CL:AIRE

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Concawe bulletin

CL:AIRE's Concawe bulletins describe the deployment of sustainable remediation techniques and technologies on sites in Europe. Each bulletin includes a description of the project context and conceptual site model along with a sustainability assessment. This bulletin focuses on the application of *in situ* thermal remediation on a UK site.

Sustainable *In Situ* Thermal Remediation

1. INTRODUCTION

The site is an active manufacturing facility located in a mixed commercial/residential area (exact location confidential). Impacts from petroleum hydrocarbons and chlorinated solvents were identified in subsurface soil and groundwater, originating from multiple point sources.

Remedial actions were performed by a contracting company, that comprised installation and operation of a pump and treat system designed to extract impacted groundwater from underlying Chalk. However, in 2010 following operation of this system for over a decade, it became clear that mass recovery had declined to levels where further operation of the system would not have been sustainable. It was also clear that a significant contaminant mass remained beneath the site.

Given this, ERM carried out additional site characterisation and a revised sustainability-focused remedial options appraisal during 2011 and 2012. This led to the replacement of the pump and treat system with a source treatment approach using *In Situ* Thermal Remediation (ISTR) to remediate the main identified source zone; this was carried out in 2014. The remedial treatment zone was located within a warehouse building used for storage.

The operational phase was completed within a four-month period, safely, on schedule, on budget and to the satisfaction of all stakeholders (including the Environment Agency – regulator in England).

This solution was implemented following a sustainability-based options appraisal (using the then newly published SuRF-UK framework (CL:AIRE, 2010) that was then enhanced by the identification and incorporation, where feasible, of Best Management Practices (USEPA, 2008)[1] in the system design and operational phases. Particular focus was placed on power consumption optimisation.

2. CONCEPTUAL SITE MODEL

The site is underlain by fill material (i.e. Made Ground), typically 0.3 m in thickness and consisting of a concrete hardstanding, over varied cohesive and granular soils. The fill is underlain by heterogeneous natural deposits consisting of mostly silty clays with rootlets and slightly sandy silts and clays with chalk gravel clasts. At a depth of circa 6 m below ground level (bgl) is the Upper Cretaceous Chalk, which is highly weathered directly underneath the Drift deposits forming 'putty chalk'.

Shallow groundwater is present within the natural deposits at depths of circa 2 m bgl forming a perched aquifer. No clearly defined groundwater flow direction could be ascertained.

The Conceptual Site Model (CSM) was refined via additional investigation using High Resolution Site Characterisation (HRSC) techniques. These techniques included use of surface geophysics using resistivity profiling to identify contaminant transport pathways, together with passive soil gas sampling to qualitatively determine the presence or absence of contaminant source zones. These results and those collected from traditional borehole drilling and sampling were synthesised via sequence stratigraphic assessments to provide a more detailed geological and hydrogeological CSM that then enabled the risks to human health and the environment to be more accurately defined.

Impact to soil from total petroleum hydrocarbons was widespread within the treatment zone at concentrations of up to 2,300 mg/kg. Chlorinated Volatile Organic Compounds (CVOCs) were also detected, including chlorobenzene at a maximum concentration of 77 mg/kg.

The main contaminants of concern within groundwater were chlorobenzene, at up to 33 mg/L, dichloromethane and trichloroethene (both compounds at up to 300 mg/L). These concentrations are indicative of the presence of Dense Non-Aqueous Phase Liquid (DNAPL).

[1] The term Best Management Practices is used in this document as the work undertaken preceded the SuRF-UK introduction of Sustainable Management Practices in 2012.

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3. RISK ASSESSMENT

The pump and treat system had been implemented based upon an assumption that contamination had migrated vertically from the Drift into the Chalk, which then represented a risk to a drinking water aquifer. However, the HRSC assessment concluded that pumping within the Chalk was making the situation worse, as it was inducing downward contaminant migration from the overlying Drift aquifer where the majority of the remaining impact was located.

The principal potential pollutant linkage was identified as between the Drift aquifer source and off-site surface water receptors, with most of the estimated contaminant mass present beneath a storage building. It was therefore agreed with the Environment Agency that the now defined contaminant source zone would be remediated on the basis of mass recovery to the extent technically and practically feasible. The remedial treatment zone comprised an area of circa 1400 m^2 (40 m x 35 m) and extended to a depth of 6 m bgl.

4. REMEDIAL OPTIONS ASSESSMENT

4.1 Identified remedial options

An updated remedial options appraisal was completed using existing UK guidance at the time (2011) including Contaminated Land Report 11 (Environment Agency, 2004) and Remedial Targets Methodology (Environment Agency, 2006) and the UK Sustainable Remediation Forum (SuRF-UK) framework (CL:AIRE, 2010), in two steps, as shown below:

- Step 1 – technology options were assessed initially by evaluating general feasibility (technical applicability). If an approach was not deemed to be technically effective, it dropped out at this stage.
- Step 2 – the technologies retained from Stage 1 that were deemed as generally feasible were taken forward for assessment of the technical effectiveness of detailed aspects of the remedial works to be carried out. The criteria at this stage were as follows and applied qualitatively:
  - ◊ Effectiveness on dissolved phase mass.
  - ◊ Effectiveness on DNAPL in soils.
  - ◊ Effectiveness on DNAPL in saturated zone.
  - ◊ Time to complete.
  - ◊ Cost range.
  - ◊ Surface infrastructure required.
  - ◊ Sustainability.

Three viable technologies were retained for more detailed evaluation, one of these being assessed for short and long term operation, giving a total of four assessments. These technologies comprised soil removal or *in situ* physical recovery processes. Injection based technologies were discounted because variability of the underlying lithology would have made subsurface delivery challenging. The presence of DNAPL would also have been expected to, at best, increase the timeframe or, at worst, inhibit the performance of either biological substrates or chemical oxidants. The retained technologies are summarised as follows:

1. Soil Excavation and Disposal: This technique would be constrained by the low headroom in some parts of the building, limited access, and the presence of foundation pads that would inevitably mean some contaminated soil would need to remain in place to maintain structural stability. Additional challenges included management of shallow groundwater and significant disruption to site activities in the context of an operational site.

2. Multi-Phase Extraction (MPE): This *in situ* technology involves simultaneous pumping of liquid and vapour from a series of wells, with contaminants removed in vapour, free and dissolved phase via in-well pumps and vacuum blowers connected to these wells. Recovered contaminants would be treated via a series of separators, air stripping and granular activated carbon technologies. MPE is a well understood technology and both short and long term approaches were considered in the assessment. However, given the variable nature of the geology, this technique would likely leave significant contaminant mass in place. MPE was assessed for both short term (6 months) and a long term (3 years) operation.

3. *In Situ* Thermal Remediation (ISTR): This technology is essentially a system that adds a heating component to a traditional ambient temperature MPE system. The heating process facilitates the liberation, mobilisation and/or degradation of contaminants. The benefits of this approach are that contaminants can be recovered independent of variations in lithology and the process can rapidly achieve a high percentage of volatile contaminant mass removal in both high and low permeability environments. This leads to greater certainty of success.

For the purposes of the sustainability assessment these retained techniques were carried forward into a semi-quantitative analysis using Multi-Criteria Analysis (MCA).

4.2 Sustainability assessment

The SuRF-UK framework describes two fundamental stages at which sustainability can be considered within a project: Stage A covers the plan/project design and Stage B is the remediation selection and implementation phase (CL:AIRE, 2010)[2]. This sustainability assessment relates to Stage B of the SuRF-UK framework, where the decision to undertake remediation has been made and the objective is to identify the most sustainable remedial option that can deliver the client's project objectives (CL:AIRE, 2010).

The technologies taken forward from the initial technical appraisal were assessed using a weighted quantitative MCA, informed by a comparative analysis of air impacts, energy and water consumption and worker safety using the US Navy SiteWise tool (US Navy, 2010). At the time of this appraisal there were few tools available and the SiteWise tool (also relatively newly published at the time) was used to provide a relative comparison of a number of predominantly environmental metrics that could inform the scoring in the MCA.

For this project, the key driver that influenced this assessment related to corporate policy and is defined as follows:

[2] The reader is referred to the SuRF-UK Framework document for a more comprehensive description of the each of the stages described here.

- Commitment to continual measurement and monitoring of its carbon footprint and to reducing this footprint through a carbon management programme.
- Sustainability as part of its Vision, Mission and Values, including:
  - ◊ To grow exceptional, long-term, sustainable value for all our stakeholders.
  - ◊ Being an employer of choice for empowered individuals in a safe and sustainable environment.

Works also had to be implemented within the context of an operational facility and the requirements of the facility and the workforce.

The sustainability assessment covers the 18 overarching categories of indicators described in the SuRF-UK framework across the three pillars of sustainability (CL:AIRE, 2010)[3], though after discussions within the project team the indicators were slightly adjusted to better reflect the key issues associated with the project (impacts on human health and safety were considered separately, impact on neighbours was renamed impact on surroundings – see Table 1).

Table 1: Overarching categories of indicators for sustainability assessment of remediation options (CL:AIRE, 2010).

Environmental	Social	Economic
• Impacts on air including climate change • Impacts on soil • Impacts on water • Impacts on ecology • Use of natural resources and generation of wastes • Intrusiveness	• Impacts on human health & safety • Ethical and equity considerations • Impacts on neighbours or regions • Community involvement and satisfaction • Compliance with policy objectives and strategies • Uncertainty, evidence and verification	• Direct economic costs and benefits • Indirect economic costs and benefits • Employment and capital gain • Gearing • Life-span and 'project risks' • Project flexibility

A relatively simple MCA was undertaken (summarised in Table 2) in which initially each of the sustainability indicators was given a weighting of 1 to 5 based on the judgment of the project team and reflecting the likely stakeholder interests. Within this site-specific context, criteria relating to impact to groundwater/air, human health risks, safety (as noted distinct from human health), legislative compliance and legacy risks were considered to be more significant indicators.

Following the weighting exercise, based upon the CSM and the identified drivers for action, each of the different remedial technologies was scored (again using the judgment of the project team) on a rating of -5 to +5 for overall net benefit (positive numbers) or cost (negative numbers) for each criterion.

In order to assist with the scoring (and in part to evaluate the usefulness of a quantitative approach within the context of an MCA) the SiteWise tool was used to quantify the relative impact of each of the short-listed options for a number of the environmental indicators. As noted above the SiteWise tool was used to help quantify the relative environmental footprint. A detailed description of the SiteWise tool is beyond the scope of this case study but the key features (as described in the SiteWise user manual) are summarised in Box 1.

Box 1: SiteWise tool summary (extract from user manual (US Navy, 2010)).

SiteWise™ is a stand-alone tool developed jointly by the U.S. Navy, U.S. Army Corps of Engineers (USACE), and Battelle that assesses the environmental footprint of a remedial alternative/technology in terms of a consistent set of metrics, including: (1) greenhouse gas (GHG) emissions; (2) energy use; (3) air emissions of criteria pollutants including oxides of nitrogen (NOx), sulfur oxides (SOx), and particulate matter (PM); (4) water consumption; and (5) worker safety. The assessment is carried out using a building block approach where every remedial alternative is first broken down into modules that mimic the remedial phases in most remedial actions, including remedial investigation (RI), remedial action constructions (RAC), remedial action operation (RA-O), and long-term monitoring (LTM). Once broken down into various modules, the footprint of each module is individually calculated. The different footprints are then combined to estimate the overall footprint of the remedial alternative. This building block approach reduces redundancy in the sustainability evaluation and facilitates the identification of specific activities that have the greatest environmental footprint. The inputs that need to be considered include (1) production of material required by the activity; (2) transportation of the required materials to the site; (3) all site activities to be performed; and (4) management of the waste produced by the activity. Materials usage is considered only for materials that are completely consumed (referred to as consumables hereafter) and cannot be reused during the application of the alternative.

For the purposes of the SiteWise assessment the default emission factors were first reviewed and adjusted where possible/practical to reflect UK conditions/practices. Then using the detailed anticipated scope and timescale associated with each alternative (using assumptions made during costing of each of the alternatives and based on a mixture of experience and initial engagement with contractors) the environmental footprint (and or other relevant metric) with each of the alternatives was calculated and the results are presented in Figure 1. The results were then used to inform the scoring used in the MCA assessment (noting that this primarily focused on environmental indicators but also included workers safety).

[3] Note that this assessment was undertaken prior to the publication of Annex 1: The SuRF-UK Indicator Set for Sustainable Remediation Assessment in late 2011.

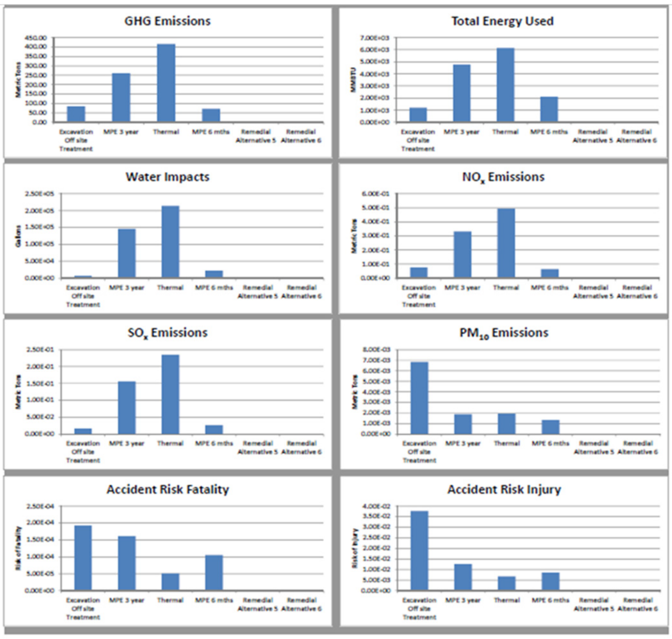

Figure 1: SiteWise outputs.

The results of the MCA are shown in Table 2 overleaf.

ISTR was selected as the preferred remedial solution, given that this was demonstrated to offer the greatest overall net sustainability benefit (+42 point score). This outcome was due to the high probability of the success due to a much higher maximum technically -achievable mass removal compared to ambient temperature MPE.

Short term ambient temperature MPE also scored highly but was lower than thermal due to lower achievable mass removal (20-30% of mass present).

Excavation scored the lowest due to health, safety and logistical challenges of soil excavation (source zone beneath a building and excavation hazards).

Although the environmental indicator for thermal remediation scored a net positive from an impact to soil and groundwater perspective, the negative scores relating to natural resource use and air emissions requires acknowledgement and was therefore focused upon during the remedial design and implementation phases.

The sustainability assessment was discussed and reviewed with the regulatory authorities (both Local Authority and the Environment Agency), who agreed with the approach and the endpoints proposed.

4.3 Thermal system overview

The ISTR system used Thermal Conductive Heating (TCH) as the heating methodology. This was selected principally due to the ability of TCH to heat the underlying lithology, irrespective of the variable permeability geology.

The system comprised 26 vapour/groundwater recovery wells and 14 gas-fired heating wells within the treatment area. 30 temperature monitoring points (thermocouples) were also installed to allow the heating process to be monitored and optimised.

The wells were linked to process equipment, which included pumps, soil vapour extraction blowers, a heat exchanger, inlet tanks and carbon vessels for treatment of vapour and liquid phase. The completed installation is shown in Figure 2.

Figure 2: Heating and recovery well array.

The system was operated for a period of 63 days, achieving the target treatment temperature of 80°C in the core of the treatment zone at depths where the majority of the contaminant mass was present (2-3 m bgl).

An estimated mass recovery of 380 kg of contaminant mass was achieved.

4.4 Further optimisation of the ISTR system to reduce carbon footprint

To reduce the carbon footprint of the remedial works, natural gas was selected as the fuel source for the TCH system. Total energy consumption for the gas used throughout the heating period was measured at 268,000 kWh (4,254 kWh per day). Had electrical power been used it is estimated that the energy consumption would equate to circa 350,000 kWh. This means that the use of gas has reduced the carbon footprint of the energy by approximately a third assuming the typical electricity generation mix in the UK at 2014.

Additionally, by the time the thermal treatment was implemented, best management practices for these technologies had been published (USEPA, 2012) and were implemented where possible. This included the use of thermocouples that allowed the subsurface heating process to be measured in near real-time, therefore enabling heating to be targeted in the areas where it was most needed or for the heat input to be reduced in zones that heated more rapidly. Once the thermocouples had shown that ground temperatures had reached the target treatment temperature in the areas of highest contamination, heating was discontinued and the pumping and vapour recovery system continued to extract in isolation for an additional 10 days.

Table 2: Results from MCA.

Sustainability criteria	Weighting (1-5)	Excavation	MPE 3 years	ISTR	MPE 6 months
Environment					
Impact on water	5	5	3	4	2
Impact on soil	1	5	3	3	2
Impact on air	5	-2	-3	-4	-1
Impact on ecology	3	5	3	4	2
Natural resource use and waste generation	4	-1	-2	-3	-1
Intrusiveness	3	-5	-1	2	1
Social					
Human health	5	-1	0	0	0
Safety	5	-4	-2	0	-1
Ethical and equity considerations	1	0	0	0	0
Policy and legislative compliance	5	4	4	4	3
Impact on surroundings	2	-2	0	1	1
Uncertainty, evidence and verification	1	3	0	0	0
Community involvement & satisfaction	3	-4	0	0	0
Economic					
Direct costs	3	-2	-2	-3	1
Indirect costs	3	-2	0	0	0
Employment opportunities & human capital	1	0	0	0	0
Gearing	1	0	0	0	0
Legacy and projects risks	5	5	3	4	2
Flexibility	1	0	0	0	0
Net environmental benefit		16	1	9	12
Net social benefit		-18	10	22	12
Net economic benefit		13	9	11	13
Overall net-benefit (Sustainability)		11	20	42	37
RANK		4	3	1	2

This led to a significant increase in VOC removal rates (10-20%) and associated mass recovery during this period, without use of additional energy for heating, saving approximately 42,500 kWh of gas. The continued recovery of VOCs from the ground without continuing to heat may have been due to reduction in steam accumulation in the vadose zone increasing the pore space available for vapour recovery, or enhanced by dissolved gas generation.

5. PROJECT HIGHLIGHTS

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

- This case study illustrates the importance of the development of rigorous CSMs early in the lifecycle of a remediation project, so that remediation can be undertaken in a sustainable manner from design to implementation, and resources not be wasted through inefficient application of remediation technologies (as occurred with the pump and treat system when the CSM was not fully understood). It also highlights the need to continuously review remedial system effectiveness against performance data on a regular basis and to optimise these systems or, as was the case here, revise the approach.
- At complex sites such as the one in this case study, HRSC tools are key to developing a robust CSM so that actual risks and, in this case, remedial approaches are designed and implemented appropriately. In this instance the HRSC underpinned the sustainable remediation approach that was carried out at this site and demonstrated how the longer term pump and treat was inappropriate to achieve remedial targets.
- 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 and is one of the first examples of use of the SuRF-UK framework.
- The remedial design phase of the project focused on energy and hence carbon footprint reduction to the extent practical, including using gas-powered TCH, to optimise energy use. This saved circa 82,000 kWh of power compared to if an electrically powered approach had been implemented.
- During the remedial implementation stage, the use of thermocouples to record temperature variations over time enabled the heating period to be reduced by ascertaining when the target treatment temperature had been achieved. Contaminant recovery continued for a period of 10 days without heating, saving another circa 42,500 kWh of energy.

6. LESSONS LEARNED

- It is recommended that sustainable management practices are considered at each stage of a project and ideally aligned with the overall sustainability objectives for the site.
- The SuRF-UK framework provided the means to improve the reliability and transparency of the remedial options appraisal process through consideration of a wide range of indicators. Subsequent remedial options appraisal processes have improved as familiarity with the framework has been gained and a workshop-type approach is now encouraged where stakeholders are directly consulted.
- Environmental footprinting can form a useful component of a sustainability appraisal but is not a sustainability appraisal in itself and its role in the context of the appraisal needs to be acknowledged. Appropriate and realistic design information and assumptions are needed to quantify each of the options and need to consider site-specific variables. The assumptions used in this process should be clearly documented.
- The ISTR solution selected via a sustainability-based options appraisal was enhanced by the identification and incorporation, where feasible, of best management practices in the system design by using gas as the energy source. Other best management practices incorporated into the systems operational phase included temperature tracking and post-heating contaminant recovery to optimise power usage. The best management practices used at the time focused on environmental indicators. Since 2012 (and updated in 2021) the Sustainable Management Practices as defined by SuRF-UK (CL:AIRE, 2021) would be the preferred approach and can be adopted to reflect the site investigation/risk assessment and remediation phases of the lifecycle.
- The HRSC approach adopted at the outset of the project was in itself a sustainable management practice but was not recognised at the time.

7. CONCLUSIONS

Whilst the use of ISTR is relatively energy intensive, this case study shows that the approach can be more sustainable than longer running pump and treat approaches, especially when HRSC is used to fully understand a CSM prior to its deployment and when best management practices are used to optimise energy consumption at design and implementation stages.

The energy reduction lessons learnt from the ISTR application at this site were that the energy source use and optimisation could be more widely applied to other sites to improve the sustainability of ISTR.

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