

How long will the LNAPL persist? Tier 3

A simple box model is provided in Tier 2 and provides a range of time required for the LNAPL to be removed by Natural Source Zone Depletion (NSZD). Users enter the estimated mass/volume of LNAPL present and the estimated NSZD rate.

Two more sophisticated computer tools that can be used to estimate how long the LNAPL might persist at a site are [REMFuel](#) ([Falta et al., 2012](#)) and [LNAST](#) ([Huntley and Beckett, 2002](#)). A short summary of each model is provided below:

Overview of REMFuel

- REMFuel is a coupled analytical source zone/plume response model distributed by USEPA.
- Based on popular [REMChlor model](#) used at chlorinated solvent sites.
- The source zone model includes a box model where the mass of the dissolution product to be modeled is entered and a relationship “gamma” that describes the mass flux out of the source at any time compared to the remaining mass is specified by the user.
- Solute transport model simulates advection, dispersion, retardation, sorption assuming simple 1-D groundwater flow.
- The user can specify any percent of source removal at any time to model plume response to active remediation.
- The user can model plume remediation at any time in three separate spatial zones by increasing first order decay constants.
- NSZD can also be simulated by entering a value for “Source Decay” although there is no discussion in User’s Guide on how to do this.
- Key output of the model are graphs showing the concentration (or mass discharge) of the constituents in the dissolved plume vs. distance from source.
- Download model from USEPA web page [here](#).

Overview of API’s LNAPL Dissolution and Transport Screening Tool (LNAST; version 2.0.4)

- LNAST is suite of calculation tools, information about LNAPL, and LNAPL parameter databases. LNAST focuses on LNAPL distribution and fate at the water table. The calculation tool part of LNAST:
 - Predicts LNAPL distribution, dissolution, and volatilization over time.
 - Calculates downgradient dissolved-phase concentration through time.
 - Shows results both with and without hydraulic recovery of LNAPL.
- LNAST simulates the smear zone and the downgradient dissolved plume.
- Combines multi-phase transport, dissolution, and solute transport.
 - Accounts for relative permeability effects caused by LNAPL.
 - Zones of high LNAPL saturation have much less groundwater flow through them, extending the longevity of these zones.
- Good tool for estimating how long an LNAPL-generated plume will persist.
- Powerful tool to see if LNAPL recovery reduces the longevity of the source and plume.
- Key output is concentration of dissolved constituents in the plume vs. time at an observation well.
- Does not account for NSZD.
- Assumes that remediation occurs shortly after the LNAPL release. You cannot release LNAPL many years ago and then start the remediation now a few decades later.
- LNAST can be downloaded [here](#).

Videos

Two short videos are available to learn more about REMFuel and LNASt:

- [REMFuel](#)
- LNASt [link to be added after Concawe review]

Checklist for REMFuel Input Data

Key input data are shown below. One key feature is that the plume produced by the source can be broken up into nine “space-time” domains with three separate time periods and three separate spatial zones. For example, the first third of the plume downgradient from a 40-year-old source can have its own first order decay coefficients for three separate time periods, such as a 20-year natural attenuation period, then a 5-year plume remediation period, then a 15-year post-remediation natural attenuation period.

While much of the input data below is commonly collected during site characterization activities (e.g., Darcy groundwater velocity, source width/height/length, porosity) the source zone gamma term may be unfamiliar to many users. Basically, gamma defines the relationship between mass flux leaving the source and the remaining mass in the source at any time. For example:

- Gamma of zero results in a constant source mass flux until mass is gone, then zero flux (a step function).
- Gamma of 0.5 results in a linear decline in source concentration based on the amount of LNAPL mass originally released and the original source concentrations.
- Gamma of 1.0 results in an exponential decline in source concentration based on the amount of LNAPL mass originally released and the original source concentrations (this is often used as a default value).

Source Zone Parameters

Source Parameters

Gamma: 1

Source Dimensions

Source Width (m): 20
Source Height (m): 2
Source Length (m): 20

Flow Parameters

Darcy Velocity (m/yr): 10
Porosity: 0.35

Source Remediation

Fraction Removed: 0.9
Source Remediation Time: 15 (Years) 15.5
Start Time (T1): End Time (T2):

Transport Parameters

Velocity: 0.2 0 2
Sigmax: vMin vMax
Number of Stream Tubes: 1000
alpha_x (m): -0.002 -0.0002
alpha_z (m):

Component Name: Benzene

Decay Rate (per year)

	Zone 1	Zone 2	Zone 3
Period 3	(1,3)	(2,3)	(3,3)
Period 2	(1,2)	(2,2)	(3,2)
Period 1	(1,1)	(2,1)	(3,1)

Daughter Name: Benzene_Daughter

Decay Rate (per year)

	Zone 1	Zone 2	Zone 3
Period 3	(1,3)	(2,3)	(3,3)
Period 2	(1,2)	(2,2)	(3,2)
Period 1	(1,1)	(2,1)	(3,1)

Select Component

Benzene
Toluene
Ethyl Benzene
o-Xylene
MTBE

Component Specific Parameters

Reaction Type:
☐ Zero Order Reaction
☒ First Order Reaction
☐ Monod Reaction

Daughter Yield From Parent: 0

Initial Source

Concentration (g/L): 0.00644 Calculate
Mass (Kg): 164 Calculate
Retardation Factor: 1.76 Calculate
Source Decay (1/yr): 1.1

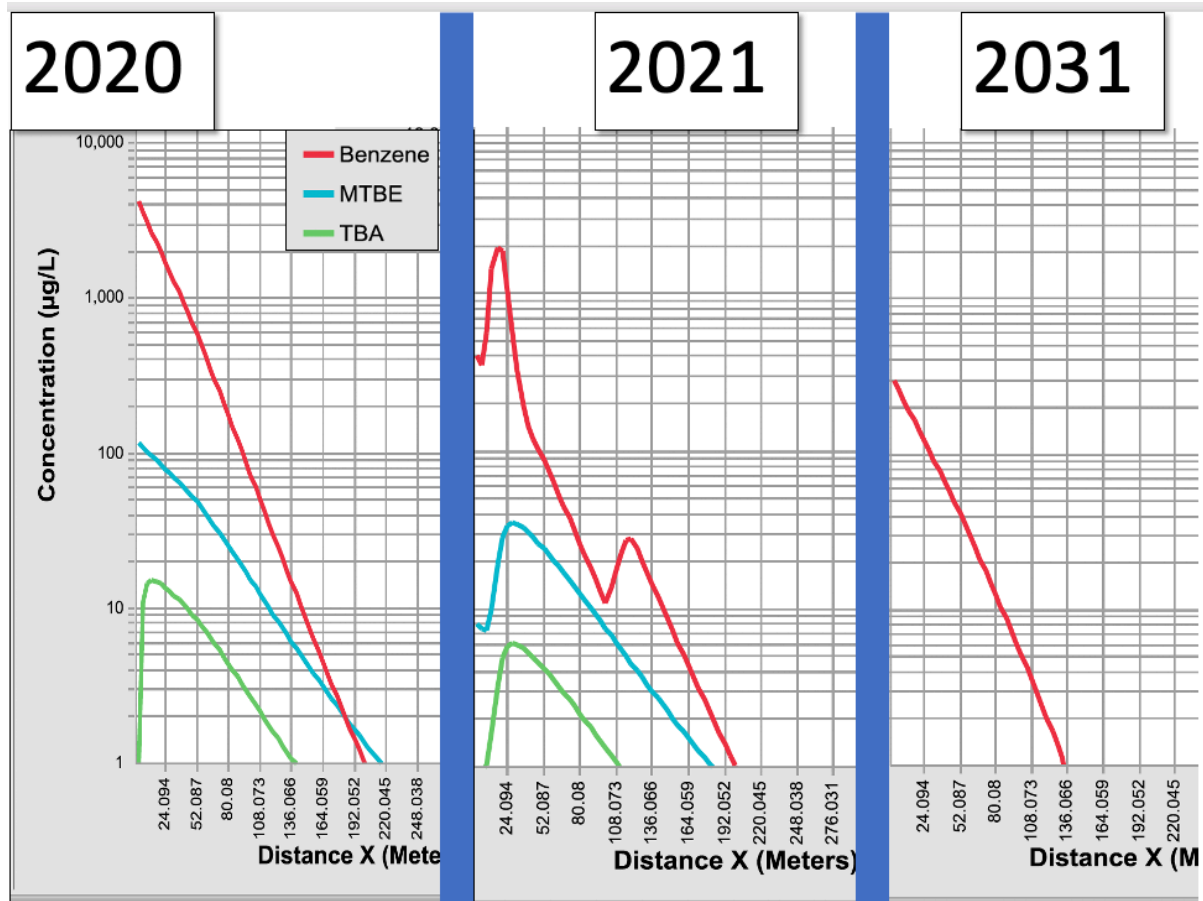
Simulation Parameters

	Intervals	Min Value	Max Value	Units
X - Direction	101	0.1	600	Meter
Y - Direction	1	-100	100	Meter
Z - Direction	1	0	0	Meter
Time	50	0	50	Year

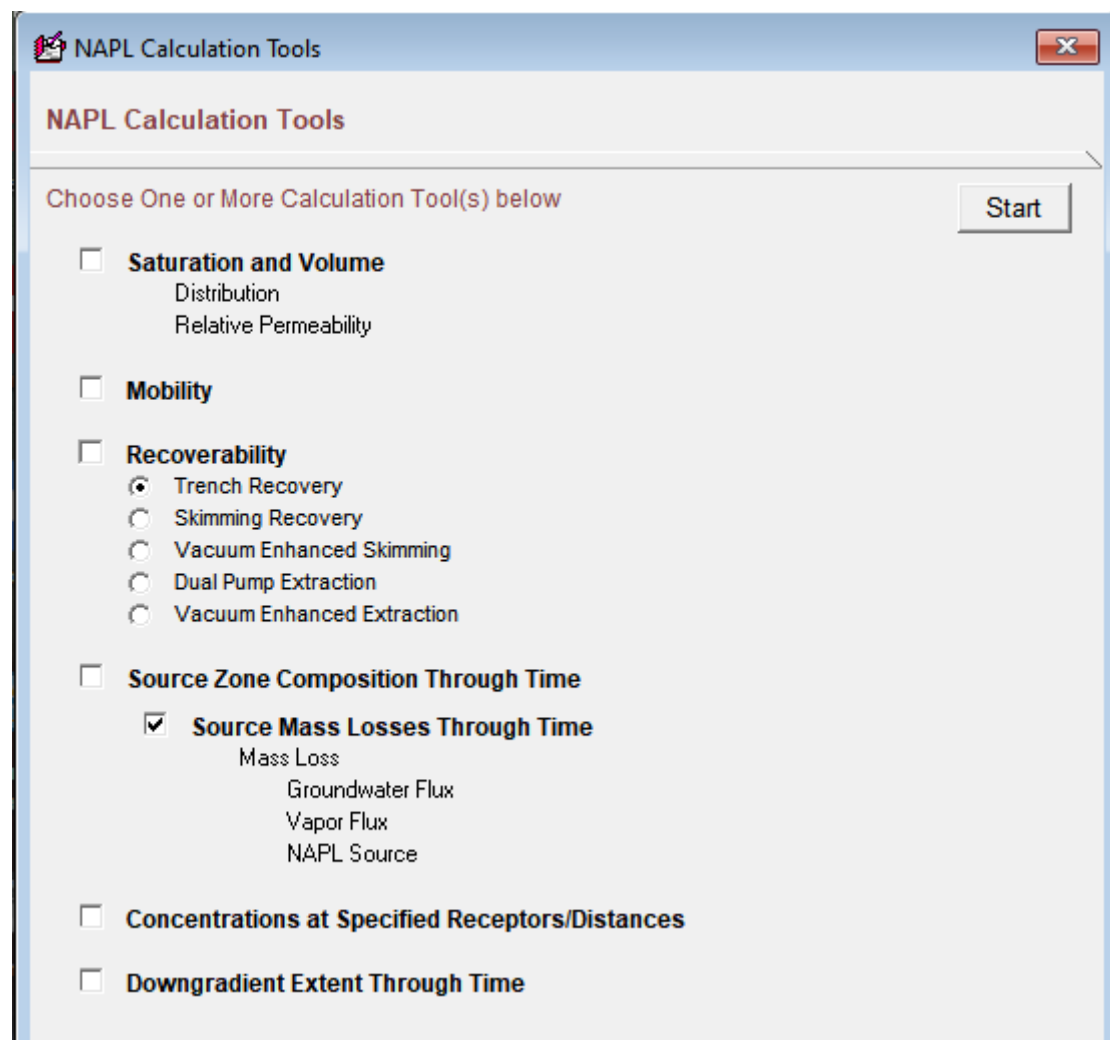
REMFuel

Example of REMFuel Output Data for Three Separate Time Periods

In this example, source remediation and plume remediation were performed, leading to the spikey concentration vs. distance curves in the 2021 panel (see the [REMFuel video](#) for a more detailed explanation). Note that the Y-axis is log-scale.



To use LNAST, the user first indicates the information desired from the tool:



The screenshot shows a software window titled "NAPL Calculation Tools". Inside the window, there is a section titled "NAPL Calculation Tools" with a subtitle "Choose One or More Calculation Tool(s) below". A "Start" button is located in the top right corner of the tool selection area. The tool selection area contains several checkboxes and sub-options:

- ☐ **Saturation and Volume**
 - Distribution
 - Relative Permeability
- ☐ **Mobility**
- ☐ **Recoverability**
 - ☒ Trench Recovery
 - ☐ Skimming Recovery
 - ☐ Vacuum Enhanced Skimming
 - ☐ Dual Pump Extraction
 - ☐ Vacuum Enhanced Extraction
- ☐ **Source Zone Composition Through Time**
 - ☒ **Source Mass Losses Through Time**
 - Mass Loss
 - Groundwater Flux
 - Vapor Flux
 - NAPL Source
- ☐ **Concentrations at Specified Receptors/Distances**
- ☐ **Downgradient Extent Through Time**

The tool then takes the user through a series of eight input screens to define soil properties, groundwater conditions, source area parameters, LNAPL properties, and solute transport.

Collecting Information

Soil Properties - Step 1 of 8

☐ English
 ☒ Metric

Soil Type: Coarse Sand

Additional Information Required For Multiple Layers:

Layer Selection: Layer 1 (Lowermost)

Thickness of Layer (m): 0.73

Elevation of Bottom of Layer (m above oil/water): 0

Oscillation Damping:

☒ None
 ☐ Moderate
 ☐ Maximum

✓ = Default Value

✓ Van Genuchten Alpha (1/m): 3.87
 ✓ Van Genuchten n: 1.62
 ✓ Saturated Hydraulic Conductivity (m/day): 11.6
 ✓ Residual Saturation of Water: 0.27
 ✓ Field Residual Saturation of LNAPL: 0.15
 ✓ Total Porosity: 0.33

Collecting Information

Groundwater Conditions - Step 2 of 8

☐ English
 ☒ Metric

✓ Groundwater Hydraulic Gradient: 0.001

Groundwater Specific Discharge (m/day): 0.0116

Conservative Solute Pore Velocity (m/day): 0.0482

✓ = Default Value

Collecting Information

Source Area Parameters - Step 3 of 8

☐ English ☒ Metric

✓ Initial Thickness of LNAPL (m)

✓ Average Depth to top of LNAPL (m)

✓ Length of LNAPL Zone (m)

✓ Width of LNAPL Zone (m)

✓ Criteria for Minimum Mobility (Hydraulic Conductivity) (m/day)

✓ = Default Value

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Collecting Information

Method Used to Calculate LNAPL Saturation Step 4 of 8

✓ ☒ Equilibrium LNAPL Distribution

☐ Distribution at Minimal Mobility

☐ Residual Saturation

☐ User Input of Saturation

✓ = Default Value

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Collecting Information

LNAPL Properties - Step 5 of 8

Hydrocarbon Type ☐ English ☒ Metric

✓ Density (gm/cc)

✓ Oil/Water Interfacial Tension (dynes/cm)

✓ Oil/Air Interfacial Tension (dynes/cm)

✓ Viscosity (cp)

✓ Dissolved Phase Properties

	Pure Phase Solubility (mg/l)	Pure Phase Vapor Conc. (mg/l)	Mass Fraction of LNAPL	Log(Koc)	Biodegradation Half-Life (days)	Target Concentration (ug/l)
MTBE	48000	1204	0.11	1	9000	40
Benzene	1780	324	0.018	2	90	5
Ethyl Benzene	135	57	0.018	3	65	700
Toluene	515	111	0.079	2.06	60	1000
Xylene	175	38	0.075	2.6	150	10000

✓ = Default Value

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Collecting Information

Solute Transport Properties - Step 6 of 8

☐ English ☒ Metric

✓ Effective Porosity

✓ Longitudinal Dispersivity (m)

✓ Horizontal Transverse Dispersivity (m)

✓ Vertical Transverse Dispersivity (m)

✓ Fractional Carbon Content

Include Volatilization From Source?
☒ Yes ☐ No

✓ Vapor Diffusion Efficiency Coefficient

✓ = Default Value

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Collecting Information

LNAPL Recovery - Step 7 of 8

✓ Period Of Recovery (yrs) ☐ English ☒ Metric

✓ Width of Trench (m)

✓ = Default Value

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Collecting Information

Distances From The Source - Step 8 of 8

Enter up to 20 distances (meters or ft for metric/english units of measure) downgradient from the source, along the downgradient axis of the resulting plume. Concentrations will be calculated as a function of time at each of these points.

☐ English ☒ Metric

1.	<input type="text" value="0"/>	11.	<input type="text"/>
2.	<input type="text"/>	12.	<input type="text"/>
3.	<input type="text"/>	13.	<input type="text"/>
4.	<input type="text"/>	14.	<input type="text"/>
5.	<input type="text"/>	15.	<input type="text"/>
6.	<input type="text"/>	16.	<input type="text"/>
7.	<input type="text"/>	17.	<input type="text"/>
8.	<input type="text"/>	18.	<input type="text"/>
9.	<input type="text"/>	19.	<input type="text"/>
10.	<input type="text"/>	20.	<input type="text"/>

<< Back Calculate

Example of LNAST Output Data

After performing the selected calculations, LNAST allows users to display results to the screen, create a report, or export the results.

Screen Results

[Create New Run](#) | [Edit Existing Run](#)

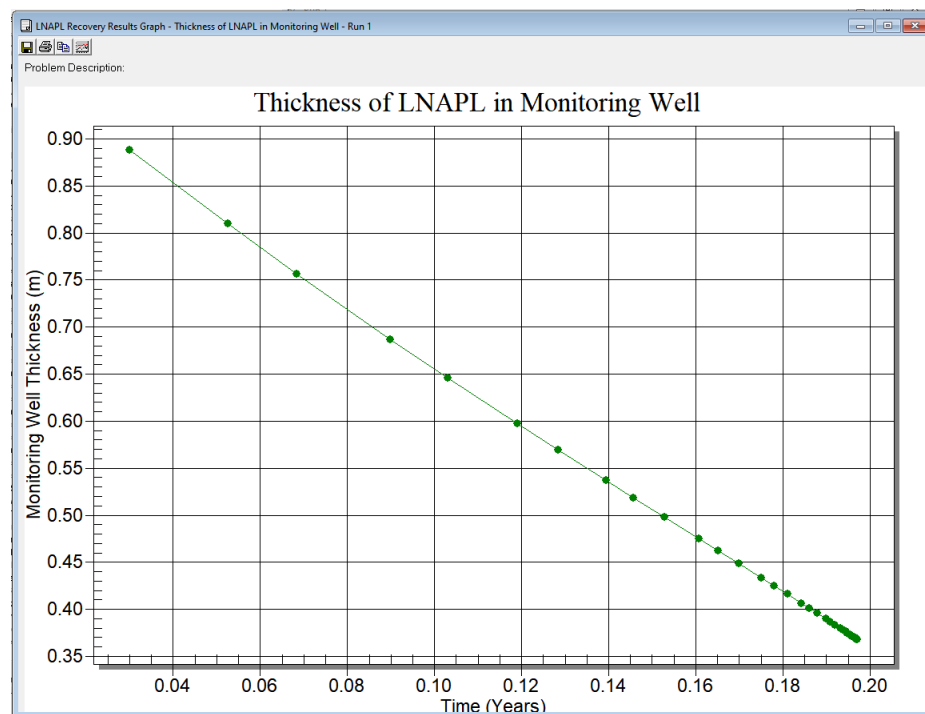
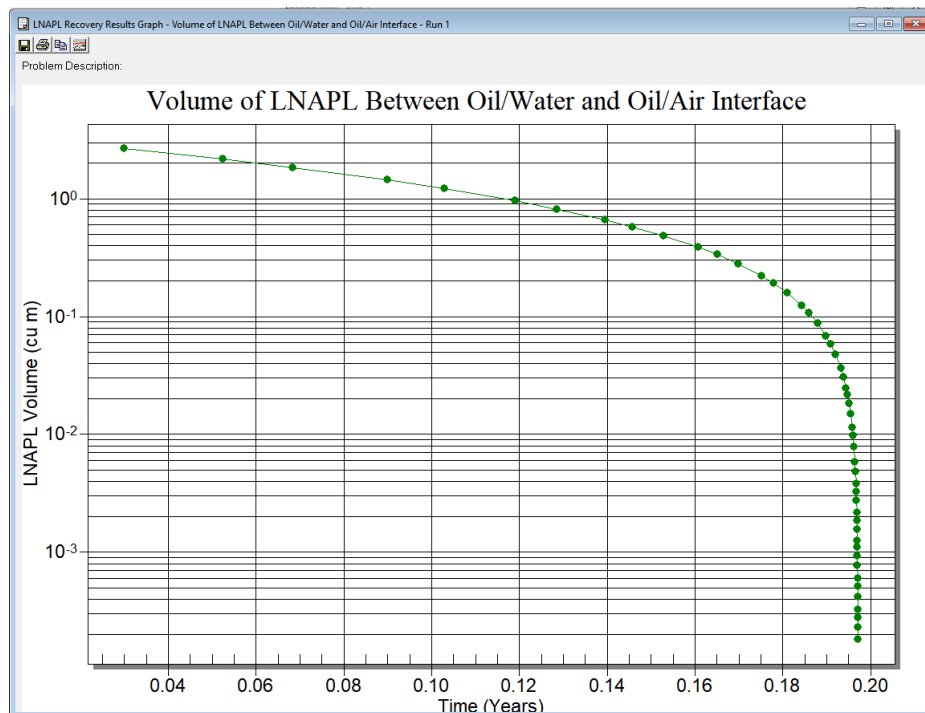
Select Results to Include:

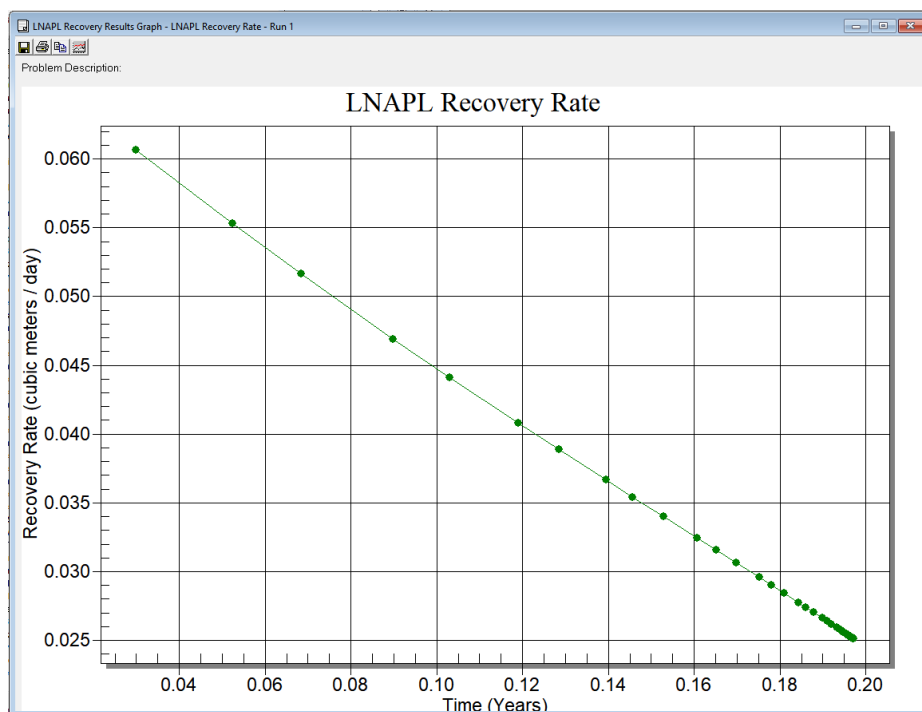
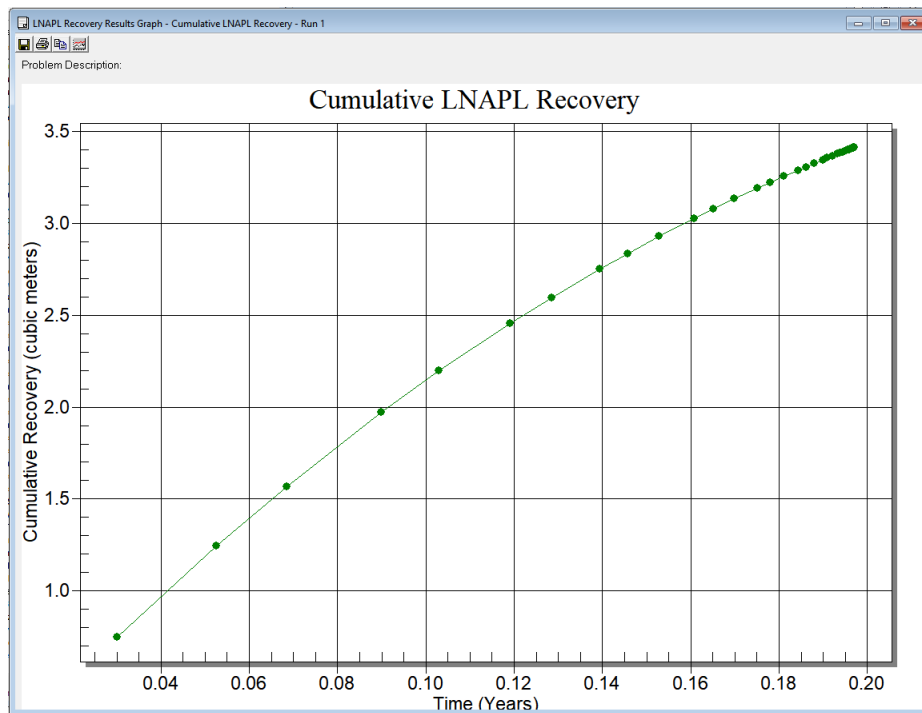
☒ Tables ☒ Graphs ☐ English ☒ Metric [Display Multiple Runs](#)

- ☐ **Saturation and Volume**
 - ☐ Run 1 Saturation of LNAPL
 - ☐ Run 1 Saturation of Water
 - ☐ Run 1 LNAPL Relative Permeability (Charbeneau)
 - ☐ Run 1 Water Relative Permeability
- ☐ **Mobility**
 - ☐ Run 1 Mobility
- ☐ **LNAPL Recovery**
 - ☐ Run 1 Thickness
 - ☐ Run 1 LNAPL Recovery Rate (cu m/day)
 - ☐ Run 1 Cumulative LNAPL Recovery (cu m)
 - ☐ Run 1 LNAPL Volume(cu m) between oil/water and oil/air interface
- ☐ **Source Zone Composition Through Time**
 - ☐ Run 1 MTBE
 - ☐ Run 1 Benzene
 - ☐ Run 1 Ethyl Benzene
 - ☐ Run 1 Toluene
 - ☐ Run 1 Xylene
- ☐ **Source Mass Losses Through Time**
 - ☐ Run 1 Remaining Mass MTBE
 - ☐ Run 1 Mass Flux - Groundwater MTBE
 - ☐ Run 1 Mass Flux - Vapor MTBE
 - ☐ Run 1 Remaining Mass Benzene
 - ☐ Run 1 Mass Flux - Groundwater Benzene
 - ☐ Run 1 Mass Flux - Vapor Benzene
 - ☐ Run 1 Remaining Mass Ethyl Benzene
 - ☐ Run 1 Mass Flux - Groundwater Ethyl Benzene
 - ☐ Run 1 Mass Flux - Vapor Ethyl Benzene
 - ☐ Run 1 Remaining Mass Toluene
 - ☐ Run 1 Mass Flux - Groundwater Toluene
 - ☐ Run 1 Mass Flux - Vapor Toluene
 - ☐ Run 1 Remaining Mass Xylene
 - ☐ Run 1 Mass Flux - Groundwater Xylene
 - ☐ Run 1 Mass Flux - Vapor Xylene
- ☐ **Concentrations at Specified Receptors/Distances**
 - ☐ Run 1 - 0 Meters
 - ☐ MTBE
 - ☐ Benzene
 - ☐ Ethyl Benzene
 - ☐ Toluene
 - ☐ Xylene
- ☐ **Downgradient Extent Through Time**
 - ☐ Run 1 MTBE
 - ☐ Run 1 Benzene
 - ☐ Run 1 Ethyl Benzene
 - ☐ Run 1 Toluene
 - ☐ Run 1 Xylene

Press Ctrl + A to select all results << Back Display Results

An example of key output for LNAPL recovery in a trench is shown below:





References

[Falta, R.W., Ahsanuzzaman, A.N.M., Stacy, M., Earle, R.C., 2012. REMFuel: Remediation Evaluation Model for Fuel Hydrocarbons User's Manual. USEPA.](#)

[Huntley, D., Beckett, G., 2002. Evaluating Hydrocarbon Removal from Source Zones and Its Effect on Dissolved Plume Longevity and Magnitude. American Petroleum Institute.](#)