

Benchmarking of Decision-Support Tools Used for Tiered Sustainable Remediation Appraisal

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Abstract Sustainable remediation comprises soil and groundwater risk-management actions that are selected, designed, and operated to maximize net environmental, social, and economic benefit (while assuring protection of human health and safety). This paper describes a benchmarking exercise to comparatively assess potential differences in environmental management decision making resulting from application of different sustainability appraisal tools ranging from simple (qualitative) to more quantitative (multi-criteria and fully monetized cost-benefit analysis), as outlined in the SuRF-UK framework. The appraisal tools were used to rank remedial options for risk management of a subsurface petroleum release that occurred at a petrol filling station in central

England. The remediation options were benchmarked using a consistent set of soil and groundwater data for each tier of sustainability appraisal. The ranking of remedial options was very similar in all three tiers, and an environmental management decision to select the most sustainable options at tier 1 would have been the same decision at tiers 2 and 3. The exercise showed that, for relatively simple remediation projects, a simple sustainability appraisal led to the same remediation option selection as more complex appraisal, and can be used to reliably inform environmental management decisions on other relatively simple land contamination projects.

Keywords Sustainable remediation · Benchmarking · Soil · Groundwater · SuRF-UK framework

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1 Introduction

Sustainable remediation comprises soil and groundwater risk management actions that are selected, designed, and operated to maximize net environmental, social, and economic benefit (SURF 2009; Bardos et al. 2011). This is conducted in a manner to ensure the protection of human health and safety that is generally built upon some form of risk assessment such as risk-based corrective action. There has been a growing interest in incorporating sustainability considerations into remediation decision making processes in recent years, and a number of sustainable remediation appraisal frameworks have been developed (CL:AIRE 2010; NICOLE 2010; Holland et al. 2011; ITRC 2011). Each of these frameworks

recommends a tiered approach for appraisal of the sustainability of remedial options, starting with simple qualitative approaches and moving on to more complex, semiquantitative, and fully quantitative methods when required. Each sustainability appraisal method involves a different level of analysis complexity, data requirements, and associated resource and operator-skill to perform, while similarly aiming to aid an assessor's identification of the best remediation option. An ideal sustainable remediation decision support tool is quick and easy to use, requires minimal capital or human resources, and supports robust management decisions—ideally the same management decisions as would be generated using a much more complex and precise analysis of the options.

Sustainable remediation is a relatively new concept (Fortuna et al. 2011; Bardos et al. 2011). Remediation project-related research has included efforts to assess the sustainability of remedial options at mining sites (Worrall et al. 2009), industrially-contaminated land (Harbottle et al. 2008a, b; Bleicher & Gross 2010), waste treatment, storage, and disposal facilities (Petruzzi, 2011) for contaminated sediments (Sparrevik et al. 2012), and on the secondary environmental impacts of remediation at diesel-impacted (Sanscartier et al. 2010) and PCB-impacted sites (Busset et al. 2012). A number of sustainability appraisal decision support tools and software are now available, either as proprietary software or as freely downloadable software from a number of central government, regulatory authority, and military (e.g., US Air Force) websites. Research on the use of qualitative approaches (Morio et al. 2011; Schädler et al. 2011), multi-criteria decision analysis (MCA) (Sparrevik et al. 2012), life-cycle analysis (Sanscartier et al. 2010; Busset et al. 2012), and cost-benefit analysis (Environment Agency 1999; Hardisty et al., 2001, 2008) for sustainable remediation appraisal has been published. A narrower field of study that only considers the environmental consequences of remediation is also discussed in the literature, and is generally referred to as “green remediation” (USEPA 2008). Green remediation only considers the environmental aspects and is, thus, not a full sustainability-based approach, since social and economic factors are not considered. Many governments and businesses have overarching policy objectives to contribute to achieving sustainable development that influence policies and practice in more specific areas, such as contaminated land and water management. Sustainable remediation frameworks help assessors apply sustainable development principles to the management of soil and groundwater risk management.

This paper compares a selection of different sustainability appraisal techniques for a single remediation problem to test whether they lead to consistent conclusions, and to inform selection of an appropriate sustainability appraisal technique by remediation practitioners. The objective of the benchmarking exercise was specifically to determine the following:

1. Whether the use of different sustainability appraisal techniques would lead to the same, or different, environmental management (remedy selection) decisions
2. Time and resources needed to undertake a sustainability appraisal by each method
3. Assessor skill requirements, and
4. Data requirements

2 Approach

A benchmarking exercise was performed by using a single gasoline-release site as a test case on which different sustainability appraisal methods were applied. The selected site, a retail filling station site in central England, had previously been investigated, risk-assessed, and then remediated to the point where all unacceptable risks to human health and the environment had been mitigated, and the project had already achieved regulatory closure.

Prior to considering any site-specific details, an appropriate sustainability appraisal framework, sustainability indicators, and “rules” for scoring the benefits and impacts under each sustainability indicator were selected and agreed by all parties to the project. In this instance, the guidance issued by SuRF-UK (CL:AIRE 2010; 2011) was adopted. Once agreed, these common sustainability indicators, and scoring “rules” were used throughout the project (i.e., at all three tiers of sustainability appraisal).

In order to approach the sustainability appraisals in an open and non-prejudicial manner, all the available information for the site was collated and provided to the assessor in stages, to reflect the data that would likely be available at each tier of an appraisal in a real-life situation. The assessor, who was an experienced land contamination professional, undertook an appraisal of the sustainability of remedial options in a stepwise manner, starting with a simple qualitative assessment, followed by MCA, and then by a monetized cost-benefit assessment (CBA). At tier 1, the assessor was provided with site-specific details such as site characterization and risk

assessment reports, remedial options analysis (focusing on technical effectiveness). Details specific to the higher tiers of appraisal (e.g., monetary valuation of remedial benefits and costs) were withheld from the assessor until the appropriate appraisal tier was reached to ensure that decisions that ought to be based on data typically available during a tier 1 qualitative assessment were not influenced by access to more detailed financial data in a CBA report.

Following appraisal of the sustainability of the remedial options at tier 1, a report was prepared by the assessor that described the results and recommendations for remediation selection. The assessor was then provided with additional information typical of that necessary to undertake a more quantitative appraisal (such as estimated CO₂ emissions, water demand and waste generated, safety performance and cost for each remedial option, and the weighting that different stakeholders placed on the various sustainability criteria), and the exercise was repeated at tier 2 using a semiquantitative MCA method. Finally, at tier 3, an expert environmental economist was commissioned to undertake a CBA of the remediation project using all the project data available to the first assessor at tier 2. This assessment was undertaken entirely independently and without knowledge of the tiers 1 and 2 appraisals. The assessor was asked to select the most sustainable remedial solution for the site using the recommendations presented in the CBA report. During the appraisals, the assessors kept records of the time, data, ease of appraisal, other observations of the practicability of the approach, and of the remedial action recommendation they would make at the end of the appraisal process.

3 Case Study Site Conceptual Model

3.1 Location

The site used as a test case in this project was an operational petroleum filling station located in a rural location in central England. The site was surrounded by agricultural land to the south, a trunk road immediately to the east, and commercial properties to the north and west. There was no proposed change of use for the site, and remedial works were required to mitigate the risks to human health and the environment associated with an accidental release of unleaded petrol and to allow continued safe use of the site for fuel storage and dispensing.

3.2 Human Health Assessment

The site was covered in asphalt, and there were no contaminated soils exposed at the surface of the site. Assessment of the risks associated with possible vapor exposure indicated that the site did not pose an unacceptable risk to human health in its impacted state (pre-remediation) based on current condition and use.

3.3 Water Resources Assessment

The site is directly underlain by sandstones of the Permo-Triassic Sherwood Sandstone Group, which comprise a thick sequence of fluvial and aeolian sandstones. Under the UK approach, the aquifer is classed as a principal aquifer and a regionally important groundwater resource (Environment Agency 2006). Water quality in the Sherwood Sandstone aquifer is generally good (BGS & EA, 2007), with the exception of nitrate concentrations, which are generally elevated—both locally and at the regional scale—in the unconfined aquifer (Rivett et al. 2007).

Environment Agency groundwater piezometric data indicated that the regional groundwater flow was towards the northeast (down stratigraphic dip), and this was confirmed by the local groundwater level data at the site. The regional hydraulic gradient in this area was about 0.0055, and the depth to water table in the unconfined aquifer at the site was about 10 m BGL. Groundwater is abstracted in large volumes for potable supply at public water supply boreholes located 2.5 km northeast of the site (licensed abstraction ~25 Ml/day), 2 km south west of site (licensed abstraction ~15 Ml/day), and 5 km west of the site (licensed abstraction ~20 Ml/day). The site lay within the hydraulic capture zone of the borehole abstraction located 2.5 km north.

The groundwater resource (“controlled waters”) is considered by the Environment Agency to be a receptor. Environment Agency guidance (Environment Agency 2006) recommends a risk-based approach to management of existing soil and groundwater impacts. The approach seeks to minimize the impacts on the wider aquifer resource, while allowing natural attenuation processes to be considered in a limited volume of aquifer. This is achieved by locating a theoretical compliance point a short distance down-hydraulic gradient of the source and managing the impacted site to achieve relevant water quality criteria at that compliance point. In this instance, a compliance point located 50 m down-gradient of the point of release was agreed

due to the high water resource value of the aquifer, the remedial objectives set for soil and groundwater at the site to protect drinking water quality in the aquifer at that compliance point, and by inference water quality at each of the more distant abstraction boreholes.

A river was located to the east of the site, and flowed in a north-easterly direction, roughly 150 m from the site boundary. The river has a modified (canalized) profile, and survey data indicated that the water level in the river was about 2 m higher than the groundwater head in the underlying aquifer. Consequently, groundwater does not discharge into the river in this locality, and any hydraulic continuity would be river seepage downwards into the underlying aquifer.

3.4 Remedial Options Shortlist

A remedial options shortlist was developed for the project to mitigate the effects of a release of about 10,000 l of unleaded petrol (gasoline) into the unsaturated zone and groundwater, in order to meet water quality objectives at the compliance point and to protect each of the potential receptors identified. The unleaded petrol released at this site did not contain ether oxygenate compounds, and the principal constituents of concern were the BTEX compounds. Sixteen (16) different remedial options or combinations of options were identified (Table 1), including a variety of physical (e.g., soil-vapor extraction, air sparge, pump-and-treat, excavation-and-disposal), biological (e.g., in situ/ex situ bioremediation, monitored natural attenuation (MNA)), and chemical techniques (e.g., in situ chemical oxidation). A short-list of 16 options is impracticable for normal commercial projects and a screening exercise to reduce such a list to 4 or 5 preferred options would typically be done for such projects. However, for the purposes of this exercise, we elected to evaluate a longer list of remedial options.

4 Methods

4.1 Project Boundaries and Objectives

Prior to undertaking the appraisals, the assessor was presented with documented project objectives and goals. These set the boundaries for the subsequent appraisal, and are presented in Table 2. Furthermore, the assessor was presented with a list of 16 remedial

alternatives that were to be assessed (Table 1). It was assumed that each of the 16 remedial options would be successful in achieving the required risk management objectives at the site (i.e., compliance with drinking water standards at 50 m compliance point in aquifer, or prevent human exposure to potentially impacted groundwater via abstraction boreholes), and the focus of the appraisal was on identifying any additional benefits provided over and above meeting regulatory compliance, and of the environmental, social, and economic impacts of undertaking remediation. No pilot or feasibility trials were undertaken to prove the likely effectiveness or durability of the 16 remedial options under consideration, and the assessor was instructed to assume that each would work effectively at the site (i.e., technical feasibility was not considered as part of this sustainability appraisal, since that would normally be part of a screening exercise to shortlist remedial options prior to sustainability appraisal).

4.2 Sustainability Appraisal Methods

A range of tools and methods are available for undertaking a sustainability appraisal, but in essence, they all seek to achieve the same goal to assess the relative environmental, social, and economic benefits and disbenefits (or costs) for a range of suitable options that meet the project goals. The appraisal methods measure the benefits and disbenefits in some way (often financial cost, but could be any form of measurable “currency”) and seek to identify whether the overall benefits of remediation exceed the overall disbenefits of doing the work, and additionally the remedial option(s) that offer the maximum benefit/cost ratio. Three sustainability appraisals techniques consistent with the SuRF-UK framework (CL:AIRE 2010) were used in this project: a simple qualitative appraisal, a semi-quantitative MCA, and a fully quantitative CBA.

4.3 Qualitative Sustainability Appraisal

In the first instance, the assessor used a simple qualitative approach, whereby the relative environmental, social, and economic benefits and impacts of different remediation options were rated as “high,” “moderate,” or “low.” The assessor did not make a detailed assessment of the individual indicators or factors that might contribute to the performance of a remedial option under each of the three overarching pillars, but sought only to

Table 1 Remedial alternatives included in sustainability appraisal

Institutional controls and base case	Physical techniques	Biological techniques	Chemical techniques
Do nothing	Air sparge (AS)	In situ bioremediation	In situ chemical oxidation
Land/water-use restrictions	Soil vapor extraction (SVE)	Ex situ bioremediation	Water treatment at abstraction borehole
Purchase/close receptor borehole	Dual phase vapor extraction (DPVE) Pump-and-treat (at source) Excavation-and-disposal SVE+AS DPVE+MNA	Monitored natural attenuation (MNA) Permeable reactive barrier (PRB)	

rate the broader environmental, social, and economic performance of each option. Remedial options were compared against a “base case” of “do nothing,” albeit a “do nothing” approach was recognized as not being an acceptable solution either from a corporate or regulatory perspective following an evaluation of health and environmental risks associated with the fuel release. Under the “base case,” the contamination conditions were considered to remain constant over time, and attenuation processes were assumed not to occur. In contrast, MNA was assumed to be protective due to the presence of monitoring that gave evidence of, and confidence in, the rate and effect of natural attenuation process on hydrocarbon fate and persistence.

For ease of recording, the high/moderate/low ratings were recorded in a spreadsheet, where high=3, moderate=2, and low=1. The spreadsheet calculated the net environmental, net social, and net economic impacts for each of the 16 remedial options, and the overall balance according to Eq. 1.

$$SR_i = (B_{env} - I_{env})_i + (B_{soc} - I_{soc})_i + (B_{econ} - I_{econ})_i \quad (1)$$

Where

- SR_i Sustainable remediation “score” for remedial option i
- B_x Benefit resulting from remediation, where x =environment, society, or economy
- I_x Impact (disbenefit) resulting from remediation, where x =environment, society, or economy

4.4 Semiquantitative Multi-criteria Analysis

In tier 2, an MCA approach was adopted using a spreadsheet tool. Similar to tier 1, the benefits and impacts of

undertaking remedial action were assessed for a range of options. In tier 2, the original 18 SuRF-UK indicator categories¹ (Table 3) were used, and the assessor also weighted the relative importance of the six different indicator categories listed under each pillar of sustainability. Care was taken to ensure the total weights applied across the indicators under each of the environmental, social, and economic headings were equal, such that there was a balanced appraisal of the environmental, social, and economic factors.

Scores were given to each of the 18 indicators for each remedial option, by scoring between 1 and 9, using the remediation matrix presented as Fig. 1 as a guide to scoring. The matrix presents scores based on a combination of the magnitude of an impact or benefit, and the duration over which the benefit/impact occurs. In undertaking the tier 2 appraisal, the views of a range of stakeholders collected during a stakeholder engagement exercise were taken into account by the assessor, in order that the scores (1–9) and weightings (1–5) represented a consensus (following discussion, debate, and negotiation) of the stakeholder panel. Weightings were applied, when considered appropriate, between a score of 1 (low importance placed on a specific indicator) to 5 (high importance placed on a specific indicator on the overall sustainability appraisal). When no justification could be made for weighting indicators differently, they were all been given an equal weighting. In this instance, the assessor sought to include stakeholder perspectives from the business representa-

¹ Since the time at which this appraisal was completed, SuRF-UK has consolidated its indicator categories down to 15 categories, as presented in CL:AIRE (2011). The coverage of those categories is essentially unchanged.

Table 2 Project objectives, constraints, and scope of sustainability appraisal

Objective or boundary	Project-specific requirements
Long-term business expectation for site	Continued retail filling station
Business constraints during remediation	Minimize disruption to site operation—continue to operate as retail filling station Minimize safety risks to works and customers Comply with all relevant legislation and corporate standards
Risk-based remedial goals	Comply with local regulatory requirements relating to human health and environmental risk-management Comply with corporate HSSE Control Framework
Stakeholders	Responsible party—business/corporate function Responsible party—HSE advisor Environmental authority regulating remedial works Neighbors (representative of elected Parish Council)
Temporal boundary for analysis	Duration of plume under natural attenuation conditions, or 30 years
Spatial boundary for analysis	Consider site operations, impact on neighborhood (e.g., transport routes), wider environmental effects (e.g., water abstraction or CO ₂ emissions)
Life-cycle boundary for analysis	Consider transport and use of machinery and plant for remediation, but not its manufacture
Sustainability indicators	SuRF-UK indicator categories (CL:AIRE 2011)
Sustainability appraisal framework	SuRF-UK framework (CL:AIRE 2010)
Remediation options evaluated	16 risk-management options presented in Table 1
Sustainability techniques	Tier 1—qualitative appraisal Tier 2—semiquantitative multi-criteria analysis Tier 3—quantitative cost-benefit analysis

tives of the responsible party, the HSE (environmental representatives of the responsible party, the environmental authority responsible for regulating the remedial works, and the local community represented by the local Parish Council. The scores for individual sustainability indicators were multiplied by their respective weighting and were then summed in a manner similar to that described for the tier 1 appraisal.

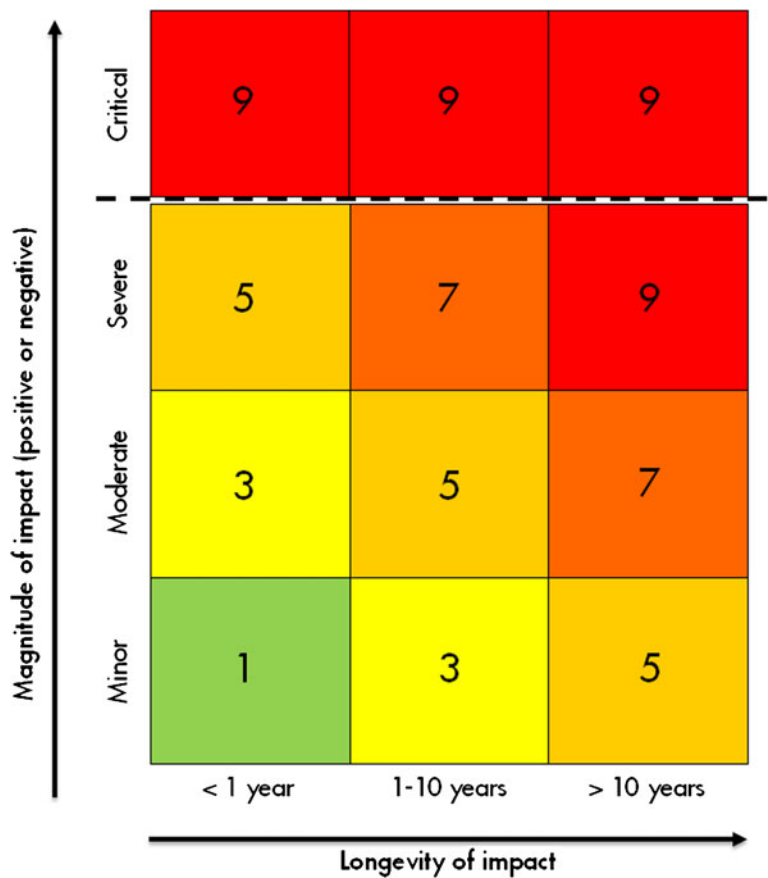
It is important to note that, at the outset of the assessment, an equal number of indicators (six) were identified under each of the environmental, social, and economic

headlines (i.e., a total of 18 indicators across the sustainability assessment) (CL:AIRE 2010). This procedure ensured that, in the absence of individual indicator weighting, the three sustainability pillars were given equal weight (i.e., the outcome is not automatically biased by a disproportionate number of indicators in a single sustainability pillar). At higher levels of assessment, where stakeholder engagement and participatory processes seek to establish consensus on the relative weighting of the three components or their constituent indicators, it may be appropriate to apply weightings to

Table 3 SuRF-UK sustainability indicator categories (after CL:AIRE 2010)

Environmental	Social	Economic
Air	Human health and safety	Direct economic costs and benefits
Soil	Ethical and equality considerations	Indirect economic costs and benefits
Water	Impacts on neighborhoods or regions	Induced economic costs and benefits
Ecology	Community involvement and satisfaction	Employment and capital gain
Natural resources and waste generation	Compliance with policy objectives and strategies	Life-span and project risks
Intrusiveness	Uncertainty and evidence	Flexibility

Fig. 1 Scoring matrix applied to tier 2 sustainability appraisals



the individual indicators to reflect the relative importance of different indicators to the stakeholders.

4.5 Fully Quantitative Cost-benefit Analysis

At tier 3, a CBA was commissioned by an independent expert environmental economist. The economist was provided with all the site-specific data available for the site, and in addition collated economic data necessary to input to a CBA. The WorleyParsons EcoNomics™ model was used in this instance, which was developed alongside development of local regulatory guidance (Environment Agency 1999, 2000; Hardisty et al. 2001).

Cost-benefit analysis applied monetized valuation of the costs and benefits of remediation. For some criteria, such as operation and maintenance costs of a remediation technology, this data may be reasonably readily available. For other indicators, particularly in the social and environmental categories, financial data is less readily available, and estimates and assumptions had to be made where data was not readily available. Particular effort was made to collate or derive economic data, where it

was believed there was likely to be a significant difference between the performance of remedial options, and less effort was made where it was considered likely that the performance of different remedial options would be very similar (and the CBA would not help to differentiate between remedial options). The key issue was to document assumptions and decisions (including the basis for cost estimation) in accordance with the principles set out by SuRF-UK (CL:AIRE 2010, section 2.1, principle 6). The economist provided a detailed report on the inputs, processes, and results of the CBA, which were provided to the assessor. The assessor then used this report, including the assumptions where economic data was limited, to make a recommendation about the best remedial options at the site at tier 3, as would be the case in a normal commercial decision process.

5 Results

The results of sustainable remediation appraisals at each of the three tiers are presented in Table 4. For

Table 4 Results of sustainability appraisals undertaken at tiers 1, 2, and 3, presented as remedial option rank in comparison to other options

Remedial option	Tier 1 qualitative*	Tier 2 Semi-quantitative*	Tier 3 [§] quantitative	Quartile [†]
Base case (Do nothing)	14	13	14 (0.4)	444
Excavation and disposal	9	12	13 (0.58)	334
DPVE	1=	4=	2 (1.11)	111
SVE	4=	8=	5 (1.05)	122
Ex situ bioremediation	8	8=	11 (0.67)	223
Pump and treat	10=	11	8 (0.8)	332
Air sparge	10=	10	12 (0.66)	333
MNA	4=	1	3 (1.09)	111
In situ bioremediation	4=	4=	6 (0.96)	112
In situ chemical oxidation	10=	7	7 (0.81)	322
Permeable reactive barrier	3	3	10 (0.7)	113
Air sparge+SVE	4=	6	4 (1.06)	121
DPVE+MNA	1=	2	1 (1.18)	111
Water treatment at receptor BH	10=	14	9 (0.75)	343
Close receptor borehole	16	15	16 (0.2)	444
Restrict water use	15	16	15 (0.25)	444

*Equals sign (=) indicates remedial options rated as equal under that tier of appraisal

§ Tier 3 results show benefit/cost ratio in parentheses

† Quartile position of ranked result in tiers 1, 2, and 3, respectively. For example, a value “232” indicates that remedial option ranked in the second quartile at tier 1, third quartile at tier 2, and second quartile at tier 3 appraisals

each tier, the ranked position of remedial options is tabulated, where 1 is the most sustainable option identified in that appraisal and 16 the least sustainable. In the tier 3 results, the table additionally presents the calculated benefit/cost ratio in parentheses. A value greater than unity indicates that the (environmental, social, and economic) benefits resulting from remediation using that technique are greater, in this instance, than the net costs. The final column of Table 4, titled “Quartile,” presents the quartile position (Q1–4) of the remedial option in each of the three tiers. For example, a value of “132” indicates that that remedial option ranked in the first quartile at tier 1 (i.e., ranked 1, 2, 3, or 4), third quartile at tier 2 (i.e., ranked 9, 10, 11, or 12), and second quartile at tier 3 appraisal (i.e., ranked 5, 6, 7, or 8).

The tier 1 appraisal was able to differentiate between a group of remedial options that were clearly better (in the context of this specific project) than another group of options. Two options, dual-phase vapor extraction (DPVE) and DPVE+MNA, were ranked joint first, and a further five options, which included MNA, in situ bioremediation, and air sparge+SVE, were ranked third/joint-fourth. The least sustainable remedial options included receptor control, treatment, and closure and pump-and-treat.

At tier 2, the more detailed appraisal (using 18 indicators instead of three) was able to differentiate between

options ranked equally at tier 1; however, the overall ranking of options was very similar. Fourteen of the 16 options evaluated fell in the same quartile of ranked results in tiers 1 and 2. At tier 2, MNA was ranked highest, and options incorporating DPVE and in situ bioremediation filled most of the top five positions.

Cost-benefit analysis at tier 3 additionally allowed calculation of benefit–cost ratios for each remedial alternative. The top three ranked remedial alternatives were DPVE+MNA (B/C=1.18), DPVE alone (1.11), and MNA alone (1.09). Similar to the results from tiers 1 and 2, the receptor-based risk management actions (e.g., receptor closure and water use restrictions) performed poorly in this analysis.

Of the seven remedial options that were ranked as Q1 at tier 1, three were also ranked in Q1 for both the subsequent tiers 2 and 3 analyses. Of the other 3 options, in situ bioremediation ranked Q2 at tier 3, air sparge-SVE ranked Q2 in tier 2, PRB ranked Q3 at tier 3, and SVE ranked Q2 at both tiers 2 and 3. The two options that ranked first and second at tier 1 (DPVE and DPVE+MNA) were the same two options that ranked top in the tier 3 analysis, albeit the order was reversed. Of the 16 options evaluated, nine ranked in the same quartile at tiers 1 and 3, and only 1 (PRB) differed by 2 quartiles (moving from Q1 to Q3 with more complex analysis). Most of the remedial options

Table 5 Observations made during sustainability appraisal benchmarking exercise

Criteria	Qualitative	Semiquantitative (MCA)	Quantitative (CBA)
Time/effort*	~0.5–1 day	1–3 days	~1 week
Data requirements	Generic data generally adequate.	Quantification of data for key indicators helped assessor assign scores (1–9) more confidently.	Site-specific valuation data necessary
Practicability	OK. Sufficiently simple ranking exercise Enjoyable process	OK. Considerable debate over scores Can be difficult for a single assessor to fairly represent a range of potential stakeholder views if attempted without direct stakeholder input.	OK. Relies on use of third-party CBA and valuation data. Debate centered on assumptions embedded in CBA.
Summary	Able to differentiate between different types of remediation option. Not able to resolve subtlety between similar remedial techniques. Quick, easy.	Added numbers to qualitative assessment, but debatable whether added robustness. Can be difficult for a single assessor to fairly represent different stakeholder views.	Able to resolve between subtly different remedial options. Full CBA is data hungry—preferable to use partial CBA to investigate differences between options rated as preferable options at tiers 1 or 2. Monetary valuation data does not exist for all indicators (particularly social).

*Time taken to perform an appraisal by assessor(s) under this project. With practice running through the process may be able to reduce timescales. Excludes time required for preparation of reports etc

that had benefit–cost ratios greater than 1 fell in Q1 for all three tiers of analysis, and all remedial options that had B/C ratios less than 0.667 fell in either Q4 (three remedial options) or Q3 (2 remedial options).

Observations on the time, data, and assessor-skill requirements and practicability of tiered sustainability appraisals are summarized in Table 5. Moving from tier 1 through to 3, the time and effort required to complete an appraisal increased. Similarly, the requirement for site-specific data (particularly at tier 3) increased considerably. In this study, the process of appraising sustainability was found to be relatively straightforward; the stakeholder discussions even enjoyable. The study considered a large number of remedial options (16), which is more than would typically be evaluated on a commercial project, and it is suggested that screening remedial options based on their likely effectiveness, durability, and practicability to a given contamination problem would help to ensure that sustainability appraisals are focused only on those techniques that are realistic remedial options. For simple projects, such as a fuel retail filling station, tier 1 appraisal proved effective in distinguishing a limited number of remedial options that were clearly better than other options. More detailed

appraisal at tiers 2 or 3, while not considered necessary for this example site, could best be used to identify differences between the short list of Q1 remedial options identified at tier 1, and specifically to help quantify areas where there is considered to be a significant difference between those remedial options. Used in this way, it would not be necessary to quantify an impact or benefit at tiers 2 or 3, where there is not considered to be a significant difference between the performance of the remedial options with regard to that impact or benefit. Rather, effort should be focused on quantifying those impacts and/or benefits where the performance of remedial options differs significantly and could lead to a different conclusion regarding relative sustainability of options, and therefore selection of a remedial solution.

6 Conclusions

Sustainability considerations are increasingly important in soil and groundwater risk management. New sustainable remediation frameworks recommend a tiered approach to sustainability appraisal. This project compared the results of appraisal undertaken at tiers 1, 2, and 3 as described in

the SuRF-UK framework (CL:AIRE 2010) and found that, for a relatively simple remediation project, a tier 1 appraisal resulted in reliable remedial option selection, which was consistent with decisions that would have been made using more complex tiers 2 and 3 appraisals. Consequently, the tiered approach set out in the new international frameworks is considered effective. Our work suggests that for relatively simple remediation projects, a simple tier 1 sustainability appraisal may be sufficient. The tier 1 appraisal proved effective in distinguishing a limited number of remedial options that were clearly better than other options. More detailed appraisal at tiers 2 or 3 could best be used to identify differences between the highest ranking options from a simple appraisal, and specifically to help quantify areas where there is considered to be a significant difference between those remedial options, which might influence their relative sustainability.

Regardless of the tier of appraisal used, it was found that clear project objectives and boundaries were critical, and that clear definitions of the scope and nature of each sustainability indicator and clear rules or guidance for how to apply weightings and scores to indicators were prerequisites for a successful appraisal. Guidance issued more recently by CL:AIRE (2011) and ITRC (2011) may prove particularly helpful in this regard.

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