

Technical summary of SUMATECS – Sustainable management of trace element contaminated soils

Science Report – SC080023/SR

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Steve Killeen

Head of Science

Executive summary

The SUMATECS project (**Sustainable Management of Trace Element Contaminated Soils**) was funded under the SNOWMAN ERANET to carry out a literature and project-based review of gentle remediation options, assessing contaminant bioavailability and the environmental and socio-economic impacts of gentle remediation.

Soils across much of the industrialised world are increasingly being contaminated with trace elements as a result of changes in industrial practices, land-use, agricultural methods and climate effects such as increases in erosion rates. Gentle remediation is central to the SUMATECS philosophy for the remediation of trace element impacted soils. The term 'gentle' defines approaches that predominantly rely on plants to extract, stabilise or immobilise trace elements over longer timescales compared to more destructive remedial approaches that potentially disrupt soil systems, generate increased waste residues for disposal and are generally more expensive.

This report summarises the work carried out and provides a view on the work in a UK context. The main findings from the project are highlighted below.

A questionnaire survey of perceptions on gentle remediation technologies identified maintenance of soil function and cost as key benefits and the need for long-term monitoring and applicability limitations as key barriers to uptake.

Decision support tools (DSTs) are needed to integrate environmental, social and economic factors in the assessment of remediation approaches within national risk management frameworks. To promote widespread consideration and uptake of gentle remediation technologies, the report recommends that a simple checklist or decision matrix is developed for appraisal of remediation options to raise awareness of the capabilities of gentle technologies. This is particularly important to emphasise the wider environmental benefits, including restoring or preserving soil function and carbon sequestration. If needed, existing tools, such as multi-criteria analysis, life cycle analysis, cost benefit analysis and socio-economic assessment could be used where feasible remediation options need to be assessed in more detail.

The value of environmental assets is discussed and problems associated with how this is currently considered are highlighted.

The SUMATECS report describes a proposed socio-economic assessment framework that follows logical steps that guide the user to define the scope of the assessment, assess impacts to weigh positive and negative consequences, and to report conclusions of the study.

It is recommended that biological and ecotoxicological monitoring is needed to assess wider impact of gentle remediation, particularly on soil function, and a number of methods are discussed. This is consistent with our approach advocated in our recent Ecological Risk Assessment framework (Environment Agency, 2008a) and the lines of evidence approach proposed for verification of remediation.

Various gentle remediation studies and investigations have been performed within the EU but it is clear that research priorities associated with gentle remediation must include larger scale field studies, and defining and valuing 'good and functional' soils, so that an effective soil legacy is made available for future generations, gaining an improved understanding of biomass valorisation and the development of useful decision support tools that incorporate socio-economic factors within the decision making process.

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1 Introduction

1.1 Background

The SUMATECS project (Sustainable Management of Trace Element Contaminated Soils) was funded under the SNOWMAN ERA-NET¹ to carry out a review of literature and projects for ‘gentle’ remediation options, assessing contaminant bioavailability and the environmental and socio-economic impacts of ‘gentle’ remediation. The SUMATECS report can be found at:

<http://www.snowman-era.net/index.php>

1.1.1 Gentle remediation

Remediation approaches for dealing with trace element contamination have traditionally relied on engineering (removal to landfill, containment), physical (e.g. soil washing) or stabilisation /solidification technologies. These methods tend to be costly and have a negative effect some or all soil functions, or transfer the risks to future generations. Several gentle soil remediation technologies have been developed in the last two decades to manage risks on-site using plants and / or soil amendments.

Gentle remediation is the application of technologies to remove or stabilise/immobilise contaminants using plants, organisms or soil amendments, in a managed way whilst maintaining or improving the physical structure of the soil. Besides their ecological advantages, gentle remediation may cost less than traditional approaches, although longer timescales are required to reach a remedial end-point. Another restriction to the use of living organisms (e.g., plants and micro-organisms) is that the presence of toxins must be within the limits of tolerance of such organisms (Gupta *et al.*, 2000). Gentle technologies are therefore not usually suitable for the remediation of heavily contaminated soils.

Examples of gentle remediation and the contaminants that these remediation approaches can address are presented in Table 1.1.

1.2 Aims

The aim of the SUMATECS project is to identify the current status of research and application in Europe of gentle remediation technologies. This involves a literature and project-based review (including country specific state of the art and current procedures) of the technologies, their application, decision support systems, and recommendations for further research. The study covers soils contaminated by trace elements (TECS – trace metals and metalloids), singly or in combination with organics, at former industrial sites.

This report summarises the findings of the SUMATECS report and distils the key learning points.

¹ The SNOWMAN ERA-NET was set up under European Commission rules between Austria, Belgium, France, Germany, the Netherlands, Sweden, and the United Kingdom to improve co-operation between national research programmes, in the field of land management under the pressure of pollution. Information on the SNOWMAN ERA-NET can be found at <http://www.snowman-era.net/index.php>.

Table 1.1 Examples of gentle remediation approaches

Remediation type	Contaminant	Plant	Amendment	Location
Phytoextraction	Cd, Zn	<i>Brassica napus</i> <i>Zea mays</i> <i>Salix sp.</i> <i>Populus sp.</i>	Compost Manure Lime	Lommel (Belgium)
Phytostabilization	Pb, Zn	<i>Alnus</i> <i>Salix</i> <i>Populus</i> <i>Larix</i>		St Helens (UK)
Immobilisation	As, Cd, Pb, Zn	<i>Lactuca Sativa</i> <i>Phaseolus vulgaris</i>	Cyclonic ashes Iron grit	Reppel (Belgium)

1.3 Approach

Research and development of gentle remediation techniques and related aspects has been carried out in many European countries. In some cases, multi-national projects were carried out and great deal of information has been published. But much work remains unpublished, hampering the exchange of information on these technologies, and reducing the opportunities for the uptake to full-scale projects.

The project collected, integrated and evaluated the current state of the art in the field of gentle remediation techniques and provided a comprehensive data set for gentle remediation technologies in Europe.

The overall structure of the project and its work packages is outlined in Figure 1.1:

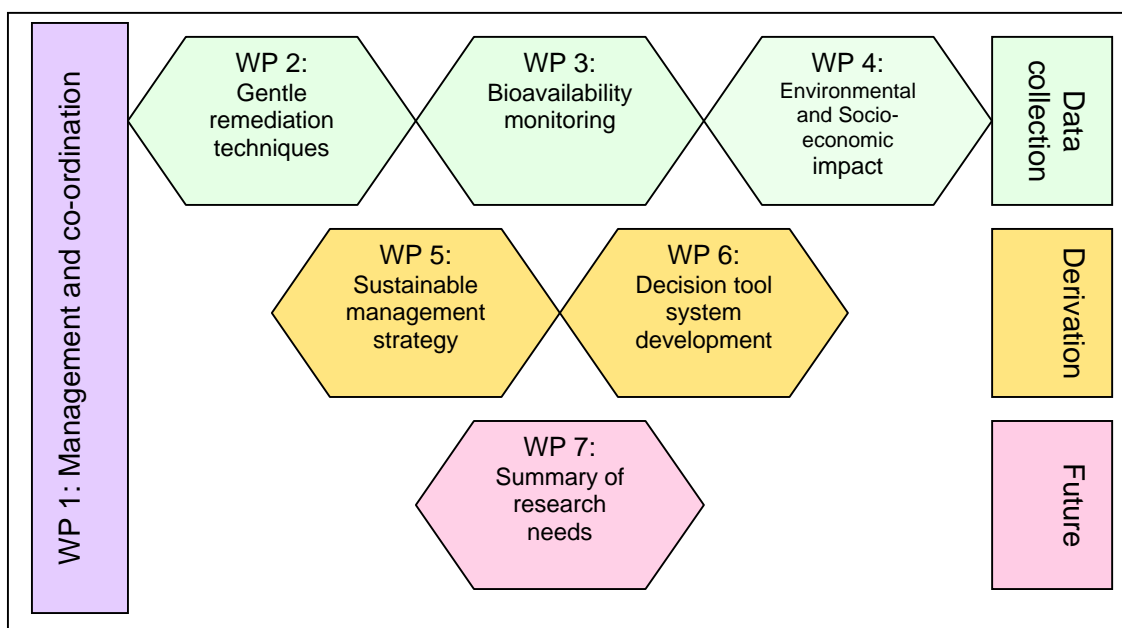


Figure 1.1 SUMATECS work packages

1.4 Valuing Environmental Assets

Current societal thinking of environmental value is founded on the rationale of assigning costs associated with restoring chemical-impacted, natural materials and resources to a state that removes the risk of significant pollution or harm.

The basis for this stems from the fact that 'environmental assets' are not assigned a value within public accounting mechanisms, therefore environmental damage does not have a debit counterpart in public accounting. However, remediation activities are 'valued' as economic activities by both public and private accounting systems (Miringoff and Miringoff, 1999) and the gross domestic product (GDP) of a country increases when environmental catastrophes are remediated (Meda, 1999).

These arguments illustrate why assigning value to environmental assets is problematic. Whilst this may seem rather esoteric for a remediation that is complete in weeks or months, it becomes increasingly important for gentle remediation processes that will be managed over years to decades.

As it is difficult to assign a value to environmental services and assets (such as soil quality) using market values, an alternative is to estimate it by costing the remediation of contaminated soil to its original condition. But this approach is fraught with difficulties as estimates based on costs and utility may diverge, the original condition may not be reproducible, and the uncertainty over costs related to remediation timescale (the relative value we give to the future).

A new approach attempts to value environmental assets through the environmental services it provides to the economy rather than simply the cost of remediation. The recent case of the Erika tanker that devastated the Brittany coast with heavy fuel provides some insight into the potential of this approach. After a decade of hearing evidence, a French high court of justice stated an historical verdict concerning socio-economic valuation of environmental assets and services (Le Monde, 2008). Fines of about 200 million Euro were levied on different bodies (currently being appealed), with the value divided as:

- About 1 million for the cost of remediation of damages to the environment (traditional approach to valuation of environmental services and assets); and
- About 199 million for reparation to the damages caused to the image and the reputation of the local territories, to be paid to different local institutions that protect the local environment.

It is clearly too early to evaluate the implications of this judgement to our future approach to valuing environmental services, but it is clear that the judgement recognised the full impact on the local economy, in this case including local land valuation and loss of tourism income.

2 Current Perception Of 'Gentle' Remediation

2.1 Questionnaire Survey

Successful adoption of gentle remediation is based on a wide range of stakeholders having all the necessary information to formulate judgements regarding the use and appropriateness of gentle remediation for different contamination scenarios. An important first step is therefore to understand the views of as wide a range of stakeholders as possible.

130 stakeholders and experts dealing with trace element contaminated sites in 15 countries were surveyed to seek their views, experience and opinions regarding gentle remediation options.

The main results of the survey are as follows:

- Most respondents were employees in public administrations either at a national or regional level (40%) or in local authorities like county and city councils (25%). About 20% were from universities and research institutions and 20% from private consultancies and companies involved in practical site remediation. No land owners or investors responded.
- Gentle remediation technologies are known to most respondents but rarely applied.
- Regulators are more sceptical about the use of gentle remediation than scientists and consultants. Although there were no responses, it is clear that owners and investors must also be engaged within the decision-making process for adoption of gentle remediation.
- The disadvantages of gentle remediation technologies are seen as the need for long-term monitoring and their limited applicability regarding contamination and land use.
- Dealing with gentle remediation technologies improves knowledge and acceptance from key stakeholders. The mixture of factors (socio-economic, environmental and economic) that must be assessed to determine if gentle remediation is a viable alternative requires a heightened sense of knowledge sharing and understanding.
- Lack of knowledge, experience and convincing pilot projects are considered to be the main obstacle for more general application of gentle remediation technologies.

Due to the sampling method and small sample size, these results may not be representative of the general perceptions and opinions of all stakeholders, administrators and scientists who are involved with trace element contaminated sites

Positive and negative perceptions of gentle remediation technologies are summarised in Table 2.1.

Table 2.1 Positive and negative aspects of gentle remediation technologies as reflected in the open answers from the respondents.

Positive	Negative
Maintain ecological soil functions: non-invasive, maintains soil structure & ecological functions of soil	Long-term monitoring is necessary
Costs : Often low cost, long term solution, low energy consumption	Not applicable to all metals/sites: What happens with the rest fraction? The use of mild remediation techniques is limited by lower urgency and therefore very low need of action can be seen
Sustainability: Can be highly sustainable, long term solution	Duration of measure: Not compatible with current administrative procedures
Suitability for large-scale treatment Possibility to treat large areas; lower amounts of direct wastes, perfect solutions for sites that are not used intensely	Lack of knowledge and practical experience: Non knowledge of successful projects working with phytoextraction. There are a few well documented references
Public acceptance : Wide public acceptance, little noise and exhausts	Costs: Higher costs of preliminary stages (lab/field). Is it economically feasible?
Reduce risks: Can reduce risks on the sites that wait for use choice	Usability during remediation: During process, people should be kept aware that the site is still polluted
Energy can be produced from biomass	
Easy to apply: pH modification can be applied by non-professionals	

2.2 Do gentle remediation approaches fit well within a risk management approach to land contamination?

In the context of land contamination, there are three essential elements to any risk: a contaminant, a receptor – in general terms, something that could be adversely affected by a contaminant, and a pathway that links the receptor to the contaminant.

Each of these elements can exist independently, but they create a risk only where they are linked together. This contaminant–pathway–receptor relationship is described as a pollutant linkage.

A structured approach to risk management should assess which pollutant linkages identified at a site are associated with unacceptable risk. Where such pollutant linkages are identified, options are then assessed and appropriate steps taken to ensure that the pollutant linkages, and therefore risks, are effectively managed.

The options appraisal and subsequent implementation of risk management measures equally apply to management options, traditional (often harsh) remediation techniques and gentle approaches. However, the case for gentle remediation approaches will rarely be compelling without wider environmental and socio-economic benefits being taken into account in the decision, primarily because of the uncertainty of managing pollutant linkages over a long period of time. Adopting gentle remediation approaches

in the UK under a number of specific situations could work as a viable low-cost remedial approach. These include:

- Stabilising spoil from mining and other industrial processes that is interacting with rainwater and the resulting runoff or leachate is impacting on local receptors such as water courses and groundwater. Gentle technologies could be effective where the land will not be redeveloped for the foreseeable future.
- Brownfield sites in urban centres where the benefit to the community of having some type of 'green-space' outweighs the need to redevelop the land for residential or commercial use. Such urban greening may contribute to the well-being and health of our urban populations and promote the concept of sustainable communities (HMG, 2005).
- Combining remediation with the production of biomass for economic utilisation, for example energy or biofuel production.
- With the (current) economic situation, potential timescales of recovery and lack of return or confidence in investment, this may be an opportunity to invest in gentle remediation to manage the potential impacts of land contamination and reduce residual risks, albeit slowly, until the economic situation improves for the construction industry.

3 Decision Support

3.1 What Do We Mean By ‘Decision Support’?

Decision Support (DS) is a step-by-step method for the evaluation of a range of technical options and approaches to solving a wide range of problems. In this particular case, ‘Decision Support’ means evaluating the merits/demerits of three key drivers for sustainable development to choose the most suitable remediation approach. These drivers are:

- Environmental – Are environmental legislation and compliance values the end-all to the decision process or other factors also important?
- Socio-economic – Different remedial approaches have differing merits and demerits with respect to societies needs on a case-by-case basis.
- Economic – Cost comparisons are made between different remediation approaches.

Where gentle remediation needs to be compared to more aggressive remedial approaches such as ‘dig and dump’ or soil washing, , some form of decision support is beneficial, to allow the user to make informed, and consistent decisions on which is the most suitable technique(s) for the particular site requiring remediation or management.

A range of tools is available to support the decision-making process. It must be stressed that the use of a tool does not replace sound, professional judgement. At the simplest level, a tool may comprise technology fact sheets, and some more complex methodologies are summarised below:

- **Cost Benefit Analysis (CBA)** – A framework for comparing monetary value of a project or policy with the monetary value of its costs. The definitions of ‘cost’ and ‘benefit’ used by economists are much wider than the definitions routinely used. Costs include, e.g., environmental costs, and benefits are not just the direct benefit of meeting the remediation objective.
- **Cost Effectiveness Analysis (CEA)** - Differs from CBA only (but significantly) in that the benefits of the project are not monetised. Once remediation objectives have been agreed, CEA provides a framework for deciding the least cost option to deliver the required remediation standard.
- **Life Cycle Analysis (LCA)** – Encompasses the whole life cycle of a product or activity - a ‘cradle to grave approach’ It considers not just the emissions from, and resources used in, the implementation, but also those associated with other parts of the economic system affected by the product or activity.
- **Multi-Criteria Analysis (MCA)** – A variety of methodologies to compare and contrast different factors relevant to a particular remedial approach (Communities and Local Government, 2009). This is particularly difficult as weighing up the merits/demerits of one factor against a very different factor requires subjective judgement. MCA techniques can be used to identify a single preferred plan, to rank options, as short-listing tools to select options for more detailed assessment, or to differentiate acceptable and unacceptable plans. A simple example is shown as Figure 3B TOOL 1 in CLR 11 (Defra and Environment Agency, 2004).

- **Socio-Economic Assessment (SEA)** – Looks at the merits/demerits of particular remedial approaches from the perspective of the local community and society in general.

Different approaches to the concept of Decision Support are taken across the EU, and the approaches taken in some states are summarised below.

United Kingdom – Heavily focused on ‘Model Procedures for the Management of Contaminated Land also referred to as Contaminated Land Report 11 (CLR 11) and consists of risk assessment, options appraisal and remediation strategy implementation and aftercare. The decision-making process for gentle remediation is consistent with other technologies and requires no further elaboration here.

Germany – Similar to the UK approach.

Netherlands – Based on ROSA and BOSS software packages. ROSA is used for the evaluation of remediation alternatives based on National Soil Protection legislation. BOSS is a web-based expert system.

Italy – Italy is one of the few countries that has a DS system, known as DESYRE, that incorporates socio-economic factors into the decision process through fuzzy logic algorithms.

Key factors in decision making are highlighted in Figure 3.1 (from CLARINET, 2002).

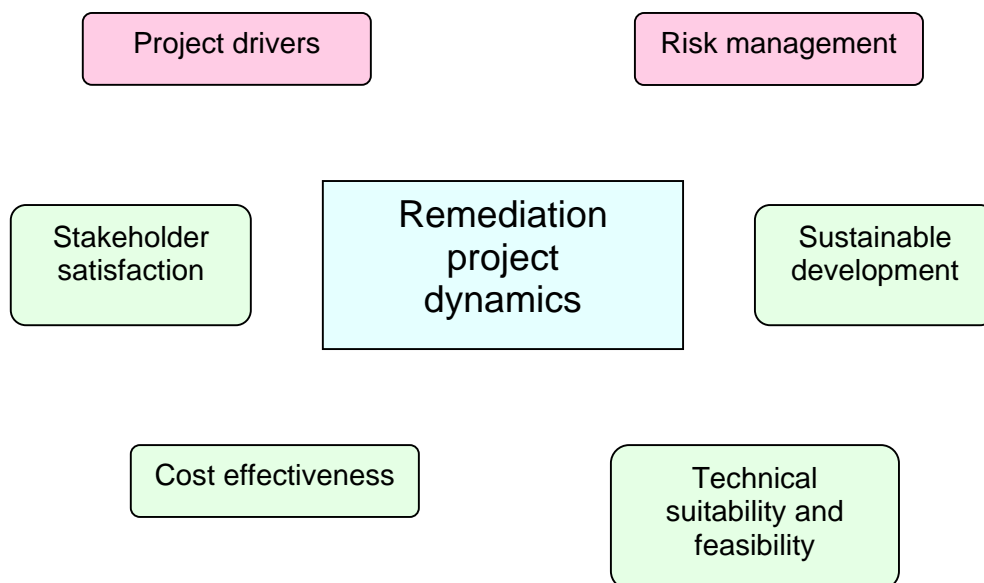


Figure 3.1 Key factors in decision making

The following factors are discussed below:

Technical suitability and feasibility – Section 3.1;

Cost-effectiveness – Section 3.2;

Sustainable development – Section 3.3; and

Stakeholder satisfaction – Chapter 4;

with the degrees of freedom for decision-making constrained by project drivers and risk-based objectives.

Key reasons why gentle remediation approaches have not been adopted as much as they could have been include:

- Prediction of the impacts in the alternative scenarios is very difficult in practice. At best, only risk estimates are often possible;
- Assessment of socio-economic benefits of ecosystems improvement will often remain qualitative (lack of information on value);
- The long timeframes make assessments difficult in terms of environmental impacts (and benefits), and economic assessment.

Decision support tools should integrate environmental, social and economic factors in the assessment of remediation approaches within national risk management frameworks. To promote widespread consideration and uptake of gentle remediation technologies, the SUMATECS report recommends that a simple checklist or decision matrix is developed for use at options appraisal to raise awareness of the capabilities of gentle technologies in both core and broad terms. This is particularly important to emphasise the wider environmental benefits, including restoring or preserving soil function and carbon sequestration. If needed, existing tools, such as multi-criteria analysis, life cycle analysis, cost benefit analysis and socio-economic assessment can be used to assess options in more detail.

3.2 Technical Suitability, Feasibility And Cost Effectiveness

3.2.1 Technical Suitability and Feasibility

A **suitable** technology is one that meets the technical and environmental criteria for dealing with a particular remediation problem. However, it is also possible that a proposed solution may appear suitable, but is still not considered **feasible**, because of concerns about:

- Previous performance of the technology;
- Expertise of the purveyor;
- Ability to verify the effectiveness of the solution when it is applied;
- Cost; or
- Acceptability to, and confidence of, stakeholders in the solution.

In general, concerns over feasibility tend to be greater for innovative, remedial approaches, even if these have long-standing track records in other countries. However, it is often these innovative solutions that are seen to offer more in terms of reducing wider environmental impacts and improving resource and energy efficiency.

A feasible remediation option is one that is likely to meet defined, site-specific objectives relating to both the pollutant linkages and the wider management context for the site as a whole.

Gentle remediation approaches include:

Phytostabilisation: This works best with fine-textured soils with high organic matter content but also works well where large areas of near-surface materials are contaminated. The technique is useful for re-establishing a vegetated cover where

natural vegetation is lacking due to elevated trace element concentrations. The technique limits transport of exposed surface soils and leaching of soil contamination to groundwater and wind erosion. The technique has been proven for treating trace elements

Rhizofiltration: This works by compounds being taken up or sorbed by roots (or sorbed to algae and bacteria).

Phytoextraction: This works by trace elements and organic chemicals being taken up by plants with water through translocation processes. Trace elements that have been remediated in this way include nickel, zinc, lead, chromium, cadmium and selenium.

Phytovolatilisation: Trace elements are taken up by plants, changed into volatile states and transpired. Subject to human health and ecological risk assessments, this method has been used to successfully treat metals include mercury and selenium.

Important factors in assessing gentle remediation approaches are:

- Soil properties and target contaminants;
- Plant selection, e.g. sunflowers and Indian mustard for lead or *Thlaspi sp* for cadmium and zinc;
- Selection of soil amendments, e.g. biosolids to add essential nutrients and organic matter to the soil, or inorganic additives (e.g. lime) for pH adjustment;
- Treatability studies to choose a suitable option and to demonstrate that the selected approach can yield the desired results; and
- Time to achieve remediation objectives.

The SUMATECS report cites numerous references for laboratory and field scale research on gentle remediation technologies². Table A.1 lists a number of field-scale trials by country that are referred to in the SUMATECS report.

The published field trials mainly relate to phytoextraction or phytostabilisation/immobilisation methods. When taking into account the achievable mass of trace elements that can be reasonably extracted, it is evident that phytoextraction is only applicable to more moderately contaminated land, and is not a feasible alternative to conventional soil remediation on more heavily polluted sites. In contrast, phytostabilisation/immobilisation methods are not limited by the degree, or mix, of trace element pollutants. A mixture of trace metals can be effectively handled when using appropriate soil additives, but the durability of the stabilisation/immobilisation of trace elements will need to be taken into account during project planning. Table A.2 summarises plant species that have been successfully used to remediate trace element impacted soils.

Total concentrations of trace elements in soils do not usually equate to the potential risks to the environment and human health. Trace elements only become potentially harmful if an organism assimilates them.

The use of soil amendments may have a positive or negative effect on the biological and biochemical functions of the soil biota, and this also needs to be considered during project planning. The SUMATECS report provides a review of methods used to measure the availability of trace elements to a range of biota³ and reviews literature

² SUMATECS report, section 6.2

³ Section 6.3. This should be read in light of the recently published framework on ecological risk assessment for land contamination (Environment Agency, 2008a) that includes detailed guidance on the use of bioassays and ecological surveys in risk assessment (Environment Agency, 2008b and c).

that examines the impact of gentle technologies, particularly soil amendments, on biological and biochemical activity⁴

The restoration of soil functionality at trace element contaminated sites strongly depends on establishing or promoting a well-structured and active community of soil organisms. Data from long-term studies on revegetated mine spoil show that biological and biochemical activity is enhanced with increasing plant density and diversity. Among the soil amendments, most measures that introduce organic matter or alkalinity to the contaminated soils also improve microbial or faunal parameters. Only a few amendments have deleterious effects on soil biota. One example is phosphate (without alkaline additions) due to acidification of the soil.

Lines of evidence are “data sets of key parameters that support the agreed remediation criteria to demonstrate the performance of remediation” (Defra and Environment Agency, 2004). The concept was introduced by the National Research Council (1993) for *in situ* bioremediation; developed from the premise that, a reduction in contaminant concentration alone does not provide unequivocal proof that it is a result of the bioremediation process. For gentle remediation, this approach could be extended, using appropriate test methods, to provide evidence that soil functionality is preserved or restored during remediation – an important benefit in support of gentle approaches.

3.2.2 Cost Effectiveness

Cost-effectiveness is intrinsically tied in to the remediation life-cycle and year-on-year costs to meeting a set objective. A Cost Effectiveness Analysis (CEA) selects the lowest cost option from a range of technologies to meet a set of predefined objectives (see 3.3.1). Such an assessment will not take into account wider environmental or socio-economic costs or benefits.

Remedial options and associated costs have been evaluated by CLARINET (2002). These costs suggest that:

- In-situ remedial technologies cost from 20-60 Euros/tonne. These include monitored natural attenuation (MNA) and phytoremediation.
- Ex-situ remedial technologies cost from 20-40 Euros/tonne for bioremediation and 80-150 Euros/tonne for stabilisation/solidification.

An important cost consideration in any phytoextraction approach is the method used for handling plant biomass after remediation. Phytoextraction involves repeated cropping of plants in contaminated soils until the metal concentration drops to an acceptable level. Each crop is removed from the site. Large quantities of contaminated biomass can be generated and this mass must be recovered or disposed of appropriately. The valorisation of biomass is reviewed and initial experiments are reported⁵. The results suggest that composting or leaching may be helpful to pre-treat contaminated biomass before incineration. It should be possible to recycle metals from contaminated biomass, residues from incineration and pyrolysis or leachates, but further developments are needed on these aspects to improve the separation of the metals from the waste.

⁴ SUMATECS report, Section 6.4.2

⁵ SUMATECS report, section 6.4.4

3.2.3 Information source for gentle remediation technologies

SUMATECS has developed a web interface or GUI that is readily accessible and captures information on studies and publications focused on gentle remediation of trace element contaminated soils.

The website is <http://w3.pierroton.inra.fr:8000/users/welcome>.

The website also enables users to create new entries related to field studies and publications, site details and experimental data.

3.3 Sustainable Development

The incorporation of the concept of sustainable development across the environmental sector is a cornerstone to both the protection of environmental assets and to handing over meaningful and useable assets to future generations. Figure 3.2 presents five key principles that should be addressed when considering the sustainability of a project:

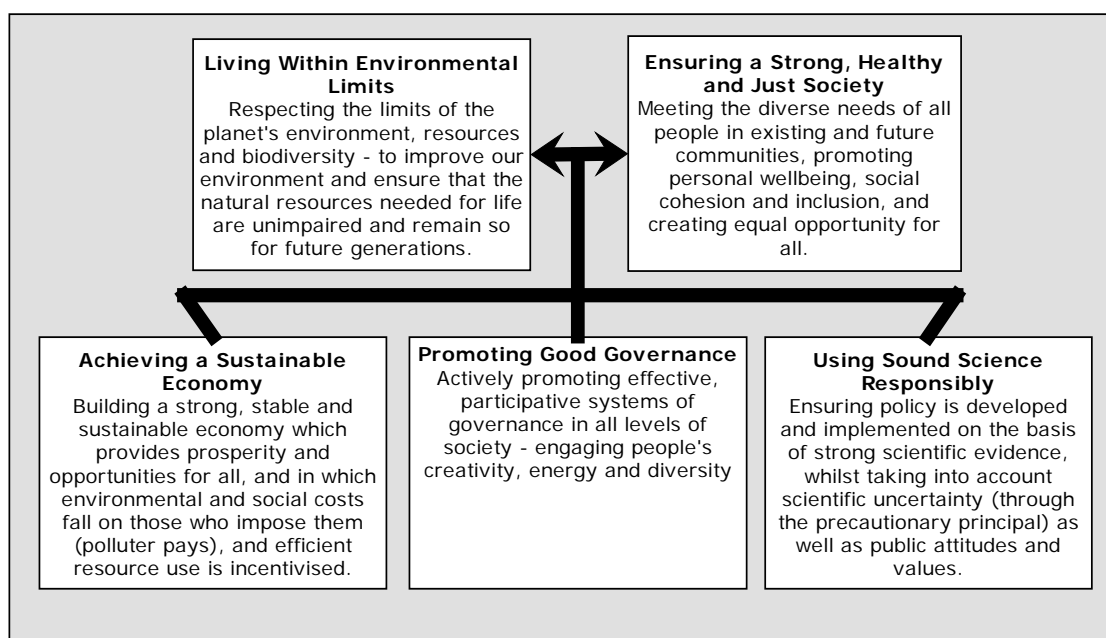


Figure 3.2 Guiding principles of sustainability⁶

All of the principles outlined above should be incorporated into any assessment for determining if gentle remediation is a viable approach for a particular site. These principles will also be incorporated into socio-economic assessments.

3.3.1 Socio-economic framework

Socio-economic assessment (SEA) is an integral part of the decision making process to assess if a gentle remediation approach is appropriate for a particular site. Generally these socio-economic factors are divided into:

- Impacts on human health and the environment along the entire chain; and

⁶ From HM Government 'Securing the Future', March 2005

- Impacts on the economy in terms of financial costs and financial benefits along the entire chain.

If quantitative remedial targets for the project are set, then there may be a variety of technical options that achieve (or surpass) the target. The role of socio-economic analysis could in this case be to determine the least cost option (in purely financial terms) that achieves the target.

If such targets are not set, then the role of socio-economic analysis could be to check whether one or different options have more socio-economic benefits than drawbacks, compared with 'no action'.

One of the challenges of a SEA is incorporating the factor of time, cost and relative benefit, particularly as gentle remediation approaches take considerably more time than traditional methods.

Section 6.4.6.3 of the SUMATECS report describes a proposed socio-economic assessment framework that follows logical steps as summarised below:

- Step 1: Define the aims and scope of the SEA (scenarios, timeframe, geographical boundaries). Key questions here are 'What are we trying to achieve, What are the objectives? Over what timeframe will the objectives be completed? How big is the problem?'
- Step 2: Assessment of the environmental and health impacts of the project for various scenarios. Different remedial approaches must be compared to describe how they address environmental and human health issues and include an assessment of societal impacts and benefits. Such wider social issues, for example public amenity, quality of life, dust or odour, will usually be expressed qualitatively.
- Step 3: Assessment of the economic impacts of the project for various scenarios. This may include CEA and CBA and must incorporate timeframe and societal needs over a longer term.
- Step 4: Use the assessments to weight the positive and negative consequences of one or several scenarios.
- Step 5: Conclude the SEA, including a description of the uncertainties and/or unknowns.
- The framework is illustrated, albeit only using financial costs, by reference to the "La Combe du Saut" project involving phytostabilisation of arsenic-contaminated spoil from the mining industry⁷.

⁷ SUMATECS Report, section 6.4.6.4

4 Communication

There is a growing recognition in the need for effective communication with a range of stakeholders during both planning and implementation of remediation. It may however be challenging to make decisions based on both technical evidence and the perceptions of a variety of stakeholders. Figure 4.1, taken from the SUMATECS questionnaire survey, highlights the difference in perception of expert and non-expert participants on a range of key factors associated with gentle remediation approaches. Perceptions can be highly variable, with generally more scepticism in non-experts. It is generally useful to understand others' viewpoints, and perhaps information needs, both when making and communicating decisions.

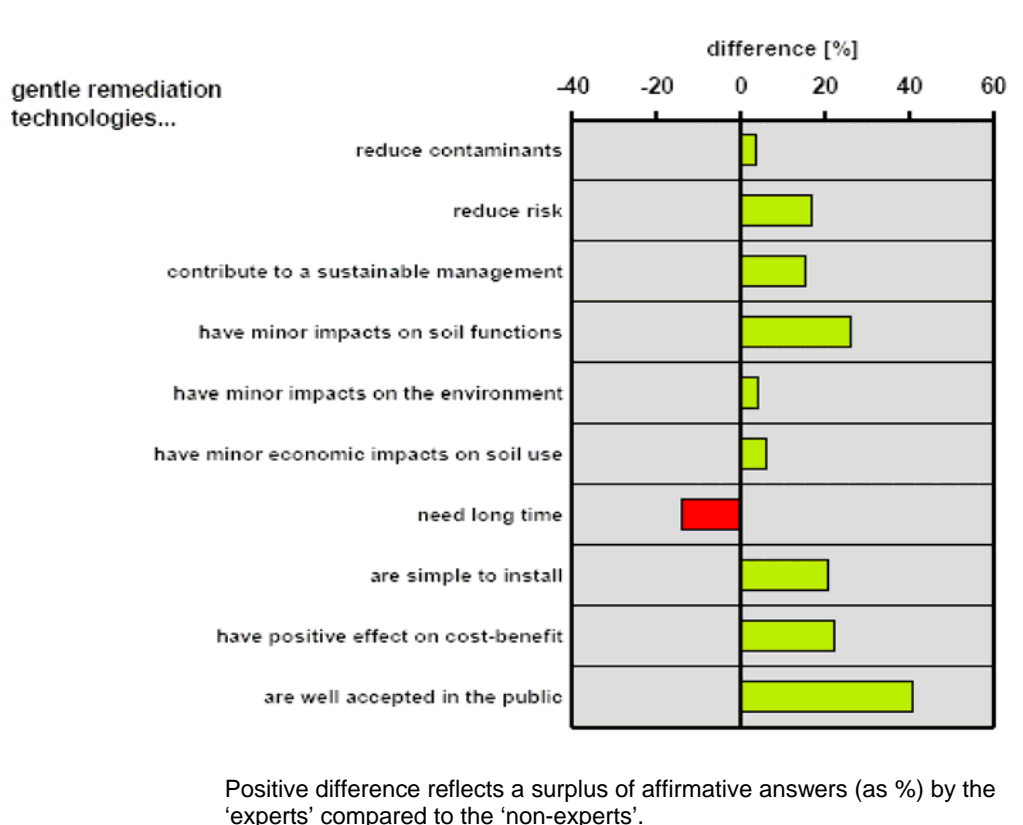


Figure 4.1 Differences in the evaluation of gentle remediation technologies between 'experts' and 'non-experts'.

Stakeholders, including local residents, may have legitimate concerns about the level of risk posed by a site, even one where gentle remediation is being practiced as it may not be immediately apparent that risks are actually being managed. Communicating information about the risks may not be easy, particularly where concerns about risk may be at odds with the scientific evidence.

A risk communication strategy will be an important element of many land contamination projects, especially for large, complex or otherwise high-profile sites or where the technical processes involved are likely to be particularly disruptive or time consuming. There are several ways of developing and delivering risk communication strategies at a site-specific level and government guidance is available from <http://www.defra.gov.uk/environment/risk/eramguide/01.htm>. SNIFFER has published guidance for communicating risks from land contamination (SNIFFER, 1999) that is currently (2008) subject to review (see <http://www.sniffer.org.uk>).

5 Research Priorities

Growth in a number of research areas would greatly enhance our understanding of the usefulness of gentle remediation approaches to mitigating soil contamination. Several important research areas are listed below:

5.1 Large-scale field demonstration projects

This would provide greater levels of information on the general performance of gentle remediation over a wider area and would also provide useful insight into how land on a larger scale behaves ecologically and from a soil function perspective. Such projects will help build a track record.

5.2 Use of microbial sensors and whole cell biosensors to improve risk assessment

A better understanding is required of soil microbiology and soil functionality, notably after remediation. Advances in gene biology and nanotechnology are facilitating the ability to detect and assess the movements and fate of contaminants in simple organisms. The development of a tool kit is recommended so that comparisons can be made for gentle remediation projects across Europe.

5.3 Financial evaluation of soil functions

This research area is linked closely to society's moral and ethical duty-of-care to pass on useful, natural resources and materials to future generations. Any valuation is likely to enhance the uptake of gentle remediation technologies as they may have little or no negative impact on soil function and other ecological services.

5.4 Biomass Valorisation

Current research suggests that biomass valorisation could be an option if the biomass were initially dried through composting to reduce its volume or underwent pyrolysis (a thermal degradation process to generate char, bio-oil and tar and fuel-gas products). Techniques for recovering metals locked up in plant biomass are currently not cost-effective and technologically challenging but these are areas of research that could provide some real benefit.

6 Conclusions

The SUMATECS report introduces the term 'gentle remediation' as a means of removing or stabilising/immobilising contaminants in soil using plants, organisms or soil amendments, in a managed way whilst maintaining or improving the physical structure of the soil. The focus of gentle approaches is clearly to manage pollutant linkages whilst maintaining or improving soil functions, in particular environmental regulation and productivity.

The options appraisal and subsequent implementation of risk management measures equally apply to management options, traditional (often harsh) remediation techniques and gentle approaches. However, the case for gentle remediation approaches will rarely be compelling without wider environmental and socio-economic benefits being taken into account in the decision, primarily because of the uncertainty of managing pollutant linkages over a long period of time.

This view is reflected in the results of the SUMATECS questionnaire survey that indicated a general awareness of gentle remediation technologies in the contaminated land sector, but low uptake. It also identified maintenance of soil function and cost as key benefits. But key barriers to uptake include the need for long-term monitoring and duration of remediation, and limitations of applicability, both in terms of the range of contaminants amenable to treatment and site characteristics.

Decision support tools (DSTs) are needed to integrate environmental, social and economic factors in the assessment of remediation approaches within national risk management frameworks. To promote widespread consideration and uptake of gentle remediation technologies, the SUMATECS report recommends that a simple checklist or decision matrix is developed for appraisal of remediation options to raise awareness of the capabilities of gentle technologies. This is particularly important to emphasise the wider environmental benefits, including restoring or preserving soil function and carbon sequestration. If needed, existing tools, such as multi-criteria analysis, life cycle analysis, cost benefit analysis and socio-economic assessment could be used where feasible remediation options need to be assessed in more detail.

The published field trials cited in the SUMATECS report mainly relate to phytoextraction or phytostabilisation/ immobilisation methods. Phytoextraction is only applicable to more moderately contaminated soil, and is not a feasible alternative to conventional soil remediation on more heavily polluted sites. In contrast, phytostabilisation/immobilisation methods may be used for a wider range of trace element pollutants with or without soil amendments.

The restoration of soil functionality at trace element contaminated sites strongly depends on establishing or promoting a well-structured and active community of soil organisms. Data from long-term studies on revegetated mine spoil show that biological and biochemical activity is enhanced with increasing plant density and diversity. Among the soil amendments, most measures that introduce organic matter or alkalinity to the contaminated soils also improve microbial or faunal parameters. Only a few amendments have deleterious effects on soil biota. One example is phosphate (without alkaline additions) due to acidification of the soil.

Biological and ecotoxicological monitoring is needed to assess the impact of gentle remediation on soil function, and a number of methods are discussed. This is consistent with our approach advocated in our recent Ecological Risk Assessment framework (Environment Agency, 2008a) and the lines of evidence approach proposed for verification of remediation.

There is a growing recognition in the need for effective communication with a range of stakeholders during both planning and implementation of remediation. It may however be challenging to make decisions based on both technical evidence and the perceptions of a variety of stakeholders. The SUMATECS questionnaire survey, highlights the difference in perception of expert and non-expert participants on a range of key factors associated with gentle remediation approaches. Perceptions can be highly variable, with generally more scepticism in non-experts. It is generally useful to understand others' viewpoints, and perhaps information needs, both when making and communicating decisions.

Gentle remediation may represent a viable low-cost remedial approach in the UK, particularly if costs can be recovered from harvested biomass. But the advantages and limitations of the technologies, with regard to site conditions and contaminants present need to be fully understood. With the (current) economic situation, potential timescales of recovery and lack of return or confidence in investment, this may be an opportunity to invest in gentle remediation to manage the potential impacts of land contamination and reduce residual risks until the economic situation improves for the construction industry.

The SUMATECS report provides a comprehensive overview of the current state-of-practice of gentle remediation technologies in Europe and provides guidance on tools that may be used to support effective decision-making.

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Glossary

Bioavailability – the degree to which a chemical can be taken into the tissues of an exposed organism.

Ecotoxicological testing – testing performed at any level of biological organization from molecular to whole organisms and populations by observing physiological changes of vital parameters (e.g. growth, reproduction or survival).

Gentle remediation – a technology that achieves remediation objectives whilst preserving or restoring soil function

Harsh remediation – a technology that achieves remediation objectives but destroys or damages soil structure or function.

Immobilisation – plant cultivation dominated by reducing contaminant transfer into plants.

In situ stabilisation – plant cultivation to reduce contaminant transfer into plants and not necessarily by removing contaminants from soils.

Phytoextraction – use of higher plants to remove inorganic contaminants, primarily metals from polluted soil

Phytostabilisation - plant cultivation not specifically performed for contaminant removal or to reduce contaminant transfer into plants.

Phytovolatilisation – the uptake and transpiration of a contaminant (e.g. Se, Hg, As) by a plant (or a plant-microbe association), with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant.

Pollutant linkage - the relationship between a contaminant, pathway and receptor.

Rhizodegradation – (also known as phytostimulation, rhizosphere biodegradation, enhanced rhizosphere biodegradation, or plant assisted bioremediation/degradation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere.

Rhizofiltration – this is the adsorption or precipitation of contaminants onto plant roots or the absorption of contaminants into the roots when contaminants are in solution surrounding the root zone.

Appendix A Summary of Gentle Remediation Applications in Europe

The SUMATECS report cites numerous references for laboratory and field scale research on gentle remediation technologies⁸. This comprises a state-of-practice review, and a summary of the published field scale trials is given in Table A.1. Table A.2 summarises plants that have been successfully used to remediate trace element impacted soils:

Table A.1 Field trials of gentle remediation technologies to manage trace element contamination in Europe⁹.

Country	Phytoextraction	Phytostabilisation	Immobilisation	Cited References
Austria	0	1	0	Vervaeke et al., 2003
Belgium	4	2	1	Mench et al., 2006
Cyprus	0	1	0	
Czech Rep	1	1	0	
France	2	4	0	Boisson et al., 1998 Mench et al., 2006a and b Bert et al. 2003, 2007, 2008
Germany	0	0	1	
Italy	1	0	0	
Netherlands	1	0	0	Grispen et al., 2006
Poland	0	2	0	Mench et al., 2003
Spain	2	2	0	Madejon et al., 2003
Sweden	2	0	0	
Switzerland	6	1	1	
United Kingdom	7	8	0	Maxted et al., 2007 Gray et al., 2006

⁸ SUMATECS report, section 6.2

⁹ SUMATECS report, table 4

Table A.2 Examples of plants used for remediation of soils moderately impacted with metals

Plant	Uses	Advantages	Disadvantages
Hyper accumulators			
Thlaspi caerulescens	Phytoextraction	Model plant, well characterised. Highly Cd/Zn tolerant, very efficient Cd/Zn hyperaccumulator, high ratio root density/aboveground biomass; a large proportion of fine roots; high BCF	Grow slowly (need to use transplants instead starting from seeds); small, low biomass (no mechanical harvest possible); shallow system little is known about its agronomic characteristics, pest management and breeding potential
Arabidopsis halleri	Phytoextraction	Zn hyperaccumulator, closely related to the non hyperaccumulaor model plant A.thaliana; high BCF	Small biomass; hyperaccumulation only Zn from geogenic metal-rich soils (this species is tolerant but does not hyperaccumulate Cd and Ni as found for T. caerulescens), shallow root system
Alyssum murale	Phytoextraction	Highly Ni tolerant; Ni hyperaccumulator, added economical value (Ni phytomining, Ni fertilizer); high BCF	
Crops and weeds			
Agrostis capillaris	Phytostabilisation	Highly metal tolerant	
Brassica juncea	Phytoextraction	High biomass	Metal specificity; low BCF
Brassica napus	Phytoextraction	High biomass; economical value (oil production, biofuel); long cultivation history	Low BCF
Festuca rubra	Phytostabilisation	High metal tolerant. Metal excluder	
Rice	Phytoextraction	Relatively high Cd accumulation. High shoot biomass	Zn phytotoxicity limits Cd accumulation
Zea mays	Phytoextraction	Very high biomass production; deep rooting system	Metal excluder, low BCF
Trees			
Salix viminalis	Phytoextraction	Economical value (wood production, bio-energy); high shoot biomass; large root system (large uptake zone, fixation); deep rooting system; BCF above 1	Low metal tolerance
	Phytostabilisation	Economical value (wood production, bio-energy); large and deep rooting system (large uptake zone, fixation); associated with microorganisms (endofytic bacteria and mycorrhiza)	Low metal tolerance

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