SOCIETY OF BROWNFIELD RISK ASSESSMENT

Non-Aqueous Phase Liquids – Guidance Notes for their Assessment in Contaminated Land Scenarios in the UK

5. BAILDOWN TEST GUIDANCE FOR LIGHT NON-AQUEOUS PHASE LIQUIDS

Version 1.0

May 2022

PUBLICATION

This series of reports and tools is published by the Society of Brownfield Risk Assessment (SoBRA). It presents work undertaken by a SoBRA sub-group composed of volunteers listed in the acknowledgments below. This publication is part of a series of work packages designed to address various issues in data collection and evaluating risks associated with non-aqueous phase liquid (NAPL).

Baildown tests are commonly carried out in wells that contain light non-aqueous phase liquid (LNAPL) to investigate its mobility, which is an important consideration for risk assessment. This baildown test guidance document provides practical guidance to support UK industry in conducting baildown tests and interpreting baildown test results; in particular, using the American Petroleum Institute’s LNAPL Transmissivity Workbook.

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SoBRA also wishes to thank the Executive Committee for their steer, encouragement and review.

[1] With AECOM until September 2020.

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1 INTRODUCTION

The Society of Brownfield Risk Assessment (SoBRA) is a UK-based learned society that aims to:

- improve technical knowledge in risk-based decision-making related to land contamination applications; and
- enhance the professional status and profile of risk assessment practitioners.

The society has a number of working groups (termed "sub-groups") comprising volunteer SoBRA members working on particular aspects to help achieve these aims. This report presents one of several outputs of the non-aqueous phase liquid (NAPL) sub-group.

The technical aims of the sub-group are to:

- support technical excellence in the assessment, estimation and evaluation of risks associated with NAPL; and,
- encourage best practice by delivering practical advice to support decisions regarding the appropriate management of NAPL risks.

It should be noted from the outset it is not the intention of the sub-group or any of its deliverables to replicate existing NAPL guidance. Instead, the overarching aim is to address gaps in current guidance, and to provide practical advice to SoBRA members when undertaking risk assessments at sites where NAPL could be or is present.

1.1 Evolution and Overall Strategy of Sub-Group

The evaluation of contaminated land risk relies on understanding sub-surface processes. NAPL can be difficult to measure, meaning conceptual site models (CSM) may be data deficient. Following several requests from our members, SoBRA created the NAPL sub-group in 2019 with a call out to the SoBRA membership for volunteers to participate.

Once the group of volunteers was assembled, initial sub-group meetings identified and prioritised areas where existing NAPL UK risk assessment guidance was lacking or would benefit from practical advice. As a result of this screening process, a series of seven working groups was formed, each tasked with producing a document or tool to address the identified need.

The overall approach developed by the sub-group to address NAPL risk assessment is summarised in Figure 1. The seven working groups cover all stages of risk assessment, ranging from establishing whether NAPL is likely to be present at a site or not, through to designing an appropriate remediation strategy. The position of this particular document within this strategy is highlighted.

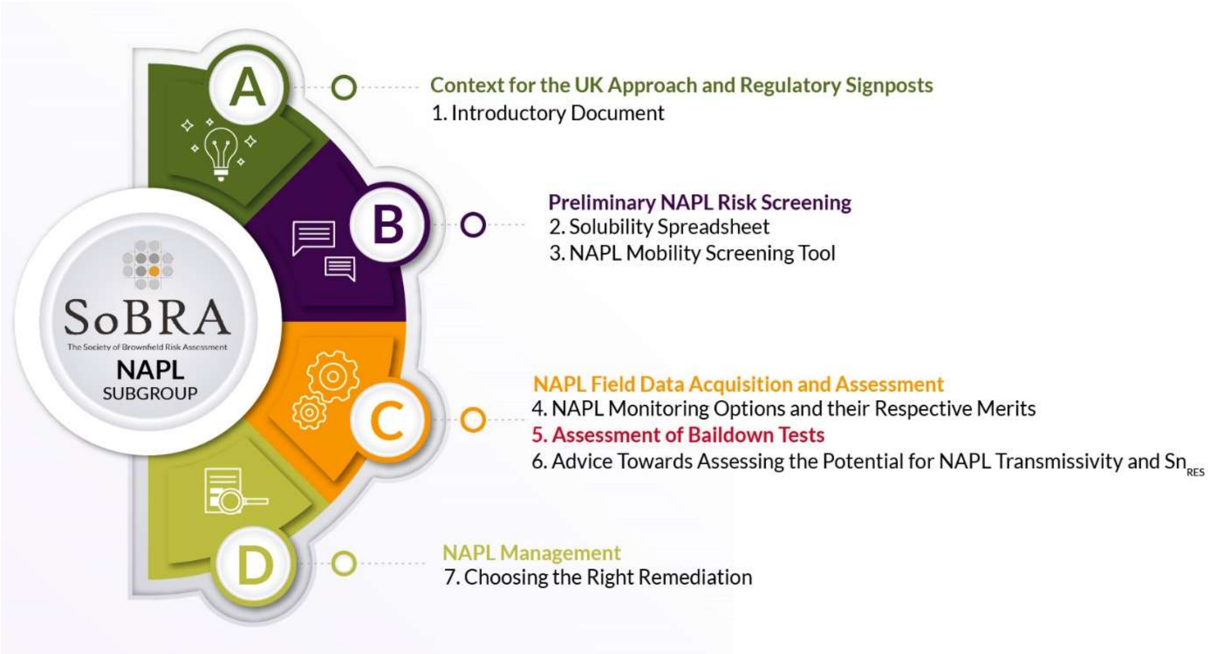


Figure 1 – Publication Strategy for NAPL Sub-Group.

1.2 Aim of this Document

Baildown tests are commonly carried out to investigate NAPL mobility, especially for light LNAPL, which is less dense than water. The test procedure involves removing a measured volume of LNAPL from a well and filter pack, and gauging fluid levels in the well as they re-equilibrate (ASTM, 2021). Test results can be interpreted to aid understanding of LNAPL mobility.

This baildown test guidance document provides practical guidance to support UK industry in conducting baildown tests and interpreting test results; in particular, by using the American Petroleum Institute's LNAPL Transmissivity Workbook.[2] It includes advice to help practitioners avoid common pitfalls both in the field and in data interpretation.

The flowchart in Appendix A provides a simplified overview of considerations relating to the field performance and office interpretation of baildown tests. It refers to numbered sections of this document where further explanation is provided.

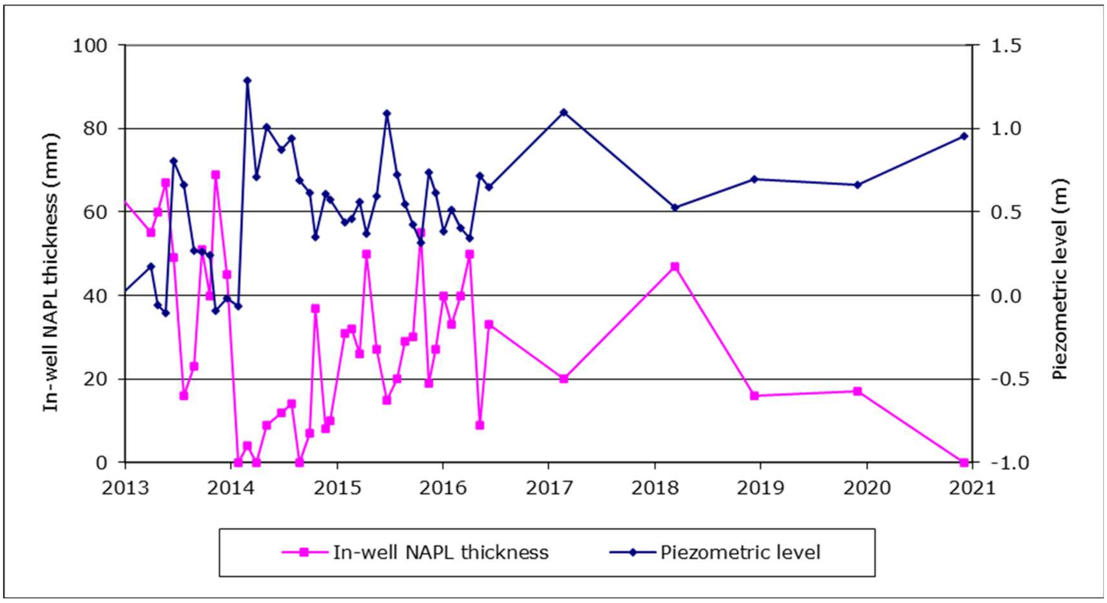
[2] https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/transmissivity-workbook

2 BACKGROUND

2.1 Why Perform a Baildown Test?

One of the important questions to ask when conducting risk assessments for sites with LNAPL is whether the LNAPL, which may represent an ongoing source of volatile and dissolved constituents of concern, will stay where it is or will migrate over time. This question cannot adequately be answered simply by reference to LNAPL thickness measurements. This is because the thickness of LNAPL in a well depends on numerous factors including the intrinsic permeability of the formation, the saturation profile of LNAPL within the formation, the density and viscosity of the LNAPL and the history of groundwater level fluctuations. Even though the volume of LNAPL in the formation may remain the same, the thickness of LNAPL in a well can increase, decrease or disappear with changing water levels.

This is illustrated by the example in Figure 2, which shows temporal variations in groundwater piezometric level and in-well NAPL thickness, for a specific well. The chart indicates unconfined LNAPL conditions: the in-well LNAPL thickness is increased when the groundwater level is low and decreased when the groundwater level is high.



Source: AECOM (anonymised data for a confidential site, used with permission)

Figure 2 – Example Hydrograph of Piezometric Level and In-well LNAPL Thickness.

Some common misconceptions arising from over-reliance on in-well LNAPL thickness measurements are summarised in Table 1.

Table 1 – Common Misconceptions Relating to In-well LNAPL Thickness.

Misconceptions	**Concepts**
If there is no LNAPL visible in a well, there is no LNAPL present	If LNAPL in soil adjacent to the well is below residual saturation, LNAPL will not appear in the well although the presence of a sheen is possible. Persistent measurable dissolved- and/or vapour-phase petroleum hydrocarbon concentrations can be indicative of the presence of LNAPL at or below residual saturation in the saturated and/or unsaturated zone. CLAIRE (2017) includes guidance on dissolved hydrocarbon concentrations in equilibrium with LNAPL. Also, LNAPL can sometimes take several weeks or months to appear in a new well installed in a low permeability formation.
Risk assessment should not be conducted if LNAPL is present in a well	Risks posed by mobile or residual LNAPL can be assessed using generally accepted risk characterisation and assessment practices. LNAPL that is migrating can pose additional risks.
In-well NAPL thicknesses are exaggerated (compared to the formation) by specific factors, or are equal to the LNAPL thicknesses in the formation	For unconfined LNAPL in uniform geology at a location not significantly affected by water table fluctuation, the in-well LNAPL thickness will be similar to the thickness of the mobile LNAPL interval in the adjacent formation. For LNAPL under confined or perched conditions, the LNAPL thickness in an adjacent well can be exaggerated. For the same in-well LNAPL thickness, the volume of LNAPL per unit footprint area (LNAPL specific volume) is generally higher in coarse-grained soils than in fine-grained soils. Due to the dependence of in-well LNAPL thickness on geology and variable groundwater hydraulics, in-well LNAPL thickness should not be used as a sole metric for LNAPL migration or recoverability.
If you see LNAPL in a monitoring well, then it is migrating. LNAPL bodies spread due to groundwater flow. LNAPL bodies continue to move long after the release is stopped.	The presence of LNAPL in a well is an indication that the LNAPL adjacent to the well exceeds residual saturation and is mobile. However, this does not necessarily mean the LNAPL body is migrating within the pore spaces of the adjacent soil. LNAPL migrates when it expands into previously unimpacted locations. Migration of LNAPL cannot occur unless LNAPL is present within the mobile range of LNAPL saturations and unless there is sufficient driving head for the LNAPL to enter adjacent pore spaces. LNAPL bodies associated with a terminated or finite source generally stop migrating within a relatively short timeframe as the driving head dissipates. LNAPL must be mobile to migrate but not all mobile LNAPL migrates. Multiple lines of evidence may be needed to distinguish between mobile and migrating LNAPL.

<u>Notes</u>

1. Adapted from ITRC (https://lnapl-3.itrcweb.org/3-key-lnapl-concepts/#3_1)

The information obtained from baildown tests provides a much better means of understanding LNAPL behaviour, mobility and recoverability than simple in-well LNAPL thickness measurements.

Baildown tests provide information on the following:

- Whether the LNAPL is present in unconfined, confined or perched conditions[3] (this information helps the assessor develop an informed conceptual model of LNAPL behaviour at the site);
- LNAPL transmissivity; and
- The potential mobility and recoverability of LNAPL in the formation.

It is important to remember that baildown tests provide information on LNAPL behaviour under the specific conditions that prevail at the time of the test. LNAPL transmissivity, mobility and recoverability all change over time due to changes in water level conditions, LNAPL saturation and LNAPL properties.

This SoBRA guidance only relates to baildown tests. Other types of test such as skimming tests are also available for wells that contain LNAPL (ASTM E2856-13R21).

2.2 Common Pitfalls

A number of mistakes and pitfalls are often made in conducting and interpreting the results of baildown tests. Some of the most common are listed in Table 2, together with reference to where in this document to find guidance to help avoid them.

Table 2 – Common Pitfalls Relating to Baildown Tests.

Stage	No.	Mistake	Outcome	How to avoid	Refer to
Prior to baildown testing	1	Well contains insufficient LNAPL	Unusable results; wasted effort	Check in-well LNAPL thickness	Section 3.1
	2	LNAPL trapped above top of well screen	Unusable results; wasted effort	Check fluid level versus screen interval	Sections 3.1 and 3.2
	3	Well does not have a good connection to the formation	Unreliable results	Develop/ redevelop well	Section 3.3
	4	Fluid levels in well not at equilibrium	Unreliable results	Conduct prior LNAPL removal (pre-test)	Section 3.3

[3] Unconfined LNAPL is able (if it has sufficient saturation and pore pressure) to move up or down in response to changes in fluid pressure. Confined LNAPL is unable to migrate vertically up above a certain elevation due to an overlying zone of lower permeability. Perched LNAPL is unable to migrate vertically down below a certain elevation due to an underlying zone of lower permeability.

Stage	No.	Mistake	Outcome	How to avoid	Refer to
During baildown testing	5	Too little LNAPL removed	Response dominated by filter pack; hard to interpret	Remove recommended volume of LNAPL	Sections 4.2 and 4.3
	6	Too much LNAPL removed	Results hard to interpret and may not be representative of formation		
	7	Lack of knowledge about background groundwater level fluctuations	Results hard to interpret; potential for incorrect conclusions	Monitor other wells; monitor test well before and after baildown event	Section 4.4
	8	Monitoring stopped too soon	Response insufficient or dominated by inflow from filter pack; hard to interpret	Monitor for longer	Section 4.5
	9	Gaps in monitoring record (e.g., overnight)	Difficult to interpret	Start earlier or use automatic logging equipment	Section 4.5
	10	Inaccurate recording of fluid levels[4]	More difficult to interpret	Use a consistent, defined method	-
	11	Inadequate record-keeping	Uncertainty over results	Use proforma data sheet or similar	Appendix B Example data sheet
Data analysis	12	Incorrect interpretation of data	Unreliable results; incorrect conclusions	Follow published guidance; use experienced personnel	Sections 5 and 6

[4] For example, it is better to measure the LNAPL/water interface 'upwards' rather than 'downwards', because downwards measurements can drag viscous LNAPL causing overestimation of LNAPL thickness.

3 IS THE WELL SUITABLE FOR BAILDOWN TESTING?

It is recommended the checks detailed below are conducted when selecting wells for baildown testing.[5] It is also worth watching the API's 14-minute video on baildown testing.[6]

3.1 Check Fluid Levels

Review the most recent fluid level information for the well (depth to LNAPL and depth to groundwater) to check:

- Is the LNAPL thickness sufficient to be worth testing? Baildown tests are not recommended if the in-well LNAPL thickness is less than 150 mm. Wells containing a smaller thickness of LNAPL (e.g., 60 mm to 150 mm) sometimes provide useful results but are not always worth the effort. However, they may be suitable for other types of testing such as manual skimming tests (ASTM, 2021).
- Is the calculated groundwater level[7] within the screened interval of the well? If it is above the top of the well screen there is no point conducting a baildown test, because LNAPL will likely be unable to enter the well.

If it is suspected that fluid levels might have changed significantly since the most recent gauging event, new gauging data should be obtained before deciding whether to conduct a baildown test in the well. For example, new gauging data is needed if the most recent previous data is from a different season of the year, if a remediation system or groundwater pumping operation is active nearby, or if the LNAPL is the result of a recent release.

3.2 Check Screened Interval

Check the well construction details against other available information to determine whether the well screen extends over the entire LNAPL interval in the formation. To do this, review the borehole log, any available vertical profile information such as from

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[5] SoBRA members may be interested to review presentation slides on NAPL baildown testing given in the SoBRA 2018 Summer Conference, available at https://sobra.org.uk/?pmpro_getfile=1&file=2022/01/4_Jonathan-Larkin&ext=pdf

[6] https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl

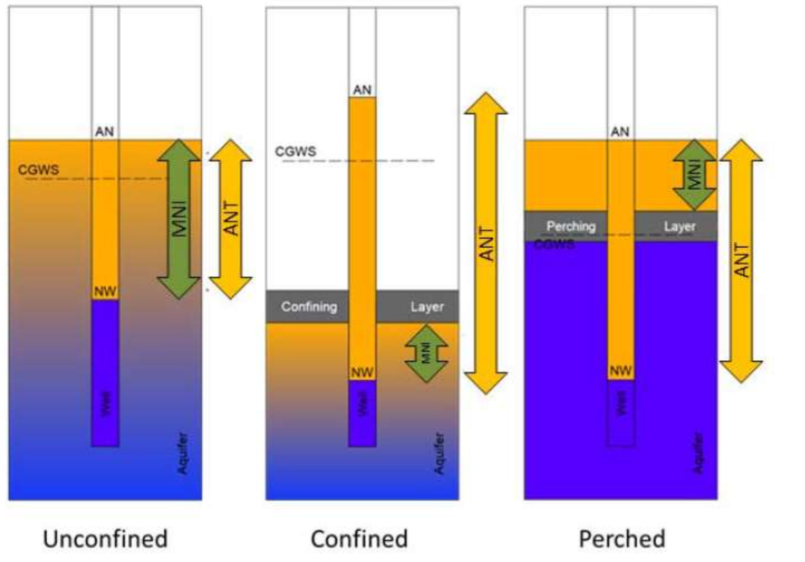
[7] The calculated groundwater level (potentiometric or piezometric level) is where the groundwater would be if LNAPL were not present. It can be calculated as [depth to LNAPL-water interface] minus [in-well LNAPL thickness multiplied by LNAPL density]. The LNAPL density can be estimated if needed based on literature values for the expected type of product.

membrane interface probe (MIP) or laser-induced fluorescence investigations (LIF), and any available soil sample results for evidence of petroleum hydrocarbon impacts. Compare the depth of the well screen with the depths that show evidence of LNAPL in the information.

Further review of fluid levels against the borehole log may help show whether the LNAPL conditions in the formation are unconfined, confined or perched (see Figure 3), or whether the well is in fractured rock (API, 2018):

- Unconfined: LNAPL in the well should be adjacent to the mobile LNAPL interval in the formation.
- Confined: LNAPL in the well may extend above the mobile LNAPL interval in the formation.
- Perched: LNAPL in the well may extend below the mobile LNAPL interval in the formation.
- Fractured rock: in fractured rocks, the presence and thickness of LNAPL in the well may bear very little relation to the volume per unit area in the formation; instead, it depends on factors such as the interconnectedness of fractures with the source zone, the magnitude of the source, and the saturation history of the fracture network.

If the well screen does not extend over the entire LNAPL interval in the formation, this does not necessarily make the well unsuitable for baildown testing but it can affect the interpretation of the data and may mean that LNAPL transmissivity is underestimated. It may therefore influence the decision of whether to test the well.



Mobile NAPL interval (MNI) and apparent NAPL thickness (ANT) at equilibrium based on the air/NAPL (AN) interface, NAPL/water (NW) interface, and calculated groundwater level or surface (CGWS).

Source: ANSR (2015b)

Figure 3 – Mobile NAPL Interval for Unconfined, Confined, and Perched LNAPL

3.3 Review the Well's History (Development and NAPL Removal)

If the LNAPL in a well is not at equilibrium when a baildown test starts, final fluid levels after recovery will not be the same as the initial levels, making the test results difficult to interpret. Disequilibrium can occur for various reasons, including:

- Fluids in the well not being in good communication with fluids in the formation. This can occur due to factors such as 'skin' effects from well installation (e.g., clay smearing), biological growth, and siltation.
- Fluid levels still recovering after well installation or previous testing.
- Fluid levels changing rapidly (e.g., due to tidal fluctuations, pumping or recent recharge events).
- LNAPL 'trapped' in well because mobility in the formation has reduced over time.

To increase the chance of well fluids being at equilibrium with those in the formation, check that the well was developed after its installation. It may be beneficial to re-develop wells that were installed a long time ago (e.g., 5 years) and that have not been much used.

If LNAPL has not been removed from the well relatively recently (e.g., within the last 3 months and certainly within 2 years), remove LNAPL from the well and allow the well to recover (e.g., for one week) before conducting the baildown test.

Note that fluid levels in wells that are screened in low permeability formations may never attain good equilibrium. This occurs when LNAPL mobility is low compared to the background rate of groundwater level fluctuation.

4 FIELD PERFORMANCE OF BAILDOWN TESTS

4.1 Health, Safety and Environment

All sitework associated with baildown tests must be conducted in a safe and responsible manner, consistent with good practice and relevant legislative requirements. Specific aspects that must be considered for baildown testing include:

- Potential for hydrocarbon vapours to be present in and around the well, with associated risks of fire and explosion. Because of this, some sites and some settings have a safety-based requirement for field equipment to be intrinsically safe or ATEX rated.
- Potential for risks to health and the environment due to hydrocarbon toxicity.
- Handling and disposal of LNAPL and any groundwater removed from the test well.

4.2 LNAPL Removal Method

LNAPL removal methods that can be used to initiate a baildown test include:

- Peristaltic pump. This is the preferred method where it can be done safely because it minimises the disturbance to the well and the undesired recovery of groundwater. However, many peristaltic pumps are not intrinsically safe or ATEX rated and their use is not always appropriate. When a peristaltic pump is used, the pump intake should be set at the calculated piezometric level (calculated groundwater level) and may need to be adjusted during the period of LNAPL removal.

  A peristaltic pump may not be the most appropriate removal method for wells that are wide diameter or where the LNAPL transmissivity is high. This is because the LNAPL removal time may be too long in comparison to the time required for re-equilibration of fluid levels. ASTM (2021) recommends that the removal time should be no more than 1% of the total test duration. However, two peristaltic pumps used side by side can help reduce the time required for LNAPL removal.
- Bailer. Bailers are good for 'instantaneous' removal of LNAPL but may cause fluid disturbance and may remove some water. It is generally best to remove only a single bailer, even though the volume of LNAPL removed in this way will be less than the preferred amount (see next section).

- Vacuum truck (not recommended). Although in principle vacuum trucks can be suitable when large volumes of LNAPL need to be removed (large diameter wells), it can be difficult to measure the volume of LNAPL removed and to know when to stop.

4.3 LNAPL Removal Volume

The recommended volume of LNAPL to remove from the well at the start of a baildown test is the volume that was initially present within both the casing itself and the adjacent filter pack.

When measuring the volume of LNAPL removed, the volume in the extraction tubing and pump should also be accounted for.

For unconfined LNAPL in a well that is screened across the full mobile LNAPL interval, the volume can be calculated from the equation in Box 1. API (2016) recommends using S_f = 0.175 unless there is a site-specific reason to select an alternative saturation value. The value of 0.175 is based on an assumed filter pack porosity of 35%, of which half (50%) is occupied by LNAPL.

For example, if the measured unconfined LNAPL thickness is 1 m in a monitoring well of 50 mm internal diameter and if the drilled diameter of the borehole is 150 mm, the recommended volume of LNAPL to remove from the well at the start of the baildown test is 4.7 litres, of which almost 2 litres is initially inside the casing and the remainder is held in the filter pack.

Box 1: Calculation of LNAPL Removal Volume

$$V = \pi b (r_c^2) + \pi b S_f (r_{bh}^2 - r_c^2)$$

Where:

V	= volume of LNAPL (m^3)
b	= thickness of LNAPL in well (m)
r_c	= internal radius of casing (m)
r_{bh}	= drilled radius of borehole (m)
S_f	= LNAPL saturation of filter pack

In the case of confined or perched LNAPL, or of LNAPL in fractured rock, the example equation in Box 1 would need to be adjusted so that it uses the appropriate vertical thickness of LNAPL in the filter pack, as this may differ from the thickness of LNAPL in the well.

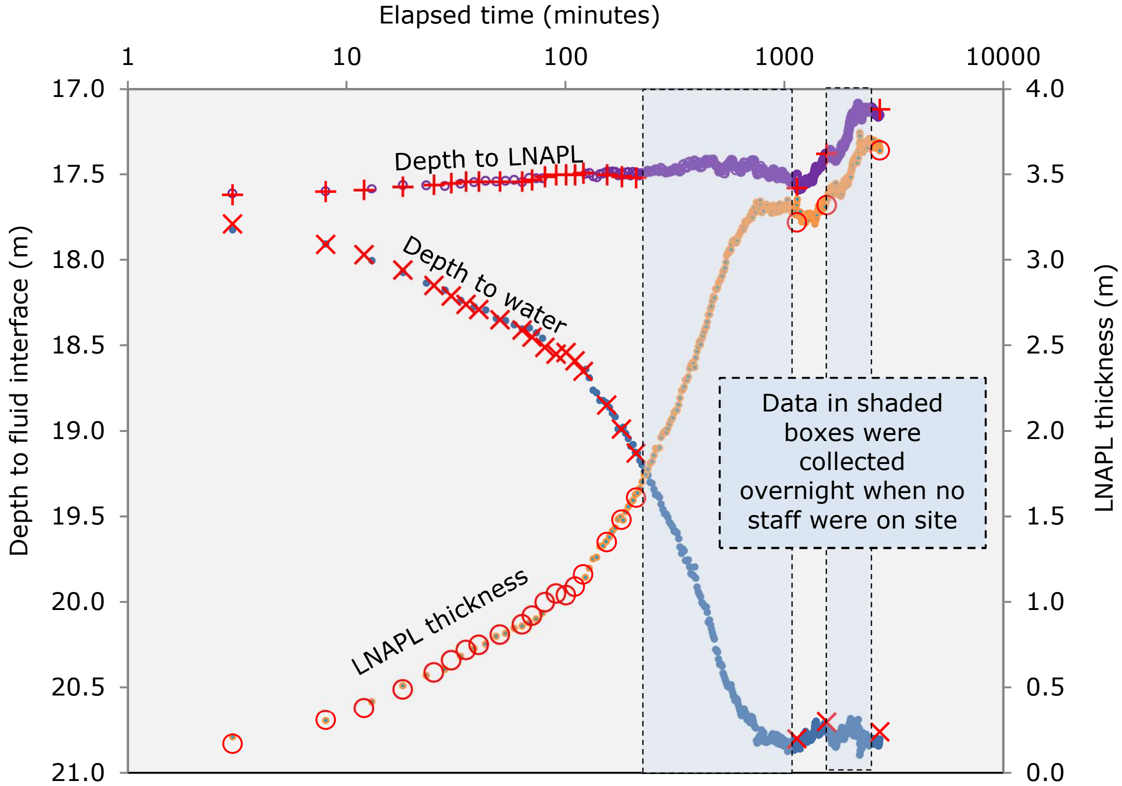
4.4 Background Groundwater Level Monitoring

If the ambient groundwater (piezometric) level changes during a baildown test, this can make the results difficult to interpret. To assess this, it is helpful if additional fluid level monitoring is conducted, such as:

- Periodic monitoring in the test well before and after the baildown test, so that the background fluctuation can be seen separately from the changes that are due to the baildown test.
- Periodic monitoring of fluid levels in at least one other nearby monitoring well screened in the same formation.

4.5 Fluid Level Monitoring

Test well fluid levels can be monitored either manually using an electronic air/oil/water interface probe, as assumed in the rest of this document, or automatically using specialist NAPL thickness monitoring equipment (see example output in Figure 4).



Source: AECOM (anonymised data for a confidential site, used with permission)

Figure 4 – Example of Manual and Automatic Baildown Test Monitoring Data

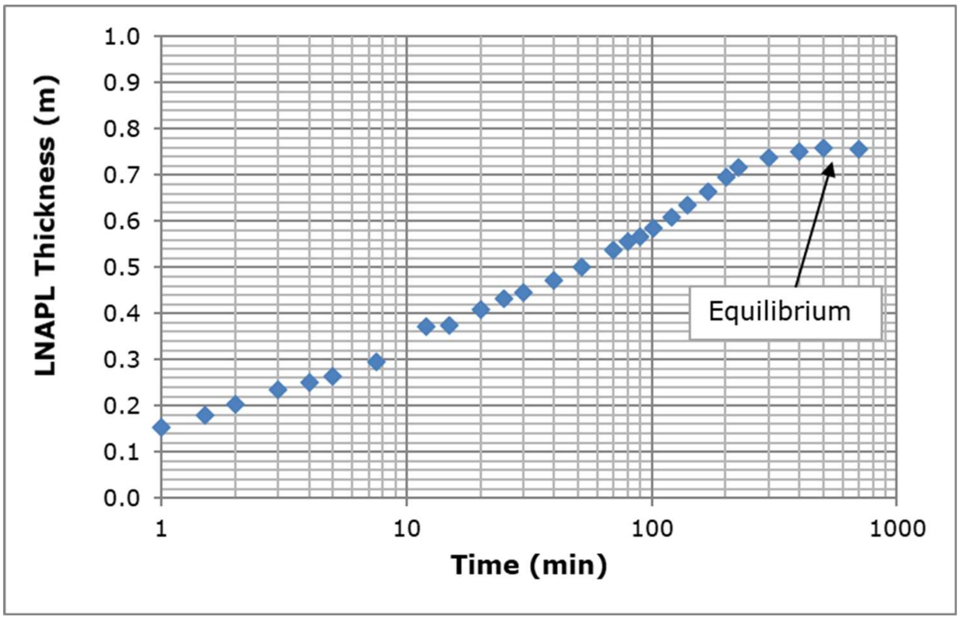
The interpretation of baildown test results requires data points that adequately represent the recovery of fluid levels to or towards equilibrium. Because the rate at which fluid levels change typically slows as the test proceeds, this means that more intensive monitoring is required at the start of the test and that the interval between monitoring points can gradually be extended.

It is generally not practicable to measure and record the depths to LNAPL and groundwater manually at intervals less than 30 to 60 seconds. This is partly because it can be difficult to differentiate accurately between LNAPL and water. This can however be accomplished by automated monitoring equipment which is detailed in the SoBRA guidance, 'LNAPL Monitoring Options and their Merits'. This frequency of measurement should commence as soon as the test has been initiated and continue until the change in fluid levels between successive measurements has reduced to less than 10 mm. The monitoring frequency can then gradually be reduced.

The collection of higher frequency data is not a problem providing that it is accurate, but it is not always necessary. Unnecessary data (e.g., data points where fluid levels have changed by less than 10 mm since the previous reading) can be removed (filtered) from the dataset prior to interpretation (see Section 5).

Monitoring should continue (if practicable) until the LNAPL layer has recovered to a stable thickness. A good way to assess this is to plot a graph of the LNAPL thickness against elapsed time, with time plotted on a logarithmic axis (see Figure 5, overleaf). This requires the practitioner to have appropriate equipment (computer or graph paper) available on site.

Because of the logarithmic time scale, this check for stability of the LNAPL thickness requires the final few time measurements to be spread across relatively large intervals (often several hours and sometimes days). Measurements that are too close together in time do not provide sufficient confidence that the LNAPL thickness has stabilised.



Source: adapted from ASTM, 2021

Figure 5 – Example Gauging Data Graph

5 DATA INTERPRETATION

This section assumes that data interpretation is to be conducted using the API LNAPL transmissivity workbook,[2] which follows the guidance contained in ASTM (2021). The guidance herein is not a user guide for the API workbook (see API, 2016); it simply provides some tips that may be helpful for baildown test interpretation.

5.1 Assess Suitability of Data for Monitoring

If the LNAPL thickness at the end of the monitoring period is less than 25% of the pre-test LNAPL thickness, it is generally not worth attempting to quantify LNAPL transmissivity using the API workbook. The limited recovery could be due to one or more of the following factors:

- The fluids were not in equilibrium and in good contact with the formation when the test was initiated.
- Monitoring stopped too soon.
- The LNAPL transmissivity is very low.

Compare the LNAPL volume removed with the initial volume present in the casing and in the filter pack (see Section 4.3). Ideally, the two volumes would be similar. If they are not, this will reduce confidence in the interpretation. If too little LNAPL was removed, the response may be dominated by inflow from the filter pack. If too much was removed, the assumption of 'instantaneous' removal may not be valid, adding uncertainty to the results of any interpretation.

Note that the volume calculation presented in Section 4.3 and used in the API workbook assumes that the screen and filter pack extend across the full mobile LNAPL interval in the formation. Refer to the borehole log to check whether this is the case. If it is not, the volume calculation will not be appropriate.

5.2 Data Filtering to Avoid API Workbook Errors

In some cases, the use of baildown data directly in the API workbook will cause errors. LNAPL recharge into the well can be variable and the levels of measurement error inherent in interface probe use can lead to data that cannot be directly processed. The API workbook can come up with errors due to the following:

- No increase in LNAPL thickness between data points. This can be avoided by taking readings only after there has been an increase in LNAPL thickness or by deleting intervening data points.

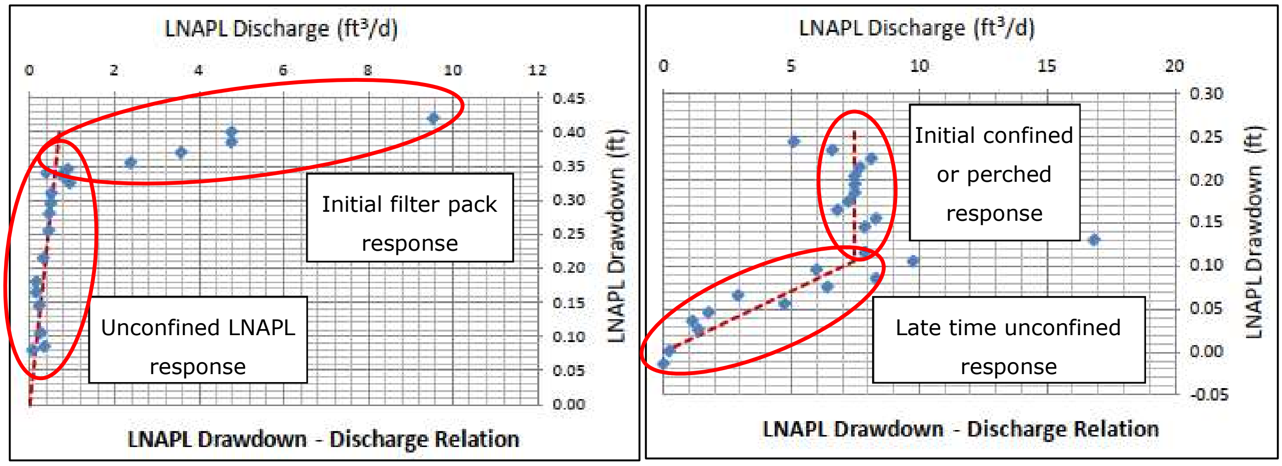
- Zero or negative calculated LNAPL discharge into the well (i.e., outflow from the well) in the interval between two measurements at any stage of the recovery period. The calculated LNAPL flows are shown in column M of the 'Data' tab in the API workbook.
- Zero or negative LNAPL drawdown (column J in the 'Data' tab of the API workbook), meaning the air-LNAPL interface has reached or risen above its pre-test elevation.

These errors can be reduced or avoided by 'filtering' the data. This is the process of removing (deleting) some of the data points such that the remaining data show a consistently increasing LNAPL thickness and decreasing LNAPL drawdown as the test progresses (see example in Appendix C). However, some baildown test data do not show any pattern and cannot be used to provide a meaningful result. A trend in the data should be apparent before 'filtering' takes place.

5.3 Check LNAPL Behaviour (Unconfined, Confined or Perched)

Review Figure 3 in the 'Figures' tab of the API workbook to assess whether the LNAPL behaviour is unconfined, confined or perched (see Figure 6), then use the appropriate sheet of the API workbook for quantitative evaluation of LNAPL transmissivity. Other lines of evidence that can be reviewed to assess the likelihood of such behaviour include:

- Borehole logs: are there finer-grained horizons that could cause perching or confinement of LNAPL?
- Diagnostic gauge plots (if sufficient time-series gauging data is available). Refer to ANSR (2011, 2015a, 2015b) for relevant advice.



Source: Adapted from API (2016)

Figure 6 – Examples of API Workbook 'Figure 3' for Different LNAPL Behaviours.

5.4 Time-out Error

If your computer gives time-out errors when using the solver to calculate LNAPL transmissivity using the Cooper, Bredehoeft and Papadopulos method (‘CB&P’ tab of the workbook), this can often be avoided by manually setting a better trial estimate of LNAPL transmissivity (cell E13 of the CB&P tab). Use the calculated LNAPL transmissivity estimate from one of the other methods (Bouwer-Rice or Cooper-Jacob) as the trial estimate.

SoBRA The Society of Brownfield Risk Assessment

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APPENDIX A

Flowchart to Support Baildown Testing and Interpretation

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Flowchart to Support Baildown Testing and Interpretation

PRE-TEST (Section 3)

PRE-REQUISITE DATA
(Section 3.1)
- Time-series LNAPL/GW elevation data

WELL REQUIREMENTS
(Section 3.2)
- Appropriate response zone (does it cover the entire impact?)
- Sufficient LNAPL thickness (typically >150mm)

WELL HISTORY
(Section 3.3)
- Has the well been developed recently?
- Previous LNAPL removal (is the well at equilibrium?)

BAILDOWN TEST (Section 4)

PUMP SELECTION
(Section 4.2)
- Peristaltic pump (recommended if safe)
- Bailer

LNAPL REMOVAL VOLUME
(Section 4.3)
- Pre-determine LNAPL removal volume (well and filter pack) using equation from Box 1
- Rapidly remove the required volume (not more), with minimal water where possible

BACKGROUND MONITORING
(Section 4.4)
- Time-series pre-test monitoring in test well
- Regular manual measurements for changing groundwater elevations on unimpacted non-test well

TEST DURATION
(Section 4.5)
- Aim for LNAPL recovery to reach stable thickness
- Final readings hours/days post-test initiation

TEST WELL MONITORING (Section 4.5)
- Manual or automatic
- Early time high frequency, late time lower frequency

INTERPRETATION (Section 5)

EVALUATE RESULTS SUITABILITY (Section 5.1)
- Compare final LNAPL volume removed to planned calculated volume (they should be similar)
- LNAPL Recovery >25% of initial for effective interpretation
- The data should show a recovery trend

API WORKBOOK
(Section 5.2, 5.3, 5.4)
- Use the LNAPL workbook user guide
- Use graphs provided to aid interpretation
- Use Bouwer & Rice estimate as input to the other calculation methods to facilitate stability of the 'solver'

FILTER THE DATA TO REMOVE ANOMALIES (Section 5.2)
- Remove negative LNAPL drawdown values
- Remove negative discharge values

LNAPL TRANSMISSIVITY

APPENDIX B

Example Baildown Test Data Sheet

Example Baildown Test Data Sheet

Well ID:			Test No:			Date:

General information

Site name	
Job number	
Performed by (name)	
Weather conditions	

Pre-test checks

Has well been developed?	Yes / No / Unsure
NAPL >150mm?	Yes / No
Top NAPL within screen?	Yes / No / Unsure
Fluid levels equilibrium?	Yes / No / Unsure
LNAPL volume (L)*	

** In casing and filter pack (see Section 4.3)*

Well information

Internal diameter (mm)	
Drilled diameter (mm)	
Well depth** (m)	
Top of screen depth** (m)	
Base of screen depth** (m)	
Drilling method	

*** Depths measured from top of casing*

NAPL removal information

Removal method	
Removal start time	
Removal end time	
Removal duration (mins)	
Vol NAPL removed (L)	
Vol water removed (L)	
Describe NAPL (colour, viscosity, etc)	
NAPL disposal method	

Initial conditions

Depth to NAPL (m)	
Depth to water (m)	
NAPL thickness (mm)	

Notes:

Time	Elapsed time (mins)	Depth to NAPL** (m)	Depth to water** (m)		Time	Elapsed time (mins)	Depth to NAPL** (m)	Depth to water** (m)

APPENDIX C

Example of Filtering Baildown Test Data

Example of Filtering Baildown Test Data

Figure C1 provides an example of data that requires filtration. There is a general trend of LNAPL recharging into the well, but at quite a slow rate. Should this data be used directly in the API workbook, it will not produce a meaningful result. In this case, the drawdown over time is sometimes negative (Figure C2) and the LNAPL discharge is also sometimes negative (Figure C3), implying that LNAPL is moving from the well into the formation.

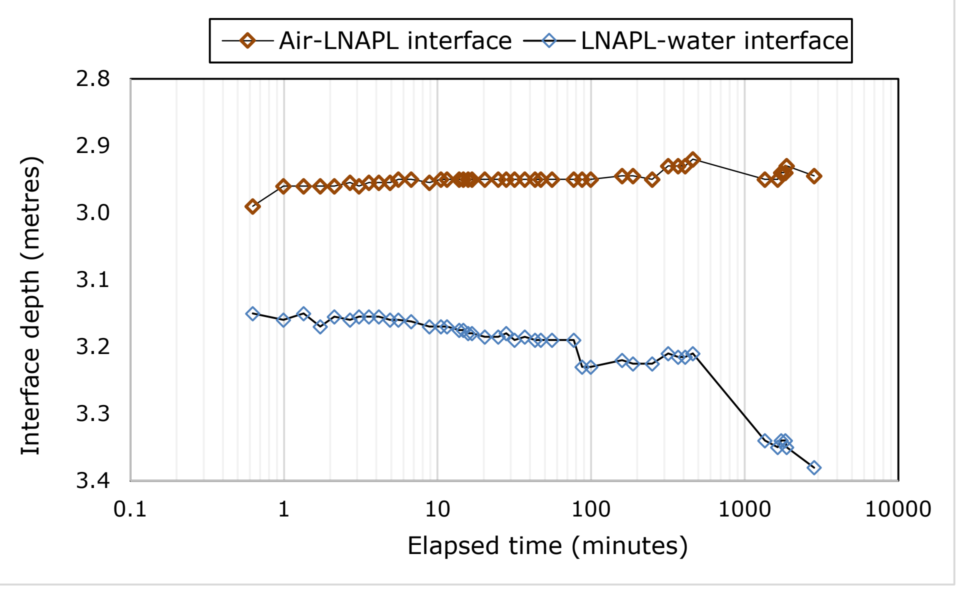

Figure C1. Example Baildown Data Showing Erratic Movement of Fluid Levels.

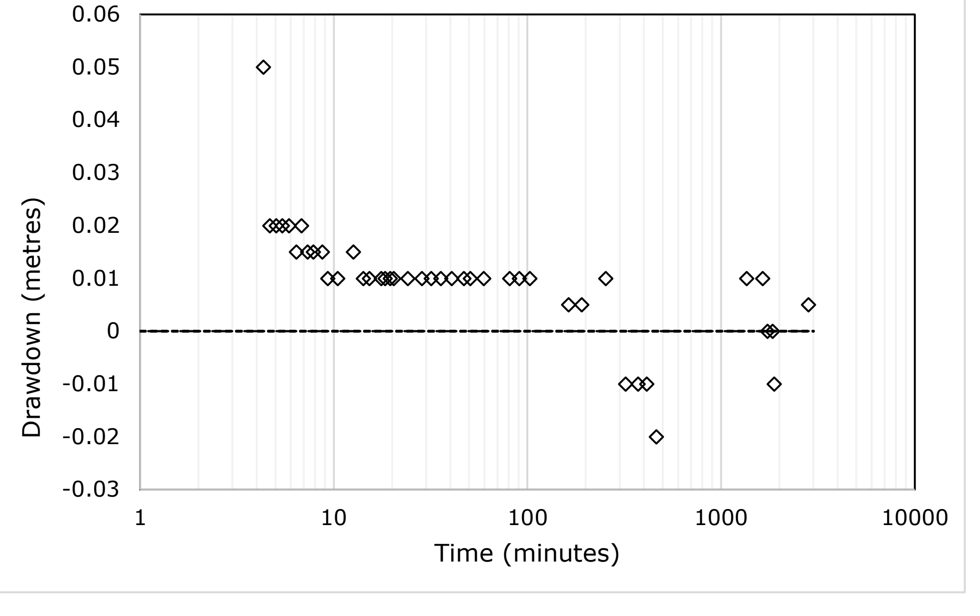

Figure C2. Drawdown Over Time Showing Negative Values.

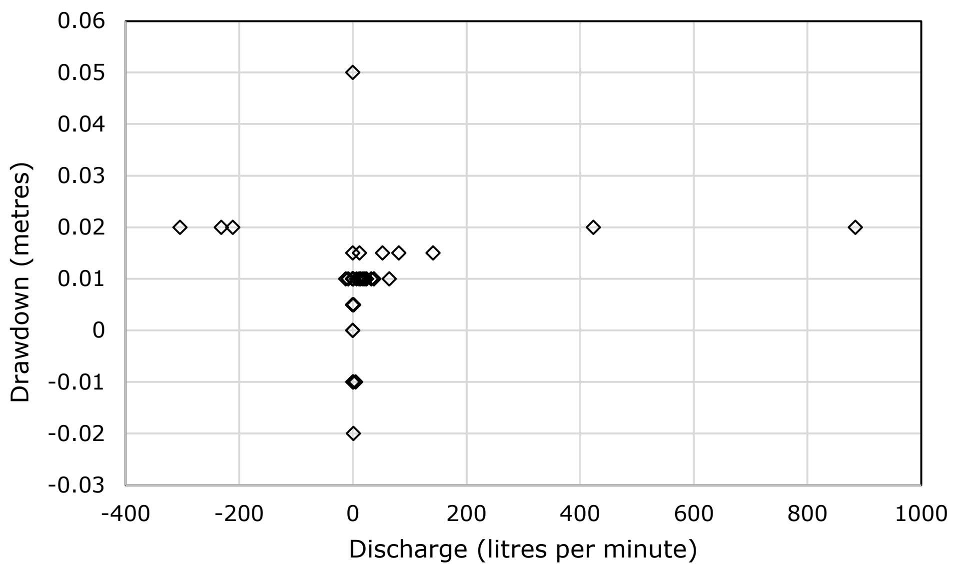

Figure C3. Discharge-Drawdown Graph with Negative Discharge Data.

Entering this example data unfiltered into the API workbook will cause an error; therefore, the data that cause the error need to be identified and removed. In the first instance, most of these data can be identified based on the apparent negative LNAPL discharge into the well (i.e., the volume of LNAPL in the well decreases).

Table C1 shows an extract of the data (from 10 to 60 mins) used to create Figures C1 to C3, with the negative and zero discharge data highlighted.

Table C1: Example Baildown Test Data Prior to 'Filtering'

Time (min)	Depth to LNAPL (m bgl)	Depth to water (m bgl)	LNAPL thickness (m)	LNAPL thickness change (m)	Discharge (L/min)
10.6	2.95	3.17	0.220	0.005	24.0
11.6	2.95	3.17	0.220	0.000	0.0
13.9	2.95	3.18	0.225	0.005	17.7
14.8	2.95	3.18	0.225	0.000	0.0
15.9	2.95	3.18	0.230	0.005	36.9
16.8	2.95	3.18	0.230	0.000	0.0
20.5	2.95	3.19	0.235	0.005	11.2
24.9	2.95	3.19	0.235	0.000	0.0
28.2	2.95	3.18	0.230	-0.005	-12.8
32.0	2.95	3.19	0.240	0.010	21.3
37.0	2.95	3.19	0.235	-0.005	-7.9
43.3	2.95	3.19	0.240	0.005	6.5
47.2	2.95	3.19	0.240	0.000	0.0
55.9	2.95	3.19	0.240	0.000	0.0

Removing the data that implied negative or zero LNAPL inflow gives Figure C4. While much clearer than Figure C1, there is still some noise, especially around 500 minutes, so another stage of data filtration is required.

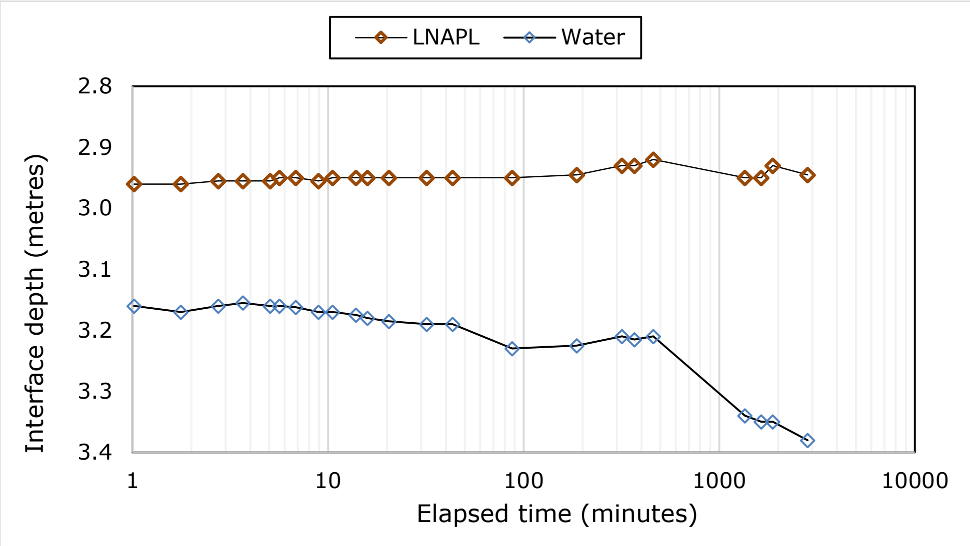

Figure C4. Example Baildown Data after Removal of Negative LNAPL Discharges.

Table C2 shows the final, filtered data that can be used in the API workbook, and Figure C5 shows these data as a graph.

Table C2. Example Filtered Data.

Time (min)	Depth to LNAPL (m bgl)	Depth to water (m bgl)	LNAPL thickness (m)	LNAPL thickness change (m)	Discharge (L/min)
1.0	2.96	3.16	0.2	-	-
2.8	2.955	3.16	0.205	0.01	141.0
5.1	2.955	3.16	0.205	0.005	52.3
5.7	2.95	3.16	0.21	0.005	64.0
6.8	2.95	3.162	0.212	0.002	13.6
9.0	2.955	3.17	0.215	0.003	11.6
10.6	2.95	3.17	0.22	0.005	24.0
13.9	2.95	3.175	0.225	0.005	17.7
15.9	2.95	3.18	0.23	0.005	36.9
20.5	2.95	3.185	0.235	0.005	11.2
32.0	2.95	3.19	0.24	0.01	21.3
87.3	2.95	3.23	0.28	0.04	32.4
1355.3	2.95	3.34	0.39	0.1	0.9
1639.3	2.95	3.35	0.4	0.01	0.3
2831.3	2.945	3.38	0.435	0.015	0.1

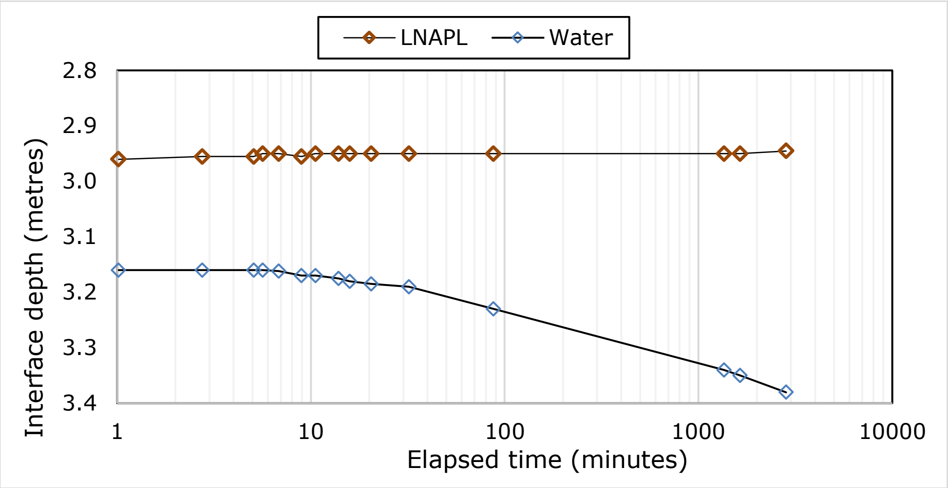

Figure C5. Example Filtered Baildown Data Ready to be Used in the API Workbook.

The resulting LNAPL transmissivity at this well was calculated to around 0.008 m^2/day. Further well-specific recovery data indicated that the LNAPL production rate was around 0.02 L/min, which is consistent with the transmissivity. However, it is quite unusual to have such information. To increase confidence in transmissivity estimates, it is therefore recommended, where practicable, to carry out further baildown tests or gather other lines of evidence such as information on aquifer properties, LNAPL properties, or time-series data on the lateral extent of LNAPL.