A review of the recent international LNAPL literature – are we missing out on something?

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Investigation and remediation of sites contaminated by LNAPLs (light non-aqueous phase liquids) remains a common concern throughout the UK. There appears, however, little published recent research arising from UK authors supporting this effort. A topic search on 'LNAPL' on the Web of Science reveals just six articles published since 2010 having authorship associated with the UK. It is hence a concern that our lack of substantial involvement may result in our awareness, especially first-hand, of any advances in the international LNAPL literature becoming low. The question then for UK practice is – are we missing out on something? To this end, a light-touch review of the international literature spanning the current decade is undertaken. Whilst searching on the topic 'LNAPL' is not a perfect barometer of modern activity, the uniqueness of the acronym to our contaminated land/groundwater industry is helpful. A Web of Science search reveals a total of 452 LNAPL publications dating from the early 1990s (compared to interestingly 1361 DNAPL publications). Recognising here though, searches failed to gather some 1980s NAPLs published work (NAPLs being first coined as a term in 1981 at a site in Niagara Falls, New York), and further recognising, relevant hydrocarbon pollution research dates back to the 1960s, well before NAPLs were invented. LNAPL publications since 2010 amount to 170, of which 89 have appeared after 2015. Despite the UK contribution being just 3%, LNAPL research globally remains buoyant with a cumulative growth in LNAPL publications since 1999 that is remarkably linear. The mean annual number of LNAPL publications produced over 1999–2018 being 16.3 $\pm$ 3.7 publications. In terms of LNAPL subjects covered since 2010, the Top Ten are; No. 1) Site assessment tools or approaches, 2) LNAPL migration, 3) Remediation methods, 4) Modelling tools or model use, 5) NSZD (natural source zone depletion), 6) Lab-scale assessment approaches, 7) Vapour intrusion/migration, 8) Source term - plume development, 9) Fluctuating water table control, and 10) LNAPL thickness/volume quantification. A brief dip is made into interesting publications within the above to see what we may be missing out on.

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Dr Michael Rivett is the founding director of GroundH2O Plus Ltd, Birmingham with whom he undertakes consultancy and applied research on groundwater contamination issues. He is a part-time Research Fellow at the University of Strathclyde responsible for publishing research from their Scottish Government funded Climate Justice Fund – Water Future research programme in Malawi, Africa. He was a Senior Lecturer in Hydrogeology at the University of Birmingham for almost 20 years and previously chair of both the IAH – GB chapter and the Hydrogeological Group of the Geological Society. Specialist areas of project activity and published research within groundwater contamination arena include the transport, fate and remediation of organic contaminants (L/DNAPL, VOC, emerging, etc.), urban-contaminated land, groundwater contamination – surface-water interaction, radiological site contamination and baseline assessment for shale-gas development.

Recent advances in the assessment of DNAPL sites

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One of the key drivers for increasing understanding of the accuracy of DNAPL site characterization is the demand to deliver more surgical and sustainable remediation technologies in complex heterogeneous geologies. The applicability of a specific remediation technology requires advanced understanding of how much mass is present in all four phases (non-aqueous, vapour, dissolved, and sorbed phases), how that mass is distributed in variable permeability media and the age of the DNAPL release. Advances in the assessment of DNAPL systems will be illustrated by reference to best practice guidance on the selection and deployment of DNAPL site characterization tools, and the conceptualization of DNAPL systems using a novel framework for mapping phase distribution at variable age DNAPL release sites.

The assessment of DNAPL sites has evolved over the past decade to include a plethora of high resolution, or diagnostic, tools. The application of these tools is often seen as a panacea to reducing uncertainty in DNAPL and plume zone mass estimation. However, despite the availability of best practice guidance, understanding of the value of information used to characterize and manage DNAPL sites is limited. Evaluation of which elements of site characterization translate to the highest value data for remedy design and performance assessment is the focus of a current research project. The value of information (VOI) project has developed a virtual site assessment and remediation tool, where conceptual site models are developed then used to design an in-situ bioremediation remedy. Variability in the outcomes from the VOI study will be discussed in the context of our groundwater profession, in particular how uncertainty, faced by practitioners making decisions regarding data evaluation for the design of remediation systems at DNAPL sites, is managed.

Professor Gary Wealthall, Geosyntec Consultants Ltd.
Gary is the Managing Director of Geosyntec's consulting business in the UK and Ireland. He is a Senior Principal with more than 25 years of experience in contaminant hydrogeology research and practice. He is also an Adjunct Professor at the University of Toronto and was previously a Principal Research Scientist with the British Geological Survey and Research Fellow at the University of Sheffield. Gary specializes in the development and application of high-resolution site characterization methodologies for the selection, design and implementation of advanced remediation technologies. He serves as a Subject Matter Expert for industry clients in Europe, North America, South America and South Africa. Gary is a member of CL:AIRE's TRG, which provides strategic review, support and steering functions for CL:AIRE's activities. Gary is an Editorial board member of QJEGH and has published numerous research papers and best-practice guidance documents on the behavior of dense and light non-aqueous phase liquids (DNAPLs and LNAPLs) in intergranular and fractured bedrock aquifers and aquitards. He is co-author of a number of best-practice documents, e.g. a Guide for NAPL Migration in Sediments (ASTM, 2019), Integrated DNAPL Site Characterization and Tools Selection (ITRC, 2015), and a Generic Work Plan to Assess Dense Non-Aqueous Phase Liquid Mobility in the Subsurface at Manufactured Gas Plant Sites (EPRI, 2015), and An illustrated handbook of LNAPL transport and fate in the subsurface (CL:AIRE, 2014). He has significant experience as a technical training instructor on leading-edge professional development courses on five continents, including co-presenter of the prestigious Princeton Remediation Courses.

Geological Society: NAPL in the UK context, does it matter?
Abstract

DNAPL source zones: only when you know enough can you answer Does it Matter?

Kevin Leahy, ERM UK Ltd

The specific geology and hydrogeology at a given DNAPL source zone will control its distribution in the sub-surface, which can be highly variable in terms of the phase (NAPL, dissolved, sorbed, vapour) and the spatial geometry in three dimensions ('architecture'). Sedimentology and structural geology are the main factors that determine the architecture of source zones in unconsolidated sediments and fractured bedrock settings respectively. High resolution site characterisation (HRSC) data sets provide the best possibility of developing a robust understanding of the sedimentology or structural geology in a source zone, but these must contextualised with data gathered outside the source zone, into the plume and around, and integrated with other data on the local- to regional-scale geological setting.

Three DNAPL source zone case studies will be presented, each in different settings and markedly different architectures, and with different answers to the question of Does it Matter? In the first two case studies, HRSC techniques enabled detailed understanding of the DNAPL source zone architecture, one in a superficial deposit (Holocene alluvial sequences) and the other in fractured bedrock (Devonian slates). The third case study had only conventional site characterisation and was again in superficial deposits (Devensian glacio-fluvial sands and glacio-lacustrine silts under Till). The conceptual site model derived from each of these framed the risk assessment and went on to inform the regulator (and client) view of 'does this matter enough to warrant remediation?' In two of three cases, the answer was 'yes' and active remediation was undertaken, however, in the third it could be seen that geological and biogeochemical factors constrain the DNAPL source zone architecture and the dissolved phase plume. In this case, the most sustainable remedial action was agreed to be monitored natural attenuation to manage risk, and in this particular case, the presence of NAPL did not, in itself, 'matter'.

Ultimately, UK environmental law means that the judgement of "Does it Matter?" is only for the Local Authority and Environment Agency to decide, based on their assessment of the scientific analysis of risk. The case studies demonstrate that an analysis based of sufficient robust evidence could realistically justify that a DNAPL source zone 'doesn't matter' at various points along the project cycle, ranging from conceptual site model stage, through the risk assessment, remedial works and sometimes only after extensive post remedial monitoring and re-assessment. We suggest the earlier stages can only be plausibly argued from the position of a lot of high confidence data, such as HRSC, and more conventionally understood DNAPL sites can have long timescales to achieving agreement that the source zone no longer matters.

NAPL and Separating Physics from Policy – A Tale of Two Countries

Michael Chendorain, Associate Director and California Professional Civil Engineer at Arup

This talk will review how NAPL is viewed in both the UK and US regulatory environments with a focus on how the physics of NAPL fate in the environment is what it is, and how the regulators in the US and UK grapple with what to do about it. Michael is a London based Associate Director at Arup who spent the first 18 years of his career in his native California before moving to London 7 years ago. As such he has a unique perspective on the political issues which often seem to muddy the waters of risk based approaches to NAPL remediation. The talk will draw on projects from the greater London area and California.

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We have a legacy WWII tank farm that was bombed in the war that we are continuing to investigated under Part 2A.

It is a complex site due to the volume (about 80,000m^3 of oil was 'lost'), current soil matrix preventing effective soil treatment and having burnt during the ensuing fire the oil in the groundwater acts as both LNAPL and DNAPL. We are undertaking some basic preventative measures to limit the impact to the marine SAC (the oil gets into the adjacent stream then to the SAC) but are in the process of refining appropriate remediation at the site.

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EVOLUTION OF A CONCEPTUAL MODEL FOR NAPL DISTRIBUTION AT A FORMER GASWORKS

At a number of gasworks sites in different geological settings across the UK, contamination has been identified in the form of coal tars and dissolved phase organics at depth beneath thick low permeability layers in important (principal) aquifers. These findings are significant because it is generally assumed that thick, low permeability layers protect underlying aquifers from surface contamination. Our experience is that this is often not the case. There are a range of possible causes of the presence of deep contamination beneath manufactured gas plant (MGP) sites, which is further considered through the use of a case study.

At the case study MGP site, there is a long history of investigation of a shallow gravel aquifer, which is contaminated by LNAPL, DNAPL and dissolved phase pollutants. This aquifer is underlain by London Clay, which was assumed to be laterally continuous and thick layer beneath the site and therefore to protect the deeper Chalk, a locally and regionally important aquifer. Drilling through the London Clay was identified as posing a risk of cross-contamination between the shallow and deep aquifers, therefore, no deep investigation boreholes had been drilled at the site. More recently however, deep piling was proposed to develop the site for high-rise residential housing, requiring an investigation of the deeper geology for geotechnical and geo-environmental purposes. This investigation found groundwater contamination at depth in the Chalk, triggering an investigation of plausible causes.

The following plausible pathways were identified: (1) gaps in the London Clay; (2) former ons-te abstraction wells from the Chalk; (3) existing or former structures that penetrate or partially penetrate the clay; (4) migration via fissures in the clay; (5) cross-contamination during the drilling investigation; and combinations of the above. Subsequent detailed investigation found evidence for pathways 1, 2, 3 and 4. These pathways (particularly former abstraction wells) have been identified at other sites. The case study shows that there are potentially multiple pathways that can bypass low permeability clays, which in the past have been assumed to provide protection to aquifers from polluting surface and shallow sub-surface activities.

We conclude that conceptual models that assume low permeability layers are protective of underlying aquifers, without supporting evidence, may underestimate the risk posed to deeper groundwater.

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SoBRA

NAPL behaviour is complex and impacted sites can prove challenging to understand in terms of NAPL behaviour and risk. While there has been some excellent guidance released on both sides of the Atlantic, mostly recently in by the ITRC in 2018, there is still a lack of pragmatic and practical information published that can help scientists directly in the field to understand the regulation in the UK context, take meaning from both chemical and physio-chemical data, and propose suitable solutions. SoBRA has therefore created a subgroup to support technical excellence in the assessment, estimation & evaluation of risks associated with NAPL and to encourage best practice by delivering practical advice to support decisions regarding the appropriate management of NAPL risks. The core aims are to encourage “good practice” in the practical applications of risk assessment to support decisions regarding the appropriate management of land contamination and to facilitate and widen access to the dissemination of knowledge regarding land contamination risk assessment.

The group aims to develop guidance in a timely manner, to periodically represent SoBRA at conferences in respect to the sharing of learning outcomes and to mentor and support each other.

During this presentation the Chair of the working group will provide an update of the work currently being progressed as well as outlining the groups vision for the future.

TITLE: Successful biostimulation and bioaugmentation treatment of DNAPL and dissolved phase mixed chlorinated solvent contamination under an active commercial site

Authors: Jack Shore (REGENESIS, jshore@regenesis.com), David Scott (Ramboll, dscott@ramboll.com)

Summary

High concentrations, including DNAPL, of mixed chlorinated solvents (TCA and TCE) was present in the groundwater under an active industrial site in Scotland. A DPVE system had been unable to achieve the remediation goal of a 75% reduction in chlorinated solvent mass. Also a supplementary MIP investigation showed that there was further contamination deeper than the maximum treatment depth of the DPVE system (> 6mBGL). Therefore it was determined that an alternative remediation method was required.

A combined biostimulation and bioaugmentation treatment was designed. Using direct push injection, a high volume, micellar electron donor and a microbial consortium specifically designed to degrade both chlorinated ethenes and ethanes, would be co-injected between 3-9mBGL across an area of 1,200m^2.

However, the MIP investigation found that progression of the rods deeper than 6mBGL was difficult, raising concerns that it would not be possible to reach 9mBGL or inject the substrate. A pilot study was therefore completed across a small area. The trial found that the injection rig could reach 9mBGL and inject the required dose. The test also showed the treatment did not affect site operations.

Using information from the MIP study and pilot test, the full-scale design was tailored to provide the most accurate and cost effective dosage across the site. 60 direct push injection points were completed over 10 nights, with no disturbance to the site operations.

18 months of validation monitoring showed no inhibition of parent compound degradation due to the mixed halogenated compound plume, with 98% and 99% reduction in mean concentration of TCA and TCE respectively. Full reductive dechlorination was achieved with no buildup in daughter products. Analysis of the data suggests that both biotic and abiotic degradation occurred; with the abiotic degradation occurring due to the production of reduced iron species as a result of the low redox conditions created and maintained by the treatment. Remediation goals were achieved.

Objectives/Lessons Learned

Using information and data from the site, this presentation will demonstrate:

- The ability of bioremediation to treat high levels of contamination, suggestive of DNAPL, to very low concentrations
- That no buildup of degradation products occurred, showing full reductive dechlorination was achieved & sustained.
- How bioaugmentation can be used to avoid inhibition of the degradation of chlorinated ethenes or ethanes by ensuring that the microbial consortia contained viable counts of dehalogenating bacteria specialising in either contaminant group.
- The stimulation of abiotic degradation can be achieved through the creation of reduced iron species.
- The value of contaminant delineation and pilot testing to ensure accurate and cost effective treatment.
- How this approach can be used to remediate an active site with no disturbance of the onsite operations.

Site Investigation, Risk Assessment & Remediation of DNAPL at a Site in Grangemouth
Chris Eccles & Mike Harper, TerraConsult Ltd

TerraConsult were initially commissioned to carry out site investigation and subsequently the remediation of a 2 ha site in Grangemouth which was part of a former chemical works. Ground investigations identified an area of the site impacted by petroleum hydrocarbons, chlorobenzene, nitrobenzene, and other VOCs and SVOCs within the underlying Tidal Flat Deposits. This included DNAPL. The principal difficulties for remediation of the site were due to the DNAPL being within a stratum with a very low permeability and that there was a demanding/short programme. The period from commencing installation of 365 remedial wells to gain regulatory sign off was only 17.5 weeks. This talk will discuss the site characterisation, risk assessment, remediation and the process of gaining regulatory agreement.