‘Best In-Situ Treatment’: Sustainable Low Temperature In-Situ Thermal Remediation of Pesticides

Introduction

ERM was commissioned to investigate and treat legacy contamination beneath a building, at a wood treatment testing facility. The site investigation activities, using a combination of traditional and High Resolution Site Characterisation techniques, identified impacts from kerosene and the pesticide dieldrin to saturated gravels that overlie the regional Chalk bedrock. Contaminant mass was present mainly as sorbed phase kerosene and other hydrocarbons, with dieldrin entrained within this product. The dieldrin was shown to present a potential risk to a nearby river and the Chalk aquifer groundwater. In order to mitigate these risks a source zone remediation strategy was implemented using an innovative steam enhanced mobilisation process to simultaneously recover kerosene and dieldrin.

Site Characterisation and Risk Assessment

Site characterisation was undertaken via an intensive programme of soil sampling and groundwater investigation using a *Modified Waterloo Profiler*, a direct push, discrete interval sampling technique. These methodologies confirmed and accurately delineated impact within the underlying high permeability gravel deposits to a depth of up to 4m below ground level (bgl). The main contaminant of concern within soil and groundwater was dieldrin, given its ability to migrate laterally and downwards into the underlying Chalk aquifer. The contaminants were predominantly located beneath an area historically used for chemical storage, as shown in *Figure 1*.

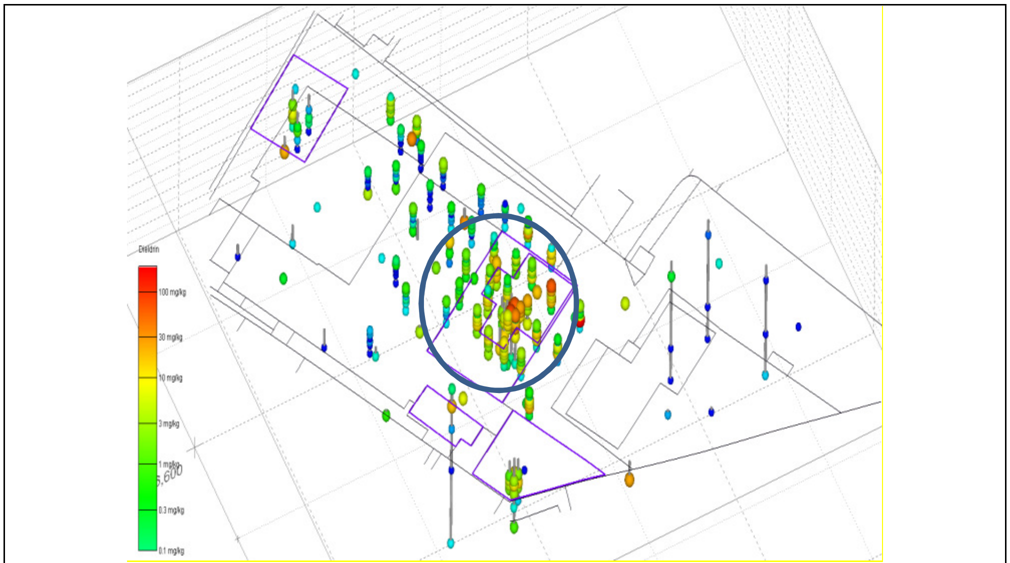

Figure 1: **Dieldrin distribution and main source zone.**

A Controlled Waters Quantitative Risk Assessment indicated that the greatest potential risk from the impact was longer term vertical migration of dieldrin towards the Chalk aquifer. The remedial strategy therefore focussed on maximising mass removal of this compound as part of a risk reduction strategy.

Remedial Options Appraisal

A remedial options appraisal was undertaken using a holistic sustainability approach, where environmental, social and economic indicators were evaluated to determine the most sustainable option in accordance with CLR11, the EA’s Remedial Targets Methodology and the UK Sustainable Remediation Forum (SuRF) framework, incorporating sustainability as an integral part of the technology selection process.

The results showed thermal remediation could address both the kerosene and pesticide impacts, although relatively high temperatures of circa 350ºC would be required to volatilise dieldrin; this could only be achieved using a series of closely spaced heating wells via In-Situ Thermal Desorption (ISTD) as the heating methodology. This high temperature strategy was assessed using PetraSim™ thermal modelling software to simulate two different well configurations and in both cases confirmed relatively high energy consumption would be required; *Figure 2* shows the estimated CO_2 kg equivalent use (Model 1: 4m heater well spacing and Model 2: 3m heater well spacing).

Given the magnitude of the CO_2 consumption and associated energy demand, ERM investigated use of an alternative lower carbon strategy of changing the heating methodology to Steam Enhanced Extraction (SEE); this was not initially considered as steam could only reach temperatures of circa 100ºC, considerably below the Target Treatment Temperature (TTT) to volatilise the dieldrin. However it was considered that if the kerosene could be recovered via mobilisation and simultaneously remove the lower mass (but higher risk) of dieldrin, then this approach could be plausible and would significantly lower the carbon footprint (*Figure 2*:

Model 3); therefore this was bench tested to confirm effectiveness of reducing total concentrations of kerosene (TPH) and dieldrin via mobilisation of the closely associated kerosene and dieldrin.

The results of the bench testing demonstrated that dieldrin was likely solubilised in the TPH and could be removed at temperatures of between 70 to 100ºC, as shown in *Figure 3*, where dissolved phase concentrations of both dieldrin and kerosene (TPH) are shown to increase at temperatures of 70ºC as a result of mobilisation, but then decline at 100ºC – a result that means mobilisation must be removing the contaminants given that this temperature is well below the boiling point of dieldrin.

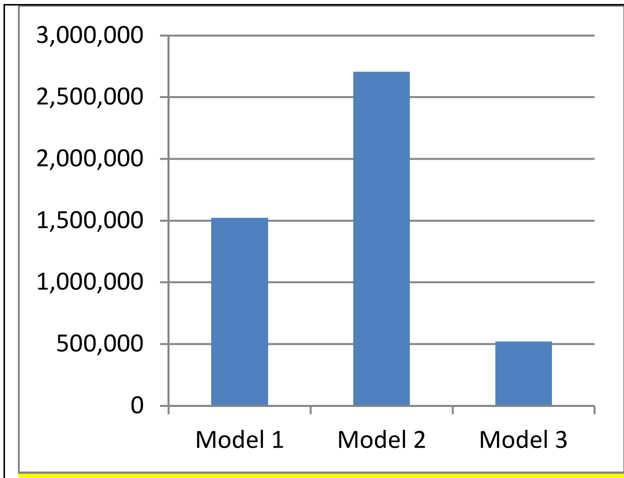

***Figure 2*: Estimated Carbon Consumption for different heating methodologies/configurations (CO_2 kg equivalent use).**

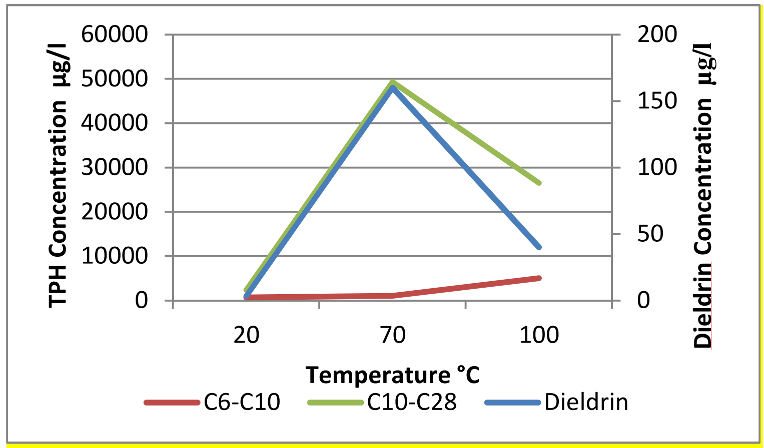

***Figure 3*: Laboratory Bench Test Results.**

Remediation Design/Installation

The modelling and bench test work confirmed a change in the traditional and originally envisaged methodology of thermal recovery (volatilisation) to one of mobilisation, with the associated TTT reduced significantly from 350°C to 70ºC. This change now meant steam rather than ISTD could be used to heat the subsurface using less wells and energy. The thermal model using steam (Model 3, outlined above) was then further developed to optimise steam injection well locations and predict heat up duration for the revised TTT. This provided further benefits to the client and wider project team in that by estimating the energy use the most economic fuel source and power tariff could be selected ; the process kit rental time could also be predicted/optimised improving cost estimates and certainty of programme schedule, a critical requirement for the client.

The results of the modelling showed that the optimum well configuration comprised 19 DPVE wells and 19 steam injection wells within the approximately 1,500m² treatment area. 90 temperature monitoring points were also installed within the treatment zone, a three different depths, to allow the heating process to be monitored and optimised. The wells were linked to process equipment, which included soil vapour extraction blowers, a heat exchanger, inlet tanks and carbon vessels for treatment of vapour and liquid phase. The completed well field is shown as *Figure 4*.

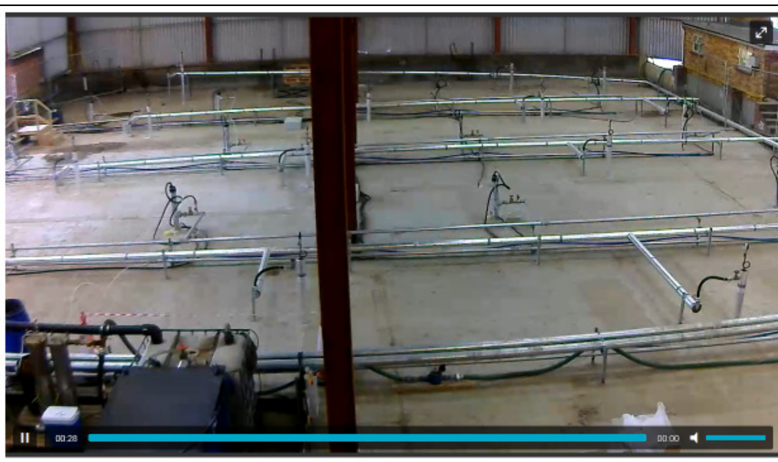

***Figure 4*: Completed well field (seen from a web-cam).**

System Operation

Following installation in January and February 2017, the pumping and SVE system were initially operated during March 2017 at ambient temperatures to confirm capture zones and extract readily recoverable mass. Steam was initiated in early April and the target temperature of 70ºC was rapidly achieved within 4 – 5 weeks and then maintained whilst significant quantities of LNAPL (containing kerosene and dieldrin) were recovered via mobilisation of the kerosene.

ERM developed an innovative data management system for this project, where data from the thermocouples was automatically uploaded to EquIS software on a daily basis and then outputted into Tableau visualisation software (see *Figure 5*). This enabled ERM to confirm model predictions, optimise the steam injection and hence minimise energy consumption; it also provided the US based client with an understanding of key performance metrics on a near real-time basis. A web-cam was installed to view the works undertaken remotely.

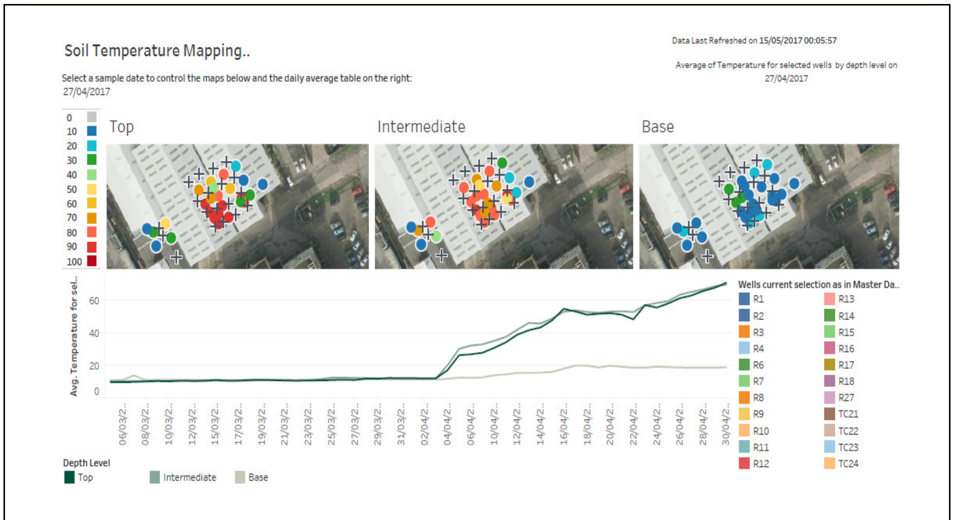

Figure 5: **Tableau Visualisation Software Output.**

Validation and Close Out

The target source zone was brought up to temperature through controlled injection of steam. Mobilization of LNAPL was observed as temperatures approached 70ºC. The majority of the mass was removed as kerosene NAPL via mobilisation (reduction in viscosity). Elevated concentrations of dieldrin have also been detected within recovered NAPL and liquids, confirming success of the lower temperature mobilisation concept and the bench test results.

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. This condition is approaching and an estimated contaminant mass of 3,000kg has been achieved to date (*Figure 6*).

In addition to a mass recovery of the same order of magnitude as the original mass balance, interim remediation groundwater sampling has not detected any dieldrin concentrations above the laboratory method detection limit, in contrast to the pre-remediation baseline sampling.

It is anticipated the system will run until the end of June 2017 to confirm recovery has been maximised.

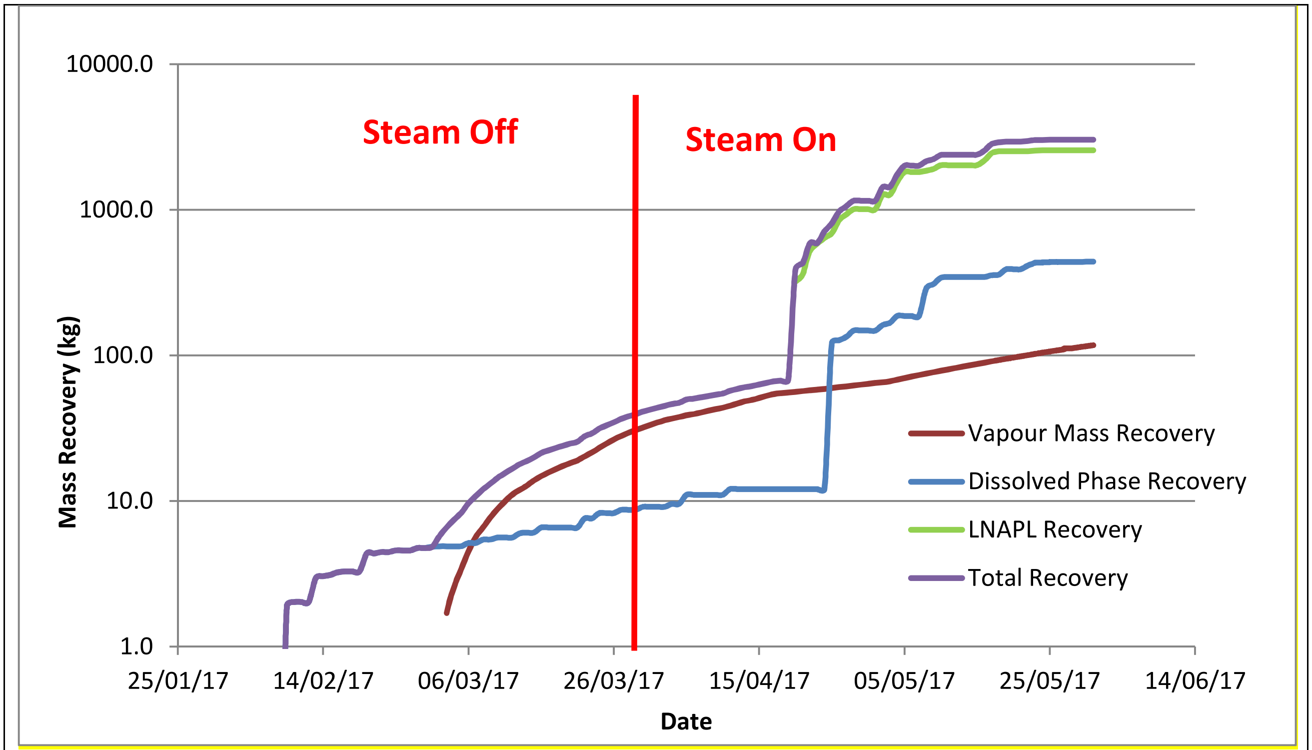

Figure 6: **Mass Recovery Estimate.**

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

- A sustainability based remedial options assessment was completed in accordance with UK Guidance. It concluded that in-situ thermal treatment would be most applicable and cost effective given the technical challenges to remove pesticides from the subsurface and that rapid remediation was required.
- The project illustrates how energy, cost and time savings can be made via a combination of thermal modelling and bench testing to demonstrate a significant change in TTT (from 350ºC to 70ºC) could be made from the originally planned concept, allowing a change in heating technique.
- Use of the thermal model also enabled system design to be optimised (well spacing and heat input), energy source to be confirmed, and operation to proceed in the most efficient way (real time data collection to confirm model results).
- The project confirms the applicability of thermal remediation to remove entrained pesticides via mobilisation of oils, at temperatures well below the boiling point of these compounds.
- The data management procedures applied at this site were well above industry standard and used an integrated database and online platform to visualise key performance data (heat up progress and mass recovery), providing benefits to ERM and the client. This also involved collaboration with Information Solution experts outside of the contaminated land industry.
- Site logistical requirements were incorporated into the design (a need to keep some areas in proximity to the remedial treatment zone operational during the entire remediation programme).
- A key focus on sustainability throughout the project lifecycle, from the remedial options appraisal to the design and implementation.
- Development of a trusted advisor role with the key stakeholders (EA and site management).
- The Health and Safety approach included evaluation of technology specific risks, integration with site operations and hazard identification processes.

Cost effectiveness and durability
The approach adopted used innovative low temperature removal mechanisms to complete the operational phase more cost effectively than was originally envisaged, as outlined above.

Significant reduction of the pollution burden
The remedial technique selected rapidly maximised mass removal at a lower temperature than conventional application of thermal technology would have achieved. This reduced energy consumption and time, reducing the overall project costs.

Community and stakeholder acceptance

All project stakeholders were consulted with throughout the project, as follows:

- **Regulators:** ERM kept the EA informed throughout the project, including facilitating a site visit/training session during operation. The robust remedial approach undertaken enabled endpoints to be agreed quickly with the regulators.
- **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 how site staff could safely access the building whilst the treatment system was operational).

The works were completed safely, on schedule, on budget and to the satisfaction of all stakeholders.

Compliance with Health and Safety

ERM and the remedial equipment supplier instigated a proactive, sustainable approach to health and safety which frequently considered the risks in the context of an operational site. The work also fell under the Construction (Design and Management) Regulations (2015), therefore the roles and responsibilities were clearly defined as per the Regulations. In addition to typical risks considered for any in-situ remediation project, the following was also undertaken:

- Process safety was carefully considered at design stage and several reviews were undertaken; the outcome of which added several process safety features to the remedial equipment.
- Thermal specific H&S hazards were included within the project risk assessments.
- A strong safety culture was embedded within the project team to ensure that any observed hazards were identified and addressed. The work was undertaken with no lost time accidents over a period of circa 3,500 hours.
- Mentoring of junior staff was undertaken face to face throughout the works.
- Five project audits were also undertaken in accordance with ERMs global Active Safety Management approach, with lessons learnt fed back into the project and wider business.

Sustainability

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

- The use of innovative investigation techniques has been demonstrated at previous sites to have a lower carbon footprint than if multiple phases of traditional site investigation had been undertaken.
- A combination of sustainability led remedial options appraisal, modelling and bench testing was key to deriving the lowest carbon footprint for the most technically applicable solution.
- The remedial approach focussed on carbon footprint reduction to the extent practical, including:
    - Using a gas powered steam boiler.
    - Use of the mobilisation methodology to enable a significantly lower TTT, reducing energy consumption and carbon footprint.
    - Use of thermocouples and real-time data review systems to optimise heat injection.