The Concawe LNAPL Toolbox

A new web-based Toolbox for understanding light non-aqueous phase liquids (LNAPLs) consists of a unique collection of useful tools, calculators, data and resources to help LNAPL scientists and engineers better understand how to manage LNAPL at their sites.

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Background

LNAPL stands for 'light non-aqueous phase liquids' or hydrocarbons that exist as a separate undissolved phase in the subsurface at some sites with legacy releases of fuels. They are referred to as 'light' because most petroleum hydrocarbons are less dense than water. Because LNAPLs can sustain dissolved groundwater plumes for long time periods, it is important to understand how much LNAPL may be present at site, whether the LNAPL can migrate, whether it can be recovered, how the LNAPL composition changes over time, how long it may persist, and how quickly the LNAPL body is attenuating.

Understanding LNAPL behaviour is complex. Concawe, with the support of GSI Environmental, has therefore compiled a unique collection of useful tools, calculators, data and resources to help LNAPL scientists and engineers better understand how to manage LNAPL at their sites. This has led to the development of the Concawe LNAPL Toolbox, a wide-ranging but easy-to-use web-based toolbox designed to deliver key LNAPL knowledge to the LNAPL remediation community.

The LNAPL Toolbox is intended to be a clear, transparent tool that regulators can use to validate site information that is given to them, and to learn about LNAPL so that they are able to make informed decisions using sound science. The Toolbox uses a three-tiered approach that provides access to more than 20 different LNAPL tools (key infographics, nomographs, calculators, mobility models, videos, checklists and other formats) with different levels of complexity, activation energy and time requirements. The three tiers of complexity are:

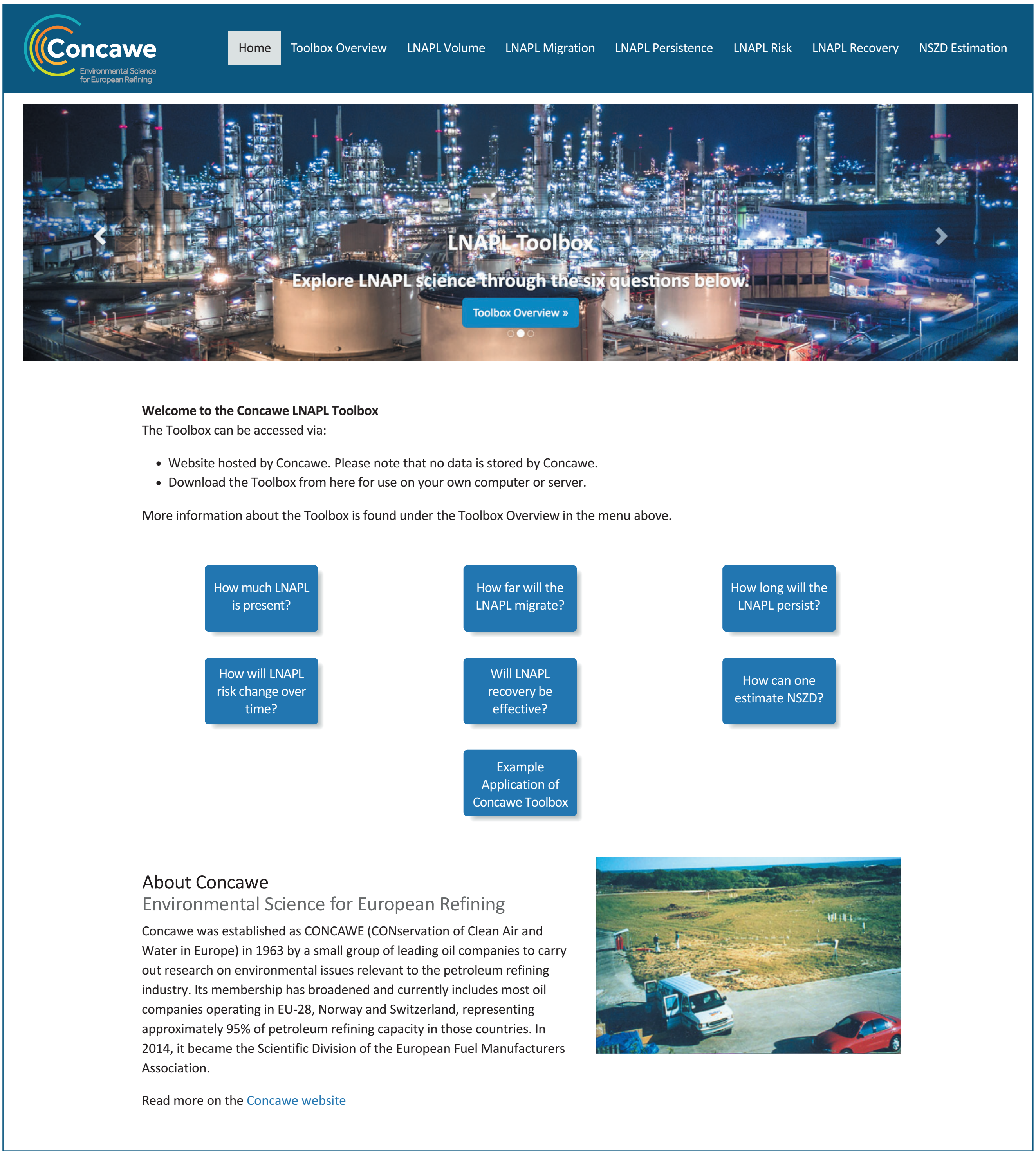
- Tier 1: Simple and quick graphics, tables and/or background Information
- Tier 2: Middle level quantitative methods and/or tools
- Tier 3: Gateway to complex models

In terms of content, the Toolbox is designed to address six questions via six different sections:

1. How much LNAPL is present?
2. How far will the LNAPL migrate?
3. How long will the LNAPL persist?
4. How will LNAPL risk change over time?
5. Will LNAPL recovery be effective?
6. How can one estimate natural source zone depletion (NSZD)?

The Concawe LNAPL Toolbox is publicly available on the internet (see Figure 1 on page 57) using a web browser (https://lnapltoolbox.concawe.eu/lnapl_toolbox) or by downloading the Toolbox code for use on a personal computer (https://github.com/concawe/LNAPL-Toolbox-).

Figure 1: Excerpt from the home page of the Concawe LNAPL Toolbox
(https://lnapltoolbox.concawe.eu/lnapl_toolbox/)



Concawe
Environmental Science for European Refining

Home | Toolbox Overview | LNAPL Volume | LNAPL Migration | LNAPL Persistence | LNAPL Risk | LNAPL Recovery | NSZD Estimation

LNAPL Toolbox
Explore LNAPL science through the six questions below.
Toolbox Overview »

Welcome to the Concawe LNAPL Toolbox
The Toolbox can be accessed via:

- Website hosted by Concawe. Please note that no data is stored by Concawe.
- Download the Toolbox from here for use on your own computer or server.

More information about the Toolbox is found under the Toolbox Overview in the menu above.

How much LNAPL is present?
How far will the LNAPL migrate?
How long will the LNAPL persist?
How will LNAPL risk change over time?
Will LNAPL recovery be effective?
How can one estimate NSZD?
Example Application of Concawe Toolbox

About Concawe
Environmental Science for European Refining

Concawe was established as CONCAWE (CONservation of Clean Air and Water in Europe) in 1963 by a small group of leading oil companies to carry out research on environmental issues relevant to the petroleum refining industry. Its membership has broadened and currently includes most oil companies operating in EU-28, Norway and Switzerland, representing approximately 95% of petroleum refining capacity in those countries. In 2014, it became the Scientific Division of the European Fuel Manufacturers Association.

Read more on the Concawe website

Quick user guide

Once a user enters the Toolbox, either through the web or by using the downloadable version, they can engage with the Toolbox in the following steps using Table 1:

- Step 1: Determine the question you would like to learn more about (column 1).
- Step 2: Decide on the level of effort you would like to apply (columns 2 through 4):
  - Tier 1: a few minutes (approximately)
  - Tier 2: a few hours (approximately)
  - Tier 3: learn about more complex tools
- Step 3: Go to the appropriate tab using the buttons on the home page or the navigation bar.

Table 1: Concawe LNAPL Toolbox organisation and structure

Key LNAPL questions	Tier 1 Quick info	Tier 2 Models/tools	Tier 3 Gateway to complex tools
How much LNAPL is present?	Text, simple table and graphic	LNAPL volume/ extent tool	LDRM resources and video
How far will LNAPL migrate?	Text and simple graphic	LNAPL additional migration tool and Mahler migration model	HSSM and UTCHEM resources and video
How long will LNAPL persist?	Text, simple graphic and table	LNAPL lifetime calculator	LNAST and REMFuel resources and videos
How will LNAPL risk change over time?	Text and simple tables	LNAPL dissolution calculator	LNAST resources and video
Will LNAPL recovery be effective?	Text and simple graphics	LNAPL transmissivity and Darcy flux calculator	Computer modelling resources
How can one estimate NSZD?	Text and simple graphic	NSZD rate converter, NSZD temperature enhancement calculator	NSZD resources and videos

Conceptual example

The use of the Toolbox can be illustrated by the following conceptual example, in which an LNAPL body is currently being recovered using LNAPL skimming wells. The site owner would like to determine whether the installed LNAPL recovery system is still needed to meet the remediation objectives. There is uncertainty about some fundamental aspects of this LNAPL site, and the conceptual site model (CSM) needs to be updated.

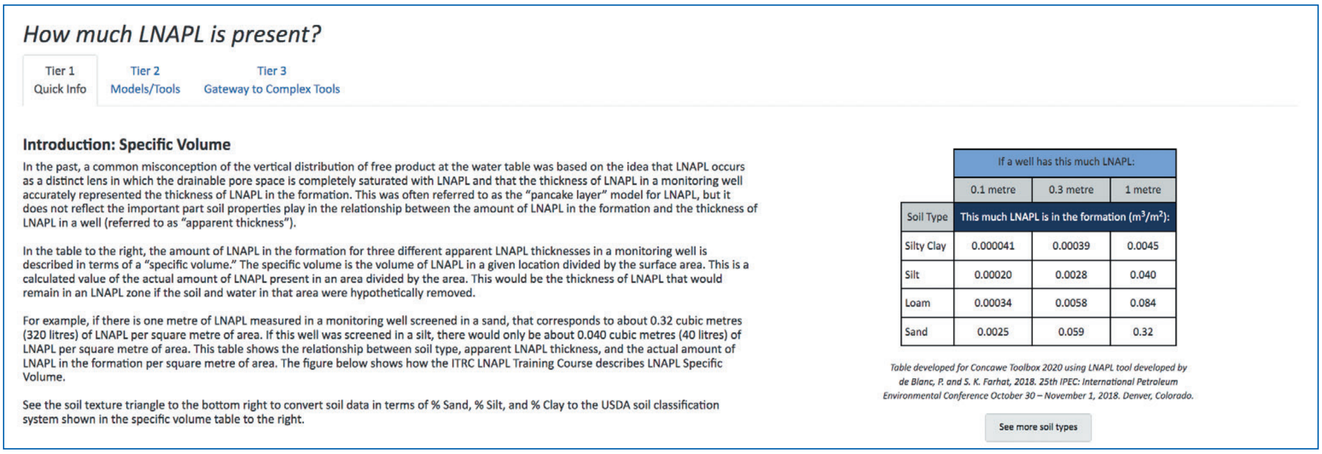
The existing LNAPL CSM (LCSM) has these problematic features:

- There is a large volume of LNAPL in the subsurface, indicated by a calculation whereby the site-wide average thickness of the LNAPL in the monitoring wells was multiplied by the area of the LNAPL body.
- It was assumed that much of this LNAPL was recoverable by the existing LNAPL skimming system, even though LNAPL recovery is much lower than the initial LNAPL recovery rate.
- It was assumed that LNAPL recovery had to continue until no more LNAPL is observed in each of the site monitoring wells (i.e. reaching an apparent LNAPL thickness of zero).
- Although long-term LNAPL monitoring data indicated that the LNAPL body was stable and no longer expanding, a US EPA LNAPL model (HSSM) had been used many years ago and indicated that the LNAPL body was likely to continue to expand for the next 30 years without LNAPL recovery. These old modelling results greatly complicated efforts to retire the existing LNAPL recovery system comprised of LNAPL skimmer wells.
- Based on the scientific knowledge from the mid-1990s, the only process that was removing LNAPL was the dissolution of higher-solubility constituents in the LNAPL; it would take hundreds of years to remove these soluble constituents, and the lower solubility compounds would likely persist forever.

How to update the LCSM using the LNAPL Toolbox

Step 1. The 'How much LNAPL is present?' Tier 1 tab (Figure 2) is used to develop a much more accurate estimate of the specific volume of LNAPL based on soil type and LNAPL apparent thickness. When the specific volume is multiplied by the LNAPL body area, an updated estimate of the LNAPL volume in the subsurface is developed. This new estimate is many times lower than the original estimate because the previous LCSM volume estimation method was based on inaccurate understanding and assumptions.

Figure 2: Excerpt from the 'How much LNAPL is present?' Tier 1 tab



How much LNAPL is present?

Tier 1 Quick Info | Tier 2 Models/Tools | Tier 3 Gateway to Complex Tools

Introduction: Specific Volume

In the past, a common misconception of the vertical distribution of free product at the water table was based on the idea that LNAPL occurs as a distinct lens in which the drainable pore space is completely saturated with LNAPL and that the thickness of LNAPL in a monitoring well accurately represented the thickness of LNAPL in the formation. This was often referred to as the "pancake layer" model for LNAPL, but it does not reflect the important part soil properties play in the relationship between the amount of LNAPL in the formation and the thickness of LNAPL in a well (referred to as "apparent thickness").

In the table to the right, the amount of LNAPL in the formation for three different apparent LNAPL thicknesses in a monitoring well is described in terms of a "specific volume." The specific volume is the volume of LNAPL in a given location divided by the surface area. This is a calculated value of the actual amount of LNAPL present in an area divided by the area. This would be the thickness of LNAPL that would remain in an LNAPL zone if the soil and water in that area were hypothetically removed.

For example, if there is one metre of LNAPL measured in a monitoring well screened in a sand, that corresponds to about 0.32 cubic metres (320 litres) of LNAPL per square metre of area. If this well was screened in a silt, there would only be about 0.040 cubic metres (40 litres) of LNAPL per square metre of area. This table shows the relationship between soil type, apparent LNAPL thickness, and the actual amount of LNAPL in the formation per square metre of area. The figure below shows how the ITRC LNAPL Training Course describes LNAPL Specific Volume.

See the soil texture triangle to the bottom right to convert soil data in terms of % Sand, % Silt, and % Clay to the USDA soil classification system shown in the specific volume table to the right.

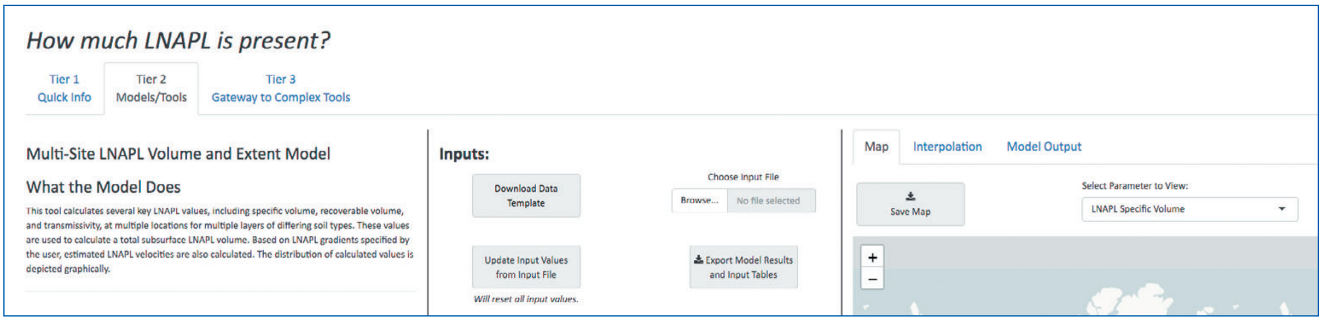
	If a well has this much LNAPL:		
	0.1 metre	0.3 metre	1 metre
Soil Type	This much LNAPL is in the formation (m^3/m^2):		
Silty Clay	0.000041	0.00039	0.0045
Silt	0.00020	0.0028	0.040
Loam	0.00034	0.0058	0.084
Sand	0.0025	0.059	0.32

Table developed for Concawe Toolbox 2020 using LNAPL tool developed by de Blanc, P. and S. K. Farhat, 2018. 25th IPEC: International Petroleum Environmental Conference October 30 – November 1, 2018. Denver, Colorado.

See more soil types

Step 2. Step 1 indicated that more detailed information would be beneficial, hence two models are evaluated: the mid-level complexity Tier 2 model in the Concawe Toolbox (Figure 3); and a more complex model called the LNAPL Distribution and Recovery Model (LDRM, API) that is explained in the Tier 3 text and videos. Based on this information, the Tier 2 model is selected, site data is compiled and entered into the input data spreadsheet, and the model is run. The 'How much LNAPL is present?' Tier 2 model provides a more refined estimate of the total LNAPL present in the subsurface, as well as additional information, namely the amount of LNAPL that is potentially mobile and the amount of LNAPL that is permanently trapped as residual LNAPL.

Figure 3: Excerpt from 'How much LNAPL is present?' Tier 2 tab

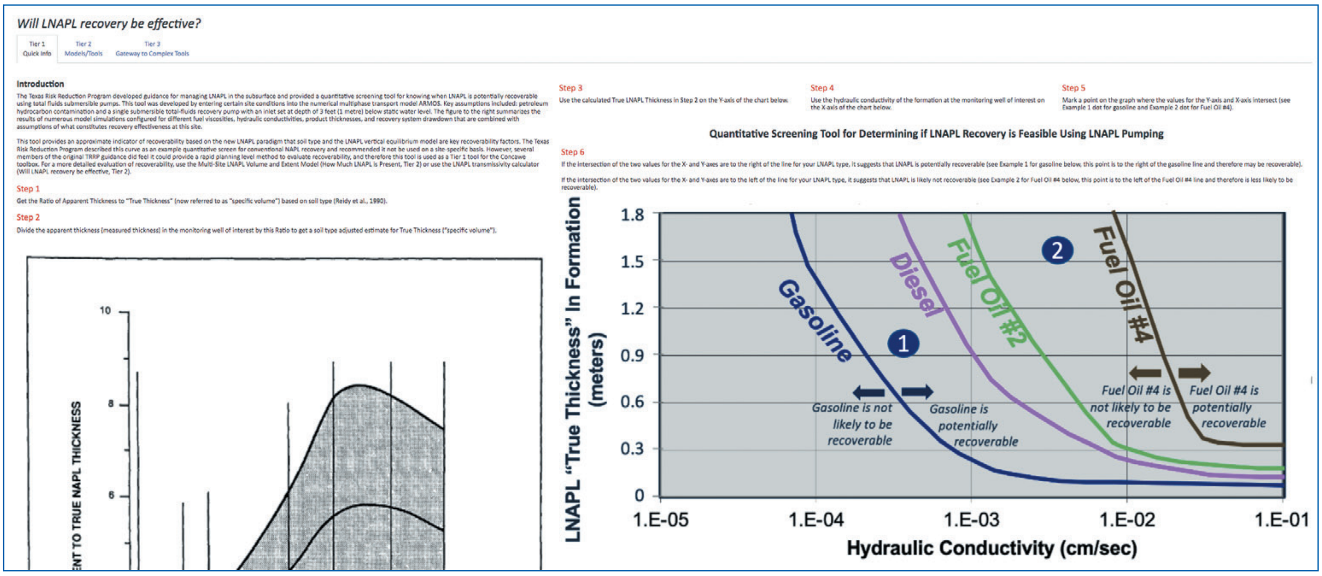


Step 3. The 'How much LNAPL is present?' Tier 2 model (Figure 3) is used to develop a map of the LNAPL transmissivity based on site-specific LNAPL properties, site-specific soil characteristics, and site-specific layering/stratigraphy. With this map, guidance from the US Interstate Technology and Regulatory Council (ITRC) is consulted, which suggests that:

- If the LNAPL transmissivity is less than 0.0093 m^2/day, hydraulic recovery of LNAPL is unlikely to be efficient, sustainable or cost-effective.
- If the LNAPL transmissivity is greater than 0.074 m^2/day, hydraulic recovery of LNAPL is likely to be effective.

Surprisingly, only one of the LNAPL skimming wells exceeds the 0.0093 m^2/day threshold, indicating that the rest of the skimming wells are not providing any significant environmental benefit. The simple 'Will LNAPL recovery be effective?' Tier 1 tab (Figure 4 on page 61) also shows similar results, increasing confidence that LNAPL recovery should be terminated at all but one of the existing LNAPL skimmer wells.

Figure 4: Excerpt from the 'Will LNAPL recovery be effective?' Tier 1 tab



Step 4. The 'How far will LNAPL migrate?' Tier 1 tab (Figure 5) indicates that NSZD is a key factor in stopping the continued migration of LNAPL bodies, and the 'How far will LNAPL migrate?' Tier 2 tab (Figure 6 on page 62) indicates that LNAPL models that do not consider NSZD are likely to overestimate LNAPL migration because of this. The site consultants and site owners determine that more NSZD information would be key to updating the LCSM but do not have a strong background in NSZD. Therefore, they consult the three Tiers in the 'How can one estimate NSZD?' tab in the Toolbox.

Figure 5: Excerpt from the 'How far will the LNAPL migrate?' Tier 1 tab

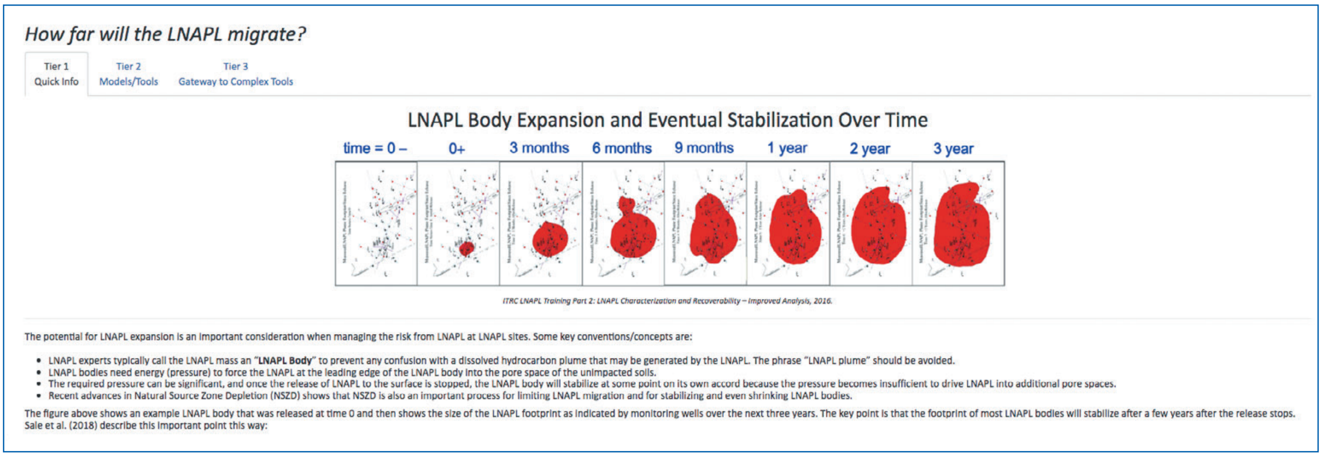
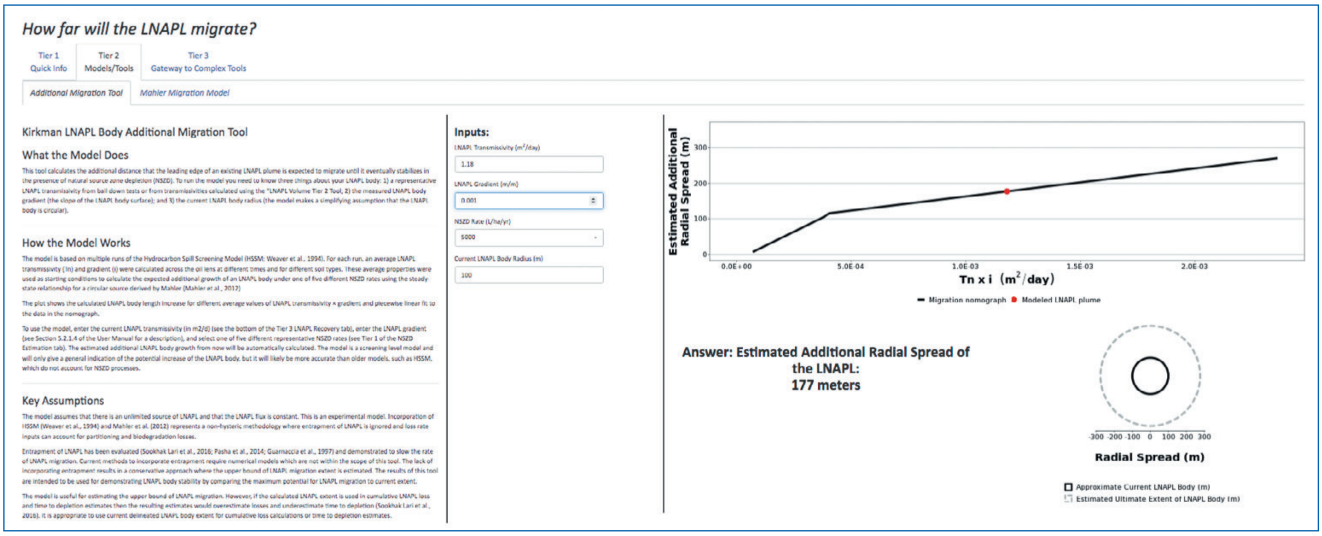


Figure 6: Excerpt from the 'How far will the LNAPL migrate?' Tier 2 tab



Step 5. Based on the discussion of NSZD in the 'How far will LNAPL migrate?' Tier 1 tab (Figure 5), the 'How can one estimate NSZD? Tier 1 tab (Figure 7) is consulted and quickly shows that almost all LNAPL bodies are naturally attenuating at 10 or 100 times the rate assumed in the existing LCSM. The new LCSM indicated that, typically, when NSZD is measured at a site, the rates are in the thousands to tens of thousands of litres of LNAPL being biodegraded by NSZD per hectare per year. The 'How can one estimate NSZD?' Tier 3 tab (Figure 8 on page 63) provides links and videos on methods to measure NSZD at an LNAPL site, and the site consultants can then begin to evaluate whether the literature NSZD values shown in the Concawe LNAPL Toolbox are sufficient to update to the new LCSM, or whether site-specific measurements are needed.

Figure 7: Excerpt from the 'How can one estimate NSZD?' Tier 1 tab

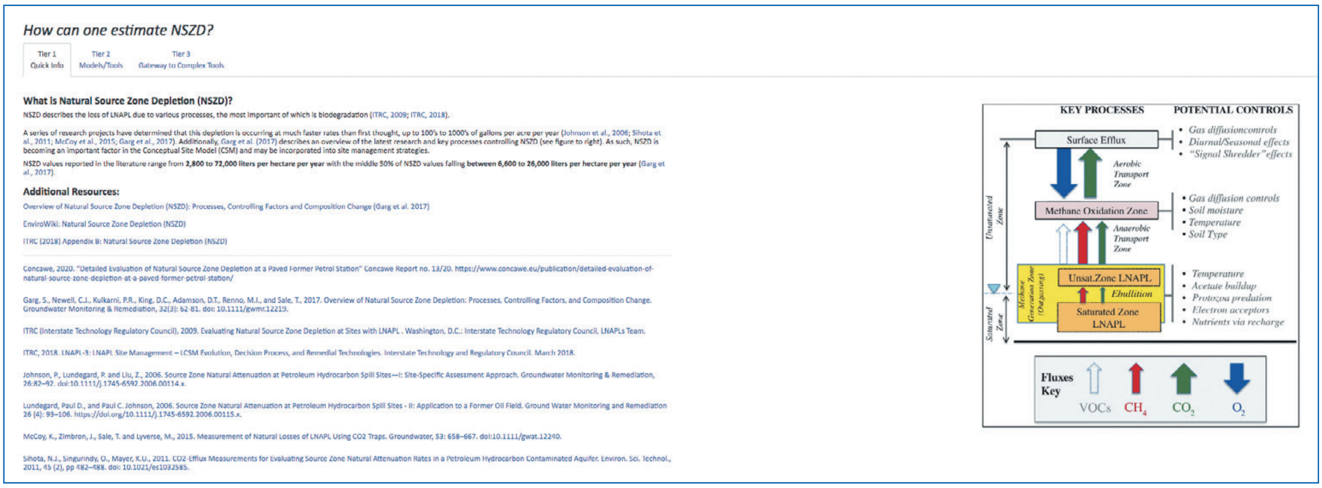


Figure 8: Excerpt from the 'How can one estimate NSZD?' Tier 3 tab

How can one estimate NSZD?

Tier 1 Quick Info | Tier 2 Models/Tools | Tier 3 Gateway to Complex Tools

Information on this page can be downloaded using the button at the bottom of the page.

Natural Source Zone Depletion (NSZD) has emerged as an important new remediation alternative for LNAPL sites. Key references and a description of what they explain about NSZD are provided below:

- The ITRC's (2018) LNAPL Site Management—LCSM Evolution, Decision Process, and Remedial Technologies guidance is heavily influenced by the developments in measuring and applying NSZD for LNAPL site management, with over 100 specific mentions of NSZD in the document and a detailed NSZD appendix. More importantly, it provides detailed information on three frequently used NSZD assessment methods:
  - The gradient method, based on soil gas composition,
  - Carbon dioxide flux-based methods, including Carbon Traps and dynamic closed flux chambers (i.e. DCC-LI-COR), and
  - The biogenic heat monitoring method (Thermal Monitoring).
- Key vendors for these methods are:
  - EnviroFlux (Carbon Traps)
  - LI-COR (DCC- LI-COR)
  - Thermal NSZD (Thermal Monitoring)
- Garg et al.'s (2017) Overview of Natural Source Zone Depletion: Processes, Controlling Factors, and Composition Change provides a detailed review of how NSZD developed, key NSZD processes, potentially NSZD-controlling factors, and how NSZD affects the composition of LNAPL (see graphic to right). It is based on roughly 100 technical references.
- Kulkarni et al.'s (2020) Application of Four Measurement Techniques to Understand Natural Source Zone Depletion Processes at an LNAPL Site describes an extensive research project where four different NSZD measurement techniques were used at a site and then compared.
- Lari et al.'s (2019) Natural Source Zone Depletion of LNAPL: A Critical Review Supporting Modelling Approaches discusses key NSZD processes required to model NSZD and the capabilities of 36 models to accommodate 21 important phenomena.
- ESTCP's Environmental Wiki has an entry describing NSZD where the significance of NSZD is discussed along with NSZD stoichiometry, the gaseous expression of NSZD through gas evolution, and measuring temperature to determine NSZD (Palaia, T., J. Fitzgibbons, and P. Kulkarni, 2019).
- CRC CARE's (2018) Technical Report 44: Technical Measurement Guidance for LNAPL Natural Source Zone Depletion provides practical guidance on the measurement of NSZD rates using various available methods. The document applies to hydrocarbon sites that have a need for theoretical, qualitative, or quantitative understanding of NSZD processes. Its Appendix B contains a checklist for practitioners.

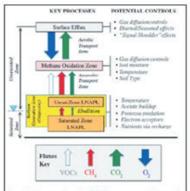


Figure 2. Conceptual model of NSZD processes, gas fluxes, and controls in an LNAPL source zone. Adapted from multiple references shown in Table 1 and Figures 1 and 3. For simplicity, the LNAPL smear zone and the capillary fringe are not explicitly shown in the processes depicted in the conceptual model.

Videos about NSZD

Two videos were developed for the NSZD article in the ESTCP Environmental Wiki. They can be viewed here:

- Carbon Traps NSZD
- Thermal Monitoring NSZD

What NSZD Rates are Seen at Hydrocarbon Sites?

The following table from Garg et al. (2017) summarizes measured NSZD rates at various hydrocarbon sites in the U.S. The middle 50% of the NSZD rates range from 700 – 2,800 gallons per acre per year.

Examples of Site-Wide Average NSZD Rate Measurements at Field Sites

NSZD Study	Number of Sites	Site Wide NSZD Rate (Gallons/Acre/Year) All Sites	Middle 50%	Reference
Refinery terminal sites	6	2100-7700	2400-3700	McCoy 2012
1979 crude oil spill	1	1600	-	Sihota et al. 2011
Seasonal range		310-1100	-	Sihota et al. 2016
Refinery/terminal sites	2	1100-1700	1250-1550	Workgroup, L.A LANPL 2015
Fuel/diesel/gasoline	5	300-3100	1050-2700	Piontek et al. 2014
Diverse petroleum sites	11	300-5600	600-800	Palaia 2016
All studies	25	300-7700	700-2800	
Saturated zone electron acceptor biodegradation capacity	9	0.4-53	1.7-19	This paper (see Appendix S1)

Notes: Middle 50% column shows the 25th and 75th percentile values. To demonstrate the significance of methanogenesis, NSZD rates calculated from the biodegradation capacity of electron acceptors in the saturated zone, ignoring methanogenesis, are shown in the last row.

SUMMARY OF NSZD RATES FROM 31 SITES

Fuel Type	Fuel Carbon Range	Number of Distinct Sites	Total No. of Measurements	Range of NSZD Rates Measured (L/ha/yr)	Median NSZD Rate (L/ha/yr)
Natural Gas Liquid*	C3-C6	5	1661	1,590 - 54,800	4,700
Mixed	--	6	855	1,760 - 57,060	4,400
Crude Oil	C8-C44	2	77	2,250 - 24,000	7,700
Gasoline	C5-C12	4	144	2,800 - 41,500	9,800
Diesel and Jet Fuel	C9-C24	12	134	650 - 99,400	12,250
Fuel-Grade Ethanol	C2H6O	2	183	123,200 - 152,500	138,000
Total		**31**	**3054**	**Median:**	**8,750**

*May also contain smaller amounts of C7-C12 hydrocarbons

Step 6. Using mid-range NSZD rates from the Tier 1 NSZD estimation tab, the 'How far will LNAPL migrate?' Tier 2 tab (Figure 6) is consulted and the Kirkman Additional LNAPL Migration Model built into the Toolbox (Figure 6) is then applied using existing site data. This shows that the existing LNAPL body is not likely to expand to any significant degree even if the LNAPL skimmer wells were shut down. This provides additional support to the assumption that most of the LNAPL skimmer wells had done their job and are ready to be retired.

Step 7. The potential longevity of the LNAPL is then evaluated to update the existing LCSM. After reviewing the 'How long will LNAPL persist?' Tier 1 tab (Figure 9), the simple Tier 2 LNAPL lifetime model is applied by entering the volume of LNAPL from Step 2, the area of the LNAPL body, and mid-range NSZD rates from the Tier 1 NSZD estimation tab (Figure 7). Two different LNAPL volume versus time graphs are obtained. One method assumes a constant NSZD rate into the future and suggests that the LNAPL would all be removed by the year 2030. The second method assumes that NSZD rates decline over time and suggests that 90% of the LNAPL present now would be gone by the year 2050. Overall, this wide range of LNAPL longevity estimates inform the new LCSM that estimates of LNAPL longevity decades into the future have significant uncertainty, but agree that LNAPL is being removed over time.

Figure 9: Excerpt from the 'How long will the LNAPL persist?' Tier 1 tab

How long will the LNAPL persist?

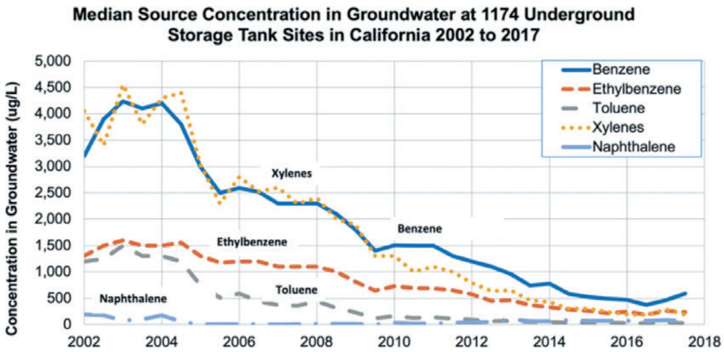
Tier 1 Quick Info | Tier 2 Models/Tools | Tier 3 Gateway to Complex Tools

Introduction

The figure to the right shows the median concentration in 1,174 Underground Storage Tank Sites in California over time. Because of stricter environmental regulations, the number and magnitude of releases has greatly diminished over time. In addition, almost all of these sites have had some form of source remediation, and all have benefitted from natural attenuation processes. Therefore, between 2004 and 2017, the median benzene concentration in groundwater at the highest concentration well in each of the 1,174 sites has been reduced by about 90%, from about 4,000 μg/L to about 500 μg/L (McHugh et al., 2013, 2019).

The table below shows the median change in benzene concentrations and in LNAPL apparent thickness from several hundred Underground Storage Tank Sites in California. Sites where companies were actively recovering LNAPL showed a benzene half-life (the time required for source zone monitoring well concentrations to decrease by 50%) of about 8 years, while sites with LNAPL in monitoring wells but no active remediation exhibited a benzene half-life of about 4 years. During the monitoring period, the thickness of the LNAPL in monitoring wells decreased by about 90% both for sites where active LNAPL recovery was on-going and sites where there was no active LNAPL recovery (Kulkarni et al., 2015).

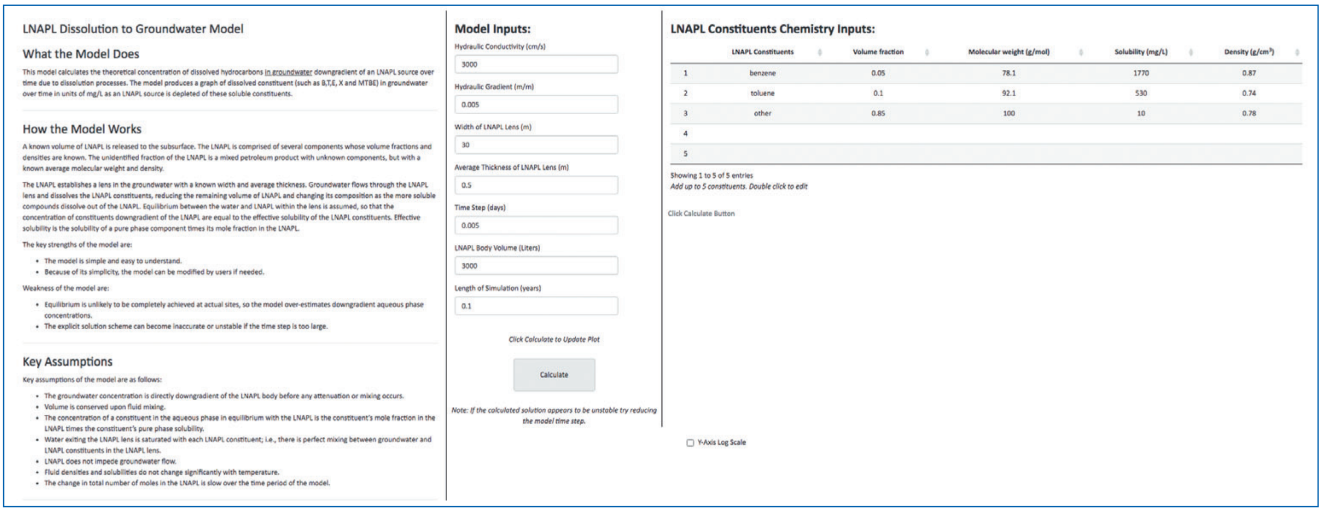
Another resource is a simple nomograph method for screening estimates of LNAPL source mass depletion times, provided by Golder (2016). The nomographs can be used for estimating hydrocarbon mass depletion times resulting from biodegradation (mass loss rate) in the vadose zone and dissolution (mass loss rate) from the saturated zone.



	Number of Sites	Minimum Monitoring Time Period (years)	Median Apparent LNAPL Thickness in Monitoring Wells During Monitoring Period (meters)	Median Reduction in Apparent LNAPL Thickness in Monitoring Wells Over Monitoring Period (% reduction)	Time for Benzene Groundwater Conc. To Be Reduced by 50% (Half Life) (years)
Sites Where LNAPL is Present and Being Recovered	327	5	1.5	0.87	7.7
Sites Where LNAPL is Present but Not Being Recovered	444	5	0.5	0.91	3.6

Step 8. Because of the uncertainty in the LNAPL longevity estimates, the site consultants and site owners become interested in estimates of how the hypothetical ingestion risk associated with LNAPL dissolution products might change over time (there is no ongoing risk at this site as no exposure pathways were complete). The 'How will LNAPL risk change over time?' Tier 2 model (Figure 10 on page 65) is run initially to obtain a forecast of the benzene concentration over time. Later, a more sophisticated LNAPL model is run, described in the 'How will LNAPL risk change over time?' Tier 3 tab, called Remediation Evaluation Model for Fuel hydrocarbons (REMFuel; US EPA); this model is run based on the comments included in the Concawe Tier 3 description of REMFuel and the information given in the video link provided in the Tier 3 tab (Figure 11 on page 65). This modelling effort shows that the risk associated with the hypothetical ingestion pathway over time reduces faster than the likely LNAPL removal rate.

Figure 10: Excerpt from the 'How will LNAPL risk change over time?' Tier 2 tab



LNAPL Dissolution to Groundwater Model

What the Model Does

This model calculates the theoretical concentration of dissolved hydrocarbons in groundwater downgradient of an LNAPL source over time due to dissolution processes. The model produces a graph of dissolved constituent (such as B,T,E, X and MTBE) in groundwater over time in units of mg/L as an LNAPL source is depleted of these soluble constituents.

How the Model Works

A known volume of LNAPL is released to the subsurface. The LNAPL is comprised of several components whose volume fractions and densities are known. The unidentified fraction of the LNAPL is a mixed petroleum product with unknown components, but with a known average molecular weight and density.

The LNAPL establishes a lens in the groundwater with a known width and average thickness. Groundwater flows through the LNAPL lens and dissolves the LNAPL constituents, reducing the remaining volume of LNAPL and changing its composition as the more soluble compounds dissolve out of the LNAPL. Equilibrium between the water and LNAPL within the lens is assumed, so that the concentration of constituents downgradient of the LNAPL are equal to the effective solubility of the LNAPL constituents. Effective solubility is the solubility of a pure phase component times its mole fraction in the LNAPL.

The key strengths of the model are:

- The model is simple and easy to understand.
- Because of its simplicity, the model can be modified by users if needed.

Weakness of the model are:

- Equilibrium is unlikely to be completely achieved at actual sites, so the model over-estimates downgradient aqueous phase concentrations.
- The explicit solution scheme can become inaccurate or unstable if the time step is too large.

Key Assumptions

Key assumptions of the model are as follows:

- The groundwater concentration is directly downgradient of the LNAPL body before any attenuation or mixing occurs.
- Volume is conserved upon fluid mixing.
- The concentration of a constituent in the aqueous phase in equilibrium with the LNAPL is the constituent's mole fraction in the LNAPL times the constituent's pure phase solubility.
- Water exiting the LNAPL lens is saturated with each LNAPL constituent; i.e., there is perfect mixing between groundwater and LNAPL constituents in the LNAPL lens.
- LNAPL does not impede groundwater flow.
- Fluid densities and solubilities do not change significantly with temperature.
- The change in total number of moles in the LNAPL is slow over the time period of the model.

Model Inputs:

Hydraulic Conductivity (cm/s)
3000
Hydraulic Gradient (m/m)
0.005
Width of LNAPL Lens (m)
30
Average Thickness of LNAPL Lens (m)
0.5
Time Step (days)
0.005
LNAPL Body Volume (Liters)
3000
Length of Simulation (years)
0.1

Click Calculate to Update Plot

Calculate

Note: If the calculated solution appears to be unstable try reducing the model time step.

LNAPL Constituents Chemistry Inputs:

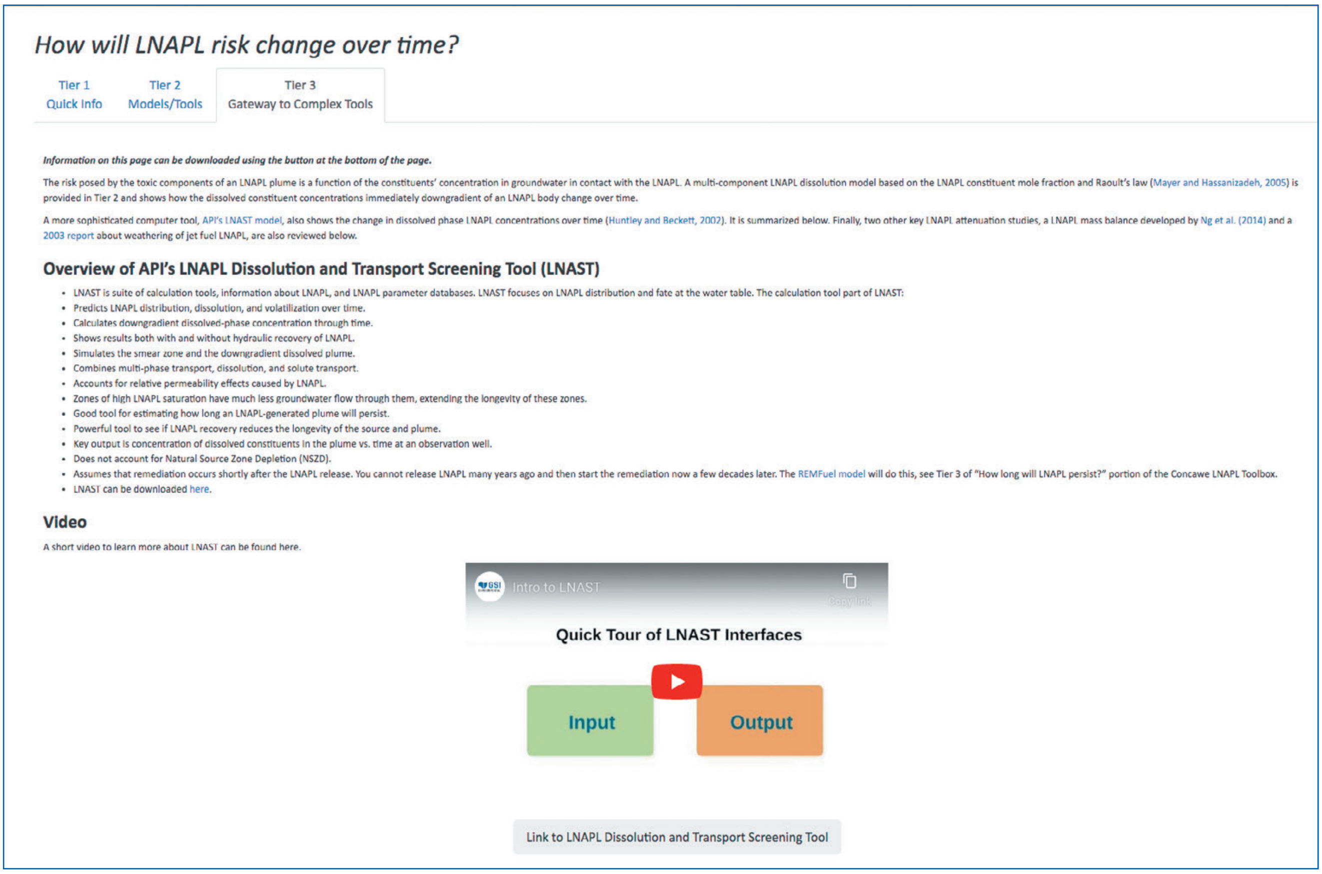
	LNAPL Constituents	Volume fraction	Molecular weight (g/mol)	Solubility (mg/L)	Density (g/cm³)
1	benzene	0.05	78.1	1770	0.87
2	toluene	0.1	92.1	530	0.74
3	other	0.85	100	10	0.78
4					
5					

Showing 1 to 5 of 5 entries
Add up to 5 constituents. Double click to edit

Click Calculate Button

Y-Axis Log Scale

Figure 11: Excerpt from the 'How will LNAPL risk change over time?' Tier 3 tab



How will LNAPL risk change over time?

Tier 1 Quick Info | Tier 2 Models/Tools | Tier 3 Gateway to Complex Tools

Information on this page can be downloaded using the button at the bottom of the page.

The risk posed by the toxic components of an LNAPL plume is a function of the constituents' concentration in groundwater in contact with the LNAPL. A multi-component LNAPL dissolution model based on the LNAPL constituent mole fraction and Raoult's law (Mayer and Hassanizadeh, 2005) is provided in Tier 2 and shows how the dissolved constituent concentrations immediately downgradient of an LNAPL body change over time.

A more sophisticated computer tool, API's LNAST model, also shows the change in dissolved phase LNAPL concentrations over time (Huntley and Beckett, 2002). It is summarized below. Finally, two other key LNAPL attenuation studies, a LNAPL mass balance developed by Ng et al. (2014) and a 2003 report about weathering of jet fuel LNAPL, are also reviewed below.

Overview of API's LNAPL Dissolution and Transport Screening Tool (LNAST)

- 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.
- 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 Natural Source Zone Depletion (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. The REMFuel model will do this, see Tier 3 of "How long will LNAPL persist?" portion of the Concawe LNAPL Toolbox.
- LNAST can be downloaded here.

Video

A short video to learn more about LNAST can be found here.

Link to LNAPL Dissolution and Transport Screening Tool

Step 9. The Toolbox helps site owners and consultants update the existing, incorrect LCSM, and greatly strengthens the case for:

- retiring most of the old, inefficient LNAPL skimming wells at the site because of low LNAPL recoverability and the expectation of little or no LNAPL expansion in the future;
- a better understanding that further significant LNAPL migration was unlikely and that benzene concentrations were expected to go down over time;
- using NSZD as the LNAPL management technology in the future; and
- continued long-term groundwater monitoring to ensure that the long-term removal of the LNAPL body by NSZD remains on-track.

Conclusions and outreach

The Concawe LNAPL Toolbox is a wide-ranging but easy-to-use web-based toolbox capable of delivering key LNAPL knowledge to the LNAPL remediation community, to help LNAPL scientists and engineers better understand how to manage LNAPL at their sites.

The Toolbox is designed to be freely accessed on the web via an internet browser (https://lnapltoolbox.concawe.eu/lnapl_toolbox) or by downloading the Toolbox code for use on a personal computer (https://github.com/concawe/LNAPL-Toolbox-). The Toolbox User Manual is also published on the Concawe website (Concawe Report 5/22, https://www.concawe.eu/wp-content/uploads/Rpt_22-5.pdf).

The Toolbox was launched in April 2022. As part of a promotional campaign, two targeted webinars were organised in May 2022. After the webinars, a pre-recording of the LNAPL Toolbox presentation was made freely available (see https://www.youtube.com/watch?v=LBkT887vjzY). Further to the webinars, the Toolbox was presented at RemTech Europe in September 2022, at the RemTEC & Emerging Contaminants Summit in October 2022, and as a dedicated webinar given under the umbrella of NICOLA in December 2022.

References

A full list of references is provided in Strasert, B., C. Newell, P. de Blanc, P. Kulkarni, K. Whitehead, B. Sackmann, and H. Podzorski (2021), *User Manual for Concawe LNAPL Toolbox*. Concawe Report 5/22, Concawe, Brussels, Belgium, Version 1 (https://www.concawe.eu/wp-content/uploads/Rpt_22-5.pdf) and within the LNAPL toolbox itself (https://lnapltoolbox.concawe.eu/lnapl_toolbox/).