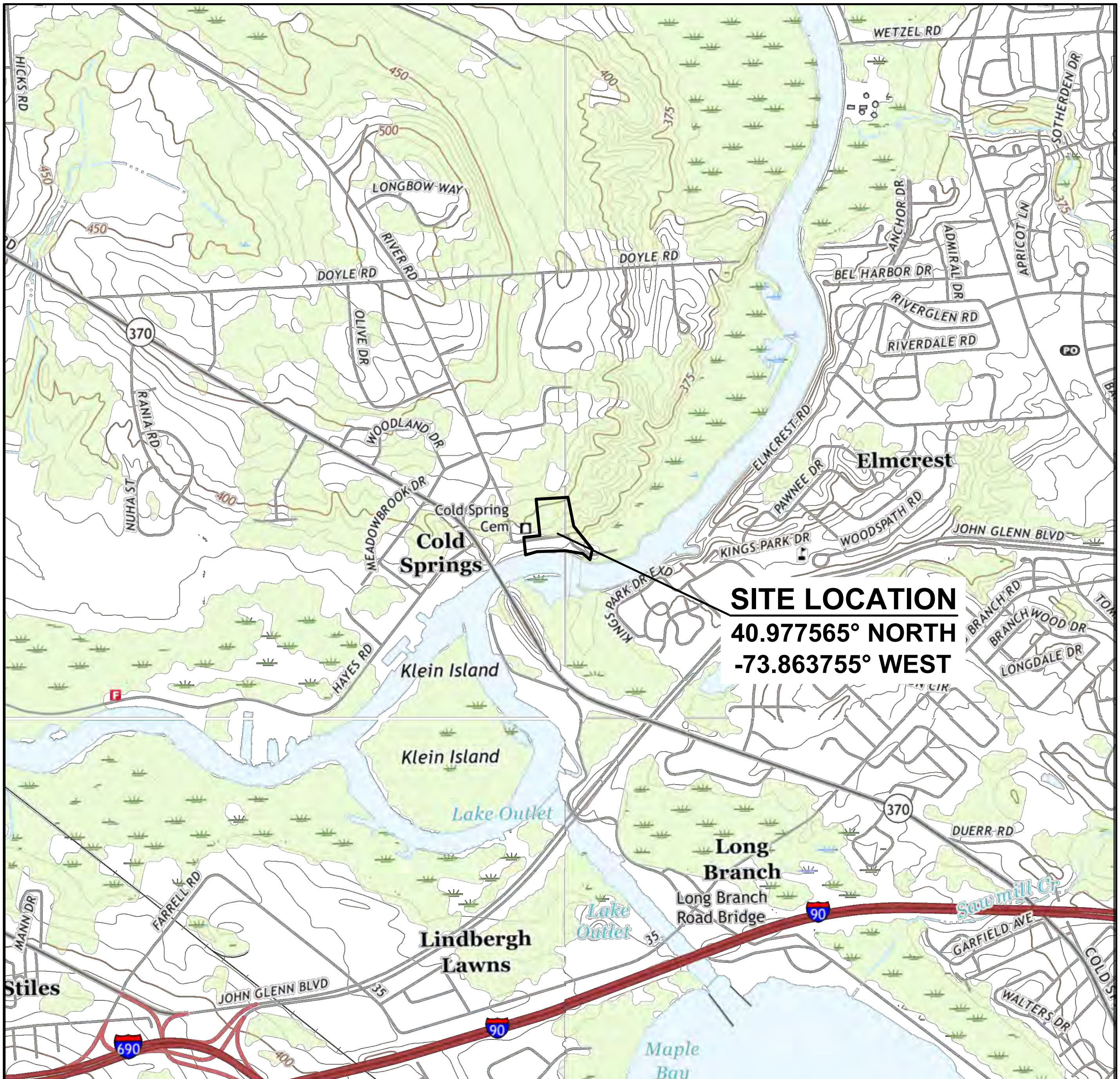
Figures

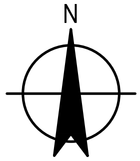


CONTOUR INTERVAL: 5 OR 10 FEET

MAP TAKEN FROM: USGS 7.5 MINUTE SERIES
TOPOGRAPHIC QUADRANGLES:
BALDWINSVILLE, NY (2019), BREWERTON, NY (2019),
CAMILLUS, NY (2019) & SYRACUSE WEST, NY (2019)
(U.S. GEOLOGICAL SURVEY WEBSITE)

0 1000 2000 3000 4000'

SCALE 1"=2000' AT ORIGINAL SIZE



SOUTHERN TERMINALS GROUP
COLD SPRINGS TERMINALS
HILLSIDE ROAD, LYSANDER, NEW YORK

SITE LOCATION MAP

Project No. 11137172
Date 12.2022

FIGURE 1

Filename: G:\564\11137172\Digital_Design\ACAD\Figures\11137172-RPT-FIG01-2022.NSZD-Site.Location.Map.dwg
Plot Date: 09 December 2022 3:58 PM

NOTES:
1. AERIAL PHOTOGRAPHS ARE 1-FOOT RESOLUTION TRUE COLOR ORTHOIMAGERY DATED 2018 AND TAKEN FROM THE NYSGIS CLEARINGHOUSE WEBSITE.
2. SITE FEATURES ARE BASED ON SURVEYS PROVIDED BY OTHERS.

N

0 50 100 150 200'

SCALE 1"=100' AT ORIGINAL SIZE

GHD

SOUTHERN TERMINALS GROUP
COLD SPRINGS TERMINALS
HILLSIDE ROAD, LYSANDER, NEW YORK

SITE LAYOUT

Project No. **11137172**
Date **12.2022**

FIGURE 2

Filename: N:\US\Syracuse\Projects\564\11137172\Digital_Design\ACAD\Figures\11137172-RPT-FIG02-2022.NSZD-Site.Layout.with.Aerial.dwg
Plot Date: 08 December 2022 10:08 AM

LEGEND

- PRE-EXISTING SOUTHERN TERMINALS MONITORING WELL LOCATION
- NESTED SOUTHERN TERMINALS MONITORING WELL LOCATION (INSTALLED NOVEMBER 2019)
- SOUTHERN TERMINALS LNAPL RECOVERY WELL LOCATION (INSTALLED NOVEMBER 2019)
- ADDITIONAL SOUTHERN TERMINALS MONITORING WELL LOCATION (INSTALLED MAY 2020)
- PRE-EXISTING NORTHERN TERMINALS MONITORING WELL
- SIGNIFICANTLY DAMAGED MONITORING WELL - CANNOT BE GAUGED
- DECOMMISSIONED MONITORING WELL (MARCH 2020)
- IMPERVIOUS SURFACES (APPROXIMATE)
- DYNAMIC CLOSED CHAMBER LOCATION (APPROXIMATE LOCATION, NOT SURVEYED)
- CO2 TRAP LOCATION (APPROXIMATE LOCATION, NOT SURVEYED)
- EXISTING WELL USED FOR NSZD ASSESSMENT (SURVEYED)

APPARENT LNAPL THICKNESS IN FEET (DECEMBER 2019 GAUGING EVENT)

0-1 2-3
1-2 3-4

WELLS USED FOR BIOGENIC HEAT AND SOIL GAS GRADIENT ASSESSMENTS		
WITHIN LNAPL AREA	ADJACENT TO LNAPL AREA	OUTSIDE OF LNAPL AREA (BACKGROUND)
RW-1	MW-11SR	MW-205
RW-2	MW-12S	MW-208
RW-3	AMW7	MW-211
RW-5	A9	AMW4
MW-5SR	MW-8S	MW-204
A10	MW-10S	
BMW5	BMW14R	
BMW13	BMW6	

NOTES:

1. SITE FEATURES ARE BASED ON SURVEYS PROVIDED BY OTHERS.

N

0 50 100 150 200'

SCALE 1"=100' AT ORIGINAL SIZE

SOUTHERN TERMINALS GROUP
COLD SPRINGS TERMINALS
HILLSIDE ROAD, LYSANDER, NEW YORK

Project No. 11137172
Date 12.2022

NSZD ASSESSMENT LOCATIONS

FIGURE 3

Filename: Z:\Projects\564\11137172\Digital_Design\ACAD\Figures\11137172-RPT-FIG03.Rev-2022.NSZD-Actual.NSZD.Locations.dwg
Plot Date: 30 January 2023 12:52 PM

LEGEND

- PRE-EXISTING SOUTHERN TERMINALS MONITORING WELL LOCATION
- NESTED SOUTHERN TERMINALS MONITORING WELL LOCATION (INSTALLED NOVEMBER 2019)
- SOUTHERN TERMINALS LNAPL RECOVERY WELL LOCATION (INSTALLED NOVEMBER 2019)
- ADDITIONAL SOUTHERN TERMINALS MONITORING WELL LOCATION (INSTALLED MAY 2020)
- PRE-EXISTING NORTHERN TERMINALS MONITORING WELL
- SIGNIFICANTLY DAMAGED MONITORING WELL - CANNOT BE GAUGED
- DECOMMISSIONED MONITORING WELL (MARCH 2020)
- LNAPL MEASURED IN WELLS (DECEMBER 2019 GAUGING EVENT)
- DYNAMIC CLOSED CHAMBER LOCATION (APPROXIMATE LOCATION, NOT SURVEYED)
- CO2 TRAP LOCATION (APPROXIMATE LOCATION, NOT SURVEYED)
- DCC ASSESSMENT LOCATIONS WITH NO RESULTS
- EXISTING WELL USED FOR NSZD ASSESSMENT (SURVEYED)
- NSZD ASSESSMENT LOCATIONS INDICATING NSZD ACTIVITY; INCLUDES CO2 TRAPS, BIO-CORRECTED DCC, BIOGENIC HEAT, AND GRADIENT METHODS

WELLS USED FOR BIOGENIC HEAT AND SOIL GAS GRADIENT ASSESSMENTS		
WITHIN LNAPL AREA	ADJACENT TO LNAPL AREA	OUTSIDE OF LNAPL AREA (BACKGROUND)
RW-1	MW-11SR	MW-205
RW-2	MW-12S	MW-208
RW-3	AMW7	MW-211
RW-5	A9	AMW4
MW-5SR	MW-8S	MW-204
A10	MW-10S	
BMW5	BMW14R	
BMW13	BMW6	

NOTES:
1. SITE FEATURES ARE BASED ON SURVEYS PROVIDED BY OTHERS.

N

0 50 100 150 200'

SCALE 1"=100' AT ORIGINAL SIZE

GHD

SOUTHERN TERMINALS GROUP
COLD SPRINGS TERMINALS
HILLSIDE ROAD, LYSANDER, NEW YORK

NSZD ACTIVITY AREAS

Project No. 11137172
Date 12.2022

FIGURE 4

Filename: Z:\Projects\564\11137172\Digital_Design\ACAD\Figures\11137172-RPT-FIG04.Rev-2022.NSZD-NSZD.Activity.Areas.dwg
Plot Date: 30 January 2023 12:51 PM

Appendices

Appendix A

DCC NSZD Data and Calculations

Natural Source Zone Depletion (NSZD)
DCC Method Rate Estimates
11137172 Cold Springs Terminal
Date: July 14-20, 2022

	Surface Coverage	Measured CO_2 Flux ($\mu mol/m^2/s$)				Correction factor	Corrected CO_2 Flux	Corrected NSZD Rate [a]		Location with respect to LNAPL area
File Name		**1-Min**	**2-Max**	**Mean**	**St Dev**		**($\mu mol/m^2/s$)**	**(gal LNAPL/acre/year)**	**(litres LNAPL/m^2/year)**	**(within, adjacent, outside)**
CS-DCC-01	100 grass	1.03	1.28	**1.15**	0.17	1.23	0.00	**-**	0.00	outside; background
CS-DCC-02	100 grass	4.52	5.99	**5.26**	1.04	1.23	4.02	**2,516**	2.35	outside
CS-DCC-03	100 grass	1.27	1.35	**1.31**	0.06	1.23	0.00	**-**	0.00	outside; background
CS-DCC-04	100 grass	4.63	4.79	**4.71**	0.12	1.23	3.48	**2,174**	2.03	outside
CS-DCC-05	100 grass	19.17	19.81	**19.49**	0.46	1.23	18.26	**11,413**	10.67	outside
CS-DCC-06	100 grass	8.26	8.65	**8.46**	0.28	1.23	7.23	**4,517**	4.22	outside
CS-DCC-07	100 grass	3.59	3.67	**3.63**	0.06	1.23	2.40	**1,500**	1.40	outside
CS-DCC-08	100 grass	9.06	10.06	**9.56**	0.71	1.23	8.33	**5,206**	4.87	outside
CS-DCC-09	100 grass	3.60	3.73	**3.67**	0.09	1.23	2.44	**1,522**	1.42	adjacent
CS-DCC-10	100 grass	7.92	9.52	**8.72**	1.13	1.23	7.49	**4,679**	4.38	within
CS-DCC-11	100 grass	8.24	8.85	**8.55**	0.44	1.23	7.32	**4,572**	4.28	within
CS-DCC-12	100 grass	3.60	3.71	**3.65**	0.08	1.23	2.42	**1,514**	1.42	within
CS-DCC-13	100 grass	6.30	6.57	**6.44**	0.19	1.23	5.21	**3,254**	3.04	adjacent
CS-DCC-14	100 grass	5.00	5.83	**5.42**	0.59	1.23	4.19	**2,616**	2.45	outside
CS-DCC-15	100 grass	6.88	8.64	**7.76**	1.25	1.23	6.53	**4,082**	3.82	within
CS-DCC-16a	100 grass	5.49	6.04	**5.77**	0.39	1.23	4.54	**2,836**	2.65	within
CS-DCC-16b	100 grass	4.65	5.06	**4.85**	0.29	1.23	3.62	**2,265**	2.12	within
CS-DCC-17	100 grass	4.74	5.41	**5.08**	0.48	1.23	3.85	**2,404**	2.25	within
CS-DCC-18	100 grass	2.47	3.19	**2.83**	0.51	1.23	1.60	**998**	0.93	within
CS-DCC-19	100 grass	3.79	3.88	**3.84**	0.07	1.23	2.61	**1,628**	1.52	within
CS-DCC-20	100 grass	6.36	6.58	**6.47**	0.16	1.23	5.24	**3,273**	3.06	within
CS-DCC-21	100 grass	6.61	6.72	**6.66**	0.08	1.23	5.43	**3,394**	3.17	within
CS-DCC-22	100 grass	5.75	6.91	**6.33**	0.82	1.23	5.10	**3,185**	2.98	within
CS-DCC-23	100 grass	6.37	6.94	**6.66**	0.40	1.23	5.43	**3,392**	3.17	adjacent
CS-DCC-24	100 grass	8.19	8.30	**8.25**	0.08	1.23	7.02	**4,386**	4.10	within
CS-DCC-25	100 grass	5.98	6.09	**6.04**	0.08	1.23	4.81	**3,003**	2.81	within
CS-DCC-26	100 grass	5.13	5.17	**5.15**	0.02	1.23	3.92	**2,449**	2.29	within
CS-DCC-27	100 grass	3.98	4.06	**4.02**	0.06	1.23	2.79	**1,744**	1.63	outside
CS-DCC-28	100 grass	3.05	3.79	**3.42**	0.53	1.23	2.19	**1,369**	1.28	within
CS-DCC-29	100 grass	12.53	13.11	**12.82**	0.41	1.23	11.59	**7,242**	6.77	within
CS-DCC-30	100 grass	5.25	5.64	**5.45**	0.28	1.23	4.21	**2,634**	2.46	within
CS-DCC-31	100 grass	5.59	5.66	**5.63**	0.05	1.23	4.40	**2,747**	2.57	within
CS-DCC-32	100 grass	4.50	4.54	**4.52**	0.03	1.23	3.28	**2,053**	1.92	within
CS-DCC-33	100 grass	5.24	6.08	**5.66**	0.60	1.23	4.43	**2,769**	2.59	within
CS-DCC-34	100 grass	9.25	9.63	**9.44**	0.27	1.23	8.21	**5,129**	4.80	outside
CS-DCC-35	100 grass	8.99	10.87	**9.93**	1.33	1.23	8.70	**5,437**	5.09	outside
CS-DCC-36	100 grass	8.71	10.05	**9.38**	0.95	1.23	8.15	**5,094**	4.76	outside
CS-DCC-37	100 grass	9.46	10.99	**10.23**	1.08	1.23	9.00	**5,623**	5.26	outside
CS-DCC-38	100 grass	9.22	10.52	**9.87**	0.92	1.23	8.64	**5,399**	5.05	within
CS-DCC-39	100 grass	11.22	13.08	**12.15**	1.31	1.23	10.92	**6,823**	6.38	adjacent
CS-DCC-40	100 grass	15.68	16.83	**16.25**	0.82	1.23	15.02	**9,389**	8.78	outside
CS-DCC-41	100 grass	10.43	12.48	**11.46**	1.46	1.23	10.22	**6,391**	5.98	outside
CS-DCC-42	100 grass	5.52	6.85	**6.18**	0.94	1.23	4.95	**3,096**	2.90	outside
CS-DCC-43	100 grass	4.59	4.80	**4.70**	0.15	1.23	3.47	**2,166**	2.03	outside
CS-DCC-44	100 grass	7.76	9.19	**8.47**	1.01	1.23	7.24	**4,527**	4.23	outside
~~CS-DCC-45~~	~~100 grass~~	~~-1.85~~	~~9.88~~	~~9.88~~	~~8.30~~	~~1.23~~	~~8.65~~	~~5,407~~	measurement error	outside
~~CS-DCC-46~~	~~100 grass~~	~~-0.52~~	~~4.75~~	~~4.75~~	~~3.73~~	~~1.23~~	~~3.52~~	~~2,200~~	measurement error	outside
~~CS-DCC-47~~	~~100 grass~~	~~0.96~~	~~0.99~~	~~0.97~~	~~0.02~~	~~1.23~~	~~0.00~~	~~-~~	measurement error	outside
~~CS-DCC-48~~	~~100 grass~~	~~-2.13~~	~~6.30~~	~~6.30~~	~~5.97~~	~~1.23~~	~~5.07~~	~~3,171~~	measurement error	outside
CS-DCC-49	100 grass	7.33	9.78	**8.56**	1.73	1.23	7.33	**4,578**	4.28	outside
~~CS-DCC-50~~	~~100 grass~~	~~1.53~~	~~4.27~~	~~2.90~~	~~1.93~~	~~1.23~~	~~1.67~~	~~1,043~~	measurement error	outside
~~CS-DCC-51~~	~~100 grass~~	~~-2.91~~	~~-1.92~~	-	~~0.70~~	~~1.23~~	-	-	-	outside
~~CS-DCC-52~~	~~100 grass~~	~~-2.58~~	~~4.97~~	~~4.97~~	~~5.34~~	~~1.23~~	~~3.74~~	~~2,338~~	measurement error	outside
~~CS-DCC-53~~	~~100 grass~~	~~-0.02~~	~~17.54~~	~~17.54~~	~~12.42~~	~~1.23~~	~~16.31~~	~~10,196~~	measurement error	outside
~~CS-DCC-54~~	~~100 grass~~	~~3.69~~	~~3.74~~	~~3.72~~	~~0.03~~	~~1.23~~	~~2.48~~	~~1,553~~	measurement error	outside
~~CS-DCC-55~~	~~100 grass~~	~~-2.06~~	~~15.22~~	~~15.22~~	~~12.22~~	~~1.23~~	~~13.99~~	~~8,743~~	measurement error	outside
							Average	**3,417**	**3.20**	

Correction Factor Locations						
File Name	**Surface Coverage**	**Measured CO2 Flux (µmol/m2/s)**		**Measured CO2 Flux (µmol/m2/s)**		**Average Mean Correction Factor**
		1-Min	**5-Max**	**Mean**	**St Dev**	**(µmol/m2/s)**
CS-DCC-01	100 grass	1.03	1.28	1.15	0.17	**1.23**
CS-DCC-03	100 grass	1.27	1.35	1.31	0.06	

Notes:
[a]Assumes that 1 $\mu mol/m^2/s$ CO_2 flux represents approximately 0.58 litres of LNAPL naturally degraded per square meter per year.
"-" indicates no result
(shaded cell) indicates lowest rates used for correction

Natural Source Zone Depletion (NSZD)
DCC Method Rate Estimates
11137172 Cold Springs Terminal
Date: July 14-20, 2022

File Name	Surface Coverage	Measured CO_2 Flux ($\mu mol/m^2/s$) 1-Min	2-Max	Mean	St Dev	Correction factor ($\mu mol/m^2/s$)	Corrected CO_2 Flux ($\mu mol/m^2/s$)	Corrected NSZD Rate [a] using bio-based CO_2 flux from CO_2 traps (gal LNAPL/acre/year)	(litres LNAPL/m^2/year)	Location with respect to LNAPL area (within, adjacent, outside)
CS-DCC-01	100 grass	1.03	1.28	**1.15**	0.17	6.51	-5.36	**0**	0.00	outside; background
CS-DCC-02	100 grass	4.52	5.99	**5.26**	1.04	6.51	-1.25	**0**	0.00	outside
CS-DCC-03	100 grass	1.27	1.35	**1.31**	0.06	6.51	-5.20	**0**	0.00	outside; background
CS-DCC-04	100 grass	4.63	4.79	**4.71**	0.12	6.51	-1.80	**0**	0.00	outside
CS-DCC-05	100 grass	19.17	19.81	**19.49**	0.46	6.51	12.98	**8115**	7.59	outside
CS-DCC-06	100 grass	8.26	8.65	**8.46**	0.28	6.51	1.95	**1218**	1.14	outside
CS-DCC-07	100 grass	3.59	3.67	**3.63**	0.06	6.51	-2.88	**0**	0.00	outside
CS-DCC-08	100 grass	9.06	10.06	**9.56**	0.71	6.51	3.05	**1907**	1.78	outside
CS-DCC-09	100 grass	3.60	3.73	**3.67**	0.09	6.51	-2.84	**0**	0.00	adjacent
CS-DCC-10	100 grass	7.92	9.52	**8.72**	1.13	6.51	2.21	**1381**	1.29	within
CS-DCC-11	100 grass	8.24	8.85	**8.55**	0.44	6.51	2.04	**1274**	1.19	within
CS-DCC-12	100 grass	3.60	3.71	**3.65**	0.08	6.51	-2.85	**0**	0.00	within
CS-DCC-13	100 grass	6.30	6.57	**6.44**	0.19	6.51	-0.07	**0**	0.00	adjacent
CS-DCC-14	100 grass	5.00	5.83	**5.42**	0.59	6.51	-1.09	**0**	0.00	outside
CS-DCC-15	100 grass	6.88	8.64	**7.76**	1.25	6.51	1.25	**783**	0.73	within
CS-DCC-16a	100 grass	5.49	6.04	**5.77**	0.39	6.51	-0.74	**0**	0.00	within
CS-DCC-16b	100 grass	4.65	5.06	**4.85**	0.29	6.51	-1.65	**0**	0.00	within
CS-DCC-17	100 grass	4.74	5.41	**5.08**	0.48	6.51	-1.43	**0**	0.00	within
CS-DCC-18	100 grass	2.47	3.19	**2.83**	0.51	6.51	-3.68	**0**	0.00	within
CS-DCC-19	100 grass	3.79	3.88	**3.84**	0.07	6.51	-2.67	**0**	0.00	within
CS-DCC-20	100 grass	6.36	6.58	**6.47**	0.16	6.51	-0.04	**0**	0.00	within
CS-DCC-21	100 grass	6.61	6.72	**6.66**	0.08	6.51	0.15	**96**	0.09	within
CS-DCC-22	100 grass	5.75	6.91	**6.33**	0.82	6.51	-0.18	**0**	0.00	within
CS-DCC-23	100 grass	6.37	6.94	**6.66**	0.40	6.51	0.15	**93**	0.09	adjacent
CS-DCC-24	100 grass	8.19	8.30	**8.25**	0.08	6.51	1.74	**1087**	1.02	within
CS-DCC-25	100 grass	5.98	6.09	**6.04**	0.08	6.51	-0.47	**0**	0.00	within
CS-DCC-26	100 grass	5.13	5.17	**5.15**	0.02	6.51	-1.36	**0**	0.00	within
CS-DCC-27	100 grass	3.98	4.06	**4.02**	0.06	6.51	-2.49	**0**	0.00	outside
CS-DCC-28	100 grass	3.05	3.79	**3.42**	0.53	6.51	-3.09	**0**	0.00	within
CS-DCC-29	100 grass	12.53	13.11	**12.82**	0.41	6.51	6.31	**3944**	3.69	within
CS-DCC-30	100 grass	5.25	5.64	**5.45**	0.28	6.51	-1.06	**0**	0.00	within
CS-DCC-31	100 grass	5.59	5.66	**5.63**	0.05	6.51	-0.88	**0**	0.00	within
CS-DCC-32	100 grass	4.50	4.54	**4.52**	0.03	6.51	-1.99	**0**	0.00	within
CS-DCC-33	100 grass	5.24	6.08	**5.66**	0.60	6.51	-0.85	**0**	0.00	within
CS-DCC-34	100 grass	9.25	9.63	**9.44**	0.27	6.51	2.93	**1831**	1.71	outside
CS-DCC-35	100 grass	8.99	10.87	**9.93**	1.33	6.51	3.42	**2139**	2.00	outside
CS-DCC-36	100 grass	8.71	10.05	**9.38**	0.95	6.51	2.87	**1796**	1.68	outside
CS-DCC-37	100 grass	9.46	10.99	**10.23**	1.08	6.51	3.72	**2324**	2.17	outside
CS-DCC-38	100 grass	9.22	10.52	**9.87**	0.92	6.51	3.36	**2101**	1.96	within
CS-DCC-39	100 grass	11.22	13.08	**12.15**	1.31	6.51	5.64	**3525**	3.30	adjacent
CS-DCC-40	100 grass	15.68	16.83	**16.25**	0.82	6.51	9.75	**6091**	5.70	outside
CS-DCC-41	100 grass	10.43	12.48	**11.46**	1.46	6.51	4.95	**3092**	2.89	outside
CS-DCC-42	100 grass	5.52	6.85	**6.18**	0.94	6.51	-0.32	**0**	0.00	outside
CS-DCC-43	100 grass	4.59	4.80	**4.70**	0.15	6.51	-1.81	**0**	0.00	outside
CS-DCC-44	100 grass	7.76	9.19	**8.47**	1.01	6.51	1.97	**1229**	1.15	outside
~~CS-DCC-45~~	~~100 grass~~	~~-1.85~~	~~9.88~~	~~9.88~~	~~8.30~~	~~6.51~~	~~3.37~~	~~2108~~	measurement error	outside
~~CS-DCC-46~~	~~100 grass~~	~~-0.52~~	~~4.75~~	~~4.75~~	~~3.73~~	~~6.51~~	~~-1.76~~	~~-1099~~	measurement error	outside
~~CS-DCC-47~~	~~100 grass~~	~~0.96~~	~~0.99~~	~~0.97~~	~~0.02~~	~~6.51~~	~~0.00~~	~~0~~	measurement error	outside
~~CS-DCC-48~~	~~100 grass~~	~~-2.13~~	~~6.30~~	~~6.30~~	~~5.97~~	~~6.51~~	~~-0.20~~	~~-127~~	measurement error	outside
CS-DCC-49	100 grass	7.33	9.78	**8.56**	1.73	6.51	2.05	**1280**	1.20	outside
~~CS-DCC-50~~	~~100 grass~~	~~1.53~~	~~4.27~~	~~2.90~~	~~1.93~~	~~6.51~~	~~-3.61~~	~~-2255~~	measurement error	outside
~~CS-DCC-51~~	~~100 grass~~	~~-2.91~~	~~-1.92~~	-	~~0.70~~	~~6.51~~	-	-	-	outside
~~CS-DCC-52~~	~~100 grass~~	~~-2.58~~	~~4.97~~	~~4.97~~	~~5.34~~	~~6.51~~	~~-1.54~~	~~-961~~	measurement error	outside
~~CS-DCC-53~~	~~100 grass~~	~~-0.02~~	~~17.54~~	~~17.54~~	~~12.42~~	~~6.51~~	~~11.04~~	~~6898~~	measurement error	outside
~~CS-DCC-54~~	~~100 grass~~	~~3.69~~	~~3.74~~	~~3.72~~	~~0.03~~	~~6.51~~	~~-2.79~~	~~-1745~~	measurement error	outside
~~CS-DCC-55~~	~~100 grass~~	~~-2.06~~	~~15.22~~	~~15.22~~	~~12.22~~	~~6.51~~	~~8.71~~	~~5445~~	measurement error	outside
							Average	**985**	**0.92**	

Correction Factor from CO_2

File Name	Bio-based CO_2 Flux ($\mu mol/m^2/s$)
CS-DCC-01	6.28
CS-DCC-02	5.74
CS-DCC-03	4.1
CS-DCC-04	10.19
CS-DCC-05	4.15
CS-DCC-06	10.55
CS-DCC-07	8.16
CS-DCC-08	6.46
CS-DCC-09	6.31
CS-DCC-10	3.14

Mean Bio-based Flux ($\mu mol/m^2/s$)
6.51

Notes:
[a]Assumes that 1 $\mu mol/m^2/s$ CO_2 flux represents approximately 0.58 litres of LNAPL naturally degraded per square meter per year.
"-" indicates no result

Appendix B

CO_2 Traps NSZD Data and Calculations

E-FLUX

Confidential Report
CO_2 Flux and NSZD Rate Results

JOANN DYSON, PH.D.
GHD
LYSANDER, NEW YORK
COLD SPRINGS TERMINAL
SAMPLING DATES:
8/11/2022 - 8/21/2022

For technical support questions contact:

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Report Date: 9/20/2022

The purpose of this document is to provide sample calculations for the reported results and to explain the method for differentiating petroleum hydrocarbon-derived CO_2 from that produced from natural soil respiration processes. The value of the ^{14}C analysis, site-specific study results and applicable notes, calculation explanations, and references are included.

The Value of the ^{14}C Analysis

How to differentiate between petroleum hydrocarbon-derived CO_2 and natural process-derived CO_2 using CO_2 flux traps:

Unimpacted soils naturally produce CO_2 due to microbial root zone activity and/or the degradation of natural organic matter. Thus, the total measured CO_2 flux at an impacted location is a function of the rates of both natural soil respiration and LNAPL degradation (Sihota and Mayer, 2012). The latter, which is caused by Natural Source Zone Depletion (NSZD), can be estimated by subtracting measured CO_2 fluxes at unimpacted locations from the total measured CO_2 fluxes at LNAPL-impacted locations (Sihota and Mayer, 2012). This spatial "background correction" assumes that bio-based CO_2 fluxes are similar at 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 vegetation cover can vary across a site. Alternatively, carbon isotope analysis can be used to carry out a location-specific correction for total measured CO_2 fluxes, and this approach effectively overcomes the limitations of the background correction.

Theory of Carbon Isotope Analysis:

Our method for NSZD rate estimation relies on the analysis of ^{14}C, an unstable carbon isotope with an absolute half-life of 5,730 years. ^{14}C is generated by cosmic rays in the atmosphere and is quickly oxidized to $^{14}CO_2$; thus, bio-based living carbon is ^{14}C-rich, while ancient fossil fuel carbon is completely ^{14}C-depleted. Additionally, bio-based organic carbon and the atmosphere have the same characteristic amount of ^{14}C. The short half-life of ^{14}C only allows for dating of samples younger than 60,000 years using accelerator mass spectrometry (Stuiver and Polach, 1977). ^{14}C analysis can therefore be used to differentiate between anthropogenic (i.e., fossil fuel) and natural sources of atmospheric carbon (see Klouda and Connolly, 1995; Levin et al., 1995; Avery et al., 2006), and this analysis is the basis for ASTM D6866-18.

For samples that contain both bio-based and fossil fuel-derived carbon, such as E-Flux's fossil fuel traps, measurement of ^{14}C enables quantitation of *both* source contributions. The fossil fuel-derived percentage of the sample (ff_{sample}) and the bio-based percentage ($1-ff_{sample}$, or bb_{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_x represents the fraction modern, a measure of how close the present $^{14}C/^{12}C$ 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 modern of the sample. Fm_{ff} is the fraction modern of only the fossil fuel portion of the sample. This number is 0, as there is no ^{14}C in fossil fuel-derived CO_2. Fm_{atm} is the fraction modern of the part of the sample derived from natural soil respiration processes. This value, currently equal to **1.02** (Cerling et al., 2016, Larsen et al., 2018), has been experimentally determined and is a fixed value at each point in time. By convention, the results of carbon isotope analysis are reported based on a 1950 NBS oxalic acid standard, and so Fm_{sample} is reported as if the analysis took place in 1950. Due to nuclear testing, current ^{14}C atmospheric levels are now higher than they were in 1950. This means that Fm_{atm} is counter-intuitively larger than 1, as the $^{14}C/^{12}C$ sample ratio is higher now than it would have been in 1950.

^{14}C Calculations:

Conversion of Fraction Modern Carbon to Fossil Fuel Carbon:

The equation for calculating the percentage of fossil fuel carbon (ff_{sample}) is derived from the following mass balance:

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

Solving for ff_{sample} yields:

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

Fraction modern (Fm_{sample}, from ^{14}C analysis) is reported by convention based on ^{14}C levels from 1950. Because of atomic testing, current environmental ^{14}C levels are approximately 2% higher than they were in 1950 (Cerling et al., 2016, Larsen et al., 2018) and Fm_{atm} is equal to 1.02. This equation then becomes:

$$ff_{sample} = 1 - \frac{Fm_{sample}}{1.02}$$

As percentages must add to 1, the percentage of bio-based carbon (bb_{sample}.) can then be calculated using the following equivalence:

$$bb_{sample} = 1 - ff_{sample} = 1 - \left(1 - \frac{Fm_{sample}}{1.02}\right) = \frac{Fm_{sample}}{1.02}$$

Converting Carbon Flux to Equivalent LNAPL Loss Rate:

The intermediate reactions for LNAPL mineralization include methanogenesis, leading to production of methane and CO_2, and the subsequent aerobic oxidation of methane into CO_2:

$$C_8H_{18} + 3.5\ H_2O \rightarrow 6.25\ CH_4 + 1.75\ CO_2 \text{ (methanogenesis)}$$

$$6.25\ CH_4 + 12.5\ O_2 \rightarrow 6.25\ CO_2 + 12.5\ H_2O \text{ (methane oxidation)}$$

$$C_8H_{18} + 12.5\ O_2 \rightarrow 9H_2O + 8\ CO_2 \text{ (overall reaction)}$$

Assuming a conservative LNAPL density of 0.77 g mL^{-1} (upper range of gasoline) and using the molecular weight of C_8H_{18} (octane, 114.23 g mol^{-1}), µmol m^{-2} s^{-1} of CO_2 can then be converted into gal. acre^{-1} yr^{-1} of LNAPL:

$$1\ \frac{\mu mol\ CO_2}{m^2\ s} \cdot \left(\frac{1\ \mu mol\ C_8H_{18}}{8\ \mu mol\ CO_2}\right)\left(\frac{1\ mol\ C_8H_{18}}{1 \times 10^6\ \mu mol\ C_8H_{18}}\right)\left(\frac{114\ g\ C_8H_{18}}{1\ mol\ C_8H_{18}}\right)\left(\frac{1\ mL\ C_8H_{18}}{0.77\ g\ C_8H_{18}}\right)$$
$$\left(\frac{1\ L}{1000mL}\right)\left(\frac{1\ gal.}{3.785\ L}\right)\left(\frac{4{,}046\ m^2}{1\ acre}\right)\left(\frac{3600\ s}{1\ h}\right)\left(\frac{24\ h}{1\ d}\right)\left(\frac{365\ d}{1\ yr}\right).$$

$$= 625.2\ \frac{gal.\ C_8H_{18}}{acre \cdot yr}$$

Note that both the LNAPL formula and its density are assumed, and so 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.

Expected Results and Recommendations:

^{14}C-based techniques offer a built-in, location-specific correction as an alternative to the standard background location correction. Early work on a limited number of samples suggested that ^{14}C-corrected results are equivalent to background-corrected results (Sihota and Mayer, 2012; McCoy et al., 2015). However, a more recent comparison spanning 4 different sites suggests that measured carbon fluxes 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 ^{14}C-corrected NSZD rate estimates can be up to one order of magnitude. In contrast, the background correction assumes that the non-fossil fuel CO_2 flux is constant across an entire site; large errors in final estimated NSZD rates might therefore be introduced if the background correction is used. Because the ^{14}C measurement is co-located with the CO_2 flux measurement, it is unbiased by spatial uncertainties related to the background location(s) (e.g., vegetation, lithology, unknown impacts, different gas transport regimes, soil moisture).

The fossil fuel CO_2 content of unexposed sorbent as used in the traps is typically around 30% (as of today) and likely results from material processing and handling (e.g., exposure to fossil fuel fumes). This small mass of fossil fuel CO_2 is removed from samples by carrying out a ^{14}C travel blank correction. ^{14}C analysis is performed on CO_2 sorbent sub-samples after homogenization of the entire bottom sorbent layer (see McCoy et al., 2015). The mass of fossil fuel CO_2 in the unexposed travel blank trap (TB) is then subtracted from the mass of fossil fuel CO_2 in each field-deployed trap.

The results in this report are based on proprietary technology used to measure soil gas efflux. All information contained herein is strictly confidential to the customer.

Easy set-up. Expert results.

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

Project: Lysander, New York Cold Springs Terminal

Customer: GHD

Customer Contact: Joann Dyson, Ph.D.

Report Date: 20-Sep-2022

Sample ID	Sampling Information			Raw Results[a]				Final CO_2 Results[b]			^{14}C Results[a]			NSZD Results[b]				
	Deployed	Retrieved	Days in Field	Moisture content (%)	Dry Sorbent Mass (g)	Avg. % CO_2[c]	CV[d] CO_2 (%)	CO_2 content (%)	CO_2 mass (g)	CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)	Fm_{sample} As Reported[e]	bb_{sample} As of Today[f]	ff_{sample} As of Today[f]	Bio-based CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)	ff_{sample} As of Today (TB-corrected)	Fossil Fuel CO_2 (g)	Fossil Fuel CO_2 Flux ($\mu mol\ m^{-2}\ s^{-1}$)	Equivalent NSZD Rate (gal. acre^{-1} yr^{-1})
10229-R1-CO2-TB	N/A	N/A	N/A	12.8%	41.86	1.51%	1.49%	-	-	-	75.16	73.68%	26.32%	-	-	-	-	-
10229-R1-CO2-01	8/11/22 8:15	8/21/22 10:50	10.1	19.8%	42.60	6.33%	1.58%	4.82%	2.05	6.59	91.98	90.17%	9.83%	6.28	4.67%	0.10	0.31	192
10229-R1-CO2-02	8/11/22 8:30	8/21/22 11:05	10.1	20.8%	42.95	5.70%	0.58%	4.19%	1.80	5.78	94.37	92.52%	7.48%	5.74	0.71%	0.01	0.04	26
10229-R1-CO2-03	8/11/22 8:40	8/21/22 11:00	10.1	20.3%	42.82	4.50%	1.69%	3.00%	1.28	4.12	92.62	90.80%	9.20%	4.10	ND	ND	ND	ND
10229-R1-CO2-04	8/11/22 8:50	8/21/22 11:10	10.1	20.5%	43.46	8.80%	0.71%	7.29%	3.17	10.19	97.40	95.49%	4.51%	10.19	ND	ND	ND	ND
10229-R1-CO2-05	8/11/22 9:00	8/21/22 11:20	10.1	21.6%	42.76	5.37%	0.33%	3.86%	1.65	5.31	78.51	76.97%	23.03%	4.15	21.75%	0.36	1.15	721
10229-R1-CO2-06	8/11/22 9:05	8/21/22 11:25	10.1	20.4%	44.01	9.62%	0.77%	8.11%	3.57	11.47	90.91	89.13%	10.87%	10.55	8.00%	0.29	0.92	573
10229-R1-CO2-07	8/11/22 9:15	8/21/22 11:35	10.1	25.1%	43.10	7.90%	3.92%	6.40%	2.76	8.86	90.40	88.63%	11.37%	8.16	7.85%	0.22	0.70	435
10229-R1-CO2-08	8/11/22 9:20	8/21/22 11:45	10.1	16.8%	43.94	9.20%	0.74%	7.69%	3.38	10.86	63.06	61.83%	38.17%	6.46	40.50%	1.37	4.40	2749
10229-R1-CO2-09	8/11/22 9:30	8/21/22 11:50	10.1	14.1%	42.64	6.52%	1.11%	5.01%	2.14	6.87	89.46	87.70%	12.30%	6.31	8.08%	0.17	0.55	347
10229-R1-CO2-10	8/11/22 9:40	8/21/22 11:55	10.1	0.0%	42.47	9.43%	3.82%	7.93%	3.37	10.82	36.91	36.19%	63.81%	3.14	70.95%	2.39	7.68	4800

- The flux equivalence is **1** $\mu mol\ m^{-2}\ s^{-1}$ = **625.2** gallons acre^{-1} yr^{-1}, assuming a representative hydrocarbon density of **0.77** g mL^{-1} with the formula C_8H_{18}.Trap cross-sectional area is **8.11 × 10^{-3}** m^2 (based on a **4-inch** receiver pipe).
- Carbonate analysis of each trap/sample is based on method ASTM 4373-14, which does not provide acceptable variability (CV) standards. Similar methods (e.g., ASTM D513-16) allow typical errors of ≤ 20%. Analysis is therefore conducted in duplicate if the coefficient of variation (CV) of the duplicates is < 5%. If CV ≥ 5%, duplicate analyses are repeated until CV < 5%.
- NA = Not Applicable; ND = Not Detectable. Based on the project capture area, sorbent mass and deployment time, and the variability of the total carbon and fossil fuel carbon analysis, the limit of detection for the NSZD rate is **18** gallons acre^{-1} yr^{-1}.

a. Raw and ^{14}C Results are not TB-corrected.

b. Final CO_2 and NSZD Results are TB-corrected.

c. Refers to the measured weight percentage of CO_2 with respect to the total dry sorbent mass.

d. Refers to the coefficient of variation of CO_2 measurements for each sample: CV = [standard deviation of %CO_2 measurements] / [average %CO_2 measurement]

e. Refers to the reported fraction modern (Fm_{sample}). As is standard in radiocarbon reporting, this value has not been corrected to account for present-day ^{14}C atmospheric levels. This number is originally reported as pMC (percent modern carbon) and is converted into *Fm* for our calculations using the relation 100.0 pMC = 1.0 *Fm* = 100% *Fm*.

f. "As of Today," means that the value has been adjusted to account for the difference between atmospheric ^{14}C levels from the 1950s and today (Stenström et al., 2011). bb_{sample} is the percentage of the total CO_2 that is derived from bio-based (non-fossil fuel) sources. ff_{sample} refers to the percentage of CO_2 that is derived from fossil fuels. The values reported in the NSZD Results section are TB-corrected, but those in the ^{14}C Results section are not TB-corrected.

Results Snapshot:

- The Travel Blank (TB) concentration is **1.51%**; typically, this number is < 2%.
- Trap tops are not saturated with CO_2 (sorbent saturation is 30%). The maximum measured (raw) top concentration is **1.82%** (sample **10229-R1-CO2-04-top**).
- Bio-based carbon fluxes represent the CO_2 contributions from natural soil respiration processes to the total carbon flux; the ^{14}C analysis corrects for this contribution. Average bio-based CO_2 flux is **6.51** µmol m^{-2} s^{-1}, and the coefficient of variation is **38%.** The range of bio-based CO_2 fluxes is between **3.14** and **10.55** µmol m^{-2} s^{-1}. If these interferences were not removed using the results of the radiocarbon analysis, the errors in the NSZD rate estimates would be between **1966**- and **6595**-gallons $acre^{-1}$ yr^{-1}.
- Samples **10229-R1-CO2-03** and **-04** show non-detectable (ND) fossil fuel CO_2 flux. The entire CO_2 flux for these samples is likely derived from non-fossil fuel sources.

Site-specific Sample Calculations:

Grams of Fossil Fuel CO_2:

The mass of fossil fuel-derived CO_2 in each trap is calculated by subtracting the total fossil fuel CO_2 in the travel blank (TB) from the total fossil fuel CO_2 in the trap. Only data that are ***not*** TB-corrected (i.e., ff_{sample} As of Today and raw % CO_2) are used in this calculation. Using sample **10229-R1-CO2-01** as an example:

$$\left(g\ CO_{2(ff)}\right)_{sample\ 1} = g_{sorbent} \cdot \left[\left((\%\ CO_2)_{sample}\left(ff_{sample}\right)\right) - \left((\%\ CO_2)_{TB}(ff_{TB})\right)\right]$$

$$\left(g\ CO_{2(ff)}\right)_{sample\ 1} = \mathbf{42.60}\ g \cdot [(\mathbf{6.33}\ \% \cdot \mathbf{9.83}\ \%) - (\mathbf{1.51}\ \% \cdot \mathbf{26.32}\ \%)]$$

$$\left(g\ CO_{2(ff)}\right)_{sample\ 1} = \mathbf{0.0958}\ g$$

Here, $g_{sorbent}$ is the mass of sorbent used in the bottom layer of the trap, $(\%CO_2)_{sample}$ is the average weight percentage of CO_2 in the sample, ff_{sample} is the percentage of carbon in the sample derived from fossil fuels, $(\%CO_2)_{TB}$ is the average weight percentage of CO_2 in the travel blank, and ff_{TB} is the percentage of carbon in the travel blank that is derived from fossil fuels. In this example, sample **10229-R1-CO2-01** contains **0.0958 g** of fossil-fuel derived CO_2.

Fossil Fuel CO_2 Flux:

Converting grams of CO_2 to CO_2 flux requires the cross-sectional area of the receiver (**8.11 × 10^{-3}** m^2 for a **4**-inch receiver), the number of days that the trap was deployed in the field, and the molecular weight of CO_2 (44 g mol^{-1}). Using trap **10229-R1-CO2-01** as an example:

$$Fossil\ Fuel\ CO_2\ Flux = \frac{g\ fossil\ fuel\ CO_2 \cdot \frac{1\ mol\ CO_2}{44\ g\ CO_2} \cdot \frac{1{,}000{,}000\ \mu mol\ CO_2}{1\ mol\ CO_2}}{days\ in\ the\ field \cdot \frac{24\ hr}{day} \cdot \frac{3600\ s}{hr} \cdot (receiver\ area)}$$

$$Fossil\ Fuel\ CO_2\ Flux = \frac{\mathbf{0.0958}\ g\ fossil\ fuel\ CO_2 \cdot \frac{1\ mol\ CO_2}{44\ g\ CO_2} \cdot \frac{1{,}000{,}000\ \mu mol\ CO_2}{mol\ CO_2}}{\mathbf{10.1}\ days \cdot \frac{24\ hr}{day} \cdot \frac{3600\ s}{hr} \cdot (\mathbf{8.11} \times \mathbf{10^{-3}}\ m^2)}$$

$$Fossil\ Fuel\ CO_2\ Flux = \mathbf{0.31}\ \frac{\mu mol\ CO_2}{m^2 \cdot s}$$

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E-FLUX

CO2 TRAP SHIPMENT AND INSTALLATION LOG
LNAPL NATURAL ATTENUATION STUDY

Date: 8 / 11 /2022

Date Returned to E-Flux: 8-22-2022

Contaminant Type	Deployment Location	Retrieval Location	Identification on Outside of Trap Box	Trap Placed in Field		Trap Recovered from Field		Comments	Depth to Ground Water	LNAPL Thickness in Well	Smear Zone Thickness	
				Date	Time	Date	Time				Vadose Zone	Groundwater
Trap Data												
PETROLEUM (ALL RANGES)	COLD SPRINGS LYSANDER, NY	COLD SPRINGS LYSANDER, NY	10229-R1-CO2-01	8-11-22	0815	~~8-22-22~~	1050	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-02	8-11-22	0830	~~8-22-22~~	1105	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-03	8-11-22	0840	~~8-22-22~~	1100	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-04	8-11-22	0850	~~8-22-22~~	1110	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-05	8-11-22	0900	~~8-22-22~~	1120	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-06	8-11-22	0905	~~8-22-22~~	1125	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-07	8-11-22	0915	~~8-22-22~~	1135	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-08	8-11-22	0920	~~8-22-22~~	1145	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-09	8-11-22	0930	~~8-22-22~~	1150	8-21-22 retrieval per JMD				
↓	↓	↓	10229-R1-CO2-10	8-11-22	0940	~~8-22-22~~	1155	IN STANDING WATER AT TIME OF RECOVERY	8-21-22 retrieval per JMD			
Travel Blanks												
				Date Received		Date Returned						
Travel Blank	COLD SPRINGS LYSANDER, NY	COLD SPRINGS LYSANDER, NY	10229-R1-CO2-TB	8-2-22	1100	8-22-22	1600					

Installation Steps - KEEP TRAPS UPRIGHT - CAUTION, CONTAINS CAUSTIC MATERIAL

1- Find the appropriate trap for the location chosen (see map). Remove housing from over Receiver.
2- Remove screw-in caps (top and bottom). Add rain cover to top. Keep trap upright.
3- Place trap on receiver in ground using 4 in rubber coupler. Tighen hose clamps on rubber coupler.
4- At end of monitoring period, reverse steps. Cap both top and bottom of the trap.
5- Keep upright while handing and shipping.

Return Traps to:
(970) 492-4360

E-Flux, LLC
200 West Lake St, RIC Room D230
Fort Collins, CO 80521-0922
Attn: E-Flux Receiving

Technician Name: IAN McNAMARA

Easy set-up. Expert results.

Appendix C

Soil Gas/Gradient Data and Calculations

Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: Cold Springs Terminal
Date: July 2022

Headspace Screening Data

Well ID	Depth to Product	Depth to Water	Screen Depth	Casing Stickup	Measurement Depth			Time lapsed	Time	CH_4 (%)	O_2 (%)	CO_2 (%)
	(ft btor)	(ft btor)	(ft bgs)	(ft)	(ft btor)	(ft bgs)	(m bgs)					
RW-1	10.2	10.53	5 - 15	1.68	1.68	0.0	0.0	1 min	828	82.1	12.9	4.9
7/13/2022								3 min	831	82.2	13.0	4.7
								5 min	833	82.2	13.3	4.5
								10 min	838	81.7	15.3	3.0
									Average	82.1	13.6	4.3
Within LNAPL Area					9.20	7.5	2.3	1 min	840	86.5	1.5	12.0
								3 min	843	86.3	2.6	11.2
								5 min	845	86.1	2.9	10.9
								10 min	850	86.0	3.5	10.5
									Average	86.2	2.6	11.2
RW-2	10.46	10.51	5 - 15	1.88	1.88	0.0	0.0	1 min	855	82.3	14.0	3.9
7/13/2022								3 min	858	81.8	14.6	3.6
Within LNAPL Area								5 min	900	81.6	15.0	3.4
								10 min	905	81.2	15.9	2.8
									Average	81.7	14.9	3.4
					9.46	7.6	2.3	1 min	907	84.8	3.4	11.8
								3 min	910	84.7	3.9	11.4
								5 min	912	84.7	4.1	11.2
								10 min	917	84.6	4.5	10.9
									Average	84.7	4.0	11.3
RW-3	10	10.16	5 - 15	2.31	2.31	0.0	0.0	1 min	1455	83.4	9.9	6.7
7/12/2022								3 min	1458	83.3	10.2	6.5
								5 min	1500	83.1	10.8	6.2
								10 min	1505	82.3	13.0	4.7
									Average	83.0	11.0	6.0
Within LNAPL Area					9.00	6.7	2.0	1 min	1507	86.1	1.7	12.2
								3 min	1510	85.8	2.8	11.4
								5 min	1512	85.7	3.0	11.3
								10 min	1517	85.5	3.2	11.3
									Average	85.8	2.7	11.6
RW-5	9.18	9.37	5 - 15	3.29	3.29	0.0	0.0	1 min	1404	81.5	16.1	2.3
7/12/2022								3 min	1407	81.4	16.5	2.1
								5 min	1409	81.4	16.4	2.1
								10 min	1414	81.5	16.4	2.2
									Average	81.4	16.4	2.2
Within LNAPL Area					8.18	4.9	1.5	1 min	1416	84.3	7.8	7.9
								3 min	1419	83.5	9.9	6.6
								5 min	1421	83.3	10.4	6.2
								10 min	1426	83.1	11.0	5.9
									Average	83.3	9.8	6.7
MW-5SR	9.53	9.56	4 - 14	2.67	2.67	0.0	0.0	1 min	1332	82.8	13.3	3.0
7/12/2022								3 min	1335	80.1	19.6	0.3
								5 min	1337	31.9	19.9	0.2
								10 min	1342	3.0	20.2	0.1
									Average	3.0	18.3	0.9
Within LNAPL Area					8.53	5.9	1.8	1 min	1344	87.8	2.3	9.6
								3 min	1347	80.2	7.5	13.4
								5 min	1349	80.0	6.1	14.2
								10 min	1354	85.8	7.9	6.3
									Average	82.0	6.0	10.9

Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: Cold Springs Terminal
Date: July 2022

Headspace Screening Data

Well ID	Depth to Product	Depth to Water	Screen Depth	Casing Stickup	Measurement Depth			Time lapsed	Time	CH_4 (%)	O_2 (%)	CO_2 (%)
	(ft btor)	(ft btor)	(ft bgs)	(ft)	(ft btor)	(ft bgs)	(m bgs)					
A10	-	9.81	4 - 14	1.37	1.37	0.0	0.0	1 min	1521	83.2	16.4	1.2
7/12/2022								3 min	1524	40.0	19.8	0.3
								5 min	1526	23.1	20.1	0.2
								10 min	1531	9.9	20.4	0.1
									Average	9.9	19.2	0.5
Within LNAPL Area					8.81	7.4	2.3	1 min	1533	85.9	2.4	11.7
								3 min	1536	87.3	1.3	11.4
								5 min	1538	87.1	1.9	11.0
								10 min	1543	86.3	4.0	9.7
									Average	86.7	2.4	11.0
BMW5	24.82	25.28	10 - 30	1.62	1.62	0.0	0.0	1 min	1522	1.0	8.7	9.0
7/11/2022								3 min	1525	0.5	15.7	3.5
								5 min	1527	0.4	16.9	2.7
								10 min	1532	0.3	19.5	0.7
									Average	0.6	15.2	4.0
Within LNAPL Area					23.82	22.2	6.8	1 min	1534	89.6	0.3	10.0
								3 min	1537	88.7	0.9	10.4
								5 min	1539	87.8	1.9	10.4
								10 min	1544	85.9	4.1	10.0
									Average	88.0	1.8	10.2
BMW13	18.96	19.1	15 - 25	2.52	2.52	0.0	0.0	1 min	1312	16.2	8.1	9.8
7/11/2022								3 min	1315	14.0	10.0	8.2
								5 min	1317	10.4	12.0	6.6
								10 min	1322	1.2	17.9	1.7
									Average	8.5	13.3	5.5
Within LNAPL Area					17.96	15.4	4.7	1 min	1324	86.3	0.2	13.5
								3 min	1327	86.0	0.1	14.0
								5 min	1329	85.9	0.1	14.0
								10 min	1334	85.6	0.2	14.2
									Average	86.0	0.2	13.9
MW-11SR	-	11.67	4 - 14	2.90	2.90	0.0	0.0	1 min	1059	35.8	6.1	3.7
7/12/2022								3 min	1102	24.5	16.0	1.1
								5 min	1104	20.2	17.8	0.6
								10 min	1109	14.4	18.8	0.3
									Average	14.4	17.5	0.7
Adjacent to LNAPL Area					10.67	7.8	2.4	1 min	1112	10.3	3.8	3.8
								3 min	1115	9.5	4.1	3.7
								5 min	1117	9.2	5.5	3.3
								10 min	1122	7.6	7.7	2.7
									Average	9.2	5.3	3.4
MW-12S	-	16.72	6 - 16	2.85	2.85	0.0	0.0	1 min	1622	2.0	14.7	4.5
7/11/2022								3 min	1625	0.8	19.6	0.9
								5 min	1627	0.8	20.4	0.4
								10 min	1632	0.7	20.9	0.2
									Average	1.1	18.9	1.5
Adjacent to LNAPL Area					15.72	12.9	3.9	1 min	1634	0.7	7.8	8.2
								3 min	1637	0.4	7.3	8.4
								5 min	1639	0.0	7.6	8.3
								10 min	1644			
									Average	0.4	7.6	8.3

Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: Cold Springs Terminal
Date: July 2022

Headspace Screening Data

Well ID	Depth to Product	Depth to Water	Screen Depth	Casing Stickup	Measurement Depth			Time lapsed	Time	CH_4 (%)	O_2 (%)	CO_2 (%)
	(ft btor)	(ft btor)	(ft bgs)	(ft)	(ft btor)	(ft bgs)	(m bgs)					
AMW7	-	12.6	5 - 18	2.29	2.29	0.0	0.0	1 min	1200	4.2	19.5	0.6
7/12/2022								3 min	1203	4.3	20.1	0.2
								5 min	1205	4.3	20.2	0.1
								10 min	1210	4.1	20.2	0.1
									Average	4.2	20.0	0.3
Adjacent to LNAPL Area					11.60	9.3	2.8	1 min	1212	2.7	7.3	10.1
								3 min	1215	2.8	9.1	8.6
								5 min	1217	3.0	10.4	7.5
								10 min	1222	3.1	13.5	5.1
									Average	2.9	10.1	7.8
A9	-	12.98	4 - 19	-0.80	-0.80	0.0	0.0	1 min	1129	6.2	19.0	0.9
7/12/2022								3 min	1132	6.2	19.8	0.1
								5 min	1134	6.5	19.8	0.2
								10 min	1139	6.5	19.8	0.2
									Average	6.4	19.6	0.4
Adjacent to LNAPL Area					11.98	12.8	3.9	1 min	1142	12.1	0.6	14.0
								3 min	1145	13.9	0.9	14.0
								5 min	1147	8.9	1.1	13.9
								10 min	1152	6.0	1.3	13.7
									Averages	10.2	1.0	13.9
MW-8S	-	8.59	4 - 14	2.81	2.81	0.0	0.0	1 min	1231	3.6	14.6	3.8
7/12/2022								3 min	1234	0.6	19.0	0.8
								5 min	1236	0.3	19.6	0.4
								10 min	1241	0.1	19.7	0.2
									Average	1.2	18.2	1.3
Adjacent to LNAPL Area					7.59	4.8	1.5	1 min	1243	8.6	4.3	11.2
								3 min	1246	5.4	10.3	6.7
								5 min	1248	2.7	14.3	4.1
								10 min	1253	0.5	19.0	0.8
									Average	4.3	12.0	5.7
MW-10S	-	8.54	4.5 - 14.5	2.46	2.46	0.0	0.0	1 min	1301	0.0	15.4	4.4
7/12/2022								3 min	1304	0.0	19.2	0.9
								5 min	1306	0.0	19.6	0.6
								10 min	1311	0.0	19.9	0.4
									Average	0.0	18.5	1.6
Adjacent to LNAPL Area					7.54	5.1	1.5	1 min	1313	0.0	7.9	12.1
								3 min	1316	0.0	8.9	11.1
								5 min	1318	0.0	10.6	9.4
								10 min	1321	0.0	13.9	6.0
									Average	0.0	10.3	9.7
BMW14R	-	15.97	5 - 20	2.13	2.13	0.0	0.0	1 min	1449	2.4	19.0	1.0
7/11/2022								3 min	1452	1.3	19.8	0.3
								5 min	1454	0.9	20.0	0.2
								10 min	1459	0.6	20.1	0.1
									Average	1.3	19.7	0.4
Adjacent to LNAPL Area					14.97	12.8	3.9	1 min	1501	0.7	5.3	8.7
								3 min	1504	0.4	7.6	8.8
								5 min	1506	0.3	8.4	8.6
								10 min	1511	0.2	9.1	8.2
									Average	0.4	7.6	8.6

Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: Cold Springs Terminal
Date: July 2022

Headspace Screening Data

Well ID	Depth to Product (ft btor)	Depth to Water (ft btor)	Screen Depth (ft bgs)	Casing Stickup (ft)	Measurement Depth (ft btor)	Measurement Depth (ft bgs)	Measurement Depth (m bgs)	Time lapsed	Time	CH_4 (%)	O_2 (%)	CO_2 (%)
BMW6 7/11/2022	-	29.5	10 - 30	2.07	2.07	0.0	0.0	1 min	947	2.6	20.3	0.2
								3 min	950	2.4	20.5	0.1
								5 min	952	2.6	20.5	0.1
								10 min	957	2.8	20.5	0.1
									Average	2.6	20.5	0.1
Adjacent to LNAPL Area					28.50	26.4	8.1	1 min	1005	2.3	17.0	2.4
								3 min	1008	2.5	16.3	2.4
								5 min	1010	2.8	15.8	2.4
								10 min	1015	3.1	15.4	2.5
									Average	2.7	16.1	2.4
MW-205 7/11/2022	-	5.48	10 - 20	2.81	2.81	0.0	0.0	1 min	820	2.8	20.5	0.1
								3 min	823	2.8	20.4	0.1
								5 min	825	3.0	20.3	0.1
								10 min	830	3.1	20.4	0.1
									Average	2.9	20.4	0.1
Outside of LNAPL Area					4.48	1.7	0.5	1 min	832	3.0	20.3	0.1
								3 min	835	3.0	20.4	0.1
								5 min	837	3.0	20.4	0.1
								10 min	842	3.1	20.4	0.1
									Average	3.0	20.4	0.1
MW-208 7/11/2022	-	10.11	5 - 20	2.81	2.81	0.0	0.0	1 min	850	3.5	18.5	1.3
								3 min	853	3.2	20.2	0.2
								5 min	855	3.2	20.3	0.2
								10 min	900	3.2	20.4	0.1
									Average	3.3	19.9	0.5
Outside of LNAPL Area					9.11	6.3	1.9	1 min	902	40.2	12.8	5.0
								3 min	905	30.1	13.9	4.2
								5 min	907	24.6	15.1	3.4
								10 min	912	16.1	17.5	1.8
									Average	16.1	14.8	3.6
MW-211 7/11/2022	-	10.81	5 - 15	2.88	2.88	0.0	0.0	1 min	1242	2.8	18.0	2.4
								3 min	1245	3.1	19.7	0.3
								5 min	1247	3.1	19.8	0.2
								10 min	1252	3.4	19.8	0.1
									Average	3.1	19.3	0.8
Outside of LNAPL Area					9.81	6.9	2.1	1 min	1254	2.5	15.0	6.5
								3 min	1257	2.5	15.6	5.8
								5 min	1259	2.6	16.1	5.2
								10 min	1304	2.7	17.4	3.4
									Average	2.6	16.0	5.2
AMW4 7/11/2022	-	12.34	5.5 - 20	-0.36	-0.36	0.0	0.0	1 min	1555	6.3	19.7	0.6
								3 min	1558	3.4	19.5	0.7
								5 min	1600	2.3	20.1	0.2
								10 min	1605	1.4	19.4	0.7
									Average	3.4	19.7	0.6
Outside of LNAPL Area					11.34	11.7	3.6	1 min	1607	1.6	11.5	5.8
								3 min	1610	0.9	11.4	6.3
								5 min	1612	1.7	11.4	6.3
								10 min	1617	0.6	12.6	6.2
									Average	1.2	11.7	6.2
MW-204 7/11/2022	-	9.14	5 - 20	2.12	2.12	0.0	0.0	1 min	918	2.9	18.5	1.4
								3 min	921	2.9	20.2	0.3
								5 min	923	3.0	20.3	0.2
								10 min	928	3.1	20.3	0.2
									Average	3.0	19.8	0.5
Outside of LNAPL Area					8.14	6.0	1.8	1 min	930	2.0	7.9	10.8
								3 min	933	2.3	10.4	8.4
								5 min	935	2.6	12.9	6.2
								10 min	940	2.6	15.5	4.0
									Average	2.4	11.7	7.4

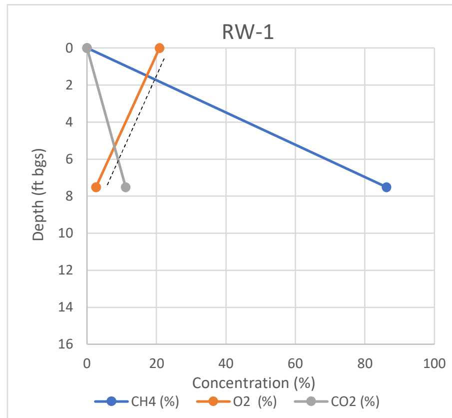
*CRC CARE 44 p. 163 - Ensure existing monitoring wells have at least 0.3 m of screen that is open to the vadose zone.

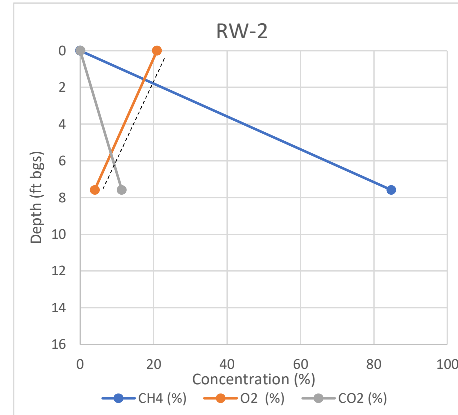
Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: Cold Springs Terminal
Date: July 2022

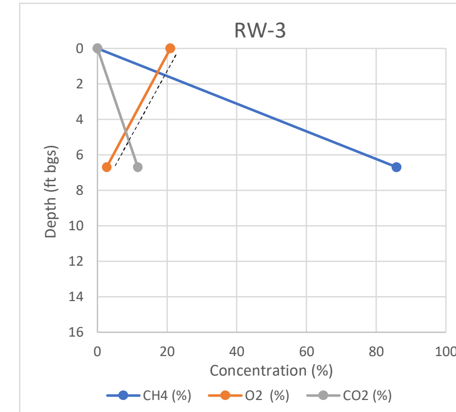
Soil Gas Trends*

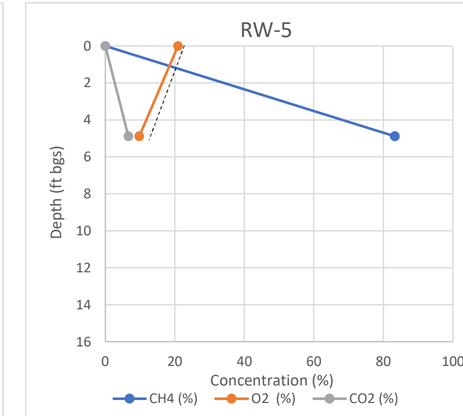
Well ID	Depth of measurement		CH_4 (%)	O_2 (%)	CO_2 (%)
	(ft bgs)	(m bgs)			
RW-1	0.0	0.0	0.0	20.9	0.03
	7.5	2.3	86.2	2.6	11.2
RW-2	0.0	0.0	0.0	20.9	0.03
	7.6	2.3	84.7	4.0	11.3
RW-3	0.0	0.0	0.0	20.9	0.03
	6.7	2.0	85.8	2.7	11.6
RW-5	0.0	0.0	0.0	20.9	0.03
	4.9	1.5	83.3	9.8	6.7
MW-5SR	0.0	0.0	0.0	20.9	0.03
	5.9	1.8	82.0	6.0	10.9
A10	0.0	0.0	0.0	20.9	0.03
	7.4	2.3	86.7	2.4	11.0
BMW5	0	0.0	0.0	20.9	0.03
	22.2	6.8	88.0	1.8	10.2
BMW13	0	0.0	0.0	20.9	0.03
	15.4	4.7	86.0	0.2	13.9
MW-11SR	0	0.0	0.0	20.9	0.03
	7.8	2.4	9.2	5.3	3.4
MW-12S	0	0.0	0.0	20.9	0.03
	12.9	3.9	0.4	7.6	8.3
AMW7	0	0.0	0.0	20.9	0.03
	9.3	2.8	2.9	10.1	7.8
A9	0	0.0	0.0	20.9	0.03
	12.8	3.9	10.2	1.0	13.9
MW-8S	0	0.0	0.0	20.9	0.03
	4.8	1.5	4.3	12.0	5.7
MW-10S	0	0.0	0.0	20.9	0.03
	5.1	1.5	0.0	10.3	9.7
BMW14R	0	0.0	0.0	20.9	0.03
	12.8	3.9	0.4	7.6	8.6
BMW6	0	0.0	0.0	20.9	0.03
	26.4	8.1	2.7	16.1	2.4
MW-205	0	0.0	0.0	20.9	0.03
	1.7	0.5	3.0	20.4	0.1
MW-208	0	0.0	0.0	20.9	0.03
	6.3	1.9	16.1	14.8	3.6
MW-211	0	0.0	0.0	20.9	0.03
	6.9	2.1	2.6	16.0	5.2
AMW4	0	0.0	0.0	20.9	0.03
	11.7	3.6	1.2	11.7	6.2
MW-204	0	0.0	0.0	20.9	0.03
	6.0	1.8	2.4	11.7	7.4

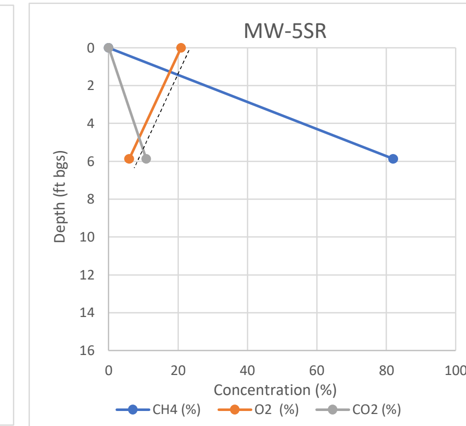
*assumes atmospheric conditions for surface since all wells have solid casing at top

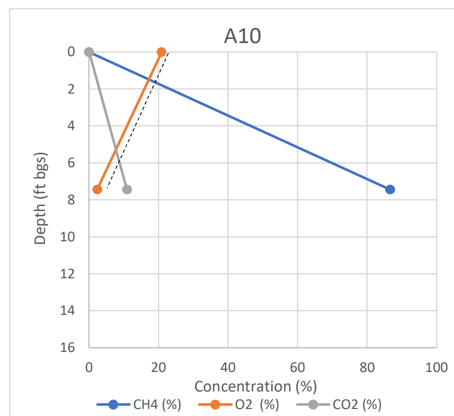


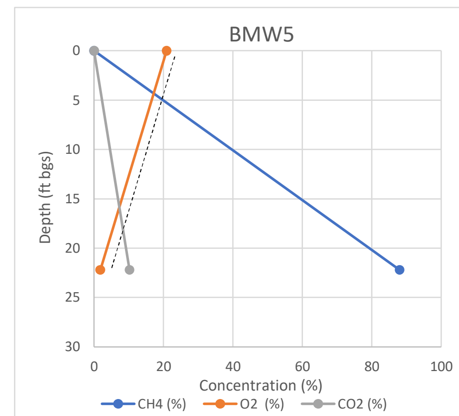


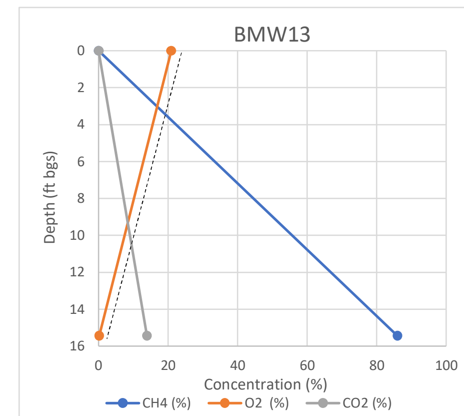


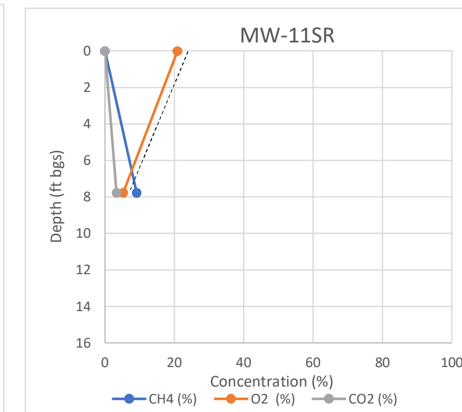


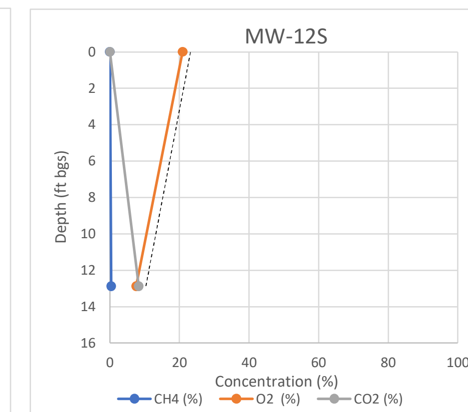


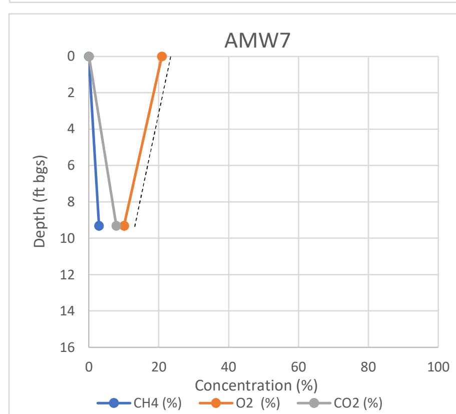


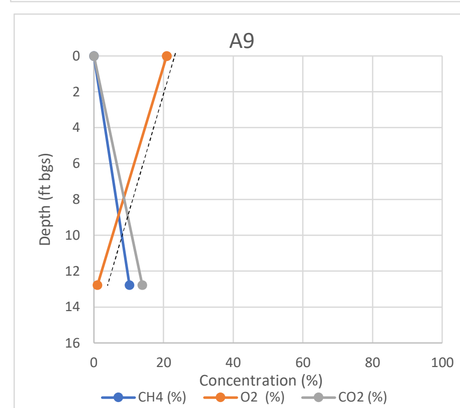


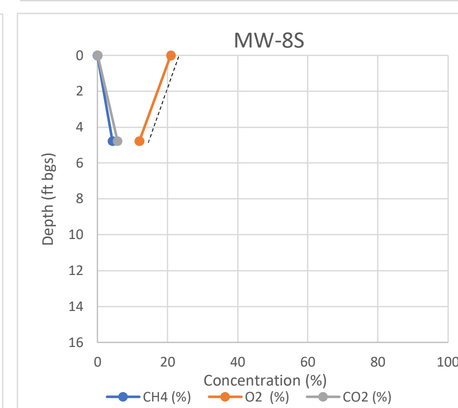


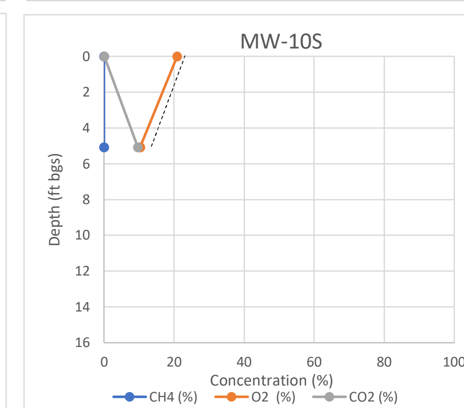


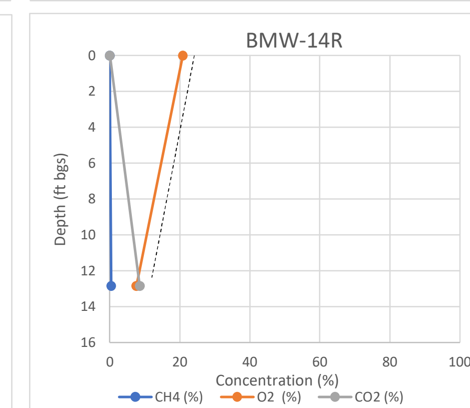


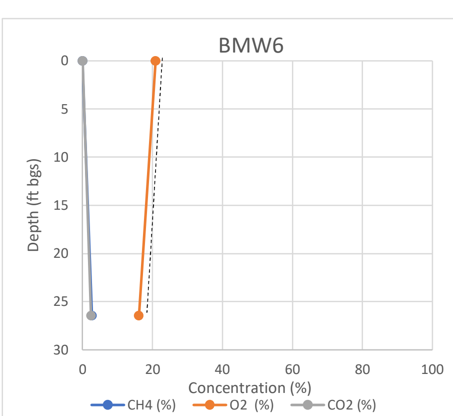


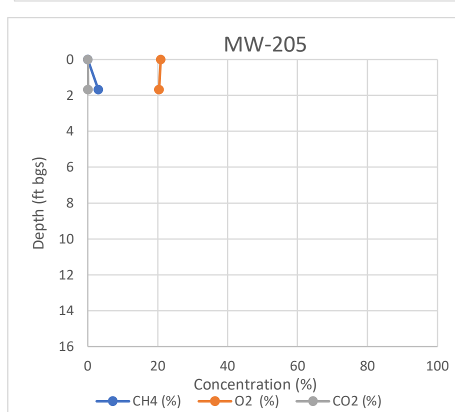


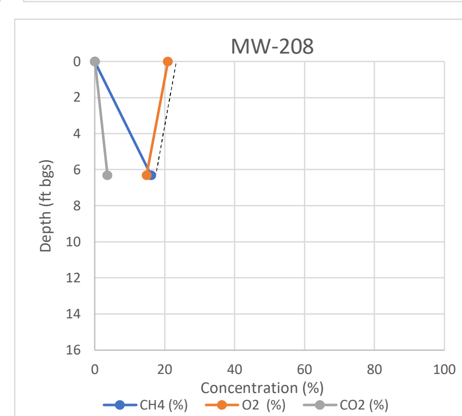


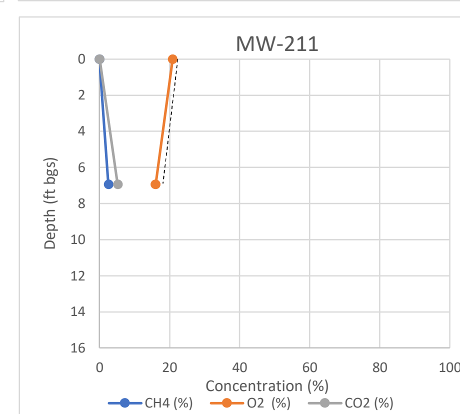


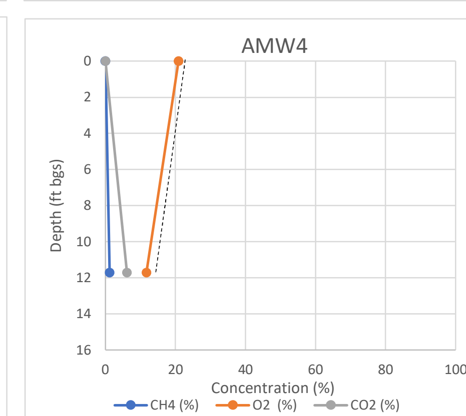


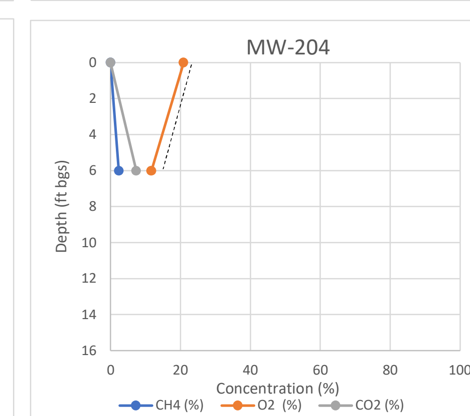












Natural Source Zone Depletion (NSZD) Assessment
Soil Vapor Gradient Method
Site: **Cold Springs Terminal**
Date: **July 2022**

Soil Gas Headspace

Well ID	Depth of measurement (ft bgs)	Depth of measurement (m bgs)	CH_4 (%)	O_2 (%)	CO_2 (%)
RW-1	0.0	0.0	0.0	20.9	0.0
	7.5	2.3	86.2	2.6	11.2
RW-2	0.0	0.0	0.0	20.9	0.0
	7.6	2.3	84.7	4.0	11.3
RW-3	0.0	0.0	0.0	20.9	0.0
	6.7	2.0	85.8	2.7	11.6
RW-5	0.0	0.0	0.0	20.9	0.0
	4.9	1.5	83.3	9.8	6.7
MW-5SR	0.0	0.0	0.0	20.9	0.0
	5.9	1.8	82.0	6.0	10.9
A10	0.0	0.0	0.0	20.9	0.0
	7.4	2.3	86.7	2.4	11.0
BMW5	0.0	0.0	0.0	20.9	0.0
	22.2	6.8	88.0	1.8	10.2
BMW13	0.0	0.0	0.0	20.9	0.0
	15.4	4.7	86.0	0.2	13.9
MW-11SR	0.0	0.0	0.0	20.9	0.0
	7.8	2.4	9.2	5.3	3.4
MW-12S	0.0	0.0	0.0	20.9	0.0
	12.9	3.9	0.4	7.6	8.3
AMW7	0.0	0.0	0.0	20.9	0.0
	9.3	2.8	2.9	10.1	7.8
A9	0.0	0.0	0.0	20.9	0.0
	12.8	3.9	10.2	1.0	13.9
MW-8S	0.0	0.0	0.0	20.9	0.0
	4.8	1.5	4.3	12.0	5.7
MW-10S	0.0	0.0	0.0	20.9	0.0
	5.1	1.5	0.0	10.3	9.7
BMW14R	0.0	0.0	0.0	20.9	0.0
	12.8	3.9	0.4	7.6	8.6
BMW6	0.0	0.0	0.0	20.9	0.0
	26.4	8.1	2.7	16.1	2.4
MW-205	0.0	0.0	0.0	20.9	0.0
	1.7	0.5	3.0	20.4	0.1
MW-208	0.0	0.0	0.0	20.9	0.0
	6.3	1.9	16.1	14.8	3.6
MW-211	0.0	0.0	0.0	20.9	0.0
	6.9	2.1	2.6	16.0	5.2
AMW4	0.0	0.0	0.0	20.9	0.0
	11.7	3.6	1.2	11.7	6.2
MW-204	0.0	0.0	0.0	20.9	0.0
	6.0	1.8	2.4	11.7	7.4

*CRC CARE 44 p. 163 - Ensure existing monitoring wells have at least 0.3 m of screen that is open to the vadose zone.

Soil Gas Gradient Method

$J = D_v \times (dC/dz)$	Fick's Law of Diffusion
where $D_v = D_{O2}(eff) = D_{O2}(air) \times O_v^{3.3} / O_t^2$	Millington and Quirk (1961) Eq.
$J_{NSZD} = J_{total} - J_{background} = D_v \times (dC/dz - dC/dz_{bkgr})$	background corrected flux
$2\ C_8H_{18} + 25\ O_2 = 16\ CO_2 + 18\ H_2O$	stoichiometric equation
NSZD rate = J_{NSZD} x conversion ratio $C_8H_{18} : O_2$	hydrocarbon ≈ octane (C_8H_{18})
NSZD rate = NSZD rate (in g C_8H_{18}/m^2day) x ρ_{LNAPL}	

Input parameter		Value	Units	Source:	Rationale for value selection:
diffusion coefficient of oxygen in ai	D_{O2}(air)	0.21	cm^2/s	CRC CARE Tech Rpt 44 p.166	constant
air-filled porosity	O_v	0.3	cm^3-vapor/cm^3-soil	CRC CARE Tech Rpt 44 p.145	CRC CARE notes this is based on Johnson et. al. (1998)
	$O_v^{3.3}$	0.019		calculation	N/A
total porosity of vadose zone soil within & above HC oxidation zone	O_t	0.38	cm^3-vapor/cm^3-soil	EPA & API	site soils - sands and silty sands
	O_t^2	0.14		calculation	N/A
effective diffusivity based on O_2	D_v	0.027	cm^2/s	calculation	Millington and Quirk (1961) equation
		0.24	m^2/day	unit conversion	N/A
molecular weight of octane	MW C_8H_{18}	114.2	g/mol	CRC CARE Tech Rpt 44	constant for C_8H_{18}, representative component of hydrocarbo
mass of octane	2*MW C_8H_{18}	228.5	g octane	calculation	based on stoichometric equation
molecular weight of oxygen	MW O_2	32	g/mol	CRC CARE Tech Rpt 47	constant for O_2
mass of oxygen	25*MW O_2	800	g O_2	calculation	based on stoichometric equation
conversion ratio octane:oxygen	$C_8H_{18} : O_2$	0.29	unitless	calculation	based on stoichometric equation
LNAPL density*	ρ_{LNAPL}	740	g HC/L	CLU-IN	estimate for site LNAPL (gasoline)

Notes:
highlight indicates site-specific values
*LNAPL density ranges from 700-900 g HC/L

Estimated NSZD Rates based on O_2 changes.

	Depth z_1	Temp* at z_1	Concentration C_1 at z_1		Depth z_2	Temp* at z_2	Concentration C_2 at z_2		Concentration gradient dC/dz		dC/dz corrected	Flux $J(O_2)$	NSZD rate	NSZD rate		
	m bgs	deg C	O_2 %	mg O_2/m^3	m bgs	deg C	O_2 %	mg O_2/m^3	mg $O_2/m^3/m$	g $O_2/m^3/m$	g O_2/m^2	g O_2/m^2day	g C_8H_{18}/m^2day	$L/m^2/yr$	L/ha/yr	US gal/acre/yr
Within LNAPL Area																
RW-1	0.0	29.30	20.9	269503	2.3	18.70	2.6	35078	102303	102.3	95.5	22.6	6.4	3.2	31,789	**3,399**
RW-2	0.0	30.80	20.9	268173	2.3	23.10	4.0	52330	93399	93.4	86.6	20.5	5.8	2.9	28,824	**3,082**
RW-3	0.0	31.50	20.9	267557	2.0	25.15	2.7	34974	114027	114.0	107.2	25.3	7.2	3.6	35,694	**3,816**
RW-5	0.0	33.30	20.9	265986	1.5	29.70	9.8	125881	94000	94.0	87.2	20.6	5.9	2.9	29,025	**3,103**
MW-5SR	0.0	31.60	20.9	267469	1.8	26.50	6.0	77442	106391	106.4	99.6	23.5	6.7	3.3	33,151	**3,545**
A10	0.0	24.80	20.9	273574	2.3	16.50	2.4	32315	106388	106.4	99.5	23.5	6.7	3.3	33,150	**3,544**
BMW5	0.0	24.60	20.9	273757	6.8	12.35	1.8	24589	36822	36.8	30.0	7.1	2.0	1.0	9,984	**1,068**
BMW13	0.0	22.40	20.9	275795	4.7	15.20	0.2	2029	58173	58.2	51.3	12.1	3.5	1.7	17,094	**1,828**
Adjacent to LNAPL Area																
MW-11SR	0.0	26.90	20.9	271659	2.4	22.50	5.3	69585	85325	85.3	78.5	18.6	5.3	2.6	26,136	**2,794**
MW-12S	0.0	27.70	20.9	270937	3.9	17.20	7.6	101638	43158	43.2	36.3	8.6	2.5	1.2	12,094	**1,293**
AMW7	0.0	26.10	20.9	272385	2.8	19.70	10.1	134175	48700	48.7	41.9	9.9	2.8	1.4	13,940	**1,490**
A9	0.0	33.90	20.9	265466	3.9	16.00	1.0	13151	64773	64.8	57.9	13.7	3.9	1.9	19,292	**2,063**
MW-8S	0.0	39.90	20.9	260378	1.5	24.50	12.0	156907	71019	71.0	64.2	15.2	4.3	2.1	21,372	**2,285**
MW-10S	0.0	27.30	20.9	271297	1.5	23.65	10.3	135674	87538	87.5	80.7	19.1	5.4	2.7	26,873	**2,873**
BMW14R	0.0	22.60	20.9	275609	3.9	13.30	7.6	103475	43969	44.0	37.1	8.8	2.5	1.2	12,364	**1,322**
BMW6 (bkgr)	0.0	20.60	20.9	277485	8.1	9.65	16.1	222378	6839	6.8	0.0	0.0	0.0	0.0	0	0
Outside of LNAPL Area																
MW-205	0.0	18.20	20.9	279771	0.5	18.20	20.4	272743	13823	13.8	shallow vadose zon	-	-	-	-	-
MW-208	0.0	18.30	20.9	279675	1.9	16.35	14.8	199718	41619	41.6	34.8	8.2	2.3	1.2	11,582	**1,238**
MW-211	0.0	18.60	20.9	279387	2.1	15.40	16.0	216595	29728	29.7	22.9	5.4	1.5	0.8	7,622	**815**
AMW4	0.0	25.40	20.9	273024	3.6	17.20	11.7	157493	32396	32.4	25.6	6.0	1.7	0.9	8,511	**910**
MW-204	0.0	18.90	20.9	279100	1.8	17.40	11.7	156714	66722	66.7	59.9	14.2	4.0	2.0	19,941	**2,132**
													Average	2.1	20,970	**2,242**

*Temperatures (deg C) used from biogenic heat temperature measurements.
T(deg K) = T(deg C) + 273.15

Range (US gal/acre/yr)

Appendix D

Biogenic Heat Data and Calculations

Biogenic Heat Natural Source Zone Depletion (NSZD)
Well Information
Site: 11137172 Cold Springs Terminal

Well ID	Northing	Easting	Top of Riser Elevation (feet)	Ground Elevation (feet)	Casing Stickup (feet)	Well Casing Diameter (inches)	Well Material	Depth to Bottom (feet bmp)	Elevation of Bottom (feet)	Screen Interval (feet bgs)		Elevation of Screen Interval (feet)		7-5-2022 Gauging Event Depth to Product	Depth to Water	Elevation of Product	Elevation of Water
Within LNAPL Area										Top	Bottom	Top	Bottom	(feet btor)	(feet btor)	(feet)	(feet)
RW-1	1141052.6333	908861.6456	373.37	371.69	1.68	6.00	PVC	17.20	356.17	5.00	15.00	366.69	356.69	10.20	10.53	362.58	362.84
RW-2	1141083.9961	908919.1729	372.78	370.90	1.88	6.00	PVC	17.30	355.48	5.00	15.00	365.90	355.90	10.46	10.51	362.86	362.27
RW-3	1141091.8827	908974.6126	373.32	371.01	2.31	6.00	PVC	17.15	356.17	5.00	15.00	366.01	356.01	10.00	10.16	362.49	363.16
RW-5	1141105.4243	909059.1389	372.49	369.20	3.29	6.00	PVC	17.30	355.19	5.00	15.00	364.20	354.20	9.18	9.37	361.34	363.12
MW-5SR	1141135.8540	909120.4974	370.52	367.85	2.67	2.00	PVC	17.40	353.12	4.00	14.00	363.85	353.85	9.53	9.56	363.64	360.96
A10	1141080.6178	908815.3434	373.17	371.80	1.37	2.00	Stainless	14.11	359.06	4.00	14.00	367.80	357.80	-	9.81	-	363.36
BMW5	1141249.4584	908820.5496	389.58	387.96	1.62	2.00	PVC	31.80	357.78	10.00	30.00	377.96	357.96	24.82	25.28	357.87	364.30
BMW13	1141243.6732	909014.8734	382.69	380.17	2.52	4.00	PVC	25.41	357.28	15.00	25.00	365.17	355.17	18.96	19.10	363.73	363.59
Adjacent to LNAPL Area																	
MW-11SR	1141038.2070	908773.1689	371.65	368.75	2.90	2.00	PVC	17.45	354.20	4.00	14.00	364.75	354.75	-	11.67	-	359.98
MW-12S	1141106.1370	908781.4181	377.59	374.74	2.85	2.00	PVC	19.38	358.21	6.00	16.00	368.74	358.74	-	16.72	-	360.87
AMW7	1141013.1605	908956.9316	375.31	373.02	2.29	2.00	PVC	16.49	358.82	5.00	18.00	368.02	355.02	-	12.60	-	362.71
A9	1141155.5042	908983.1398	376.67	377.47	-0.80	4.00	PVC	17.24	359.43	4.00	19.00	373.47	358.47	-	12.98	-	363.69
MW-8S	1141057.2350	909142.2698	369.23	366.42	2.81	2.00	PVC	16.81	352.42	4.00	14.00	362.42	352.42	-	8.59	-	360.64
MW-10S	1141019.7722	909341.9481	371.67	369.21	2.46	2.00	PVC	16.82	354.85	4.50	14.50	364.71	354.71	-	8.54	-	363.13
BMW14R	1141257.7744	909096.3565	379.96	377.83	2.13	2.00	PVC	19.83	360.13	5.00	20.00	372.83	357.83	-	15.97	-	363.99
BMW6	1141286.0738	908914.0483	395.04	392.98	2.07	2.00	PVC	32.34	362.70	10.00	30.00	382.98	362.98	-	29.50	-	365.54
Outside of LNAPL Area																	
MW-205	1141543.5858	908866.5743	398.05	395.24	2.81	2.00	PVC	22.65	375.40	10.00	20.00	385.24	375.24	-	5.48	-	392.57
MW-208	1141526.8914	909079.9571	397.23	394.42	2.81	2.00	PVC	22.07	375.16	5.00	20.00	389.42	374.42	-	10.11	-	387.12
MW-211	1141377.9524	909200.1678	387.40	384.52	2.88	2.00	PVC	17.27	370.13	5.00	15.00	379.52	369.52	-	10.81	-	376.59
AMW4	1141132.7950	908633.9925	378.43	378.79	-0.36	2.00	PVC	13.80	364.63	5.50	20.00	373.29	358.79	-	12.34	-	366.09
MW-204	1141427.2962	908979.9805	395.02	392.90	2.12	2.00	PVC	21.77	373.25	5.00	20.00	387.90	372.90	-	9.14	-	385.88

- No measurable apparent LNAPL thickness

Biogenic Heat Natural Source Zone Depletion (NSZD)
Field Measurements
Site: 11137172 Cold Springs Terminal
Date: 7/7/2022

Thermocouple above ground check (ambient air or water):

	RW-1	RW-2	RW-3	RW-5	MW-5SR	A10	BMW5	BMW13	MW-11SR	MW-12S	AMW7	A9
Time	15:12	15:25	15:38	15:48	15:56	14:55	14:26	14:08	13:03	13:15	13:52	11:00
1	26.8	26.2	29.4	24.9	27.4	31.4	21.8	21.6	23.8	23	21.7	25.7
2	30.3	31.6	36	30.8	32.9	35	27.1	26.1	28.2	27.5	25.2	28.8
3	28.8	28.7	33.4	28.9	32	31	25.9	25.7	27	27.1	24.8	27
4	32.5	32	34.2	33.3	34	34.3	26.9	27.1	30	26	28.3	30.1
Ambient Temp:	27.2	31.6	39.7	39.1	38.7	31.3	27.1	26	28.7	30	33.8	25

	RW-1			RW-2			RW-3			RW-5			MW-5SR			A10		
Depth	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp
ft bgs	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)
1	2.7	29.30		2.9	30.80		3.3	31.50		4.3	33.30		3.7	31.60		2.4	24.80	
2	3.7	25.20	5.39	3.9	26.30	6.49	4.3	27.70	7.89	5.3	26.10	6.29	4.7	27.80	7.99	3.4	20.60	0.79
3	4.7	25.30	7.72	4.9	27.80	10.22	5.3	29.80	12.22	6.3	25.50	7.92	5.7	26.50	8.92	4.4	21.90	4.32
4	5.7	22.50	6.78	5.9	22.10	6.38	6.3	22.60	6.88	7.3	21.20	5.48	6.7	21.80	6.08	5.4	20.10	4.38
5	6.7	22.40	8.17	6.9	26.10	11.87	7.3	27.70	13.47	8.3	27.30	13.07	7.7	26.70	12.47	6.4	21.10	6.87
6	7.7	18.70	5.62	7.9	20.10	7.02	8.3	22.90	9.82	9.3	15.90		8.7	22.90	9.82	7.4	16.50	3.42
7	8.7	19.60	7.38	8.9	22.10	9.88	9.3	25.10	12.88	10.3	16.70		9.7	16.20		8.4	18.60	6.38
8	9.7	19.10	7.50	9.9	14.70	3.10	10.3	14.50		11.3	14.00		10.7	13.90		9.4	17.60	6.00
9	10.7	14.90		10.9	17.50		11.3	17.50					11.7	15.50		10.4	14.90	
10	11.7	12.90		11.9	13.20		12.3	13.20					12.7	13.10		11.4	12.70	
11	12.7	14.10		12.9	16.10		13.3	16.90					13.7	13.50		12.4	14.70	
12	13.7	12.40		13.9	12.40		14.3	12.80					14.7	11.70		13.4	12.70	
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	BMW5			BMW13			MW-11SR			MW-12S			AMW7			A9		
Depth	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp	Depth	Measured Temp	Corrected Temp
ft bgs	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)	ft btoc	(deg C)	(deg C)
1	2.6	24.60		3.5	22.40		3.9	26.90		3.9	27.70		3.3	26.10		0.2	33.90	
2	3.6	22.50	2.69	4.5	19.80	0.00	4.9	23.80	3.99	4.9	26.30	6.49	4.3	21.80	1.99	1.2	24.10	4.29
3	4.6	21.80	4.22	5.5	20.40	2.82	5.9	24.60	7.02	5.9	26.90	9.32	5.3	23.00	5.42	2.2	25.80	8.22
4	5.6	18.60	2.88	6.5	18.70	2.98	6.9	21.80	6.08	6.9	20.40	4.68	6.3	20.50	4.78	3.2	23.10	7.38
5	6.6	20.30	6.07	7.5	20.00	5.77	7.9	22.50	8.27	7.9	26.40	12.17	7.3	22.10	7.87	4.2	25.20	10.97
6	7.6	16.80	3.72	8.5	17.50	4.42	8.9	19.20	6.12	8.9	22.70	9.62	8.3	18.70	5.62	5.2	20.00	6.92
7	8.6	18.00	5.78	9.5	18.30	6.08	9.9	20.40	8.18	9.9	23.10	10.88	9.3	19.70	7.48	6.2	21.60	9.38
8	9.6	16.50	4.90	10.5	17.20	5.60	10.9	19.40	7.80	10.9	18.60	7.00	10.3	18.20	6.60	7.2	20.00	8.40
9	10.6	17.00	5.80	11.5	17.20	6.00	11.9	14.80		11.9	21.20	10.00	11.3	19.70	8.50	8.2	19.70	8.50
10	11.6	14.40	3.43	12.5	15.10	4.13	12.9	13.20		12.9	17.20	6.23	12.3	16.20	5.23	9.2	16.40	5.43
11	12.6	15.50	3.64	13.5	15.80	3.94	13.9	13.80		13.9	18.90	7.04	13.3	14.70		10.2	18.30	6.44
12	13.6	14.70	3.02	14.5	15.90	4.22	14.9	12.50		14.9	16.00	4.32	14.3	13.60		11.2	17.40	5.72
13	14.6	13.80	2.25	15.5	15.20	3.65				15.9	18.20	6.65	15.3	12.90		12.2	16.00	4.45
14	15.6	12.20	0.74	16.5	13.30	1.84				16.9	12.70		16.3	13.90		13.2	13.30	
15	16.6	13.30	1.90	17.5	14.30	2.90				17.9	15.20					14.2	14.50	
16	17.6	13.60	2.24	18.5	14.70	3.34				18.9	12.20					15.2	12.90	
17	18.6	12.30	0.95	19.5	11.30													
18	19.6	11.20	-0.16	20.5	10.60													
19	20.6	12.20	0.81	21.5	11.20													
20	21.6	12.80	1.38	22.5	10.90													
21	22.6	11.90	0.46															
22	23.6	11.10	-0.45															
23	24.6	11.90	0.24															
24	25.6	10.90																
25	26.6	11.40																
26	27.6	10.90																
27	28.6	11.50																
28	29.6	11.10																
29																		
30																		

	RW-1		RW-2		RW-3		RW-5		MW-5SR		A10	
Fluid level (ft bTOR)	10.20		10.46		10.00		9.18		9.53		9.81	
TOR elev. (ft)	373.37		372.78		373.32		372.49		370.52		373.17	
Ground surface elev. (ft)	371.69		370.90		371.01		369.20		367.85		371.80	
Casing stickup (ft)	**1.68**		**1.88**		**2.31**		**3.29**		**2.67**		**1.37**	
Total well depth (ft bTOR)	17.20		17.30		17.15		17.30		17.40		14.11	
Well diameter (in)	6		6		6		6		2		2	
screen interval (ft bgs)	5	15	5	15	5	15	5	15	4	14	4	14
Fluid level elev. 7-5-22 (ft)	363.17		362.32		363.32		363.31		360.99		363.36	stainless
	LNAPL		LNAPL		LNAPL		LNAPL		LNAPL		H2O	

	BMW5		BMW13		MW-11SR		MW-12S		AMW7		A9	
Fluid level (ft bTOR)	24.82		18.96		11.67		16.72		12.60		12.98	
TOR elev. (ft)	389.58		382.69		371.65		377.59		375.31		376.67	
Ground surface elev. (ft)	387.96		380.17		368.754		374.738		373.02		377.47	
Casing stickup (ft)	**1.62**		**2.52**		**2.90**		**2.85**		**2.29**		**-0.80**	
Total well depth (ft bTOR)	31.80		25.41		17.45		19.38		16.49		17.24	
Well diameter (in)	2		4		2		2		2		4	
screen interval (ft bgs)	10	30	15	25	4	14	6	16	5	18	4	19
Fluid level elev. 7-5-22 (ft)	364.76		363.73		359.98		360.87		362.71		363.69	
	LNAPL		LNAPL		H2O		H2O		H2O		H2O	

MW-8S

13:43

1	23.6
2	30
3	27.8
4	31.2
	41

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.8	29.90	
4.8	24.50	4.69
5.8	26.50	8.92
6.8	21.30	5.58
7.8	24.00	9.77
8.8	16.00	
9.8	17.30	
10.8	14.50	

8.59		
369.23		
366.419		
2.81		
16.81		
2		
4	14	
360.64		
H2O		

MW-10S

13:33

1	25.1
2	32.7
3	29.9
4	30.3
	40.4

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.5	27.30	
4.5	22.10	2.29
5.5	25.20	7.62
6.5	20.70	4.98
7.5	22.70	8.47
8.5	14.30	
9.5	17.30	
10.5	13.00	

8.54		
371.67		
369.21		
2.46		
16.82		
2		
4.5	14.5	
363.13		
H2O		

BMW14R

12:28

1	21.2
2	24.5
3	24
4	26
	28.2

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.1	22.60	
4.1	19.70	0.00
5.1	20.30	2.72
6.1	18.10	2.38
7.1	19.00	4.77
8.1	16.10	3.02
9.1	16.70	4.48
10.1	16.20	4.60
11.1	15.10	3.90
12.1	12.70	1.73
13.1	13.90	2.04
14.1	14.40	2.72
15.1	16.80	5.25
16.1	9.70	
17.1	10.80	
18.1	9.80	

15.97		
379.96		
377.83		
2.13		
19.83		
2		
5	20	
363.99		
H2O		

BMW6

11:35

1	23.8
2	25.6
3	24.2
4	26.1
	29

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.1	20.60	
4.1	18.10	0.00
5.1	19.10	1.52
6.1	18.90	3.18
7.1	15.80	1.57
8.1	13.60	0.52
9.1	14.80	2.58
10.1	15.60	4.00
11.1	12.60	1.40
12.1	10.90	0.00
13.1	12.30	0.44
14.1	13.10	1.42
15.1	10.50	0.00
16.1	9.40	0.00
17.1	10.05	0.00
18.1	10.80	0.00
19.1	9.60	0.00
20.1	8.70	0.00
21.1	9.70	0.00
22.1	10.10	0.00
23.1	9.50	0.00
24.1	8.70	0.00
25.1	9.70	0.00
26.1	9.80	0.00
27.1	9.50	0.00
28.1	8.80	0.00
29.1	9.80	0.00
30.1	9.20	
31.1	9.60	
32.1	9.00	

29.50		
395.04		
392.98		
2.07		
32.34		
2		
10	30	
365.54		
H2O		

MW-205

8:30

1	18
2	19
3	19
4	19.4
Ambient Temp:	18.9

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.8	18.20	
4.8	17.00	0.00
5.8	16.00	
6.8	14.90	
7.8	14.40	
8.8	13.40	
9.8	13.20	
10.8	12.40	

5.48		
398.05		
395.24		
2.81		
22.65		
2		
10	20	
392.57		
H2O		

MW-208

9:00

1	18.6
2	19.3
3	19.3
4	19.5
Ambient Temp:	18.9

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.8	18.30	
4.8	16.80	0.00
5.8	16.30	0.00
6.8	16.40	0.68
7.8	14.70	0.47
8.8	13.50	0.42
9.8	13.40	1.18
10.8	11.60	
11.8	11.20	
12.8	10.70	
13.8	10.60	
14.8	10.20	

10.11		
397.23		
394.42		
2.81		
22.07		
2		
5	20	
387.12		
H2O		

MW-211

9:50

1	18.4
2	21.9
3	21.4
4	22
Ambient Temp:	21.8

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.9	18.60	
4.9	17.00	0.00
5.9	16.40	0.00
6.9	15.40	0.00
7.9	14.70	0.47
8.9	13.00	-0.08
9.9	13.20	0.98
10.9	13.00	
11.9	12.00	
12.9	10.20	
13.9	11.30	
14.9	9.60	

10.81		
387.40		
384.52		
2.88		
17.27		
2		
5	15	
376.59		
H2O		

AMW4

10:19

1	24.5
2	28.1
3	27.5
4	25.9
Ambient Temp:	25.3

Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
0.6	25.40	
1.6	22.40	2.59
2.6	25.10	7.52
3.6	22.10	6.38
4.6	23.60	9.37
5.6	18.80	5.72
6.6	21.80	9.58
7.6	19.40	7.80
8.6	19.40	8.20
9.6	15.50	4.53
10.6	18.70	6.84
11.6	17.20	5.52
12.6	16.90	
13.6	14.30	
14.6	NA	

NA - bottom of well encountered before reaching final target depth.

12.34		
378.43		
378.79		
-0.36		
13.8		
2		
5.5	20	
366.09		
H2O		

MW-204

9:27

1	20.5
2	20.9
3	20
4	20.4
Ambient Temp:	20.7

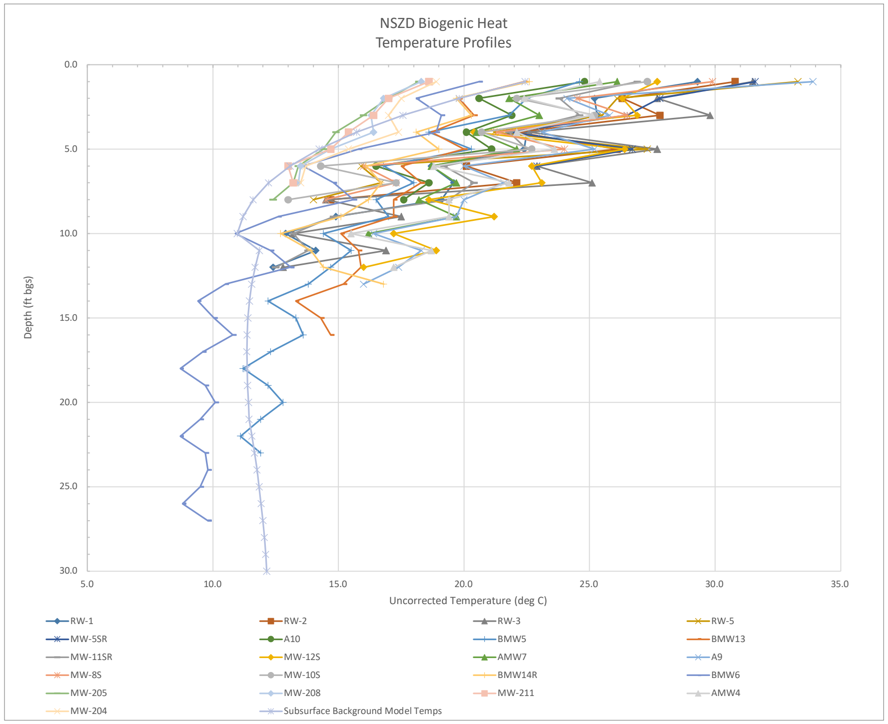
Depth ft btoc	Measured Temp (deg C)	Corrected Temp (deg C)
3.1	18.90	
4.1	17.50	0.00
5.1	17.00	0.00
6.1	17.40	1.68
7.1	15.40	1.17
8.1	13.70	0.62
9.1	13.50	1.28
10.1	12.10	
11.1	12.00	
12.1	11.10	
13.1	11.10	
14.1	10.40	

9.14		
395.02		
392.90		
2.12		
21.8		
2		
5	20	
385.88		
H2O		

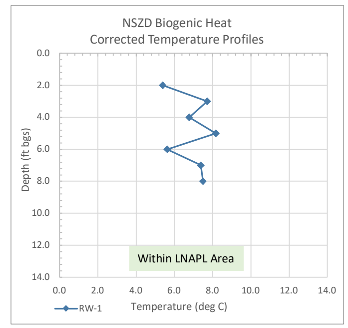
Background Correction

Depth ft bgs	Average Background Well Temps (deg C)
1	18.5
2	17.1
3	16.6
4	16.4
5	14.9
6	13.4
7	13.4
8	
9	
10	
11	
12	
13	
14	
15	
16	

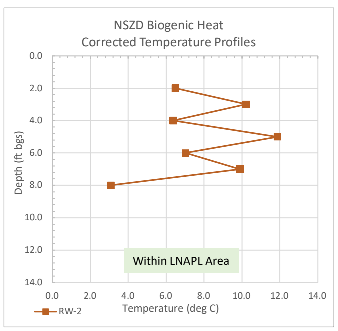
Depth ft bgs	Subsurface Background Model Temps (deg C)
1	22.4
2	19.8
3	17.6
4	15.7
5	14.2
6	13.1
7	12.2
8	11.6
9	11.2
10	11.0
11	11.9
12	11.7
13	11.5
14	11.5
15	11.4
16	11.4
17	11.4
18	11.4
19	11.4
20	11.4
21	11.4
22	11.6
23	11.7
24	11.8
25	11.8
26	11.9
27	12.0
28	12.1
29	12.1
30	12.1
31	12.2
32	12.2



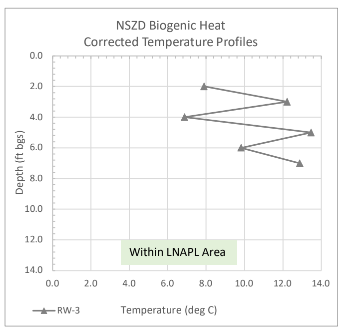
NSZD Biogenic Heat
Temperature Profiles
Depth (ft bgs)
Uncorrected Temperature (deg C)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
RW-1
RW-2
RW-3
RW-5
MW-5SR
A10
BMW5
BMW13
MW-11SR
MW-12S
AMW7
A9
MW-8S
MW-10S
BMW14R
BMW6
MW-205
MW-208
MW-211
AMW4
MW-204
Subsurface Background Model Temps



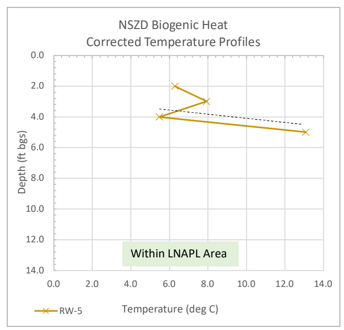
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
RW-1
Within LNAPL Area



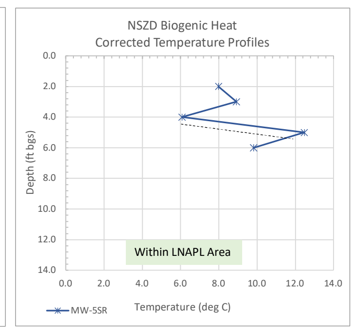
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
RW-2
Within LNAPL Area



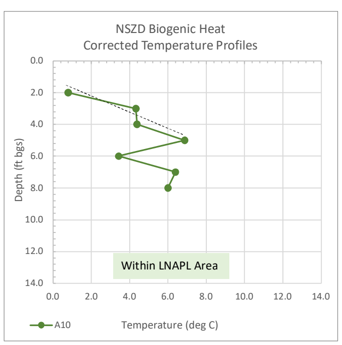
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
RW-3
Within LNAPL Area



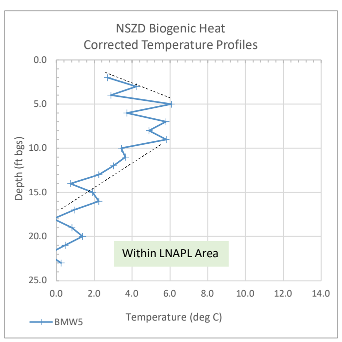
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
RW-5
Within LNAPL Area



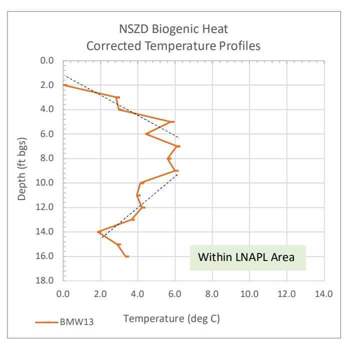
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
MW-5SR
Within LNAPL Area



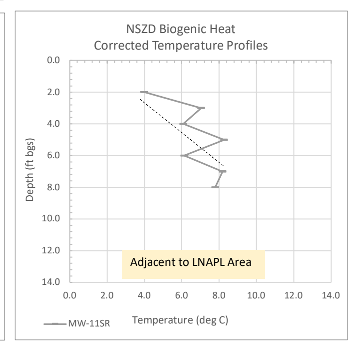
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
A10
Within LNAPL Area



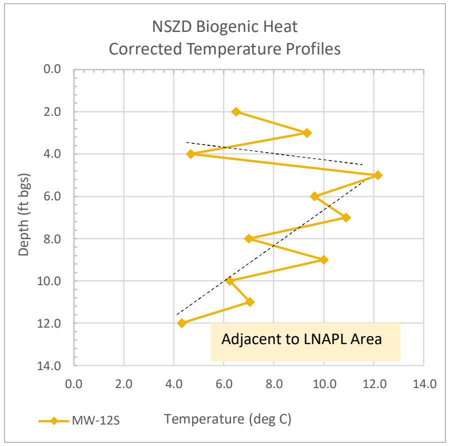
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
BMW5
Within LNAPL Area

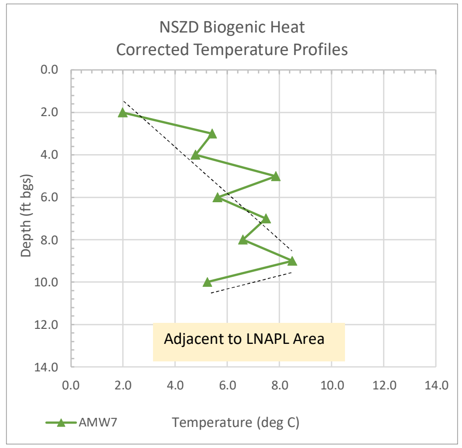


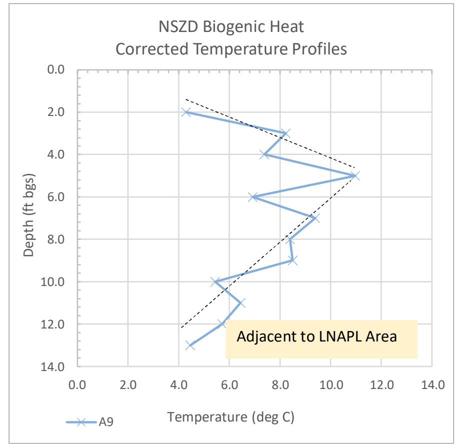
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
BMW13
Within LNAPL Area

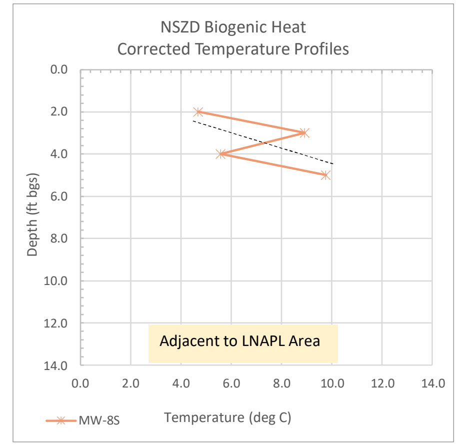


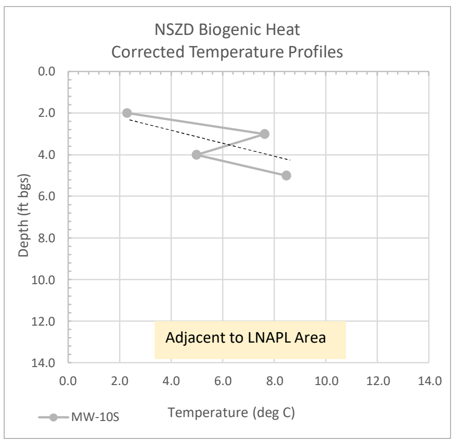
NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
Temperature (deg C)
MW-11SR
Adjacent to LNAPL Area

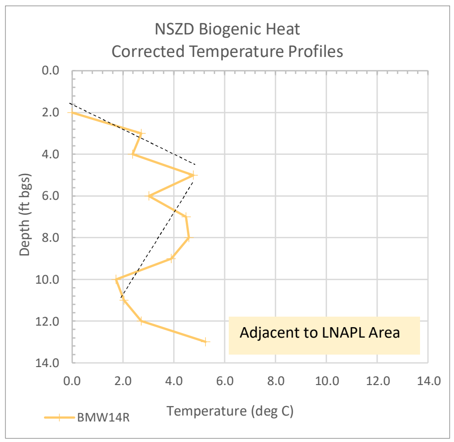

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
MW-12S

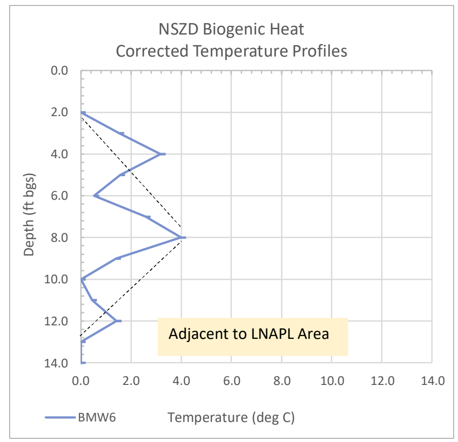

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
AMW7

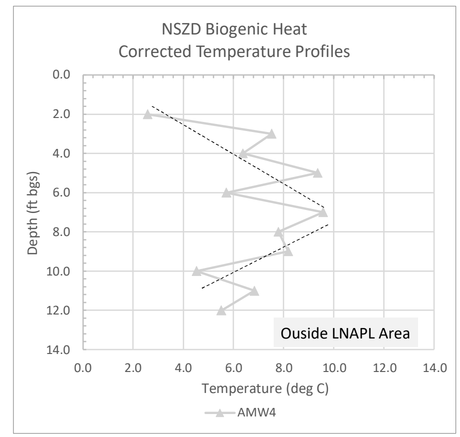

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
A9

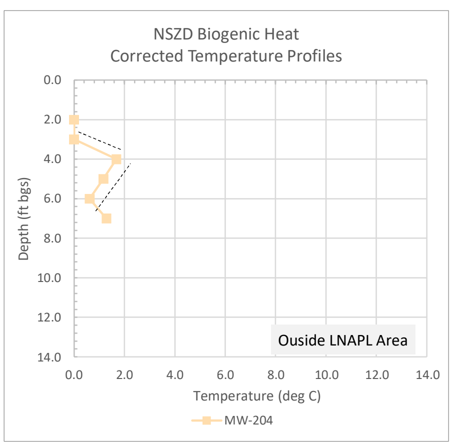

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
MW-8S

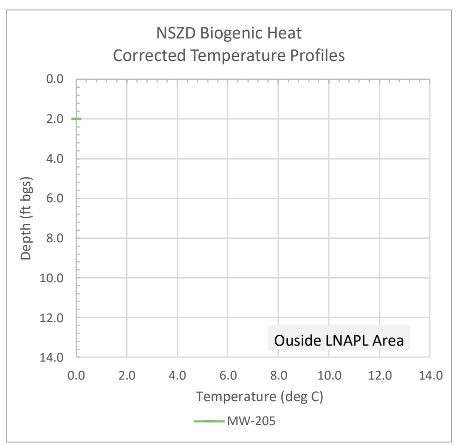

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
MW-10S

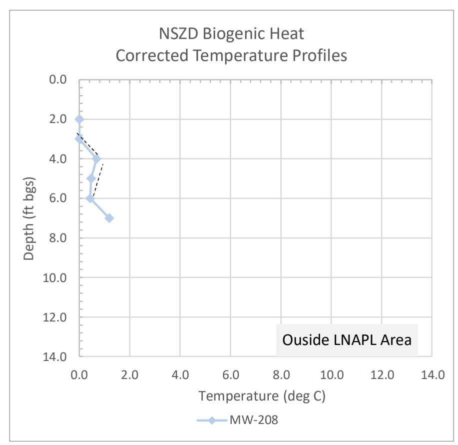

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
BMW14R

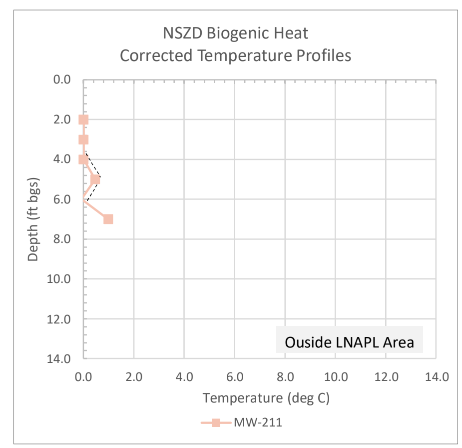

NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Adjacent to LNAPL Area
BMW6


NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Ouside LNAPL Area
AMW4


NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Ouside LNAPL Area
MW-204


NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Ouside LNAPL Area
MW-205


NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Ouside LNAPL Area
MW-208


NSZD Biogenic Heat
Corrected Temperature Profiles
Depth (ft bgs)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Temperature (deg C)
0.0 2.0 4.0 6.0 8.0 10.0 12.0 14.0
Ouside LNAPL Area
MW-211

Natural Source Zone Depletion (NSZD)
Biogenic Heat Rate Estimates

Site: 11137172 Cold Springs Terminal
Date: 7/7/2022

Location ID	Temp gradient, dT/dz			Heat Flux, q	NSZD Rate	NSZD Rate		
	Up	Down	Total					
	(deg C/m)			(J/m2/s)	(g/m2/s)	(L/m2/yr)	(L/Ha/yr)	(U.S. gal/acre/yr)
Within LNAPL Area								
RW-1	inconclusive		-	-	-	-	-	**-**
RW-2	inconclusive		-	-	-	-	-	**-**
RW-3	inconclusive		-	-	-	-	-	**-**
RW-5	7.59	0	7.59	10.63	0.0002271	9.7	96,761	**10,346**
MW-5SR	6.39	0	6.39	8.95	0.0001912	8.1	81,463	**8,710**
A10	2.03	0	2.03	2.84	0.0000606	2.6	25,837	**2,763**
BMW5	1.13	0.64	1.77	2.48	0.0000530	2.3	22,579	**2,414**
BMW13	1.22	0.57	1.79	2.50	0.0000535	2.3	22,801	**2,438**
Adjacent to LNAPL Area								
MW-11SR	0.84	0	0.84	1.17	0.0000251	1.1	10,683	**1,142**
MW-12S	7.49	0.88	8.37	11.72	0.0002505	10.7	106,747	**11,414**
AMW7	0.64	3.27	3.91	5.48	0.0001171	5.0	49,901	**5,336**
A9	2.23	0.82	3.04	4.26	0.0000910	3.9	38,777	**4,146**
MW-8S	1.69	0	1.69	2.37	0.0000507	2.2	21,587	**2,308**
MW-10S	2.06	0	2.06	2.88	0.0000616	2.6	26,262	**2,808**
BMW14R	1.59	0.46	2.05	2.86	0.0000612	2.6	26,071	**2,788**
BMW6	0.67	0.80	1.47	2.05	0.0000439	1.9	18,698	**1,999**
Outside of LNAPL Area								
MW-205	inconclusive		-	-	-	inconclusive		
MW-208	0.68	0.13	0.81	1.13	0.0000242	1.0	10,326	**1,104**
MW-211	0.47	0.47	0.94	1.32	0.0000281	1.2	11,984	**1,281**
AMW4	1.40	1.68	3.08	4.31	0.0000922	3.9	39,282	**4,200**
MW-204	1.68	0.53	2.21	3.09	0.0000661	2.8	28,174	**3,012**
					Average NSZD Rate:	**3.8**	**37,525**	**4,012**

Assumed thermal conductivity, K (J/m/C/s)		1.4	conservative value for vadose zone (Sweeney and Ririe 2014)
Assumed heat of reaction, dH (kJ/g)		-46.8	
LNAPL Density (based on published avgs) (g/L)		740	(Petrol 0.74 & diesel 0.885)

Thermal Properties of Air, Water, and Soil Types*

Material	Heat Capacity Cg (J/kg-K)	Heat Capacity Cv ((10^6 J/m^3-K)	Thermal Conductivity *k* (J/m-s-K)	Thermal Diffusivity α (10^{-8} m^2/s)
Air	1004	0.001	0.03	1938
Water	4181	4.18	0.60	14
Soil	800	1.44	0.17–3.98	12–276
Sand (saturated)	1257	2.64	2–4	76–152
CTS	1089	1.76	1.67	95
M-FTS	1508	2.14	1.26	59
Sand (dry)	794	1.27	0.15–0.25	12–20
CTS (dry)	838	1.34	0.17	13
M-FTS (dry)	838	1.09	0.10	10

CTS = coarse-textured soil; M-FTS = medium to fine-textured soil.
Note: De Vries and Afgan (1975).
*Modified from Wisconsin.edu—soils website.

Ambient Weather Data
Site: Cold Springs Terminal
Location: Lysander, NY

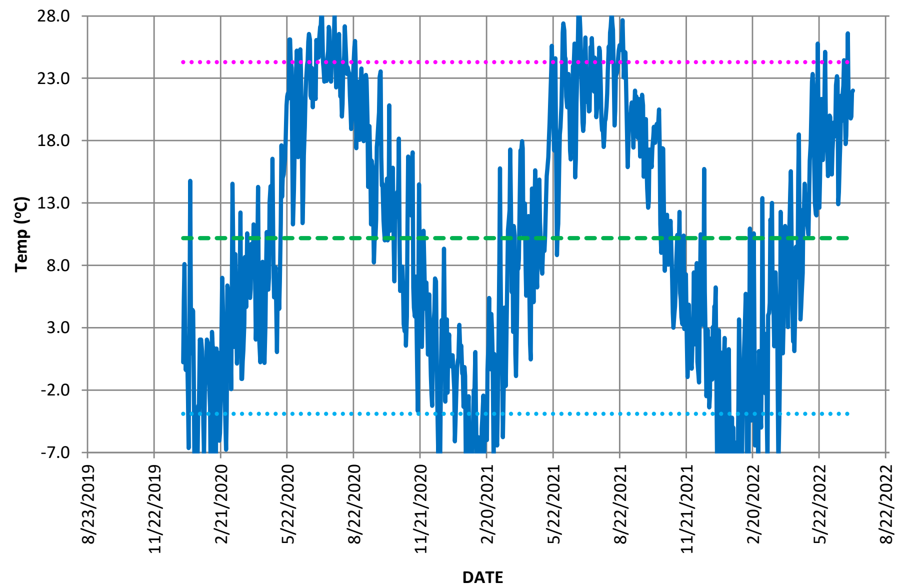
Table 1: Published Weather Data

Need a minimum of one year.

Keep date, Max, Mean, Min columns in order below.

Date	Max Temp (°C)	Mean Temp (°C)	Min Temp (°C)
1/1/2020	1.7	0.2	-2.2
1/2/2020	10.6	5.2	-2.2
1/3/2020	10.0	8.1	5.6
1/4/2020	5.0	2.6	0.6
1/5/2020	0.6	-0.4	-1.1
1/6/2020	3.3	1.4	-1.1
1/7/2020	1.7	0.3	-2.2
1/8/2020	0.6	-2.6	-6.7
1/9/2020	-1.1	-6.7	-12.8
1/10/2020	8.9	5.0	-0.6
1/11/2020	19.4	14.8	6.1
1/12/2020	17.8	4.3	-2.2
1/13/2020	3.9	0.9	-2.2
1/14/2020	8.9	4.4	0.6
1/15/2020	6.1	4.3	1.7
1/16/2020	3.3	-0.5	-7.2
1/17/2020	-7.8	-11.2	-14.4
1/18/2020	1.7	-5.9	-13.3
1/19/2020	2.2	-3.5	-8.3
1/20/2020	-7.2	-9.3	-12.8
1/21/2020	-2.8	-7.3	-15.6
1/22/2020	2.2	-3.3	-6.7
1/23/2020	2.2	-3.7	-8.9
1/24/2020	7.8	2.1	-3.9
1/25/2020	3.3	1.8	1.1
1/26/2020	3.3	2.1	1.1
1/27/2020	2.2	1.1	0.6
1/28/2020	0.6	-1.1	-2.8
1/29/2020	-2.8	-4.7	-10.6
1/30/2020	-2.2	-7.1	-12.2
1/31/2020	2.8	-1.6	-6.7
2/1/2020	0.6	-0.7	-1.1
2/2/2020	2.8	-0.1	-2.2
2/3/2020	6.7	2.1	-1.1
2/4/2020	2.8	1.8	0.0
2/5/2020	1.1	-1.4	-3.3
2/6/2020	0.6	-1.4	-4.4
2/7/2020	0.6	-3.4	-6.7
2/8/2020	-7.2	-9.4	-15.6
2/9/2020	2.8	-7.0	-17.2
2/10/2020	4.4	2.7	0.0
2/11/2020	2.2	1.1	0.6
2/12/2020	3.9	1.4	-1.1
2/13/2020	2.2	-0.7	-8.9
2/14/2020	-10.6	-13.4	-16.7
2/15/2020	-0.6	-8.7	-20.0
2/16/2020	3.9	1.3	-1.1
2/17/2020	-0.6	-1.9	-4.4
2/18/2020	6.1	1.0	-3.3
2/19/2020	2.8	-2.3	-6.1
2/20/2020	-5.0	-6.1	-7.8
2/21/2020	-1.1	-5.4	-11.7
2/22/2020	3.9	-1.8	-11.1
2/23/2020	8.9	3.1	-6.1
2/24/2020	11.7	7.0	3.9
2/25/2020	6.1	3.6	1.7
2/26/2020	5.0	3.4	1.7
2/27/2020	4.4	-1.3	-4.4
2/28/2020	-1.7	-3.7	-5.0
2/29/2020	-3.9	-6.8	-8.9
3/1/2020	2.2	-3.9	-10.6
3/2/2020	14.4	6.4	-0.6
3/3/2020	10.6	5.9	3.9
3/4/2020	8.3	3.3	0.6
3/5/2020	7.2	2.5	0.6
3/6/2020	7.2	2.3	-0.6
3/7/2020	1.7	-1.9	-5.6

Fig. 1: Ambient Temperature (Mean)



$$T(z=0,t)=T_{mean}+A_0\cdot\sin(\omega\cdot t)$$

Select Data Range to Evaluate. (Clear any old data outside of this range from chart on left.)

Start Date for Range	1/1/2020
End Date for Range	7/8/2022

Data will automatically plot on chart abovet. If errors, check date and number formatting.

Statistics based on data:

Mean Temp in Range	**10.1**	°C	**= T_{mean}**
Avg of 40 Smallest Mean Temps	-10.0	°C	
Avg of 40 Largest Mean Temps	26.8	°C	
Suggested Positive Amplitude	16.7	°C	
Suggested Negative Amplitude	20.1	°C	
Suggested Average Amplitude	**18.4**	°C	**= A_0**

Determine Mean Temp and Amplitude Values to fit graphed Data (horizontal dashed lines on Fig 1)

Selected Mean Temp	**10.2**	**°C**	**= T_{mean}**
Selected Average Amplitude	**14.1**	**°C**	**= A_0**
Annual Minimum Temp	-3.9	°C	
Annual Max Temp	24.3	°C	

Enter Source of Weather Data and Description:

SYRACUSE HANCOCK INTERNATIONAL AIRPORT STATION

Syracuse, NY Weather History | Weather Underground (wunderground.com)

3/8/2020	13.9	5.3	-3.9
3/9/2020	21.1	14.6	8.9
3/10/2020	16.7	10.3	2.2
3/11/2020	3.9	1.4	-2.2
3/12/2020	12.2	5.8	0.6
3/13/2020	13.3	8.9	3.9
3/14/2020	4.4	2.9	1.7
3/15/2020	3.9	0.1	-3.3
3/16/2020	10.0	2.1	-6.7
3/17/2020	7.2	5.6	2.2
3/18/2020	8.9	3.6	-3.3
3/19/2020	10.6	7.7	4.4
3/20/2020	23.3	12.2	1.7
3/21/2020	1.7	-1.1	-4.4
3/22/2020	4.4	-1.1	-6.7
3/23/2020	2.2	0.3	-0.6
3/24/2020	3.9	1.2	-0.6
3/25/2020	8.3	3.3	-1.1
3/26/2020	17.2	8.7	0.6
3/27/2020	10.6	5.8	1.1
3/28/2020	7.8	4.7	-1.1
3/29/2020	16.1	10.6	5.6
3/30/2020	10.0	8.3	5.6
3/31/2020	10.6	6.4	3.9
4/1/2020	8.9	5.6	1.7
4/2/2020	10.6	5.4	-1.1
4/3/2020	7.8	6.1	3.9
4/4/2020	13.3	9.7	6.1
4/5/2020	12.8	9.4	4.4
4/6/2020	13.3	7.9	1.1
4/7/2020	17.2	11.3	6.7
4/8/2020	11.7	8.6	6.7
4/9/2020	10.6	6.5	3.9
4/10/2020	5.0	2.1	0.6
4/11/2020	7.8	3.8	0.6
4/12/2020	16.7	9.7	-0.6
4/13/2020	21.1	14.3	5.0
4/14/2020	8.9	5.8	2.8
4/15/2020	6.1	1.8	-0.6
4/16/2020	3.9	0.2	-1.1
4/17/2020	6.7	2.4	-0.6
4/18/2020	8.3	3.0	0.6
4/19/2020	16.1	8.3	2.8
4/20/2020	9.4	4.0	-1.1
4/21/2020	9.4	3.9	-0.6
4/22/2020	5.0	0.2	-2.2
4/23/2020	9.4	3.2	-3.3
4/24/2020	11.1	7.6	5.0
4/25/2020	17.2	10.7	3.3
4/26/2020	11.1	7.7	5.0
4/27/2020	7.8	6.1	2.8
4/28/2020	14.4	7.0	-0.6
4/29/2020	19.4	13.1	7.8
4/30/2020	19.4	14.3	11.1
5/1/2020	12.8	10.4	6.1
5/2/2020	18.9	10.0	2.2
5/3/2020	24.4	16.6	9.4
5/4/2020	10.0	8.2	7.2
5/5/2020	8.9	5.4	0.6
5/6/2020	12.8	7.0	0.6
5/7/2020	16.1	7.8	1.1
5/8/2020	8.3	4.3	0.6
5/9/2020	3.9	1.1	-1.1
5/10/2020	11.1	5.3	1.7
5/11/2020	12.8	6.6	3.9
5/12/2020	9.4	4.5	0.6
5/13/2020	12.8	6.7	-0.6
5/14/2020	20.0	11.3	0.6
5/15/2020	27.2	17.6	12.8
5/16/2020	17.8	13.5	10.0
5/17/2020	22.2	15.0	6.1
5/18/2020	17.8	15.3	13.3
5/19/2020	21.1	16.0	10.6
5/20/2020	23.3	16.5	6.7
5/21/2020	26.1	17.8	6.7
5/22/2020	27.2	20.8	11.1
5/23/2020	27.8	21.6	17.8
5/24/2020	27.8	21.8	14.4
5/25/2020	28.3	21.4	15.6
5/26/2020	32.8	26.1	18.3
5/27/2020	31.1	26.1	20.0
5/28/2020	27.8	24.4	20.6
5/29/2020	30.0	23.8	19.4
5/30/2020	21.1	16.4	12.2
5/31/2020	14.4	11.3	6.7

6/1/2020	19.4	14.0	8.3
6/2/2020	19.4	16.9	12.8
6/3/2020	23.3	18.4	15.0
6/4/2020	30.0	23.0	13.9
6/5/2020	30.6	25.2	21.7
6/6/2020	25.6	21.9	15.6
6/7/2020	21.1	16.7	12.8
6/8/2020	23.3	17.0	8.9
6/9/2020	30.6	21.9	11.7
6/10/2020	31.7	25.3	18.3
6/11/2020	27.8	23.6	18.3
6/12/2020	21.1	17.2	10.6
6/13/2020	16.1	11.4	8.3
6/14/2020	19.4	13.4	6.1
6/15/2020	23.3	16.8	10.0
6/16/2020	27.2	19.1	10.0
6/17/2020	29.4	21.4	11.1
6/18/2020	30.6	22.8	13.9
6/19/2020	30.0	24.1	17.2
6/20/2020	32.2	24.4	17.2
6/21/2020	32.2	25.9	19.4
6/22/2020	32.8	26.6	20.0
6/23/2020	32.8	26.1	21.1
6/24/2020	26.7	21.6	16.1
6/25/2020	28.3	21.4	14.4
6/26/2020	30.0	23.8	17.8
6/27/2020	26.1	20.7	16.1
6/28/2020	27.2	22.7	19.4
6/29/2020	28.9	23.4	17.2
6/30/2020	24.4	21.6	18.3
7/1/2020	28.9	21.3	16.1
7/2/2020	33.3	26.1	18.3
7/3/2020	29.4	25.8	22.8
7/4/2020	31.7	25.4	18.3
7/5/2020	32.2	24.7	15.0
7/6/2020	33.3	26.2	18.3
7/7/2020	31.7	27.1	20.6
7/8/2020	32.2	27.2	22.2
7/9/2020	35.6	28.4	21.1
7/10/2020	34.4	27.9	22.8
7/11/2020	31.7	24.3	21.7
7/12/2020	30.0	23.7	21.1
7/13/2020	26.1	22.7	20.0
7/14/2020	28.3	22.8	18.3
7/15/2020	30.0	24.1	17.2
7/16/2020	27.2	22.8	20.6
7/17/2020	28.3	24.6	21.1
7/18/2020	31.7	25.2	17.2
7/19/2020	33.9	27.1	19.4
7/20/2020	30.6	26.8	23.3
7/21/2020	28.3	23.5	18.9
7/22/2020	26.7	22.7	18.3
7/23/2020	28.9	24.8	20.6
7/24/2020	29.4	24.2	18.9
7/25/2020	31.1	24.4	17.8
7/26/2020	31.1	26.3	19.4
7/27/2020	33.9	28.1	23.3
7/28/2020	29.4	25.2	20.6
7/29/2020	26.1	22.3	18.3
7/30/2020	28.3	22.7	17.8
7/31/2020	28.9	22.8	15.0
8/1/2020	30.0	24.1	17.2
8/2/2020	32.2	26.6	20.6
8/3/2020	27.8	24.1	21.1
8/4/2020	22.8	21.6	20.6
8/5/2020	25.6	21.8	18.3
8/6/2020	25.6	19.9	14.4
8/7/2020	26.1	20.9	14.4
8/8/2020	30.0	23.7	18.9
8/9/2020	30.6	24.8	18.9
8/10/2020	32.2	27.2	22.8
8/11/2020	32.8	25.9	20.6
8/12/2020	28.3	24.2	18.9
8/13/2020	30.0	23.3	16.7
8/14/2020	30.6	23.9	17.8
8/15/2020	28.9	23.6	17.8
8/16/2020	27.8	23.3	18.3
8/17/2020	26.7	21.6	17.8
8/18/2020	25.6	20.4	17.8
8/19/2020	23.3	18.9	14.4
8/20/2020	26.1	19.9	12.2
8/21/2020	28.9	22.6	14.4
8/22/2020	30.0	23.9	18.9
8/23/2020	32.2	25.5	18.3
8/24/2020	32.8	26.0	18.9
8/25/2020	28.3	24.1	18.3
8/26/2020	21.1	17.4	12.8
8/27/2020	28.3	20.5	16.7

8/28/2020	24.4	20.4	17.8
8/29/2020	30.0	22.7	18.9
8/30/2020	21.7	18.1	14.4
8/31/2020	25.0	18.9	11.1
9/1/2020	24.4	22.5	20.6
9/2/2020	28.3	23.8	21.1
9/3/2020	26.7	20.4	16.1
9/4/2020	24.4	20.4	16.1
9/5/2020	23.3	17.9	11.1
9/6/2020	23.9	18.9	15.0
9/7/2020	27.8	23.2	15.6
9/8/2020	29.4	23.3	18.3
9/9/2020	30.6	22.8	16.1
9/10/2020	27.2	19.6	16.1
9/11/2020	18.3	14.3	9.4
9/12/2020	24.4	16.5	7.2
9/13/2020	21.7	19.2	17.2
9/14/2020	18.3	15.6	8.9
9/15/2020	18.9	11.3	5.6
9/16/2020	23.9	16.4	6.7
9/17/2020	17.8	15.8	12.2
9/18/2020	16.7	11.6	6.7
9/19/2020	15.0	8.2	1.7
9/20/2020	17.2	9.9	3.9
9/21/2020	18.9	10.3	1.7
9/22/2020	20.0	11.7	3.9
9/23/2020	24.4	17.5	11.1
9/24/2020	25.6	18.1	11.7
9/25/2020	27.2	19.4	13.9
9/26/2020	28.3	20.3	12.2
9/27/2020	28.3	23.1	18.9
9/28/2020	28.9	23.6	18.3
9/29/2020	23.3	16.7	13.9
9/30/2020	18.9	14.4	11.7
10/1/2020	18.9	14.6	8.9
10/2/2020	16.7	11.6	6.7
10/3/2020	15.0	10.7	7.8
10/4/2020	17.2	10.0	4.4
10/5/2020	16.1	11.9	7.8
10/6/2020	19.4	13.9	6.1
10/7/2020	18.3	14.9	11.7
10/8/2020	12.8	10.0	6.7
10/9/2020	18.9	11.9	5.6
10/10/2020	27.2	20.8	15.0
10/11/2020	16.1	10.8	5.6
10/12/2020	17.8	12.6	9.4
10/13/2020	15.6	11.3	6.7
10/14/2020	17.8	11.1	5.6
10/15/2020	25.6	15.8	9.4
10/16/2020	11.1	9.4	3.3
10/17/2020	14.4	6.7	0.0
10/18/2020	16.1	11.3	3.9
10/19/2020	15.0	13.6	12.8
10/20/2020	16.1	11.9	9.4
10/21/2020	21.1	13.9	9.4
10/22/2020	15.0	12.5	10.0
10/23/2020	27.2	18.2	9.4
10/24/2020	20.6	10.4	5.6
10/25/2020	9.4	5.9	0.6
10/26/2020	9.4	6.8	4.4
10/27/2020	8.3	7.1	6.1
10/28/2020	11.7	7.9	5.6
10/29/2020	8.3	6.4	4.4
10/30/2020	5.6	3.3	0.0
10/31/2020	7.2	2.7	0.6
11/1/2020	11.1	6.1	1.7
11/2/2020	6.7	1.6	-0.6
11/3/2020	7.8	3.9	0.6
11/4/2020	20.6	11.2	-0.6
11/5/2020	22.2	16.7	10.6
11/6/2020	21.7	16.2	9.4
11/7/2020	22.8	14.3	6.7
11/8/2020			
11/9/2020	23.9	12.0	3.9
11/10/2020	25.6	16.6	5.0
11/11/2020	19.4	17.1	9.4
11/12/2020	8.9	6.2	0.0
11/13/2020	10.6	4.6	-2.2
11/14/2020	6.1	3.9	-1.1
11/15/2020	11.7	7.1	-1.1
11/16/2020	7.8	5.5	4.4
11/17/2020	4.4	1.8	-1.7
11/18/2020	-1.7	-3.7	-5.6
11/19/2020	12.8	6.1	-3.3
11/20/2020	18.9	14.5	11.1
11/21/2020	11.7	6.7	3.3
11/22/2020	10.0	4.9	1.1
11/23/2020	11.1	4.8	1.7

11/24/2020	3.3	1.4	-1.7
11/25/2020	10.6	6.2	0.6
11/26/2020	15.6	10.8	7.2
11/27/2020	10.0	8.6	6.7
11/28/2020	7.2	5.1	-1.7
11/29/2020	12.2	4.5	-2.8
11/30/2020	8.9	6.6	3.3
12/1/2020	7.8	4.3	0.6
12/2/2020	2.8	0.8	-0.6
12/3/2020	7.8	4.3	-0.6
12/4/2020	8.3	5.7	4.4
12/5/2020	4.4	2.7	-0.6
12/6/2020	0.0	-0.8	-1.7
12/7/2020	-1.1	-2.3	-3.9
12/8/2020	-0.6	-3.3	-4.4
12/9/2020	3.3	1.7	0.0
12/10/2020	5.6	3.6	-0.6
12/11/2020	12.8	4.3	-0.6
12/12/2020	13.3	6.9	1.1
12/13/2020	13.3	6.7	3.3
12/14/2020	3.3	1.4	-0.6
12/15/2020	0.0	-2.9	-7.2
12/16/2020	-3.9	-7.1	-8.9
12/17/2020	-2.8	-5.6	-7.2
12/18/2020	-2.2	-6.4	-11.1
12/19/2020	-0.6	-7.6	-14.4
12/20/2020	2.8	0.4	-2.2
12/21/2020	5.6	3.6	2.2
12/22/2020	3.9	2.3	0.0
12/23/2020	5.6	2.2	-1.1
12/24/2020	11.1	9.3	5.6
12/25/2020	11.7	4.1	-1.7
12/26/2020	-1.7	-2.9	-5.0
12/27/2020	1.7	-0.2	-1.7
12/28/2020	6.7	3.7	1.1
12/29/2020	-0.6	-2.2	-5.0
12/30/2020	6.7	1.1	-5.6
12/31/2020	5.6	2.4	1.1
1/1/2021	1.7	0.2	-0.6
1/2/2021	2.8	0.6	-0.6
1/3/2021	1.1	-0.1	-2.8
1/4/2021	1.7	0.8	0.0
1/5/2021	1.7	0.8	-1.1
1/6/2021	1.1	-0.3	-1.7
1/7/2021	-0.6	-1.9	-3.3
1/8/2021	-3.9	-6.1	-9.4
1/9/2021	1.1	-4.5	-9.4
1/10/2021	0.0	-2.6	-6.1
1/11/2021	3.3	-0.2	-2.2
1/12/2021	2.2	0.3	-0.6
1/13/2021	2.2	0.6	-1.1
1/14/2021	5.6	3.2	0.6
1/15/2021	5.0	1.7	-2.2
1/16/2021	2.8	1.3	0.6
1/17/2021	3.3	1.6	0.6
1/18/2021	0.6	-0.7	-1.7
1/19/2021	1.7	-0.7	-2.2
1/20/2021	-1.7	-3.3	-6.7
1/21/2021	3.3	-0.2	-6.7
1/22/2021	2.2	-0.9	-4.4
1/23/2021	-4.4	-7.1	-8.9
1/24/2021	-6.1	-9.7	-15.0
1/25/2021	-0.6	-7.3	-13.9
1/26/2021	-2.2	-3.7	-6.1
1/27/2021	-1.7	-2.5	-4.4
1/28/2021	-4.4	-7.4	-10.6
1/29/2021	-9.4	-11.6	-15.0
1/30/2021	-5.6	-8.8	-11.1
1/31/2021	-6.1	-9.8	-15.0
2/1/2021	-1.1	-6.1	-8.3
2/2/2021	-1.7	-4.6	-6.7
2/3/2021	1.1	-2.0	-3.3
2/4/2021	2.8	-2.4	-7.2
2/5/2021	6.1	1.1	-4.4
2/6/2021	-1.7	-4.0	-10.6
2/7/2021	-2.8	-7.3	-12.8
2/8/2021	-5.0	-8.4	-12.2
2/9/2021	-2.8	-5.8	-7.8
2/10/2021	-3.3	-6.1	-8.3
2/11/2021	-3.3	-7.3	-13.9
2/12/2021	-8.3	-13.2	-18.3
2/13/2021	-5.0	-9.9	-16.1
2/14/2021	-3.9	-5.1	-6.1
2/15/2021	-2.8	-4.2	-6.1
2/16/2021	1.7	-2.4	-7.2
2/17/2021	-4.4	-8.2	-13.3
2/18/2021	-2.8	-5.7	-8.3
2/19/2021	-0.6	-3.0	-5.6

2/20/2021	-2.8	-4.2	-6.1
2/21/2021	0.0	-6.0	-12.8
2/22/2021	2.8	-0.3	-2.2
2/23/2021	3.3	1.7	-0.6
2/24/2021	10.6	5.4	-0.6
2/25/2021	2.8	0.2	-3.9
2/26/2021	3.3	-0.3	-2.8
2/27/2021	7.8	4.1	0.0
2/28/2021	6.7	2.8	-2.8
3/1/2021	7.8	0.8	-8.9
3/2/2021	-3.9	-7.5	-11.7
3/3/2021	6.1	0.9	-5.6
3/4/2021	2.8	-2.2	-5.6
3/5/2021	-1.1	-4.2	-8.3
3/6/2021	-4.4	-5.8	-8.3
3/7/2021	-2.2	-6.4	-12.2
3/8/2021	2.8	-3.6	-13.3
3/9/2021	9.4	3.3	-2.2
3/10/2021	17.2	8.3	-3.3
3/11/2021	22.2	15.8	9.4
3/12/2021	14.4	7.3	-1.1
3/13/2021	4.4	0.2	-3.9
3/14/2021	3.9	0.5	-5.0
3/15/2021	-2.2	-5.8	-8.9
3/16/2021	6.1	-1.2	-7.8
3/17/2021	10.6	4.6	1.1
3/18/2021	6.1	3.8	1.1
3/19/2021	2.2	-1.7	-5.6
3/20/2021	13.3	3.8	-6.1
3/21/2021	17.8	7.3	-2.8
3/22/2021	20.6	10.8	-0.6
3/23/2021	20.6	11.8	1.7
3/24/2021	15.0	12.4	8.3
3/25/2021	23.9	17.3	8.3
3/26/2021	21.7	13.3	5.6
3/27/2021	10.6	5.8	3.3
3/28/2021	16.1	10.6	4.4
3/29/2021	6.1	2.7	-0.6
3/30/2021	21.1	11.2	-0.6
3/31/2021	15.6	10.4	5.0
4/1/2021	5.0	0.9	-3.9
4/2/2021	2.8	-0.9	-4.4
4/3/2021	10.0	3.7	-3.9
4/4/2021	14.4	8.3	2.8
4/5/2021	13.9	7.7	1.1
4/6/2021	17.2	8.5	0.0
4/7/2021	22.2	13.9	7.2
4/8/2021	26.1	17.2	8.3
4/9/2021	20.6	17.1	12.8
4/10/2021	26.7	17.9	7.8
4/11/2021	22.2	17.4	13.9
4/12/2021	12.2	10.4	8.9
4/13/2021	18.3	11.2	5.0
4/14/2021	21.1	12.9	5.6
4/15/2021	11.1	7.9	5.0
4/16/2021	8.3	5.6	4.4
4/17/2021	12.2	7.3	3.3
4/18/2021	16.7	10.7	7.2
4/19/2021	16.7	11.9	5.6
4/20/2021	11.7	7.4	3.3
4/21/2021	3.3	1.7	0.6
4/22/2021	5.6	0.4	-2.2
4/23/2021	16.7	9.2	0.6
4/24/2021	19.4	14.2	7.8
4/25/2021	15.0	10.8	3.9
4/26/2021	9.4	5.1	1.7
4/27/2021	19.4	11.3	2.8
4/28/2021	21.1	15.6	11.7
4/29/2021	13.9	11.8	8.9
4/30/2021	10.6	7.4	1.7
5/1/2021	13.9	6.2	1.7
5/2/2021	18.9	12.2	9.4
5/3/2021	21.7	14.6	9.4
5/4/2021	20.0	14.9	12.2
5/5/2021	15.0	11.4	8.3
5/6/2021	13.9	9.6	5.6
5/7/2021	13.3	7.7	2.2
5/8/2021	11.1	7.3	5.0
5/9/2021	14.4	9.8	5.6
5/10/2021	14.4	9.5	7.2
5/11/2021	12.8	9.2	4.4
5/12/2021	17.8	10.3	5.6
5/13/2021	20.0	13.3	5.0
5/14/2021	22.2	15.2	7.2
5/15/2021	23.3	15.7	6.7
5/16/2021	25.6	16.7	7.2
5/17/2021	25.0	18.2	10.6
5/18/2021	26.7	19.4	10.6

5/19/2021	30.0	21.1	11.1
5/20/2021	32.8	23.5	14.4
5/21/2021	33.3	25.6	15.6
5/22/2021	29.4	23.3	17.8
5/23/2021	24.4	20.8	12.2
5/24/2021	25.6	17.2	8.3
5/25/2021	30.0	22.8	15.6
5/26/2021	31.1	24.6	21.1
5/27/2021	20.0	15.4	9.4
5/28/2021	10.0	8.8	7.8
5/29/2021	16.7	10.6	6.7
5/30/2021	14.4	11.3	8.3
5/31/2021	22.2	16.0	10.6
6/1/2021	25.0	18.5	11.7
6/2/2021	24.4	19.1	10.0
6/3/2021	25.0	20.8	17.8
6/4/2021	28.9	23.2	17.8
6/5/2021	33.3	26.7	20.6
6/6/2021	33.3	27.4	21.1
6/7/2021	33.3	26.8	20.0
6/8/2021	27.8	24.7	22.2
6/9/2021	30.0	24.6	19.4
6/10/2021	27.8	21.6	13.9
6/11/2021	26.7	20.7	14.4
6/12/2021	27.2	21.2	17.2
6/13/2021	30.0	23.3	15.0
6/14/2021	26.1	20.6	17.2
6/15/2021	20.6	17.2	15.6
6/16/2021	20.0	16.5	11.7
6/17/2021	23.9	18.3	11.1
6/18/2021	27.8	20.2	11.1
6/19/2021	30.6	24.0	18.9
6/20/2021	29.4	23.7	16.1
6/21/2021	32.8	25.8	20.0
6/22/2021	18.9	15.1	11.1
6/23/2021	22.8	16.5	9.4
6/24/2021	28.3	21.0	11.1
6/25/2021	29.4	23.9	16.7
6/26/2021	32.2	26.7	22.8
6/27/2021	34.4	29.8	25.6
6/28/2021	35.6	28.7	25.0
6/29/2021	34.4	26.9	22.2
6/30/2021	29.4	24.9	21.1
7/1/2021	26.1	22.6	20.0
7/2/2021	24.4	19.4	16.7
7/3/2021	22.8	18.8	16.1
7/4/2021	25.6	19.4	14.4
7/5/2021	32.2	23.7	13.3
7/6/2021	31.1	26.3	21.7
7/7/2021	29.4	23.7	18.9
7/8/2021	27.8	21.1	17.8
7/9/2021	28.3	22.8	20.0
7/10/2021	26.1	21.5	18.3
7/11/2021	23.9	20.3	16.7
7/12/2021	24.4	20.4	17.8
7/13/2021	30.6	25.5	20.6
7/14/2021	28.9	24.2	20.6
7/15/2021	32.2	26.2	18.9
7/16/2021	28.9	24.9	22.2
7/17/2021	24.4	22.2	19.4
7/18/2021	28.3	21.9	18.9
7/19/2021	31.1	24.7	18.9
7/20/2021	30.0	23.9	18.9
7/21/2021	24.4	19.9	17.2
7/22/2021	25.0	20.6	15.0
7/23/2021	26.7	21.3	16.7
7/24/2021	28.9	22.6	14.4
7/25/2021	29.4	25.4	21.7
7/26/2021	30.6	25.2	20.6
7/27/2021	29.4	22.3	18.9
7/28/2021	25.6	19.6	15.6
7/29/2021	22.2	18.8	13.3
7/30/2021	21.1	19.2	16.1
7/31/2021	22.8	17.5	11.7
8/1/2021	23.3	18.2	13.9
8/2/2021	23.9	19.6	15.0
8/3/2021	26.1	19.7	11.1
8/4/2021	27.2	20.7	13.9
8/5/2021	28.9	21.8	14.4
8/6/2021	30.6	23.7	15.6
8/7/2021	30.6	25.6	19.4
8/8/2021	28.9	24.3	20.0
8/9/2021	32.2	26.7	21.7
8/10/2021	31.7	27.1	22.8
8/11/2021	33.3	28.3	25.0
8/12/2021	30.0	27.4	23.9
8/13/2021	32.2	26.9	21.7
8/14/2021	26.7	22.6	17.2

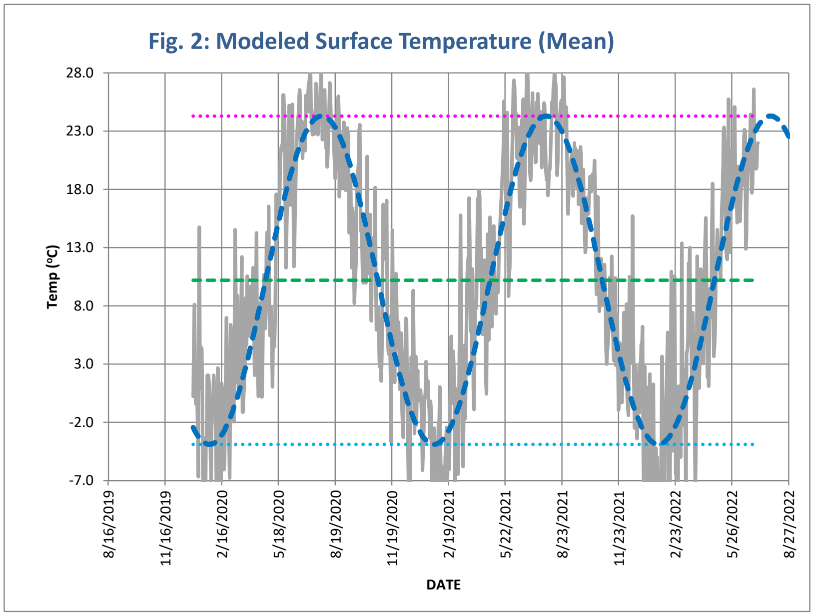
8/15/2021	24.4	19.2	13.3
8/16/2021	26.7	20.4	12.2
8/17/2021	28.3	23.2	20.6
8/18/2021	24.4	23.4	22.2
8/19/2021	26.7	23.7	22.2
8/20/2021	29.4	24.6	20.0
8/21/2021	30.0	25.2	22.8
8/22/2021	31.7	25.7	21.1
8/23/2021	29.4	25.3	22.8
8/24/2021	30.0	25.3	21.1
8/25/2021	33.3	26.2	19.4
8/26/2021	32.8	27.7	23.9
8/27/2021	30.0	25.4	21.1
8/28/2021	26.7	23.1	19.4
8/29/2021	28.9	25.1	20.6
8/30/2021	28.9	25.1	21.1
8/31/2021	27.2	22.5	18.9
9/1/2021	21.1	18.6	14.4
9/2/2021	20.0	15.9	11.1
9/3/2021	22.2	17.5	14.4
9/4/2021	26.1	19.6	13.9
9/5/2021	24.4	20.1	16.1
9/6/2021	23.9	19.6	16.1
9/7/2021	25.6	20.7	15.0
9/8/2021	25.0	21.1	16.7
9/9/2021	23.9	19.1	15.0
9/10/2021	22.8	17.4	13.3
9/11/2021	26.1	20.1	12.2
9/12/2021	25.6	22.0	19.4
9/13/2021	23.9	18.7	15.6
9/14/2021	28.9	21.6	13.3
9/15/2021	25.6	21.2	16.7
9/16/2021	23.9	18.2	13.3
9/17/2021	28.3	21.3	15.6
9/18/2021	25.6	20.8	15.0
9/19/2021	22.8	16.7	11.1
9/20/2021	26.7	18.2	10.0
9/21/2021	24.4	20.6	17.2
9/22/2021	25.0	21.7	18.9
9/23/2021	24.4	20.8	15.6
9/24/2021	21.1	15.1	10.6
9/25/2021	24.4	17.1	9.4
9/26/2021	21.7	16.8	12.2
9/27/2021	25.0	19.7	13.9
9/28/2021	20.0	15.9	10.6
9/29/2021	18.9	14.2	8.9
9/30/2021	15.6	12.6	9.4
10/1/2021	17.8	13.1	9.4
10/2/2021	25.0	17.3	9.4
10/3/2021	18.3	16.8	14.4
10/4/2021	17.8	16.4	14.4
10/5/2021	18.3	15.9	14.4
10/6/2021	22.8	17.3	14.4
10/7/2021	25.6	18.3	14.4
10/8/2021	25.6	19.1	15.0
10/9/2021	22.2	17.9	15.6
10/10/2021	22.8	17.8	14.4
10/11/2021	25.6	19.1	13.9
10/12/2021	25.6	19.3	13.3
10/13/2021	23.9	18.6	15.6
10/14/2021	25.0	19.2	16.1
10/15/2021	25.6	20.5	16.7
10/16/2021	22.8	17.7	12.2
10/17/2021	12.8	11.3	9.4
10/18/2021	10.0	9.0	6.7
10/19/2021	19.4	13.3	7.2
10/20/2021	23.3	17.4	13.9
10/21/2021	22.8	17.3	13.3
10/22/2021	16.1	10.6	3.9
10/23/2021	11.7	7.6	3.3
10/24/2021	14.4	8.7	2.8
10/25/2021	17.8	11.9	9.4
10/26/2021	13.3	12.1	10.0
10/27/2021	14.4	10.0	5.6
10/28/2021	15.0	8.1	2.8
10/29/2021	13.3	9.4	6.1
10/30/2021	13.9	10.2	7.2
10/31/2021	13.3	11.6	8.9
11/1/2021	12.2	9.8	6.7
11/2/2021	9.4	6.9	3.9
11/3/2021	7.8	4.2	1.1
11/4/2021	7.2	3.0	-0.6
11/5/2021	9.4	4.1	-0.6
11/6/2021	12.2	4.7	-1.7
11/7/2021	15.6	6.0	-1.7
11/8/2021	16.7	8.3	1.1
11/9/2021	16.7	10.4	3.9
11/10/2021	13.3	9.4	3.3

11/11/2021	15.6	8.3	0.6
11/12/2021	17.2	12.3	6.1
11/13/2021	8.9	5.8	3.9
11/14/2021	7.8	5.2	3.3
11/15/2021	5.6	3.8	2.2
11/16/2021	5.0	3.3	1.7
11/17/2021	13.9	7.9	0.0
11/18/2021	16.1	10.4	5.6
11/19/2021	5.0	2.9	0.6
11/20/2021	7.2	3.5	-1.7
11/21/2021	10.6	7.3	3.3
11/22/2021	8.3	3.2	-0.6
11/23/2021	1.1	-0.9	-3.9
11/24/2021	7.2	0.3	-6.1
11/25/2021	10.0	4.8	-0.6
11/26/2021	8.3	2.2	-0.6
11/27/2021	1.1	0.0	-2.2
11/28/2021	1.1	0.3	-0.6
11/29/2021	1.7	-0.3	-2.8
11/30/2021	3.9	2.4	-0.6
12/1/2021	5.6	3.8	2.2
12/2/2021	11.7	7.4	3.9
12/3/2021	2.8	1.7	0.0
12/4/2021	7.8	2.8	0.6
12/5/2021	9.4	3.7	1.1
12/6/2021	13.9	8.2	2.2
12/7/2021	2.2	0.3	-1.7
12/8/2021	1.7	-0.7	-2.2
12/9/2021	1.1	-1.4	-2.2
12/10/2021	7.8	3.9	1.1
12/11/2021	17.8	10.5	3.3
12/12/2021	8.3	4.2	1.7
12/13/2021	12.2	7.6	4.4
12/14/2021	8.3	3.2	-1.1
12/15/2021	10.6	5.4	-1.7
12/16/2021	19.4	15.7	10.6
12/17/2021	11.7	5.9	1.7
12/18/2021	2.2	1.4	0.0
12/19/2021	0.0	-2.5	-3.9
12/20/2021	3.9	-1.0	-6.7
12/21/2021	4.4	2.8	-0.6
12/22/2021	3.9	0.6	-2.2
12/23/2021	-1.1	-3.4	-6.1
12/24/2021	1.1	-2.5	-4.4
12/25/2021	3.3	2.1	0.0
12/26/2021	3.9	1.7	-1.1
12/27/2021	2.2	-1.2	-3.3
12/28/2021	6.1	3.1	1.1
12/29/2021	4.4	2.4	1.1
12/30/2021	6.7	4.7	3.3
12/31/2021	10.6	4.3	1.1
1/1/2022	9.4	6.2	1.7
1/2/2022	2.2	-3.7	-7.2
1/3/2022	-6.7	-9.3	-11.1
1/4/2022	1.1	-3.5	-11.7
1/5/2022	6.1	2.8	-1.1
1/6/2022	1.7	-0.9	-2.8
1/7/2022	-2.8	-4.9	-9.4
1/8/2022	-0.6	-9.3	-17.8
1/9/2022	5.0	1.0	-2.2
1/10/2022	-3.3	-6.4	-10.6
1/11/2022	-9.4	-14.2	-18.3
1/12/2022	2.2	-0.3	-8.3
1/13/2022	5.6	2.2	0.6
1/14/2022	2.2	-4.9	-16.7
1/15/2022	-14.4	-18.1	-21.1
1/16/2022	-1.1	-9.9	-19.4
1/17/2022	1.7	-2.3	-5.6
1/18/2022	-3.3	-5.7	-11.7
1/19/2022	6.7	1.3	-10.0
1/20/2022	0.0	-7.7	-11.7
1/21/2022	-10.0	-13.8	-17.8
1/22/2022	-2.8	-11.1	-22.2
1/23/2022	-1.7	-4.2	-7.2
1/24/2022	-5.6	-8.1	-13.9
1/25/2022	-2.2	-5.0	-8.3
1/26/2022	-7.8	-12.6	-19.4
1/27/2022	-1.1	-8.8	-21.7
1/28/2022	-1.7	-6.2	-16.1
1/29/2022	-11.7	-14.9	-17.2
1/30/2022	-5.6	-13.3	-22.8
1/31/2022	0.0	-7.3	-14.4
2/1/2022	3.9	-3.2	-12.8
2/2/2022	6.7	3.7	-0.6
2/3/2022	4.4	-0.6	-7.2
2/4/2022	-7.2	-8.3	-10.0
2/5/2022	-7.8	-10.9	-17.8
2/6/2022	-0.6	-7.9	-17.8

2/7/2022	5.6	-1.8	-9.4
2/8/2022	1.7	-1.4	-6.1
2/9/2022	9.4	1.4	-8.9
2/10/2022	6.7	3.8	1.7
2/11/2022	10.6	5.7	-1.1
2/12/2022	7.2	0.4	-6.1
2/13/2022	-6.1	-8.5	-12.8
2/14/2022	-8.9	-11.7	-15.0
2/15/2022	-3.3	-7.3	-12.2
2/16/2022	10.0	2.3	-9.4
2/17/2022	13.3	10.9	7.8
2/18/2022	7.2	-4.3	-9.4
2/19/2022	-0.6	-4.4	-8.3
2/20/2022	5.6	-3.8	-11.1
2/21/2022	14.4	7.6	2.2
2/22/2022	15.6	10.6	3.9
2/23/2022	15.0	2.5	-6.7
2/24/2022	-1.7	-6.4	-10.6
2/25/2022	-3.3	-6.1	-8.9
2/26/2022	-1.7	-5.6	-8.9
2/27/2022	1.1	-1.2	-4.4
2/28/2022	-5.0	-8.1	-12.2
3/1/2022	7.2	1.1	-7.2
3/2/2022	3.3	0.6	-1.7
3/3/2022	0.6	-3.2	-8.9
3/4/2022	-0.6	-5.0	-10.6
3/5/2022	7.2	0.2	-7.2
3/6/2022	23.9	13.4	5.6
3/7/2022	5.6	3.6	1.7
3/8/2022	2.8	-0.1	-3.9
3/9/2022	2.2	-1.3	-4.4
3/10/2022	5.0	-2.3	-7.2
3/11/2022	10.0	2.5	-2.8
3/12/2022	0.0	-4.5	-7.8
3/13/2022	-7.8	-8.1	-8.3
3/14/2022	9.4	4.0	-1.7
3/15/2022	7.8	4.2	0.0
3/16/2022	12.2	5.0	1.7
3/17/2022	20.0	11.7	1.1
3/18/2022	20.0	10.8	2.8
3/19/2022	20.6	13.0	8.9
3/20/2022	9.4	5.7	2.8
3/21/2022	11.1	5.5	0.0
3/22/2022	6.7	1.5	-2.8
3/23/2022	7.2	2.7	-2.2
3/24/2022	15.0	7.4	3.9
3/25/2022	10.0	5.4	1.7
3/26/2022	8.9	4.7	1.7
3/27/2022	1.1	-2.2	-6.7
3/28/2022	-6.7	-8.1	-8.9
3/29/2022	-1.7	-4.2	-6.7
3/30/2022	5.0	-0.3	-6.1
3/31/2022	21.1	12.3	5.0
4/1/2022	6.7	3.0	0.6
4/2/2022	7.2	2.4	0.0
4/3/2022	3.3	0.9	-1.7
4/4/2022	6.7	3.3	1.7
4/5/2022	17.2	8.3	0.6
4/6/2022	16.1	11.2	6.1
4/7/2022	10.0	8.0	6.1
4/8/2022	12.2	7.6	5.0
4/9/2022	10.0	6.3	3.3
4/10/2022	5.6	3.1	0.6
4/11/2022	17.8	8.7	-1.7
4/12/2022	16.1	11.7	7.2
4/13/2022	24.4	13.8	3.9
4/14/2022	25.0	15.6	6.7
4/15/2022	15.6	10.7	5.6
4/16/2022	8.9	4.4	1.7
4/17/2022	7.2	1.9	-1.7
4/18/2022	13.3	4.1	-2.8
4/19/2022	3.9	1.1	0.0
4/20/2022	10.0	5.2	1.7
4/21/2022	12.8	9.5	1.7
4/22/2022	12.8	8.6	3.9
4/23/2022	12.2	7.1	0.6
4/24/2022	24.4	15.0	6.7
4/25/2022	26.1	18.5	11.7
4/26/2022	16.1	10.4	7.2
4/27/2022	7.2	3.7	2.2
4/28/2022	8.3	4.6	1.1
4/29/2022	11.7	5.8	-1.1
4/30/2022	13.9	7.4	-1.1
5/1/2022	21.7	12.5	1.1
5/2/2022	16.1	12.5	10.6
5/3/2022	18.9	14.6	10.0
5/4/2022	16.1	12.4	9.4
5/5/2022	16.7	11.3	4.4

5/6/2022	16.7	12.2	7.2
5/7/2022	16.7	11.1	6.1
5/8/2022	18.9	10.4	1.1
5/9/2022	22.8	13.5	2.2
5/10/2022	23.9	16.4	6.7
5/11/2022	26.7	17.8	8.3
5/12/2022	28.9	20.2	10.0
5/13/2022	27.8	22.7	14.4
5/14/2022	27.2	23.3	18.3
5/15/2022	26.1	22.0	16.7
5/16/2022	22.8	16.2	10.6
5/17/2022	17.2	13.0	10.0
5/18/2022	16.7	12.1	7.2
5/19/2022	16.1	12.0	8.9
5/20/2022	27.8	19.0	8.3
5/21/2022	32.2	25.8	20.6
5/22/2022	26.1	17.6	10.6
5/23/2022	17.2	12.6	8.3
5/24/2022	22.2	14.9	6.7
5/25/2022	23.3	18.1	11.1
5/26/2022	27.2	21.3	16.1
5/27/2022	23.3	19.8	17.2
5/28/2022	21.1	16.4	12.2
5/29/2022	25.0	18.4	12.2
5/30/2022	29.4	21.6	12.2
5/31/2022	31.1	25.1	17.2
6/1/2022	21.1	20.1	18.3
6/2/2022	22.2	18.4	14.4
6/3/2022	22.8	17.3	12.2
6/4/2022	19.4	15.2	10.0
6/5/2022	23.9	16.8	7.2
6/6/2022	26.1	20.0	13.9
6/7/2022	22.2	19.9	16.1
6/8/2022	22.2	16.9	12.8
6/9/2022	17.8	15.3	13.3
6/10/2022	21.7	17.2	12.8
6/11/2022	24.4	18.2	11.1
6/12/2022	23.3	19.4	15.0
6/13/2022	22.8	18.3	13.9
6/14/2022	26.1	19.3	11.7
6/15/2022	29.4	22.4	13.9
6/16/2022	29.4	23.2	19.4
6/17/2022	25.6	22.8	16.7
6/18/2022	18.3	12.9	10.6
6/19/2022	18.3	13.9	8.3
6/20/2022	23.3	16.7	10.0
6/21/2022	27.2	18.2	11.1
6/22/2022	28.9	21.6	15.0
6/23/2022	23.9	19.6	16.7
6/24/2022	27.8	21.8	15.6
6/25/2022	30.6	22.4	13.3
6/26/2022	32.8	24.4	17.2
6/27/2022	22.8	20.4	15.0
6/28/2022	22.8	17.7	13.3
6/29/2022	25.0	18.4	11.7
6/30/2022	28.3	21.1	13.3
7/1/2022	31.1	26.6	21.7
7/2/2022	27.2	21.6	18.3
7/3/2022	23.9	20.1	15.6
7/4/2022	26.7	20.2	12.8
7/5/2022	22.2	19.8	17.8
7/6/2022	26.1	19.9	16.1
7/7/2022	28.9	21.9	14.4
7/8/2022	28.3	22.0	16.1

Modeled Atmospheric Temperature
Site: Cold Springs Terminal
Location: Lysander, NY



$$T(z=0,t) = T_{mean} + A_0 \cdot \sin(\omega \cdot t)$$

Where,
z = depth below ground surface (L)
z_0 = depth at ground surface (z = 0)
t = time = startday - offset (days)
T_{mean} = mean annual ambient temperature(^{o}C)
A_0 = amplitude of annual temperature oscillation (^{o}C)
ω = angular frequency of temperature oscillation = 2π/P (t^1) = 2π/365.25 days^1
where P = period of oscillation = 365.25 days

Range from "WeatherData" tab. Do not change here.

Start Date for Range	1/1/2020	
End Date for Range	7/8/2022	

Mean and Amplitude Values from "WeatherData" tab.

Selected Mean Temp (°C)	10.2	= T_{mean}
Selected Average Amplitude (°C)	14.1	= A_0
Annual Minimum Temp (°C)	-3.9	
Annual Max Temp (°C)	24.3	

Subsurface Background Temperature Model

Site: **Cold Springs Terminal**
Location: **Lysander, NY**

1. Enter the maximum vertical depth to be modeled. The model will compute depths for 100 discrete layers from the surface to the specified depth.

Maximum Depth to be Modeled	34.0	ft	=	10.36	m
Number of intervals (for 1 foot intervals, enter same # as depth above):	34	ft	=	10.36	m
Vertical Resolution Interval	1.00	ft	=	0.30	m

From Weather Data tab:

Mean Annual Surface Temperature ($T_{mean}(z=0)$) =	10.20	°C
Amplitude of Temperature Oscillation at Ground Surface (A_0) =	14.10	°C
Period of Temperature Oscillation (P) =	365.25	day
Angular Frequency of Temperature Oscillation (ω) =	0.017	rad/day

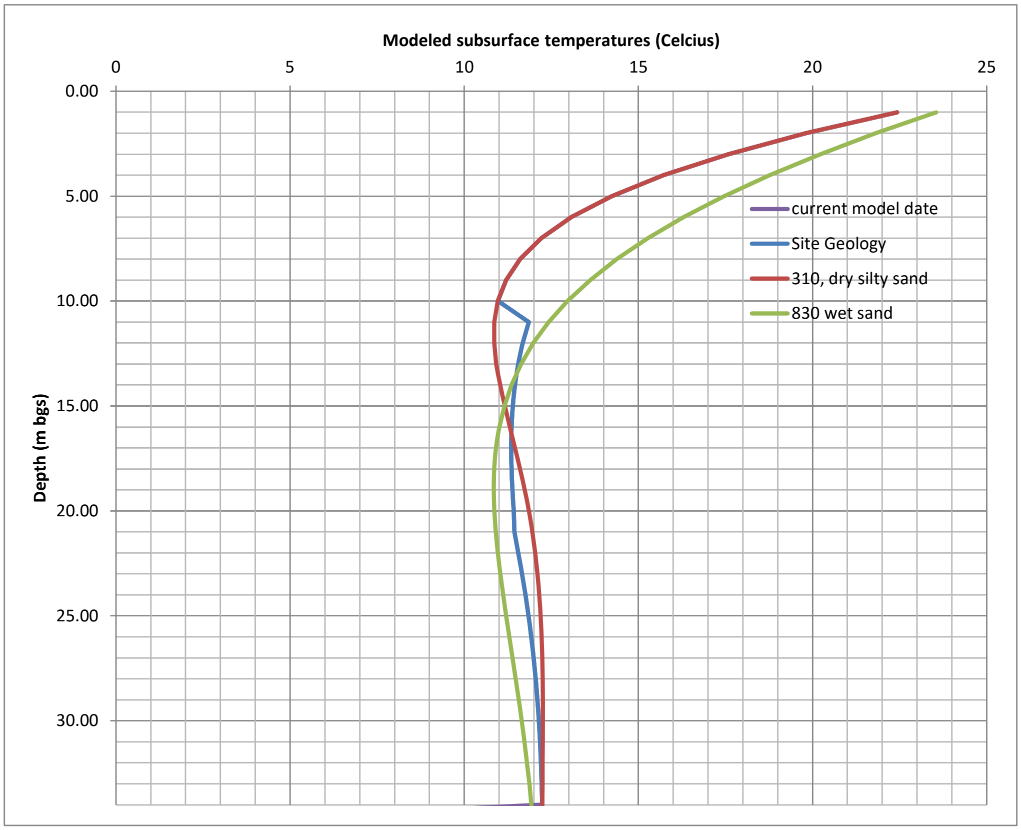
2. Enter soil layer data below. Up to 5 layers can be entered; thermal diffusivity values can be estimated based on information in the Reference sheet. table 1

Soil Layer Data	Description / moisture %	Thermal Diffusivity of Soil (m^2/sec) ($x10^{-9}$)	Top (ft)	Bottom (ft)	Top (m)	Bottom (m)	Phase Velocity (m/d)	Layer Thickness (m)
Layer 1	Silty sand, dry	310	0	10	0.00	3.05	0.03	0.93
Layer 2	Sand, wet	830	10	20	3.05	6.10	0.05	0.93
Layer 3		500	20	34	6.10	10.36	0.04	1.30
Layer 4					0.00	0.00	0.00	0.00
Layer 5					0.00	0.00	0.00	0.00

3. Enter a temperature offset constant (expressed as a uniform increase to predicted subsurface temperatures, after Wu and Nofziger 1999). Suggested default is 2°

Temperature Offset = 2.00 (°C)

Date of field work = July 7, 2022 (Must be within period on Modeled Surface Temp tab.)



Site	depth (ft)	
310	0	10
830	10	20
500	20	34

'C.

Subsurface Temperature Model Calculations - Do not change

Time within period (t) = 435.75 days

current model c date: 7/7/2022

Depth (ft)	Depth (m)	Soil Layer	Thermal Diffusivity of Soil (m^2/sec) ($x10^{-9}$)	Thermal Diffusivity of Soil (m^2/d)	Damping depth (m)	Amplitude at depth (deg C)	Time of Maximum Temp within Period(d)	Phase velocity (m/d)	Phase Offset for Overlying Layers (d)	Subsurface Temperature (deg C)	Site Geology	830 wet sand	310, dry silty sand
0.00	0.000	Layer 1	310.00	2.68E-02	1.76	14.10	91.3	3.04E-02	0				
1.00	0.30	Layer 1	310.00	2.68E-02	1.76	11.86	101.4	3.04E-02	0	22.43	22.43	23.55	22.43
2.00	0.61	Layer 1	310.00	2.68E-02	1.76	9.98	111.4	3.04E-02	0	19.81	19.81	21.82	19.81
3.00	0.91	Layer 1	310.00	2.68E-02	1.76	8.40	121.4	3.04E-02	0	17.58	17.58	20.22	17.58
4.00	1.22	Layer 1	310.00	2.68E-02	1.76	7.07	131.5	3.04E-02	0	15.72	15.72	18.77	15.72
5.00	1.52	Layer 1	310.00	2.68E-02	1.76	5.94	141.5	3.04E-02	0	14.23	14.23	17.46	14.23
6.00	1.83	Layer 1	310.00	2.68E-02	1.76	5.00	151.6	3.04E-02	0	13.08	13.08	16.30	13.08
7.00	2.13	Layer 1	310.00	2.68E-02	1.76	4.21	161.6	3.04E-02	0	12.22	12.22	15.27	12.22
8.00	2.44	Layer 1	310.00	2.68E-02	1.76	3.54	171.6	3.04E-02	0	11.60	11.60	14.38	11.60
9.00	2.74	Layer 1	310.00	2.68E-02	1.76	2.98	181.7	3.04E-02	0	11.20	11.20	13.62	11.20
10.00	3.05	Layer 1	310.00	2.68E-02	1.76	2.51	191.7	3.04E-02	0	10.97	10.97	12.97	10.97
11.00	3.35	Layer 2	830.00	7.17E-02	2.89	2.26	158.8	4.97E-02	-31	11.86	11.86	12.43	10.86
12.00	3.66	Layer 2	830.00	7.17E-02	2.89	2.03	164.9	4.97E-02	-31	11.68	11.68	11.99	10.86
13.00	3.96	Layer 2	830.00	7.17E-02	2.89	1.83	171.1	4.97E-02	-31	11.55	11.55	11.63	10.92
14.00	4.27	Layer 2	830.00	7.17E-02	2.89	1.64	177.2	4.97E-02	-31	11.46	11.46	11.36	11.03
15.00	4.57	Layer 2	830.00	7.17E-02	2.89	1.48	183.4	4.97E-02	-31	11.40	11.40	11.15	11.16
16.00	4.88	Layer 2	830.00	7.17E-02	2.89	1.33	189.5	4.97E-02	-31	11.36	11.36	11.01	11.31
17.00	5.18	Layer 2	830.00	7.17E-02	2.89	1.20	195.6	4.97E-02	-31	11.35	11.35	10.91	11.46
18.00	5.49	Layer 2	830.00	7.17E-02	2.89	1.08	201.8	4.97E-02	-31	11.36	11.36	10.86	11.60
19.00	5.79	Layer 2	830.00	7.17E-02	2.89	0.97	207.9	4.97E-02	-31	11.39	11.39	10.85	11.73
20.00	6.10	Layer 2	830.00	7.17E-02	2.89	0.87	214.0	4.97E-02	-31	11.42	11.42	10.86	11.85
21.00	6.40	Layer 3	500.00	4.32E-02	2.24	0.76	257.3	3.86E-02	-49	11.44	11.44	10.90	11.95
22.00	6.71	Layer 3	500.00	4.32E-02	2.24	0.66	265.2	3.86E-02	-49	11.55	11.55	10.96	12.03
23.00	7.01	Layer 3	500.00	4.32E-02	2.24	0.58	273.2	3.86E-02	-49	11.66	11.66	11.03	12.10
24.00	7.32	Layer 3	500.00	4.32E-02	2.24	0.51	281.1	3.86E-02	-49	11.76	11.76	11.12	12.15
25.00	7.62	Layer 3	500.00	4.32E-02	2.24	0.44	289.0	3.86E-02	-49	11.84	11.84	11.20	12.19
26.00	7.92	Layer 3	500.00	4.32E-02	2.24	0.39	296.9	3.86E-02	-49	11.92	11.92	11.29	12.22
27.00	8.23	Layer 3	500.00	4.32E-02	2.24	0.34	304.8	3.86E-02	-49	11.99	11.99	11.39	12.24
28.00	8.53	Layer 3	500.00	4.32E-02	2.24	0.29	312.7	3.86E-02	-49	12.05	12.05	11.48	12.25
29.00	8.84	Layer 3	500.00	4.32E-02	2.24	0.26	320.6	3.86E-02	-49	12.10	12.10	11.56	12.26
30.00	9.14	Layer 3	500.00	4.32E-02	2.24	0.22	328.5	3.86E-02	-49	12.14	12.14	11.65	12.26
31.00	9.45	Layer 3	500.00	4.32E-02	2.24	0.20	336.4	3.86E-02	-49	12.18	12.18	11.73	12.26
32.00	9.75	Layer 3	500.00	4.32E-02	2.24	0.17	344.3	3.86E-02	-49	12.20	12.20	11.80	12.25
33.00	10.06	Layer 3	500.00	4.32E-02	2.24	0.15	352.2	3.86E-02	-49	12.22	12.22	11.87	12.25
34.00	10.36	Layer 3	500.00	4.32E-02	2.24	0.13	360.1	3.86E-02	-49	12.24	12.24	11.93	12.24

Appendix E

Comparison of NSZD Rates to Skimmer and Manual Recovery Rates

Comparison of NSZD Raters to Skimmer and Manual Recovery rates

Report Table 6.2 Location-specific NSZD rate comparisons

CO_2 Traps		Nearest DCC			Nearest NSZD Well			Site Location
CO_2 Trap ID	NSZD estimate	DCC ID	NSZD estimate corrected with lowest DCC bkgr	NSZD estimate corrected with mean CO_2 trap bkgr	Well ID	NSZD estimate Gradient method	NSZD estimate Biogenic heat method	Terminal (NT or ST) & current LNAPL area (within, adjacent to, outside)
CO2-2	26	DCC-44	4,578	1,229	MW-208	1,238	1,104	NT; outside
CO2-4	0	DCC-41	6,391	3,092	MW-211	815	1,281	NT; outside
CO2-5	721	DCC-38	5,399	2,101	BMW13	1,828	2,438	NT; within
CO2-6	573	DCC-35	5,437	2,139	BMW5	1,068	2,414	NT; within
CO2-7	435	DCC-29 DCC-30	7,242	3,944	RW-1	3,399	inconclusive	ST; within
		DCC-31	2,634	0				
		DCC-32	2,747	0				
			2,053	0				
CO2-8	2,749	DCC-21 DCC-22	3,394	96	RW-2,	3,082	inconclusive,	ST; within
		DCC-24	3,185	0	RW-3	3,816	inconclusive	
			4,386	1,087				
CO2-9	347	DCC-16a	2,836	0	RW-5	3,103	10,346	ST; within
		DCC-16b	2,265	0				

Average of 2326 gal / acre / yr equates to 246 gal / wk

52	wk per year
43560	sq ft in acre
239,950	sq ft in CST LNAPL area
5.5	acres in CST LNAPL area

Mobile LNAPL Recovery via Skimmers and Manual Bailing for April 11, 2022- August 2, 2022

Date	Time in period	Well ID																			Total amount over period	**Total LNAPL removal rate**	**Total mobile LNAPL removal rate**	
		Southern Terminals Group														Northern Terminals Group								
	(days)	A10	AMW5	RW-1	MW-1S	RW-3	MW-2S	AMW3	RW-4	MW5SR	RW-5	MW-7S	A14	RW-2	S3	B13	BMW13	S13	BMW5	PZ102S	(gal)	(gal LNAPL per day)	**Date**	(gal LNAPL per wk)
4/11/2022	-	1	0	2.4	0.4	0.8	2.4	0	0	2.8	1.4	0	0	0	0	0	0	0	0	0	11.2	-	4/11/2022	
4/18/2022	7	0	0	2.6	0.4	0.8	0.8	0	0	1.6	1.2	0	0	0	0	0	0	0	0	0	7.4	1.1	4/18/2022	7.4
4/25/2022	7	0	0	0.8	0.4	1.8	0.8	0	0	2.8	3	0	0	0	0	0	0	0	0	0	9.6	1.4	4/25/2022	9.6
5/2/2022	7	0	0	0.8	0	0	0	0	0	0	0	0	0	2.5	0.13	0.13	0	0.5	0	0.13	4.19	0.6	5/2/2022	4.2
5/9/2022	7	0	0	0	0	0.2	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0.4	0.1	5/9/2022	0.4
5/16/2022	7	0	0	0.2	0	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.1	5/16/2022	1
5/23/2022	7	0	0	0.2	0	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0.4	0.1	5/23/2022	0.4
5/31/2022	8	0	0	0.6	0	0	0	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0.8	0.1	5/31/2022	0.7
6/6/2022	6	0	0	0	0	0	0	0	0	0	0	0	2	0.25	0.25	0.05	0.05	0	0.25	0.13	2.98	0.5	6/6/2022	3.5
6/14/2022	8	0.4	0	0.4	0	0.8	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2.6	0.3	6/14/2022	2.3
6/20/2022	6	0.6	0	0	0	0.6	0	0	0	0	0.6	0	0	0	0	0	0	0	0	0	1.8	0.3	6/20/2022	2.1
6/28/2022	8	0.2	0	0.6	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1.8	0.2	6/28/2022	1.6
7/5/2022	7	0	0	1	0	0.2	0	0	0	0.6	0.4	0	0.5	0	0	0	0	0.5	0	0.13	3.33	0.5	7/5/2022	3.3
7/15/2022	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	7/15/2022	0
7/25/2022	10	0	0	0.8	0	0.6	0	0	0	0.2	0.4	0	0	0	0	0	0	0	0	0	2	0.2	7/25/2022	1.4
8/2/2022	8	0	0	0	0	0	0	0	0	0	0	0	0.5	0	0	0	0.25	0.25	0.5	0	1.5	0.2	8/2/2022	1.3
Total LNAPL		2.2	0	10.4	1.2	6.6	4	0	0	8.4	9.2	0	3	2.75	0.38	0.18	0.3	1.25	0.75	0.39	51		**Average**	**2.6**

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