Towards a Framework for Selecting Remediation Technologies for Contaminated Sites

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Abstract

A risk-based approach to contaminated land management has been adopted in many European countries based on the pollutant linkage paradigm. Six key sets of factors can be distinguished for the selection of an optimal risk management solution: the drivers and goals for the remediation project concerned, risk management, sustainable development, stakeholders' (third party) views and technical feasibility and suitability.

Key words: remediation technology, remediation technique, risk management, sustainable development, contaminated land, pollutant linkage, redevelopment, wider environmental value, technical feasibility, technical suitability, decision-making framework

INTRODUCTION

CLARINET Working Group 7 (WG7, Remediation Technologies and Techniques) is reviewing and cataloguing the present status on use of remediation technologies in Europe. This framework document outlines the interim results of the joint work of WG2 (Risk Management and Decision Support) and WG7 (WG2/WG7).

For the purposes of this review, remediation technology is defined as:

> A specific technology, a set of technologies or a technological solution or approach used to reduce risks from a contaminated site. This can include a chain of different technologies as well as broader approaches incorporating elements that cannot be properly described as technologies, such as the imposition of land-use restrictions.

There are a number of factors that need to be considered in selecting an effective remediation solution (Bardos *et al*. 1999):

- the drivers and goals for the remediation work;
- risk management;
- sustainable development;
- stakeholders' views;
- cost-effectiveness; and
- technical suitability and feasibility.

In addition, it is also important to consider the manner in which a decision is reached. This should be a balanced and systematic process founded on the principles of transparency and inclusive decision-making. Any decisions made about the selection of remedial techniques must be made on the basis of a clear understanding of the risk management context.

KEY FACTORS IN REMEDIATION SELECTION

Drivers and goals for the remediation work

Most remediation work has been initiated for one or more of the following reasons:

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- to protect human health and the environment. In most countries, legislation requires remediation of land posing significant risks to human health or other receptors in the environment such as groundwater or surface water. The contamination could either be from 'historic' contamination or a recent spill of toxic substances from a process or transport accident. Groundwater protection has in many countries become an important driver for remediation projects;
- to enable redevelopment. Redevelopment of formerly used land may take place for strictly commercial reasons, or because economic instruments have been put in place to support the regeneration of a particular area or region; and/or
- to limit potential liabilities. Remediation may then take place on a voluntary basis ahead of any regulatory requirement, or could take place as an investment to realise a gain in land value. Owners may perceive that a particular site could potentially have an environmental impact – or that its improvement could enhance its value.

These scenarios generally apply to contamination that has occurred in the past. In the future, Integrated Pollution Prevention and Control (IPPC) regimes and soil protection concerns might also drive remediation projects. Under IPPC the goal is pollution prevention, and contamination may well be required to be removed to the extent that the site is restored to its original condition. This is far more stringent than the 'suitable for use' goals typical for the remediation of past contamination.

Technical decisions for remedial works cannot take place in isolation but must be considered alongside the wider non-technical objectives of any works, as was evident from the comments from a number of land owners at the recent conference on reuse of derelict land held in Duisberg, Germany (UBA 1999). The principal objectives of any proposed works must be clearly identified and any necessary constraints and opportunities established.

For each project a particular combination of these drivers and constraints will set the *core goals* of the remediation scheme. An important point is that some form of environmental quality objectives will normally underpin any project dealing with land contamination. However, these objectives may also be driven by a combination of technical criteria, third party views and non-technical perception of risk.

Remediation work is often an integral part of a larger redevelopment project which may itself be part of a programme of interlinked projects. The core goals of a remediation project are often strongly influenced by this broader context.

Risk management

A risk-based approach has been adopted for the man-

EXAMPLES OF THE RISK-BASED APPROACH IN DIFFERENT COUNTRIES

In Italy draft regulations have been put out for consultation. These include a risk assessment to determine acceptable residual concentrations following remediation. These are compared against a set of 'standard' values, and on the basis of this comparison temporary or permanent restrictions may be placed on site use, and monitoring or further remedial action may or may not be required.

In Norway, management of contaminated land is described in a guidance manual (Norwegian Pollution Control Authority, SFT 1997). A detailed guideline on risk assessment of contaminated sites describes a three tiered risk assessment approach (Norwegian Pollution Control Authority, SFT 1999). A set of 'standard' soil quality values for most vulnerable land-use can be used for decision making in Tier 1, while in Tier 2, these are modified to the present or future land-use of the site. In addition, other site specific environmental objectives need to be met. These are often linked to the protection of surface water including fjords (marine environment) against further pollution since groundwater in many parts of Norway is not the principal water resource.

In the UK the aims of remediation must take account not only of risk-based environmental quality objectives but also cost effectiveness and appropriateness (DETR 2000). This requires remedial action to be taken where:

- the contamination poses unacceptable actual or potential risks to health or the environment; and
- there are appropriate and cost-effective means available to do so, taking into account actual or intended use of the site.

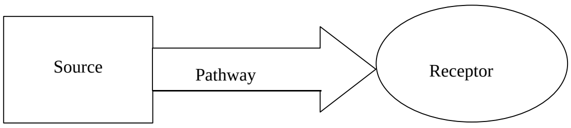

Figure 1. The pollutant linkage (including source, pathway and receptor) analysis needs to be addressed when considering the risk of a contaminated site.

agement of contaminated land in many countries (CLARINET and NICOLE 1998; Ferguson and Kasamas 1999).

The assessment and management of land contamination risks is based on pollutant linkages. These include three components:

- the source of contamination (e.g. metal polluted soils, a leaking oil drum);
- the receptor (i.e. the entity that could be adversely affected by the contamination); and
- the pathway (the route by which a receptor could come into contact with the contaminating substances).

In most countries risk control is based on breaking the pollutant linkage, see Figure 1. For example, this can be done by:

- reducing or modifying the source (e.g. *in situ* bioremediation of diesel contaminated soil);
- managing or breaking the pathway (e.g. by pump and treat or use of a physical barrier);
- modifying the exposure to the receptor (e.g. by limiting the access to the area, restricted land-use).

Risks are usually considered by countries on the basis of a 'suitable for use' (land-use) approach on a site by site basis. For example in the UK the 'suitable for use' approach consists of three elements:

(a) ensuring that land is suitable for its current use;
(b) ensuring that land is made suitable for any new use – as official permission is given for that use; and
(c) limiting requirements for remediation to the work necessary to prevent unacceptable risks to human health or the environment in relation to the current use or officially-permitted future use of the land (DETR 2000).

Sustainable development

The concept of sustainable development was first considered at the United Nation's Earth Summit conference in Rio de Janeiro in 1992. A number of definitions for sustainable development have been proposed, although the commonly used definition is; ' ... *development that meets the needs of the present without compromising the ability of future generations to meet their own needs*' (Brundtland 1987).

In the UK, the Government has set itself to achieve sustainable development which it defines as:

- social progress which recognises the needs of everyone;
- effective protection of the environment;
- prudent use of natural resources; and
- maintenance of high and stable levels of economic growth and employment.

At a strategic level, the remediation of contaminated sites supports the goal of sustainable development by helping to conserve land as a resource, preventing the spread of pollution to air and water, and reducing the pressure for development on greenfield sites. However, it is also important to ensure that the implementation of individual contaminated land management actions is consistent with the principles of sustainable development.

In Norway, R&D is focusing on environmental sustainable development in general, including constraints, opportunities and instruments. In Norway, it is accepted that achieving sustainable development requires broad-based, comprehensive research on the economic, technological, social and cultural dimensions of environmental problems, and on the possibilities for remedial measures. However, no sustainable development policy has so far been specifically developed for remediation of contaminated land in Norway, since the instruments for monitoring sustainable remediation are not yet considered to be available.

Decisions about which risk management option(s) are most appropriate for a particular site need to be considered in a holistic manner. Key decision-making factors are:

- the effectiveness of the remedial technique in dealing with the identified risks;
- the wider environmental effects of the remedial operation(s); and
- broader considerations of the relevant economic, social and political values that apply to the circumstances.

Some of the objectives of a remediation project will relate to environmental and health risks, some to performance of geotechnical / construction measures, and some to social / economic indicators (including time scales). For each project some or all of these factors will make up the *core goals* of the remediation scheme.

The wider environmental effects are consequences of particular remedial options and will vary from site to

ASSESSMENT OF NON-CORE EFFECTS: CASE STUDY

In The Netherlands the term 'environmental merit' is used to describe these non-core environmental effects.

In The Netherlands a decision support system involving the weighing of the various remediation alternatives, is being used (Nijboer 1998). This enables objective comparison of the different remediation technologies' contribution to risk reduction, environmental merit and costs. The costs and benefits for the environment are weighed as well. A remediation alternative can be chosen using the following strategy:

- Primary risk assessment;
- Time available/needed (considering natural processes in soil);
- Use the 'self-cleaning capacity' of the soil (investigating if this is sufficient);
- Stimulate natural processes (investigating the possibility);
- Intensive *in situ* remediation if necessary (investigating the possibility);
- Quantify financial risk of a remediation alternative (NOBIS 1995*a*,*b*; Hetterschijt *et al.* 1999).

site according to the type of contaminant(s) present and the treatment employed. There may be **temporary** negative effects during remediation (e.g. caused by lorry movements, traffic problems, noise, energy use/CO_2 emission) or **permanent** (e.g. loss of soil function). The effects may also be positive (e.g. improving soil function or the ecosystem) as well as negative (e.g. loss of soil structure and integrity, release of volatile emissions, increased water emissions, or increasing amounts of waste entering hazardous waste dump sites or sanitary landfills by the disposal of slightly contaminated soil).

Good practice in risk management for contaminated land includes the setting of clear risk management goals and the identification of a shortlist of potentially feasible remedial techniques able to reach the 'core goals' which can then be considered more closely. Techniques can be compared with each other against a range of sustainability appraisal criteria. These can be used to *refine* the shortlist of remedial techniques, according to their wider effects, and pick up any inconsistencies in how the environmental, economic and social elements were considered at the 'core' stage. In extreme cases, these non-core considerations may also flag any previously unanticipated and potentially severe impacts that might lead to a re-evaluation of the core goals of a remediation project.

Hence, decision-making for contaminated site remediation can be divided across two dimensions: (1) the (three) elements of sustainable development and (2) core/non-core issues. Together these ensure a consistent approach to considering sustainable development for remediation projects across sites. This 'core/non-core' model is summarised in Table 1. The model proposes that the 'value' of the project core is fixed, being a function of the risk reduction and redevelopment goals. The non-core 'value' of the choice of remedial technique is variable, depending, obviously, on the choice made. The overall 'value' of the project is the sum of the core and non-core 'values' for each sustainability element.

Examples of economic non-core elements include:

- impacts on local business and inward investment;
- impacts on local employment.

Examples of non-core environmental elements are:

- environmental side effects of increased energy use

Table 1. The core/non-core model for sustainable risk management of contaminated sites

Sustainability elements	**Core**	**+ Non-core**	**= Total (Overall performance)**
Economic (includes liabilities)	Fixed	Variable	= Economic value
± Environmental (includes risk reduction)	Fixed	Variable (merit?)	= Environmental value
+ Social	Fixed	Variable	= Social value
= **Total (overall 'sustainability')**	Core value	+ Efficiency	= **Overall performance in achieving sustainable development**

and CO_2 emissions from transportation of contaminants off site;
- waste generation by dumping contaminated soil in landfills or hazardous waste sites;
- emissions to water and air during remediation, and increased noise and traffic;
- resource recovery when reusing treated contaminated soil or recovering energy during remediation;
- reusing contaminated land as opposed to using undisturbed land.

Examples of social non-core issues might include:

- employment creation;
- removal of stigma.

However, these might also be explicitly included as core objectives. This illustrates that what is included as core or non-core can vary from site to site, depending on the broader needs of the remediation project concerned.

Considering stakeholders in contaminated land management

The principal stakeholders in land remediation are typically:

- land owners / problem holders;
- regulatory and planning authorities;
- site users, workers, visitors;
- financial community (banks, funders, lenders, insurers);
- site neighbours (tenants, dwellers, visitors);
- campaigning organisations and local pressure groups;
- consultants, contractors and technology vendors; and possibly
- researchers (in some circumstances).

Each will have their own perspective, priorities, concerns and ambitions regarding any particular site. The most appropriate remedial actions are likely to be those which offer a balance between meeting as many needs as possible, including also the need to protect the environment, without unfairly disadvantaging any individual stakeholder. It is worth noting that for some stakeholders, the end conditions of the site are likely to be significantly more important than the actual process used to arrive at that condition. Such actions are more likely to be selected where the decision-making process is open, balanced, and systematic. Given the range of stakeholder interests, agreement on project objectives and project constraints such as use of time, money and space, can be a time consuming and expensive process. Seeking consensus between the different stakeholders in a decision is an important tool in helping to achieve sustainable development.

Risk communication and risk perception issues need special consideration. A diverse range of stakeholders may need to reach agreement before specific remedial objectives can be set, for example, site owner, regulators, planners, consultants, contractors, site neighbours and perhaps others (SNIFFER 1999; US EPA 1998). Unsurprisingly, once these remedial objectives are agreed, it may be hard to renegotiate them.

The members of the decision-making team who are finally responsible for the choices of technology are the landowner, the regulator and the service provider. All other stakeholders are in a position of influence but in most cases their input does not control the decision.

Landowners looking at land as an opportunity, may define a project (and hence the technology employed) as cost-effective, if the selected technology delivering ‘cleaner’ land than required by the regulator, can be implemented at a lower cost than the value of the treated land. This reflects the basis on which the decision is made whereby directors of public companies are obliged to make decisions that are: (1) legal and (2) in the best interests of the company’s shareholders. They are not obliged or necessarily authorised to consider any other factors.

A regulator’s perspective in the same circumstances may be significantly different. Other than in special cases (e.g. financial hardship etc.), project economics are not a priority. It is quite conceivable that either or both of the project scenarios could be regarded as non-cost effective in terms of environment and public health issues, as well as considerations such as: amenity, road safety, noise, etc. This is an interesting parallel to the landowners’ position as it reflects a superficially similar set of constraints. Regulators are obliged to make decisions that are: (1) legal (same rules as landowners); and (2) in the best interests of their shareholders (the public). ‘Best interests’ is the key: whose interests, which interests, whose costs, which costs?

Service providers operate within a highly competitive arena, reacting to priorities set by landowners and regulators. They make decisions on technology selection, but only insofar as translating the landowners’ defined needs into deployed processes that deliver projects on time, within budget, to a specified quality and within regulatory constraints. This usually represents the complete obligation. There is often no consideration of other factors. Cost-effectiveness is measured in exclusively economic units.

Clear and inclusive decision support tools are vital to enable informed choices that do not over-compromise stakeholder(s).

Cost-effectiveness

The aim of the assessment of costs and benefits is to provide a clear view of the value of the remediation investment, and to allow comparisons between different remedial options. Cost benefit analyses consider the diverse range of impacts that may differ from one proposed solution to another such as the effect on human health, the environment, the land use, and issues of stakeholder concern and acceptability in common units.

In many instances, it is difficult to attach a strictly monetary value to many effects of a remediation project. Hence assessments can involve a combination of qualitative, formal cost benefit analysis (CBA) and MCA methods (Crumbling 2000; Environment Agency 1999; NOBIS 1995*a*,*b*).

The potential for developing more cost-effective solutions is large. Experience from Germany and UK is that this can be achieved by reducing the cost of remediation, increasing the value of the land or, ideally, a combination of the two. The highest cost-reducing potential results from reducing volumes of soil needing to be treated and by increasing the proportion of materials to be recycled and reused. Experienced and professional project management, relevant and adequate site investigations, and high site efficiency, can significantly improve the reliability of remediation cost forecasts. These issues need to be addressed not *only* as 'problem definition' or 'solution provision' targets. They are interdependent, e.g. appropriate site investigation not only highlights problems, it also acts as a guide to the solution. Inappropriate site investigation does neither. All procurement of services needs to be done with a view to value, not cost. In current terms this is 'intelligent procurement', concentrating on value and confidence in achievement of objectives.

There are two further factors that impact on the cost-effectiveness of remediation technologies. The first is the impact of waste legislation and regulation that, in certain nations, determines the fate of contaminated soil, the potential for its treatment, disposal, recovery, recycling and reuse. The second is the designated land-use of remediated sites, which has a profound effect on site values and hence the options available for remediation.

Technical suitability

A *suitable* technology is one which 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:

- track record of the solution for the particular risk management problem (in the countries);
- ability to offer validated performance information from previous projects;
- expertise of the purveyor;
- ability to verify the effectiveness of the solution when it is applied;
- confidence of stakeholders in the solution and in its costing;
- acceptability of the solution to stakeholders who may have expressed preferences for a favoured solution or have different perceptions and expertise.

Feasible remediation approaches therefore are a subset of those that are generally suitable candidates for dealing with the problem in question.

In general, concerns over feasibility in a particular industry 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 furthering the cause of sustainable development.

There are five key sets of questions that underpin the consideration of the suitability of different remedial techniques and approaches for the management of risks on individual contaminated land sites. The questions provide a framework in which it is possible to assess:

- whether a particular remedial technique or approach can appropriately be applied on a given site, to manage an identified set of risks;
- what technical precautions might need to be included in any permit for the use of the technique or approach;
- whether there are gaps in knowledge concerning the performance of different remedial techniques or approaches (i.e. if it is not possible to answer one or more of the questions); and
- whether there are gaps in knowledge or availability of techniques for the on-site evaluation and monitoring of the use of different remedial techniques and approaches.

The five sets of questions are:

1. What do we *expect* the remedial approach to achieve, in terms of 'source reduction', 'pathway control' or 'receptor protection'? This is, in effect, the core of the remedial approach – what it actually seeks to do.
2. What do we *anticipate* might be obstacles to that achievement? For example, are there particular site characteristics – such as presence of other contaminants, waterlogged ground, presence of buildings on site – which would prevent the approach from working at all on any particular site?

3. What are the likely wider *implications* of using the remedial approach? These might include adverse environmental side effects, resources needed, time constraints, energy use, noise, costs (investment and operational), social acceptance, etc.
4. What criteria, during the *operation* of the remedial approach, will affect its actual success or failure? These could include control over process chemistry, ability to carry out engineering works to the required specification, etc.
5. How, after we have carried out the remedial approach, can we *verify* that it has been successful or, conversely, discover that it has not? What monitoring and evaluation processes are needed?

DETERMINING SUITABILITY

The general issues that affect the suitability of a remediation technology for a particular site are (Bardos *et al.* 1999):

- risk management application (see above);
- treatable contaminants and materials;
- remedial approach (e.g. containment, bioremediation etc.);
- where the action takes place (e.g. *in situ* or *ex situ*, on site or off site);
- treatment strategy;
- implementation; and
- outcome.

Treatable contaminants and materials

Remediation processes treat contaminants in materials. These materials might include groundwater, soil, filling materials, debris, site refuse, non-aqueous liquids, tars, sediments or sewage sludges. The type of treatment and the likely success of any particular technique will depend upon the nature of the material treated as well as the type of contamination. Contaminant properties affecting treatment include, not just the chemical types present, but also their concentration range, their source, and their age. Further information is summarised by WG7 (Vik *et al*. 2000).

Remedial approach

Results of the WG7 European survey of the state of the art of implementation of remediation technologies throughout Europe show that the difference in technology implementation between countries in Europe is large. Several countries have a well-established market for soil remediation while others have barely begun. (NB most of the answers are based on estimations of which technologies are used, and only in a few cases on firm statistics).

The most common solution for contaminated sites seems to be some kind of containment, either physical or hydraulic. The second most common solution, or for some countries the most common solution, is the excavation and removal of the polluted soil. The excavated soil is then either treated or brought to a landfill.

Biological methods seem to be, by far, the most common on-site treatment approach in Europe, excluding containment and landfilling. In some countries, especially those with a well-established soil remediation market, a range of off-site treatment facilities are available. Of these other methods the most common are thermal treatment and soil washing. In most countries treatment off site is more common than on site.

It seems to be only in a few countries that *in situ* treatment, other than containment, has been established as an alternative to excavation. The *in situ* methods that are mentioned most frequently in the survey are soil venting (soil vapour extraction), air sparging, bioventing and biodegradation.

Treatment strategy

A strategic approach may be taken to using treatment-based solutions, for example:

- integrated or combined approaches;
- active versus passive measures;
- long-term/low input (‘extensive’) versus short-term /high input (‘intensive’);
- use of institutional measures (such as planning controls combined with long-term treatments).

Implementation

Implementation encompasses the processes of applying a remedial approach to a particular site and involves:

- planning remedial operations;
- site management;
- verification of performance;
- monitoring process performance and environmental effects;
- public acceptability and neighbourhood relationships (risk communication and risk perception);
- strategy for adaptation in response to changed or unexpected circumstances, i.e. flexibility and aftercare.

Considering how a remedial solution is implemented should be a material consideration in determining the remediation approach. These examples of implementation issues represent activities that are likely to be a significant cost element for a remediation project. The WG7 Final Report will include a catalogue summarising how remediation technologies are being implemented in Europe. Information about this report will be posted on the CLARINET website in the second part of 2001 (*www.clarinet.at*).

Outcome of the remedial approach

In terms of dealing with the contaminants contained in the materials to be treated, process-based treatments may provide one of several outcomes:

- **destruction** may be the result of a complete biological and/or physico-chemical degradation of compounds, for example at elevated temperatures by thermal treatments;
- **removal** of contaminants may be brought about by: (a) some process of mobilisation and recapture, e.g. leaching and sorption; (b) some process of concentration and harvesting, e.g. by physical separation; or (c) a combination, e.g. via hyper-accumulator plants;
- **recycling** might be the 'ultimate' form of removal;
- **stabilisation** describes a process in which a contaminant remains *in situ* but is rendered less mobile and/or less toxic by some combination of biological, chemical or physical processes. For most practical site remediation some combination of these outcomes is achieved;
- **containment** is a process in which the contaminated matrix is contained in a way which prevents exposure of the surrounding environment.

From a simple outlook, outcomes could be ranked in order of preference, in terms of the environmental benefit of permanently removing a contamination problem:

Recycling* > *Destruction* > *Removal* > *Stabilisation* > *Immobilisation

However, this simple hierarchy does not take into account the wider environmental effects of the approach proposed, other benefits or costs. For example, destruction might only be achieved with significant environmental impacts from emissions, use of fuel (CO_2 emissions) and other resources, or destruction may require a process that is unacceptable to a local community.

It is also important to understand the fate of contaminant compounds. For example, destruction does not equate with simple disappearance of compounds, as degradation may have been incomplete, creating unacceptable daughter compounds. Hence the degradation process must be tracked to an acceptable outcome. A related issue is the permanence of the solution where a stabilisation-based approach is used. Understanding these outcomes is critical to demonstrating a risk management benefit of the treatment process employed.

CONCLUSIONS

The process of selecting the appropriate remedial option for a contaminated site include considerations of:

- stakeholders' views;
- risk management;
- cost-effectiveness;
- sustainable development; and
- technical suitability.

Along with definition of the problem and the undertaking of works to a known and specified quality, selecting the right remedial approach represents a vital and pivotal component in the management of land contamination. In the last decade the number of available remedial techniques has increased considerably such

Table 2. Factors affecting the suitability of remedial approaches

RISK MANAGEMENT APPLICATION	CONTAMINANTS / MATERIAL TREATED	REMEDIAL APPROACH	PROCESS LOCATION
• source reduction • pathway interruption • protection of receptors	• contaminant(s) • concentration range • source and age • bulk / materials-handling characteristics	• removal • containment • rehabilitation • biological treatment • chemical treatment • physical treatment • solidification / stabilisation • thermal treatment	• *in situ* • *ex situ* • on site • off site • in-vessel

STRATEGY	IMPLEMENTATION	OUTCOME
• integration / combined approaches • active / passive measures • long term / low input • carrier (for *in situ* techniques, i.e. air or water) • institutional measures	• process planning • site management • verification • monitoring • neighbourhood impacts • aftercare • flexibility	• destruction of contaminants • removal of contaminants (elsewhere) • stabilisation of contaminants • containment

that the selection of the most appropriate option critically depends on a systematic and well-documented appraisal process. Key issues in determining the suitability of remedial approaches are summarised in Table 2.

Most cities throughout Europe have large areas of contaminated land, and whether excavation and landfilling can be considered sustainable land development for all of these areas is being questioned in many countries. The term 'sustainable remediation' is now being used but it needs a clear definition. Existing market forces are not necessarily likely to ensure that the most environmentally sound solutions are selected. *In situ* treatment methods appear to have great potential in the sustainable remediation of contaminated land in urban areas, but the WG7 survey shows a very low degree of implementation of such methods.

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