Light Non Aqueous Phase Liquid (LNAPL) Automatous Monitoring System

Summary

A baildown test is a seemingly simple method to measure LNAPL mobility. However, the interface probes used are not very precise, the tests can be very long and a small part of human error can change the result quite significantly. Ecologia have found an innovative way to get around these problems, by developing a LNAPL Automatous Monitoring System.

Synopsis

The key recoverability criteria for free-phase Light Non Aqueous Phase Liquid (LNAPL) in contaminated soils is its mobility, expressed as transmissivity. It is now more understood, following the publication of the CL:AIRE LNAPL guidance in 2014, that significant thickness of LNAPL can be present in a well, but that this does not mean that meaningful quantities of LNAPL can be recovered.

The characterisation and assessment of the risk that may be posed, and the ability to recover a free-phase LNAPL are all dependent on a robust understanding of the behaviour of the LNAPL and the factors that may affect this. The metric is transmissivity, which is an expression of the mobility of the LNAPL. It integrates the relative permeability and physico-chemical characteristics of the LNAPL and the nature of the soil.

Whilst measuring the mobility of the LNAPL is conceptually straightforward, it is practically less so. A number of methods exist, but the most common and practical method is a baildown test. This involves instantaneous removal of the free product in the well when it is at equilibrium with the formation, and then measurement of the recharge over time until equilibrium is again reached. The interfaces of the LNAPL between the air and the water are recorded using an interface probe, which requires that an operative is present throughout the test. Essentially, a gradient (called the drawdown) is created in the LNAPL, and the plume's response to it is then measured. The data from the test is then applied to an equation, and a figure for the transmissivity is produced.

However, in some conditions, particularly when the mobility of the LNAPL is quite low, the recharge of the well may take a number of days or even weeks. It is not practical or possible in these cases for an operative to take manual measurements – the well may be at an active, high risk site, for example a train depot or refinery, where access to wells is contingent on the operation of the site.

This can be a particular problem if the well has confined or perched LNAPL. These are conditions where the LNAPL is trapped underneath, or is resting on the top of a low permeability layer, such as clay. These conditions are often found at refineries build on floodplains where there can be complex geology in the vadose zone. The LNAPL recharge in these wells behaves differently to non-confining conditions, but this may not be apparent until after several hours - after any operatives have left site.

A final problem lies with the interface probes themselves. There may be inconsistencies in measurement caused by for example, twists in the tape, and if extended periods of monitoring are needed overnight, then fatigue can become an issue for the operative, leading to misreadings. Different operators also have different small biases when measuring. These can errors can become compounded, and lead to a large margin of error in the final transmissivity value. Additionally the need to have operative present on often high risk sites, for prolonged periods of time increase the health and safety risks.

Scientific Problem

The problems lies with the ability to measure two interfaces simultaneously in the field. Conversely, for a well containing only water, this is simple. A data-logging pressure transducer ('diver') can be used to record the total fluid head, consisting of the mass of water and the mass of the atmosphere. In combination with barometric diver, the effects of the atmosphere can be accounted for. When LNAPL is present in a well, there is no method to identify the location of the water- and air-LNAPL interfaces: only the atmosphere can be accounted for.

As the LNAPL moves in the well, more water is displaced, and this pushes the water level down. The LNAPL is generally of a density of 0.7 g/ml to 0.99 g/ml (by definition), and so the extent to which the LNAPL will displace the water is specific to any given LNAPL. As the LNAPL increases in thickness, it may pass over zones of soil where the permeability is significantly different (confining or perched conditions), and so the rate of recharge may not always decrease with decreasing drawdown.

Figure 1 shows the geometry of an idealised well, and the best current method of measuring fluid head using divers.

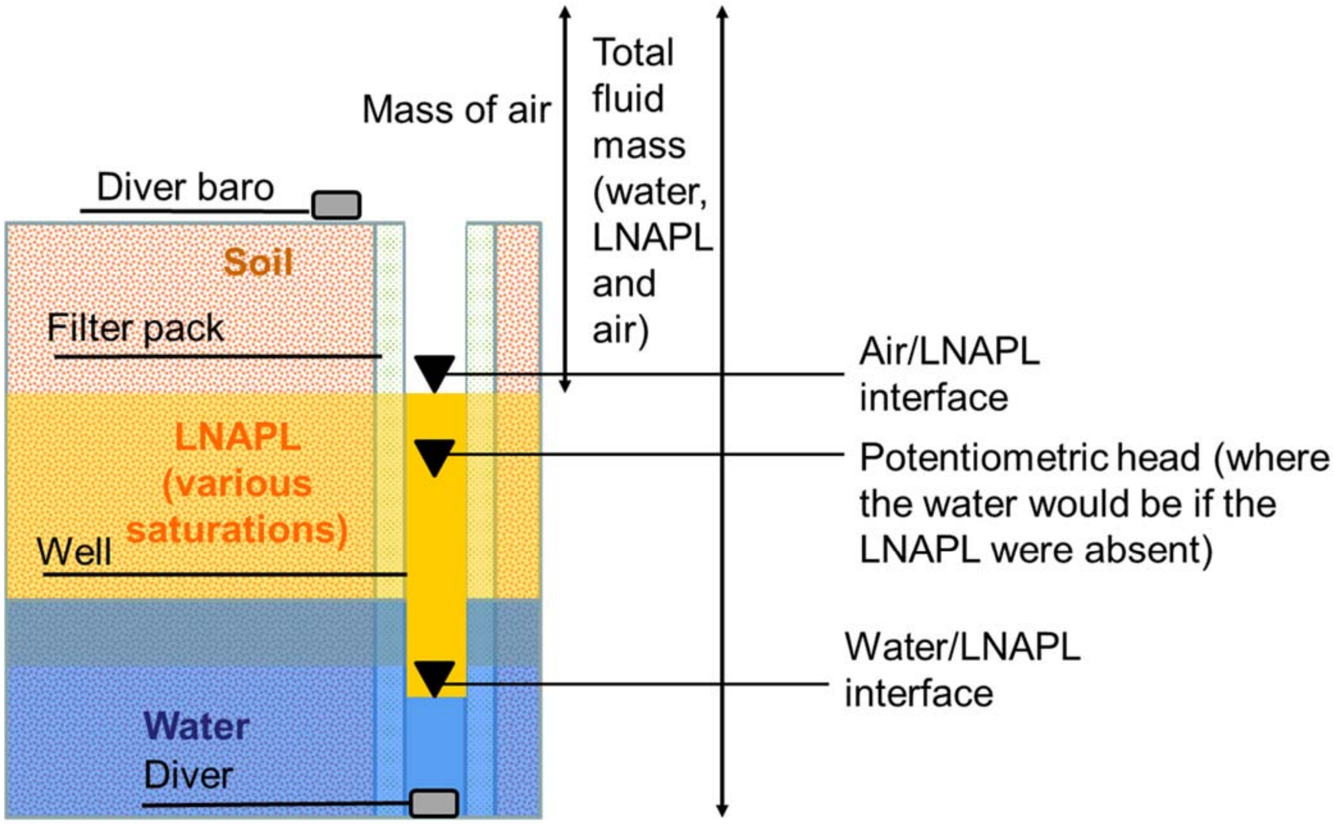

Figure 1. An idealised non-confined well showing a thickness of LNAPL in a well. There is no current method to infer the location of the air- and water-LNAPL interfaces, and they must be measured by hand using an interface probe.

A number of researchers have attempted to simultaneously measure the two LNAPL interfaces in the field. The most notable were efforts to use sonar and pressure-sensitive tape for the top LNAPL level, with divers used to measure the total fluid head. The water-LNAPL interface was inferred from the data. However, these techniques used three separate measurements (in-the-well and barometric divers, and air-LNAPL interface monitoring), which each had their own measurement error. When combined to give interface levels, they were too ‘noisy’ to be of practical use.

Solution - Scientific Advance

Ecologia’s system is automatous and uses a guided wave radar sensor to measure the fluid interfaces, without the need for diver data. This provided a much cleaner signal and avoided the requirement for multiplication of measurement error. The guided wire radar sensor is also energy efficient, so can be powered by a 12 V battery. A full charge on a 72 Ah battery lasts around 550 hours, or over 22 days.

How it Works

A guided wave radar works by sending a weak an electromagnetic signal down a metal conductor. If the conductor passes through a substance that has a different dielectric constant, this causes some of the signal to be reflected. The dielectric constant of air, LNAPL and water are all different. Air is around 1, LNAPLs are typically around 2 to 3, and water is around 70. The air is ignored by the sensor as a background constant, but the sensor can pick up the change from air to LNAPL, and from LNAPL to water. These signals are then decoded by the sensor, and the interfacial levels are given as outputs. This technology is known as Time Domain Reflectometry (TDR), and is generally used for soil moisture measurement.

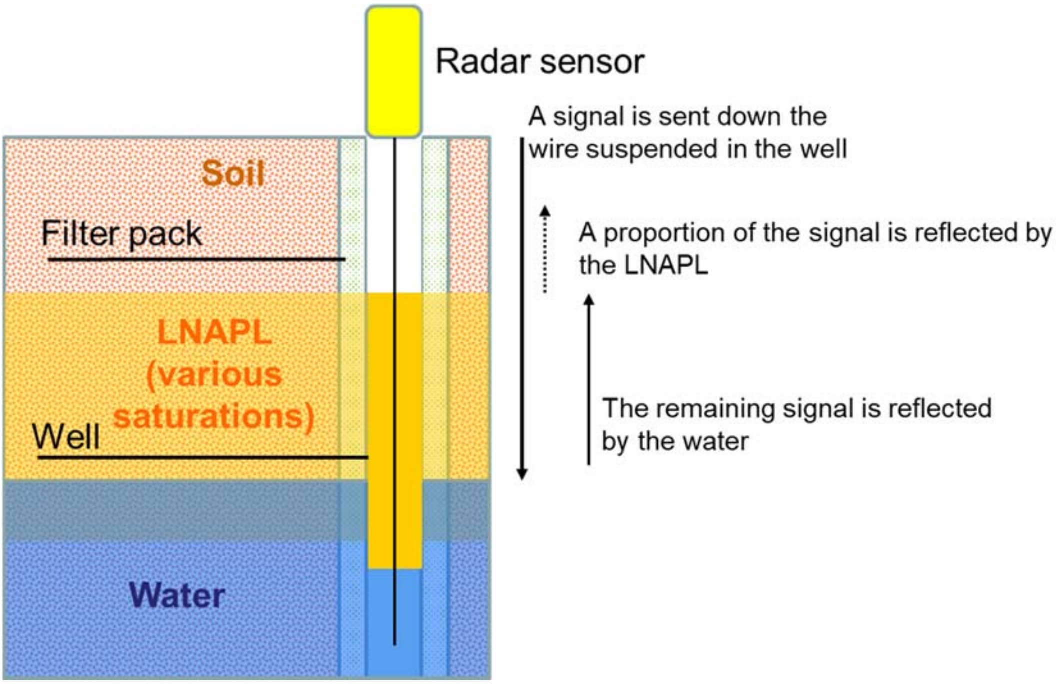

Figure 2. The theory of measurement for the radar sensor. By measuring the time (hence Time Domain) a signal takes to return (Reflectometry) the device can calculate the location of the air- and water-LNAPL interfaces.

The data can then be used to monitoring changing LNAPLs levels, most importantly during the potentially long LNAPL recharging stages of a baildown test.

The sensor records data in two different ways. It can save what is known as an 'echo curve' which is the graph of the TDR, and it can record data points, where the sensor takes an estimate of the levels. The echo curves allow the data points to be independently checked and if needed, corrected.

Laboratory Trials

Initial trials were conducted in Ecologia's laboratory. Vegetable oil was used as a safe substitute for LNAPL, in the first instance, and then diesel was used to replicate site conditions as closely as possible. The set-up was found to be able to accurately and precisely track levels of the diesel and water as they were manipulated under laboratory conditions (Figure 3).

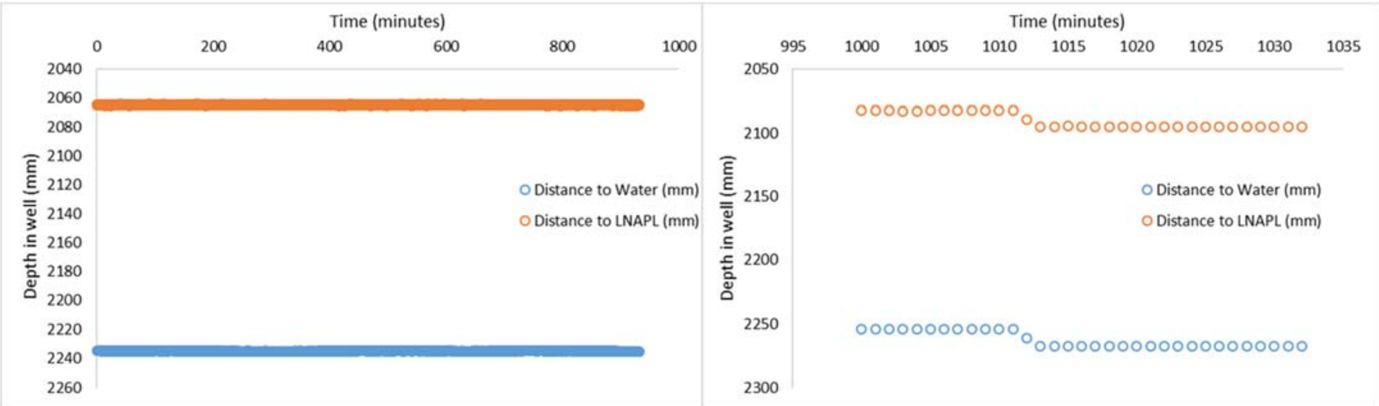

Figure 3. Data from laboratory trials. The sensor was set to run overnight in a constant temperature room. The left graph shows the overnight readings, and right graphs shows the point at which the levels were manually dropped.

Figure 3 showed a remarkably high degree of both accuracy and precision. The artificial well was a clear permeameter and so the LNAPL could be measured using a tape measure, and any issues of the interface probe avoided. In these tests, the sensor was set to record the levels once every minute. In the overnight test, 935 readings were taken over 15 hours. The greatest variation in reading for the water level was 1.125 mm, for the LNAPL, it was 0.975 mm, and for the recorded thickness of the LNAPL, it was 0.75 mm. It is not possible to produce data of this resolution with an interface probe.

Field Trials

A site was identified where there were significant thickness (up to 900 mm) of LNAPL present in some wells. The monitoring wells had not displayed any LNAPL after drilling, but aged diesel migrated into them between weekly monitoring after around 6 months. The thickness of LNAPL in the wells then varied from week to week.

A baildown test was carried out to measure the mobility of the LNAPL, with the result to be used as a tool to decide the most appropriate course of action. The radar system was set up to monitor the LNAPL levels immediately before and after the test, and left in place over several days to record the recharge of the LNAPL back into the well.

Figure 4. An Ecologia employee installing the device. The system is set up using a laptop computer, and then runs from a 12V battery.

The sensor was set to record the interface levels for 15 minutes before the baildown test took place. These showed a mostly stable LNAPL. The water level fell around 2.5 mm over the course of the monitoring, and the LNAPL level around 1.2 mm. An interface probe was also used to record the LNAPL and water levels. The results were consistent with the radar sensor. Figure 5 shows the pre-test conditions and LNAPL recharge. These data are a combination of echo curve interrogation and sensor-interpreted levels.

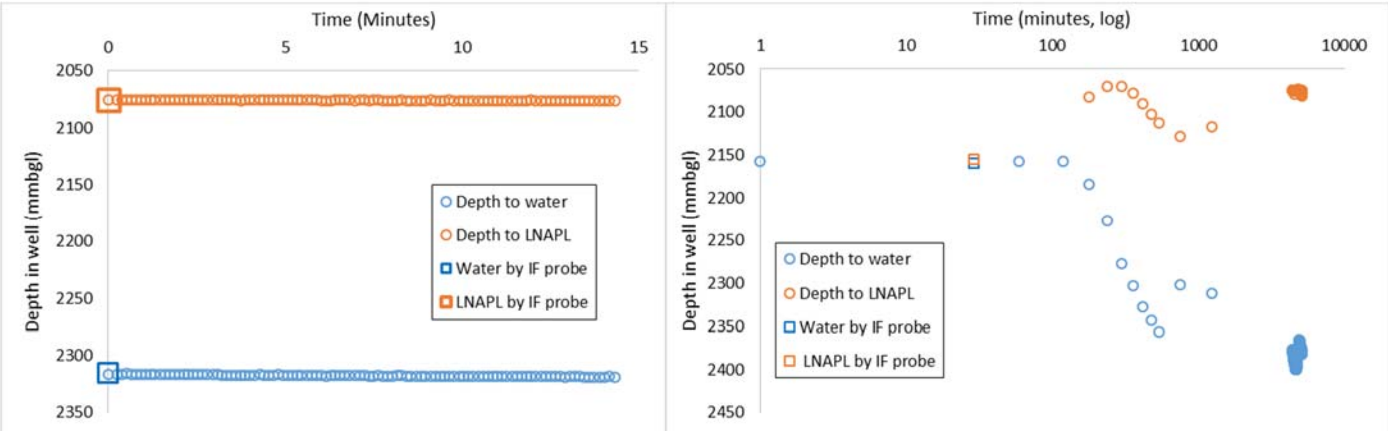

Figure 5. Data from the field test. The graph on the left shows the pre-test conditions, and the graph on the right, the LNAPL recharge over 7000 minutes on a semi-log scale.

The data gathered was appied to the Bouwer and Rice (1976) modified equation for the calculation of transmissivity. It was found that the transmissivity of the LNAPL in this well was 0.003 m^2/day. This is far below what is hydraulically recoverable.

Ecologia experts on the ground

Figure 6, below, shows a typical echo curve. These were generated by the device and then later interogated. The data was corrected against them.

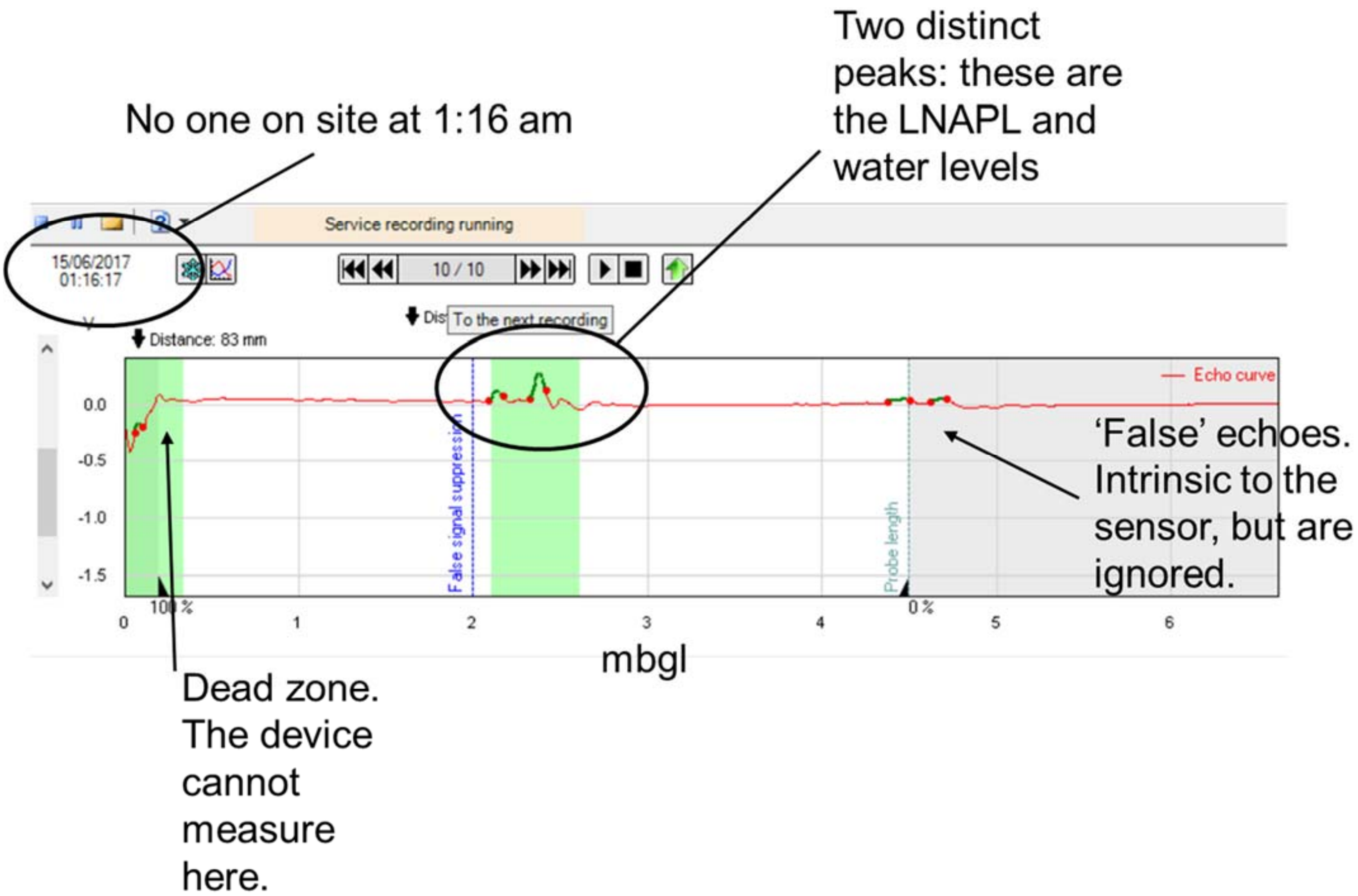

Figure 6. A typical echo curve from the sensor. Two distinct peaks can be seen. The sensor also picks up false echoes, which it is programmed to ignore, and has a dead zone in the first 30 cm of the well. However, it is uncommon to find fluids at this shallow depth.

Conclusions

Ecologia designed and built a system to automatically track two moving interfaces, without the need for a constant operative presence. The system produces higher quality and more robust data than the use of an interface probe would allow. The data are repeatable, less prone to error, and the system can run over the course of several days without outside agency. The system can be deployed and left in-situ to collect repeatable, more robust, high quality near continuous data, without the need for operatives to spend extended time in the field. This reduces uncertainty, provides increased confidence associated with the data collection, and minimises the associated health and safety risks with being on-site for prolonged periods.

Future work

Future work for the system will include monitoring of more complex sites with wider ranging temporal affects such as tidal sites, and developing updated well mountings and software. It is anticipated that the device will also be used in site characterisation to support risk assessment and remediation technology selection, based on a solid understanding of the LNAPL behaviour on any given site.