Science of the Total Environment 563–564 (2016) 755–768

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The rationale for simple approaches for sustainability assessment and management in contaminated land practice

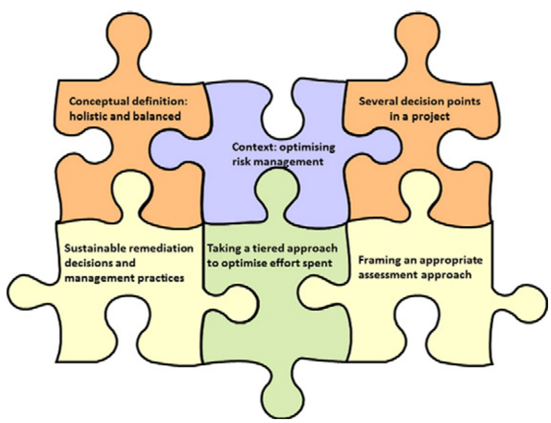
R. Paul Bardos [a,b,*], Brian D. Bone [c], Richard Boyle [d], Frank Evans [e], Nicola D. Harries [f], Trevor Howard [g], Jonathan W.N. Smith [h,i]

[a] r[3] environmental technology UK Ltd, University of Reading Whiteknights Campus, Reading, UK
[b] School of Environment and Technology, University of Brighton, Brighton, UK
[c] Bone Environmental Consultant Ltd., Mickleton, Chipping Campden, UK
[d] Homes and Communities Agency, Rivergate, Temple Quay, Bristol, UK
[e] National Grid Property, National Grid House, Warwick Technology Park, Gallows Hill, Warwick CV34 6DA, UK
[f] CL:AIRE, 32 Bloomsbury Street, London WC1B 3QJ, UK
[g] Environment Agency, Horizon House, Deanery Road, Bristol BS1 5AH, UK
[h] Shell Global Solutions (UK) Ltd, Lange Kleiweg 40, 2288 GK Rijswijk, The Netherlands
[i] Groundwater Protection & Restoration Group, University of Sheffield, Kroto Research Institute, Sheffield, UK

HIGHLIGHTS

- Sustainable remediation is used to optimise the selection of remediation activities
- Since 2007 SuRF-UK has produced comprehensive guidance on sustainable remediation
- It advocates a tiered approach to minimise cost and complexity in decision making
- A framing process has been developed to support consistent assessment at all tiers
- SuRF-UK guidance is informed by and consistent with international state of the art.

GRAPHICAL ABSTRACT



A distillation of the SuRF-UK approach to sustainable remediation.

ARTICLE INFO

Article history:
Received 13 August 2015
Received in revised form 1 December 2015
Accepted 1 December 2015
Available online 4 January 2016

Keywords:
Sustainable remediation
Contaminated land management

ABSTRACT

The scale of land-contamination problems, and of the responses to them, makes achieving sustainability in contaminated land remediation an important objective. The Sustainable Remediation Forum in the UK (SuRF-UK) was established in 2007 to support more sustainable remediation practice in the UK. The current international interest in 'sustainable remediation' has achieved a fairly rapid consensus on concepts, descriptions and definitions for sustainable remediation, which are now being incorporated into an ISO standard. However the sustainability assessment methods being used remain diverse with a range of (mainly) semi-quantitative and quantitative approaches and tools developed, or in development. Sustainability assessment is site specific and subjective. It depends on the inclusion of a wide range of considerations across different stakeholder perspectives. Taking a tiered approach to sustainability assessment offers important advantages, starting from a

* Corresponding author at: r[3] environmental technology UK Ltd, University of Reading Whiteknights Campus, Reading, UK.
E-mail addresses: paul@r3environmental.co.uk (R.P. Bardos), brian.bdbone@gmail.com (B.D. Bone), Richard.Boyle@hca.gsi.gov.uk (R. Boyle), Frank.Evans@nationalgrid.com (F. Evans), nicola.harries@claire.co.uk (N.D. Harries), trevor.howard@environment-agency.gov.uk (T. Howard), Jonathan.W.Smith@shell.com (J.W.N. Smith).

http://dx.doi.org/10.1016/j.scitotenv.2015.12.001

Remediation
Option appraisal
Sustainability assessment
SuRF-UK

qualitative assessment and moving through to semi-quantitative and quantitative assessments on an 'as required' basis only. It is also clear that there are a number of 'easy wins' that could improve performance against sustainability criteria right across the site management process. SuRF-UK has provided a checklist of 'sustainable management practices' that describes some of these. This paper provides the rationale for, and an outline of, and recently published SuRF-UK guidance on preparing for and framing sustainability assessments; carrying out qualitative sustainability assessment; and simple good management practices to improve sustainability across contaminated land management activities.

1. Introduction

Land contamination is recognised as a threat to soil and water quality, and to the wider environment (Van-Camp et al., 2004), and it can also pose significant health, environmental and social pressures (Environment Agency, 2009). Land contamination problems are common around the world. For example, Van Liedekerke et al. (2014) estimated that 2.5 million sites are potentially contaminated across Europe. The management of contaminated land imposes substantial economic costs, amounting to billions of pounds worldwide each year. The scale of land-contamination problems, and of the responses to them, makes achieving sustainability in contaminated land remediation an important objective (Bardos et al., 2011a, 2011b). There is now an active international debate about how best to ensure that land contamination is managed in a sustainable manner (Bardos, 2014). In this context, sustainable remediation is the process of effectively managing contaminated land risks to human health and the environment in a manner that minimises the environmental footprint, maximises societal benefits, and minimises the costs of those remediation activities. Ideally all three outcomes are achieved, but where trade-offs are necessary, the assessment provides a framework to identify and select the best, or most sustainable, remediation solution.

The Sustainable Remediation Forum in the UK (SuRF-UK) is an initiative established in 2007 to support more sustainable remediation practice in the UK by providing guidance based on multilateral inputs from different practitioners and stakeholder interests (CL:AIRE, 2010).

This paper describes SuRF-UK's latest guidance on preparing for and defining ('framing') the sustainability assessment and for a simple qualitative 'entry-level' to sustainability assessment in remediation projects (CL:AIRE, 2014a) It also presents suggested 'sustainable management practices' for application across all phases of contaminated land activities from planning and procurement, site investigation through to implementation and verification of remediation works (CL:AIRE, 2014b).

2. Historical context

For the past decade the prevailing international consensus, at least across much of Europe, has been that risk assessment is the most rational approach for determining remediation need and urgency (CLARINET and NICOLE, 1998; NICOLE and Common Forum, 2013, Vegter et al., 2002). Risk assessment provides a means of understanding which receptors might be affected, and how severely. It evaluates both the magnitude of any consequence and likelihood of the consequence. On this basis decisions can be made on behalf of society about how to best allocate scarce resources. In many countries risk assessment takes into consideration the proposed use of the site following remediation (Nathanail et al., 2013), so that more sensitive end-uses require more stringent remediation goals than less sensitive uses.

The importance of sustainability in this discussion is manifold, but is related to the effective *delivery* of whatever risk management is necessary to protect human health or the wider environment (Hou and Al-Tabbaa, 2014; Holland et al., 2013; Plant et al., 2015):

- Some technical means of delivering remediation may be more beneficial than others, or have fewer negative impacts;
- In some cases the use of generic risk management thresholds may lead to an over-design of the remediation leading to unacceptable impacts elsewhere, for example compared with a site specific approach;
- There may be opportunities for synergy, for instance with renewable energy, green building, and waste recycling where remediation processes could deliver multiple benefits (*e.g.* biomass production as well as risk management, from phytoremediation (Licht and Isebrands, 2005);
- The potential negative outcomes of delivering a particular set of remediation goals may suggest reconsideration of the design of site-use originally envisaged;
- There may be opportunities to make sustainability gains by considering remediation as part of an overall land management planning process, for example taking into account a mosaic of land uses or changes in approach to the design and layout of buildings;
- Potentially developments in policy and legislation, combined with the limited availability of public funds, provide a major opportunity to shift the policy focus for contaminated sites from management of costs and liability, to value creation.

It could be argued that suitably professional project designers should already have many of these ideas in mind. However, explicit consideration of sustainability puts these considerations into a systematic structure, and perhaps widens the range of available considerations to allow for a more holistic assessment. Properly executed sustainability assessment also allows for these considerations, their assumptions and their evidence to be more effectively discussed across stakeholder interests, transparently recorded, properly documented and ultimately verified (CL:AIRE, 2010).

Since the mid-1990s a broad range of tools have been developed for or applied to the assessment of the wider impacts, or latterly the sustainability, of remediation measures. One of the first was a system developed by TNO in The Netherlands called STEPS in the early 1990s (Aelmans et al., 1993, van Veen et al., 1997; Ferdinandy and Weenk, 1999). This evolved into the 'REC' tool from The Netherlands which provides three indices related to risk reduction effectiveness, cost and 'environmental merit' (Beinat et al., 1998) to support choices in remedial method selection. Both were derived from life cycle assessment (LCA) concepts, as was the 'Sinsheim' tool developed in Germany (Bender et al., 1998). REC and other LCA based tools continue to be researched as tools for remediation decision-making (Cappuyns and Kessen, 2013). Around the same time the German Federal Environmental Protection Agency was promoting a semi-quantitative approach to support option appraisal for brownfields development. This was based on three indices calculated on the basis of a prescribed series of categories and weightings, intended to be related to monetary value: 'site potential index', 'exploitation potential index' and 'site value' (Grimski et al., 1998). In 2000 the Environment Agency of England and Wales published a review of approaches for understanding the 'wider environmental value' of remediation which suggested a more qualitative approach (Environment Agency, 2000a). Around the same time the Environment Agency also published approaches for cost benefit analysis and cost effectiveness analysis for remediation (Environment Agency, 1999 and 2000b).

In 2002 the outputs of EU funded CLARINET networking project[1] recognised that sustainability in remediation was an integrated consideration of social, economic and environmental factors (Bardos et al., 2002), in line with the concept of sustainable development advanced by the Brundtland Commission (Brundtland, 1987). The initiation of the various sustainable remediation networks described in Table 1 has led to a proliferation of method development for the application of sustainability assessment to remediation.

Sustainability has also developed in importance as a criterion in decision making for brownfields redevelopment. Indeed explicit consideration of social and economic goals took place as early as 1961 for the feasibility study for the Lower Swansea Valley restoration work (Bromley and Humphrys, 1979; US EPA, 1992).[2] Its terms of reference were to '*establish the factors which inhibit the social and economic use of land in the Lower Swansea Valley and to suggest ways in which the area should be used in the future*'.[3] While brownfields restoration is a broader context than remediation, there are obvious cross-overs, not least that the management of land contamination is frequently required as part of a brownfields restoration (BenDor et al., 2011; CABERNET, 2006). A range of sustainability assessment techniques have been developed for brownfields decision making. A qualitative approach was developed in Scotland in the late 1990s (Curran and Hart, 1998). In the mid-2000s the European 'RESCUE' project developed a semi quantitative 'sustainability assessment tool' based on site-specific scores and weightings developed through a stakeholder process to identify sustainable development priorities (RESCUE Consortium, 2005). This approach was endorsed by the European 'REVIT' project in 2007 (REVIT Consortium, 2007). The UK SUBR:IM project (Sustainable Urban Brownfield Regeneration: Integrated Management) also suggested that indicators for sustainability assessment for brownfields restoration should be based on a similar process of identifying priorities (CL:AIRE, 2007b). In Germany the 'SAFIRA' project produced an integrated numerical sustainability and economic assessment model (Schädler et al., 2011) called the MMT tool. This software offers two different indicator-based approaches to assess sustainability. The first one, a set of fixed indicators allows assessing the suitability of different land-use types in regional context of the particular site. This makes use of 15 general and normative sustainability goals developed by (Bleicher and Groß, 2010). The second approach explicitly considers spatial planning options. Here, stakeholders define site-specific problems and relate them to indicators suitable for measuring sustainable development (Morio et al., 2011).

3. Current state of the art for sustainable remediation

Across the world there is now a developing consensus about the definitions and concepts underpinning what is broadly described as 'sustainable remediation' (Bardos, 2014; Rizzo et al., 2016) and a growing technical understanding of how it should be implemented. Table 1 provides a timeline of some of the key developments in the evolution of sustainable remediation. Experiences have been shared in three international sustainable remediation conferences[4] (Copenhagen 2009, Vienna 2012, Ferrara 2014) and a special issue of *Journal of Environmental Management* is planned on the topic in 2016. Many of the organisations and networks involved meet quarterly 'on-line' with

Table 1
A timeline of some of the key events in the evolution of the sustainable remediation concept (in part summarised from Bardos et al., 2012; Bardos et al., 2013; Bardos, 2014).

Year	Event
1961	Terms of reference for the Feasibility Study for the Lower Swansea Valley Regeneration project (one of the first ever restoration projects), specifically couched in terms of social and economic benefit
1979–1985	UK led international NATO Challenges of Modern Society (CCMS) study on contaminated land which included a conclusion that treatment based solutions were environmentally preferable to solutions based on containment or removal to landfill (Smith, 1985)
1978–1983	Major land contamination incidents for example in The Netherlands (Lekkerkerk, 1980–81) and the USA (Love Canal — 1978, Time Beach — 1983) trigger widespread concerns about hazards from land contamination. To see an example of the shock of these events read Eckardt C. Beck in the EPA Journal, January 1979a[a]
1986–2007	A series of NATO/CCMS Pilot Studies involving various NATO Countries and others (*e.g.* Australia, Japan, EPAC) focusing on treatment based remediation approaches[b]
1987	Publication of the Brundtland Report
1995	Publication of the REC method in The Netherlands, the first well established decision framework considering three metrics: risk reduction, cost and 'environmental merit' (NOBIS, 1995a,b)
1998	Publication of the findings of the EU funded network on the scientific basis for risk assessment for contaminated land (the 'CARACAS' project, 1995–1998) which established a broad technical basis for risk based decision-making for contaminated land management (Ferguson et al., 1998).
1999/2000	Publication in the UK of Environment Agency reports of the wider environmental value of remediation, and of cost benefit analysis for remediation (Environment Agency, 1999, 2000a, 2000b)
2002	Publications of the findings of the EU funded 'CLARINET' network[c],1998–2001) which established risk-based land management as the principal rationale for decision-making for contaminated land management (Vegter et al., 2002), sustainability explicitly recognised as a consideration in risk management decision making (Bardos et al., 2002)
2004	Publication of the 'Model Procedures' in the UK which anticipated the importance of wider concerns (such as stakeholder opinions and wider impacts of remediation) in contaminated land management decision-making (Environment Agency and Defra, 2004))
2006	Initiation of the Sustainable Remediation Forum (SURF) in the USA which was the first cross-sectoral stakeholder forum explicitly focused on developing sustainability as a consideration in remediation outcomes
2007	Initiation of the Sustainable Remediation Forum in the UK (SuRF-UK), which although quite independent of SURF, was inspired by it, and continues to work with it.
2008	Publication of the first guidance on 'green remediation' by the US EPA
2009	Initiation of SuRF-Australia and New Zealand (they published a sustainable remediation framework based on SuRF-UK in 2011[d])
2010	Publication of SuRF-UK framework for sustainable remediation, which was the first cross sectoral sustainable remediation guidance document accepted by national regulatory organisations (CL:AIRE, 2010)
2010–2013	Establishment of SuRF networks in The Netherlands (2010), Brazil (2010), Canada (2011), Italy (2012), Taiwan (2012) and Colombia (2013).
2011	Publication of a sustainable remediation framework in the USA by SURF (Holland et al., 2011)
2011	Publication of the NICOLE 'road map' for sustainable remediation, the first internationally agreed guidance (NICOLE, 2011)
2011	Interstate Technology & Regulatory Council (ITRC) Report on green and sustainable remediation' (ITRC 2011)
2012	Establishment of 'SURF-International' an informal quarterly forum where many of the SURFs and NICOLE gather in web conference calls to exchange information, experiences and ideas[e]
2012	Initiation of ISO/DIS 18504 to draft a descriptive standard for 'Sustainable Remediation'.
2013	Risk-Informed and Sustainable Remediation — Joint Position Statement by NICOLE and COMMON FORUM
2013	ASTM Standard Guide for Integrating Sustainable Objectives into Cleanup, E2876-13
2013	The International Committee on Contaminated Land (an international policy and regulatory network) tabled its first discussions on 'green and sustainable remediation' in Durban, South Africa. www.iccl.ch

[1] Concerted Action CLARINET – Contaminated Land Rehabilitation Network for Environmental
Technologies – started on 1.7.1998 and terminated on 30.6.2001. www.umweltbundesamt.at/en/umweltschutz/altlasten/projekte1/international1/clarinet/clarinet_results
[2] See also http://www.archiveswales.org.uk/anw/get_collection.php?inst_id=35&coll_id=11283&expand.
[3] Quoted on www.welshcopper.org.uk/en/copper-guides_lsvp_history.htm.
[4] www.eugris.info/newsdownloads/GreenRemediation/, www.umweltbundesamt.at/sustainable_remediation2012 and www.sustrem2014.com.

Table 1 (*continued*)

Year	Event
2016	Planned publication date for a special issue on sustainable remediation in the *Journal of Environmental Management*
2016	Anticipated publication of ISO 18504 on Sustainable Remediation

[a] http://www2.epa.gov/aboutepa/love-canal-tragedy Accessed July 2015.
[b] NATO/CCMS Pilot Study information and some of the later reports can be found at: www.cluin.org/global Accessed July 2015.
[c] The Contaminated Land Rehabilitation Network For Environmental Technologies in Europe.
[d] See http://landandgroundwater.com/page/sustainable-remediation-forum-for-australia-new-zealand-surf-anz accessed July 2015.

secretarial support from CL:AIRE.[5] In addition, members of many of these initiatives, along with other practitioners, have collaborated as experts nominated by their respective national standards bodies under the auspices of the International Standards Organisation (ISO/DIS 18504) to draft a proposed *informative* standard for 'Sustainable Remediation'. The proposed standard aims to draw together an international consensus on the nature and process of identifying sustainable remediation on a site specific basis (ISO 2015). In addition to sustainable remediation, within the US a number of government organisations and networks have been developing a related concept of 'Green Remediation', as defined in US EPA (2008a).

Green remediation is intended to reduce the demand placed on the environment during clean-up actions and to conserve natural resources. Green remediation anticipates that the major decision making elements setting the boundaries for remediation action, including economic and social considerations, have already taken place. 'Green remediation focuses on the environmental footprint of Superfund response actions. The broader realm of site sustainability examines environmental issues but also includes social and economic aspects that are typically addressed by site users and local or regional communities' (US EPA, 2010a). The Interstate Regulatory Council (ITRC) in the USA has combined these concepts as 'green and sustainable remediation' — GSR (ITRC, 2011).

From the perspective of implementing sustainable remediation, analogous to the consideration of risk in contaminated land decision-making, two broad activities can be identified (based on Bardos et al., 2011b; NICOLE, 2011):

- Sustainability management: using sustainability as a criterion in decision-making with a view to optimising outcomes
- Sustainability assessment: the process of gaining an understanding of possible outcomes across all three elements (environmental, social and economic) of sustainable development.

In this structure sustainability assessment is used as a tool to support appropriate, sustainable land management.

Within the USA, ASTM have published standards for both green and sustainable remediation, which consider sustainability assessment (ASTM, 2013) and guidance has been produced by the EPA and ITRC (ITRC, 2011; US EPA, 2008a) and other public sector organisations (*e.g.* NAVFAC, 2012). These allow significant flexibility in approach rather than being strictly prescriptive. There is a wide range of possible sustainability assessment 'tools' (approaches, methods and software) being used/developed in the USA (Holland et al., 2011). The draft ISO standard (ISO 2015) also allows for a range of possible sustainability assessment tools to be used, while setting out the broad principles by which they should be designed and used. SuRF-UK's guidance is very much in line with this approach of setting broad guidelines for how sustainability assessment should be carried out, without prescribing exactly how it should be done (CL:AIRE, 2010 and 2014a). It seems likely the 'standard' to be complied with will generally be determined by the project funder. The Austrian Environmental Protection Agency has, for example, published a required method for publically funded projects in Austria (Döberl et al., 2013).

Table 2 summarises the broad approaches that SuRF-UK has identified as potentially applicable to supporting sustainable remediation assessments (CL:AIRE, 2010). This table also indicates each approach's coverage of the environmental, economic and social elements of sustainable development; whether techniques are quantitative, semi-quantitative or qualitative; and whether contaminated land management applications are known to exist at present. A number of practical examples are analysed in more detail by Beames et al. (2014).

Both qualitative and semi-quantitative methods, such as use of multicriteria analysis (*e.g.* Harbottle et al., 2008a,b) can be structured across a broad range of considerations (Smith and Kerrison, 2013; Beames et al., 2014). With the *possible* exception of cost benefit analysis or approaches to cost-effectiveness (see below), quantitative methods do not even approach a full scope of sustainability considerations. Carbon footprint based measurements are self-evidently one dimensional, albeit covering one important environmental consideration. Life cycle assessment approaches partially cover environmental considerations, but cannot evaluate impacts on important factors for some contexts such as soil functionality or landscape changes which may be particular assets for the non-built re-use of land. LCA also does not speak to social and economic considerations, although attempts are being to adapt the rigour of life cycle thinking to sustainability assessment (Calcas Consortium, 2009).

Cost benefit assessment describes a process of comparing the likely costs of a project with its benefits and is a form of economic valuation. Where this assessment is based on conversion to strictly monetary terms it is described as cost benefit analysis – CBA (Commonwealth of Australia, 2006). The common feature of formal CBA is an attempt to express all values (costs and benefits) using a single monetary unit, which some see as facilitating clear-cut decisions about overall benefit (Brouwer and van Ek, 2004). Including 'externalities' into the CBA process allows wider benefits and impacts to be considered and costed (*e.g.* Doick et al., 2009). There are two significant limitations for the use of CBA as a means of sustainability assessment: the scope of externalities being considered and the approach taken to valuing externalities. There are a range of technical approaches to the valuation of externalities (Cellini and Kee, 2010; Defra, 2010). However, all valuation methods are subject to errors and bias based on the assumptions used when they are applied, are complex and are not always seen as reliable by project stakeholders, particularly when they are not economists (Atkinson and Mourato, 2008). Cellini and Kee (2010) suggest some externalities and benefits may be regarded as impossible to value. The other important limitation is scope, which is a pragmatic consideration. The time and data needed to prepare a CBA may make wide ranging and holistic assessment of externalities prohibitively expensive.

Taking a staged or tiered approach, starting with simple qualitative approaches, and moving through to more quantitative methods should the need arise, has advantages in terms of cost and resource efficiency as well as providing a structure that is as inclusive as possible and combines the relative strengths of the methods available (CL:AIRE, 2010; EURODEMO, 2007, NICOLE, 2011; SURF, 2009). This is also in line with other suggestions for good practice in sustainability assessment (Pollard et al., 2004; Therivel, 2004). Therivel (2004) suggests that the appropriate point of trade-off between comprehensiveness, rigour, transparency, user friendliness and costs for sustainability assessment tools should depend on the decision that the tool is informing. Furthermore, the amount of time and effort needed as an input should be proportional to the benefits provided as an output. He suggests two stage tools or processes, with a 'shallow' initial stage which gives a broad-brush analysis of a problem, and a 'deep' focus on those issues that were identified in the first stage as being particularly problematic,

[5] www.claire.co.uk/index.php?option=com_content&view=article&id=616&Itemid=140.

Table 2
Selected decision support techniques with relevance to sustainable remediation assessments. Taken from CL:AIRE, 2010. © CL:AIRE, 2015. Reproduced by permission.

	Environment	Economy	Society	Type	CLM
Scoring/ranking systems (including multi-criteria analysis), *e.g.* Balasubramaniam and Voulvoulis (2005)	Narrow to Wide	Narrow to Wide	Narrow to Wide	Qual	Yes, *e.g.* Bleicher and Groß, 2010
Carbon footprint ('area'), *e.g.* Carbon Trust et al. (2008b)	Narrow	–	–	Quan	Yes, Ellis and Hadley (2009)
Carbon balance (flows), *e.g.* Defra, 2006	Narrow	–	–	Quan	
Cost benefit analysis, *e.g.* Environment Agency (1999, 2000b)	Narrow to Wide	Narrow to Wide	Narrow to Wide	Quan	Yes, *e.g.* Environment Agency (2000b)
Cost effectiveness analysis, *e.g.* Environment Agency (1999)	Narrow to Wide	Narrow to Wide	Narrow to Wide	Qual	Yes, *e.g.* Environment Agency (1999)
Eco-efficiency	Narrow	–	–	Quan	Yes, *e.g.* Sorvari et al. (2009)
Ecological footprint[a]	Narrow	–	–	Quan	Yes, *e.g.* Ferdos and Rosén (2013)
Energy/intensity efficiency	Narrow	–	–	Quan	Yes, Ellis and Hadley (2009)
Environmental risk assessment	Narrow to Wide	–	–	Qual/Quan	Yes, Environment Agency and Defra (2004)
Human health risk assessment		–	Narrow	Qual/Quan	Yes, Environment Agency and Defra (2004)
Environmental impact assessment [for projects]/Strategic environmental assessment [for policies], DCLG, 2006, ODPM 2005	Narrow to Wide	–	–	Qual	Yes, ODPM 2005, Stroud District Council (2015)
Financial risk assessment	–	Narrow	–	Quan	Yes, Finnamore et al. (2000)
Industrial ecology[b]	Narrow to Wide	Narrow to Wide	–	Quan	
Life Cycle Assessment (based)	Narrow to Wide	–	–	Quan	*Yes*, *e.g.* Cappuyns and Kessen (2013)
Quality of life assessment (US EPA, 1973)	Wide	Wide	Wide	Qual	

Key:
Qual = Qualitative (including semi-quantitative methods)
Quan = Quantitative
CLM = Contaminated Land Management application examples available
Narrow: indicates that relatively few of the SURF-UK indicator categories are considered by the this method
Wide: indicates that many of the SURF-UK indicator categories could be considered by the this method

- The table describes each technique in terms of its *typical* coverage of particular aspects of sustainability. For example, a carbon footprint appraisal focuses on a 'narrow' segment of environmental sustainability issues (ignoring for example soil functionality, biodiversity and landscape impacts), whereas all of these aspects could be considered by a cost-benefit analysis, providing it was suitably specified.
- A dash (—) means that the technique has no coverage.

[a] E.g. http://www.footprintnetwork.org/en/index.php/GFN/page/footprint_basics_overview/ Accessed November 2015.
[b] http://www.gdrc.org/sustdev/concepts/16-l-eco.html Accessed November 2015.

contentious or important to the decision making process. Within many European countries the contaminated land sector is very familiar with the use of tiered approaches in risk assessment for similar reasons (Environment Agency and Defra, 2004; Nathanail et al., 2013), so this concept already links well with established practices.

However, there can be strong stakeholder demands for quantitative assessments, particularly where one or more stakeholders have a requirement for cost benefit analysis based decision making, or particular quantified organisational/corporate sustainability goals, for example related to use of fossil carbon (*e.g.* NAVFAC, 2014; or in a more general sense: HM Treasury, 2011; JRC-IES, 2011). There may also be cultural leanings towards qualitative or quantitative methods (Rizzo et al., 2016). A tiered approach, starting with more holistic qualitative appraisal, is still useful in these circumstances, in particular to (a) test the assumptions and relevance of any subsequent quantitative appraisals, and (b) provide a more broad ranging benchmark for comparison with the outcomes of quantitative assessments. Furthermore, Smith and Kerrison (2013) have found that 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 relatively simple land contamination projects.

As part of a tiered approach, qualitative sustainability assessment might be an important adjunct for cost benefit assessments, where these are required. The qualitative assessment provides a relatively simple means of identifying which of the many possible sustainability considerations are most greatly differentiated between the remediation or other project options being considered. The qualitative assessment provides both a holistic assessment which might be prohibitively expensive to execute as CBA, and also a rationale for a clear range of externalities which should be considered in the CBA. Additionally, qualitative or semi-quantitative assessments can be used in tandem with CBA to distinguish non-monetisable values between options. Such a combined 'cost-effectiveness' approach to decision has been adopted already for sustainable remediation decision making by public investors in Austria (Döberl et al., 2013).

4. SuRF-UK guidance

SuRF-UK is coordinated by an independent charity, Contaminated Land: Applications in Real Environments (CL:AIRE). It operates *via* a Steering Group who have overseen a series of meetings and projects. Since 2009 SuRF-UK has produced a wide range of outputs, on the basis of funding and in-kind contributions from a wide range of public and private sector contributors from across the UK. These outputs are listed in Fig. 1 and are freely downloadable from www.claire.co.uk/surfuk.

There are a range of potential benefits from sustainable remediation practice (CL:AIRE, 2014a):

- Supporting effective risk management
- Generating value by finding optimal solutions for soil and groundwater projects
- Identifying and avoiding project risks
- Demonstrable compliance with government and/or corporate policies and goals for sustainable development
- Providing a positive contribution towards delivery of corporate social responsibility (CSR) programmes, reputation and public relations
- Being a contributor to sustainable development.

SuRF-UK's 'framework for assessing the sustainability of soil and groundwater remediation' (CL:AIRE, 2010), and all of its guidance, has been developed on the basis of consultative processes with a wide range of practitioners drawn across different stakeholder types. The various reports of this process are all available from www.claire.co.uk/surfuk. From the outset SuRF-UK identified the requirement for simple, yet robust, approaches to assist sustainable remediation decision-making as the likely complexity of understanding sustainability was seen as being a potentially significant burden on project management decision-making effort and cost (CL:AIRE, 2007a, CL:AIRE, 2007b). Given that the adoption of sustainable remediation, in the UK at least, is effectively voluntary (CL:AIRE and NICOLE, 2015), significant increases in the cost of decision making disincentivises uptake.

Sustainability was also recognised as being subjective, and assessment approaches as lacking in transparency. Table 3 summarises the constraints on sustainability assessment methods relevant to sustainability management for contaminated sites. Another concern expressed form an early stage of the consultation process was that sustainability might be seen as a substitute criterion for risks to human health and the environment, and so undermine the level of protection from contaminated land management.

As a consequence SuRF-UK has set out clear underpinning principles for effective sustainable remediation which make explicit the primary role of risk assessment and management in contaminated land decision making (see Table 4) in its sustainable remediation framework. In addition, SuRF explicitly advocates a tiered approach to sustainability assessment to minimise cost and complexity in decision making. SuRF-UK has also provided guidance on identifying which sustainability considerations should be considered to ensure a consistent and holistic approach to determinations of scope, shown in Table 5 (CL:AIRE, 2011). The tiered approach, coupled with the SuRF-UK framework's underpinning principles and its guidance on scope also support engagement, consistency, ensuring suitable quality of evidence and transparency, to provide robust and effective decision-making (CL:AIRE, 2010). The ASTM (2013) standard and the proposed ISO standard (ISO 2015) also recognise the benefits of taking a tiered approach, and the SuRF-UK principles have been adopted in the proposed ISO standard.

In parallel to providing a framework and guidance for the management and assessment of sustainability in remediation decision making, SuRF UK also recognised that simple operational guidance might significantly improve the sustainability of contaminated land practices. This was partly inspired by the best management practice guidance from the USEPA's 'Green Remediation' programme (US EPA 2008A). Hence overall SuRF-UK identifies two starting points for enabling more sustainable contaminated land management approaches, as part of a tiered process as shown in Fig. 2 (CL:AIRE, 2014b):

Table 3
Limiting factors for sustainability assessment in remediation decision making.[a]

Factor	Relevance and limitations
Subjectivity	Consideration of 'sustainability' in remediation is subjective (Bardos et al., 2011b; Pediaditi et al., 2005; RESCUE, 2005; Sardinha et al., 2013). Sustainable remediation/regeneration frameworks or decision support tools therefore need to provide a flexible, systematic, transparent and recordable process of making these subjective choices.
Stakeholder engagement and transparency	Inclusion of a broad range of stakeholder perspectives is a necessary part of understanding broader value and sustainability (Cundy et al., 2013; Hardi and Zdan, 1997; Pediaditi et al., 2005; Pediaditi et al., 2010; Plant et al., 2015; Rizzo et al., 2016; Sardinha et al., 2013). Practical constraints may mean that engagement activities have to be prioritised (*e.g.* Bartke and Schwarze, 2015). Simpler (qualitative) approaches seem more likely to be inclusive and engaging for a broader range of stakeholders than more complex processes, especially where assumptions may be 'hidden' in numeric form or the basis for valuations may be contentious (Bardos et al., 2011a).
Scope	In line with the 'Bellagio Principles', sustainability considerations are wide ranging across all three elements of sustainability, environmental, economic and social, see for example the SuRF-UK categories shown in Table 4.
Life cycle thinking	Life cycle thinking (LCT), making use of the disciplines of life cycle assessment, can provide some clear ground rules for effective sustainability assessment to ensure clear goals for the assessment and boundary setting (Bardos et al., 2011b). These disciplines are important parts of the framing of any sustainability assessment, whether it is qualitative, semi-quantitative or quantitative.
Framing an assessment and decision making cost	Assuming that whatever approach adopted has been adequately framed, *and* is adequately inclusive of stakeholder opinions, then the starting points for qualitative, semi-quantitative or quantitative approaches are broadly equivalent. Incremental costs will tend to be lowest for qualitative approaches as data and calculation effort is less, and consequently highest for quantitative methods. Quantitative methods also require framing and engagement and should not be used as a short cut to circumvent adequate framing and engagement

[a] Additional detail is available in the Supplementary Information accompanying this paper (See Table S1).

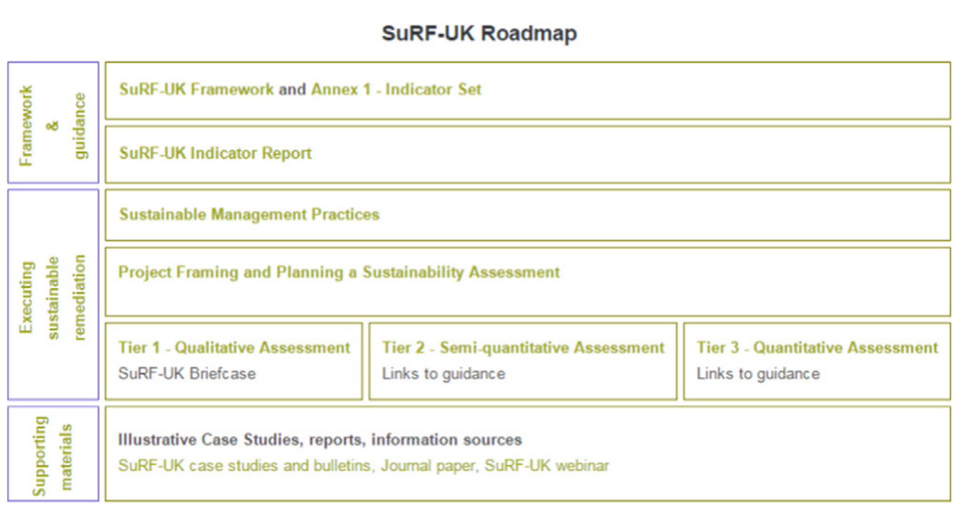


Fig. 1. SuRF-UK Outputs © CL:AIRE 2015, reproduced by permission.

Table 4
Key principles associated with sustainable remediation (CL:AIRE, 2010) © *CL:AIRE, 2015. Reproduced by permission.*

Principle 1: Protection of human health and the wider environment.	Remediation [site-specific risk management] should remove unacceptable risks to human health and protect the wider environment now and in the future for the agreed land-use, and give due consideration to the costs, benefits, effectiveness, durability and technical feasibility of available options.
Principle 2: Safe working practices.	Remediation works should be safe for all workers and for local communities, and should minimise impacts on the environment.
Principle 3: Consistent, clear and reproducible evidence-based decision-making.	Sustainable risk-based remediation decisions are made having regard to environmental, social and economic factors, and consider both current and likely future implications. Such sustainable and risk-based remediation solutions maximise the potential benefits achieved.[a] Where benefits and impacts are aggregated or traded in some way this process should be explained and a clear rationale provided.
Principle 4: Record keeping and transparent reporting.	Remediation decisions, including the assumptions and supporting data used to reach them, should be documented in a clear and easily understood format in order to demonstrate to interested parties that a sustainable (or otherwise) solution has been adopted.
Principle 5: Good governance and stakeholder involvement.	Remediation decisions should be made having regard to the views of stakeholders and following a clear process within which they can participate.
Principle 6: Sound science.	Decisions should be made on the basis of sound science, relevant and accurate data, and clearly explained assumptions, uncertainties and professional judgement. This will ensure that decisions are based upon the best available information and are justifiable and reproducible.

[a] In certain projects it is recognised that non-optimum remediation decisions may be made because other factors are more influential in optimising the benefit from a wider development scheme. Considering regulatory implications and recording why such a decision was taken should be a minimum requirement for any decision making process.

- Simple good management practices to mitigate known negative impacts and promote known benefits (sustainability management practices)
- Qualitative sustainability assessment for planning, design and option appraisal.

There is a broad range of possible sustainability assessment approaches available at least for quantitative and semi-quantitative tools that might be applied to sustainability assessment, as previously described. Within each of the categories there may be a range of proprietary tools and services (*e.g.* Beames et al., 2014; Ellis and Hadley, 2009). The SuRF-UK consultations indicated a general view that it would be counter-productive to try and reduce these down to a smaller set of SuRF-UK prescriptive methods, and that this exercise would also undermine competition between service providers and disenfranchise them from the (voluntary) SuRF-UK assessment process.

SuRF-UK's conclusion is that the values and broad rules applied to sustainability assessment are more important than the exact details of methodology. SuRF-UK has therefore set out a series of broad procedural steps, as illustrated in Fig. 3, to support consistency across all methodologies in the assessment, design, implementation and reporting of sustainable remediation schemes and so establish a reproducible, transparent and robust approach. The application of these principles and procedural stages is specific to each site/project, and SuRF-UK has called this implementation process the 'framing' of the sustainability assessment (CL:AIRE, 2010).

Table 5
Overarching SuRF-UK Sustainable Remediation Categories (CL:AIRE, 2011) © *CL:AIRE, 2015. Reproduced by permission.*

Environmental	Social	Economic
1 Emissions to air	1 Human health and safety	1 Direct economic costs and benefits
2 Soil and ground conditions	2 Ethics and equity	2 Indirect economic costs and benefits
3 Groundwater and surface water	3 Neighbourhoods and locality	3 Employment and employment capital
4 Ecology	4 Communities and community involvement	4 Induced economic costs and benefits
5 Natural resources and waste	5 Uncertainty and evidence	5 Project lifespan and flexibility

Appropriate framing should underpin all sustainability assessments, even if they are only qualitative in nature. SuRF-UK's approach to framing is broadly consistent with the approach taken by the Dutch Sustainable Remediation Forum (SURF Netherlands et al., 2015) and NICOLE (NICOLE, 2011), and has been applied by the SURFs in Australia, New Zealand and other countries (Bardos et al., 2013; SURF-ANZ, 2011) as well as by the proposed ISO standard (ISO 2015).

The most recent outputs from SuRF-UK have therefore been concerned with this framing process, sustainable management practices; and also *qualitative* sustainability assessment, as the SuRF-UK consultations had shown that this was relatively poorly supported by published methodologies.

5. SuRF-UK guidance on framing a sustainability assessment

The overall structural approach to sustainability assessment favoured by SuRF-UK has already been reviewed (Bardos et al., 2011b). The importance of reproducible and transparent structures for sustainability assessment are made very clear in the Bellagio principles, and operational examples of goal setting and setting boundaries are clear from life cycle thinking. SuRF-UK guidance on the 'framing' of sustainability assessment for contaminated land decisions has been designed to be consistent both with the Bellagio Principles and lifecycle thinking.[6] Effective framing provides a more substantive basis for the contaminated land sector to deliver sustainability assessment tools with an appropriate structure and in line with SuRF-UK's sustainable remediation framework principles.

This guidance includes an interactive slide set (in *Adobe PDF* format) supported by a template for a 'log-book' to record decisions (in *Microsoft docx* format), and subsequently a spreadsheet to record assessments (in *Microsoft xlsx* format). These are freely downloadable from www.claire.co.uk/surfuk and are summarised in CL:AIRE (2014a). The guidance was reviewed as it was developed by a series of four practitioner workshops over 2012–13 across the UK, along with the sustainable management practices and qualitative assessment guidance, also reported on the SuRF-UK web site.

The framing process is needed for all tiers of a sustainability assessment process whether qualitative, semi-quantitative or quantitative. Framing includes two groups of activities each with a number of broad steps: the preparation for sustainability assessment followed by the definition of the sustainability assessment approach, as shown in Fig. 3.

[6] Table S3 in the Supplementary Information provided with this paper benchmarks SuRF-UK's approach with the Bellagio Principles and Life Cycle Thinking.

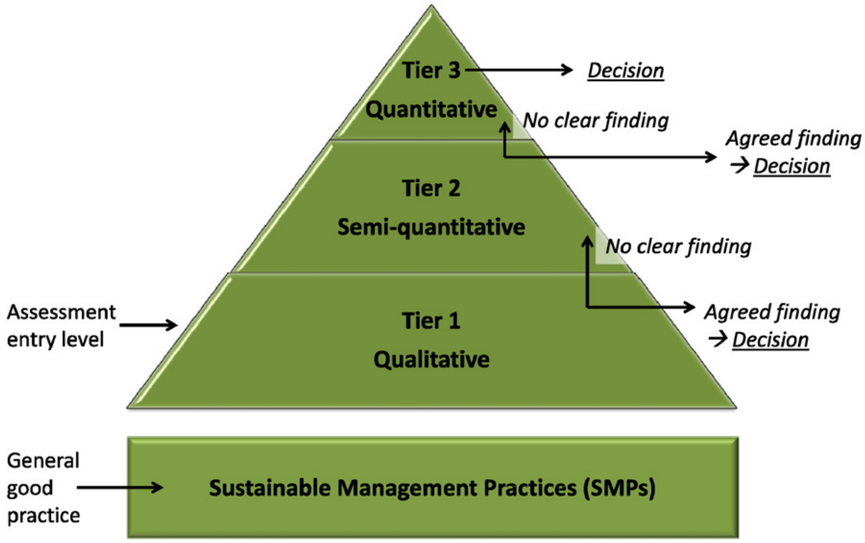


Fig. 2. Tiered approach to sustainability assessment © *CL:AIRE 2015, from* CL:AIRE, 2014a, *reproduced by permission.*

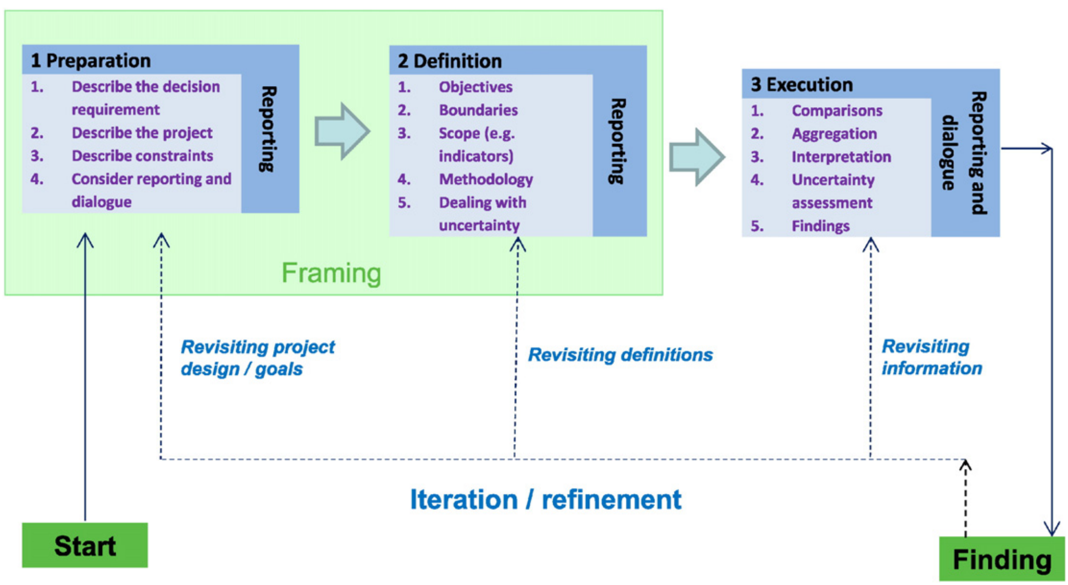


Fig. 3. SuRF-UK Approach to Sustainability Assessment (CL:AIRE, 2014a) © *CL:AIRE, 2015. Reproduced by permission.*

- There are four broad steps in preparation for a sustainability assessment: (1) describing the decision requirement, (2) describing the project, (3) describing opportunities and constraints and (4) considering reporting and dialogue. These preparation activities provide the broad frame in which the sustainability assessment must be defined.
- The process of definition considers five issues: (1) objectives, (2) assessment boundaries, (3) scope – sustainable remediation indicators, (4) sustainability assessment methodology, and (5) dealing with uncertainty.

The framing guidance is based on hyperlinked slides that take the user backwards and forwards between slides at different levels of detail according to need. The 'logbook' is intended to assist note-taking by sustainability assessment teams (if required). The aim is to help project managers and sustainability assessors to frame their approach for a sustainability assessment, in several contexts:

- Use the framing slides as an interactive learning aid
- Use the framing slides as a step by step process of *aide memoire* to develop the sustainability assessment approach
- Use the framing slides to support discussions at meetings
- Use the logbook as a proforma for recording assumptions and findings.

6. SuRF-UK guidance on qualitative sustainability assessment

As for the framing guidance, the SuRF-UK 'guidance on qualitative assessment[7] comprises an interactive slide set (in *Adobe PDF* format) supported by a template for a 'log-book' to record decisions (in *Microsoft docx* format). A spreadsheet tool has been produced which systematically guides users through the key stages of preparation, definition and execution of a qualitative Tier 1 assessment, and encourages

[7] Table S4 in the Supplementary Information describes the qualitative assessment stages in more detail.

transparent documentation of decisions. These are freely downloadable from www.claire.co.uk/surfuk and summarised in CL:AIRE, 2014a.

While Tier 1 is the simplest tier, it still requires that sufficient framing and planning for the assessment has been carried out in advance. Furthermore, while the assessment is qualitative, readily available quantitative information can and should be exploited. The output of the assessment is comprised of simple tables using qualitative categories, such as 'good' or 'neutral' or 'better', or simple rankings (see Fig. 4). If these provide suitably clear differentiation between the options being compared, then more detailed assessment at Tier 2 and 3 may not be needed. The spreadsheet tool was developed to assist sustainability assessment work being undertaken on a commercial basis with multiple stakeholders. During this practical application development it was found that simple rankings (supported by a colour scheme from *green* = *best* to *red* = *worst*) provided the most clarity in differentiating options and indicating patterns of behaviours across the sustainability criteria used. While the sustainability assessments themselves are commercial in confidence, Fig. 5 illustrates an example of the framing and qualitative assessment outputs for a fictitious site.

7. SuRF-UK guidance on sustainable management Practices

The use of good practice by the contaminated land sector has been encouraged in the UK for a few decades, with guidance on environmental risk management first published in 1995 (Department of the Environment, 1995), since superseded in 2000 (DETR, 2000) and 2011 (Defra, 2011). This is supported by a robust range of standards, codes of practice and technical guidance published by authoritative institutions and organisations. Framework documents of note that highlight key principles to be followed and signpost readers to technical advice and guidance include the '*Guiding Principles for Land Contamination*' (Environment Agency, 2010) and the '*Model Procedures for the Management of Land Contamination*' (Environment Agency and Defra, 2004).

The application of best practice was introduced, but not defined, in a wider context for green remediation in Environmental Protection Agency's (USEPA) 'Principles for Greener Cleanups' (2009). This was extended to green and sustainable remediation by the Interstate Technology and Regulatory Council (ITRC, 2011); following the principles introduced in USEPA (2009), but also includes consideration of social elements. The development of SuRF-UK sustainable management practices was informed by these US initiatives. SuRF-UK defines sustainable management practices (SMPs) as 'relatively simple, common sense actions that can be implemented at any stage in a land contamination management project to improve its environmental, social and/or economic performance' (CL:AIRE, 2014a and CL:AIRE, 2014b).

The SuRF-UK SMPs have been linked to the main stages for the management of land contamination (based on two generic management activities and the stages of management of land contamination outlined in Environment Agency and Defra (2004):

- Procurement (ITRC, 2011; WRAP, 2003)
- Land use planning (CL:AIRE, 2010 — Stage A assessment)
- Risk assessment (primarily Site Investigation)
- Options Appraisal
- Implementation of remediation — Design
- Implementation of remediation — Construction and Operation
- Implementation of remediation — Verification/Long-term Monitoring and Closure

SMPs can be used to improve the benefits (*e.g.* resource efficiency, cost) or reduce the negative impacts (*e.g.* spillages, complaints) of a project, leading to project 'sustainability gains'. SMPS are intended for use without the need for a formal sustainability assessment. They may also be used where sustainability gains are sought at a programme of work level using generic criteria or standards that can apply to a range of project types. Hence, the use of SMPs is seen by SuRF-UK as very much an entry level activity underpinning whatever additional sustainability based decision making takes place. The use of SMPs to achieve 'sustainability gains' without formal assessment is similar in concept to the 'Level 1' assessment for *Green and Sustainable Remediation* described by ITRC (2011). Fig. 6 describes the implementation process for making use of these SMPs.

SMPs offer a way of changing behaviours or actions to reduce the cost, use of natural resources and/or the negative impact on community or the environment. Actions are mapped against the SuRF-UK indicator categories (see Table 5) to place even simple and low cost actions in a sustainability context. Table 6 sets out selected SMPs identified by SuRF-UK, the source of information, and how they map to SuRF-UK indicator categories. The SMPs themselves were collated from published best practice guidance and codes of practice developed for the land contamination and other sectors in the UK and abroad, as shown for the SMPs in Table 6. The SMPs are mapped against the indicator categories used by SuRF-UK to place simple and low cost actions in a sustainability context. A policy of preventing machinery and transport from being left idling can have multiple sustainability benefits across the environmental, social and economic pillars. Indeed, the Oak Ridge National Laboratory published best practice guidance on idle reduction to improve fuel efficiency, reduce emissions, reduce engine wear and reduce health impacts (ORNL, 2013).

SuRF-UK's contention is that SMPs provide practical and generally inexpensive actions that can yield demonstrable 'sustainability gains' for a project. They should be selected where there is a clear benefit in doing so on a project-by-project basis. The SMPs are provided in an *Microsoft Excel* spreadsheet file, downloadable from www.claire.co.uk/surfuk. A report is also available that describes the development of SMPs and instructions for use of the SMP spreadsheet (CL:AIRE, 2014b).

8. Conclusions

The wider impacts of remediation have been recognised as important decision criteria in remedy selection for more than 20 years. This consideration was made explicit and extended to recognise the importance of sustainability in risk management decision making by the CLARINET network in 2002. However it is only more recently that the structures (tools, guidance, protocols) for achieving this have begun to emerge; catalysed by the emergence of the sustainable remediation fora in the mid-to-late 2000s. The current international interest in 'sustainable remediation' has resulted in a fairly rapid consensus on descriptions and definitions, that are now being crystallised into an ISO standard.

However, approaches to methodologies in detail remain diverse with a range of (mainly) semi-quantitative and quantitative tools developed, or in development. SuRF-UK recognised the need of practitioners to adapt and develop approaches specific to their own needs, but has also identified the need to provide some underpinning guidance ('framing') so that the overall structure of these approaches is consistent, and complies with a set of key principles.

The importance of taking a holistic approach has been underlined by a recent survey undertaken by the Austrian Environmental Protection Agency (reported in Rizzo et al., 2016), which made an analysis of case studies in papers submitted to a number of recent scientific conferences. This found that assessments tended towards 'off the shelf' methodologies such as carbon footprint or life cycle assessments to assess environmental impacts. However a number of key impacts, related for instance to quality of soil, or to the landscape, are not always addressed. This was seen as a sign of the relative immaturity of consultancy practice in sustainable remediation (Döberl and Muller-Grabherr, 2015).

Sustainability assessment is site specific and subjective. There is not, and it is difficult to conceive, an SI unit for sustainability. It depends on the inclusion of a wide range of factors across different stakeholder perspectives. Taking a tiered approach to sustainability assessment offers important advantages, starting from a qualitative

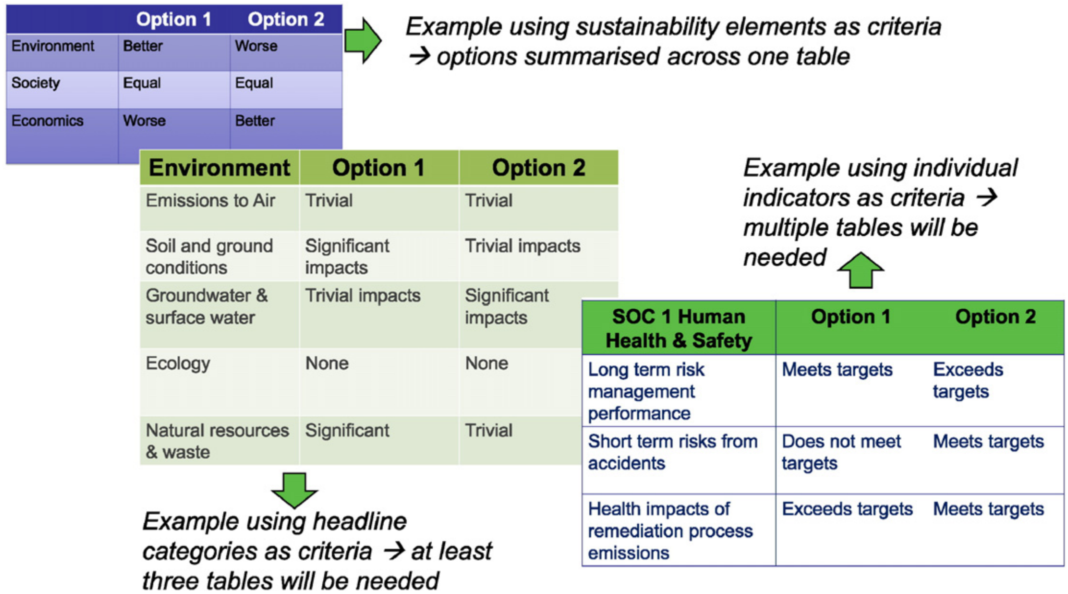


Fig. 4. Illustration of how the selection of *level of detail* for criteria across the SuRF-UK Indicator Set (CL:AIRE, 2011) affect the comparison table outputs © *CL:AIRE 2015, reproduced by permission.*

assessment and moving through to semi-quantitative and quantitative assessments on an 'as required basis' only. These benefits are (1) the level of effort in decision making is proportionate; (2) a tiered approach supports a more inclusive and transparent approach; (3) the relative strengths and weaknesses of the different tiers are combined in a way that allows both a holistic assessment, and if necessary more detailed assessments for example CBA to be mutually reinforcing; and (4) a tiered approach provides a clear rationale for detailed assessments to be specifically focussed on considerations of high importance. The availability of guidance for 'entry level' qualitative sustainability assessment was found to be lacking and SuRF-UK has therefore provided introductory guidance that is free to access and apply.

It is also clear that there are a number of 'easy wins' that could reduce a range of wider impacts right across the site management process. SuRF-UK has provided a checklist of 'sustainable management practices' to support mitigation of the wider impacts of site management.

SuRF-UK's guidance on framing, qualitative sustainability assessment and sustainable management practices was only released in 2014. The concept of framing has been taken forward by the developing ISO/DIS 18504 standard on Sustainable Remediation.

Across all of the SURF initiatives the major imperatives now are on the collection of case studies of the practical implementation of sustainable remediation concepts in contaminated land management projects, and on the dissemination and training of the broader contaminated land community. This evidence base will grow, and with this tools and approaches can be refined and broader analyses conducted, for example by the academic community. This will lead to better tools and guidance, broader understanding and wider adoption – and ultimately more sustainable development.

Assessment criteria	Key Categories	Remediation Options for Ranking					Justification of Scores (refer to 'Execution Supporting' Tab for more detail)	Uncertainty Arising (Description)	Uncertainty Arising (Extent)
		Option A	Option B	Option C	Option D	Option E			
Environmental									
Emissions to air	2*	5	4	3	1	2	CO_2, SOx, NOx dominated by power consumption, off site generation. Option D should be less energy intensive given that there is a significant reduction in operational time. Differences between extent of ozone depleting substances and particulates considered to be of marginal effect overall.	There is a high degree of confidence in the data used. Data used are semi quantitative with emission directly related to power conumption.	Timeframes are worst case consideration
Soil and ground conditions	1*	3	2	1	4	4	D and E achieve no benefit to soils, A & B marginal difference, little improvement, C best	There is a high degree of confidence in the data.	The extent oif soil impact is reasonably well defined.
Groundwater and surface water	4*	3	4	2	1	5	Mass removal will have a beneficial affect if applied in the correct location. Based on mass removal, Option D will provide better coverage than Option C and result in betterment of groundwater quality over a larger area.	It is currently uncertain whether mass recovery will be required. Mass recovery estimates are based on knowledge of operation and performance of systems: field trials have been carried out so the extent of effective recovery for Option D is known.	Timeframes are worst case consideration
Ecology		1	1	1	1	1	Based on general disturbance &noise, at ground level and above, impacting bird and other small animals (No significant differences)	There are limited data on ecology at the sites as the driver for risk management is associated with groundwater imapct.	The assesment is opinion based, considering limited data set, but also considering risk drivers.
Natural resources and waste	1*	4	3	1	2	5	Option E only has water waste, other options have water waste plus carbon plus PSH and ongoing chemical usage. Time frames of operation accounted for.	There is a hgh degree of confidence in the data available. Data used are semi quantitative based principally on waste water volumes as those are more significant.	The extent of waste production and natural resource usage is reasonably well defined.

Fig. 5. Example qualitative assessment output, © *AECOM 2015, reproduced by kind permission of AECOM.*

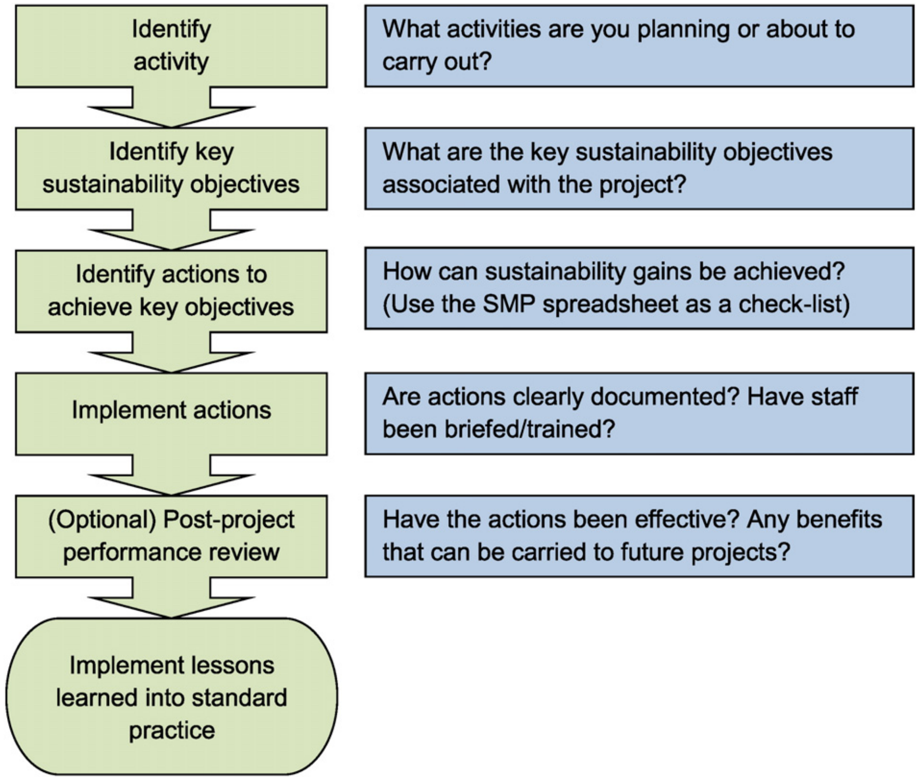


Fig. 6. Making use of SuRF-UK Sustainable Management Practices © *CL:AIRE 2015, reproduced by permission.*

Table 6
Selected sustainable management practices (SMPs) identified by SuRF-UK. Adapted from CL:AIRE (2014b).

SMP	Applicable SuRF-UK indicator category					Source
Adopt a sustainable procurement policy	ALL					WRAP (2003), SPRC[a]
Implement the Considerate Constructors Scheme Code of Considerate Practice	SOC1	SOC3	ECON2	SOC4	ENV4	http://www.ccscheme.org.uk/index.php/ccs-ltd
Consider non-intrusive surveys to delineate sources and areas affected by contamination	ENV5	SOC5	ECON1			BSI (2011)
Plan to re-use boreholes through each phase of investigation, remediation and long-term monitoring	ENV5	SOC1	SOC3	ECON1		US EPA (2008b,2009)
Consider the use of a mobile laboratory and/or field testing techniques to reduce off-site shipment of samples and improve spatial data	ENV5	SOC3	SOC5	ECON1	ENV1	ITRC (2011)
Identify location of underground services before excavation or drilling	SOC1	SOC3	ECON2			HSE (2014)
Identify drainage systems on-site and design measures to mitigate pollution risks	ENV3	ECON2	SOC3			EA (2012, 2013)
Ensure proper maintenance of vehicles, plant & equipment	ENV1	ENV5	SOC1	SOC3	ECON1	US EPA (2010b); VOSA (2013)
Consider electronic data transfer systems for information exchange between parties, reporting and archiving	ENV5	SOC5	ECON1			ITRC (2011)
Work with local communities to preserve characteristics of the locality	SOC2	SOC4				GLA (2007)

[a] SPRC — Sustainable Procurement Resource Centre www.sustainable-procurement.org/resources.

Acknowledgements

This work was supported by members of the SuRF-UK steering group *via* financial and in-kind contributions. The authors would like to acknowledge the many comments and experiences shared by members of the practitioner community through the development of all of SuRF-UK's outputs since 2007. We would also like to thank Ged Sojka of AECOM for providing Fig. 5, and the kind assistance of Johan van Veen and Frank Swartjes regarding early stage work in The Netherlands.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.scitotenv.2015.12.001.

References

Aelmans, A.J., Hoekstra, E.J., Leget, A.C., van Veen, H.J., 1993. Sustainable soil use a TNO-concept. TNO Environmental and Energy Research Report. Available from www.eugris.info/displaynewsitem2.asp?NewsID=970; Accessed August 2015.
ASTM 2013 Standard Guide for Integrating Sustainable Objectives into Cleanup, E2876-13, ASTM International, West Conshohocken, PA, 2013, www.astm.org
Atkinson, G., Mourato, S., 2008. Environmental cost benefit analysis. Annu rev. Environ. Resourc. 33, 317–344.
Balasubramaniam, A., Voulvoulis, N., 2005. The appropriateness of Multicriteria Analysis in environmental decision-making problems. Environ. Technol. 26 (9), 951–962.
Bardos, P., 2014. Progress in sustainable remediation. Remediation Journal Winter 2014, 23–32. http://dx.doi.org/10.1002/rem.21412.
Bardos, R.P., Lewis, A. J., Nortcliff, S., Mariotti, C., Marot, F. and Sullivan, T. 2002 Review of Decision Support Tools for Contaminated Land Management, and their use in Europe. Final Report. Austrian Federal Environment Agency, 2002 on behalf of CLARINET, Spittelauer Lände 5, A-1090 Wien, Austria. www.commonforum.eu/publications_clarinet.asp. Accessed July 2015
Bardos P., Bakker, L., Slenders, H. and Nathanail, P. 2011a Sustainable remediation. Pp 889–948 in. Swartjes F.A. (Ed.), Book on Contaminated Sites. From Theory Towards Practical Application, Springer Publishers, Dordrecht. ISBN: 978-90-481-9756-9.

Bardos, R.P., Bone, B.D., Boyle, R., Ellis, D., Evans, F., Harries, N., Smith, J.W.N., 2011b. Applying sustainable development principles to contaminated land management using the SuRF-UK framework. *Remediation Journal* Spring 2011, 77–100.
Bardos, P., Knight, M. and Humphrey, S. 2012 Sustainable remediation. Environmental Scientist August 2012 pp 46–49. www.ies-uk.org.uk/resources/contaminated-issue
Bardos, P., Bakker, L., Darmendrail, D., Harries, N., Holland, K., MacKay, S., Pachon, C., Slenders, H., Smith, G., Smith, J., Wiltshire, L., 2013. Sustainable and green remediation — global update, ThS E3 sustainable use of the subsurface. Proceedings Aquaconsoil 2013 Barcelona, Spain. April 2013. http://dx.doi.org/10.13140/2.1.1812.2887.
Bartke, S., Schwarze, R., 2015. No perfect tools: trade-offs of sustainability principles and user requirements in designing support tools for land-use decisions between greenfields and brownfields. J. Environ. Manag. 153, 11–24.
Beames, A., Broekx, S., Lookman, R., Touchant, K., Seuntjens, P., 2014. Sustainability appraisal tools for soil and groundwater remediation: how is the choice of remediation alternative influenced by different sets of sustainability indicators and tool structures? Sci. Total Environ. 470–471, 954–966.
Beinat, E., van Drunen, M.A., Janssen, R., Nijboer, M.H., Loolenbrander, J. G. M., Okx, J.P., Schutte, A.R. 1998 The REC Decision Support System for comparing soil remediation alternatives. Phase 2: A methodology based on Risk reduction, Environmental merit and Costs. NOBIS-report 95-1-03, The Netherlands. http://soilpedia.nl/Bikiwiki%20documenten/NOBIS/Risicoreductie,%20Milieuverdienste%20en%20Kosten%20(RMK)%20-%2095-1-03/95-1-03%20rap2.pdf Accessed July 2015
Bender, T., Volkwein, S., Battermann, G., Hurtig, H.W., Klopffer, W., Kohler, W., 1998. Life cycle assessment for remedial action techniques: Methodology and Application. in Contaminated Soil'98, Proc 6th Intern FZK/TNO Conference on Contaminated Soil, 17-21 May 1998. Edinburgh, UK. ISBN: 07277 26757, pp. 367–376.
BenDor, T.K., Metcalf, S.S., Paich, M., 2011. The dynamics of brownfield redevelopment. Sustainability 2011 (3), 914–936. http://dx.doi.org/10.3390/su3060914.
Bleicher, A., Groß, M.S., 2010. Sustainability assessment and the revitalization of contaminated sites: operationalizing sustainable development for local problems. International Journal of Sustainable Development & World Ecology 17 (1), 57–66.
Bromley, R.D.F., Humphrys, G. (Eds.), 1979. Dealing With Dereliction the Redevelopment of the Lower Swansea Valley. Pub University of Swansea, Swansea, Wales.
Brouwer, R., van Ek, R., 2004. Integrated ecological, economic and social impact assessment of alternative flood control policies in The Netherlands. Ecol. Econ. 50, 1–21.
Brundtland, G.H. 1987 Our Common Future. World Commission on Environment and Development. Oxford University Press. www.un-documents.net/our-common-future.pdf Accessed August 2015
BSI — British Standards Institution 2011 Investigation of potentially contaminated sites — Code of Practice. British Standards Institution, London. BS 10175:2011.
CABERNET 2006 Sustainable brownfield regeneration: CABERNET network report. Eds: Ferber, U., Grimski, D., Millar, K. and Nathanail, P. ISBN 0-9547474-5-3 (University of Nottingham, Nottingham)
Calcas Consortium — Co-ordination Action for innovation in Life-Cycle Analysis for Sustainability 2009 D20 Blue Paper on Life Cycle Sustainability Analysis. EC Framework 6 Programme Project no.037075. http://fr1.estis.net/sites/calcas/default.asp Accessed July 2015
Cappuyns, V., Kessen, B., 2013. Combining life cycle analysis, human health and financial risk assessment for the evaluation of contaminated site remediation. J. Environ. Plan. Manag. http://dx.doi.org/10.1080/09640568.2013.783460.
Carbon Trust, Defra and BSI British Standards 2008b PAS 2050:2008 Specification for the assessment of the life cycle GHG emissions of goods and services. BSI, 389 Chiswick High Road, London W4 4AL, UK. IISBN 978 0 580 50978 0
Cellini, S.R. and Kee, J.E. 2010 Cost-Effectiveness and cost–benefit analysis. Pp 493–530 in Handbook of Practical Program Evaluation, 3rd Edition (Eds Wholey, J.S., Hatry, H.P. and Newcomer, K.E.). Wiley. ISBN: 978-0-470-52247-9
CL:AIRE (2007a and onwards Meetings, Presentations and Consultations. Listing of activities since 2007. http://www.claire.co.uk/index.php?option=com_content&view=article&id=745:meetings-presentations-and-consultations&catid=963:surf-uk&Itemid=78 Accessed July 2015
CL:AIRE 2007b. Measuring sustainability: what's in a Number? subr:im Bulletin SUB 4. CL:AIRE, London, UK. www.claire.co.uk Accessed August 2015
CL:AIRE 2010. A framework for assessing the sustainability of soil and groundwater remediation. March 2010, CL:AIRE, London, UK. ISBN 978-1-905046-19-5. www.claire.co.uk/surfuk Accessed August 2015
CL:AIRE, 2011 The SuRF-UK indicator set for sustainable remediation assessment, CL:AIRE London, UK. ISBN 978-1-905046-1292-5 DoI DOI: 10.13140/RG.2.1.3130.8246 www.claire.co.uk/surfuk Accessed August 2015
CL:AIRE 2014a The SuRF-UK Bulletin 4, March 2014, CL:AIRE London, UK. www.claire.co.uk/surfuk Accessed August 2015
CL:AIRE 2014b. Sustainable Management Practices for Management of Land Contamination, March 2014, CL:AIRE London, UK. www.claire.co.uk/surfuk Accessed August 2015
CL:AIRE and NICOLE 2015 A review of the legal and regulatory basis for sustainable remediation in the European Union and the United Kingdom, CL:AIRE, London, UK. ISBN 978-1-905046-27-0 Accessed August 2015
CLARINET and NICOLE 1998 Better decision making now. The use of Risk Assessment and Risk Management for tackling the problems of contaminated land. NICOLE, Netherlands. www.nicole.org/uploadedfiles/1998-the-use-of-risk-assesment-and-risk-management.pdf Accessed July 2015.
Commonwealth of Australia 2006 Introduction to Cost-Benefit Analysis and Alternative Evaluation Methodologies January 2006 FINANCIAL MANAGEMENT REFERENCE MATERIAL NO. 5 ISBN 1 921182 02 4 www.finance.gov.au/sites/default/files/Intro_to_CB_analysis.pdf
Cundy, A.B., Bardos, R.P., Church, A., Puschenreiter, M., Friesl-Hanl, M., Müller, I., Neu, S., Mench, M., Witters, N., Vangronsveld, J., 2013. Developing principles of sustainability and stakeholder engagement. J. Environ. Manag. 129, 283–291.
Curran, J. and Hart, I. 1998 Sustainable redevelopment: incorporation into project design. pp 201–207. In Land Reclamation Achieving Sustainable Benefits. (Fox, H.R., Moore, H.M., McIntosh, A.D. Eds.) Proc. 4th Intern Conf. Intern. Affiliation of Land Reclamationists. Nottingham, UK, 7–11 Sept 1998. Pub Balkema, ISBN 905809002 7.
Department for Communities and Local Government — DCLG 2006 Environmental Impact Assessment: a guide to good practice and procedures. A consultation Paper, DCLG, London, http://webarchive.nationalarchives.gov.uk/20100410180038/http://communities.gov.uk/planningandbuilding/planning/sustainabilityenvironmental/environmentalimpactassessment/, Accessed November 2015
Department for Environment Food and Rural Affairs — Defra 2006 Carbon balances and energy impacts of the management of UK wastes. Defra R&D Project WR0602 Final Report. ERM and Golder Associates Defra, London, UK. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14644 Accessed November 2015
Defra — Department for Environment, Food and Rural Affairs 2010 Valuing environmental impacts: practical guidelines for the use of value transfer in policy and project appraisal technical report February 2010. Economics for the Environment Consultancy. https://www.gov.uk/ecosystems-services Accessed October 2013
Defra — Department for Environment, Food and Rural Affairs 2011 Guidelines for environmental risk assessment and management. https://www.gov.uk/government/publications/guidelines-for-environmental-risk-assessment-and-management-green-leaves-iii Accessed August 2015
DETR — Department of the Environment, Transport and the Regions, Environment Agency and Institute for Health and the Environment, 2000g. Guidelines for Environmental Risk Assessment and Management. The Stationery Office, Norwich, UK.
Department of the Environment, 1995. A Guide to Risk Assessment and Risk Management for Environmental Protection. HMSO, London, UK.
Döberl, G. and Muller-Grabherr, D. 2015 Recent trends in the assessment of sustainable remediation — does the tail wag the dog? Page 109. Programme and Book of Abstracts of the 13th International UFZ-Deltares Conference on Sustainable Use and Management of Soil, Sediment and Water Resources 9–12 June 2015, Copenhagen, Denmark. http://www.aquaconsoil.org/assets/acs2015__cg_web.pdf Accessed July 2015
Döberl, G., Ortmann, M. and Frühwirth, W. 2013 Introducing a goal-oriented sustainability assessment method to support decision making in contaminated site management Env, Sci. Policy 25 207–217
Doick, K.J., Sellers, G., Castan, B.V., Silverthorne, T., 2009. Understanding success in the context of brownfield greening projects: the requirement for outcome evaluation in urban green space success assessment. Urban Forestry and Urban Greening. 8 (3), 163–178.
Ellis, R., Hadley, P., 2009. Sustainable remediation white paper—integrating sustainable principles, practices, and metrics into remediation projects. Remediation Journal September 2009, 5–114.
Environment Agency 1999 Cost Benefit Analysis for Remediation of Land Contamination, R&D Technical Report P316, prepared by Risk Policy Analysts Ltd. and WS Atkins. Environment Agency, Bristol, UK. ISBN 185705 0371.
Environment Agency 2000a Assessing the Wider Environmental Value of Remediating Land Contamination. Bardos, R.P., Nathanail, C.P., and Weenk, A. Environment Agency R&D Technical Report P238. Environment Agency, Bristol, UK. ISBN 185705 0371, DOI: 10.13140/2.1.1255.6486
Environment Agency 2000b Costs and Benefits Associated with Remediation of Contaminated Groundwater: Framework for Assessment, R&D Technical Report P279, prepared by Komex Clarke Bond & EFTEC Ltd., Environment Agency, Bristol, UK.
Environment Agency 2009 Human Health Toxicological Assessment of Contaminants in Soil. Science Report — Final SC050021/SR2 Environment Agency, Bristol, UK. ISBN: 978-1-84432-858-1
Environment Agency 2010 Guiding principles for land contamination. Environment Agency, Bristol, UK. https://www.gov.uk/government/publications/managing-and-reducing-land-contamination Accessed August 2015
Environment Agency 2012 Working at construction and demolition sites: PPG6 pollution prevention guidelines PMHO0412BWFE-E-E. Environment Agency, Bristol, UK. www.gov.uk/government/uploads/system/uploads/attachment_data/file/290139/pmho0412bwfe-e-e.pdf Accessed August 2015
Environment Agency 2013 Pollution prevention guideline PPG 1. Environment Agency, Bristol, UK. www.gov.uk/government/uploads/system/uploads/attachment_data/file/290124/LIT_1404_8bdf51.pdf Accessed August 2015
Environment Agency and Department for Environment, Food and Rural Affairs 2004 Model procedures for the management of land contamination. Environment Agency R&D Report CLR11. Environment Agency, Bristol, UK. www.gov.uk/government/uploads/system/uploads/attachment_data/file/297401/scho0804bibr-e-e.pdf Accessed July 2015
EURODEMO Project Consortium. 2007. Framework for sustainable land remediation and management. Deliverable reference number: D 5-3. Project no. (GOCE) 003985. Umweltbundesamt, Vienna, Austria.
Ferdos, F., Rosén, L., 2013. Quantitative environmental footprints and sustainability evaluation of contaminated land remediation alternatives for two case studies. Remediat. J. 24 (1), 77–98.
Ferguson, C., Darmendrail, D., Freier, K., Jensen, B.K., Jensen, J., Kasamas, H., Urzelai, A., Vegter, J., 1998. Risk Assessment for Contaminated Sites in Europe. Volume 1. Scientific Basis. LQM Press, Nottingham.
Ferdinandy, M., and Weenk, A. 1999 Milieubeoordeling van verwerkingsketens voor verontreinigde baggerspecie. Eindrapport… RIZA rapport: 97.04. ISBN: 90 369 51 216. www.helpdeskwater.nl/publish/pages/404/posw_2_deel_22.pdf Accessed August 2015

Finnamore, J. R., Denton, B. and Nathanail, C.P. 2000 Land contamination — management of financial risk. Report C545, Construction Industry Research and Information Association (CIRIA) publications, London, ISBN 0 86017 545 6

GLA — Greater London Authority 2007 Planning for equality and diversity in London. Supplementary Planning Guidance. GLA, London, UK. ISBN 978 1 84781 068 7 www.london.gov.uk/sites/default/files/archives/mayor-strategies-sds-docs-spg-planning-for-equality.pdf Accessed August 2015

Grimski, D., Doetsch, P., Rupke, A., 1998. Brownfield versus Greenfield sites under economic and long term environmental considerations. in Proceedings of the Sixth International FZK/TNO Conference on Contaminated Soil, Edinburgh 17-21 May 1998 vol 1. Published by Thomas Telford, London, pp. Pp 651–660.

Harbottle, M.J., Al-Tabbaa, A., Evans, C.W., April 2008a. Sustainability of land remediation, Part 1: overall analysis. Proceedings of the Institution of Civil Engineers Geotechnical Engineering 161 (Issue GE2), 75–92. http//www.icevirtuallibrary.com/content/article/10.1680/geng.2008.161.2.75 Accessed August 2015.

Harbottle, M.J., Al-Tabbaa, A., C.W, Evans, June 2008b. Sustainability of land remediation, Part 2: impact assessment. Proceedings of the Institution of Civil Engineers Geotechnical Engineering 161 (Issue GE3), 117–127 www.icevirtuallibrary.com/content/article/10.1680/geng.2008.161.3.117 Accessed August 2015.

Hardi, P. and Zdan, T.J. 1997 Assessing sustainable development International Institute for Sustainable Development, 161 Portage Avenue East — 6th Floor, Winnipeg, Manitoba, R3B 0Y4, Canada, ISBN 1-895536-07-3, http://www.iisd.org/pdf/bellagio.pdf Accessed August 2015

HM Treasury 2011 The green book. Appraisal and Evaluation in Central Government. Treasury Guidance, TSO, London. www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf Accessed August 2015

Holland, K., Lewis, R., Tipton, K., Karnis, S., Dona, C., Petrovskis, E., Bull, L., Taege, D., and Hook, C. 2011. Framework for integrating sustainability into remediation projects. Remediation Journal, 21(3):7–38, see also 'Supplement to Framework for Integrating Sustainability into Remediation Projects June 2011' www.sustainableremediation.org/library/guidance-tools-and-other-resources/metrics-toolbox/Framework%20supplement.pdf Accessed July 2015

HSE — Health and Safety Executive 2014 Avoiding danger from underground services. HSG47 (Third Edition). Health and Safety Executive. www.hse.gov.uk/pUbns/priced/hsg47.pdf Accessed August 2015

Holland, K., Karnis, S., Kasner, D.A., Butler, P.B., Hadley, P.W., Nathanail, P., Ryan, J., Smith, L.M., Wice, R., 2013. Integrating remediation and reuse to achieve whole-system sustainability benefits. Remediation Journal Spring 2013, 5–17. http://dx.doi.org/10.1002/rem.21345.

Hou, D., Al-Tabbaa, A., 2014. Sustainability: a new imperative in contaminated and remediation. Environmental Science and Policy 39, 25–34.

International Standards Organisation — ISO 2015 ISO/DIS 18504 Soil quality – Guidance on sustainable remediation http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=62688 Accessed November 2015

ITRC — Interstate Technology and Regulatory Council 2011 Green and sustainable remediation: a practical framework. Framework Report GSR-2 ITRC, Washington. www.itrcweb.org/GuidanceDocuments/GSR-2.pdf Accessed August 2015

JRC-IES, European Commission Joint Research Centre, Institute for Environment and Sustainability 2011 Analysis of existing environmental footprint methodologies for products and organizations: recommendations, Rationale, and Alignment. Deliverable 1 to the Administrative Arrangement between DG Environment and Joint Research Centre No. N 070307/2009/552517, including Amendment No 1 from December 2010. http://ec.europa.eu/environment/eussd/pdf/Deliverable.pdf Accessed August 2015

Licht, L.A., Isebrands, J.G., 2005. Linking phytoremediated pollutant removal to biomass economic opportunities. Biomass Bioenergy 28, 203–218.

Morio, M., Schädler, S., Finkel, M., Justen, A., Bleicher, A., Bartke, S. and Gross, M. 2011 Megasite management tool suite (MMT) users guide. Version 1.2.0, March 2011. www.ufz.de/index.php?en=19610 Accessed July 2015

Nathanail, C. P., Bardos, R.P., Gillett, A., McCaffrey, C., Ogden, R., Scott, D. and Nathanail, J. 2013 International Processes for Identification and Remediation of Contaminated Land. Final Report Project SP1004, Defra, London, UK. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16289#Description Accessed July 2015

NAVFAC — Navy Facilities Engineering Command 2012 Department of the Navy guidance on green and sustainable remediation. User's Guide UG-2093-ENV Rev.1. NAVFAC, Port Hueneme, California 93043–4370, USA. www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/gpr/navfacesc-ev-ug-2093-env-gsr-20120405r1.pdf Accessed August 2015

NAVFAC — Navy Facilities Engineering Command 2014 Green and sustainable remediation. ESAT N62583-11-D-0515/TO 0046 NAVFAC, Port Hueneme, California 93043–4370, USA. www.navfac.navy.mil/content/dam/navfac/Specialty%20Centers/Engineering%20and%20Expeditionary%20Warfare%20Center/Environmental/Restoration/er_pdfs/g/navfac-ev-fs-gsr-201405v7.pdf Accessed August 2015

NICOLE 2011 Road map for sustainable remediation (co-author) NICOLE secretariat, Dutch Sino Business Promotions, Postbus 28249, 3003 KE Rotterdam, The Netherlands. www.nicole.org/pagina/22/Thematic_Documents.html Accessed August 2015

NICOLE and COMMON FORUM 2013 Risk-informed and sustainable remediation. Joint Position Statement by NICOLE and COMMON FORUM, 9 June 2013. www.commonforum.eu/Documents/DOC/PositionPapers/1177_DDC_FLYER_SR_Joint_snijlijn_def_2.pdf Accessed August 2015

NOBIS — Netherland Onderzoeksprogramma Biotechnologische In situ Sanering 1995a Risk Reduction, Environmental Merit and Costs. REC-Method, Phase 1. Document 95-1-03, CUR/NOBIS,

NOBIS — Netherland Onderzoeksprogramma Biotechnologische In situ Sanering 1995b Risk Reduction, Environmental Merit and Costs. REC-Method, Phase 2: A methodology based on Risk reduction, Environmental merit and Costs. Document 951-03, CUR/NOBIS, Gouda, The Netherlands,

Office of the Deputy Prime Minister 2005 A Practical Guide to the Strategic Environmental Assessment Directive. ODPM, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/7657/practicalguidesea.pdf, Accessed November 2005

ORNL — Oak Ridge National Laboratory 2013 ORNL operations best practice guide: idle reduction. Sustainable Campus Initiative. ORNL/LTR-2013/102. https://sustainability-ornl.org/documents/ORNL%20Idle%20Reduction%20Guide.pdf Accessed August 2015

Pediaditi, K., Doick, K., Moffat, A.J., 2010. Monitoring and evaluation practice for brownfield regeneration to green space initiatives. A meta-evaluation of assessment and monitoring tools. Landsc. Urban Plan. 97, 23–36.

Pediaditi, K., Wehrmeyer, W., Chenoweth, J., 2005. Monitoring the sustainability of brownfield redevelopment projects. The redevelopment assessment framework (RAF). Contaminated Land and Reclamation 13 (2), 173–183.

Plant, R.A., Chong, J., Lederwasch, A., Prior, J., Asker, S., Boydell, S., 2015. CRC for Contamination Assessment and Remediation of the Environment. Value-based Land Remediation: Improved Decision-making for Contaminated Land, no. CRC CARE Technical Report No. xx, pp. 1–33 (see http://www.uts.edu.au/staff/roelof.plant, unpublished).

Pollard, S.J.T., Brookes, A., Earl, N., Lowe, J., Kearney, T.E., Nathanail, C.P., 2004. Integrating decision tools for the sustainable management of land contamination. Sci. Total Environ. 325 (1–3), 15–28.

RESCUE Consortium 2005 Best Practice Guidance for Sustainable Brownfield Regeneration. May 2005. Land Quality Press, a Division of Land Quality Management Ltd. ISBN 0-9547474-0-2

REVIT Consortium 2007 Working towards more effective and sustainable brownfield revitalisation policies. Ensuring sustainability in Brownfield revitalisation. www.hartvanzuid.nl/downloads/REVIT_booklet.pdf Accessed July 2015

Rizzo, E., Bardos, P., Pizzol, L., Critto, A., Giubilato, E., Marcomin, A., et al., 2016. Comparison of international approaches to sustainable remediation. Submitted to Journal Environmental Management (in prep).

Sardinha, I.D., Craveiro, D., Milheiras, S., 2013. A sustainability framework for redevelopment of rural brownfields: stakeholder participation at SÃO DOMINGOS mine, Portugal. Journal of Cleaner Production 57, 200–208.

Schädler, S., Morio, M., Bartke, S., Rohr-Zänker, R., Finkel, M., 2011. Designing sustainable and economically attractive brownfield revitalization options using an integrated assessment model. J. Environ. Manag. 92, 827–837.

Smith, M.A. – ed 1985 Contaminated Land: Reclamation and Treatment Publisher: New York: Plenum Press ISBN: 0306419289. NATO Challenges of Modern Society; v. 8

Smith, J.W.N., Kerrison, G., 2013. Benchmarking of decision-support tools used for tiered sustainable remediation appraisal. Water Air Soil Pollut 224 (1706). http://dx.doi.org/10.1007/s11270-013-1706-y.

Sorvari, J., Antikainen, R., Kosola, M.L., Hokkanen, P., Haavisto, T., 2009. Eco-efficiency in contaminated land management in Finland: barriers and development needs. J. Environ. Manag. 90 (5), 1715–1727.

Stroud District Council 2015 Development of potentially contaminated land — guidance for developers, Consultants and Agents. April 2015 (3rd Edition). https://www.stroud.gov.uk/info/contaminated_development.pdf Accessed November 2015

SURF — Sustainable Remediation Forum, 2009. Integrating sustainable principles, practices and metrics into remediation projects. In: Ellis, D., Hadley, P. (Eds.), Remediation Journal 19, pp. 5–114 (3).

SuRF-ANZ 2011 A framework for assessing the sustainability of soil and groundwater remediation. http://www.surfanz.com.au/pdfs/SuRF%20Australia%20Framework%20April%2011%20FINAL.pdf Accessed July 2015

SURF Netherlands, SKB and Bodembreed Forum 2015 CAHIER Duurzaam saneren en beheren doe je zo! January 2015, SKB, The Netherlands. http://www.surf-nl.com/publicaties/CAHIER_DuurzaamSaneren_Beheren.pdf Accessed July 2015.

Therivel, R. 2004 Sustainable urban environment — metrics, Models and Toolkits: Analysis of sustainability/social tools, Report to the sue-MoT consortium. 9 June 2004 http://download.sue-mot.org/soctooleval.pdf Accessed July 2015

US EPA — US Environmental Protection Agency 1973 The quality of life concept. A potential new tool for decision makers. Available from http://www2.epa.gov/nscep. Accessed November 2015

US EPA — US Environmental Protection Agency 1992 Reclamation and redevelopment of contaminated land: Volume II European case studies. EPA/600/SR-92/031

US EPA — US Environmental Protection Agency 2008a Green remediation: Incorporating sustainable environmental practices into remediation of contaminated sites EPA/542/R/08/002, USA. https://clu-in.org/download/techdrct/epa-542-f-08-002.pdf Accessed August 2015

US EPA — US Environmental Protection Agency 2008b Green Remediation: Best Management Practices for Excavation and Surface Restoration. EPA 542-F-08-012. EPA Office of Superfund Remediation & Technology Innovation. http://epa.gov/tio/download/remed/gr_quick_ref_fs_exc_rest.pdf Accessed August 2015

US EPA — US Environmental Protection Agency 2009 Design and installation of monitoring wells. SESDGUID-101-R0. EPA Science & Ecosystem Support Division. www.epa.gov/region4/sesd/fbqstp/Design-and-Installation-of-Monitoring-Wells.pdf Accessed August 2015

US EPA — US Environmental Protection Agency 2010a Superfund Green Remediation Strategy. September 2010. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Superfund Remediation and Technology Innovation www.epa.gov/superfund/greenremediation/sf-gr-strategy.pdf

US EPA — US Environmental Protection Agency 2010b Green Remediation Management Practices: Clean Fuel & Emission Technologies for Site Cleanup. EPA 542-F-10-008.

EPA Office of Superfund Remediation & Technology Innovation. www.epa.gov/tio/download/remed/clean-fuel-emis-gr-fact-sheet.pdf Accessed August 2015

Van-Camp L., Bujarrabal, B., Gentile, A-R., Jones, R.J.A., Montanarella, L., Olazabal, C. and Selvaradjou, S-K. 2004. Reports of the technical working groups established under the thematic strategy for soil protection. EUR 21319 EN/1, 872 pp. Office for Official Publications of the European Communities, Luxembourg.

Van Liedekerke M., Prokop G., Rabl-Berger S. et al. 2014. Progress in the Management of Contaminated Sites in Europe, JRC Reference Report. European Commission EUR 26376, http://dx.doi.org/http://dx.doi.org/10.2788/4658.10.2788/4658

van Veen, H. J. and Weenk, A. and Bardos, R.P. 1997 Selection and setting priorities for remediation options. 5th International FZK/TNO Conference on Contaminated Land. Masastricht, The Netherlands, October 30th to November 3rd 1995. Contaminated Soil'95, Pp 1465–1474, (van den Brink, W.J., Bosman, R. and Arendt, F. Eds) Kluwer Acad Pub., The Netherlands.

Vegter, J., Lowe J., & Kasamas, H. (Eds), 2002. Sustainable Management of Contaminated Land: An Overview. Report. Austrian Federal Environment Agency on behalf of CLARINET, Spittelauer Lände 5, A-1090 Wien, Austria. www.commonforum.eu/publications_clarinet.asp.

VOSA — Vehicle and Operator Services Agency 2013 HGV Inspection Manual Consolidated Edition. www.gov.uk/government/uploads/system/uploads/attachment_data/file/416627/heavy-goods-vehicle-hgv-inspection-manual.pdf, Accessed August 2015

WRAP — Waste and Resources Action Programme (2003) Sustainable procurement — making it happen. Available from www.1010global.org/sites/default/files/sustainable-procurement-making-it-happen.pdf Accessed August 2015