‘Best In-Situ Treatment’ Category: Solvent Spillage Emergency Response, using Sustainable Thermally Enhanced Degradation

Summary

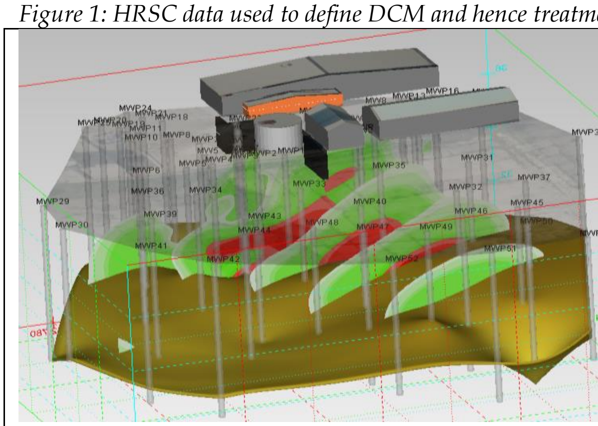
Following the accidental release to ground of circa 11 tonnes of dichloromethane (DCM), resulting from a solvent line failure at an active manufacturing facility, ERM was commissioned to investigate and treat the contamination. Whilst most remediation projects address legacy contamination, this project involved rapid assessment and clean-up of a recent spill to reduce potential risks to surface water courses circa 400m downgradient. Whilst in-situ thermal treatment has been applied at a number of legacy sites, this is believed to be the first time globally that it has been deployed to address an ‘emergency response’ situation.

The works were undertaken at an operational site and adjacent third party land, which has also been impacted by the spill. The operational phase was completed in a challenging 9 month time-frame, safely, on schedule, on budget, to the satisfaction of all stakeholders (including the Environment Agency (EA). The sustainable system design and method of contaminant removal represents a technical advance for in-situ thermal remediation that could be applied at other sites.

Site Characterisation

Initial investigations confirmed the presence of free phase DCM as Dense Non-Aqueous Phase Liquid (DNAPL) and elevated dissolved phase concentrations within the underlying high permeability sand and gravel aquifer. Below the aquifer is a relatively low permeability formation (mudstone) at depths of circa 4m to 5m below ground level. A detailed High Resolution Site Characterisation (HRSC) programme was completed beneath the client and third party land site. Works comprised detailed saturated zone characterisation using two Modified Waterloo Profilers, which are direct push discrete interval groundwater sampling devices, together with real-time analysis of 141 groundwater samples in an on-site laboratory. Samples were collected for analysis of DCM and the results are shown below on *Figure 1*.

Figure 1: HRSC data used to define DCM and hence treatment zone extent



Key Points:

- 3D visualisation of the data allowed the remedial treatment zone to be accurately defined and highlighted where DNAPL was likely to be present (red area on *Figure 1*).
- The underlying geology was also accurately mapped enabling the topography of low permeability mudstones present beneath the alluvium to be mapped. This assisted with understanding DNAPL distribution within ‘low’ points and targeting of removal of this material.
- Sequence stratigraphy evaluation identified the present of a high permeability channel within the alluvium, through which the data showed that DNAPL had rapidly migrated to off-site locations where this feature is present.

A Controlled Waters Quantitative Risk Assessment was carried out assuming two scenarios (with and without biological degradation). The results indicated that the risks to the river could not be easily mitigated without assuming biodegradation was occurring, the biodegradation of DCM is well documented in literature, and the remedial strategy hence focussed on maximising DNAPL mass removal to encourage biological activity within the aquifer to occur.

Remedial Options Appraisal

Given the magnitude of the spillage, regulatory pressure to quickly remediate and the fact that much of the treatment zone was on third party land (incurring a substantial land rental cost); the main objectives of the works were to complete remediation safely, as rapidly as possible and to minimise business interruption to the client.

ERM completed a remedial options appraisal in accordance with existing UK guidance including CLR11, the EA’s Remedial Targets Methodology and the UK Sustainable Remediation Forum (UK SuRF) framework incorporating sustainability as an integral part of the technology selection process. To supplement and help inform this decision making process, additional works consisting of field scale evaluation of a number of technologies including Soil Vapour Extraction (SVE) and total fluids pumping were carried out. Whilst SVE was shown to be effective at achieving vapour capture, radius of influence (ROI) was relatively low and it was clear that a closely spaced network of extraction locations would be required. Total fluids pumping showed that several thousand metres cubed per day groundwater abstraction rates would be needed to achieve even a modest ROI, making pumping in isolation a non-viable approach due to the lack of discharge points at the site and treatment challenges of large volumes. Silting of wells and equipment was also a significant challenge.

Given that rapid timescale was a key issue and the remedial trial ruled out sustainable liquid phase extraction, in-situ thermal treatment technology was selected as the remedial option to implement and was demonstrated to offer the greatest overall net sustainability benefit.

Remediation Design/Installation

Following selection of the remediation technique, thermal modelling was undertaken using PetroSim™ PC based software. This informed the technical design and enabled greater certainty for the client in terms of project duration and cost, and also enabled initial system settings (such as steam injection and vapour recovery rates) to be determined.

The design focussed not only on the technical aspects (such as flow rates, pressures and equipment sizing, which the model assisted with determining), but was also heavily influenced by site operational constraints, including limited space availability for remedial process equipment and restricted water supply capacity. These constraints meant the size and capacity of the steam injection boiler was limited to a 1,000kg/hr. These restrictions were factored into the design in terms of operational approach which was modified from the originally envisaged steam injection into all wells simultaneously, to splitting the treatment area into 4 distinct zones, meaning the available steam could be optimised.

In total 30 steam injection wells and 101 SVE wells were initially proposed, comprised from stainless steel (heat and chemical resistant and in the case of screened sections carefully manufactured to minimise silt ingress). Some wells were placed downgradient of the DNAPL areas in the event that subsequent migration occurred between site investigation and remedial system operation, given that, unusually for this type of project, the spill was recent rather than historical.

Business continuity issues during the works (especially the installation stage) were also of the upmost importance, and the system was designed to allow access routes for forklift trucks between storage and loading areas, by placing some of the on-site wells and pipework below ground in a series of narrow diameter trenches, which would then be backfilled to allow light vehicle access. This was undertaken in the smallest area possible, to enable the maximum possible amount of infrastructure to remain above ground to reduce costs. Trenching was also undertaken in pre-defined areas on different days to facilitate use of the goods yard for vital deliveries and shipments, via regular coordination with site management.

A key cost and sustainability consideration for thermal treatment systems is vapour treatment of VOCs generated via the heating process and captured within an SVE system. Having discounted alternatives to GAC on a cost and implementability basis, an innovative upstream vapour conditioning plant was procured to keep the incoming air stream at the optimum temperature (20^{0}C) and also reduce moisture content, thus reducing GAC consumption.

The installation is shown on *Figure 2* and *Figure 3*.

***Figure 2*: Treatment Equipment (Far Left)**

***Figure 3*: Above Ground Pipework (Left)**

It was decided that the treatment zones upgradient would be the first areas treated, partly to address the source areas first and minimise the risk of recontamination if this approach was not taken, but also to realise benefits of heat migration onto the off-site land (i.e. once the area under the clients property had been treated, the heat could effectively be reused once it had migrated to the off-site land).

During the operational phase of the works, thermocouples were interpreted spatially using PC based software, which together with VOC quantification, facilitated reaching the endpoint more rapidly, hence reducing CO_2 emissions.

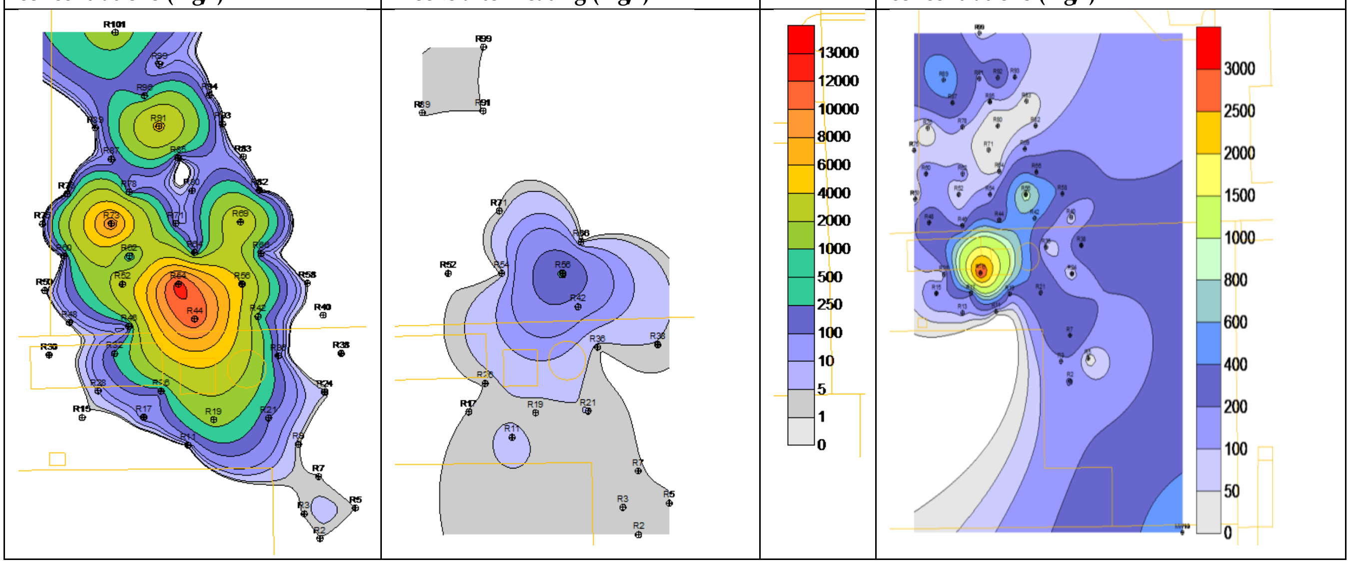
The design was implemented by ERM to achieve the remediation criteria within a relatively short period of time. The effort spent on the innovative engineering design was vindicated for such a complex system with a total system downtime of less than 5% and the active vapour recovery process completed within 25 weeks.

Validation and Closeout

The remedial strategy agreed with the client, regulators and other stakeholders was a risk reduction approach of mass recovery to the extent technically and practically feasible with the identified technique, with an endpoint of achievement of asymptotic contaminant recovery.

Whilst some mass was recovered via volatilisation as initially envisaged, after temperatures reached far in excess of DCMs boiling point, the cumulative mass removed remained low in comparison to the total quantity spilt. However, interim groundwater sampling undertaken after 16 weeks of operation identified a 90% reduction in DCM concentrations compared to baseline (*Figure 4* and *Figure 5*) in areas that had been heated by that point. Sampling also identified the presence of significantly elevated chloride concentrations (up to 3,000mg/l – *Figure 6*) compared to a baseline of circa 50mg/l; with the maximum chloride concentrations correlating to the vicinity of the DCM spillage. It is therefore thought that abiotic reactions occurred to degrade the DCM to chloride at relatively low temperatures. The remainder of the plume was therefore heated to lower temperatures than initially carried out, saving energy, time and cost for the remainder of the programme.

Figure 4: Pre-remediation DCM concentrations (mg/l) | **_Figure 5_: DCM concentrations – 16 weeks after heating (mg/l)** | **_Figure 6_: Interim Sampling chloride concentrations (mg/l)**



Post treatment sampling confirmed >95% DCM reduction had been achieved within the entire treatment zone. The data confirms the potential applicability of low temperature mechanism for thermal remediation. The EA has approved the works and did not take enforcement actions against the client.

Best Practice

Best practice was demonstrated in several elements of the design, for example:

- Use of innovative HRSC techniques to define the treatment zone extent, increasing certainty of remediation performance and lowering carbon footprint of these works and the remediation undertaken.
- A sustainability based remedial options assessment was completed. It concluded that in-situ thermal treatment would be most applicable given that rapid remediation was required. This represents the first application of the technique for 'emergency response', rather than is more typical for legacy site remediation.
- Whilst the treatment zone was accurately defined with the HRSC, additional recovery wells were installed downgradient of the defined DNAPL locations, as it was recognised that the plume of solvents may still be mobile between the time the site investigation was undertaken and the remediation works commenced.
- Site logistical requirements were incorporated into the design (limited equipment space and a need to keep the site operational during the entire remediation programme).
- Process engineering design was undertaken to reduce GAC consumption (via a vapour conditioning plant).
- Many of the design tasks and system installation proceeded in parallel, rather than sequentially, as would usually be the case. This approach posed unusual project management challenges, but was successfully completed with the entire system designed, installed and commissioned in around 4 months, an extremely rapid timescale compared to similar projects.
- A key focus on sustainability throughout the project lifecycle, from the remedial options appraisal to the actual design itself. Development of a strong working relationship with all stakeholders (EA, offsite land owner and site management).
- The Health and Safety approach included evaluation of technology specific risks, integration with site operations and hazard identification processes taken from other industries.
- Once it was identified that contaminant degradation rather than volatilisation was the key removal mechanism, this knowledge was applied to expedite completion and reduce costs and energy consumption.

Cost effectiveness and durability
The HRSC approach adopted minimised the duration of the site investigation and at this site finalised the CSM without the need for multiple phases of investigation that are typical with conventional borehole drilling/monitoring well installation approaches. The remedial system design also included a number of innovations to make the works as cost effective as possible (see above remedial design section). Additionally, innovative low temperature removal mechanisms were exploited to complete the operational phase more rapidly than would otherwise have been possible.

Significant reduction of the pollution burden
The remedial technique selected rapidly maximised mass removal via a variety of mechanisms. It is expected that mass reduction will enable biological activity to attenuate any residual contamination. It is unlikely that any other technique would have achieved the large percentage DCM removal observed within the rapid timescale that the project was completed within.

Community and stakeholder acceptance
All project stakeholders were consulted with during the design stage, as follows:

- **Regulators:** ERM kept the EA informed throughout this phase of the project. The use of HRSC enabled a defensible conceptual model to be derived, and for the remediation scheme and endpoints to be agreed quickly with the regulators. This approach was crucial to effectively engage with stakeholders and achieve the goal of remediating the site in the safest, most efficient and sustainable manner possible.
- **Offsite Land Owner:** ERM communicated the nature and requirements of the work to this stakeholder, who was unfamiliar with the process. ERM also assisted the client with negotiation of the commercial aspects of the site access agreement and costs to rent the land whilst remediation was undertaken.
- **Client:** ERM held weekly meetings with the client to discuss a wide range of issues, including H&S and integration of remedial activities with site activities (for example the design included some pipework which had to be buried to allow the works to proceed but also allow access to certain parts of the site); this involved careful planning to allow excavation of a series of trenches in a certain order to fit with operational activities.

Compliance with Health and Safety
ERM, the client and the remedial equipment supplier instigated a proactive approach to health and safety which frequently considered the risks in the context of an operational site. In addition to typical risks considered for any in-situ remediation project, the following was also undertaken:

- Process safety was also carefully considered at design stage and a review was undertaken including evaluation of the effects of process failures, suitability of materials, appropriateness of equipment, utility failure scenarios and operational safety, taking into account temperature, pressure, flow and contingency planning; the outcome of this review added several process safety features to the remedial equipment.
- A Hazard Identification Study was also undertaken and included ERM, the client and the remedial subcontractor. The assessment was facilitates by ERMs Risk team and bought beneficial practises often undertaken in other industries (such as the oil and gas sector) into a brownfield remediation project. The outcome of this review identified several integration issues between site and ERMs activities and mitigations for the work to be undertaken (for example: Issue: Electrical failure, Consequence: SVE equipment shutdown, vapour capture off, risk of vapour intrusion into buildings, Mitigation: additional equipment on standby, weekend access if required via site contacts, monitoring regime within building)
- Thermal specific H&S hazards were included both within the Hazard Identification Study and H&S Plan, which included assessment for the potential of thermal burns (hot surfaces), hot pressurised gas issues, water hammer within pipework, heating of subsurface fire water pipes (legionella), and PPE required during the works (steam resistant suits, gloves and face visors).

Sustainability
Sustainability has been a key consideration throughout the projects lifecycle, as summarised below:

- The use of HRSC was not only more rapid in defining the source zone architecture, but has also been demonstrated at previous sites to have a lower carbon footprint than if multiple phases of traditional site investigation had been undertaken.
- The remedial options appraisal was undertaken using a holistic sustainability approach, where environmental, social and economic indicators were evaluated to determine the most sustainable option.
- The remedial approach focussed on carbon footprint reduction to the extent practical, including:
    - Innovative design features to reduce carbon use (vapour conditioning plant).
    - Adapting the steam boiler to run on gas rather than electric.
    - Operational aspects of the remediation included within the system design (heat optimisation and reuse).
    - Use of lower temperatures mechanisms to remove the DCM (reducing carbon and steam consumption).