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 describes how a sustainability assessment helped to close-out a remediation.

Sustainability Assessment Case Study – Groundwater Remediation Close-Out

1. INTRODUCTION

Between 2007 and 2013 AECOM carried out active groundwater remediation to treat chlorinated hydrocarbons (CHC) which were detected within a sandstone aquifer below the site. The works formed part of a longer-term, 15-year programme of investigation and remediation of the site, a former chemical storage and distribution depot located in the United Kingdom.

AECOM completed a Sustainable Remediation Assessment (SRA) as part of the close-out of the remediation at the site. The SRA supported a 'lines of evidence' approach agreed with the regulators to evaluate if residual risks to the aquifer were acceptably low and if remediation could then cease.

2. SITE DESCRIPTION AND PROJECT CONTEXT

Initial investigation and monitoring works carried out in 2000 were to assess the condition of the soil and groundwater at the site and the contamination risks associated with historical site-use. The site had previously stored organic and inorganic chemicals, including chlorinated solvents, which were kept in above-ground storage tanks (ASTs). Figure 1 illustrates the site layout and area.

The investigation works identified the following CHC within soil and groundwater at the site: tetrachloroethene (PCE); trichloroethene (TCE); cis-1,2-dichloroethene (DCE); trans-1,2-dichloroethene; and 1,1-dichloroethane. Potential risks to human health were identified from vapour intrusion studies, together with potential risks to groundwater quality within the underlying sandstone bedrock aquifer, a regionally important groundwater resource. To address these potential risks a remediation strategy was developed and implemented.

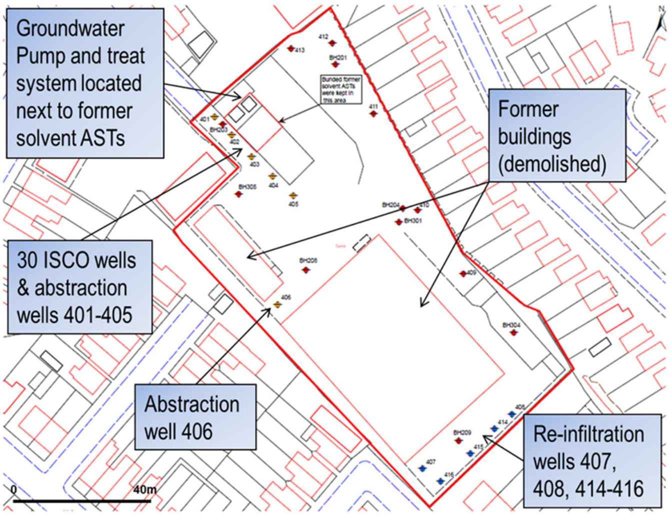

Figure 1: Site layout.

Initially a Soil Vapour Extraction (SVE) system was employed on-site, which operated from Spring 2002 until late 2003. SVE was used to mitigate potentially hazardous organic vapours and reduce contamination in the unsaturated soils in the area of the former ASTs. This remediated the unsaturated zone source and reduced the potential for further groundwater contamination. The system recovered approximately 2,100 kg of contaminant mass and was shutdown following a significant reduction in contaminant recovery rates, an updated assessment of the residual risk and agreement with the regulators that the SVE system had achieved its objectives.

To address the saturated zone impacts active groundwater remediation was undertaken from 2007 to 2013, which consisted of Pump and Treat (PT) and from 2011, *In Situ* Chemical Oxidation (ISCO). Active remediation was stopped at the end of 2013 to allow aquifer conditions to re-adjust before monitoring and further assessments were undertaken in Spring 2014.

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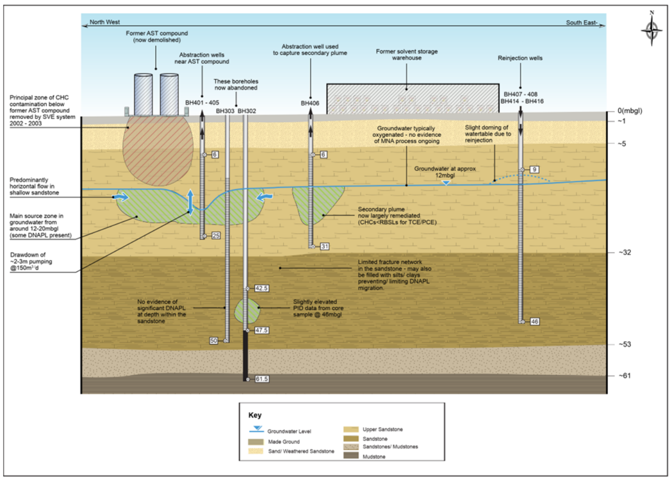
3. CONCEPTUAL SITE MODEL

The site is situated on sandstone bedrock which is overlain by sand covered with Made Ground. The groundwater table is located within the sandstone at approximately 12 m below ground level (bgl) and varied between 9 m to 15 m bgl. The principal contamination source identified was below the former ASTs area, with CHC detected in both the unsaturated soils and within the saturated sandstone, where Dense Non-Aqueous Phase Liquid (DNAPL) was present. Figure 2 illustrates the conceptual site model prior to and during remediation.



MNA: Monitored Natural Attenuation; PID: Photo-Ionisation Detector; CHC: Chlorinated Hydrocarbons; DNAPL: Dense Non-Aqueous Phase Liquid; RBSL: Risk-Based Screening Level

Figure 2: Conceptual site model.

The sandstone aquifer was identified as the critical receptor. This supported a number of licensed abstractions for both potable and non-potable use in the wider area. The closest operational abstraction at the time of the SRA was located approximately 0.5 km from the site. Groundwater also provided base flow to local rivers, the closest of which was approximately 1 km down-hydraulic gradient of the site.

Potential human health receptors identified at the site were future site workers (assuming an on-going industrial site use) and occupiers of off-site commercial and residential buildings. These could potentially be exposed to and affected by CHC vapours volatilising from shallow contamination (subsequently remediated by the SVE system) or deeper, dissolved phase contamination (remediated by PT and ISCO).

4. ASSESSMENT FUNCTION

Following the completion of the SVE implementation, the works carried out from 2007 to 2013 focused on the sandstone aquifer, primarily on monitoring, assessment of potential migration pathways and risks, and then active remediation to mitigate these. To achieve the remediation objectives, PT and ISCO were used to reduce CHC impacts in the saturated sandstone present below the site.

PT remediation activities from 2007 to 2013 were estimated to have treated a total volume of groundwater of 158,863 m^3 (98 m^3 per day). As a result, 616 kg of contaminant mass was estimated to have been removed (of which approximately 400 kg was before the start of ISCO). The PT remediation gradually depleted CHC concentrations within the sandstone aquifer.

ISCO was carried out alongside PT between 2011 and 2013 to reduce the mass of CHC contamination via mobilisation of sorbed and DNAPL phases into groundwater, so that they were more easily recovered by the PT system, and through oxidation (breakdown) of a proportion of the CHC present in groundwater, and in doing so, enhance PT operation and shorten the duration of groundwater remediation. A total of 30 injection wells were installed at shallow and deeper levels in the saturated sandstone around the ASTs source area. Four rounds of sodium persulfate injection were carried out during which a total of 12,500 kg of reagent was injected. Monitoring indicated good distribution of reagents within the aquifer for treatment. It was estimated that the volume of sodium persulfate used was capable of destroying a CHC mass in the range of 1,100 kg to 3,200 kg, based on pre-injection, bench trial data. Results identified that using a combined approach of PT and ISCO preferentially removed TCE from the source area rather than PCE. Due to the removal of TCE and a reduction in PCE present within the source area the total combined mass discharge from the site was significantly reduced. When comparing the results of the groundwater monitoring from 2004 to 2014, the maximum detected concentration of TCE had dropped from 39.50 mg/l to 0.23 mg/l. It was conservatively estimated that 1,100 kg of CHC mass had been removed from the aquifer by the ISCO implementation, giving a total estimated mass removal of 1,716 kg by both PT and ISCO.

The cessation of active remediation and the scope of close-out monitoring, assessment and reporting were agreed with regulators in advance of the ISCO implementation. This included taking a 'lines of evidence' approach to reach an end point for the remediation, which would consider:

- concentrations of CHC remaining in groundwater;
- evidence of mass removed;
- evidence of effective distribution of ISCO reagent;
- assessment of source depletion;
- revised quantitative risk assessment (to show lower risk);
- lines of evidence that full breakdown of PCE and TCE had taken place; and
- cost benefit of further remediation.

Active groundwater remediation was stopped at the end of 2013 to allow aquifer conditions to stabilise. Following this, a close-out groundwater monitoring programme was completed in 2014 and 2015. A review of the lines of evidence described above was undertaken, including a SRA.

5. SUSTAINABILITY ASSESSMENT

A SRA was used to assess the cost/benefit of further groundwater remediation and to support and inform decision making. It was agreed with the regulators that a Multi-Criteria Analysis (MCA) approach would be taken due to the complicated nature of the conditions on-site. The SRA was carried out in 2014 post-completion of active remediation works and a monitoring period during which groundwater conditions were allowed to stabilise.

The overall objective of the SRA was to assess whether it would be sustainable to continue active remediation at the site or to change to passive Monitored Natural Attenuation (MNA). This objective was achieved through the completion of the following tasks:

- assessment of the potential options for further remediation for the site using the MCA approach with an in-house sustainable remediation tool; and
- quantification of carbon emissions and costs associated with active remediation options to support the MCA.

The SRA was completed using an in-house sustainable remediation tool developed by an AECOM legacy company. This adopted the UK Sustainable Remediation Forum (SuRF-UK) definition of sustainable remediation by addressing the three pillars of sustainability equally, which is considered to be vital for a truly sustainable assessment.

The sustainable remediation tool enabled comparison of different remediation options, by way of a semi-quantitative assessment, against a set of sustainability criteria and indicators. The indicators were grouped into assessment criteria, divided into economic, environmental and social categories. The criteria and indicators used were based upon those published by SuRF-UK (CL:AIRE, 2010). Furthermore, the sustainable remediation tool allowed quantifiable and qualitative data to be collected to inform decision making and cost analysis, including a high-level carbon footprint assessment.

Four remediation options were considered in this assessment including three active and one passive option. The active options comprised further application of the two technologies already employed at the site, PT or ISCO, either individually or in combination. The passive option comprised MNA i.e. no further action would be taken at the site to address the groundwater contamination following completion of an agreed period of post system-shutdown monitoring. Table 1 provides an overview of all four options.

Table 1: Summary of the remediation options.

Remediation Option	Description
1	Pump and Treat (PT). An active method designed to hydraulically contain contaminated groundwater on site, remove contaminant mass from the aquifer and then treat it by stripping out the contamination using blown air and activated carbon.
2	*In Situ* Chemical Oxidation (ISCO). An active method designed to destroy and mobilise CHCs, using a reagent e.g. sodium persulfate and activator e.g. iron citrate and controlled reagent delivery within the contaminated zone.
3	PT and ISCO. Enhancement of PT by the use of ISCO.
4	Monitored Natural Attenuation (MNA). A passive option, requiring no active works and relying on natural processes to clean up or attenuate CHCs in groundwater, as assessed by a limited programme of further monitoring before completion of the remediation is agreed with regulators.

The sustainable remediation tool allowed for qualitative and quantitative assessment of the sustainability assessment criteria and indicators. During this project, an initial review of criteria and indicators was undertaken, followed by a semi-quantitative assessment of indicators identified during the initial review as being relevant to the site.

Multi-Criteria Analysis

The first step of the SRA comprised an initial qualitative assessment that drew upon the project team's knowledge of the site and remediation techniques, and reflected key stakeholder preferences. The stakeholders considered in this SRA were:

- the client (considered in terms of the objectives for the remediation and for the site);
- the consultant (responsible for completing the SRA, whilst taking account of the other stakeholders' perspectives);
- regulatory authorities (which had been consulted on, and had agreed the use of the SRA and the methodology to be used); and
- occupiers of neighbouring residential and commercial properties (considered in terms of potential effects of the remediation options).

The project team reviewed the criteria and provided a justification of each one that was considered relevant to the site. Following the initial review, weightings were selected for each criterion, using key relevant indicators to help inform the scoring.

In addition to the criteria, the other limits, or boundaries to the SRA were:

- method of evaluation – the effect of each remediation option was assessed relative to each criteria and the associated indicators by considering performance against the indicator consistently, to provide a 'like for like' comparison of options;
- lifecycle – the SRA was limited to site-based remediation activities, and as described below for the carbon footprint assessment;
- spatial extent – this was limited to the site, the underlying aquifer and neighbouring land uses, as described in the conceptual site model; and
- timescale – this was the time needed for completion of further remediation.

Fifteen sustainable remediation criteria were used as part of the SRA with all of them defined as within either economic, social, or environmental categories (Table 2).

A weighting of "0" was applied by the project team to criteria that were not considered relevant to the SRA, a weighting of "1" reflected low importance and a weighting of "5" indicated the highest importance. If two or more assessment criteria were equally important they were given the same weighting. The criteria highlighted in bold in Table 2 were identified as those with the highest importance according to stakeholders and assigned the greatest weighting. Weightings are shown on Figure 3.

Table 2: Indicators used to assess the sustainability of remediation options.

Economic	Environmental	Social
Direct Economic Costs and Benefits	Impacts on Air	**Human Health and Safety**
Indirect Economic Costs and Benefits	Impacts on Soil and Ground Conditions	Ethics and Equity
Employment and Employment Capital	**Impacts on Groundwater and Surface Water**	Neighbourhood and Locality
Induced Economic Costs and Benefits	Impacts on Ecology	Communities and Community Involvement
Project Lifespan and Flexibility	**Use of Natural Resources and Waste Generation**	Compliance, Uncertainty and Evidence

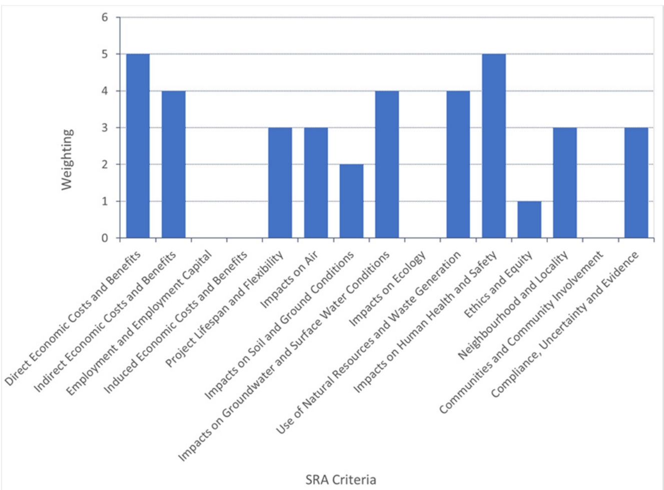


Figure 3: SRA criteria weighting for each social, environmental, and economic indicator.

The weighting process allowed the assessment criteria to be considered in relation to the site and the preferences of stakeholders. This enabled specific client or regulatory aims to be prioritised where necessary.

Following the weighting process, the project team held a workshop to review and select the scoring of the technology-specific remediation options. The workshop allowed subjectivity to be avoided as much as possible during the scoring process. The selection of scores was based on the project team's judgment of the degree to which the technology addressed the sustainability criteria, and the associated indicators, by considering performance against the indicator consistently for each remediation option.

The technology scores ranged from 1 to 5. A score of 1 indicated that the technology was the least favourable of the options at addressing the sustainability criteria. A score of 5 indicated that the technology was the most favourable alternative.

For each remediation option and assessment criterion, the technology score was multiplied by the sustainability weighting. The weighted scores are presented on Figure 4.

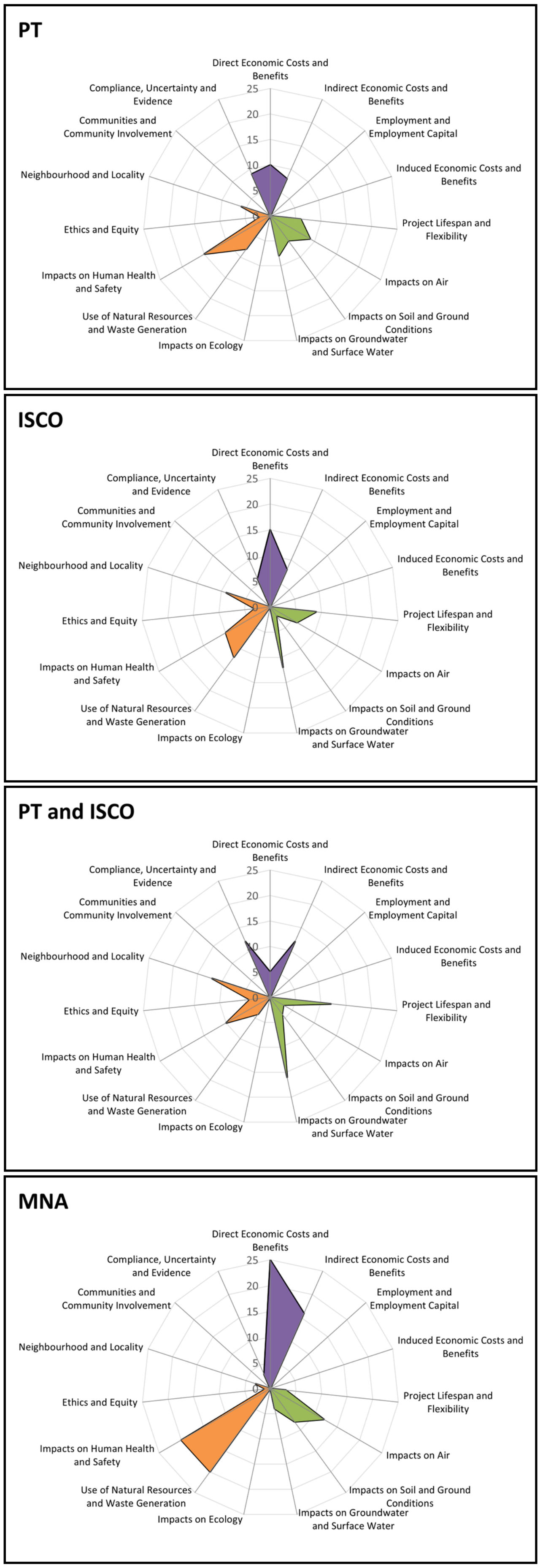


Figure 4: Weighted sustainability assessment scores.

The resultant weighted scores (Figure 4) were then expressed as a percentage of the maximum score possible and this was then normalised, to provide equal standing between environmental, economic, and social categories. These are presented in Table 3. This enabled a semi-quantitative assessment of the relative merit of each technology to be undertaken.

Table 3: Overall weighted score for each category (as a percentage of the maximum score possible).

Assessment Criteria	Maximum Score	PT	ISCO	PT and ISCO	MNA
Economic	60	40%	53%	48%	73%
Environmental	65	48%	49%	42%	68%
Social	60	53%	47%	63%	45%
% of Maximum Score (assuming 33% for each theme)		47%	50%	51%	62%

The assessment results were reviewed to ensure that the values were correctly reflecting the qualitative assessment. Values were then converted to percentage (%) with a higher percentage indicating a more sustainable remediation option. Figure 5 illustrates the results of the MCA.

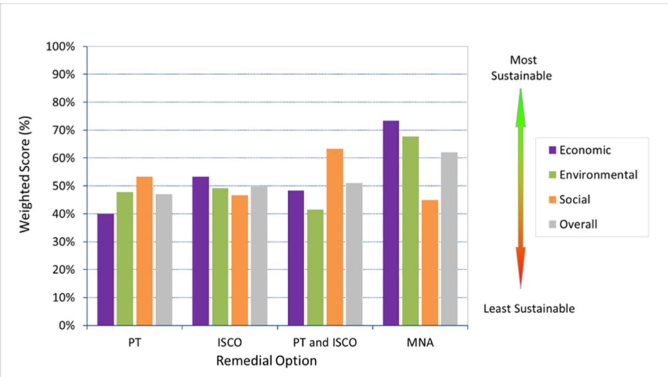


Figure 5: Normalised weighted sustainability assessment scores.

The MCA (as illustrated on Figure 5) identified that MNA was the most sustainable remediation option, with an overall weighted score of 62%. A combination of both PT and ISCO had an overall score of 51%, whilst ISCO alone scored 50%. The least sustainable remediation option identified was to use PT alone, with an overall weighted score of 47%.

The MNA remediation option scored well against economic and environmental indicators (scores of 73% and 68%), but for social indicators it was the lowest ranked of all remediation options, scoring 45%. A combined approach of using PT and ISCO scored the highest social sustainable factor, with 63%. This resulted from the technique able to remove greater contamination mass, returning the site to beneficial use more rapidly and with a reduced risk of regulators requiring further work.

A sensitivity analysis was performed on the MCA to see how changes to assessment criteria weighting and scoring would affect the overall weighted score for each of the four remediation options. The sensitivity analysis showed that the MNA option was not sensitive to changes in cost, project duration and flexibility and environmental impact. Whilst these changes resulted in a small percentage increase for each of the other three remediation technologies the weighted score of MNA remained greater.

Carbon Footprint Assessment

The second part of the SRA of remediation activities was to calculate the carbon footprints produced over the lifespan of the active treatment options (PT and ISCO) based on their implementation at the site to date. The passive option, MNA, was not assessed as no further action would be undertaken after the completion of the post-system shutdown monitoring. Inputs covered utilities (power and water), consumables (activated carbon and ISCO reagents), waste disposal, system operation and maintenance, and system performance monitoring. The footprint assessments were limited to site-based remediation activities, with emissions due to office or laboratory-based activities, or associated with consumables, such as tubing, gloves and laboratory testing equipment excluded.

Data were collected during monitoring rounds for utilities, waste, and equipment. Whereas for transport mileage data were used to estimate emissions for vehicular transportation of goods and site staff.

The emission factors were sourced from Government guidance for utilities and transport (Defra/DECC, 2012) and from the EcoInvent Database for materials (Swiss Centre for Life Cycle Inventories, 2009). Those for activated carbon assumed this would be re-activated carbon, originally sourced from coal. The relevant emission factors were applied to the data to give the carbon emissions arising for each activity. These were then summed to give the total carbon footprint for PT and for ISCO. The outputs enabled the carbon footprint to be compared to the cost of remediation, as well as the contaminant removal achieved at the site by each technology. Table 4 provides a summary of the carbon footprint assessment of PT and ISCO.

Table 4: Summary of carbon footprint assessment.

Remediation Option	Duration (years)	Contaminant Mass Removed (kg)	Total CO2e Emissions (kg)	Total Cost (£)	CO2e Emissions per 1 kg contaminant (kg)	Cost per 1 kg Contaminant (£)
PT	6.5	616	379,330	1,000,000	616	1,623
ISCO	2.5	1,100	43,695	500,000	40	455

Based on the carbon footprint calculations, ISCO was considered the better option, removing nearly twice the amount of the contaminant mass as PT, with lower carbon emissions and expenditure, and a shorter project duration. When comparing the above remediation options against MNA, it was considered that minimal emissions would be produced due to no further activities being carried out. However, MNA was the option considered least able to deal with changing circumstances at the site such as different land-uses or timescales.

The SRA was presented to the regulators in conjunction with the other lines of evidence including the results of further groundwater monitoring and solute concentration trend analysis, mass discharge estimation, update of the conceptual site model and updated quantitative risk assessments. Based on the remediation undertaken to date at the site, the results of the SRA and these other lines of evidence, further active remediation of the residual contamination in the saturated sandstone was not considered necessary, assuming on-site and off-site land uses did not change.

The regulators agreed that further active remediation to treat residual contamination in the saturated sandstone was not sustainable and that the remediation strategy for the site was complete.

6. PROJECT HIGHLIGHTS

Key project highlights include:

- application of a SRA to inform the future remediation strategy and the requirement for further remediation;
- regulators supported the use of MCA to assess the sustainability of the remediation options used on-site;
- thorough carbon footprint analysis to inform the decision-making process when identifying the most sustainable remediation option; and
- regulators agreed that further active remediation of residual contamination was not sustainable.

7. LESSONS LEARNED

A key lesson learned from this project was the value in using quantitative data to inform the decision-making process through estimating potential emissions for each active remediation option. Furthermore, this project illustrates the benefit of using a SRA, with other lines of evidence, to review the need for further active remediation.

8. CONCLUSIONS

A SRA was carried out to identify the most sustainable remediation option to address residual groundwater contamination following six years of active remediation comprising PT and ISCO. The assessment was based on environmental, social, and economic criteria and indicators using MCA and supported by an analysis of carbon footprints of potential options for further active remediation. The criteria and associated weightings reflected key stakeholder preferences. Findings from the assessment identified that the four potential remediation options varied in their sustainability impact, with MNA considered to be the most sustainable remediation option overall. Further active remediation of the residual contamination in the saturated sandstone was not considered justifiable, given the remediation undertaken to date at the site, the results of the SRA and the other lines of evidence. The regulators agreed that further active remediation to treat residual contamination in the saturated sandstone was not sustainable and that the remediation strategy for the site was complete.

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