CL:AIRE

CON 01
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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 sustainable remediation approach was applied on a UK site.

Sustainable Remediation of a Former Vehicle Maintenance Facility for Mixed Use Development

1. INTRODUCTION

This bulletin discusses a project in the London area, where a sustainability assessment was conducted to select the most appropriate remediation option for a 1.71 ha brownfield site to be redeveloped for mixed use. The aim of the bulletin is to demonstrate how the most sustainable option was selected using a publicly available digital tool - SURE by Ramboll ('SURE') - and the way sustainable approaches were deployed during full-scale implementation. In this bulletin the background to the project is summarised, the conceptual site model is presented and the remedial options selection process is described. Highlights of the project are provided, and conclusions are drawn regarding the role of sustainability assessment in achieving project goals.

2. SITE DESCRIPTION AND PROJECT CONTEXT

The site, which is located within East London, had been occupied by a vehicle showroom with associated vehicle maintenance operations taking place over approximately 40 years. Prior to this, a tin plate works and railway sidings were present. The client LocatED, on behalf of the Department for Education, which had purchased the site, was granted planning permission for a scheme of mixed high-rise residential and commercial (retail) development as well as a school, as part of a wider community regeneration scheme. The site had undergone a series of site investigations by various parties and following a Phase II intrusive investigation, Ramboll conducted a Detailed Quantitative Risk Assessment (DQRA) to assess the requirement for remediation, based on the presence of compounds of potential concern.

A site plan is provided in Figure 1, illustrating the sources of contamination.

3. CONCEPTUAL SITE MODEL

The conceptual site model is summarised in Figure 2.

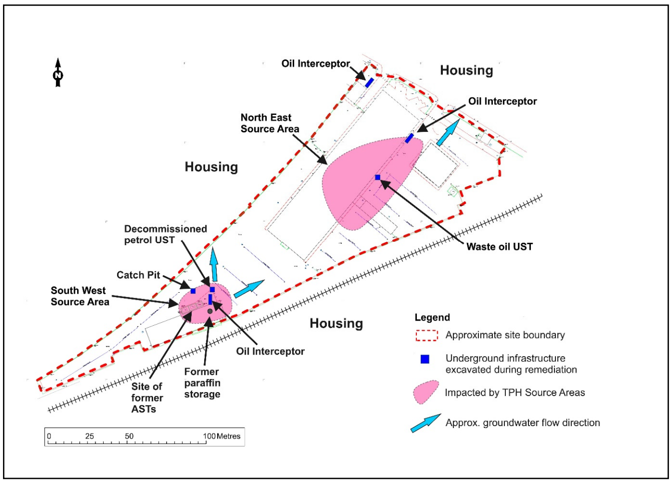

Figure 1: Site plan showing key source areas for remediation.

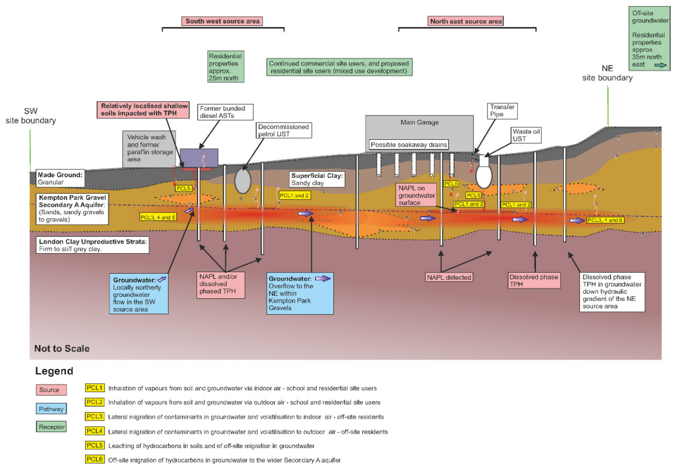

Figure 2: Conceptual site model (pre-demolition and remediation).

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There were three key sources of contamination, which together with the associated migration pathways, are described below:

Source Area 1 (north-east), diesel and lubrication grade petroleum hydrocarbons with Light Non-Aqueous Phase Liquid (LNAPL): The key source of contamination within this locality was a former waste oil Underground Storage Tank (UST). Leakage from this UST or its associated infrastructure had resulted in free phase lubricating oil and diesel migrating directly into the Kempton Park Gravel where on reaching the water table it had formed LNAPL. This has provided a continuing source of dissolution to the groundwater as dissolved phase contamination (measured as elevated Total Petroleum Hydrocarbons, TPH). Evidence of groundwater flow towards the north-east indicated that there was a potential for off-site migration of dissolved phase into the wider aquifer.

Additionally, potential leakage from the transfer pipelines may have impacted the made ground[1] and/or gravelly clay horizon directly above the overlying Kempton Gravels.

Source Area 2 (south-west), paraffin and diesel petroleum hydrocarbons with LNAPL: The assumed sources of contamination within this locality were likely to have originated from Above Ground Storage Tanks (ASTs) containing diesel and paraffin. Leakages and spillages from ASTs had resulted in localised hydrocarbon contamination in soil (particularly in made ground), whilst drummed paraffin storage in the former vehicle wash area is thought to have been a significant contributor to the groundwater impact as noted by the presence of NAPL characterised as kerosene. These hydrocarbons had impacted the made ground, then following downward migration through the Kempton Gravels had migrated laterally as NAPL, providing an ongoing source of dissolved phase hydrocarbons to the groundwater and presenting a theoretical vapour risk. Widespread hydrocarbons were present across a smear zone arising from groundwater fluctuations across the LNAPL impacted area.

Source Area 3, Diffuse made ground contaminants: The made ground contained low but diffuse concentrations of asbestos fibres together with elevated heavy metals and polycyclic aromatic hydrocarbons, collectively referred to as 'Made Ground Contaminants' (MGC) which posed a risk if they remained exposed at the surface after redevelopment.

The principal receptors to contaminants identified on site were therefore future site users, off-site residential site users and groundwater within the Kempton Park Gravel down hydraulic gradient of the site.

4. ASSESSMENT FUNCTION

Based on the above conceptualisation, the remediation requirements according to the substrata are set out in Table 1.

The Environment Agency's remediation option applicability matrix (Environment Agency, 2019) was used to screen potential remediation techniques for addressing the compounds of concern in each of the substrata identified in Table 1, based on the technical feasibility and practicability of implementation at the subject site. A number of the potentially applicable remedial techniques were combined into five remedial options, which were then short-listed for detailed assessment. These were as follows, the abbreviated title of the option highlighting the predominant remedial approaches (E&D: Excavation and off-site disposal; ESB: *Ex situ* bioremediation; ISB: *In situ* bioremediation; CAP: Capping (with minor off-site disposal)).

- **Remedial Option 1: E&D ISB**: Excavation and disposal of (i) made ground impacted by MGC and TPH, and (ii) deeper soil impacted by TPH and NAPL within smear zone and reinstatement with 'clean' imported backfill. Removal of residual NAPL by skimming pump or absorbent (depending on thickness) and treatment of dissolved phase by enhanced bioremediation through oxygen release, with a preliminary

Table 1: Summary of remediation requirements (receptors indicated in parentheses).

Contamination issue	Soil zone		
	Unsaturated zone	Smear zone	Saturated zone
MGC	Remove / treat source or interrupt pathway (on-site residents)	NA	NA
MGC & TPH	Remove / treat source or interrupt pathway (on-site residents)	NA	NA
TPH	Remove / treat source to achieve Site Specific Target Levels (SSTLs) (on-site residents)	Enhance oxidation status (during saturation phase) to enable natural attenuation to address residual concentrations (controlled waters)	NA
TPH as NAPL	No action required	Remove LNAPL as far as reasonably practicable (controlled waters)	NA
TPH as dissolved phase (various bands)	NA	NA	Achieve SSTLs as per DQRA (on & off-site residents)

NA: Not applicable

[1] Artificial man-made deposits such as fill material, re-worked soils and/or materials arising from previous demolition and importing.

Table 2: Short-listed options for review indicating target matrix.

Matrix/substratum	Options				
	Option 1	Option 2	Option 3	Option 4	Option 5
	E&D ISB	ESB ISB CAP	ESB ISB E&D	ISB CAP	ISB E&D
Made ground (asbestos & heavy metals)	Excavation & disposal	Containment	Excavation & disposal	Containment	Excavation & disposal
TPH-impacted soil		*Ex situ* bio	*Ex situ* bio	*In situ* bio (proprietary-Gypsum & GAC)	*In situ* bio (proprietary-Gypsum & GAC)
LNAPL	Skimmer/ absorbent	Skimmer/ absorbent	Skimmer/ absorbent		
Groundwater	*In situ* bio/chem	*In situ* bio/chem	*In situ* bio/chem		

phase of chemical oxidation if necessary. Creation of reactive zone at site boundary to promote ongoing natural attenuation.

- **Remedial Option 2: ESB ISB CAP:** Excavation of (i) made ground impacted by TPH, and (ii) deeper soil impacted by TPH and NAPL within smear zone and treatment on site by ESB. Removal of residual NAPL by skimming pump or absorbent (depending on thickness) and treatment of dissolved phase by enhanced bioremediation through oxygen release, with a preliminary phase of chemical oxidation if necessary. Creation of oxidative reactive zone at site boundary to promote ongoing natural attenuation. Segregation of made ground with unacceptable levels of asbestos and disposal off-site. Reinstatement of remaining MGC-impacted soil on site under planned infrastructure, in landscaped areas, with suitable capping where appropriate.
- **Remedial Option 3: ESB ISB E&D**: As for Option 2 but with off-site disposal of all MGC-impacted soil instead of containment.
- **Remedial Option 4: ISB CAP**: Treatment of TPH-impacted soil, NAPL and groundwater using a proprietary ISB approach based on gypsum (as sulfate) combined with granular activated carbon (GAC). Limited ESB of unsaturated zone TPH. Creation of oxidative reactive zone at site boundary to promote ongoing natural attenuation. Segregation of MGC-containing made ground with unacceptable asbestos and disposal off-site. Reinstatement of remaining MGC-impacted soil on site under planned infrastructure, in landscaped areas, with suitable capping where appropriate.
- **Remedial Option 5: ISB E&D**: As for Option 4 but with off-site disposal of all MGC-impacted soil instead of containment.

The applicability of the various techniques comprising each option to the substrata for treatment is summarised in Table 2.

5. SUSTAINABILITY ASSESSMENT

5.1 Methodology and project framing

A sustainability assessment of the five short-listed options was undertaken in general accordance with the guidance provided by the Soil Quality-Soil Remediation Standard ISO 18504 (BSI, 2017). This was conducted using Ramboll's in-house tool which has subsequently been developed into SURE and now made publicly available (https://ramboll.com/sure). SURE has essentially three functions; to assess the options, engage with stakeholders and report the results using a digitally-based platform. The assessment has therefore been re-run using SURE, with a similar output (the main difference being that the previous assessment had used 15 indicator categories whereas the SURE assessment used 25 indicators as criteria drawn from the updated SuRF-UK listing (CL:AIRE, 2020).

SURE enables the project details and framing to be recorded, prior to indicator selection and weighting. The assessment was framed in terms of the relevant boundary conditions (relating to restrictions imposed upon the evaluation of impacts and benefits), these being spatial (whether within the immediate footprint or on a wider scale), temporal (the planning horizon over which benefits/impacts are considered) and life cycle (in terms of the plant and equipment components of the remediation) as presented in Table 3.

Table 3: Boundary conditions used in the SURE assessment.

Spatial	Temporal	Life Cycle
Global, based on client commitment to action on global heating and overall sustainability ethos.	Extending indefinitely into the future, as driven by overall sustainability issues and intergenerational equity considerations.	All elements of the remediation, except manufacture of plant, reagents and equipment.

5.2 Selection and weighting of indicators

The assessment then proceeded as follows. A total of 73 indicators based on the updated SuRF-UK listing were reviewed for their applicability to the site, of which 25 in total were selected, nine, seven and nine from the domains of Environment, Society and Economy respectively. The indicators were weighted according to their relative importance on a scale of 1 to 5 as set out in Table 4, which groups the indicators according to the categorisation of SuRF-UK.

Table 4 (a): Indicators used, relative weighting (W) and rationale: Environment Domain

Category/indicator	W	Rationale
Emissions to air		
Greenhouse gases	5	Climate emergency
Ground Air Quality	3	Impact on local environment
Soil & Ground Conditions		
Soil functionality	1	Suitable for use, but restricted to specific development
Geotechnical properties	1	Suitable for use, but restricted to specific development
Groundwater & Surface Water		
Water uses	1	Moderate potential for future use
Legally binding objectives	5	Compliance
Ecology		
Disturbance	1	Urban site, limited
Natural Resources & Waste		
Energy & fuels use/generation	5	Climate emergency
Primary resources & waste	5	Global importance

Table 4 (b): Indicators used, relative weighting (W) and rationale: Social Domain

Category/indicator	W	Rationale
Human Health & Safety		
Long term risk management	5	Ethical & compliance
Direct risks	5	Ethical & compliance
Ethics & Equity		
Intergenerational equity	3	Moderate relevance
Neighbourhood & Locality		
Nuisance impacts	5	Potentially significant for local residents
Uncertainty & Evidence		
Robustness & rigour	1	Reasonable degree of information available for options but just need to assess from stakeholder perspective
Degree of uncertainty	3	Moderate importance, particularly in relation to achieving objectives
Validation/verification requirements	5	Onerousness of importance in demonstrating achievement of objectives for stakeholder benefit

5.3 Evaluation of options and scoring

The five options were then scored according to their positive or negative impacts on each of the indicators on a 1 to 5 scale, five representing the best performance. Scoring was undertaken proportionately, with options being assigned equivalent scores where differences between them were marginal. SURE computed the total weighted score, normalised on a percentage basis to the maximum score achievable, provided a breakdown of option performance against indicator category and also identified the relative

Table 4 (c): Indicators used, relative weighting (W) and rationale: Economic Domain

Category/indicator	W	Rationale
Direct Economic Costs & Benefits		
Direct costs/benefits	5	Key issue for client
Other costs	1	Of lesser significance in relation to direct costs
Uplift in site value	1	Low significance
Liability discharge / ease of divestment	5	Key issue for client
Indirect Economic Costs & Benefits		
Risk of damage	1	Limited concerns over selected options
Corporate reputation	3	Moderate importance for client
Project Lifespan & Flexibility		
Duration/timing of benefit	3	Reasonably important in order to fulfil development programme requirements
Chances of success	5	Key to fulfilling objectives
Flexibility to change in circumstances	3	Flexibility of intermediate significance

contribution to each of the 17 United Nations Sustainable Development Goals (UN SDGs). The latter was based on the linkages between each of the selected indicators and the relevant UN SDGs as have been identified by SURF-UK (CL:AIRE, 2020) for which SURE pre-assigns a linkage weighting on a scale of 0 to 5, based on the number of linkages to a particular UN SDG for the selected indicator.

Figure 3 shows the output from SURE at domain level. Option 2, (ESB, ISB, CAP) returned the best overall performance followed by Options 1 (E&D, ISB) and 4 (ISB, CAP). Substituting excavation of the MGC in place of capping significantly reduced the sustainability of Option 3 (ESB, ISB, E&D) compared to Option 2, as it did for Option 5 (ISB, E&D), compared to Option 4.

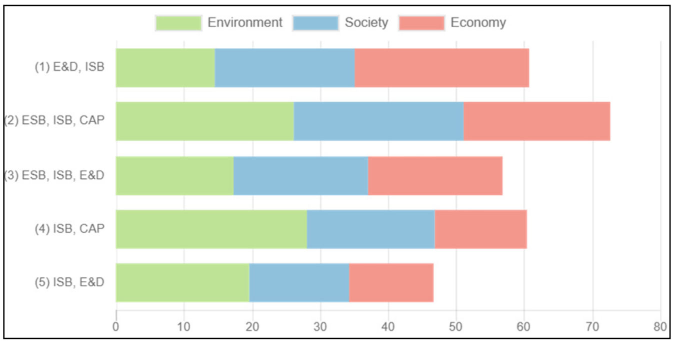

Figure 3: Total scores for each option, showing contribution of scores by domain. Normalised score expressed as a percentage of the maximum achievable score.

Remedial Option 2 delivered a good overall performance for each of the three domains, particularly Society, where it was also the best option, though Option 4 was marginally better for Environment, and Option 1 for Economy. Figure 4 provides a breakdown of the option scores for the indicator categories within each domain.

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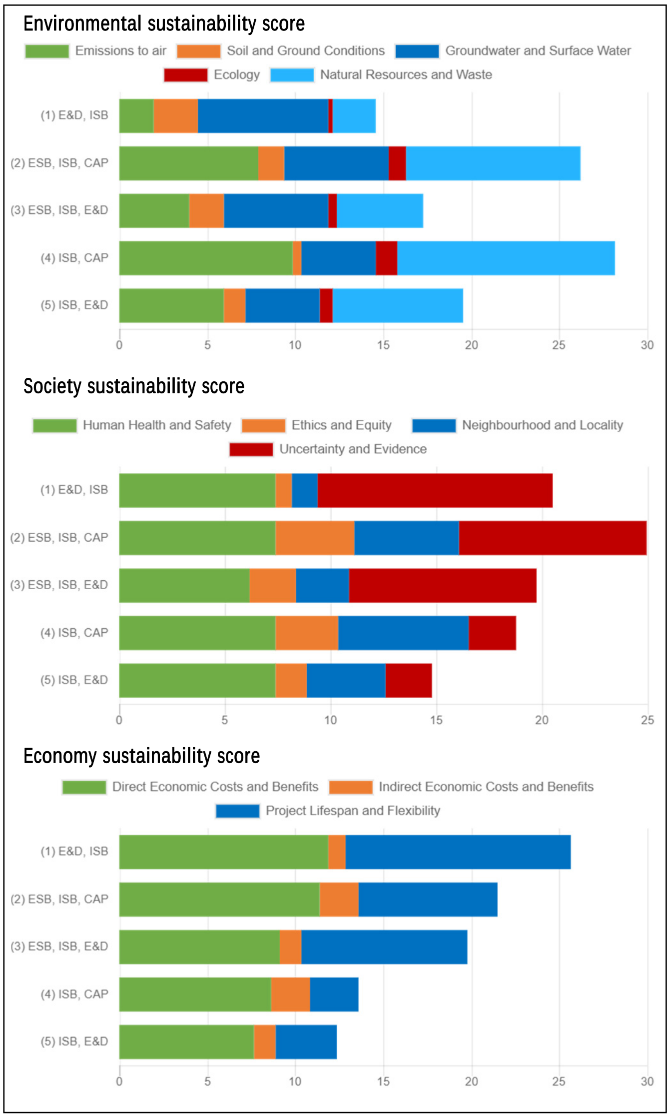


Figure 4: Option scores per indicator category for each domain.

For the Environmental criteria, the lowest scores were ascribed to the three Remedial Options (1, 3 and 5) involving excavation and off-site disposal, as this would likely have the biggest impact on carbon footprint, as well as representing relatively high waste generation, resource consumption and potentially other environmentally deleterious aspects such as releasing dust and volatiles. Remedial Option 4 avoids these issues through being an *in situ* approach, and whilst for such reasons it also scored better against the *ex situ* treatment option, it scored slightly less on soil and groundwater quality which Option 2 may address more efficiently and without imparting elevated calcium sulfate into the ground, as would be the case with the proprietary ISB approaches.

As noted in Table 3, the carbon footprint of the reagents used, including slow release oxygen or chemical oxidation was excluded due to such information not being readily available. Overall however, it is not considered that this would have made a significant difference to the outcome, given the magnitude of *ex situ* versus *in situ* differences driving the assessment and the fact that the same reagents were to be used in Options 1, 2 and 3 with Options 4 and 5 deploying an alternative approach, but also involving proprietary reagents.

For the Social criteria, Remedial Option 2 also scored highest, avoiding issues relating to vehicle movements that could impact neighbourhoods, and by using a destructive approach leaving less of a legacy for future generations than Option 1 (excavation). Whilst this was also the case for the two proprietary *in situ* approaches (Options 4 and 5) these performed less well regarding the uncertainty and evidence issue - inherent to *in situ* soil treatments to some extent but especially where NAPL is concerned and the difficulties of verification, particularly in the short term. The human health and safety category includes two indicators, one relating to the degree of mitigation of human health through the remediation process, the second relating to worker exposure and whilst the remedial options differed significantly for each of these indicators, the combined performances resulted in a similar overall score for each option.

Finally for Economic criteria, the off-site disposal option (Remedial Option 1) offered a more rigorous degree of mitigation in terms of contaminant removal, liability discharge, uplift in site value, and scored relatively well for indicators such as duration/timing of benefit, chances of success and flexibility. The best overall option, Option 2, however, is not far behind, but the proprietary approaches (Options 4 and 5) both perform less well due to the degree of uncertainty in treatment success, less flexibility and the extended time and costs required for laboratory treatability testing (including collection of additional samples).

A further means of assessing the relative performance of the options is through the UN SDGs. As examples, the relative contribution of Options 1, 2 and 5 to each of the 17 UN SDGs is presented in Figure 5 (overleaf), as respectively representing the best two and the worst performing options.

Whilst Remedial Option 2 performed better in the sustainability scoring than Option 1, the excavation-based option made greater positive contributions to the following UN SDGs:

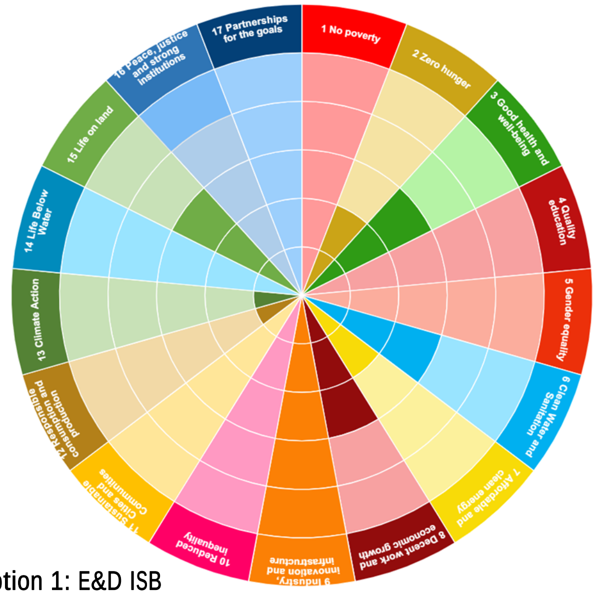
- SDG3 Ensure healthy lives and promote well-being for all;
- SDG6 Ensure availability and sustainable management of water and sanitation;
- SDG8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all; and
- SDG9 Build resilient infrastructure, promote inclusive and sustainable industrialisation and foster innovation,

than either Options 2 or 5. Both Options 2 and 5 did however make greater contributions to:

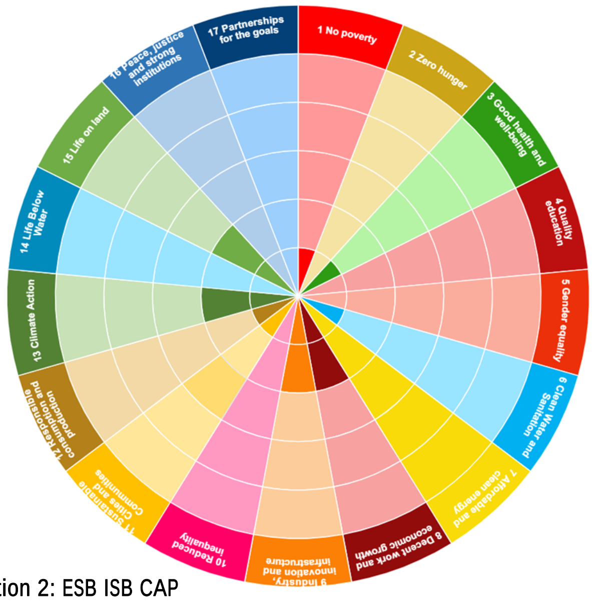
- SDG7 Access to affordable, reliable, sustainable and modern energy for all; and
- SDG13 Urgent action to combat climate change,

than Option 1. Option 2 also made a contribution to SDG 1 No poverty, unlike the other two and made equal or greater contributions to the remaining goals than Option 5, apart from SDG number 3 (health).

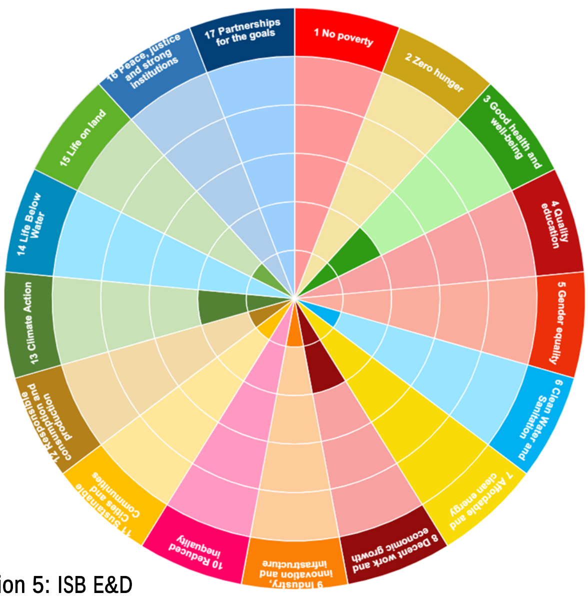
Based on the sustainability assessment undertaken using the SuRF-UK aligned indicators, Remedial Option 2 was selected as the best approach and subsequently developed into a formal remediation strategy.



Option 1: E&D ISB



Option 2: ESB ISB CAP



Option 5: ISB E&D

Figure 5: Comparative contribution to UN SDGs: Options 1, 2 and 5.

6. IMPLEMENTATION OF REMEDIATION WORKS

The remedial works were tendered and the contract awarded to Soilfix who implemented the following remedial actions in accordance with Ramboll's sustainable remediation strategy, based on Option 2:

- removal of decommissioned underground fuel and oil storage tanks and other potentially contaminative infrastructure including oil / water interceptors and catch pits, and sub-surface hydraulic rams;
- proof dig of the site to two metres below ground level to remove sub-surface obstructions and to handpick visible fragments of asbestos-containing material;
- excavation and on-site *ex situ* enhanced bioremediation of 1,074 m^3 of soils from two source areas;
- removal of 700 litres of LNAPL from groundwater via a series of horizontal recovery trenches (and disposed to a licensed waste management facility) and 224 m^3 of groundwater impacted with dissolved phase hydrocarbons (treated on site and discharged to foul sewer);
- in the saturated zone, *in situ* addition of proprietary reagents to promote desorption of free-phase hydrocarbons for enhanced recovery;
- enhanced aerobic bioremediation of residual hydrocarbons in the smear zone and saturated zone in two source areas using an extended oxygen release compound – using a combination of soil mixing and direct-push injection techniques.

All soil movements were completed in accordance with Soilfix's Materials Management Plan, compiled in accordance with Version 2 of the Definition of Waste: Development Industry Code of Practice (DoWCoP) (CL:AIRE, 2011), to achieve a zero materials balance. Opportunities for recycling of materials were maximised: demolition material was processed to create a high quality 6F2 graded aggregate for constructing the development platform, uncontaminated made ground arising from removal of obstructions was processed for re-use as engineered fill and 940 m^3 of coal tar impacted bituminous material was recycled at a dedicated recovery centre.

The remediation was verified in accordance with the requirements of the remediation strategy through:

- regular groundwater and ground gas monitoring from a network of monitoring wells across the site, including wells down hydraulic gradient of the source areas and comparison against site specific target levels (SSTLs) which are protective of on-site and off-site human health (volatilisation pathway);
- revision of the conceptual site model and SSTLs to more closely reflect the proposed development and conditions encountered during the remediation (whilst maintaining a level of conservatism in the assessment);
- collection of soil samples from excavations and comparison to SSTLs which are protective of on-site and off-site human health (volatilisation pathway) and groundwater;
- collection of soil samples during *ex situ* bioremediation and comparison to SSTLs which are protective of on-site and off-site human health (volatilisation pathway) and groundwater; and,

- collection of samples from materials to be re-used on site and comparison to SSTLs.

With respect to the clean cover system, this was to be undertaken as part of a separate construction phase remediation strategy, which would include an assessment of the ground gas and vapour monitoring data and the potential requirement (if any) for ground gas protection to be incorporated into the proposed development.

The scope of the remediation work as implemented was therefore fully consistent with the elements set out in Option 2.

7. PROJECT HIGHLIGHTS

The largest (north eastern) source area was impacted by significant quantities of free-phase weathered engine oil. Mass excavation and on-site treatment would have been logistically challenging and treatment to below SSTLs using bioremediation techniques unlikely to be viable within a realistic programme. The contractor, Soilfix therefore entered a non-compliant 'value engineered' proposal at tender stage that allowed for horizontal recovery trenches to be advanced across this source area to enable more efficient recovery of free-phase oils (Figure 6).

Figure 6: Recovery trench constructed in north eastern source area.

Following sufficient pumping to remove visible product, the NAPL recovery process was enhanced through direct push injection of Regenox® Part A (an *in situ* chemical oxidant) and Petrocleanze™ (a percarbonate-based reagent with detergent-like properties), both manufactured by Regenesis, at 50 injection points. Injection of these reagents promoted desorption of residual product and subsequent oxidation once mobilised in the dissolved phase. This was followed by residual polishing of the saturated zone by injecting, as well as *in situ* mixing, an oxygen release compound (ORC Advanced™, also manufactured by Regenesis) that promoted enhanced biodegradation of residual hydrocarbon contamination within soils and groundwater over a 12 month period.

This approach resulted in approximately 6,000 tonnes of soil being retained on-site rather than potentially requiring removal off-site for treatment or landfilling. Segregated hydrocarbon impacted soils from the south western source area (containing free phase paraffin/diesel impact) underwent bioremediation treatment before being reused on-site. Unnecessary over-excavation of this source area into the saturated zone was avoided through *in situ* soil mixing of a granulated oxygen release compound product (PermeOx® Ultra, manufactured by Evonik), to promote enhanced biodegradation of residual hydrocarbons within deeper soils and groundwater. Implementation of this activity is illustrated in Figures 7, 8 and 9.

Figure 7: Photo showing that the depth of the dig was just beneath the groundwater level to reduce over-excavation.

Figure 8: Photo showing the excavator adding the oxygenating compound. The machine used for subsequent mixing is seen in the background.

Figure 9: Photo showing mixing the reagent into the top layer of material using a specialist attachment on the arm of the excavator.

A combination of these approaches avoided removal of approximately 3,000 tonnes of hazardous waste from the site to landfill.

In total, across both the south western and north eastern source areas, the remediation techniques adopted saved 475 HGV loads (9,500 tonnes) of soil from being removed off-site to a permitted hazardous waste facility. As the site had a neutral material balance, this resulted in a further saving of 475 lorry loads of material imported into the site. In total around 950 lorry movements were therefore removed from the congested local highway network.

A view of the site post-completion is provided in Figure 10.

Figure 10: Photo showing the site following completion of works.

8. CONCLUSIONS

The following factors have been the primary contributors to maximising the sustainability of this project:

- Sustainability of the short-listed options was assessed using a procedure based on the principles of ISO 18504 (BSI, 2017).
- Effective use was made of DoWCoP (CL:AIRE, 2011) to plan, manage and implement a sustainable materials management solution with a zero materials balance being achieved.
- Site won hardcore from above and below ground demolition was processed into a high quality 6F2 graded aggregate and re-used for construction of a development platform.
- Coal tar impacted macadam requiring removal from site was sent to a recovery facility to be recycled rather than to a landfill.
- General (uncontaminated) Made Ground arising from obstructions removal was processed to a suitable grading for re-use as engineered fill.
- *In situ* treatment processes were used to promote enhanced removal of free-phase oil contamination and enhanced biodegradation of residual hydrocarbons in soils and groundwater within a Secondary Aquifer.
- Regular groundwater monitoring and review of the DQRA during the works programme ensured that the remedial scope was optimised and practicable, but still achieved significant environmental betterment.

A significant contribution to the overall success of the project was the collaborative spirit entered into by the client, consultant and contractor: the client being receptive to a sustainable strategy as developed by the consultant and the value-engineered proposal of alternative, less intrusive and more sustainable remedial methods for challenging contaminants (free-phase weathered engine oils and paraffin), as presented by the contractor. Going forward, the facility for online participation in the sustainability assessment process as is afforded by SURE, is expected to enhance the degree of stakeholder engagement in future projects.

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This project won the Best Application of Remediation Technologies category at the 2022 Brownfield Awards. It was also "Highly Commended" in the Best Sustainable Re-use of Materials category and the SURE tool was "Highly Commended" in the Best Research, Innovation or Advancement of Science in the Brownfield Sector category.