Project No. SN-01/20

SUMATECS

Sustainable management of trace element contaminated soils – Development of a decision tool system and its evaluation for practical application

Final Research Report

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1 Abstract

The development of “gentle”, in-situ remediation technologies (i.e. phytoremediation, in situ immobilisation, etc.) has been under intensive research over the last few decades. A great deal of progress has been achieved at the experimental level, but the application of these technologies as practical solutions is still at its early stage. First; methods for determination of the trace element (metals and non-metals) fractions relevant for their ecotoxicology (i.e., the bioavailable fraction) still have their limitations since they may insufficiently reflect the potential risks. Second, a number of gentle in-situ remediation options are available and thus a decision tool system has to be developed allowing to choose the most suitable technique. Third, the application of gentle remediation options may have significant implications for the environment and the socio-economic situation of the local population. TECS (trace element contaminated soils) management moved into a new century where environmental decisions must be ‘socially-robust’ within a context of sustainable development and is a part of the conceptual framework “Risk-based land management”. All efforts need to ensure management and/or remediation is affordable, feasible, effective and sustainable. The aim of this project was to summarise the current state of the art using data from literature (SCI journals, project reports) and from a questionaire that has been sent to all kind of experts involved in remeddiation of trace element contaminated soils (scientists, stakeholders, policy makers, etc.). All collected information was used to identify the current status of research and application in Europe and to (i) derive decision tool systems, remediation scenarios including the potential impacts on the local environment and (ii) define further research needs.

2 Executive Summary

State-of-the-art of research and development of various gentle remediation options

Phytoremediation holds great potential and in order to develop this potential a multidisciplinary approach is required. The success of phytoextraction, as an environmental cleanup technology, depends on several factors including the extent of soil contamination, metal availability for uptake into roots (bioavailability), and plant ability to intercept, absorb, and accumulate metals in shoots. In order for phytoextraction to evolve into a suitable technique, either the extraction efficiency requires to be further increased or the produced biomass needs to have an economical value (e.g. for bioenergy production). In addition, when taking into account the achievable mass of metals which can be reasonably extracted per hectare and per year, it becomes evident that the technology is only applicable to decontaminate soils with low to moderate metal concentrations. For soils with a high load or with a deep penetration of metals, phytoextraction is not a realistic option. In those cases phytostablization is recommended instead. The efficiency of phytostabilization can also be further increased by optimizing agronomic practices, such as irrigation, fertilization, planting and harvest time and the timing of amendment application. To conclude, more fundamental research is still needed to better exploit the metabolic diversity of the plants themselves, but also to better understand the complex interactions between contaminants, soil, plant roots and micro-organisms (bacteria and mycorrhiza) in the rhizosphere.

Review and evaluation of the existing methods for determination of the bioavailable trace element fractions in soil

Bioavailability of trace elements is not a single value that can be measured by a single chemical or even biological method. It is a process that, as any processes in nature, varies in time and space. We can only estimate a fraction of TE that is bioavailable at that moment and organism in question. Therefore total trace element concentrations in soil are, and most likely will be, considered in risk assessment of contaminated sites, even though they do not reflect the real environmental and health risk associated with the site contamination.

Environmental and socio-economic aspects of remediation and related technologies

Technological intervention in management and monitoring is needed to shorten the restoration time, maintenance costs, and final destination. The reviewed literature shows that evolution of phytoremediated sites is reflected in increased functionality of contaiminated soils or spoils wastes. Soil functions, being sensitive to the pedo-environmental conditions and responsible for biogeochemical nutrient cycles, can be used as synthetic indicators of the progress and also the efficiency of given phytoremediation approaches. However, their use should be coupled to the knowledge of the site history, and related to the development of the soil profile and to the organic matter content and humification. In evaluating the biochemical parameters in relation to SUMATECS and progress of the vegetation the nutrient cycling should be assessed, to better the eventual plant-soil-microbe balance of nutrients, to prevent nutrient shortage. Better study of soil formation, evolution and fertility is important for an optimal SUMATECS, because often after treatment use is proposed on an unsuitable soil.
It is concluded that further research should focus on systematic studies on the short- and long-term effects of gentle remediation technologies on soil biological parameters and on the identification of general and site-specific sensitive biological indicators for the restoration of soil functions.
Biomass valorization of highly contaminated plant material is an unsolved problem. Nevertheless, a lot of research is ongoing and should give technological answers in the near future. Regarding regulations and plants that are used or that should be used in phytoextraction, it can be assumed that mostly contaminated biomass issued after harvest has to be considered as a hazardous waste. As shown by regulations, the options for hazardous wastes are provided by the landfill directive, the incineration directive and any other possibly recovery solution. As a pre-requisite, it is not allowed to mix hazardous wastes with other hazardous wastes, or with any other wastes, substances or matters. Mixture includes dilution of hazardous wastes. Contaminated biomass can’t be placed in landfill for hazardous waste because one criterium for acceptance

is not met. An incineration plant means any technical equipment used for the incineration by oxidation of hazardous wastes with or without recovery of the combustion heat generated, including pre-treatment as well as pyrolysis or other thermal treatment process. Our results show that composting or leaching may be helpful to pre-treat contaminated biomass before incineration in hazardous waste plant. In addition, our results may suggest that the ash residue enriched in metals would be placed in a hazardous landfill if the ash meets the criteria and in particular the TOC criterium. In such a case, ash can be, for instance, stabilised. Regarding recovery or valorisation, it should be possible to recycle metals from contaminated biomass, residues from incineration and pyrolysis or leachates. Further developments are needed on these aspects to improve the separation of the metals from the waste.
Regarding the socio-economic aspects of gentle soil remediation, there still is much research to be done and socio-economic changes to impulse in order to be capable of rigorously valuing and governing environmental assets and services, and to proceed to proper socio-eco assessment of eco-technological options. But the current world financial crisis, which is connected to a crisis in social valuation of the future, may allow some ecological “new deal”.
Although numerous studies applying gentle remediation technologies have been conducted and published in the past 20 years, not much of this knowledge has been adapted in practice. Since the reasons for this are unclear, we have interviewed experts dealing with trace element contaminated sites about their experience and opinions regarding gentle remediation options. The result of this questionaire-based interviews are that (i) gentle remediation technologies are known to most respondents but rarely applied, (ii) regulators are more sceptical than scientists and consultants, (iii) the disadvantages of gentle remediation technologies are seen in the need for long-term monitoring and the limited applicability regarding contamination and land use, (iv) dealing with gentle remediation technologies improves knowledge and acceptance, and (v) lack of knowledge, experience and convincing pilot projects are the main obstacle for more general application of gentle remediation technologies.

Sustainable management strategies for trace element contaminated soils and surrounding environments: evaluation and development

a)Information on management strategies for TECS and their surroundings, from bench scale through field scale to catchment’s scale, especially in Europe and worldwide similar climatic areas has been reviewed.
b) A non exhaustive list of gentle remediations has been identified
c) Detailed evaluation of gentle remediation options is included in the main report and also one detailed report is written for several gentle options.
d) Besides, we have promoted contact with networks, authorities, environment agencies, consultants, companies, and anyone else having reported on TECS sustainable management, and summarised
We have developed a software for managing a database dedicated on experiments carried (from bench scale to field experiments) on the management of TECS with gentle remediation options. After the analysis and the definition of templates for loading the digital data from each experiment, we have worked of the web navigation and the server. This database is currently filled by WP5 members and other partners.
We have carried the three steps of a sustainable management strategy, *i.e.* Risk assessment, option appraisal, implementation on site, at a Cu-contaminated site (contamination source: washing of treated timbers). This site surface is 6ha. Selections of sustainable strategy (minimizing the risks, produce plants such as wood and sunflower for biofuels) and of feasible options (aided phytostabilisation, phytoextraction) have been done. Phytostabilisation, aided phytostabilisation with and without associated microbes (mycorhiza), in situ stabilisation, and aided phytoextraction passed the tests of option appraisal. Biostimulation of phytostabilisation with endophytes is currently tested. Several remediation options, aided phytostabilisation, phytostabilisation, and aided phytoextraction have been implemented (in general the field experiment was 150 m², with replicated plots).

Decision Tool Systems for the Selection of Gentle Remediation Approaches

Decision support tools need to be easy to use (a tiered approach, in line with several national guidelines, is arguably the simplest and most valid approach), incorporate sustainability and socio-economic measures (via life cycle assessment, Cost Benefit Analysis or similar), and consider the potential use of gentle remediation technologies as part of integrated site solutions i.e. in combination with other methods. There is a need for gentle remediation, and for decision support which focuses on gentle remediation options, to be more strongly incorporated into existing, well-established (national) DSTs / decision-frameworks, to promote their widespread use and uptake.The potential impact of forthcoming legislative changes on the decision support process, and on the use of gentle remediation options generally (particularly the proposed Soil Framework Directive and its emphasis on consideration of maintaining soil function), needs to be monitored.The recommended form of a gentle remediation-focused DST is that it should take the form of a simple checklist or decision matrix, integrated (where possible) into existing national framework guidelines /

DSTs as a tier, probably at the options appraisal stage (following the initial risk and site assessment stage). This decision matrix or checklist should clearly state (based on current knowledge and field trials) the capabilities of gentle remediation options in broad terms, allowing a decision to be made on their potential use, and then should refer the user to a bundled information package on gentle remediation options.

Priorities of Research Topics

- There is a need for large-scale field demonstration projects for all gentle remediation techniques:

- Based on the practical application the following specified needs arise for the whole procedure, from the site characterisation, to risk assessment, option appraisal, decision for any technique as well as the approval of the sustainability.

- Improvements of the risk assessment using appropriate techniques such as microbial biosensors as well as whole cell biosensors are still needed. The development of a tool box (selected tests in a set kit) is suggested which where able to compare sites (e.g. EU wide) as well as risks.

- A financial valuation of soil functions must be implemented (new systems should be developed) in order to allow the financial comparison of various remediation options. It can be suggested doing this in terms of monetary values or at least in intangible values. This can and should lead to a broader awareness of the positive and necessary soil functions for all living systems.

- Further, there is a need to minimize potential negative impacts of gentle remediation techniques (e.g., negative effects on soil microbes).

- Development of simple checklists or decision matrices providing a good basis for decision makers integrating gentle remediation-focused decision support tool in existing DST should be enforced.

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4 Background of SUMATECS

As a consequence of industrialization during the last centuries, the heavy metal concentration of soils has increased worldwide (Adriano 2001). Hot spots of soil contamination are located in areas of large industrial activities where surrounding areas are affected by atmospheric deposition of heavy metals. Agricultural practices, such as the application of sewage sludge or phosphate fertilisers have resulted in increased metal concentrations in some agricultural soils (Adriano 2001; Puschenreiter et al. 2005).

Conventional remediation technologies aim at the removal ("dig and dump"), incineration or washing of the contaminated soil (Raskin et al., 1997). All these methods are costly, and affect some or all soil functions negatively. As an alternative approach, a number of gentle soil remediation technologies have been developed in the last 2 decades. Many of these methods are based on the use of plants and / or soil amendments. The principle of these gentle rermediation methods are shown in Figure 1.

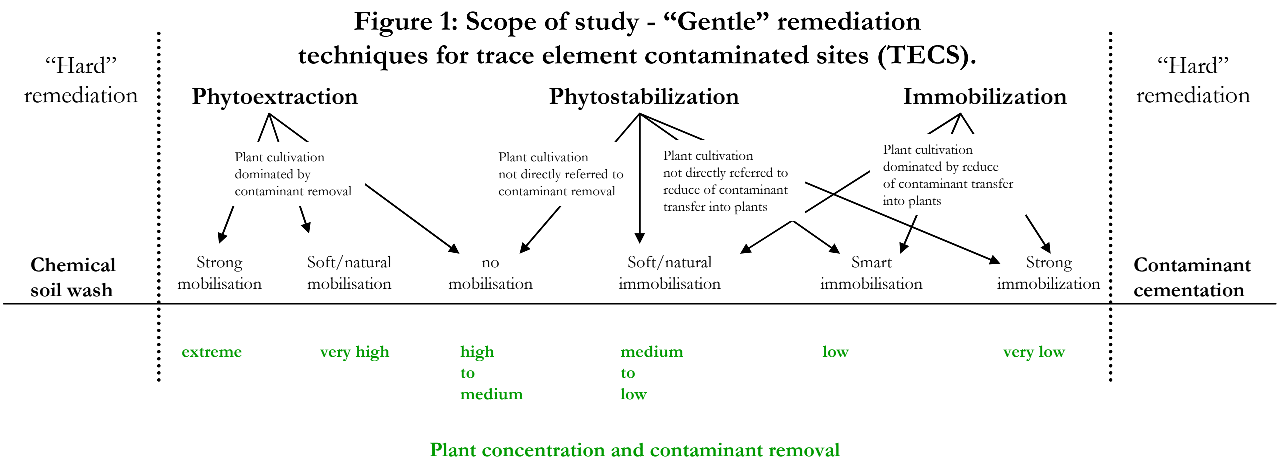

Figure 1: Overview on the principles of gentle soil remediation methods.

Although good progress has been achieved at laboratory and greenhouse scale, the number of applications under field conditions and the use of such methods to clean up soils has been surprisingly low. The aim of SUMATECS is therefore to review and evaluate these methods in detail and to clarify reasons of hindrance to apply such methods for soil remediation. SUMATECS focuses on all aspects involved, including methods to determine relevant fractions of trace elements in soil, sustainable managment methods and the use of decision support tools.

5 Aims of the project

The development of “gentle”, in-situ remediation technologies (i.e. phytoremediation, in situ immobilisation, etc.) has been under intensive research over the last few decades. A great deal of progress has been achieved at the experimental level, but the application of these technologies as practical solutions is still at its early stage. On the one hand, methods for determination of the trace element (metals and non-metals) fractions relevant for their ecotoxicology (i.e., the bioavailable fraction) still have their limitations since they may insufficiently reflect the potential risks. On the other hand, a number of in-situ remediation options are available and thus a decision tool system has to be developed allowing to choose the most suitable technique. TECS (trace element contaminated soils) management moved into a new century where environmental decisions must be ‘socially-robust’ within a context of sustainable development & is a part of the conceptual framework “Risk-based land management”. All efforts need to ensure management and/or remediation is affordable, feasible, effective & sustainable.

Additionally, further aspects that are closely related to the remediation process were previously only partly covered by research projects. These aspects include the potential impacts on the local environment (soil processes and functioning, socio-economic impacts on the local population, etc.), but also the principal question on the sustainability of the remediation process and its target.

The aim of this project was to make a literature and project-based review (including country specific state of the art and current procedures) to identify the current status of research and application in Europe and to (i) derive decision tool systems, remediation scenarios including the potential impacts on the local environment and (ii) define further research needs. Furthermore, we have conducted a questionaire to investigate the current perception of gentle soil remediation options by different groups of experts inolved (stakeholders, policy makers, scientists).

The study covers soils contaminated by trace elements (TECS) (singly or in combination with organics), at sites (legacies from the past, recent pollution due to negligence) and their surrounding agricultural or urban areas.

All partners involved have excellent research experience in the field of gentle remediation techniques and related aspects (soil processes, environmental impact, use of biomass, etc). Many of them have previously worked together in other European initiatives (such as COST Actions 859 and 837) and projects. This consortium acted as a professional “think tank”, bringing together the state of the art, compiling and evaluating this and clearly defining the major knowledge gaps. This provides a sound basis for any successful further research and development in this very important environmental area.

6 Results

6.1 Project coordination (WP1)

Puschenreiter M., Mench M., Müller I.

6.1.1 Meetings

The main activities of WP1 were the organisation and management of the kick-off meeting in Vienna (organised by BOKU) on October 18-19 2007 (M1.1), the mid-term meeting in Bordeaux (organised by UMR BIOGECO INRA 1202) on March 13-14 2008 (M1.2), and the final meeting in Dresden (organised by LfUG) on September 18-19 2008 (M1.3).

Table 1: Dates and participants of the 3 SUMATECS project meetings

Date	Place	Participants
Oct 18-19, 2007	Vienna, BOKU University (AT)	Bert Valerie (INERIS) Boulet Jana (HAU) Cochet Nelly (UTC) Cundy Andy (UoB) Friesl-Hanl Wolfgang (ARC) Kumpiene Jurate (LTU) Magnie Marie-Claire (INERTEC) Marschner Bernd (RUB) Mench Michel (INRA) Müller Ingo (LfUG) Nordmark Desiree (LTU) Puschenreiter Markus (BOKU) Renella Giancarlo (UniFi) Ruttens Ann (HAU) Tlustoš Pavel (CULS) Wenzel Walter (BOKU)
March 13-14, 2008	UMR BIOGECO INRA 1202, Bordeaux (FR)	Bes Clemence (INRA) Bert Valerie (INERIS) Cundy Andy (UoB) Hego Elena (INRA) Jaunatre Renaud (INRA) Onwubuya Kene (UoB) Kumpiene Jurate (LTU) Magnie Marie-Claire (INERTEC) Marschner Bernd (RUB) Mench Michel (INRA) Müller Ingo (LfUG) Puschenreiter Markus (BOKU) Raspail Frederic (INRA) Ruttens Ann (HAU) Soularue Jean Paul (INRA) Tlustoš Pavel (CULS)

		Vialletelle Frédérique (INERTEC)
Sept. 18-19, 2008	Development Bank of Saxony, Dresden (DE)	Adriaensen Kristin (HAU) Bert Valerie (INERIS) Böhm Katharina (LfUG) Cochet Nelly (UTC) Cundy Andy (UoB) Friesl-Hanl Wolfgang (ARC) Hurst Stephanie (LfUG) Jollivet, Pascal (UTC) Kumpiene Jurate (LTU) Magnie Marie-Claire (INERTEC) Marschner Bernd (RUB) Mench Michel (INRA) Müller Ingo (LfUG) Onwubuya Kene (UoB) Puschenreiter Markus (BOKU) Renella Giancarlo (UniFi) Tlustoš Pavel (CULS) Vialletelle Frédérique (INERTEC)

6.1.2 International Workshop

On the first day of the final SUMATECS project meeting in Dresden, an international workshop was hold. This symposium was mainly organised by Dr. Müller (LfUG), Dr. Katharina Böhm (LfUG) and Dr. Markus Puschenreiter (BOKU). The aim of this symposium was to present SUMATECS results and to discuss all aspects of gentle soil remediation with the audience. The list of non-SUMATECS participants is shown in Table 2.

Table 2: List of non-SUMATECS participants at the international workshop in Dresden.

Nr	Name, Title, First name	from [Organisation/University/Company]	Country
1	Antosiewicz, Dr. Danuta Maria	Warsaw University	Poland
2	Barbu, Prof. Dr. Horia	“Lucian Blaga” University of Sibiu	Romania
3	Carpena-Ruiz, Dr. Ramon	Universidad Autonoma de Madrid	Spain
4	De Sloovere, Amy	OVAM	Belgium
5	Felix-Henningsen, Prof. Dr. Peter	Universität Giessen	Germany
6	Greger, Ass. Prof. Maria	Stockholm University - Department of Botany	Sweden
7	Hanauer, Thomas	Universität Giessen	Germany
8	Iordache, Dr. Virgil	University of Bucharest	Romania
9	Kiesewalter, Sophia	Saxon State Office for the Environment, Agriculture and Geology	Germany
10	Kutschke, Dr. Sabine	Research Centre Dresden-Rossendorf e.V.	Germany

11	Lux, Prof. Dr. Alexander	Comenius University	Slovakia
12	Nehnevajova, Dr. Erika	Free University of Berlin	Germany
13	Schaller, Dipl.-Ing. J.	Technical University of Dresden	Germany

6.1.2.1 Program of the symposium (Thursday, 18th September 2008):

9.00 Opening & Organisational remarks
(Saxon State Office for the Environment, Agriculture and Geology, Germany)

9.15 Introductory remarks on SUMATECS and its work packages (WP)
Dr. M. Puschenreiter (BOKU Vienna, Austria)

09.30 Presenting gentle remediation options and their efficiency (WP2)
Dr. K. Adriaensen (Hasselt University, Belgium)

10.00 Bioavailability - how to measure success and impact of remediation? (WP3)
Dr. J. Kumpiene (Lulea University, Sweden)

10.45 (Added) Value, impact and the public perception of gentle remediation (WP4)
Prof. Dr. B. Marschner (Ruhr University Bochum), Dr. V. Bert (INERIS, France)

11.15 How to implement gentle remediation into sustainable management strategies? (WP5) Prof. Dr. M. Mench (INRA, France)

11.45 Decision tool systems for selection of gentle remediation options (WP6)
Prof. Dr. A. Cundy (University of Brighton, U.K.)

13.15 Is gentle remediation actually an option for trace element contaminated soils ? (General discussion in plenum)

14:15. Round table discussion (votes, results), first part

15.15. Round table discussions, second part

16.30 Findings from the discussion tables (plenum)

17.30 Concluding remarks
Dr. M. Puschenreiter (BOKU Vienna, Austria)

18.00 Closing the workshop
Dr. I. Müller (Saxon State Office for the Environment, Agriculture and Geology, Germany)

6.1.2.2 Round table discussions:

After the introduction of the SUMATECS work packages in the morning session, all participants could give votes for topics they would like to discuss in the round table discussions. The topics and the votes each topic has got is shown in Table 3.

Table 3: Topics for round table discussions and the number of votes that each topic has got.

No Discussion topics	Votes
1 Contaminant removal or risk reduction: Is gentle remediation really effective? (Kristin Adriaensen / Andy Cundy)	1
2 Soil functions and ecosystem services maintained or provided by gentle remediation (Bernd Marschner / Valerie Bert)	2
3 How to measure and proof remediation success and environmental impacts? (Jurate Kumpiene / Giancarlo Renella)	12
4 Gentle remediation as a part of sustainable management strategies for large sites (Michel Mench / Pavel Tlustos)	8
5 Economics: How to sell gentle remediation? (Pascal Jollivet / Nelly Cochet)	6
6 Biomass valorisation: How to valorize biomass from gentle remediation sites? (Valerie Bert / Frederique Vialletelle)	10
7 The different point of view: Perception and acceptance of gentle remediation (Bernd Marschner / Ingo Müller)	6
8 The „perfect“ site for gentle remediation – all your dreams come true! (Pavel Tlustos / Markus Puschenreiter)	4
9 Sustainabitity in remediation: Is this an selling argument in practice? (Michel Mench / Kristin Adriaensen)	4
10 The main reasons of hinrance for gentle remediation and how to overcome (Ingo Müller / Valerie Bert)	3
11 Decision support tools for gentle remediation options between expectations and reality (Andy Cundy / Kene Onwubuya)	5
12 Future research and development in gentle remediation: What are the different needs? (Markus Puschenreiter / Wolfgang Friesl)	10

Each participant could be part of two discussion groups. Since some topics received only a small number of votes and because of time limits, some topics were combined and discussed together. After the round table discussions, the main results for each topic were presented and discussed in the plenum together with all participants.

In the following, the main results of these discussions are summarized:

Topic 1, 2, 3, 6, 7 (presented by Bernd Marschner): The main problem of all gentle remediation options (GRO) is still the long time needed. However, a few success stories are available for a reasonable time of 5 years. All GRO methods need long term monitoring, but this requires relatively little effort. The question how to determine success is still dependent on the legislation, which is (in allmost all European countries) still based on total concentrations in soil. It should be considered that alternative methods for determining more relevant heavy metal fractions in soil are available and should be considered. Overall, the main aim of all GRO is the reduction of risk. Additionally, GRO would be much more competitive if ecological factors would be included in the decision process.

Topics 4, 9 (presented by Michel Mench): More field experiments are necessary to evaluate the sustainability of GRO. Further, there is a need to minimize potential negative impacts of GRO. To some extent, the setting of priorities for resarch needs in not really possible. In order to make GRO more competitive, the natural capital should be valorised. Finally, the question remains, who will approve the sustainability of GRO.

Topic 8 (presented by Pavel Tlustoš): The “perfect” site for applying GRO is a land where there is no urgent need for other land use options. The site should not be under pressure. Overall, the application of GRO should be integrated into long term land management and into the management of a large system, including the surrounding of the contaminated site.

Topics 5, 7 (presented by Pascal Jollivet): In general, the ecosystem service of a contamianted vs the remediated land has to be valorised. There is a need for a cost-benefit analysis, which is also acceptable if it is not 100 % precise.

Topic 6, 10 (presented by Valerie Bert): The biomass valorisation is no problem for low contaminated biomass. Highly contaminated biomass needs some pretreatment.

Topic 11 (presented by Andy Cund): Decision support tools (DST) should be integrated into national framework guidelines. A simple DST is the best DST (e.g., a decision matrix). Ideally, a DST should first focus on risk asssessment and then on the option appraisal.

A final comment was given by Bernd Marschner, who stated that (i) there is an urgent need for BUNDLED information in the NATIONAL languages and (ii) there is a need to show success stories of pilot field experiments.

All the results of this workshop are also included in the following chapters (reports of the other SUMATECS workpackages).

6.2 State-of-the-art of research and development of various gentle remediation options

Adriaensen K., Ruttens A., Vangronsveld J., Mench M.,

6.2.1 Overview and technical description of potential sustainable gentle remediation options for TECS

6.2.1.1 INTRODUCTION

Various physical, chemical and biological processes are used to remediate contaminated soil. These processes either ‘decontaminate’ the soil, or ‘stabilize’ the pollutant within it. Decontamination reduces the amount of pollutants within the soil by removing them. Stabilization does not reduce the quantity of pollutant at a site, but aims to reduce or eliminate environmental risks posed by the contaminants by reducing the exposure to the contaminant or prevent the contaminants from being spread to the surroundings and the groundwater.

“Gentle” remediation technologies refer to in-situ techniques that do not significantly impact soil function or structure, such as phytoremediation, in situ immobilisation, etc. (Figure 1 in background of SUMATECS). These phytotechnologies are plant-based techniques for the removal, degradation or immobilization of dangerous/toxic contaminants from or in soils or water. However in many cases of phytoremediation, plants are not the ‘exclusive players in the game’. A very important role can be attributed to plant-associated bacteria and mycorrhiza (Barac et al., 2004; Di Gregorio et al., 2006; Lebeau et al., 2008; Lodewyckx et al., 2002; Zhuang et al., 2007).

6.2.1.2 IMMOBILIZATION

Plant cultivation dominated by reduce of contaminant transfer into plants

a) Objective:

The main objectives for successful immobilization are: (1) to change the trace element speciation in the soil aiming to reduce the easily soluble and exchangeable fraction of these elements; (2) to stabilize the vegetation cover and limit trace element uptake by crops; (c) to reduce the direct exposure of soil-heterotrophic living organisms and (d) to enhance biodiversity (Vassilev et al., 2004). To realize this in situ remediation makes use of metal immobilizing soil additives that enhance geochemical processes such as precipitation, sorption, ion exchange, and redox reactions (Mench et al., 2000). The formation of insoluble contaminant species results in a reduced metal mobility and bioavailability reduces leaching through the soil profile and biological interactions with living organisms. Soil amendments also can restore appropriate soil conditions for plant growth by balancing pH, adding organic matter, restoring soil microbial activity, increasing moisture retention, and reducing compaction (Vangronsveld et al., 1996; Vangronsveld et al., 1995a).

A large number of different additives have been proposed and tested for in situ immobilisation of heavy metals in soils (Adriano et al., 2004; Kumpiene et al., 2008; Mench et al., 1998; Mench et al., 2007). They all have a different effect on bioavailability of the metals, micronutrient availability, soil solution pH and soil microstructure (Lombi et al., 2003; Mench et al., 2000; Oste et al., 2002). Obviously they must possess a strong metal binding capacity, but they should not impair soil structure, soil fertility or the ecosystem and their effect should be sustainable on a long-term scale (Oste et al., 2002). The type, mix, and amounts of soil amendments will vary from site to site in response to the local mix of site contaminants, soil conditions, and type of desired vegetation. The first and most essential components of any soil amendment strategy are an accurate assessment of existing site-soil conditions and knowledge of the range of target soil conditions appropriate for the revegetation species of interest.

b) Types of soil amendments

Appropriate soil amendments may be inorganic (e.g., liming materials), organic (e.g., composts) or mixtures (e.g., lime-stabilized biosolids). This section briefly describes soil amendments and organizes them by use: organic soil amendment, pH soil amendment, and mineral soil amendment.

b.1. Organic soil amendments

A wide array of organic soil amendments, with varying levels of processing and characterization is available in most regions. Organic amendments most frequently are used to provide essential nutrients (such as N and P), to rebuild soil organic matter content, and re-establish microbial populations. Benefits directly associated with improved organic matter content are: enhanced water infiltration and moisture-holding, aggregation, aeration, nutrient supply for plant growth, and microbial activity. Biosolids can be combined with different alkaline materials such as limestone, and cyclonic ashes. This combined application of biosolids and lime should increase pH of the soil and reduce trace element availability.

- **Biosolids** are the primary organic solid byproduct produced by municipal wastewater treatment processes that have been treated to meet federal and state land-application standards.
- **Compost** is the stable soil conditioning product that results from aerobically decomposing raw organic materials, such as yard trimmings, food residuals, or animal byproducts.
- e.g. manure, papermill sludges, ….

b.2. Soil Acidity/pH Soil Amendments

Many degraded sites are plagued by low soil pH conditions and associated problems, including heavy metal bioavailability and direct toxicity to microbes. Fortunately, a wide array of alkaline soil amendments is available. All liming/alkaline soil amendments should be tested for their net neutralizing power. This is commonly expressed on a calcium-carbonate-equivalent (CCE) basis. The particle size of liming materials also is very important in that sand-sized or larger (> 0.05 mm) particles are much slower to react than finer-textured materials.

- **Lime**. Liming is the oldest and likely most widely adopted metal immobilizing soil treatment. Several reasons have been attributed to the lime-induced immobilization of metals (Hamon et al., 2002): increase in negative charges on soil components (Oste et al., 2002); formation of hydroxy metal species with strong sorption behavior; precipitation of metals as hydroxides or carbonates; and sequestration due to enhanced microbial activity. A disadvantage associated with liming in the context of *in situ* metal immobilization is the gradual disappearance of its effect in the course of time due to dissolution and leaching of the liming agent, possibly accelerated by acid depositions. This means that repeated applications are required to maintain metal immobilization.
- **Cyclonic and coal fly ashes**. Cyclonic ashes e.g. 'Beringite' are a modified aluminosilicate, originating from the fluidized bed burning of coal refuse.
- **Sugar Beet Lime**. During purification of sugar from sugar beets or cane, lime is added to neutralize organic acids present in the plant materials along with sugar. Sugar beet lime, the limestone byproduct of this process, is available wherever sugar is produced or packaged. It usually has a fine particle size, and may include byproduct organic matter needing application. These byproduct limestones contain organic matter and have relatively high CCE values.
- **Red mud** is a by-product of aluminium (Al) manufacturing, and is the material remaining after treatment of bauxite with sodium hydroxide during Al extraction. It is an alkaline material which is also rich in iron (Fe) (typically 25e40%) and Al oxides (15e20%) (Gray et al., 2006)

b.3. Mineral Soil Amendments and Conditioners

While organic matter and lime/alkaline soil amendments are used most often, a wide range of mineral byproduct materials with significant soil amendment, conditioning, or even soil substitute properties may be available locally. All materials should be characterized prior to use.

- **Zeolites** are crystalline aluminosilicate minerals. They are generally formed in nature when water of high pH and high salt content interacts with volcanic ash causing a rapid crystal formation. Zeolites are also industrially synthesized. The framework consists of $[SiO_4]^{4-}$ and $[AlO_4]^{5-}$ tetrahedra linked at all corners. The framework is open and contains channels and cavities in which cations and water molecules are located. The channel structure of zeolites is responsible for their function as a molecular sieve, but is also important for "selective" cation exchange (Oste et al., 2002). Although the binding capacity of synthetic zeolites can be very high, an increase in soil pH without a simultaneous addition of Ca can raise the dissolved organic matter (DOM) concentration in the soil (Oste et al., 2002). An increase in DOM might increase metal leaching (McCarthy and Zachara, 1989; Temminghoff et al., 1997).
- **Na silicates**. Commercial Na-silicates are produced when sand is heated under increasing pressure and in the presence of Na_2O resulting in the formation of single or short strains of SiO_4 tetraheders (Geebelen et al., 2006).
- **Phosphates and apatites**. Phosphate minerals and specifically apatite show promise for environmental cleanup because they can form stable compounds (hydroxypyromorphite) with a wide range of cationic contaminants. However, phosphate minerals naturally accumulate some heavy metals that may cause additional contamination of the environment if used improperly (Knox et al., 2006).
- **Fe- and/or Mn oxides or Fe- and or Mn-rich materials**. Iron, Al and Mn oxides commonly occur in soils and react with trace elements and As (Knox et al, 2001). The OH-OH distance in Fe, Mn, and Al oxides matches well with the coordination polyhedra of many trace elements. Such hydroxyl groups form an ideal template for bridging trace elements (Manceau et al., 2002). Reactions with trace elements can be promoted when these (hydr)oxides are combined with alkaline materials (Mench et al, 1998).
    - Zero valent Iron, steel shots, Iron grit are an industrial material intended for shaping metal surfaces prior to coating. They consist mainly of iron (Fe°) and contain native impurities such as Mn.

b.4. Microorganisms

Another way to immobilize metals involves the inoculation of soils with specific microorganisms. Some of these organisms can accumulate a considerable proportion of the soil pool of particular metals, despite the fact that they constitute a minor fraction of the total soil biomass (Jezequel and Lebeau, 2008). The advantage of bioaugmentation over classic soil additives is that thanks to the microbial turnover it is not necessary to reinoculate the soil (Ueno and Shetty, 1998).

6.2.1.3 PHYTOSTABILIZATION

Plant cultivation not directly referred to contaminant removal
Plant cultivation not directly referred to reduce of contaminant transfer into plants

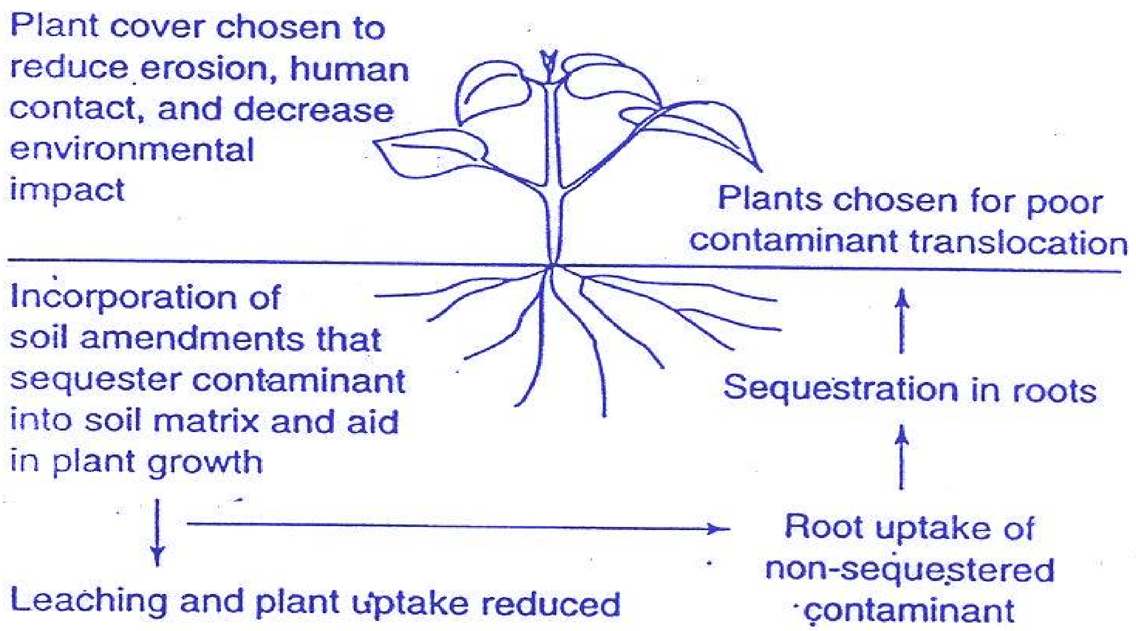

Figure 2. Processes involved in the phytostabilization of contaminants from soils (Cunningham et al., 1995).

a) Objective:

Plant-based *in situ* stabilization, termed "phytostabilization", reduces the risk posed by a contaminated soil by reducing the bioavailability of the trace elements making use of plants (Vangronsveld et al., 1996; Vangronsveld et al., 1995a). The role of plants is to increase the sequestration of the contaminant by reducing water percolation through the soil, incorporating residual free contaminant into the roots (or root zone), and preventing wind and rain erosion. Plants can be chosen that alter the chemical form or further sequester pollutants by mechanisms such as: redox reactions; precipitating the contaminant into the insoluble form; or incorporating organics into the plant lignin (subsequently unextractable in chemical solvents and animal feeding tests) (Cunningham et al., 1995). The microorganisms (bacteria and mycorrhiza) residing in the rhizosphere of these plants also perform an important role in these processes: they can not only actively assist to change the speciation of the trace elements, but they can also help the plant in overcoming phytotoxicity, thus assisting in the revegetation process (Van der Lelie, 1998).

For the establishment of a vegetation cover soil amendments are often essential, this is sometimes referred to as "aided phytostabilization". Due to the application of suitable amendments (see paragraph on immobilization), trace element uptake by (crop) plants, for instance, can be strongly decreased resulting in a reduction of trace element transfer to higher trophic levels (Vangronsveld et al., 1996; Vangronsveld et al., 1995a). Besides a strong metal sequestering effect soil amendments also can restore appropriate soil conditions for plant growth by balancing pH, adding organic matter, restoring soil microbial activity, increasing moisture retention, and reducing compaction.

b) Plants used for phytostabilization

Phytostabilization of trace element contaminated soils requires plants tolerant to the trace element concentrations and other growing conditions for a given site. Often, the plants chosen for phytostabilization include pioneer dicotyledonous and grass species that are rather fast growing to provide a quick and complete surface coverage; by preference, these species should possess many shallow roots to stabilize soil and take up soil water, and should be easy to care for once established.

PHYTOEXTRACTION

Plant cultivation dominated by contaminant removal

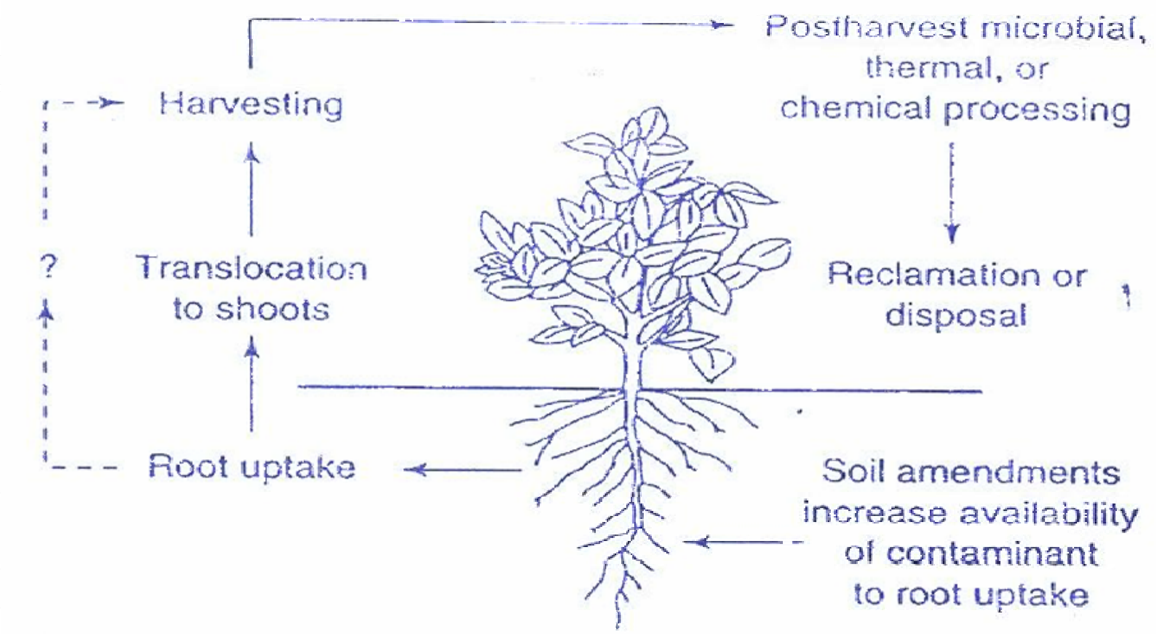

Figure 3. Processes involved in the phytoextraction of contaminants from soils (Cunningham et al., 1995).

a) Objective:

Phytoextraction is the use of higher plants to remove inorganic contaminants primarily metals from polluted soil. In this approach, plants capable of accumulating high levels of metals are grown in contaminated soil. At maturity metal-enriched aboveground biomass is harvested and a fraction of soil metal contamination removed, without damaging the soil or its disposal to landfill (Lasat, 2002).
A special case of phytoextraction is 'bioavailable contaminant stripping' (BCS). It is identical to phytoextraction but where phytoextraction aims at decreasing the total metal concentration, BCS aims the extraction of only the most labile, bioavailable metal pools. It is the available pool that causes environmental risks, and thus should be kept low enough to be harmless. This concept might be promising since cleanup time can be substantially shortened. However, in order to apply the technique efficiently and safely, it is necessary to assess the kinetics of replenishment of the bioavailable pool in the long term (Fitz et al., 2003)(→WP3).
Recently reviews on varied aspects of phytoextraction have appeared from several research groups with each discussing the potential merits of phytoextraction from their unique point of view (Chaney et al., 2007; Dickinson and Pulford, 2005; Hernandez-Allica et al., 2008; Lasat, 2002; Robinson et al., 2003; Van Nevel et al., 2007)

b) Plants used for phytoextraction:
Fundamentally plants for phytoextraction should have, among others, the following characteristics: (i) tolerant to high levels of the targeted metal that may be coupled with low macronutrient and soil organic matter content, (ii) accumulate reasonably high levels of the metal in easily harvestable plant parts, (iii) rapid

growth rates, (iv) produce reasonably high biomass in the field, and (v) profuse root system (Garbisu and Alkorta, 2001).

Most plants that occur naturally on metalliferous soils are recognized as being excluders. Plants that do not occur naturally on metalliferous soils usually behave as 'indicators' when grown in the presence of the non-essential elements. These plants have a relatively constant root absorption factor over a wide range of metal concentrations in the soil solution. In this case, the concentration in the plant has a near linear relationship to the metal concentration in the soil solution (Robinson et al., 2003). A third category of plants exists who tolerate very high concentrations of metal in their aerial parts and even have an active uptake mechanism for the nonessential metal. These plants are known as 'hyperaccumulators'.

b.1. Hyperaccumulators:

Hyperaccumulation was a term first mentioned by (Brooks et al., 1977) to describe plants that contain greater than 0.1% nickel (Ni) in their dried leaves, ever since their potential use for the extraction of heavy-metals from soils has been investigated. In the last few years, an important number of metal-tolerant and metal-accumulating plants have been identified. These species are capable of accumulating metals at levels 100-fold greater than those typically measured in shoots of the common nonaccumulator plants. Thus, a hyperaccumulator will concentrate more than 10 ppm Hg; 100 ppm Cd; 1000 ppm Co, Cr, Cu, and Pb; 10 000 ppm Zn, and Ni. To date there are known around 400 plant species from a number of different families such as the Asteraceace, Brassicaceae, Caryophyllaceae, Poaceae, Violaceae and Fabaceae that possess the ability to tolerate very high levels of heavy metals in the soil and, more importantly, in the plant shoot (Baker et al., 2000). Most of these species accumulate Ni, about 30 accumulate either Co, Cu, and Zn, even fewer accumulate Mn and Cd, and there are no known Pb hyperaccumulators (most important/studied examples). The Brassicaceae are the best represented amongst these metal-hyperaccumulator families with 87 Brassica species classified as metal hyperaccumulators. Two species in particular, *Thlaspi caerulescens and Arabidopsis halleri*, have been studied extensively for their ability to hyperaccumulate several heavy metals, mainly zinc (Zn), cadmium (Cd) and nickel (Ni). In particular, certain ecotypes of *T. caerulescens* can accumulate as much as 30 000 ppm of Zn and approx. 10 000 ppm Cd in the shoot biomass without any signs of toxicity (typical shoot levels are 100–200 ppm Zn and 0.1–10 ppm Cd). *Thlaspi caerulescens* is mostly used as a model system to study the mechanisms of metal uptake, accumulation, and tolerance as they relate to metal phytoextraction and to investigate the physiology and biochemistry of metal accumulation in plants (Milner and Kochian, 2008).

b.2. High biomass plants:

Nowadays, fast-growing, high biomass crop plant species that accumulate moderate levels of metals in their shoots are actively being tested for their metal phytoextraction potential. Over the past years, many crop and related weed species have been screened for metal uptake, translocation and tolerance. Much effort has centered on the Brassica family to which many hyperaccumulator species belong (Kumar et al., 1995). Similarly, many grasses such as maize, barley, oat, ryegrass, etc. have also been reported to tolerate and accumulate relatively high concentrations of metals in soil (Ebbs et al., 1997; Hernandez-Allica et al., 2006; Shen et al., 2002). To date, the results of these screening efforts indicate that, although many heavy-metal cations are easily taken up and accumulated in plants roots, translocation of these cations to the shoots, as well as tolerance to these metals, is often limited (Chaney et al., 2007). However, some authors consider that, in some cases, a greater shoot biomass can more than compensate for a lower shoot metal concentration (Ebbs and Kochian, 1997). Ebbs and Kochian (1997) reported that in hydroponics *Brassica juncea* removed fourfold more Zn than the hyperaccumulator *T. caerulescens* from a soil contaminated with >11000 mg Zn kg^{-1} soil. This was due primarily to the fact that, in 6 weeks, *B. juncea* produced 10 times more biomass than *T. caerulescens*.

In addition short rotation coppice cultures of several tree species have been studied for there use in phytoextraction. Clones of *Salix viminalis* and a number of other species and hybrids in this genus are already extensively grown as a biomass energy crop on agricultural land, usually in a 3-year harvest cycle, and there is a widely recognized opportunity for wider planting on Brownfield land (Dickinson and Pulford, 2005).

c. Aided phytoextraction:

Crop manipulation to increase metal uptake to levels comparable to those found in hyperaccumulators has been called aided phytoextraction, also referred to as induced hyperaccumulation, chemically assisted phytoextraction or chelant-assisted phytoextraction (in case metal chelating agents are involved). The two main bottlenecks hampering an efficient phytoextraction process are the limited bioavailability of heavy metals in the soil matrix and the limited subsequent translocation of the heavy metals extracted from the soil to aboveground plant parts (Herzig et al., 2000). Mobility and phytoavailability of heavy metals within the soil matrix varies widely between different soils and sediments and not only depends on soil total content but is largely determined by physico-chemical soil characteristics such as texture class, organic matter content, soil pH and CEC (Meers et al., 2007a). In addition, translocation efficiency of metals absorbed by plants from root to shoot is generally lower for non-essential metals in comparison to nutrients and essential trace metals (Meers et al., 2004). The use of soil amendments is aimed at increasing the phytoavailability of trace metals in the rhizosphere and/or the translocation efficiency of the assimilated minerals.

c.1. Chemicals

For most metals, with the exception of mercury, uptake into roots takes place from the aqueous phase. Strong binding to soil particles and/or precipitation renders a significant soil metal fraction insoluble, and largely unavailable for plant uptake (→WP3). Low soil bioavailability is a major factor limiting the potential for phytoextraction of significant metal contaminants such as, lead (Lasat, 2002). To enhance metal uptake by plants, chelating agents that increase metal solubility are added to the soil (Huang et al., 1997). The literature to date reports a number of synthetic chelates that have been used for chelate-induced hyperaccumulation. These chelates, however, are not specific to heavy metals and are subject to numerous interferences with other cations present in soil at much higher concentrations as e.g Ca and Fe (Nowack et al., 2006). Many synthetic chelates and their complexes with heavy metals are toxic and poorly photo-, chemo-, and biodegradable in soil environments (Grcman et al., 2003; Nowack et al., 2006). Authors investigating chelate-enhanced phytoextraction have also pointed out the risk of possible transference of Pb and other heavy metals from soil to ground water and promotion of off-site migration (Cooper et al., 1999; Shen et al., 2002). Chelate enhanced metal mobilization may also increase metal availability for soil micro-organisms (→WP4) (Bouwman et al., 2005; Romkens et al., 2002). Chelant-enhanced phytoextraction may nonetheless have a role in enhancing the uptake of essential trace metals. Such a role warrants further investigations into the use of biodegradable chelants such as ethylenediaminedisuccinic acid (EDDS) (Nowack et al., 2006).

c.2. Bioaugmentation

In Lebeau et al. (2008) a nice review is given on the potential use of soil microorganisms for altering the mobility of metals in porous matrices (soil and sediment), resulting in higher metal concentrations in plants, thanks to microorganisms producing biosurfactants, siderophores and organic acids and/or the enhancement of the biomass of plants by associating them with Plant Growth Promoting Rhizobacteria (PGPR) and/or Arbuscular Mycorrhizal fungi (AMF).

PHYTOVOLATILIZATION

Phytovolatilization is 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. Hg phytovolatilization development is an example of gene transfer that was successful (Heaton et al., 2003). However, public acceptance has been difficult because Hg_0 is volatilized at the soil surface and will eventually be re-deposited.

RHIZOFILTRATION

Rhizofiltration 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. The plants are raised in greenhouses hydroponically (with their roots in water rather than in soil). Once a large root system has been developed, contaminated water is diverted and brought in contact with the plants or the plants are moved and floated in the contaminated water. The plants are harvested and disposed as the roots become saturated with contaminants.

RHIZODEGRADATION

Rhizodegradation (also called 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. Natural substances released by the plant roots—such as sugars, alcohols, proteins and acids—contain organic carbon that act as nutrient sources for soil microorganisms, and the additional nutrients stimulate their activity. Microorganisms (yeast, fungi, and/or bacteria) consume and degrade or transform organic substances for use as nutrient substances. In the case of TECS contaminants can be organic chemical species of trace elements, or can be organic compounds mixed with trace elements. Rhizodegradation is aided by the way plants loosen the soil and transport oxygen and water to the area.

6.2.2 Current state of development of gentle remediation options for TECS. How far from practice? Phytoremediation in the field.

6.2.2.1 HOW FAR FROM PRACTICE? PHYTOREMEDIATION IN THE FIELD

Table 4: Overview of phytoremediation field trials in Europe

Remediation type	Contaminant	Receptor	Amendments	Location	Publication
phytoextraction	Cd, Cr, Cu, Ni, Pb, Zn	*Salix viminalis*		Menen (B)	(Vervaeke et al., 2003) (Meers et al., 2005a)
phytoextraction	Cd, Zn	*Brassica napus*		Balen (B) Budel (Nl)	(Grispen et al., 2006)
phytoextraction	Cd, Zn	*Brassica napus* *Zea mays* *Salix* sp. *Populus* sp.	Compost Manure Lime	Lommel (B)	(Meers et al, in prep)
phytoextraction	Cd, Pb	*Zea mays*	Mineral fertilization Manure EDTA	Pribram (Cz)	(Neugschwandtner et al., 2008)
phytoextraction	Pb	*Pelargonium cultivars*		Bazoches (F) Toulouse (F)	(Arshad et al., 2008)
Phytoextraction	Cd, Pb, Zn	*Thlaspi caerulescens*	Sewage sludge	La Bouzule (F)	(Schwartz et al., 2003)
phytoextraction	As, Cu, Cd, Co, Pb, Zn	*Helianthus annuus* *Sorghum bicolor*	Mineral fertilization Cow manure	Torviscosa (I)	(Marchiol et al., 2007)
phytoextraction	Pb, Zn, Cu, Cd	*Brassica carinata*		Aznalcollar (Sp)	(del Rio et al., 2000)

		Brassica juncea			
phytoextraction	Cd, Cr, Cu, Ni, Pb, Zn	*Salix viminalis*	Sludge Ashes	Uppsala (S) Enköping (S)	(Dimitriou et al., 2006)
phytoextraction	Cd	*Salix viminalis*	N fertilizers Sludge	Uppsala (S) lake Malaren (S)	(Klang-Westin and Eriksson, 2003)
phytoextraction	Cd, Cu, Zn	*Salix viminalis* *Thlaspi caerulescens* *Alyssum murale*	Sewage sludge	(CH)	(Greger and Landberg, 1999)
phytoextraction	Cd, Cu, Zn	*Salix viminalis* *Nicotiana tabacum* *Helianthus anuus*	NTA Elemental sulphur	Dornach (CH)	(Kayser et al., 2000)
phytoextraction	Cd, Cu, Zn	*Salix viminalis* *Nicotiana tabacum* *Helianthus anuus* *Brassica juncea* *Thlaspi caerulescens* *Alyssum murale* *Zea mays*		Dornach (CH)	(Keller et al., 2003)
phytoextraction	Cd, Zn	*Salix viminalis*	Fertilizer	Caslano (CH) Dornach (CH)	(Hammer et al., 2003)
phytoextraction	Cd, Cu, Zn	*Thlaspi caerulescens*		Caslano (CH) Dornach (CH)	(Hammer and Keller, 2003)
phytoextraction	Cd, Cu, Zn	*Betula pendula* *Salix viminalis* *Alnus incana* *Fraxinus excelsior* *Sorbus mougeotii*		Le Locle (CH)	(Rosselli et al., 2003)

phytoextraction	Cd, Cu, Ni, Zn	*Salix spp.*		Nottingham (UK)	(Pulford et al., 2002)
phytoextraction phytostabilization	As, Cd, Cu, Ni, Pb, Zn	*Betula* *Alnus* *Salix* *Populus* *Larix*		Liverpool (UK) St Helens (UK)	(French et al., 2006)
phytoextraction phytostabilization	Cd, Cu, Zn	*Salix* *Populus* *Alnus*		Warrington (UK)	(King et al., 2006)
phytoextraction	Cd, Zn	*Thlaspi caerulescens* *Arabidopsis halleri*	EDTA, NTA Citric acid	Bedfordshire (UK)	(McGrath et al., 2006)
phytoextraction	Cd, Zn	*Thlaspi caerulescens*	Sulfuric acid, KCl EDTA	Nottingham (UK)	(Maxted et al., 2007b)
phytoextraction	Cd, Zn	*Salix*		Nottingham (UK)	(Maxted et al., 2007a)
phytostabilization phytoextraction	Cd, Cu, Zn	*Fraxinus exelcior* *Quercus robur* *Populus alba* *Acer pseudoplatanus*		Deinze (Be)	(Vandecasteele et al., 2008)
Aided phytostabilization phytoextraction	As, Bi, Cd, Cu, Pb, Sb, Tl, Zn	*Quercus ilex* *Olea europea* *Populus alba* *Mediteranean shrubs*	Organic matter Ca rich amendments	Aznalcollar (Sp)	(Dominguez et al., 2008)
Aided phytostabilization phytoextraction	Cu	*Betula pendula* *Alnus cordata* *Alnus incana* *Alnus glutinosa* *Crataegus monogyna*	Lime Sugar beet washings	Walsall (UK) Merseyside (UK) Manchester (UK)	(Dickinson, 2000)

		Salix caprea *Salix* sp.			
Aided phytostabilization	As, Cd, Pb, Zn	*Barley*	Red Mud, Lime, Gravel sludge	Arnoldstein (Au)	(Friesl et al., 2006) (Friesl-Hanl et al., 2007) (Friesl-Hanl et al., 2008)
Aided phytostabilization	Cd, Pb, Zn	*Festuca rubra* *Agrostis capillaris* *Lolium perenne* Vegetable crops	Cyclonic ashes Compost	Lommel (B)	(Vangronsveld et al., 1995b) Vangronsveld *et al.* 1998
immobilisation	As, Cd, Pb, Zn	*Lactuca sativa* *Phaseolus vulgaris*	Cyclonic ashes Iron grit	Reppel (B) (semifield)	(Mench et al., 2006b)
Aided phytostabilization	Cu	*Pistacia terebinthus,* *Cistus creticus,* *Pinus brutia* *Bosea cypria*	Wine waste product (vinassa) Chicken fertilizer	Skouriotissa (Cy)	(Johansson et al., 2005)
Aided phytostabilization	Cd, Zn	Mustard Oat Rye	Lime Zeolites Muck Organic loamy shales	(Cz)	(Vacha et al., 2000)
phytostabilization	Cd, Pb, Zn	*Trifolium repens* *Lollium perenne*		(F)	(Bidar et al., 2007)
Aided phytostabilization	Cd, Ni	*Zea mays* *Lactuca sativa*	Cyclonic ashes Iron grit	Gironde (F)	(Boisson et al., 1998) (Mench et al., 2006a)
Aided phytostabilization	As, Cu, Cr	*Agrostis capillaris* *A. gigantea*	Iron grit Lime	Biogeco (F)	(Bes and Mench, 2008)

			Compost		
Aided phytostabilization	As	Grasses and weeds	Iron grit	Salsigne (F)	Unpublished
immobilization	As, Cd, Pb	Vegetable crops	Phophates Iron-oxides Zeolites Metasorb Clay Lime	Duisburg (DE) Wuppertal (DE)	Unpublished
Aided phytostabilization	As, Cd, Cu, Pb, Zn	Trees *Holcus lanatus*	Coal fly ash Compost Iron grit	Jales (Po) (semifield)	(Mench et al., 2003) (Mench et al., 2006a) (Renella et al., 2008)
Aided phytostabilization	As, Bi, Cd, Cu, Pb, Sb, Tl, Zn	*Helianthus anuus*	Biosolid compost, Leonardite Sugar beet lime	Aznalcóllar (Sp)	(Madejon et al., 2003) (Madejon et al., 2006)
phytostabilization	Cd, Cu, Zn	*Lactuca sativa L.*		Dornach (CH)	(Geiger et al., 1993)
Aided phytostabilization	As, Bi, Cd, Cu, Pb, Sb, Tl, Zn	*Agrostis stolonifera*	Biosolid compost, Leonardite Sugar beet lime	Aznalcóllar (Sp)	(Perez-de-Mora et al., 2006a) (Perez-de-Mora et al., 2006b) (Perez-de-Mora et al., 2007)
immobilization	Zn, Cu, Cd	*Lactuca sativa L.* Ryegrass	Gravel sludge	Dottikon (CH) Rafz (CH) Giornico (CH)	(Krebs et al., 1999)
Aided phytostabilization	As	Vegetable crops	Fe-oxides Lime	Cornwall (UK) Northhampton (UK) Merseyside (UK) Sommerset (UK)	(Warren et al., 2003)
Aided	Cu	*Agrostis capillaris*	Zeolites	Merseyside (UK)	(Lepp et al., 1997)

phytostabilization					
Aided phytostabilization	Cd	Vegetable crops	Zeolites Irongrit Lime	Northampton Staffordshire	(Lepp et al., 2000)
Aided phytostabilization	Zn, Cd, Pb, Cu, Cr and Ni	*Festuca rubra*	Red Mud Lime	Avonmouth (UK)	(Gray et al., 2006)
Aided phytostabilization	Al, Cd, Cu, Pb, Zn	grasses	Lime	Rothamsted (UK)	(Goulding and Blake, 1998)
Aided phytostabilization	Cd, Zn, Cu, Pb, As	*Deschampsia cespitosa* and *Festuca rubra,* spontaneous plant species	hydroxylapatite and TBS	Lallaing (Fr)	Bert et al. 2003b, 2007, 2008

6.2.2.2 IN SITU STABILIZATION

Plant cultivation dominated by reduce of contaminant transfer into plants
Plant cultivation not directly referred to contaminant removal
Plant cultivation not directly referred to reduce of contaminant transfer into plants

The effectiveness of soil amendments has been assessed in several different ways including chemical methods (e.g. selective or sequential chemical extractions, isotopic dilution techniques, adsorption-desorption isotherms, long term leaching, and weathering simulations) and biological methods (e.g. plant growth and dry matter yield, plant metabolism, ecotoxicological assays on soil invertebrates, and bacterial and microbial populations) (Vassilev et al., 2004). Making a comparison of the efficiency of the different additives throughout the numerous immobilization studies mentioned above, to come to a selection of ‘the best additive’ or to a ranging of additives in order of increasing immobilizing capacity, is not evident or even impossible. The use of different evaluation methods by different research groups e.g. to estimate exchangeable metal fractions, or the use of different plant species to evaluate reductions in crop metal uptake contribute to the difficulty. Moreover the remedial action of an additive seems to be soil dependent (Geebelen et al., 2003; Lombi et al., 2002a; Lombi et al., 2002b). Several factors including soil pH, the nature and extent of the metal pollution, the presence of other ions in solution,... may influence the extent of metal immobilization in a certain soil. This means that an additive, which proved to be very successful in one type of soil, may be less efficient in another soil. This soil type dependence of the immobilization process has to be taken into account when developing remediation options for a specific site. When one has to make decisions about the suitability of a product for in situ applications, durability of the effect is an important aspect. Even if the duration of a satisfactory immobilization treatment depends on several parameters such as land use, treatments costs and acceptable risks (Mench et al., 2003), it is generally recognized that the stronger the metal binding, and the longer the proven durability of a treatment, the higher the chance that decision makers will allow to use it. Compared to model studies and pot experiments, the most valuable information about the chances of immobilization can be obtained from long-term field experiments and outdoor mesocosms (Geebelen et al., 2006; Hamon et al., 2002; Lombi et al., 2002a; Lombi et al., 2002b; Vangronsveld et al., 1996; Vangronsveld et al., 1995b). Results obtained in pot experiments may differ from those obtained in the field due to differences in microbial activity, environmental conditions,… Moreover pot experiments only deliver information on the short term. In table 6.2.2 an inventory of European field trials is presented classified by the additive applied (only for the most intensive investigated additives in Europe) and the contaminant studied, including an evaluation of their observed efficiency and durability based on results of the exchangeable metal fraction and plant metal content obtained on polluted soils with and without addition of soil additives.

1. Lime

Lime has been tested as a metal immobilizing soil additive in several field experiments (Dickinson, 2000; Friesl et al., 2006; Goulding and Blake, 1998; Gray et al., 2006; Madejon et al., 2006; Perez-de-Mora et al., 2007; Warren et al., 2003). The results of 2 studies (Friesl et al., 2006; Gray et al., 2006) together with some specific information are presented in table 6.2.2. Reductions in the exchangeable fraction of Cd, Cu, Pb, and Zn as well as decreases in plant metal concentrations were frequently observed.

2. Red mud

Red mud is a by-product of the alumina industry that is alkaline and rich in Al/Fe oxides. Several pot experiments have demonstrated its efficacy for remediation of metal contaminated soils over relatively long time periods (Mench et al, 2000). Friesl et al (2006) and Gray et al (2006) have designed long term field experiments to assess the effectiveness of these amendments, the results of these studies are presented in table 6.2.2. Application of red mud increased soil pH and decreased Cd, Cu, Pb, and Zn availability to the plants.

3. Cyclonic ashes

Cyclonic ashes were shown to possess a very strong immobilizing capacity for several trace elements (Cd, Cu, Ni, Pb, Zn) in polluted soils with differing physical properties and pollution profiles (Vangronsveld and Clijsters, 1992; Vangronsveld et al., 1996; Vangronsveld et al., 1995a; Vangronsveld et al., 1995b). Cyclonic ashes proved to reduce plant exposure to Cd, Cu, Ni, Pb and Zn and to restore a vegetation cover at several different sites (Bleeker et al., 2002; Boisson et al., 1998; Mench et al., 2003; Mench et al., 2006b; Renella et al., 2008; Vangronsveld et al., 1996; Vangronsveld et al., 1995b). In the case of the Lommel-Maatheide experiment (Belgium), 12 years after the treatment the vegetation (mainly *Agrostis capillarisi* and *Festuca rubra*) is healthy and regenerating by both vegetative means and seeds (Vangronsveld et al., 1996). Biological evaluations of the phytotoxicity of polluted soils treated with cyclonic ashes (test system presented by (Van Assche and Clijsters, 1990) confirm strong reduction or even elimination of phytotoxicity. However, the use of amendments as Beringite that will lead to alkaline soil conditions must be carefully considered in relation to their potential impact on soil As partitioning (Mench et al., 2003; Mench et al., 2006a; Mench et al., 2006b).

4. Zero valent iron

Single applications of zero valent iron have been made in various contaminated soils and several pot experiments have been carried out to determine the changes in trace element mobility and plant availability (Boisson et al., 1998; Didier et al., 1993; Mench et al., 2003; Mench et al., 2006b; Mench et al., 1994; Renella et al., 2008; SappinDidier et al., 1997). Results from field applications are presented in table 6.2.2. In all soils studied, the addition of zero valent iron appeared to decrease Cd, Cu, Ni, Pb and Zn mobility. In most cases uptake into plants was also reduced. However oxidation of zero valent iron, combined with cyclonic ashes had the greatest effect on soil pH and reducing phytotoxicity (Mench et al., 2006b).

5. Zeolites

Lepp and coworkers (1997, 2000) demonstrated that 12 months after the addition of zeolites water extractable metal fractions were clearly reduced. While continuing emissions from the factory had increased this fraction in the untreated plots. This is a clear indication of the durability of zeolite effects. Due to this ongoing deposition, foliar metal analysis could not be used as an indicator of changing soil metal fractions.

Table 5: Summary of results from field trials: exchangeable metal fraction and plant metal content obtained on polluted soils with and without addition of soil additives. Absolute values are given as well as percentages (relative to the value of the untreated material). References of the data are indicated in the first column.

LIME

Cd

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	4.7	untreated - cv Hellana		1.09	100	2.00	100	0.22	100
	pH	untreated - cv Bodega		1.13	100	0.79	100	0.06	100
	4.9	lime		0.05	4	0.83	73	0.14	148
Friesl et al (2007)			2005						
		untreated - cv Hellana				0.87	100	0.09	100
		untreated - cv Bodega				0.63	100	0.06	100
		lime				0.55	75	0.06	83
Friesl et al (2008)			2006			Plantago		Holcus	
		untreated - cv Hellana				2.50	100		
		untreated - cv Bodega				2.49	100		
		lime				1.63	65		
			2007						
		untreated - cv Hellana		0.82	100	8.37	100	0.50	100
		untreated - cv Bodega		0.66	100	11.35	100	0.60	100
		lime		0.06	8	2.74	28	0.55	100
			2008						
		untreated - cv Hellana						0.23	100
		untreated - cv Bodega						0.26	100

	lime		0.24	99

Gray et al (2006)		Months after treatment		soil					Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	79	untreated		4.51	33	100					
		lime		4.79	28	85					
			2								
		untreated		4.72	39	100	3.92	100			
		lime		5.93	19	49	1.30	33			
			5								
		untreated		4.51	31	100	4.94	100			
		lime		5.64	23	74	1.80	36			
			10								
		untreated							0.2	15	100
		lime							5.0	5	33
			14								
		untreated		4.89	32	100					
		lime		5.20	26	81					
			21								
		untreated							2	17	100
		lime							8	5	29
			25								
		untreated		4.81	33	100	2.79	100			
		lime		6.03	18	55	1.32	47			

Cu

Gray et al (2006)		Months after treatment		soil					Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	311	untreated		4.51	15.7	100					
		lime		4.79	6.9	44					
			2								
		untreated		4.72	18.1	100	1.23	100			
		lime		5.93	1.4	8	0.20	16			
			5								
		untreated		4.51	12.8	100	1.46	100			
		lime		5.64	2.6	20	0.18	12			
			10								
		untreated							0.2	30	100
		lime							5.0	14	47
			14								
		untreated		4.89	10.4	100					
		lime		5.20	2.5	24					
			21								
		untreated							2	50	100
		lime							8	8	16
			25								
		untreated		4.81	12.6	100	0.68	100			
		lime		6.03	1.0	8	0.15	22			

Zn

Friesl et al (2006)	dystric cambisol	soil	crop

	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%		
	465.0	untreated - cv Hellana		48.8	100	632	100	102	100		
	pH	untreated - cv Bodega		47.5	100	617	100	81.5	100		
	4.9	lime		0.38	1	368	59	81.4	90		
Friesl et al (2007)			2005								
		untreated - cv Hellana				262	100	72.2	100		
		untreated - cv Bodega				276	100	76.3	100		
		lime				164	61	60.5	82		
Friesl et al (2008)			2006			Plantago		Holcus			
		untreated - cv Hellana				173	100				
		untreated - cv Bodega				140	100				
		lime				95	61				
			2007								
		untreated - cv Hellana		44.55	100	435	100	72	100		
		untreated - cv Bodega		35.25	100	605	100	89	100		
		lime		0.90	2	124	25	61	76		
			2008								
		untreated - cv Hellana						102	100		
		untreated - cv Bodega						114	100		
		lime						52	48		
Gray et al (2006)		Months after treatment		soil					Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	3970	untreated		4.51	1428	100					
		lime		4.79	1205	84					

			2								
		untreated		4.72	1930	100	182	100			
		lime		5.93	849	44	35	19			
			5								
		untreated		4.51	1536	100	249	100			
		lime		5.64	980	64	67	27			
			10								
		untreated							0.2	1400	100
		lime							5.0	600	43
			14								
		untreated		4.89	1434	100					
		lime		5.20	1044	73					
			21								
		untreated							2	600	100
		lime							8	200	33
			25								
		untreated		4.81	1078	100	131	100			
		lime		6.03	552	51	52	40			

Pb

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	752.0	untreated - cv Hellana		8.65	100	12.4	100	0.52	100
	pH	untreated - cv Bodega		8.52	100	12.5	100	0.37	100
	4.9	lime		0.08	1	6.6	53	0.26	60

Friesl et al (2007)			2005								
		untreated - cv Hellana				4.97	100	0.37	100		
		untreated - cv Bodega				6.32	100	0.38	100		
		lime				3.67	66	0.21	56		
Friesl et al (2008)			2007			Plantago		Holcus			
		untreated - cv Hellana		5.73	100	5.09	100	6.97	100		
		untreated - cv Bodega		4.33	100	7.23	100	5.19	100		
		lime		0.17	3	2.17	36	5.02	84		
			2008								
		untreated - cv Hellana						10.51	100		
		untreated - cv Bodega						7.95	100		
		lime						5.92	65		
Gray et al (2006)		Months after treatment		soil					Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	4210	untreated		4.51	377	100					
		lime		4.79	334	89					
			2								
		untreated		4.72	396	100	1.72	100			
		lime		5.93	57	14	0.46	27			
			5								
		untreated		4.51	358	100	1.82	100			
		lime		5.64	136	38	0.42	23			
			10								
		untreated							0.2	160	100

	lime							5.0	90	56
		14								
	untreated		4.89	375	100					
	lime		5.20	179	48					
		21								
	untreated							2	700	100
	lime							8	160	23
		25								
	untreated		4.81	434	100	1.35	100			
	lime		6.03	80	18	0.33	24			

RED MUD

Cd

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	4.7	untreated - cv Hellana		1.09	100	2.00	100	0.22	100
	pH	untreated - cv Bodega		1.13	100	0.79	100	0.06	100
	4.9	red mud		0.22	20	1.85	163	0.15	159
Friesl et al (2007)			2005						
		untreated - cv Hellana				0.87	100	0.09	100
		untreated - cv Bodega				0.63	100	0.06	100
		red mud				0.29	40	0.03	51
Friesl et al (2008)			2006			Plantago		Holcus	
		untreated - cv Hellana				2.50	100		

		untreated - cv Bodega				2.49	100				
		red mud				2.25	90				
			2007								
		untreated - cv Hellana		0.82	100	8.37	100	0.50	100		
		untreated - cv Bodega		0.66	100	11.35	100	0.60	100		
		red mud		0.31	42	10.30	107	0.19	35		
			2008								
		untreated - cv Hellana						0.23	100		
		untreated - cv Bodega						0.26	100		
		red mud						0.17	70		
Gray et al (2006)			soil						Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	79	untreated		4.51	33	100					
		red mud		4.72	33	100					
			2								
		untreated		4.72	39	100	3.92	100			
		red mud		6.90	11	28	0.47	12			
			5								
		untreated		4.51	31	100	4.94	100			
		red mud		6.23	15	48	0.51	10			
			10								
		untreated							0.2	15	100
		red mud							7.9	5	33

		14								
	untreated		4.89	32	100					
	red mud		6.02	15	47					
		21								
	untreated							2.0	17	100
	red mud							8.8	7	41
		25								
	untreated		4.81	33	100	2.79	100			
	red mud		6.49	16	48	0.68	24			

Cu

Gray et al (2006)		soil						Festuca rubra		
total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
311	untreated		4.51	15.7	100					
	red mud		4.72	11.0	70					
		2								
	untreated		4.72	18.1	100	1.23	100			
	red mud		6.90	1.8	10	2.48	202			
		5								
	untreated		4.51	12.8	100	1.46	100			
	red mud		6.23	1.5	12	0.68	47			
		10								
	untreated							0.2	30	100
	red mud							7.9	13	43

			14								
		untreated		4.89	10.4	100					
		red mud		6.02	1.3	13					
			21								
		untreated							2.0	50	100
		red mud							8.8	14	28
			25								
		untreated		4.81	12.6	100	0.68	100			
		red mud		6.49	0.8	6	0.23	34			

Zn

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	465.0	untreated - cv Hellana		48.8	100	632	100	102	100
	pH	untreated - cv Bodega		47.5	100	617	100	81.5	100
	4.9	red mud		5.61	12	558	89	78.2	86
Friesl et al (2007)			2005						
		untreated - cv Hellana				262	100	72.2	100
		untreated - cv Bodega				276	100	76.3	100
		red mud				149	55	62.4	84
Friesl et al (2008)			2006			Plantago		Holcus	
		untreated - cv Hellana				173	100		
		untreated - cv Bodega				140	100		
		red mud				150	97		

			2007								
		untreated - cv Hellana		44.55	100	435	100	72	100		
		untreated - cv Bodega		35.25	100	605	100	89	100		
		red mud		11.50	29	514	102	46	58		
			2008								
		untreated - cv Hellana						102	100		
		untreated - cv Bodega						114	100		
		red mud						69	64		
Gray et al (2006)			soil						Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	3970	untreated		4.51	1428	100					
		red mud		4.72	1396	98					
			2								
		untreated		4.72	1930	100	182	100			
		red mud		6.90	376	19	12	7			
			5								
		untreated		4.51	1536	100	249	100			
		red mud		6.23	535	35	10	4			
			10								
		untreated							0.2	1400	100
		red mud							7.9	300	21
			14								
		untreated		4.89	1434	100					

		red mud		6.02	490	34					
			21								
		untreated							2.0	600	100
		red mud							8.8	250	42
			25								
		untreated		4.81	1078	100	131	100			
		red mud		6.49	356	33	19	15			

Pb

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	752.0	untreated - cv Hellana		8.65	100	12.4	100	0.52	100
	pH	untreated - cv Bodega		8.52	100	12.5	100	0.37	100
	4.9	red mud		5.61	65	9.98	80	0.39	90
Friesl et al (2007)			2005						
		untreated - cv Hellana				4.97	100	0.37	100
		untreated - cv Bodega				6.32	100	0.38	100
		red mud				3.28	59	0.21	56
Friesl et al (2008)			2007			Plantago		Holcus	
		untreated - cv Hellana		5.73	100	5.09	100	6.97	100
		untreated - cv Bodega		4.33	100	7.23	100	5.19	100
		red mud		1.35	27	9.71	163	4.97	84
			2008						
		untreated - cv Hellana						10.51	100

		untreated - cv Bodega						7.95	100		
		red mud						6.56	72		
Gray et al (2006)			soil						Festuca rubra		
	total		0	pH	NH4NO3	%	pore water	%	yield	metal conc	%
	79	untreated		4.51	377	100					
		red mud		4.72	369	98					
			2								
		untreated		4.72	396	100	1.72	100			
		red mud		6.90	52	13	3.18	185			
			5								
		untreated		4.51	358	100	1.82	100			
		red mud		6.23	118	33	1.35	74			
			10								
		untreated							0.2	160	100
		red mud							7.9	90	56
			14								
		untreated		4.89	375	100					
		red mud		6.02	82	22					
			21								
		untreated							2	700	100
		red mud							9	200	29
			25								
		untreated		4.81	434	100	1.35	100			

	red mud	6.49	67	15	0.34	25

RED MUD & GRAVEL SLUDGE

Cd

Friesl et al (2006)	dystric cambisol			soil		crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	4.7	untreated - cv Hellana		1.09	100	2.00	100	0.22	100
	pH	untreated - cv Bodega		1.13	100	0.79	100	0.06	100
	4.9	red mud & gravel sludge		0.06	5	0.55	49	0.17	180
Friesl et al (2007)			2005						
		untreated - cv Hellana				0.87	100	0.09	100
		untreated - cv Bodega				0.63	100	0.06	100
		red mud & gravel sludge				0.53	72	0.05	79
Friesl et al (2008)			2006			Plantago		Holcus	
		untreated - cv Hellana				2.50	100		
		untreated - cv Bodega				2.49	100		
		red mud & gravel sludge				1.25	50		
			2007						
		untreated - cv Hellana		0.82	100	8.37	100	0.50	100
		untreated - cv Bodega		0.66	100	11.35	100	0.60	100
		red mud & gravel sludge		0.07	10	2.42	25	0.63	114
			2008						
		untreated - cv Hellana						0.23	100
		untreated - cv Bodega						0.26	100

		red mud & gravel sludge						0.11	44

Zn

Friesl et al (2006)	dystric cambisol		soil			crop			
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	465.0	untreated - cv Hellana		48.8	100	632	100	102	100
	pH	untreated - cv Bodega		47.5	100	617	100	81.5	100
	4.9	red mud & gravel sludge		0.44	1	315	50	78	86
Friesl et al (2007)			2005						
		untreated - cv Hellana				262	100	72.2	100
		untreated - cv Bodega				276	100	76.3	100
		red mud & gravel sludge				164	61	59.9	81
Friesl et al (2008)			2006			Plantago		Holcus	
		untreated - cv Hellana				173	100		
		untreated - cv Bodega				140	100		
		red mud & gravel sludge				84	54		
			2007						
		untreated - cv Hellana		44.55	100	435	100	72	100
		untreated - cv Bodega		35.25	100	605	100	89	100
		red mud & gravel sludge		1.17	3	140	28	61	76
			2008						
		untreated - cv Hellana						102	100
		untreated - cv Bodega						114	100
		red mud & gravel sludge						53	49

Pb

Friesl et al (2006)	dystric cambisol		soil			crop				
	total		2004	NH4NO3	%	Barley (straw)	%	Barley (grain)	%
	752.0	untreated - cv Hellana		8.65	100	12.4	100	0.52	100
	pH	untreated - cv Bodega		8.52	100	12.5	100	0.37	100
	4.9	red mud & gravel sludge		0.09	1	5.38	43	0.2	46
Friesl et al (2007)			2005						
		untreated - cv Hellana				4.97	100	0.37	100
		untreated - cv Bodega				6.32	100	0.38	100
		red mud & gravel sludge				3.94	71	0.19	51
Friesl et al (2008)			2007			Plantago		Holcus	
		untreated - cv Hellana		5.73	100	5.09	100	6.97	100
		untreated - cv Bodega		4.33	100	7.23	100	5.19	100
		red mud & gravel sludge		0.20	4	2.68	45	7.23	122
			2008						
		untreated - cv Hellana						10.51	100
		untreated - cv Bodega						7.95	100
		red mud & gravel sludge						4.67	52

CYCLONIC ASHES

As

Mench et al (2006)		soil				crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	169	0.891	100	1.55	100	0.96	100

	beringite	5.89		0.595	67	1.26	81	1.04	108

Mench et al (2003)		soil				crop							
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated	4.18	1325	0.172	100	< 0.2	NA	no growth	NA	no growth	NA	0.97	100
	beringite	6.71		0.64	372	< 0.2		no growth		8.1		144	14845

Bleeker et al (2002)		soil			crop			
		pH	CaNO3	%	holcus lanatus	%	agrostis castellana	%
	untreated	4.1	0.32	100	2.11	100	0.63	100
	beringite	5.1	0.36	113	1.2	57	0.4	63

Cd

Vangronsveld et al (1996)		soil	crop						
		pH	total	spinach	%	lettuce	%	celery	%
	untreated	-	5.85	0.92	100	0.29	100	0.6	100
	beringite			0.41	45	0.09	31	0.29	48

Boisson et al (1998)		soil			crop			
	SOIL 1	total	CaNO3	%	maize (grain)	%	maize (straw)	%
	untreated	38.4	5.5	100	0.4	100	31.7	100
	beringite	34.6	1.2	22	0.2	50	15.7	50
	SOIL 2							
	untreated	111.1	8	100	0.4	100	26.7	100
	beringite	122	3.5	44	0.4	100	31.5	118

Mench et al (2006)		soil				crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%

	untreated	4.91	0.6	0.06	100	3.2	100	0.3	100
	beringite	5.89		0.0091	15	2.05	64	0.102	34

Mench et al (2003)		soil				crop					
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%
	untreated	4.18	3.8	0.244	100	23.7	100	no growth	NA	no growth	NA
	beringite	6.71		0.029	12	5.4	23	no growth		0.2	

Cu

Mench et al (2003)		soil			
Renella et al (2008)		pH	total	CaNO3	%
	untreated	4.18	15.2	0.149	NA
	beringite	6.71		< DL	

Ni

Boisson et al (1998)		soil		crop			
	SOIL 1	total	CaNO3	%	maize (grain)	%	maize (straw)	%
	untreated	83.9	10	100	1.7	100	1.9	100
	beringite	81.4	2	20	1.3	76	0.8	42
	SOIL 2							
	untreated	259.6	22	100	2.8	100	2.4	100
	beringite	269	9	41	1.9	68	1.9	79

Pb

Mench et al (2003)		soil

Renella et al (2008)		pH	total	CaNO3	%
	untreated	4.18	170	0.071	100
	beringite	6.71		0.004	15

Zn

Vangronsveld et al (1995)			soil			
		1990	pH	total	aqueous extraction	%
	untreated		4.5			
	beringite		6.5			
Vangronsveld et al (1996)		1995				
	untreated		5.55	11425	141	100
	untreated with natural vegetation		5.77	960	10.4	7.4
	beringite		7.5	12075	2.1	1.5

Mench et al (2006)		soil				crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	70.1	5.4	100	175	100	73	100
	beringite	5.89		0.35	6	135	77	40.2	55

Mench et al (2003)		soil				crop							
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated	4.18	165	13.825	100	902	100	no growth	NA	no growth	NA	43.5	100
	beringite	6.71		0.925	7	82	9	no growth		13		43	100

ZEROVALENT IRON GRIT

As

Mench et al (2006)		soil				crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	169	0.891	100	1.55	100	0.96	100
	iron grit	5.21		0.081	9	0.64	41	0.92	96

Mench et al (2003)		soil				crop							
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated	4.18	1325	0.172	100	< 0.2	NA	no growth	NA	no growth	NA	0.97	100
	iron grit	6.06		0.63	366	< 0.2				11.1		7.9	32	3299

Bleeker et al (2002)		soil			crop			
		pH	CaNO3	%	holcus lanatus	%	agrostis castellana	%
	untreated	4.1	0.32	100	2.11	100	0.63	100
	iron grit	4.3	0.36	112.5	1.73	82	0.36	57

Cd

Boisson et al (1998)		soil			crop			
	SOIL 1	total	CaNO3	%	maize (grain)	%	maize (straw)	%
	untreated	38.4	4.2	100	0.3	100	31.7	100
	iron grit	19.6	2	48	0.5	167	15.2	48
	SOIL 2							
	untreated	111.1	8	100	0.3	100	26.7	100
	iron grit	102.5	4.5	56	0.8	267	34.9	131

Mench et al (2006)		soil				crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%

	untreated	4.91	0.6	0.06	100	3.2	100	0.3	100
	iron grit	5.21		0.0479	80	2.46	77	0.083	28

		soil				crop					
Mench et al (2003)											
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%
	untreated	4.18	3.8	0.244	100	23.7	100	no growth	NA	no growth	NA
	iron grit	6.06		0.13	53	4.6	19	1.1		0.28	

Cu

Bes and Mench (2008)		soil				crop	
		pH	total	CaNO3	%	bean primary leaves	%
	untreated		2600	5.3	100	62.4	100
	iron grit			0.04	1	30.1	48

		soil			
Mench et al (2003)					
Renella et al (2008)		pH	total	CaNO3	%
	untreated	4.18	15.2	0.149	NA
	iron grit	6.06		< DL	

Ni

Boisson et al (1998)		soil			crop			
	SOIL 1	total	CaNO3	%	maize (grain)	%	maize (straw)	%
	untreated	83.9	7	100	1.7	100	1.9	100
	iron grit	51.6	3	43	1	59	0.7	37
	SOIL 2							
	untreated	259.6	22	100	2.8	100	2.4	100
	iron grit	241.6	12.5	57	2.2	79	1.3	54

Pb

Mench et al (2003)		soil				
Renella et al (2008)			pH	total	CaNO3	%
	untreated		4.18	170	0.071	100
	iron grit		6.06		0.005	15

Zn

Mench et al (2006)		soil					crop				
			pH	total	CaNO3	%		lettuce	%	bean primary leaves	%
	untreated		4.91	70.1	5.4	100		175	100	73	100
	iron grit		5.21		3.04	56		160	91	37.7	52

Bes and Mench (2008)		soil					crop		
			pH	total	CaNO3	%	bean primary leaves		%
	untreated			57.7	0.65	100		68.7	100
	iron grit				2.2	338		32.8	48

Mench et al (2003)		soil					crop									
Renella et al (2008)			pH	total	CaNO3	%		maize	%	bean primary leaves		%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated		4.18	165	13.825	100		902	100	no growth	NA		no growth	NA	43.5	100
	iron grit		6.06		7.42	54		61	7		29			17	30.2	70

CYCLONIC ASHES + IRON GRIT

As

Mench et al (2006)	soil	crop

		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	169	0.89	100	1.55	100	0.96	100
	beringite + iron grit	6.46		0.08	9	0.3	19	0.67	70

Mench et al (2003)	soil					crop							
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated	4.18	1325	0.172	100	< 0.2	NA	no growth	NA	no growth	NA	0.97	100
	beringite + iron grit	6.67		0.424	247	< 0.2		10.4		12.5		14	1443

Bleeker et al (2002)	soil			crop				
		pH	CaNO3	%	holcus lanatus	%	agrostis castellana	%
	untreated	4.1	0.32	100	2.11	100	0.63	100
	beringite + iron grit	4.8	0.54	169	0.81	38	0.43	68

Cd

Mench et al (2006)	soil					crop			
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	0.6	0.06	100	3.2	100	0.3	100
	beringite + iron grit	6.46		0.0052	9	1.17	37	0.03	10

Mench et al (2003)	soil					crop					
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%
	untreated	4.18	3.8	0.244	100	23.7	100	no growth	NA	no growth	NA
	beringite + iron grit	6.67		0.016	7	4.4	19	no growth		0.4	

Cu

Mench et al (2003)	soil				
Renella et al (2008)		pH	total	CaNO3	%

	untreated	4.18	15.2	0.149	NA
	beringite + iron grit	6.67		< DL	

Pb

Mench et al (2003)	soil				
Renella et al (2008)		pH	total	CaNO3	%
	untreated	4.18	170	0.071	100
	beringite + iron grit	6.67		0.011	15

Zn

Mench et al (2006)	soil				crop				
		pH	total	CaNO3	%	lettuce	%	bean primary leaves	%
	untreated	4.91	70.1	5.4	100	175	100	73	100
	beringite + iron grit	6.46		0.13	2	128	73	42	58

Mench et al (2003)	soil				crop									
Renella et al (2008)		pH	total	CaNO3	%	maize	%	bean primary leaves	%	holcus lanatus	%	pine needles	%
Mench et al (2006)	untreated	4.18	165	13.825	100	902	100	no growth	NA	no growth	NA	43.5	100
	beringite + iron grit	6.67		0.313	2	75	8	31		32		30.5	70

ZEOLITES

Cd

Lepp et al (1997)	soil		
		aqueous extr	%
	untreated	0.75	100

	zeolite P		0.42	56											
	zeolite 4A		0.47	63											
Lepp et al (2000)	loamy soil	soil		crop											
		1998	total	calabrese	%	cabbage	%	lettuce	%	spinach	%	radish leaf	%	radish root	%
	soil 1														
	untreated		47	5.12	100	3.58	100	18.58	100	16.7	100				
	zeolite 4A			5.41	106	3.85	108	12.54	67	12.6	75				
	soil 2														
	untreated		16												
	zeolite 4A														
		1999													
	soil 1														
	untreated							28.9	100			16.3	100		
	zeolite 4A							21.7	75			15.4	94		
	soil 2														
	untreated			2.65	100			28.8	100						
	zeolite 4A			1.80	68			15.7	55						
		2000													
	soil 1														
	untreated			3.20	100			24.7	100			21.5	100	12.4	100
	zeolite 4A			2.50	78			23.7	96			20.6	96	13.2	106
	soil 2														
	untreated			1.58	100			12.5	100	13.3	100				

zeolite 4A	1.77	112	9.93	79	9.26	70

Cu

Lepp et al (1997)	soil		
		aqueous extr	%
	untreated	14.46	100
	zeolite P	3.76	26
	zeolite 4A	4.13	29

Pb

Lepp et al (1997)	soil		
		aqueous extr	%
	untreated	2.63	100
	zeolite P	2.1	80
	zeolite 4A	2.3	87

Zn

Lepp et al (1997)	soil		
		aqueous extr	%
	untreated	2.8	100
	zeolite P	1.4	50
	zeolite 4A	1.4	50

6.2.2.3 PHYTOEXTRACTION

Plant cultivation dominated by contaminant removal

Despite intensive research on the phytoextraction potential of different plants in the last decade very few field trials or commercial operations that demonstrate successful phytoextraction have been realized. In Table 4 an overview is given of the different field trials performed in Europe, 25 of them evaluated the phytoextraction potential of approximately 15 different plants. In table 6.2.3 an evaluation is presented of their observed phytoextraction efficiency. As can be seen in the following equation, the potential for phytoextraction depends on three variables: plant biomass, the bioaccumulation factor and the soil mass that requires remediation (Zhao et al., 2003): % of soil metal removed by one crop = (Plant metal concentration × Biomass) /(Soil metal concentration × Soil mass in the rooting zone) × 100. We have selected those field trials that studied the hyperaccumulator, *Thlaspi caerulescens* or two high biomass crops, *Zea mays* or *Salix* spp*.*. We only evaluated their efficiency for Cd and Zn phytoextraction, because most results were found for these combinations. To compare the efficiency and success of phytoextraction with one of these 3 crops we have selected in each field trial the best case scenario, this means we have always used the results of the treatment that gave the highest metal removal. However, the results of these calculations should be interpreted with precaution because we did not take into account the origin of the plant material (different subspecies, cultivars, ..), the soil type, source of contamination and environmental factors that can greatly influence the metal uptake and biomass production by the plants. These factors probably can explain the big differences in metal concentration and biomass production per plant species observed.

Table 6: Biomass production and ranges of metal concentrations in different plants used for phytoextraction in field trials with reference to their estimated clean up times.

	Metal crop mg/kg DW	BCF*	Aerial biomass ton/ha	Metal removal g/ha/year	clean up time**	Reference
Cd					**5->2 mg/kg**	
Thlaspi caerulescens	257	92	2.1	539	21	(Hammer and Keller, 2003)
	1563	208	2.69	4204	3	(McGrath et al., 2006)
	124	3.59	2.52	312	36	(Maxted et al., 2007b)
	184	92	0.9	166	68	(Keller et al., 2003)
	12.1	1.53	2.93	35	317	(Greger and Landberg, 1999)
Zea mays	0.6	0.3	15.6	9	1202	(Kayser et al., 2000)
	0.3	0.15	14.2	4	2641	(Keller et al., 2003)
	0.39	0.08	9.4	3.7	3069	(Neugschwandtner et al., 2008)
	1.07	0.17	15	16.05	700	(Meers et al, in prep)
Salix spp.	3.4	1.7	13.2	45	250	(Keller et al., 2003)
	22.2	2.81	10	222	51	(Greger and Landberg, 1999)
	4.2	20	6.1	26	439	(Klang-Westin and Eriksson, 2003)

	8.1	0.18	7.6	62	183	(Pulford et al., 2002)
	4.7	1.01	17.8	83	135	(Meers et al., 2005a)
	4.3	1.43	11.5	49	227	(Vervaeke et al., 2003)
Zn					**1000 -> 600 mg/kg**	
Thlaspi caerulescens	9800	8	2.1	20000	75	(Hammer and Keller, 2003)
	10858	43	2.69	29208	51	(McGrath et al., 2006)
	980	0.45	2.52	2470	607	(Maxted et al., 2007b)
	5265	8.05	0.9	4739	317	(Keller et al., 2003)
Salix spp.	294	0.45	13.2	3881	387	(Keller et al., 2003)
	108	0.05	7.6	821	1827	(Pulford et al., 2002)
	283	0.4	17.8	5034	298	(Meers et al., 2005a)
	362.5	0.83	11.5	4169	360	(Vervaeke et al., 2003)

[*] Bioconcentration factor (BCF) = the metal concentration in plant tissues (mg kg^{-1}) / metal concentration in substrate (mg kg^{-1}). Soil concentration taken as 'total': usually aqua regia- or HNO_3-extractable.
[**] We used a zero order kinetic equation, which assumes no decrease in plant heavy metal concentration or yield, to calculate the number of years necessary to decrease the total metal concentration with a defined amount. The following additional assumptions were made: the depth for remediation is 0.25 m and soil density is 1.5 g cm^{-3}.

From this analysis we must conclude that the hyperaccumulator *T.caerulescens* despite its low biomass production is by far the most efficient phytoextractor for Cd in the field, except from one trial performed by Greger and Landberg (1999) where willows seemed to be more efficient. As was shown by Mc Grath et al (2006) repeated and multiple croppings of *T.caerulescens* within a single season would be required for successful phytoextraction but optimizing the husbandry of *T.caerulescens* to maximize Cd off-take has yet to be resolved (Maxted et al., 2007). The higher phytoextraction potential of *T.caerulescens* can be explained by the bioconcentration factor (BCF) being a 100 times higher than that of the other plants. The BCF is one of the most important factors determining the feasibility of phytoextraction, BCF ratios above 1 mean that the plant actively concentrates the metal in its tissues (French et al., 2006). Zhao et al (2003) even argue that phytoextraction is unlikely to be efficient if the BCF is below 10. In most field trials with *Salix* a BCF above 1 was reached but only in the experiment of Klang-Westin and Eriksson (2003) a BCF higher than 10 was reached. But in this experiment a fairly low biomass yield was attained so in the end this experiment seemed to be the less efficient compared to the others. Combining an intermediate biomass yield (10 t/ha) with a high metal uptake (22.2 mg/kg Cd) a reasonably short clean up time of 50 years, in the same range as with *T.caerulescens*, can be reached with willows in the field (Greger and Landberg, 1999). Dickinson and Pulford (2005) also calculated that with an annual yield of 15 t ha^{-1} containing 25 mg Cd kg^{-1} soil concentrations in the surface 20 cm would reduce by 5 ppm in 27 years. This would appear to represent (i) an uptake ratio that is currently and realistically achievable (ii) a time period that may be considered appropriate and (iii) the approximate length of the productive lifecycle of short-rotation coppice. It has been shown that *Salix* has the ability to accumulate more cadmium than most other agricultural crops like for example maize. Maize does not seem to be an option for phytoextraction with clean up times ranging from 700 years until 3000 years. But this is not so surprisingly knowing that maize is a metal excluder (Meers et al., 2005b).

So, although results from hydroponic experiments indicate that fast-growing, high biomass crop plant species have genetic potential for metal root uptake and root to shoot translocation (Kumar et al., 1995); this does not necessarily mean that they are suitable for phytoextraction. Out of the three processes which are involved in phytoextraction, i.e., solubilization of the metals from soil and their transfer to the roots, uptake of the metals into the roots, and translocation to the above-ground biomass, hydroponic experiments can only be used to investigate the latter two processes and they cannot be directly extrapolated to phytoextraction performance in the field. After all, in soil, the genetic potential of a certain plant for metal phytoextraction will not be fully realized unless the metals are in a phytoavailable form. In turn, high concentrations of bioavailable metals in the soil will limit the utilization of cultivars which are not metal-tolerant, because of metal phytotoxicity impeding their establishment and/or proper growth. Then, it must be emphasized that the potential of high biomass cultivars for the phytoextraction of metal polluted soils depends not only on their ability to accumulate metals in their shoots but also, most importantly, on their capacity to tolerate relatively high soil metal concentrations while maintaining fast rates of growth (Chaney et al., 2007). Most importantly, if a certain plant is to be considered for metal phytoextraction, it is essential to test its phytoextraction potential in the specific soil to be remediated. However, this does not mean that hydroponic or compost experiments are useless. On the contrary, they provide a simple, most valid procedure for the screening of the genetic potential of plants for phytoextraction.

6.2.3 SWOT analysis of the different options

6.2.3.1 SOIL AMENDMENTS

Soil amendments can reduce the bioavailability of a wide range of contaminants while simultaneously enhancing revegetation success and, thereby, protecting against offsite movement of contaminants by wind and water. As such, they can be used in situations ranging from time-critical contaminant removal actions to long-term ecological revitalization projects. Using residual materials (industrial byproducts) offers the potential for significant cost savings compared to traditional alternatives. In addition, land revitalization using soil amendments has significant ecological benefits including benefits for the hydrosphere and atmosphere. In table 6.2.4 an overview is given of the different additives together with their mechanisms of immobilization, their side effects and durability.

Table 7: Overview of the mechanisms of immobilization, side effects and durability of different soil additives.

Additive	Mechanisms of immobilization	Metals immobilized	Side effects	Durability
Lime	Through increase in pH metal complexation on hydroxylated surface sites of soil minerals. Deprotonation of functional groups on humic substances results in increased cation exchange and complexation reactions. Metal hydrolysis reactions may be responsible for an increased metal sorption. Precipitation of metal hydroxides. Precipitation of metal carbonates. Increase Ca.	All cationic metals.	A rise in pH may mobilize toxic anions such arsenates and chromates, or organic contaminants by increasing soluble organic matter fractions. Agricultural limestone has low solubility and can become coated and ineffective at severely acidic sites. Can be source of fugitive dust.	Liming is only effective on the short term. Repeated lime applications are required to maintain metal immobilization.
Red mud	Increase pH; Sorbent.	Cd, Cu, Pb, Zn		
Cyclonic ashes (CA)	High immobilizing capacity is based on ion exchange, chemical precipitation and crystal growth.	Cd, Cu, Mn, Ni, Pb, Tl and Zn	In sandy soils an additional advantage of CA addition is a significant enhancement of the soil water retention capacity. High levels of Ca en SO_4 in the product.	12 years proven in the field (Mench et al, 2006), 30 years as shown in a simulation experiment (Vangronsveld et al., 1998) and 70 years as predicted from lab experiments (Wessolek and Fahrenhorst, 1994).
Fe, Mn oxides	Their hydroxyl groups form an ideal template for bridging trace metals.	Cu, Cd, Ni, Pb, Zn	High Mn levels may cause phytotoxicity. Decrease in availability of Ca, K, Mg and P.	At least 5 years in a semi-field study (Mench et al.,2006)
Zeolites	High cation exchange capacity. Due to their ion sieve properties they can either trap or exclude ions depending on size.	Cd, Cu, Pb and Zn	At higher application rates, sometimes necessary to obtain the desired metal immobilization, nutrient deficiencies can occur. Some zeolites can cause negative effects on soil structure. pH stability is uncertain.	At least 3 year in the field (Lepp, 2000).

6.2.3.2 PLANTS USED FOR PHYTOREMEDIATION

Table 8: List of the various plants used for phytoremediation along with their uses, advantages, and disadvantages.

Plant	**Uses**	**Advantages**	**Disadvantages**
Hyperaccumulators:			
Thlaspi caerulescens	phytoextraction	Model plant, well characterized; 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 of starting from seeds); small, low biomass (no mechanical harvest possible); shallow root system; little is known about its agronomic characteristics, pest management and breeding potential
Arabidopsis halleri	phytoextraction	Zn hyperaccumulator; closely related to the non hyperaccumulator, model plant *A.thaliana*; high BCF	Small biomass; hyperaccumulates 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	phytostabilization	Highly metal tolerant. Metal excluder.	
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	phytostabilization	Highly 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;
	phytostabilization	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;

6.2.3.3 PHYTOEXTRACTION VERSUS IN SITU STABILIZATION

Table 9: List of the opportunities and limits of the main gentle remediation options according to the contaminant.

Metal	Opportunities	Limits
Phytoextraction		
Cd	Metal removal;	metal specificity; Zn phytotoxicity limits Cd accumulation; reasonable clean up time up to 5 ppm;
Cu	Metal removal;	Long clean up time; metal specificity
Ni	Metal removal; economical value (Ni recovery, Ni fertilizer);	metal specificity
Pb	Metal removal;	Low bioavailability;
Zn	Metal removal;	Long clean up time; metal specificity
Phytostabilization		
Cd	Effective in field trials up to 120 ppm	No metal removal;
Cu	Effective in field trials up to 2600 ppm	No metal removal;
Ni	Effective in field trials up to 270 ppm	No metal removal;
Pb	Effective in field trials up to 4200 ppm	No metal removal;
Zn	Effective in field trials up to 12000 ppm	No metal removal;

When taking into account the achievable mass of metals which can be reasonably extracted per hectare and per year, it becomes evident that phytoextraction is only applicable to more moderately contaminated land, and cannot serve as a full-blown alternative for conventional soil remediation on more heavily polluted sites. In contrast phytostabilization is not limited by the degree of metal pollution and mixed contaminations can be handled in the same time when using a mixture of appropriate soil additives.

6.3 Review and evaluation of the existing methods for determination of the bioavailable trace element fraction in soils

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6.3.1 INTRODUCTION

The enormous amount of potentially contaminated sites identified in Europe (up to several mln) requires search for ways to prioritise remediation efforts. This is often done by the risk assessment of contaminated site to the environment and human health. Determination of the total trace element (TE) concentration is considered as the first step in the risk assessment. Countries that have guideline values (e.g. Sweden) use the total TE concentration to determine the level of contamination. But the total TE concentration does not define the actual or even potential risk, for example, the same amount of TE in calcareous, neutral and high CEC-having soil does not necessary cause equal effects on the environment as the same TE amount present in sandy, acidic or low in CEC and organic matter soil. This means that the link between soil total TE concentrations and ecological effects is not straightforward.

The concept of bioavailability appears more and more often in the context of the management of contaminated sites. The increasing interest in bioavailability arises from the observations that the actual risk of a trace element contaminated site to the environment and humans does not correlate with the total TE concentrations in soil, but rather to TE bioavailability. The bioavailability of TE is considered as the main risk-defining factor, meaning that a trace element becomes harmful only if an organism assimilates it at elevated concentrations. Bioavailability of trace elements is becoming of considerable importance for the management and remediation of contaminated sites. A demonstration that higher concentrations of trace elements can be left in soil without further risk can promote an application of less invasive or "gentle" remedial approaches. This in turn would lead to decreased remediation costs and smaller volumes of soil to be excavated and transported off site.

Use of bioavailability in management of contaminated sites in EU

The importance of bioavailability and its use in management of contaminated sites varies in different EU countries. For instance, in France and Italy there is no consideration of these parameters in studies concerning human health risk assessment. In other EU countries like UK or Netherlands, bioavailability is currently used or is advised to be used. In UK, this concept is however not recognized by Environment Protection Agency, but its use is admitted in the local context, although the protocol of assessing bioavailability strongly differs within the country. In Netherlands, the used of bioavailability is recommended by the Dutch National Institute for Public Health and the Environment (RIVM). This bioavailability is estimated from an experimental determination of bioaccessibility (i.e. potential bioavailability). In the German federal soil protection law, the health risk from ingested soil is explicitly considered as one critical exposure pathway. The so-called trigger values are partly based on epidemiological studies. In practice, in-vitro bioaccessibility determinations according to the DIN 19738 are used for site-specific investigations, but no guidelines for the evaluation of the results are available.

The Swedish EPA has developed generic guideline values for a number of organic and inorganic contaminants that are used in risk assessment of contaminated sites in Sweden (SEPA, 1997). The values were developed taking into consideration both human health and effects on the environment. Contaminant transport to plants is assessed by the bioconcentration factor (BCF - defined as the ratio of trace element concentration in plant to that in soil). Exposure pathways that have been considered for human health effects include direct intake of contaminated soil, dermal contact with contaminated soil or dust, inhalation of dust at the site, inhalation of vapors, intake of drinking water for land-use with groundwater extraction, intake of vegetables grown on the contaminated site and intake of fish from nearby surface water. The Swedish guideline values were developed using methodologies and data from Netherlands, USA and Canada and approach is similar to that of UK. This means that bioaccessibility to humans was considered in developing generic guideline values, but is not used in later stages of the management of contaminated sites or determining residual risks after *in situ* soil remediation.

6.3.2 BIOAVAILABILITY/BIOACCESSIBILITY

The main question however remains: what is the bioavailability and how to measure it? The definition of bioavailability is still ambiguous and is a common subject of discussions between the professionals of various disciplines. There are over 20 different definitions found in literature including those of, absolute bioavailability, relative bioavailability, bioaccessibility, bioavailable fraction, etc (US NRC, 2002). For example, environmental scientists define bioavailability as the accessibility of a chemical for assimilation and possible toxicity. Mammalian toxicologists refer to bioavailability as the capability of a substance for crossing a cell membrane and entering a cell (Alexander, 2000), while in pharmacology and toxicology it is the availability of xenobiotic after intravenous or oral dosing (Klaassen, 1986).

A group of scientists (e.g. Ehlers and Luthy, 2003; Semple et al., 2004) have suggested to consider bioavailability as a process, similarly to what was earlier described by the US National Research Council (US NRC, 2002): **"**Bioavailability processes are defined as the individual physical, chemical, and biological interactions that determine the exposure of plants and animals to chemicals associated with soils and sediments" (US NRC, 2002) (Fig. 4).

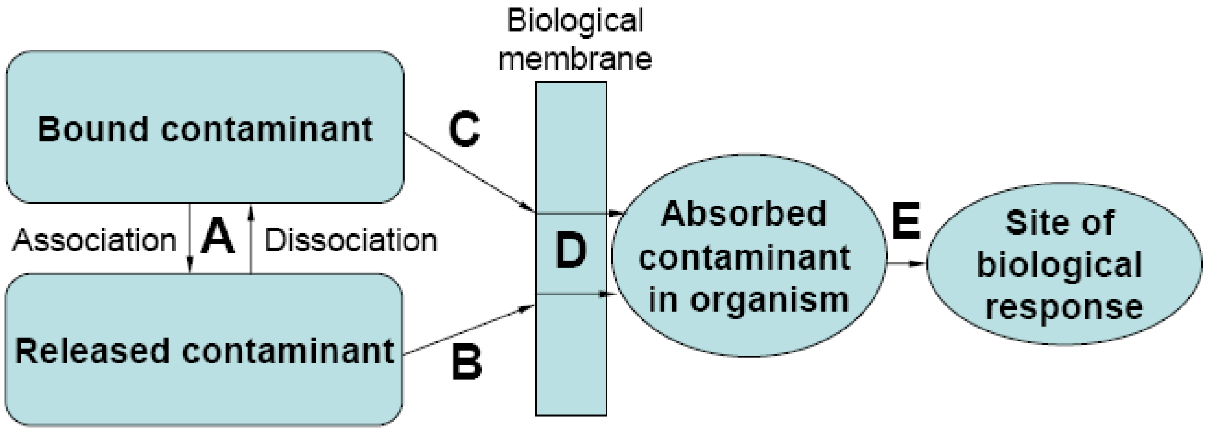

Figure 4. *Bioavailability processes in soil including A – release of a solid-bound contaminant and B - consequent transport; C – transport of a solid-bound contaminants; D – uptake across a physiological membrane; E – incorporation into a living system. A, B, and C can occur internal to an organism such as in the lumen of the gut (US NRC, 2002).*

According to this scheme, bioavailability process describes trace element interaction with the biological world through a number of steps. The interaction is dynamic and can change in time and space. Soils can affect exposure in various ways through, for example, regulating TE binding and release ("A"). Weathering and acidification, redox reactions, complexation, biochemical processes, amount of sorptive sites (e.g. clays, organic matter, metal oxides), etc. can increase or decrease TE solubility and hence uptake into living organisms ("B"), although soil-bound trace elements can directly be taken up ("C") e.g. through an oral pathway. "D" describes trace element movement from the external environment through a biological membrane into a living organism (whether these are plant roots or gut membranes of animals and humans). The biological membrane itself can interact with trace elements and modify their uptake. Hence, each step in the bioavailability process can be considered as a barrier that can affect exposure.

For the bioavailability process to be used in risk assessment it should be quantifiable. There are no simple analytical methods to quantify the bioavailability that could provide results extrapolative to all living organisms and scenarios. It therefore requires the use of multiple tools. Two general approaches are used to determine TE bioavailability: 1) by chemical methods for assessing the potential bioavailability outside a cell and 2) bioassays for determining bioavailability inside a cell.

To make a distinction between the bioavailability inside a cell and that assessed by chemical methods, the term *bioaccessibility* (also referred to as potential bioavailability) is applied in the latter case.

6.3.2.1 Bioaccessibility (potential bioavailability outside cell)

In this approach, assuming that an element bioavailability is correlative to its solubility and consequent mobility, various leaching tests and chemical extractions are being used to predict risks related to the contaminant behaviour under specific environmental conditions.

The simplest method to estimate the dissolved (hence potentially bioavailable) TE concentration in soil is by extraction of soil solution or soil pore water (i.e. water filling the pores or spaces between soil particles) and analysis using spectrometric techniques. Leaching tests are also relatively simple methods, due to significant simplifications of the leaching process. Leachants tend to dilute the soil solution and may change its chemistry depending on the applied liquid to solid ratio (L/S). However, leaching tests are often used in environmental studies, especially on excavated contaminated soil. Dug out contaminated soil is considered as waste, therefore waste characterisation procedures, including leaching tests, are widely applied. In such cases, the dissolution of constituents in soil upon contact with water is regarded as a main mechanism of a substance release which causes a potential risk to the environment (EN 12457/1-4).

An overview of soil extraction methods used to assess potentially bioavailable fraction of TE in soil are summarised by Peijnenburg et al. (2007). Authors distinguish seven groups of commonly used extractants:

- weak extractions (water, aqueous salt solutions);
- reductive extractants (e.g. NH_2OH HCl, sodium ascorbate);
- weak acids (diluted organic acids, e.g. citric or acetic acids);
- strong complexing agents (e.g. EDTA, DTPA);
- combination of salt-acid extractants;
- diluted strong acids (inorganic acids, such as HNO_3, HCl, etc.);
- concentrated strong acids (inorganic acids and their combinations).

Extractions can be done in one step (single extractions) or in several steps consecutively increasing the strength of the extractant (sequential extractions). The latter methods are usually used to differentiate TE fractions present in soil rather than to predict TE bioavailability. Several references describing of the use of single solvents for assessing the bioavailable fractions of TE in soil are listed in Table 10.

Table 10. *Extractants used for assessing bioavailable fractions of TE in contaminated and remediated soils.*

Extractant	Concentration (Mole)	References
H_2O		McBride et al. (1997)
$MgNO_3$	10^{-2}	Ganai et al. (1982)
$CaCl_2$	10^{-2}	Brümmer et al. (1986)
NH_4NO_3	1	Prueβ (1998)
NH_4Cl	1	Krishanmurti et al. (1995)
DTPA	10^{-2}	Lindsay and Norwell (1978)
EDTA	$2 \cdot 10^{-2}$	Prueβ (1992)
LMWOA*	10^{-2}	Krishanmurti et al. (1997)

*LMWOA - low molecular weight organic acids and amino acids, such as acetic, citric, oxalic, malic, glutamic acid.

Among single step and sequential extraction procedures, two methods have been standardized: the protocol for the quantification of the soluble and exchangeable TE fraction using NH_4NO_3 (DIN 19730, 1995; Prueß, 1998) and a four-step sequential extraction set up by the BCR (Community Bureau of Reference of the European Commission, now called Standards, Measuring and Testing Programme). The DIN 19730 protocol, based on the work by Symeonides and McRae (1977), consists of an end-over-end extraction of 20 g of air-dried soil in 50 ml of 1 M NH_4NO_3 for 2 h at room temperature shaking at 20 rpm in 100 ml polyethene bottles. This protocol is used in Germany to derive background, action and threshold values for mobile trace elements in soils. For example, based on this protocol, Germany has set the 'action value' for NH_4NO_3 -extractable Cd at 40 (ng g^{-1}), which is the critical element concentration for edible plants not exceeding the 95% of the cases. Adoption of this protocol by other EU countries has been proposed (Anderson et al., 1994).

The BCR was established to standardize sequential extraction schemes (Ure et al,. 1993), allow the fractionation of trace elements into operationally defined soluble/exchangeable, reducible, oxidisable and residual phases, to evaluate the TE release scenarios from soils. The original BCR procedure has been modified including changes of the reagents concentration and pH (e.g. Sahuquillo et al., 1999; Renella et al., 2004; Larner et al., 2006) to improve the selectivity of the dissolution steps and the precision between laboratories. The aqua regia digestion step of the final solid residue provided information on the quality of the data through the comparison of the sum of the four protocol steps and an independent aqua regia analysis on a second portion of sample (Rauret et al., 1999).

Pore water, also called soil solution, is soil water that is present between soil particles and is held there by the capillary forces. Ideally, concentration of TE in pore water is in equilibrium with that sorbed to soil particles. Pore water is much more concentrated than leachate in respect to TE and it is assumed that trace elements found in pore water are directly available for uptake by soil organisms and plant roots.

Soil pore water can be extracted by centrifugation (*ex situ*) or using soil moisture samplers (*in situ*), Figure 2. In the former case, the method is suitable only when very low volumes of soil solution are needed. In the latter case, porous tubes that simulate plant roots are inserted into soil and soil solution is extracted by connecting to a vacuumed flasks. In such case, samples can be collected repeatedly from the same point without disturbing soil. Most scientists prefer using soil moisture samplers for the collection of pore water due to the simplicity of the method.

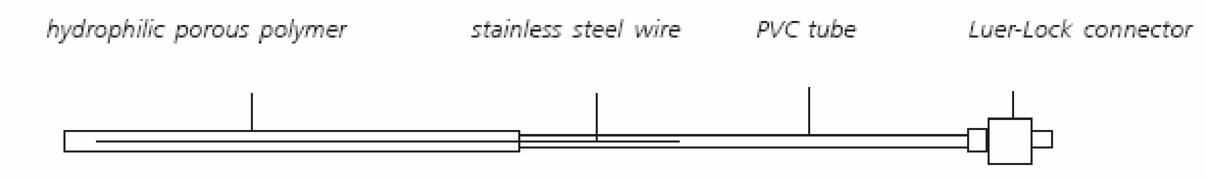

Figure 5*. Example of a soil moister sampler (Rhizon SMS) produced by* Eijkelkamp, the Netherlands.

Trace element speciation and hence bioavailability can change during leaching or extraction as affected by e.g. temperature, pH, used chemicals, etc. Therefore in situ passive sampling was suggested as a method that can bypass the named limitations. Diffusive gradients in thin films (DGT) is a devise that has been developed for in-situ sampling of dissolved trace element ions in water, sediments and soil. The DGT-technique is based on diffusion of dissolved TE ions through a diffusive layer of hydrogel and accumulation in a resin layer. DGT devices are placed in soil for a given period of time during which TE ions from soil solution accumulate in the resin layer. Then the mass of accumulated TE is measured. Dissolved TE ions diffusing through the gel are considered to be bioavailable.

DGT technique is promising for estimation of TE bioavailability to plants (phytoavailability), but is not suitable for predicting bioavailability to earth dwelling organisms, mammals or humans that have oral intake pathway, i.e. when soil-bound contaminants are ingested.

TE bioaccessibility to humans: In the risk assessment procedure, oral bioavailability of the contaminant in the soil is set equal to the oral bioavailability of the contaminant in the matrix used in toxicity studies (Kelley et al., 2002; Paustenbach, 2000). Concerning human, the orally bioavailable fraction of soil-borne contaminants is the resultant of the three steps: i) bioaccessibility, ii) transport across the gastric and intestinal epithelia and iii) the first pass effect (Oomen et al., 2006). Concerning some metals, such as lead (Pb), no metabolism is anticipated to occur.

For human health risk assessment, absolute bioavailability is generally defined as the fraction of the pollutant which is absorbed in the organism and defined as the following ratio (Kelley et al., 2002; Paustenbach, 2000):

$$AB = \frac{absorbed\ dose}{ingested\ dose}$$

In most of risk assessment models human health is considered as the highest priority. However, the absolute bioavailability cannot be determined for humans by experiments, therefore the bioaccessibility, which is defined as a fraction of pollutant extracted by digestive fluids, is used instead. A conceptual scheme in Figure 6 illustrates the link between bioavailability and bioaccessibility.

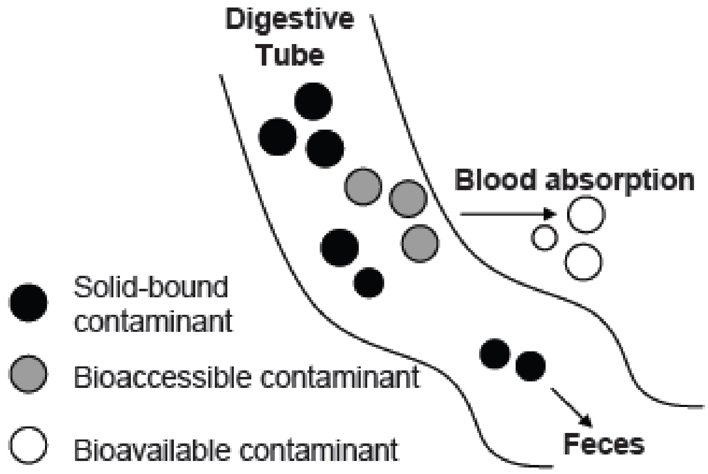

Figure 6. *A conceptual scheme of the link between bioavailability and bioaccessibility.*

Bioaccessibility assessment to humans can be useful, for example, when contaminant concentrations slightly exceed the guideline values and the site has low priority for remediation actions, but soil is exposed to humans and actual risk for human health should be evaluated. The method can also be used to assess residual risks when conventional remediation techniques are not technically, economically or environmentally feasible and alternative methods are considered for *in situ* soil remediation (e.g. immobilisation).

In the case of assessment of TE bioaccessibility to humans, numerous tests are available in the literature. An overview of these tests is given in Table 11. Main differences in these tests are:

- the number of simulated digestive compartment (mouth, stomach, intestine);
- the addition of food surrogates (i.e. powdered milk, wheat flour)
- the pH of each compartment;
- the L/S ratio;
- the residence time.

In addition, these tests were applied for a limited number of chemical elements: Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn.

Table 11. *Overview of the different methods available in the literature to estimate the bioaccessibility a soil pollutant to humans.*

Method	Type of extraction procedure	Simulated digestive compartment	pH	T, °C	L/S ratio*	Residence time	Tested elements
PBET	Batch	Stomach Small intestine	2.5 7	37 37	100/1 100/1	1 h 4 h	As, Pb
SBET	Batch	Stomach	1.5	37	100/1	1 h	As, Cd, Pb
IVG	Batch	Stomach Small intestine	1.8 5.5	37 37	150/1 150/1	1 h 1 h	As
US P	Batch	Stomach	1	37	1000/1	2 h	Pb, Cr, As, Cd, Ni
MB & SR	Batch	Mouth Stomach Small intestine	6.4 2 7.5	37 37 37	160/1 2160/1 4770/1	5 s 2 h 4 h	Pb, Cr, As, Cd
DIN	Batch	Mouth Stomach Small intestine	6.4 2 7.5	37 37 37	15/1 50/1 100/1	0.5 h 2 h 6 h	As, Cd, Pb, Cr, Hg
SHIME	Batch	Stomach Small intestine	5.2 6.5	37 37	2.5/1 4/1	3 h 5 h	As, Cd, Pb
RIVM	Batch	Mouth Stomach Small intestine	6.5 1.5 5.5	37 37 37	15/1 37.5/1 97.5/1	5 min 2 h 2 h	As, Cd, Pb
TIM	Dynamic	Mouth Stomach Small intestine	5 2 7	37 37 37	5/1 30/1 51/1	5 min 1.5 h 6 h	As, Cd, Pb
AOAC	Batch	Stomach	1.12	37	150/1	16 h	Cu, Zn, Mn, Fe, Al

*L/S - liquid-to-solid ratio (L kg^{-1}) used in the extractions.

6.3.2.2 Bioavailability inside cell (toxicity, in vivo tests)

Chemical extractions enable differentiating between various soil constituents and quantifying the content of individual TE in soil. But impact of contaminated soil on living organisms is complex and difficult to predict by only knowing concentrations of extracted TE. Soil properties, such as pH, salinity, amount of dissolved organic matter, lack of nutrients, can amplify or damper toxic effects of TE on organisms. Therefore biological tests are often used as a direct measure of soil toxicity.

Ecotoxicological testing of environmental samples can be 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) (Wadhia and Thompson, 2007). For testing contaminated soils, three main groups of tests are available: 1) microbial tests (including cellular biosensors); 2) plant tests; and 3) invertebrate tests. In vivo tests to measure bioavailability using mammals are also performed. For example, juvenile swine might be used as a model for young children. The biological response is determined from the area under the blood TE concentration-time curve, metal concentration in targets organs. The response is determined as a function of an orally administered soluble metal salt. In the USA this relative bioavailability is used in the risk assessment. However, these testing methods are considered as very costly and ethically problematic.

a) Microbial tests:

In the management of contaminated sites, microbial tests are usually used for toxicity screening of a large number of samples (in situ or ex situ) to identify the areas of the highest risk within a contaminated site. Most of the toxicity screening tests are based on the observations of the luminescent light emitted by the marine bacteria *Vibrio fischeri* isolated from the flashlight fish. The light intensity usually decreases with the increasing toxicity of a sample as bioluminescence is reduced in case of membrane damage, presence of uncouplers or direct enzyme inhibition. Application of bioluminescent bacteria for the toxicity measurements in environmental samples has been studied for several decades. Hundreds of publications are available on the technique and its application results with several commercial test systems using Vibrio fischeri, Escherichia coli, Bacillus spp. available (Microtox, BioTox, LumiStox, ToxAlert, MetPAD, MetPLATE, etc.). Toxicity screening tests are used to gain quick information on the total toxicity of samples and as supplements to other bioassays and chemical tests. A summary of the commercially available microbiotests, where the toxic effects of TE are measured by determination of population growth, is given in Table 12.

Table 1. *Commercially available bacterial microbiotests (modified after Wadhia and Thompson, 2007)*

Test organism /Assay	Test criterion/measurement	Exposure
Vibrio fischeri		
Microtox	Enzymatic activity	5–30 min
Microtox Solid Phase	Bioluminescence	
BioTox	Bioluminescence	15-30 min
Flash test (kinetic test)	Bioluminescence	
Escherichia coli	β-galactosidase activity/colorometric	60 min
Toxi-chromotest		
Sediment chromotest		
Escherichia coli	β-galactosidase activity/colorometric	2 h
MetPAD		
MetPLATE		
SOS-chromotest		
SOS lux test		
Bacillus spp.	Dehydrogenase activity/colorimetric	24 h
ECHA biomonitor		

Bioluminescent bacteria *V. fischeri* is also employed in field screening-test Rapid On-site Toxicity Audit System (ROTAS), produced by Cybersense Biosystems. According to the producer’s information, the system based on a portable luminometer has been extensively trialled across Europe on over 700 soil samples from over 30 different sites. The system showed >80% correlation between chemical contamination and toxic response of samples detected by the ROTAS assay.

Bioluminescent fungi such as *Armillaria mellea* and *Mycena citricolour* or yeasts can be used to estimate the general inhibitory effects of TE to microeucaryotes (Weitz et al., 2002).

Whole cell biosensors: Interactions between microorganisms and specific substances in the soil still remain in many cases unknown. An important progress for the study of this type of interactions has come from the use of the gene reporter biotechnology, through the creation of cellular biosensors. A reporter gene is a gene whose activity (e.g. induction, repression) responds to specific chemical and physical stimuli; it can be present either naturally in a microorganism or can be inserted in a specific region of the microbial genome. In the today's common meaning, a reporter gene is defined as a gene whose phenotypical expression can be measured simply and quickly and ‘reports’ on the genetic and metabolic activity of the host cell. A whole cell biosensor is therefore a natural or genetically modified microorganism capable of signalling the activation of a metabolic pathway, in response to the bioavailability of a given analyte. The signals produced by reporter microrganisms should be interpreted in terms of flows of analytes able to induce and to support a metabolic response, rather than in terms of single events of overcoming of the biological membranes (Semple et al., 2004).

The used reporter genes traditionally used in microbiology and biochemistry such as *lac*Z (coding for the β-galactosidase), *xyl*E (catechol 2,3-dioxygenase), *tfd*A (coding for the 2,4 - dichlorofenoxyacetate oxidase), are not useful to study the metabolic activity of the microorganisms in soil because their product cannot be easy targeted against the abundant background of such enzymes in soil. Therefore, the most useful whole cell biosensors are based on the expression of the *lux* gene of the bacterial luciferase that produce bioluminescence, and those based on the *gfp* and *Ina*Z coding for the green fluorescent protein (GFP) and ice nucleation protein, respectively, which are also persistent products after the end of the induction.

Natural whole cell biosensors. The first environmental tests employing microbial biosensors were based on the responses of the naturally luminescent bacteria such as *P*. *phosphoreum* and *V*. *fischeri* as the cellular biosensor, devised from Isenberg (Bulich and Isenberg, 1981). Since then, commercially available systems such as the MicroTox® based on the bioluminescence of *P*. *phosphoreum* (Hermens et al., 1985), and the BioTox® based on the bioluminescence of *V*. *fischeri* (Lappalainen et al., 1999) have been developed and early applied for the analysis of water bodies (Bulich and Isenberg 1981), sediments (Brouwer et al., 1990), wastes (Symons and Sims, 1988), toxicity of the soil pore water (Dutka et al., 1991) and for the evaluation of the effectiveness of the soil decontamination (Wang et al 1990). A test for the assessment of toxicity towards the eucariotic organisms has been set up measuring the natural bioluminescence of two microscopic fungi *Armillaria mellea* and *Nycena citricolour* (Weitz et al., 2002).

Natural biosensors provide information on the general toxicity of a soil because the luciferase activity depends on the integrity of the cellular metabolism, and is reduced from any toxic effect. Although the TE or organic compound toxicity may vary in different organisms, from the comparison of more than 1200 chemical substances it was found that median effective concentration (EC_{50}) of such substances were comparable for procariotics, eucariotics and humans (Quershi et al., 1998).

Constructed biosensors. G. Sayler was the first to devise a *P*. *fluorescens* (HK44) strain inserted with the *lux* gene so as to become luminescent in presence of naphtalene (King et al., 1990). Analogously, Burlage et al. (1990) modified the *P*. *putida* strain RB1353 in which the *lux*CDABE gene was fused with the *nah* operone of the plasmide NAH7, under the control of a salycilate induced promoter. These two papers demonstrated that a regulatory genetic circuit of a microorganism could be artificially fused with a promoterless gene so that the transcription of the regolator, as a result of its interaction with a specific chemical compound. Therefore, the expression of a reporter gene that it could be measured, calibrated and interpreted through its well defined signal (bioluminescence). Since then, a large number of cellular biosensors has been constructed following the above mentioned scheme, following two main strategies: *i*) the reporter *lux*, *gfp* and *ina*Z systems have been inserted under the control of a constitutive promoter, and therefore an effect on the genetic activity is indicated generally from the reduction of the signal, or *ii*) the reporter systems reporter are under the control of inducible promoters, therefore an effect on the genetic activity is indicated from the increase of the signals. Examples of whole-cell biosensors constructed for monitoring TE bioavailability:

- Bioavailable Hg: has been set up by inserting the *lux*CDABE gene under control of the promotor Pmer (Selifonova et al., 1993), or regulator protein *mer*R (Hansen and Sørensen, 2000).
- Bioavailable As: has been set up by Ramanathan et al. (1997) inserting the *lux*AB in the regulator arsR gene in the plasmidial ars operone transformed in E. coli. The authors reported no interferences by PO_4^{3-}, SO_4^{2-} o NO_3^{-}.

- Bioavailable Cr: has been set up by inserting the *lux* gene under control of gene the *chr*BA¢, through the plasmid pEBZ141 (Corbisier et al., 1999).
- Bioavailability of different cationic trace elements (e. g. Cd, Zn, Cu, Pb) have been set up inserting reporter systems in chromosomal or plasmidial genetic sequences coding for the P-type.

Applications to soil and rhizosphere studies. The first cellular biosensors for the determination of the TE bioavailability in soil were *lux* constructs based on *E*. *coli* HB101 pUCD607, *P*. *fluorescens* 10586rs *R*. *leguminosarum* bv *trifolii* in which bioluminescence was constitutively expressed (Paton et al., 1995; 1997). Inducible cellular biosensors from specific heavy metals have been constructed inserting the *lux*, *gfp* or *ina*Z reporter systems are under the control of promoter/operator sequences coding for the mechanisms of TE resistance in the in the microbial chromosomes or plasmids, in which the repressor acts from selective bioreceptor that identifies the TE and lead to the gene reporter expression, with the production of the signal. As an example, of the operone the knowledge of the regulation of the *mer* operon present in plasmids, transposons or chromosomes, coding for enzymes of the metabolic ways that reduce Hg^{2+}, allowed to insert the *lux*CDABE gene in the Pmer promoter (Selifonova et al., 1993), or in the regolator protein *mer*R (Hansen and Sørensen, 2000). Ramanathan et al. (1998) inserted the regolarotor gene *ars*R with the gene *lux*AB in the plasmidial operon *ars* transformed in *E*. *coli* which responds to the As bioavailability without interference from structurally similar anions which PO_4^{3-}, SO_4^{2-} or NO_3^-. A biosensor for detecting bioavailable Cr was constructed by Corbisier et al. (1999), by a fusion between the gene *chr*BA¢, responsible for the resistance to Cr and *lux*CDABE in *R*. *eutropha* CH34. Biosensors responding to bioavailability TE in cationic form such as Cd, Cu, Ni, Pb, Zn have been constructed inserting reporter systems in genetic sequences present in chromosomes or plasmids responsible for the TE resistance in various microorganisms. Biosensors based on and *E*. *coli* strains in which the *lux* gene has been fused with the promoter of the genes conferring multiple TE resistance through the synthesis of P-type ATPases have been constructed by Corbisier et al. (1993), or by transcriptional fusion of the *lux*CDABE gene with the regolator gnes of *cop*, *pbr*, *czc* operons present in the plasmid and the megaplasmids of *R*. *eutropha*, induced specifically by Cu, Pb or Cd, respectively (Corbisier et al., 1999).

Whole cell biosensors that are able to detect organic pollutant might be used in mixed TE-organic polluted soils.

Perspectives of the research on the cellular biosensors. The improvement of the knowledge of the genes been involved in the microbial metabolism along with the improvement of the techniques of genetic engineering will concur to construct new stable genic fusions and cellular biosensors, capable of responding in a more sensitive and selective way. As an example, the specificity of the response mechanisms can be improved by means of the new design of receptor protein (Looger et al., 2003). The possibility to create cellular biosensors that react by means of periplasmic receptor proteins, constructed by means of the fusion of proteins with fluorophores (Deuschle et al., 2005) is still in its infancy, but they could provide information on the ability of the microorganisms to act as ligands in the soil environment, and therefore to not necessarily signal the presence of determined analites as a result of their assimilation. The approach of Okumoto et al. (2005) to study the excitement mechanisms responsible for the neuronal transmission could be used for monitoring the *in vivo* assimilation of nitrogen forms by microorganisms. In this approach, the concentration of glutamate inside and to the surface of the cells was indicated from specific fluorescent proteins (GLU/ASP binding protein *ybe*J) fused with two variants of GFP. These biosensors respond to the presence of extracellular glutamate. Moreover, the description of the genes responsible for the synthesis of the periplasmic transport proteins ABC that are involved in the assimilation of large organic molecules from the external membrane towards the cytoplasm of soil microorganisms (Momma et al., 2005) might lead to the construction of cellular biosensors to study the dynamics of polisacharides, peptides, of siderophores and other organic macromolecules in soil and rhizosphere. Many studies of topological localization of bioavailable specific compounds have been carried out on biofilms (Møller et al., 1998) and epiphitic bacteria (Leveau and Lindow, 2001), seldom on soil microorganisms. A suitable approach may be the use of the whole cell bionsensors coupled to the soil thin sections, in which the structure and the characteristics of microbial microhabitat can be preserved. Such studies may provide both the visualization of the microbial physical habitat and define the metabolic reactions that occur through the use of *gfp* or *ina* based whole cell biosensors.

Notwithstanding the remarkable progresses in the construction of genic fusions and new cellular biosensors, the application of this biotechnology for the study of the biochemical processes in soil and rhizosphere are still the most problematic. A problem in the use of cellular biosensors for the risk analysis for the TECS and for soils polluted by organic compounds is the absence of method standardization. Generally, reporter bacteria need a reconstitution medium (Table 13), which may affect the soil constituents and therefore alter the bioavailability of the analites.

Table 13. Reconstitution media needed for reporter bacteria used in cellular biosensor tests.

Whole cell biosensor	Reconstitution medium
E. coli HB101 (pUCD607)	0.1 M KCl
P. fluorescens DF5740E7, DF57-N3, DF57-11D1	Liquid Luria-Bertani medium, 0.9% NaCl
P. fluorescens HK44 (pUTK21)	Yeast–peptone–glucose extract, 1 M KCl
V. fischeri (BioTox® test)	2.0% NaCl
R. metallidurans (BIOMET®)	Glucuronic acid
P. aureofaciens PGS12	Minimal Ayer culture medium + 25 mM HEPES
N. europea (ATCC 25978)	NH_4^+-N
A. tumefaciens C58 GMI 9023	Minimal salt colture media

b) Plant Tests:

Various plants can be used to assess phytotoxicity of contaminated soil (*Sorghum* spp., *Lepidium sativum*, *Cucumis sativus*) through the evaluation of two endpoints:

- seed germination, and
- root elongation.

Several standards are available for phytotoxicity assessment, such as ISO (11269-2) and OECD (208). ASTM (E1598) standard practice for conducting early seedling growth tests was withdrawn 2003 without replacement. The tests can take up to 28 days to implement, but are relatively simple and usually do not require advanced analytical instrumentation.

The toxicity of soil aqueous extracts and soil pore water can also be tested by observing survival of freshwater micro-algae *Pseudokirchneriella subcapitata* (ISO, 2004). It is a chronic toxicity test taking 4 days and used to evaluate the algal reproduction rate.

c) Invertebrate tests:

Survival and reproduction of soil dwelling invertebrates are often used in soil ecotoxicology to measure acute and chronic toxicity of soil. Standardized tests have been developed using earthworms (ISO, 1998a; ISO, 1998b, ISO/CD, 2003, ASTM E1676; OECD, 1984), potworms (*Enchytraeus crypticus*) (ISO, 2004; ASTM E1676) and springtail *(Folsomia candida*) (ISO, 1999). Earthworm species included in the standards are *Eisenia fetida* and *Eisenia Andrei.* Earthworms of *Lumbricus* species are also used for research purposes. Aquatic invertebrates *Daphnia magna* (EN ISO, 1999) and *Paramecium caudatum* can be used for toxicity testing of soil leachate or soil solution. *D. magna* is particularly sensitive to TE.

6.3.2.3 Links between TE availability, speciation and biochemical activities in soils

In the case of human health risk assessment, more research is needed to clearly elucidate the link between bioaccessibility/bioavailability and speciation. For lead, USEPA gives the following range of bioavailability regarding the association between the lead and its mineralogical association in soils (Table 14).

Table 14. *Bioavailability of Pb to humans regarding the association between the Pb and its mineralogy in soils (USEPA, 1999).*

Potentially lower bioavailability < 25 %	**Intermediate bioavailability 25 to 75%**	**Higher bioavailability >75%**
Galena	Pb Oxide	Cerrussite
Anglesite	PbFe Oxides	PbMn
Pb(O)Oxides	Pb Phosphates	Oxides
PbFe	Slags	
Sulfates		
Native Pb		

However Table 14 was set up for pure minerals. Denys et al. (2007) has performed research on mining waste. The authors confirmed that most of lead bioaccessibility was controlled by cerrusite in carbonated materials, but bioaccessibility of lead associated to sulfur-containing minerals was also shown to be significant.

Concerning elements having different toxic effects according to their redox state, an important topic is the possible evolution of the speciation of the element along the digestive tract due to particular pH (in the stomach) and redox (in the intestine) conditions in the different compartments. For antimony (Sb), which has different toxicity levels according to its speciation, Denys et al. (2006) demonstrated using voltametry methods that Sb(V), the major form of Sb in soils was not subject to reduction from the soil to the digestive tract. In this case, it is then accurate to establish a link between Sb speciation in soils and its bioavailabilty to humans. When comparing the results from in-vitro and in-vivo determinations of Pb bioavailability in soils, Marschner et al. (2006) speculate that the solubility and uptake of Pb-compounds in the alkaline intestine may largely be controlled by low redox potentials.

6.3.3 CORRELATION BETWEEN BIOLOGICAL AND CHEMICAL TESTS

Chemical tests are often compared with bioassays by making correlation or regression analyses between TE fraction extracted from soil by chemicals and those found in living organisms (usually in plants, hence called phytoavailability, Table 6). By this, an attempt is made to predict bioavailable TE fraction is soil using physicochemical methods, although true bioavailability can be assessed only using living organisms. Chemical tests are somewhat simpler to perform and usually provide less variable results than biological tests. Therefore it is desirable to find a chemical solution that would extract only the amount of TE that is bioavailable, i.e. a fraction that poses the highest risk for living organisms and environment.

Total TE concentration in soil, extracted using strong acids, usually is acknowledged as a pore predictor of TE bioavailability (relatively low correlation/regression coefficients, Table 15). While 0.01 M $CaCl_2$ extractable TE fraction is often suggested as the best predictor of TE concentration that is available for plant uptake (e.g. Houba et al., 1996; Peijnenburg et al., 2000; Koster et al., 2005). However, other studies show that DTPA (Moreno et al., 2006) or TE extracted using DGT (Zhang et al., 2001) can also be good predictors of potentially available TE concentrations to plants and microorganisms. Generally, correlation between extracted TE from soil and those measured in plants are different for different species, soils, plant parts (shoots vs roots) and also depends on a number of other factors (e.g. soil moisture, pH, salinity).

Responses of whole cell biosensors are seldom compared with chemical extractions methods. The toxicity of the solution of Cd, Zn or Cu contaminated soil has been tested using cellular biosensors by Chaudri et al. (1999), Vulkan et al. (2000), Tiensing et al. (2001), Dawson et al. (2006). Renella et al (2004) compared the H_2O soluble and 1M NH_4NO_3 exchangeable fraction of long term Cd contaminated soils with the responses of the BIOMET cellular biosensor based on *R. eutropha*; the result showed that while the amounts of Cd extracted with H_2O or NH_4NO_3 gradually increased upon soil contamination degree, the BIOMET biosensor signaled Cd bioavailability only in the most polluted soils. However, the data of the BIOMET were in agreement with the indicators of microbial stress and toxicity symptoms observed in the plants, confirming that the responses of the whole cell biosensors may reflect the TE bioavailability in soil rather than specific chemical pools of TE in soil.

Tibarzawa et al. (2001) reported the reduction of bioavailable Ni in soils stabilized with zerovalent Fe and beringite using a *lux*-inserted *R. eutropha* responding specifically to Ni and Co, and that the lower bioavailability correlated with lower Ni absorption by maize and potato crops. Lombi et al. (2002) reported that red mud, beringite and lime could reduce the bioavailability of Cd, Cu, Ni, Pb and Zn in the soil pore water, as detected by *lux*-inserted *Escherichia coli* (HB101 pUCD607) and *Pseudomonas fluorescens* (10586rs pUCD607) strains; the responses of these two biosensors were in agreement with those of the soil microbial communities and to the lower phytotoxicity of the treated soils. Geebelen et al. (2003) showed that the BIOMET biosensor responses to Pb in contaminated soils was related to the water soluble and exchageable fractions and that soil amendment with cyclonic ash, zerovalent iron (steel shots) or phosphate rock had variable effects on the Pb bioavailability, depending on the sources of contamination and efficiency of cyclonic ash and lime in reducing BIOMET Pb bioavailability and phytotoxicity.

Table 15. *Summary of chemical tests used to estimate phytoavailable TE concentration in soil.*

Chemical	Concen-tration	Tested TE	Tested plant	Compart-ment	Correlation/ regression coefficient	Ref.
Aqua regia		Cu, Zn	*Sylene vulgaris,Lolium perenne*	shoot	0.35-0.77	1, 2, 4
			Lactuca sativa, Zea mays,			
			Elsholtzia splendens			
		Cu	*Sylene vulgaris, Zea mays,*	root	0.74-0.84	1, 4
			Elsholtzia splendens			
HNO_3-$HClO_4$-HF	Conc.	Cd, Pb, Zn, Cu	*Triticum aestivum*	grains	-0.04-0.72	8
HNO_3	Conc.	Cu, Cd, Zn	*Lactuca sativa, Lolium perenne*	shoot, leaves, hypocotyl s	-0.07- 0.76	3, 5
			Raphanus sativa			
HNO_3	0.43 M	Zn spiked	*Lolium perenne, Lactuca sativa*	shoot	0.199-0.341	2
EDTA	0.05 M (pH 7.0); 0.01 M	Cu	*Sylene vulgaris, Zea mays,*	shoot	0.24-0.78	1, 6, 4
			Lepidium heterophyllum Benth,.			
			Elsholtzia splendens			
		Cu	*Sylene vulgaris, Zea mays,*	root	0.75-0.90	1, 4
			Elsholtzia splendens			
DTPA	0.005 M	Cu, Cd	*Zea mays, Lolium perenne*	shoot	0.26-0.99	4, 7
		Cu	*Zea mays*	root	0.93	4

NH_4OAc	1 M	Cu	*Zea mays*	shoot	0.32	4
		Cu	*Zea mays*	root	0.89	4
NH_4NO_3	1 M	Cu	*Sylene vulgaris,* *Elsholtzia splendens*	shoot	0.79-0.86	1
		Cu	*Sylene vulgaris,* *Elsholtzia splendens*	root	0.92-0.93	1
$CaCl_2$	0.01 M	Zn spiked	*Lolium perenne, Lactuca sativa*	shoot	0.31-0. 98	2
		Zn, Cu, Cd,	*Lupinus nanus, Zea mays,* *Lactuca sativa*	shoot	0.71-0.81	2, 4, 5
		Cu	*Zea mays*	root	0.44	4
Soil solution (pore water)	100% WHC (1 week)	Cu, Zn, Cd	*Sylene vulgaris* *Elsholtzia splendens* *Lupinus nanus, Lactuca sativa* *Lepidium heterophyllum Benth.*	shoot	0.63- 0.85	1, 2, 5, 6
		Cu	*Sylene vulgaris* *Elsholtzia splendens*	root	0.90- 0.92	1
		Zn spiked	*Lolium perenne, Lactuca sativa,* *Lupinus nanus*	shoot	0.42-0.93	2
Free element (activity)	selective electrode (Cu-ISE, ORION94-29)	Cu	*Sylene vulgaris,* *Elsholtzia splendens,* *Lactuca sativa, Lolium perenne,* *Lepidium heterophyllum Benth.,* *Raphanus sativa*	shoot, leaves, hypocotyls	0.67-0.853	1, 3, 6
		Cu	*Sylene vulgaris,* *Elsholtzia splendens*	root	0.77-0.80	1
	Calculated	Cd, Zn	*Lactuca sativa*	shoot	0.56-0.78	5
Effective concentr., C_E	DGT 100% WHC	Cu	*Sylene vulgaris,* *Lepidium heterophyllum Benth.,* *Elsholtzia splendens*	shoot	0.78-0.95	1, 6

	Cu	*Sylene vulgaris,*	root	0.92-0.93	1
		Elsholtzia splendens			
DGT 70% WHC	Zn spiked	*Lolium perenne, Lactuca sativa*	shoot	0.525-0.90	2
		Lupinus nanus			
	Zn	*Lupinus nanus*	shoot	0.399	2

1. Song et al., 2004; 2. Koster et al., 2005; 3. Sauvé et al., 1996; 4. Brun et al., 2001; 5. Peijnenburg et al., 2000; 6. Zhang et al., 2001; 7. Moreno et al., 2006; 8. Nan et al., 2002.

6.3.4 SELECTION OF BIOASSAYS

Two methods can be applied for selecting bioassays in order to establish a test battery:

- an “a priori” method, in which the selection is made, independently of the results, according to decision criteria such as standardization of the method, ecological relevance of test organisms, or cost (Keddy et al., 1995; Van Gestel et al., 1997),
- an “a posteriori” method, in which the selection is made after analyzing test results obtained on a large series of bioassays (Rojickova-Padrtova et al., 1998; Clément et al., 1996).

Most of the publications on the selection of test batteries are based on the latter strategy. However, the use of multivariate data analyses (MVDA) remains underexploited (Clément et al., 1996; Manusadzianas et al., 2003, Ren and Frymier, 2003). MVDA provides graphical information on the characteristics of the complex toxicity data and enables interpretation of complex and extensive systems (Devillers and Karcher, 1991).

6.3.4.1 Battery of bioassays

An experimental test strategy was developed in France to assess ecotoxicological properties of wastes using a battery of six standardized bioassays, within the context of waste classification (Hazardous Waste Council Directive 91/689/EEC), and focused on “ecotoxic” property (H14) (Table 16; Pandard et al., 2006). This is a combination of direct and indirect approaches integrating two solid-phase tests: emergence and growth inhibition of *Lactuca sativa* (14 days), mortality of *Eisenia fetida* (14 days) and four standardized tests performed on water extracts from wastes: growth inhibition of *Pseudokirchneriella subcapitata* (3 days), inhibition of mobility of *Daphnia magna* (48 h), inhibition of reproduction of *Ceriodaphnia dubia* (7 days), and inhibition of light emission of *Vibrio fischeri* (30 min). Preliminary conclusions were reported on relevancy of this experimental test strategy, based on data obtained since 1998. Results were analyzed from the combined use of hierarchical cluster analysis, principal component analysis and non-linear mapping. These multivariate analyses clearly showed that it was possible to reduce the number of tests without changing the typology of waste. A battery of bioassays including one solid phase test and two tests performed on water extracts (*L. sativa*, *V. fischeri* and *C. dubia*) was found as an optimal solution for characterizing the toxicity of the studied waste. This battery was relevant for determining the H14 property.

***Table 16**. Battery of bioassays used for ecotoxicity test characteristics of hazardous waste (after Pandard et al., 2006).*

Organisms	Type of toxicity	Endpoints	Expression of results	Test duration	Test methods

Micro-algae		Growth inhibition	EC 20[a]	3 days	NF T 90-375
P. subcapitata	Chronic				(AFNOR, 1998)
Plants		Emergence; Inhibition of growth[b]	EC 50	14 days	ISO 11269-2
L. sativa	Acute				(ISO, 1995)
Micro-crustaceans					NF EN ISO 6341 (AFNOR 1996)
D. magna	Acute	Inhibition of mobility	EC 50	48 h	NF T 90-376
C. dubia	Chronic	Inhibition of reproduction	EC 20	7 days	(AFNOR, 2000)
Earthworms					ISO 11268-1
E. fetida	Acute	Mortality	EC 50	14 days	(ISO, 1993)
Bacteria					NF EN ISO 11348-3
V. fischeri	Acute	Inhibition of light emission	EC 50	30 min	(AFNOR, 1999)

[a] Expressed as growth rate. [b] Mass of shoots of seedlings (dry weight).

Such battery of bioassays could be also applied for assessment of initial and residual risks of contaminated and remediated sites. However, this set of bioassays is not well adapted to TECS: bacteria are not representative of the soil conditions (BIOMET might be more suitable), at least three plant families should be included in soil testing, earthworm in the above test is adapted to decayed OM, which is not representative of bulk soil conditions. Hence, there is a need of selecting and validating test batteries that are relevant for soil conditions.

6.3.5 EFFECT OF TE ON NUTRIENT FLUXES IN SOIL

Nitrogen cycling in soil including N_2- fixation, mineralization, nitrification and denitrification mediated by microorganisms are known to be sensitive to elevated concentrations of trace elements (e.g. Bardgett et al., 1994; Giller et al., 1998; Yin et al., 2003). However, tests with soils from contaminated sites and those artificially contaminated using metal salts showed that inhibition effect on N cycling in spiked soils was substantially higher than in field samples. Such a difference is, on one hand, due to the reduced bioavailability of TE in field over time and, on the other hand, due to the ability of bacteria to adapt to elevated concentrations of TE and develop TE tolerance during prolonged exposure in field (De Brouwere et al., 2007). Similarly to N, reduced carbon mineralization is often observed at elevated levels of TE in soil. (e.g. Doelman and Haanstra, 1984; Saviozzi et al., 1997; Merckx et al., 2001).

A symbiotic nitrogen fixation in white clover at the presence of clover rhizobia (*Rhizobium leguminosarum* bv. *trifolii*) was shown to be significantly affected by elevated concentrations of soil TE, such as Zn and Cd (Chaudri et al., 1992; Smith, 1997; Broos et al., 2004, 2005). Based on such studies, Broos et al. (2005) suggested that the elevated Zn levels in soil can have an irreversible effect on soil fertility.

6.3.6 NEEDS FOR HARMONIZATION AND STANDARDIZATION OF THE METHODS FOR PREDICTION OF LONG-TERM EFFECTS (SUSTAINABILITY) OF GENTLE REMEDIATION TECHNIQUES

There are standards for various tests available at national (e.g. BSI, DIN, NEN, SIS, ASTM, etc.), regional (CEN) and international (ISO) levels. The most widely applicable standards have been produced by the Organisation for Economic Co-operation and Development (OECD) and the International Organisation for Standardisation (ISO).

The choice of standard procedures to test TE effects on microorganisms and plants is quite large, but limited for whole cell biosensors. Rigorous standardization of the procedures for the use of the cellular biosensors across various soil types and extended comparisons of their responses with results of the chemical analyses are advisable prior to suggesting their use to asses the efficiency of the remediation measures, in soil protection policy, and before the adoption of the tests based on the cellular biosensors in the environmental legislation.

To predict long term effects of soil remediation is a challenging task, if possible at all. Bioavailability of TE that determines their toxicity is changing in time and space depending on a large number of factors. A thorough and extensive set of tests, both biologic and chemical, complemented with geochemical modeling and advanced spectroscopic techniques (e.g. synchrotron radiation based methods) might be required. However, extensive studies are impractical and hardly applicable for routine site investigations. The choice of methods may also be limited by the availability of advanced analytical instruments. Therefore a selection and inter-laboratory validation of a smallest set of tests is still to be performed.

6.4 Environmental and socio-economic aspects of remediation and related technologies (WP4)

Müller I., Bert V., Böhm A., Brignon J-M., Cochet N., Gombert D., Haag R., Jollivet-Courois P., Kumpiene J, Magnie M-C., Marschner B., Renella G., Rouïl L., Schoefs O., Tack K., Viatelle F., Tlustoš P.

6.4.1 Introduction and Objective

Gentle remediation options should be effective and successful regarding the remediation process, e.g. reducing or removing risk and/or contaminants from soil. These aspects underwent intense discussion in chapter 6.2. But decision on remediation options should not be based on their grade of success only but take into account that all remediation activities may have impacts on the environment and affect socio-economic aspects as well. These impacts could be negative or positive and depends strongly on the specific remediation option, the recent situation of the contaminated site and the environmental and socio-economic goods or assets to look at. And the view and perception of these impacts – as shown later on – depends on the different roles and positions of those involved in the issue of soil contamination and remediation.

In this study a review and evaluation of gentle remediation options was performed regarding their impact on environment and socio-economic parameters. The main issues were as follows:

- Review on ecosystem services and other environmental aspects with a focus on soil biological activity
- Review on public and social aspects - from contamination to remediation
- Biomass valorisation and the end point of contaminants
- Are we able to prepare a socio-economic analysis for gentle remediation options?
- Evaluation of the current perception of gentle remediation options

The impact was read mainly from reports and publications about pilot scale applications and field studies, sometimes amended by information from green house or lab tests. Additionally the information pool is completed with arguments, positions and reasons provided by practitioners, regulators and stakeholders (e.g. land owners or land users, regulatory decision makers and local authorities, scientists, environmental consultants and local engineers, etc.) in all SUMATECS countries by means of a questionnaire to gather personal experience and opinion reflecting the current knowledge of the gentle remediation methods within the above mentioned groups.

The reasons of hindrance why gentle remediation option were not used more widely in practice regarding their impacts on environment and socio-economic aspects and the possible ways to overcome were analyzed and reported in chapter 6.7 for a bundled review.

6.4.2 Effects of gentle remediation technologies on soil biological and biochemical activities - a literature review.

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Abstract

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 re-vegetated mine spoils 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 few amendments, such as phosphates without alkalizing agents and TMT have deleterious effects on soil biota. Soil microbial biomass and the activity of the enzymes phosphatase and arylsulphatase were identified as suitable and sensitive biological indicators for soil health.

6.4.2.1 Introduction

Remediation technologies for trace element contaminated sites primarily aim at reducing the risks for human health, i.e. reducing the transfer of contaminants into the food chain or to surface and ground waters. Technologies may be as simple as establishing a vegetation cover on a formerly barren soil to prevent erosion and reduce leaching, which, however in several cases needs to be accompanied by certain soil amendments capable of reducing plant availability of the contaminants and acute phytotoxicity in soils used for food production or other biomass crops. Since such amendments reduce plant availability of the contaminants, they are also considered for contaminated soils that are used for the production of food crops or other biomass to reduce contaminant transfer into the plants. Another approach is phytoextraction aiming at extracting the contaminants with plants, which can be enhanced by increasing the plant availability of the contaminants through the use of chelating agents.

While the effects of many amendments on metal plant availability, phytotoxicity and metal mobility have been widely investigated, relatively few studies have focused on the effects on soil biological and biochemical parameters. The fact, that reduction of risks does not necessarily imply restoration of soil functionality is rarely addressed directly. Since soil biological activity is essential for the functioning of soils within any ecosystem, a sustainable restoration of all soil functions is only possible, if the amendments have no adverse effects on soil biota or even better, if they also promote the diversity and vitality of soil organisms.

It is in our opinion noteworthy to underline that gentle remediation, based on natural or man-controlled revegetation of trace element contaminated soils have been practiced all over the world since the emergence of the first serious pollution problems caused by large emissions during the progress of industrialization since the beginning of the twentieth century. In fact, no technological processes of soil treatments (e.g. soil washing, thermal vitrification) not even large scale excavations facilities were available at that time. However, to our knowledge, so far no investigation has been carried out that systematically evaluates different gentle remediation technologies in terms of their beneficial or negative impact on soil biota. This review therefore compiles the available publications where these issues have been addressed. One focus will also be on literature from the 1960s to the 1990s, which is generally not easily accessible to modern web-based search engines. We attempt to come to a first summary evaluation and point out the future research needs.

6.4.2.2 Phytoremediation

Public opinion has been always aware that contaminated soils and wastes represented a serious threat to the environmental and human health. It was also recognised that the loss of soil fertility and unusability of contaminated soils had negative socio-economical consequences on the local human communities due to increasing population and food demand. For such reasons, soils surrounding the mine tailings or polluted by industrial emissions or agricultural practices, mine spoils and wastes have been remediated through phytoremendiation approaches since the problem became a serious issue. However, earlier reported of scientifically sound field interventions date back to the late 1959s-early 1960s, and records can be retrieved from the literature of several countries all over the world. Most of the first interventions aimed at converting contaminated and bare soil into agricultural and forest soils, or into soils used for urbanization and civil activities. Evolution of the remediated soils was followed from the under the aspects of the pedogenesis (i.e. profile development, humification), soil functionality (key microbial species, soil respiration, enzyme activity,) richness of plant community composition (either experimentally or naturally occurring plant species); therefore these field evidences are of theoretical interest for the scopes of this review.

Old literature, is generally poorly available because difficult to get and written in native language. Very differently from today, old field trials relied on real contaminated sites, were very scrupulously documented and lasted for relatively long periods (even decades). Revaluation of such studies, might be interesting for better better interprete the modern data of the recovery in soil functions with the phytoremediation approach, but also to assess its socio-economical pros and cons. The old experimental field trials also provide estimates on the time required for the evolution of spoil heaps in the simplest ‘technic’ soils. For example, Keleberda (1977) reported that spoil heaps revegetated with various tree and herb species required more than 15 years, even if spoil functionality increased much earlier.

6.4.2.3 Revegetation of coal mine spoils and ash deposits

Among soil functions, variations in enzyme activities, microbial biomass, soil respiration, nitrogen fixation, generally responded positively to soil revegetation, in some case also in relation to the complexity and the age of the plant community (*Miller,* 1978). For example, enzymes more strictly related to plant residue decompostion such as pectinase, or invertase are particularly active during the plant community development (Herseman and Temple), and this activity may have profound influence on the genesis and ecology of the remediated soils. Pancholy et al. (1975), reported low urease and dehydrogenase activities in soils of a bare area near an abandoned zinc smelter in Oklahoma (USA), and Cundell (1977) was among the first to related the lack of soil funcitonality with the lack of revegetation of this soil.

One of the first ‘assisted phytoremediation’ field experiments was carried out by (Lindemann et al., 1984), through incorporating bottom ashes from a power plant into a coal mine spoil. Spoils were divided into replicated plots, and treated with soil inocula, grasses, sewage sludge, mycorrhized plants, and inorganic fertilizers. The results showed that seeding of hay grasses and sewage sludge led to a faster increase in soil functionality and sustained more complex microbial communites.

Gilewska & Bender (1978) and Bender (1989) reported the functionality of strip mine spoil heaps cultivation for 10 years with spring barley (fertilized or not), as compared that of adjacent arable soils not affected by the strip mining. The results showed that several enzyme activities were at the same level or even higher in the cultivated mine spoils (fertilized) as compared to those of control soils, even if a significant increase was detectable already 3 year after the cultivation.

Use of fly ash as spoil amendment, can be dated back to the revegetation experiments showing their effectiveness in increase microbial activity, enzyme activity, and plant growth (Osmanczyk-Krasa, 1987). Naprasnikova and Markova (1992) demonstrated that in revegetated mines spoils, the difference between microbial biomass and biochemical activity between the rhizosphere and bulk soil decreased with time of the revegetaion. Moreover, the variation coefficients of the measured biochemical parameters were reduced, likely due to the soil homogenization operated mainly by the soil fauna. The humus formation is also a key phenomenon because this soil layer generally hosts the highest biochemical activity, as compared to the other soil horizons.

After 10 years of cultivation on ashes produced by the Halemba power plant (Poland) with various crops Balicka and Wegrzyn (1984) reported that bacterial counts, dehydrogenase and catalase activities, and nitrification potential were increased by cultivation, with variations depending on the crop, and enhanced by N fertilization.

The work of Paunescu and Stefanic (1989) showed also the importance of irrigation and fertilization on the microbial counts dehydrogenase, catalase, invertase, urease, and phosphatase activities of ashes from a power plant cropped with various cultures. Their results also showed that cropping induced a more rapid development of soils than volunteer vegetation.

Klubek et al. (1992) studied coal ashes from a power plant at the Savannah River Site (South Carolina). Two abandoned sites (15 and 25 years old) colonized by sweet gum, sycamore, lobdolly pine, longleaf pine and myrtle, hybrid poplar, red maple, willow were amended with either cyclone or bottom ashes and compared with a control soil with the same plant community. The authors reported that microbial numbers and diversity increased with age but the lack of nutrients (mainly N) were the main limiting factors to microbial activity and the vegetation development.

6.4.2.4 Revegetation of ferrous mine spoils

Dragan Bularda et al. (1987), compared dehydrogenase, catalase and invertase activities in spoils of iron strip mine and in non contaminated (control) soils, and found that the activities in the spoils were much lower than in the soils, and reported that revegetation with sainfoin and orchard grass for 3 years increased enzyme activities to values similar to those of the control soils, being higher in the plots with sainfoin than with orchard grass.

Increase of invertase, urease and protease activities, nutrient and humus contents of manganese quarry revegetated with oleaster, Scotch pine, black alder, several years (8-20) as compared to non revegetaed plot have been reported (Keteberda, 1978; Dan'ko et al., 1980; Uzbek, 1986; 1989; 1991). Again, time and vegetation cover and phytocenosis composition were critical factors.

Clark and Clark (1981) reported the correlation between total (8000-78000 mg kg-1) and extractable (311-21.800 mg kg-1) Pb, and revegetation degree by metal tolerant (e.g. Minutaria verna, Agrostis tenuis, Festuca ovina), and reported that also microbial biomass and respiration and enzyme activities showed the same trend as the plant colonization.

Sorenau (1983) studied the bare and vegetated wastes at the Saar mine (Romania), contaminated by Cu, Cd, Pb and Zn, and reported that grasses, legume, sunflower or perennial grasses increased invertase, dehydrogenase, phosphatase and urease activites as comapred to non vegetated wastes, and that mineral fertilzation had adjunctive positive effects, apricularly on the plant yields. After 5 years, the enzyme activity values did not however reach values comparable to those on an uncontaminated soil.

Interesting data on the trends of vegetation and functionality of remediated bauxite mine spoil covered by topsoil were obtained by Jasper et al. (1998), reporting that normalised difference vegetation index values increased peaked between 4 and 6 years, whereas soil microbial biomass between 4 and 8 years. In this light, soil microbial activity may represent more as a measure of revegetation progress, than a basic requirement for revegetation purposes.

6.4.2.5 Amendments involving additions of organic or inorganic materials

Chelators (Tab. 17):

The uptake of metals by plants is generally limited by their low solubility and bioavailability. In order to improve the efficiency of phytoextraction, chelating agents such as EDTA can be added to soils that induce metal desorption or dissolution and thus increase root uptake and transfer into the above-ground biomass (Nowack et al., 2006). One major drawback with the use of chelants is the enhanced leaching of the target metals and non-target nutrients (Lasat, 2002; Römkens et al., 2002; Liphadzi and Kirkham, 2006; Nowack et al., 2006). Due to the phytotoxicity of synthetic chelants like EDTA and DTPA (Grčman et al., 2001; Shen et al., 2002; Solhi et al., 2005), some recent studies have assessed the potential use of naturally occurring chelants.

In a greenhouse column experiment, Grčman et al. (2001) applied 5 and 10 mmol EDTA kg-1 in a single dose or cumulative over three weeks to a moderately heavy metal contaminated soil (Pb: 1100 mg kg-1, Cd 5.5 mg kg-1, Zn 800 mg kg-1). The treatments not only depressed dry matter yield of red clover but also reduced mycorrhizal infection substantially. Based on PLFA analysis, the microbial biomass of other soil fungi also decreased with increasing EDTA dose, while bacteria and actinomycetes seemed unaffected. The microbial toxicity of EDTA was also reflected in an increasing trans/cis ratio of the PLFAs and by an increasing proportion of dead biomass (Grčman et al., 2001). Since these experiments were only conducted with the contaminated soil it is unclear if the observed toxic effects of EDTA are due to the chelant or due to the increased metal solubility.

In a follow-up study with the same soil the more biodegradable chelant ethylene-diamine-disuccinate (EDDS) was tested at the same dosage (Grčman et al., 2003). It proved to be less effective than EDTA in mobilizing Pb for plant uptake but similarly effective for Zn and Cd. In contrast to EDTA, EDDS did not reduce or even promoted plant growth while in this experiment, mycorrhizal infection was not affected by either chelant. With EDDS, fungal biomass was also slightly reduced but to a lesser degree than with EDTA and the trans/cis-ratio of the PLFAs indicated far less stress to the microbial populations than with EDTA.

In a column experiment, Bouwman et al. (2005) added the non-biodegradable chelant glycoletherdiamine tetra acetic acid (EDGA) to a Zn/Cd-contaminated soil at rates of 2.5 and 5.0 mM kg-1. The treatment greatly increased heavy metal concentrations in the soil solution but had no effects on bacterial biomass or the synthesis of proteins or DNA. However, numbers of nematodes were significantly reduced by the EDGA treatment, in particular the bacterivores.

Cao et al. (2007) tested two easily biodegradable chelants, EDDS and methylglycinediacetic acid (MGDA) in a Pb/Zn contaminated soil at rates of 4 and 8 mM kg-1. While MGDA was more effective in mobilizing the metals into the soil solution, both chelants increased bacterial numbers considerably, especially in the rhizosphere soil. This was attributed to the substrate value of the chelant. At the same time, these microbial populations were more susceptible to added Pb and Zn-salts, indicating that the growth of metal sensitive microorganisms was selectively promoted by the chelants.

Jones et al. (2007) tested the effects of EDTA additions of 0.1 g kg-1 on the earthworm Eisenia fetida in four metalliferous soils. The chelant increased Pb and Ni uptake in two soils, but not for the other metals in the soils. In the acidic soil (pH 4.2), EDTA decreased worm survival by almost 50%, but had no effect in the other soils, while cocoon production was reduced by EDTA in another soil.

Tab. 17: Summary of observed effects of chelant additions on biological and biochemical parameters in trace element contaminated soils

positive effects	negative effects	neutral effects
Lettuce yield doubled after EDDHA + Thlaspi (4 mo) *(Keller & Hammer 2004)*	DTPA, EDTA reduced plant growth *(Sohli et al. 2005, Shen et al. 2002, Grcman et al. 2001)*	EDDS not toxic to fungi *(Grcman et al. 2001)*
EDGA increased microbial biomass *(Bouwman et al. 2005)*	EDTA toxic to soil fungi *(Grcman et al. 2001, 2003)*	EDDHA not toxic (BioMet sensor) *(Keller & Hammer 2004)*
EDDS, MGDA increased CFU greatly *(Cao et al. 2007)*	EDDS, MGDA increased metal susceptibility of bacteria *(Cao et al. 2007)*	
	EDTA reduced survival and cocon production of earthworms *(Jones et al. 2007)*	
	EDGA altered nematode population *(Bouwman et al. 2005)*	

Biosolids (Tab. 18):

In many countries, application of biosolids to agricultural lands is a common practice due to their beneficial effects on soil organic matter and nutrient status which generally enhances crop production (Düring and Gäth, 2002). Due to these properties, their low costs and good availability biosolids have also been extensively applied for the rehabilitation and revegetation of derelict and barren lands, such as mine spoils (Brown et al., 2005). Numerous studies have shown that biosolids applications generally enhance soil microbial biomass and activities such as respiration, enzyme activities and N-mineralization (Marschner et al., 2003; Speir et al., 2004; Banks et al., 2006; Bünemann et al., 2006). However, detrimental effects on soil biological properties have also been reported, such as reduced microbial biomass, metabolic quotient, worm or nematode survival and reproduction and elevated toxicity of leachates (Speir et al., 2004; Bünemann et al., 2006; Cogger et al., 2006; Alvarenga et al., 2007). These effects are generally attributed to elevated salt or heavy metal contents or to pH changes and have to be taken into account when evaluating biosolids as amendments for trace element contaminated lands.

Stroo and Jencks (1982) studied an acidic barren mine soil, sparsely vegetated with tall fescue (Festuca arundinacea), treated with lime, fertilizers, sewage sludge and mixed treatments. Most of the treatments except liming alone, increased the enzyme activity and respiration significantly over control soil, and also tall fescue colonization rate. Perez de Mora et al. (2005; 2006) conducted greenhouse experiments with an acidic alluvial soil polluted with heavy metals from the Aznácollar mine accident in 1998 in Spain. The addition of a biosolid-compost mixture at an equivalent of approximately 80 Mg ha-1 increased pH by two units and reduced the CaCl2-extractable Cd, Cu and Zn concentrations by 80 to 90%. Microbial biomass, glucose mineralization and activities of the enzymes arysulfatase, -glucosidase and dehydrogenase all increased in response to the amendment, some however, only at the second sampling date after 6 months (Pérez de Mora et al., 2005). Other organic amendments had similar effects and the authors attribute this to changes in the microbial community structure in response to the organic matter and nutrient supply, the pH increase and the reduced metal availability (Perez-de-Mora et al., 2006).

Conder et al. (2001) added lime stabilized and anaerobically digested biosolid to a heavily with Zn and Cd contaminated soil (290 and 12300 mg kg-1) at rates of 100 g kg-1. Only the lime stabilized biosolid reduced earthworm mortality significantly from 100% to about 10%, while the other biosolid even accelerated complete mortality from 48 h in the control to 24 h in the treatment. The positive effect of the lime stabilized biosolid was related to a pH increase from 6.2 to 7.3 and a more than 90% decrease in Ca(NO3)2-extractable Zn, which was not observed in the soil amended with the other biosolid.

In a field study in the vicinity of a zinc smelter, Kelly et al. (2003) observed a decrease in microbial PLFAs at the sites with the highest metal concentrations. In plots that had been amended with a surface application of 73 Mg ha-1 of a biosolid/fly ash mixture, the PLFA profiles resembled those of the uncontaminated sites, suggesting that several microbial populations recovered due to the remediation. However, the authors speculate, that this effect may be largely due to the pH increase in the amended sites which reduced Zn solubility and consequently its bioavailability and toxicity.

Karaca et al. (2002) spiked a slightly acidic pasture soil (pH 5.4) with Cd at 50 mg kg-1 and assessed the effects of biosolids added at a rate of 2 Mg ha-1 on soil microbial parameters. In the course of the 16 wk experiment, water soluble Cd decreased in the control from 39 to 26 mg kg-1, but increased in the biosolid treatment from 0.16 to 0.84 mg kg-1. While the Cd treatment alone depressed urease, N-acetyl-glucosamidase, phosphatase, arylsulphatase and -galactisodase activities compared to the unspiked control, the Cd+biosolid treatment increased the activities of these enzymes over the control levels, especially for urease and the acid and alkaline phosphatases. Total bacterial, fungal and pseudomonad counts were similarly affected.

Tab. 18: Summary of observed effects of biosolid additions on biological and biochemical parameters in trace element contaminated soils

positive effects	**negative effects**	**neutral effects**
increased microbial biomass, diversity *(Perez de Mora et al. 2006)*	decreased nematode diversity *(Cogger et al. 2006)*	no effect on no. of CFU *(Karaca et al. 2002)*
increased enzyme activity *(Perez de Mora et al. 2006, Karaca et al. 2002)*	decreased earthworm survival *(Alvarenga et al. 2007)*	
reduced Zn toxicity to earthworms *(Conder et al. 2001)*	lower EC50 for toxicity tests *(Alvarenga et al. 2007)*	
	decrease in certain PLFAs *(Kelly et al. 2003)*	

	increased earthworm mortality (Conder et al. 2001)	

Other organic amendments (Tab. 19):

Various other organic amendments have been used for the remediation of trace element contaminated sites, including composts of different origins, manures, peat and litter. Similar to the application of biosolids, these materials have generally been are applied to soils or substrates with very low native organic matter content, so that apart from metal immobilisation, the main objective of these measures often is to supply nutrients and improve water holding capacity so that the establishment of a vegetative cover becomes possible.

As pointed out in the extensive review of Bünemann et al. (2006), any increase of organic matter in soils will also increase soil biological activity. Consequently, almost all studies that evaluated biological parameters of organically amended contaminated soils report of positive effects. Toxic or inhibitory effects from organic amendments have only been found in a few cases and are generally attributed to contaminants present in the materials, as in biosolids or municipal waste compost (Alvarenga et al., 2007).

In a greenhouse study, Perez-de-Mora et al. (2005; 2006) added biosolid compost, municipal waste compost, leonardite and deciduous forest litter at 100 Mg FW ha-1 to a moderately heavy metal contaminated soil (Pb 201 mg kg-1, Zn 226 mg kg-1, Cd 2.4 mg kg-1, Cu 78 mg kg-1, As 120 mg kg-1). All amendments significantly increased the pH of the acidic soil by 1-2 units and reduced heavy metal solubility. Microbial biomass and enzyme activities of arylsulphatase and □-glucosidase increased with all amendments, while dehydrogenase activity was only stimulated by the compost additions. All amendments also caused shifts in microbial community structure.

In a similar study, van Herwijnen et al. (2007) tested four composts (from biosolids+wood chips, spent mushrooms, green garden waste and coconut husks) as amendments for three contaminated and an uncontaminated soil at additions of 20% (w/w). In the two most contaminated soils, earthworms only survived in the amended treatments. Leachates from the two most contaminated soils were highly toxic to the bioluminescent bacterium Vibrio fischeri which was greatly improved by the addition of green waste compost. In the most contaminated soil (16,000 mg Pb kg-1, 9400 mg Zn kg-1 and 1300 mg Cu kg-1), the spent mushroom compost reduced this toxicity only to a small degree. This was attributed to the metal mobilizing effects of this treatment, as reflected in greatly increased metal concentrations in the soil leachates. But since toxicity of the leachates was reduced despite the higher metal concentrations, the metals were apparently organically complexed and thus less bioavailable.

Clemente et al. (2006; 2007) added cow manure and olive production wastes to two heavy metal contaminated field sites. The acidic pyrite waste site was amended with 36 t ha-1 of cow manure or 13.6 t ha-1 of olive mill compost annually for two vears, the calcareous site was amended once with the equivalent of 15 t ha-1 cow manure and olive husks. In the acidic soil, liming was necessary to establish crop growth, but no treatment effects were observed for DTPA-extractable metals (Clemente et al., 2006). Microbial biomass was higher in the amended soils, but differences were not significant due to high variability within the plots which was apparently caused by variations in soil pH.

In the calcareous soil, the organic amendments had no effect on DTPA-extractable metals after 15 months (Clemente et al., 2007). However, in the course of the experiment, soil microbial biomass increased about 10-fold in the olive husk treatment and about 3-fold in the manure treatment. Soil respiration also increased, but differences to the control were consistently significant only in the olive hulk treatment. The respiratory quotient qCO_2 decreased similarly in both treatments to about 30% of the control values, indicating a more efficient use of the C-sources, which is generally attributed to a reduction in environmental stress (Killham, 1985).

Pearson et al. (2000) spiked an artificial soil with heavy metals and then tested the effect of different amendments on the bioavailability of the metals to the earthworm Eisenia fetida. While P-additions reduced Pb-uptake by the worms (see above), composted leaves increased Pb-uptake compared to the unamended control by about 20%. The authors speculate that this could be due to the better food supply in the compost amended soil which stimulated the worms to consume larger amounts of soil. Zn and Cd uptake were not affected by either treatment. When P and compost were added in combination, Pb uptake in worms was also reduced, but to al esser degree than in the P-alone treatment.

Various other studies have tested similar combinations of organic and inorganic amendments for contaminated sites with the aim to immobilize the metals with the inorganic component and improve soil fertility with the organic material. Kumpiene et al. (2007) added a mixture of coal fly ash and peat to an acidic Pb/Cu-contaminated soil poor in SOM. This caused a pH increase to near neutral and reduced soluble metal concentrations by over 99%. As a consequence, the initial strong toxicity of the soil extracts to Vibrio fischeri was eliminated.

Vangronsveld et al. (1996) amended a field site adjacent to a zinc smelter with a mixture of beringite and compost and seeded it with various plant species. Five years after establishment of the experiment, abundance of saprophytic soil fungi had greatly increased and the mycorrhizal infections of grass roots were much more abundant in the treated plots, which in turn promote the revegetation of the site.

Paper mill sludge containing about 30% carbonate was also shown to effectively reduce metal concentrations in leachates from an acidic mine spoil and thus reduce their toxicity to Vibrio fischeri (Calace et al., 2005). In contrast, another sludge containing only 2% carbonates showed no effects on leachate toxicity, most likely due to higher Cu and Zn concentrations than in the leachates from the soil treated with

Tab. 19: Summary of observed effects of various organic matter additions on biological and biochemical parameters in trace element contaminated soils

	positive effects	**negative effects**
leonardite	increased enzyme activity *(Pérez-de-Mora et al. 2005)*	
sugar beet lime	increased enzyme activity *(Pérez-de-Mora et al. 2005)*	
litter ***(Castanea sativa)***	increased enzyme activity *(Pérez-de-Mora et al. 2005)*	
peat	reduced Cu and Pb toxicity (Lum) *(Kumpiene et al. 2007)*	
coal fly ash	reduced Cu and Pb toxicity (Lum) *(Kumpiene et al. 2007)*	
fly ash	increased microbial & enzyme activity *(Osmanczyc-Krasa, 1987)*	
peat + coal fly ash	reduced Cu and Pb toxicity (Lum) *(Kumpiene et al. 2007)*	
paper mill sludge	reduced toxicity (Lum) *(Calace et al. 2005)*	
compost + lime	increase in microbial biomass *(Clemente et al. 2006)*	
compost	reduced toxicity (Lum) *(Herwijnen et al. 2007)*	

Phosphates (Tab. 20):

The addition of phosphates to Pb contaminated sites has been shown to be a potential remediation measure in numerous studies because this promotes the formation of insoluble pyromorphites that are stable over a wide range of environmental conditions (Sonmez and Pierzynski, 2005). The solubility and plant availability of Cd and Zn has also been reduced after phosphate additions (Karaca et al., 2002; Malkowski et al., 2003; Brown et al., 2004) but it still is debated if this is due to precipitation or sorption (Bolan et al., 2003). There are various forms of phosphates available, ranging from natural rock phosphates and apatites to manufactured fertilizers or chemicals which vary in their solubility and chemical reactivity over a wide range. Some of the fertilizers such as monocalcium phosphate or triple super phosphate are acidic and thus may reduce soil pH if applied in higher amounts to poorly buffered soils (Malkowski et al., 2003; Stolz, 2008), which needs to be taken into account when evaluating the effects on soil biological parameters. Phosphates may also mobilize As by competition for the same sorption sites, so it is not recommended for sites with elevated soil As concentrations (Malkowski et al., 2003; Chrysochoou et al., 2007; Stolz, 2008).

In a study with phosphate rock additions in 10 differently contaminated soils, Geebelen et al. (2003) found no consistent reductions in $CaCl_2$-extractable Pb and similarly only in two soils slight reductions in microbially available Pb detected with the BIOMET biosensor which utilizes the genetically modified bacterium Vibrio fischeri. In their experiment with a Cd-spiked soil, Karaca et al. (2002) found the inhibiting effects on enzyme activities (phosphatases, arylsulphatase, urease, □-galactosidase) to be reduced after addition of the equivalent of 250 kg P ha-1 as $Na_4P_2O_7.10H_2O$. In an international inter-laboratory study, different amendments including 2% TSP were added to a contaminated soil with over 5000 mg Pb kg-1 and 18 530 mg Zn kg-1 (Brown et al., 2005). Microbial biomass was extremely low in the untreated soil (34-72 mg C kg-1) and TSP was the only treatment that caused an increase to 148-157 mg C kg-1.

In a well designed laboratory study, Stolz (2008) added 1% (w/w) of triplesuperphosphate to contaminated garden soils and accounted for the associated pH-decrease with a control acid treatment. Thus, most of the observed negative effects of the TSP treatment on microbial biomass and enzyme activities were clearly attributed to the acidification. Only soil respiration and phosphatase activities were more inhibited by TSP than by an equivalent acidification with H_2SO_4, which may be due to the strong As mobilization in the TSP treatment. However, in an accompanying field study with the same soils where the TSP associated acidification was controlled by liming, microbial biomass and numerous enzyme activities were reduced in this treatment (Marschner et al., 2009), especially phosphatase (- 40-50%) and arylsulphatase (-60%). An increased respiratory activation quotient (+ 20-30%) furthermore indicated that the microorganisms experienced elevated stress.

Various other studies have used the earthworm Eisenia fetida as bioindicators for treatment effects. In an experiment with soil spiked with metal nitrates, Pearson et al. (2000) added mono potassium phosphate (MKP) at rates of 1.3 and 2.6 g kg-1 and observed similarly reduced Pb bioaccumulation factors in earthworms at both rates, but unaffected or even increased Cd and Zn bioaccumulation factors. Maenpaa et al. (2002) compared the effects of two different P-sources (MKP and TSP) at two rates on the metal bioaccumulation factors in worms. They did not observe any effects at the lower rate of 600 mg P kg-1 soil, but similar reductions in worm uptake for both P sources at 5 g kg-1 for all tested metals (Pb, Zn, Cd). In a follow-up study, Ownby et al. (2005) tested additional P-sources at 5 g kg-1 to two soils contaminated with Pb and Zn. They report significantly reduced Pb- and Zn-bioaccumulation factors in the TSP treated soils, reaching only 7-17% of the control values for Pb. Rock phosphate was similarly effective for Zn, but not for Pb and the other P-sources (TCP and MCP) had no effect on metal uptake by the worms. This agrees with results of Morgan et al. (2002), who also found reduced Zn-uptake by earthworms after addition of hydroxylapatite. However, in an extremely contaminated soil (Zn: 12 300 mg kg-1, Cd 290 mg kg-1), even rock phosphate additions of 100 g kg-1 could not prevent complete earthworm mortality, only increase the survival time by 10-50 hours compared to the unamended control (Conder et al., 2001).

Tab. 20: Summary of observed effects of phosphate additions on biological and biochemical parameters in trace element contaminated soils

positive effects	**negative effects**	**neutral effects**
reduce Pb- and Zn-uptake by earthworms *(Ownby et al. 2005, Maenpaa et al. 2002, Pearson et al. 2000)*	decreased survival of earthworms *(Ownby et al. 2005)*	no effect on CFU *(Karaca et al. 2002)*
increase in enzyme activity *(Karaca et al. 2002,*	decreased microbial biomass	no effect on soil respiration

Stempelmann 2008)	*(Stolz 2008)*	*(Stolz 2008)*
	decreased enzyme activity *(Stolz 2008, Stempelmann 2008)*	
	decreased mycorrhizal infection *(Bolan et al. 2003)*	

Fe-oxides, red mud and Fe^{o} (Tab. 21):

Due to their high sorption capacity for metals, iron oxides have been widely suggested as amendments for heavy metal contaminated soils. Their sorption capacity varies with pH and depends on the Fe minerals. Pure Fe-oxides like ferrihydrite have the highest sorption capacities, but are expensive and not available in large amounts. Therefore, Fe-oxide rich industrial by-products like red mud, red gypsum, water treatment residuals have been considered as amendments in various studies (Peacock and Rimmer, 2000; Lombi et al., 2001; Brown et al., 2005). Elemental Feo in the form of steel shots or iron grits have also been tested (Shokes and Moller, 1999; Kumpiene et al., 2006), as they will readily transform to oxides in the soil environment.

Among the few studies that assessed biological effects of such amendments in soils, Lombi et al. (2002) were among the first to show that metal toxicity to soil biota is reduced by 2% additions of red mud to two contaminated soils. Soil microbial biomass increased by 30-40% in both soils and functional diversity as determined with the BIOLOG substrate utilization test was highest in the red mud treatments. This treatment also was the most effective in reducing the toxicity of soil pore water as determined by the bioluminescence of the biosensors E. coli and P. fluorescence. However, in a companion paper, the authors point out, that many of the observed chemical effects of this treatment are due to the pH increase from 5.5 and 6.4 in the control soils to about 8.0 in the red mud treatments (Lombi et al., 2002). This may at least partly explain the biological effects. A strong pH increase after the addition of 4% red mud also occurred in the study of Garau et al. (2007). This was accompanied by a profound decrease in Ca(NO3)2-extractable Pb, Cd and Zn and a significant increase in fast growing heterotrophic bacteria and activities of the enzymes urease and dehydrogenase. That this may largely be a pH-effect was revealed with a principal component analysis of the substrate utilization patterns determined with the BIOLOG system, where the data from the red mud and lime treatments grouped in a composite cluster.

Kumpiene et al. (2006) used 1% additions of iron grit to a soil contaminated with Cr, Cu and As, which greatly reduced soluble and plant available As and Cr. The toxicity of the soil pore water as determined with the luminescent biosensor V. fischeri was reduced by 64-67%. Most enzyme activities also recovered from very low levels, but differences to the untreated control were only significant for the two phosphatases and for arylsulfatase. Since the Cu concentrations in soil pore water remained high in the treated soil, the authors assume that this still causes considerable toxic effects.

In one of the rare long-term field studies, the effects of 1% iron grit additions to a Cd- and Ni-contaminated site were assessed seven years after the initial amendments (Mench et al., 2006; Mench et al., 2006). While soil microbial biomass, bacterial species richness and soil respiration were not affected by the treatments, soil enzyme activities were restored to different extents. As in the previously cited study, the activities of the acid and alkaline phosphatases and of arylsulfatase increased significantly, while urease, protease and β-glucosidase showed no response to the treatment (Mench et al., 2006). Nodulation of bean roots was not established by this treatment, only when combined with 1% beringite which alone also failed to promote nodulation (Mench et al., 2006). An earthworm avoidance test showed that Dendrobaena octaedra preferably moved to the untreated soil if given the choice between different treatments, but upon 3 week exposure to the soil, survival and biomass of the worm was about doubled in the iron grit treatment compared to the untreated control. Here too, the combination of beringite with iron grit improved the earthworm vitality even more (Mench et al., 2006).

In her laboratory experiments with three contaminated soils, Stolz (2008) added 1% water treatment residue which caused a strong reduction in NH4NO3-extractable Cd and Zn. In the two most contaminated soils, this treatment also increased basal respiration slightly (+ 15%) but had no effects on microbial biomass or most enzyme activities. Only alkaline phosphatase and β-D-glucosidase activities increased in single soils. However, in the field, the same treatment caused a strong increase in basal respiration (+ 70%) and in the respiratory activation quotient (+ 50%) one year after the initial treatment (Marschner et al., 2009). The activity of arylsulfatase also increased by 80% in the field after one year (Marschner et al., 2009) and was still greatly elevated relative to the unamended site, three years later (Stolz, 2008; Marschner et al., 2009).

Tab. 21: Summary of observed effects of Fe-oxide or Fe^{o} additions on biological and biochemical parameters in trace element contaminated soils

positive effects	negative effects	neutral effects
increased enzyme activities *(Kumpiene et al. 2006, Stempelmann, unpubl.)*	increased leaching of Cd & Pb *(Hartley et al. 2004)*	no effect on enzymes or microbial biomass *(Stolz 2008)*
decreased microbial toxicity (BioTox, Luminesc.) *(Lombi et al 2002, Kumpiene et al. 2006)*		
plant biomass doubled *(Kumpiene et al. 2006, Ruttens et al. 2006)*		
increased earthworm survival *(Mench et al. 2006)*		
increased microbial biomass and diversity (red mud) *(Lombi et al 2002)*		
increased nodulation (w/ beringite) *(Mench et al. 2006)*		
increased soil respiration (WWS) *(Stolz 2008)*		
increased nitrification (WWS) *(Stempelmann, unpubl.)*		

Zeolites (Tab. 22)

Zeolites are alkaline porous alumino-silicates with a negative surface charge and occur naturally, mainly as the mineral clinoptilite, but are also industrially synthesized for various purposes, such as detergent additives. They are used in water treatment for the removal of metals (Wingenfelder et al., 2005) and have also shown to be effective in reducing heavy metal solubility and plant availability in soils (Tsadilas et al., 1997; Garcia-Sanchez et al., 1999; Castaldi et al., 2005). But it is not clear, if these effects are not mainly caused by the associated pH increase, since liming was equally or even more successful in promoting plant growth (Tsadilas et al., 1997; Castaldi et al., 2005). Due to their lower charge and specific surface area, natural zeolites have lower sorptive capacities for heavy metals than synthetic zeolites (Singh et al., 2000).

Five studies were found that evaluated biological parameters in soils treated with zeolites. In an extensive laboratory study. Chander & Joergensen (2002) treated an acidic Pb/Zn-contaminated soil with 0.5% synthetic zeolite alone and with combinations of lime and compost. Zeolite increased pH to 7.2, but combinations with lime were more effective in reducing NH4NO3-extractable Pb. Microbial biomass increased by over 30%, which was more than in the lime treatment at a comparable pH. The zeolite treatment depressed the ergosterol content, by promoting bacterial and inhibiting fungal growth. Microbial respiration more than tripled with zeolite addition and added 14C-labelled glucose was mineralized to higher degree than in the control and lime treatments. The authors point out that these effects indicate some specific interactions between the microorganisms and the zeolite surfaces which they evaluate as a serious disturbance of soil ecology.

Usman et al. (2005) used a natural zeolite at 2% as an amendment for a sewage-sludge contaminated soil. After 11 days of incubation, metal extractability decreased considerably, and microbial biomass increased by 28% with little change in microbial respiration. The resulting decrease in the metabolic quotient is interpreted as a reduction in environmental stress by the treatment.

Garau et al. (2007) added 10% natural zeolite to a heavily Pb/Zn-contaminated acidic soil and determined biological parameters after 6 months of incubation. Here, zeolite increased the pH of the soil only slightly from 4.2 to 4.8 but reduced $Ca(NO_3)_2$-extractable Pb and Cd by over 80%. Still, only minor significant biological effects were detected, with a 30% increase in dehydrogenase activity and a 10% decrease in fast growing heterotrophic fungi. Similarly, in the field study of Marschner et al. (2009), the addition of 1% synthetic zeolite caused no significant changes in any of the analyzed soil biological parameters during the 3-year investigation period.

The bioaccumulation of Zn in earthworms tended to be reduced in 1% synthetic zeolite treated soils, but results with different soils and soil mixtures were inconsistent (Morgan et al., 2002).

Tab. 22: Summary of observed effects of zeolite additions on biological and biochemical parameters in trace element contaminated soils

positive effects	**negative effects**	**neutral effects**
increase in microbial biomass *(Chander and Jorgensen, 2002; Usman et al., 2005)*	reduced ergosterol (*Chander and Jorgensen,* 2002)	small shift in microbial community structure *(Garau et al. 2007)*
decrease in qCO_2 (*Usman et al.,* 2005)		no effects on enzymes, microbial biomass, nitrification (*Marschner et al.,* 2009)
increase in dehydrogenase activity *(Garau et al. 2007)*		
reduced Zn uptake by earthworms (*Morgan et al.,* 2002)		

Beringite (Metasorb) (Tab. 23):

The alumino-silicate beringite is a modified cyclonic ash from the combustion of paleozoic coal schists from the Westphalian deposits in Belgium (Wessolek and Fahrenhorst, 1994). Due to its high sorption capacity for heavy metals it has been used in several laboratory and field studies as an amendment for contaminated soils (Wessolek and Fahrenhorst, 1994; Boisson et al., 1998; Lombi et al., 2003). After the coal combustion for energy production ended, the production of beringite was continued in 1999 by a private enterprise and marketed as Metasorb®. However, it appears to be no longer commercially available.

In the Louis Fargue long-term field experiment on a Cd/Ni-sludge contaminated site, 5% beringite had been added as a treatment alone in 1995 and the plots were sampled seven years later (Mench et al., 2006). The NH_4NO_3-extractable Cd concentrations in the treated soil were about 30% of the control values and the activities of alkaline phosphatase (+ 12%) and arylsulphatase (+ 14%) were significantly higher than in the untreated plot. Bacterial species richness was not affected by the treatment.

In contrast, Lombi et al. (2002) found an increased species richness in two contaminated soils treated with 5% beringite as indicated by the BIOLOG substrate utilization assay. Microbial biomass and bioluminescence of two biosensors increased only in one of the two beringite treated soils.

Oste et al. (2001) showed that the additions of 1.25 to 10% beringite to three Cd/Zn contaminated soils reduced $CaCl_2$-extractable metal concentrations considerably, which was fully due to the associated pH increase. But earthworm survival, cocoon production and metal accumulation were not affected by the treatments, indicating that the easily soluble metal fraction is not controlling metal availability for worms.

Mench et al. (2006) also found no reduction in metal uptake by earthworms exposed to a As-contaminated soil that had been treated with 5% beringite six years before. Instead, metal tissue concentrations were even up to 4-fold higher than in the untreated control, which apparently had no detrimental effects on worm health since survival rates and biomass also increased in the beringite treatment.

Tab. 23: Summary of observed effects of beringite additions on biological and biochemical parameters in trace element contaminated soils

positive effects	negative effects	neutral effects
improves earthworm survival (Mench et al. 2006)		reduced biosolid mineralization *(Mench et al. 2006)*
increase in mycorrhizal infection *(Vangronsveld et al. 1996)*		no effects on enzymes, microbial biomass, nitrification *(Stempelmann et al. 2008)*
decrease in Pb availability (w/ Fe_o) *(Geebelen et al. 2003)*		no effect on metal uptake by earthworms *(Oste et al. 2001)*
increase in nodulation (w/ Fe_o) *(Mench et al. 2006)*		
increased microbial diversity *(Lombi et al 2002)*		

6.4.2.6 Summary of amendment effects on soil biological and biochemical parameters

It has been shown in this review that the effects of the different remediation technologies on soil biological and biochemical activities vary greatly. This is not surprising, as each contaminated soil or site is characterized by a unique combination of physical, chemical and biological parameters, including the type and level of contamination. Furthermore, the applied remediation technologies are also diverse in the studies, such as type and amounts of added amendments or plant species used for revegetation, and the reported effects stem from short-term lab-experiments to long-term field studies.

Still, we feel that a general evaluation of the different treatment technologies regarding their qualitative effects on soil functionality is possible. The evaluation summarized in Tab. 8 is largely based on the analyzed literature and supplemented by some common knowledge of soil biological, biochemical and physiological processes.

The establishment of a plant cover on a formerly barren or sparsely vegetated site generally promotes all reported biological soil parameters and thus has a positive effect on the restoration of soil functions. This can be attributed to the combined effects of increased substrate inputs from the plant biomass and the increasing sorption capacity of soils with increasing levels of organic matter. Plant specific effects such as N-fixation by legumes or mycorrhizae from woody species may additionally improve the soil environment for soil biota.

However, little is known about the effects of certain hyper accumulating plants on biological soil properties. It may well be, that the ability for increased metal uptake is due to increased metal solubilisation in the rhizosphere, which could thus be detrimental to microorganisms at these micro-sites. Since much of the metal accumulation occurs in the roots, their microbial utilization as a substrate may also be inhibited. But the main critical aspects of phytoextraction technologies are chelator additions that increase metal bioavailability and may be even directly toxic to soil organisms. A restoration of soil functionality in chelate treated sites can thus be only expected once the chelating agents have been removed from the soil by leaching, degradation or plant uptake. At least a few of the tested chelators are not toxic and biodegradable, so that negative effects may be short-term and restricted to increased metal bioavailability.

Organic amendments such as biosolids or various composts generally have beneficial effects on improving soil quality for plant growth and soil biota, if they do not themselves contain toxic levels of contaminants, salts or NH4. Detailed chemical analyses and preliminary lab tests should therefore be made before applying such materials in the field. There is little known about the long-term sustainability of these treatments. The positive effects on growth and activity of soil organisms may subside when substrate availability and sorption sites decrease with the degradation of the organic matter.

The effects of phosphates on soil biota are ambiguous, but the observed inhibitions of microbial activity or earthworm survival seem to be mainly due to soil acidification from certain P-compounds. If this is corrected through addition of alkalizing materials such as lime, the precipitation of metal-phosphates can reduce bioavailability and toxicity of metals and thus contribute to the restoration of soil functions. Due to the high affinity of phosphates to As-binding sites, this amendment may increase As solubility and toxicity and should thus not be applied to soils with elevated As concentrations.

With the use of Fe-oxides and ferric Feo as amendments, no detrimental effects on biological or biochemical soil properties are reported. Instead, the minerals added or formed with these amendments are common in soils and probably also promote microbial activity by providing large surfaces for the colonization with biofilms.

Natural zeolites are also soil minerals and their synthetic analogues are very similar in structure and chemical properties. Their positive effects on biological activities have only been observed in acidic soils and therefore may largely stem from their alkalizing properties. This may also be the main explanation for the beneficial effects of fly ash on soil biota, which additionally provides micro-nutrients.

Other amendments such as beringite or TMT can not be evaluated adequately as they have been used only in a few studies. The same holds true for the numerous reports of combined treatments that are generally unique due to their site-specificity. Generally, soil organisms are responsive to treatments that provide organic substrates and/or buffer soil acidity. The reduction of metal bioavailability or toxicity through sorption or precipitation is of minor importance, as many biological and biochemical soil processes seem to be not very sensitive to the metal concentrations encountered in soils that would be considered for gentle remediations.

Tab. 24: Summary evaluation of the effects of different gentle treatment technologies on soil biological and biochemical parameters.

treatment technology	main effects	overall rating
phytostabilization	Plant growth generally promotes the restoration of biological soil functions	+++
phytoextraction	No data on effects on soil biota available	o
chelators	Many synthetic chelators are toxic to soil biota and increase the risk of TE leaching	--
biosolids	The beneficial effects from TE sorption and SOM addition can be outweighed by negative effects on soil biota ➔ b.s. composition is important	o
phosphates	The negative effects on microbial activity and earthworm survival may simply be pH effects	+
Fe-oxides, red mud, Fe^{o}	Generally positive effects on soil biota, but mechanisms remain obscure (reduction of metal toxicity, fresh surfaces for biofilms, … ?)	+++
zeolites	Generally, minor or positive effects on soil biology, but risk of soil physical deterioration	+

beringite (Metasorb®)	Generally, minor or positive effects on soil biology, seems to be no longer available	**+**
other organic additives	Generally, positive effects on soil biology, promote plant growth and thus contribute to the restoration of soil functions. Some organic amendments provide not enough buffering capacity for acidic soils, which then requires combinations with alkaline inorganic materials (i.e. fly ash, lime)	**++**
fly ash	Provides buffering capacity and micronutrients with generally beneficial effects on soil biology	**++**
TMT	Highly toxic to soil biota	**---**

Finally, this review can be used for evaluating the different biological and biochemical parameters for their suitability as indicators for metal toxicity or for the restoration of soil functionality on trace element contaminated sites (Tab. 25). As some highly contaminated mine spoils can be considered as virgin soils with low OM content supporting only a small community of soil organisms, any increase in these parameters will contribute to the restoration of soil functionality. On such sites, soil microbial biomass is a very sensitive and suitable indicator. Microbial respiration and the respiratory quotient, on the other hand, are good indicators for the overall microbial activity, but high values may also be induced by physiological stress from toxic metals or other environmental parameters. In any case, microbial biomass and respiration are only "global" parameters whose contributions to soil functionality also strongly depend on the composition of the microbial community.

For the evaluation of specific soil functions, enzyme activities related to nutrient cycling or certain microbial groups may be more suitable. The alkaline and acid phosphatases are important enzymes in the microbial P-acquisition and therefore essential for the availability of this nutrient. As with most other enzymes, phosphatase activity is related to the overall biological activity, but it also seems to be specifically sensitive to elevated levels of bioavailable heavy metals as it is also stimulated by all immobilizing amendments. The same is true for arylsulfatase, an important enzyme in the soil S-cycle, as it mobilizes organically bound S for microbial uptake. This enzyme is known for its high sensitivity to heavy metals and therefore is a good indicator for amendment effects on metal bioavailability. The other enzymes listed in Tab. # have only been analyzed in a few studies so that their suitability as indicators for soil functionality can not be evaluated.

Dehydrogenase is an enzyme common to many soil organisms, so that its increased activity is generally associated with higher microbial biomass and mineraloization activity and thus not indicative for metal toxicity or soil functionality.

With the recent methodological progress made in analyzing the microbial community structure with molecular genetic and PLFA analyses, it is now possible to obtain a more complex picture of the microbial diversity in soils. However, changes or differences between soils or treatments are difficult to interpret, as little is known about the functions of specific organisms within the community. Generally, increases in diversity are considered beneficial for soil functioning and can thus be a good indicator for the evaluating remediation technologies.

The survival and vitality of earthworms in soils are commonly used toxicity indicators and they strongly relate to soil functionality because earthworms play an important role in many soils by increasing the availability of plant residues to other organisms. But both parameters are also very sensitive to soil acidity and elevated salt concentrations and thus not specific for metal toxicity or its alleviation. On the other hand, metal uptake by earthworms is considered to be a good indicator for faunal metal bioavailability.

The commonly applied toxicity tests with aquatic organisms in soil leachates or extracts are generally well related to the metal concentrations in the solutions and EC50 or similar toxicity measures can be easily obtained with dilutions. However, the organisms are generally also sensitive to other solution parameters like pH and salts, so that reactions are not metal specific. Since metal concentrations can be analyzed more reliably with technical means and the activity or survival of the aquatic test organisms can not be related to biological soil processes, these systems are not suitable for evaluating soil functionality.

6.4.2.7 Conclusions

The information provided by the old reclamation experiments is interesting because it shows unequivocally that even the most recalcitrant and degraded ecosystems have an inherent potential for recovery. Nevertheless, in TECS, trace element toxicity hamper the recovery. Therefore, technological intervention in management and monitoring is needed to shorten the restoration time, maintenance costs, and final destination.

Soil functions, being sensitive to the pedo-environmental conditions and responsible for biogeochemical nutrient cycles, can be used as synthetic indicators of the progress and also the efficiency of given remediation approaches. However, their use should be coupled to the knowledge of the site history, and related to the development of the soil profile and to the organic matter content and humification.

In evaluating the biochemical parameters in relation to SUMATECS and progress of the vegetation the nutrient cycling should be assessed, to better the eventual plant-soil-microbe balance of nutrients, to prevent nutrient shortage. Better study of soil formation, evolution and fertility is important for an optimal SUMATECS, because often after treatment use is proposed on an unsuitable soil. For example, a soil with limited depth may support herbs not tree crops.

Tab. 25: Evaluation of biological and biochemical parameters as indicators for the restoration of soil functionality

parameter	observed effects	sensitivity and suitability to indicate restored soil functionality	comments
microbial biomass	increases with re-vegetation, organic matter additions and pH increase; sensitive to acid, less sensitive to heavy metals; increases with most immobilizing amendments	**+++**	many positive treatment effects due to increases in pH and/or OM-content; contribution to soil functions depends on microbial community structure
microbial respiration	increases with re-vegetation, organic matter additions, pH increase; increases with most immobilizing amendments	**++**	increased respiration may be due to stress and will cause accelerated SOM depletion
respiratory quotient qCO_2	not much data available, decreases with some treatments (zeolite, compost)	**++**	non-specific stress indicator, also dependent on microbial community structure
enzyme activities			
phosphatase	increases with re-vegetation, organic matter additions and most other immobilization treatments; sensitive to heavy metals	**+++**	very sensitive to changes in soil chemistry; important for soil functionality
arylsulphatase	increases with re-vegetation, organic matter additions and most other immobilization treatments; sensitive to heavy metals	**+++**	known sensitivity to heavy metals
dehydrogenase	increases with re-vegetation, organic matter additions and most other immobilization treatments; reacts more slowly and less pronounced to soil	**++**	non-specific enzyme for microbial activity, mainly

parameter	observed effects	sensitivity and suitability to indicate restored soil functionality	comments
	amendments		fast growing bacteria (?)
β-glucosidase	not much data available, increases with organic matter additions, not with iron grit or iron oxides.	**O**	primarily sensitive to fresh OM additions
urease	increase with re-vegetation, organic matter, pH	**+**	important for N-turnover, sensitive to N-rich OM
protease	little data available, increase with re-vegetation, insensitive to immobilizing agents	**O**	important for N-turnover, not enough data available
microbial and functional diversity	increases with all organic matter additions and with re-vegetation, increase with beringite and red mud, possibly due to pH-increase	**++**	few studies, but very relevant for soil functionality
soil fungi	decreased biomass with EDTA and zeolite additions, strong increase in beringite+compost treated soils	**+**	
mycorrhizae	increase with re-vegetation and beringite treatments, decrease with EDTA	**O**	only few studies, depends strongly on plant species
earthworm vitality	no worms reported from re-vegetated mine spoils (< 20 yrs); Lab: increase with composts and compost/lime; decrease with some biosolids, EDTA, TSP	**O**	very sensitive to soluble salts, pH
earthworm metal uptake	increased Pb- and Ni-uptake with EDTA and some compost treatments; decreased Pb- and Zn-uptake with P-treatments	**++**	good faunal indicator for metal bioavailability
leachate toxicity tests (BioMet, luminescence, Dapnia etc.)	increased toxicity of some biosolid and compost treatments (soluble salts?, heavy metal complexes?); reduced toxicity when soluble metals decreased	**O**	sensitive to salts and soluble metals, relevance for soil functionality is questionable

6.4.3 Public and social aspects of gentle remediation

Anna-Katharina Böhm; Ingo Müller

6.4.3.1 Introduction

The contamination of soils with heavy metals and other inorganic contaminants is now a days a serious ecological problem (Vassilev et al., 2004). Lewandowski et al. (2006) assume that looking at Europe and the US probably several 100,000 ha is contaminated by trace elements, e.g. heavy metals. Due to manifold environmental and socio-economic risks caused by contaminated sites (Harris & Herbert 1998), the remediation of contaminated sites is an important task. Today many sites are still waiting for remediation. Gentle remediation options like phytoremediation are seen as an emerging and ecological sustainable technology in soil remediation (Blaylock et al., 1999; Hesske et al., 1998; Vangronsveld & Cunningham 1998; Vassilev et al., 2004). Pulford and Watson (2003) define the task of phytoremediation "… as the use of plants to remove pollutants from the environment or to render them harmless." It is a so called gentle remediation option because it comprises non-destructive techniques such as phytoextraction and phytostabilization (Vassilev et al., 2004) which implement the decontamination of soils by in-situ remediation (Pulford & Watson 2003). That means that the soil ecosystem itself (Hesske et al., 1998) and its specific structures and functions are still maintained during remediation (Pulford & Watson 2003). In the last decade a great deal of research regarding phytoremediation was made (Robinson et al., 2003) pointing at its advantages and usefulness in the business of soil remediation. But surprisingly only a few commercial phytoremediation operations has been realised up to now (Robinson et al., 2003, Schmidt 2003). The literature on phytoremediation is often giving the advice to appreciate socio-economic aspects and impacts of remediation actions when to compare with technical treatment (e.g. Kemp et al., 1998; Martin et al., 1998) But approaches or examples on how to perform a detailed and precise analysis of socio-economic impacts can be found in very few studies only (e.g. Grasmück & Scholz 2005; Hugo et al., 1999; Weber et al., 2001).

According to these facts, the aim of this chapter is to summarize the knowledge about socio-economic aspects of gentle remediation options focussing on phytoremediation. The first result to be read from the study of literature so far is that only a few papers deal with such aspects like exposure and risk perception, communication and acceptance at the stage of decision-making about the appropriate technique before realizing a certain remediation project. And only single papers are working on aspects like communication or acceptance after finishing a remediation project (Heisters & Welpmann 2008).

6.4.3.2 Exposure and Risk perception

The experiences from the literature show that exposure to risk, risk perception and the acceptance of a certain risk as well as to decontamination measures are closely connected with each other. Nevertheless the attempt should be made to examine these three topics as far as possible separately.

Risk and its perception and acceptance are the first arguments on the way to decide on remediation. Contaminated areas are causing different risks, to which environmental media, organisms and especially humans are exposed and therefore it is necessary to analyse and assess the exposure in the process coming from soil contamination and leading to its remediation. This process of decision making has to be addressed more widely that looking on soil and technical/scientific aspects only. There are people affected by contamination and remediation as well and the look on exposure is the first step in this process. Exposure assessment is one step of an entire risk assessment and comprises the identification and the quality of exposure levels for organisms or environmental media - especially in the assessment of human exposure the characterisation and quantification of magnitude, frequency, duration and route of exposure for human contact with environmental media are important aspects (Mathews & Exner 2002). Furthermore the main exposure pathways have to be identified and pollutant concentrations in the pathway-specific contact media should be measured or estimated for calculation of pathway-specific intake-rates. Human exposure to soil contamination can be classified into an acute or chronic, direct or indirect exposure and can take place via ingestion, inhalation and dermal uptake. To record exposure in a comprehensive manner the assessment may consider past, present and future exposure (Fig. 7), including different scenarios on the management of the contaminated site (Mathews & Exner 2002).

Beside the assessment of exposure itself (in a scientific way using preconceptions), exposure plays a significant role on the risk perception of people who are affected by contaminated soils. In particular the effective exposure, and thus the potential risk, varies for inhabitants. In this way exposure may be seen as one part of an entire risk arising from contamination. Grasmück & Scholz (2005) could show that individual risk perception and its acceptance as well is more independent from a person's exposure to a local risk source than the perception for others. They studied two different groups from which one was living closer to the pollution source (high-exposure group), a former brass smelter in the northern Swiss and the other one lived in greater distance (low-exposure group). Both groups perceived their own risk being similar but people in the low-exposure group perceived and rated risk for others to be higher. One reason for this behaviour may be that people in the low-exposure group recognize a group of other persons who are more exposed, whereas those living closer to the metal-plant do not. The fact that both groups rated the risk for oneself similar, indicate a kind of internal self-regulation process, meaning that people are willing to accept a certain upper risk level for oneself.

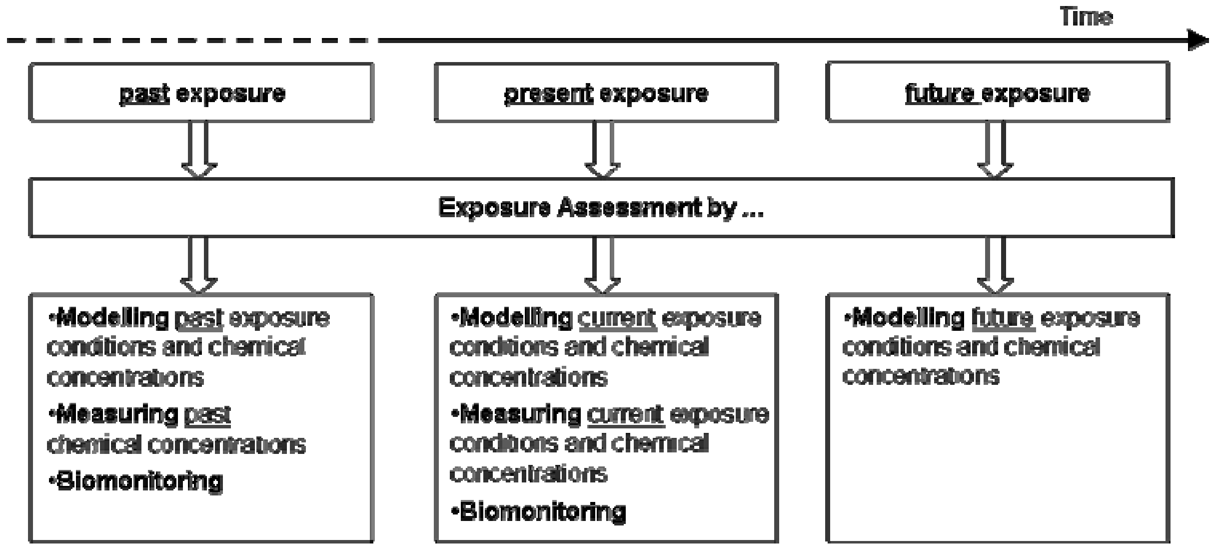


Fig. 7: *Appropriate methods for quantification of past, present and future exposure (Mathews & Exner 2002)*

Risk acceptance usually occurs if the perceived benefits outweigh the perceived negative and harmful outcomes. Similar results were found by Weber et al. (2001) who investigated an exposed and a non-exposed group of residents. As to be expected exposed people perceived their risk for themselves and others as higher than the control group did. Particular in the case of a heavy metal contamination exposed people rated contamination and risk less catastrophic and less fearful than did non-exposed (Weber et al., 2001). The risk caused by a heavy metal contaminated soil was perceived as more or less uncontrollable compared to an oil contamination (Weber et al., 2001).

Exposure, its perception and acceptance strongly influence the decision about the remediation strategy e.g. weather to choose decontamination or measures of risk reduction. Weber et al. (2001) could show that people who are living on a contaminated site believe that decontamination is necessary. But in contrast to this finding Grasmück & Scholz (2005) reported that the longer people live in a contaminated area the less they express their need for decontamination. The study of Weber et al. (2001) investigated also decisions, which were made by people regarding the decontamination method. The respondents were asked to choose between two bioremediation methods (willow and tobacco) and a usual technical remediation. They were asked to rate these options in respect to aesthetics, effectiveness, costs and environmental performance. Both groups rated bioremediation positively with respect to its ecology, cost and aesthetics and classical remediation positively to its effectiveness. But exposed people perceived classical remediation as less aesthetic but as more effective than did non-exposed. Both groups judged environmental performance of decontamination as most important and sustainability as a precautionary issue correlated highest with the rating of whether bioremediation is a useful option. In the case of sustainability the non-exposed people had an even higher correlation and rated this item higher than exposed people did. Especially the exposed group thought that precautionary issues were one of the most important criteria when evaluating decontamination methods because of the needs of future generations (Weber et al., 2001). Grasmück & Scholz (2005) could show the same phenomenon, where people who include thoughts about sustainability and precautionary issues in their judgements have a stronger need for decontamination. Independently from the exposure people preferred bioremediation methods particularly if they consider sustainability (Weber et al., 2001).

Furthermore individual risk perception is exclusively determined by emotional concern and the knowledge about the contamination and the risk respectively. On the one hand emotional concern correlates significantly with exposure in the manner that residents of the high exposure group were less emotionally involved than those in the low-exposure group (Grasmück & Scholz 2005). On the other hand emotional concern has an influence on both risk acceptance and on judgement on the need for decontamination versus risk reduction. Emotional concern is correlated positively with desire for additional information, knowledge and also social responsibility and sustainability but negatively with self-estimated knowledge and the use of simple heuristics (Grasmück & Scholz 2005). But on the opposite, the longer people have been living at the contaminated site the more likely they use dissonance-reducing heuristics and the less they are emotionally concerned. Dissonance-reducing heuristics are a kind of mental trivialization and protection process e.g. based on empiric arguments highlighting uncritical or even positive aspects. For example one argument was '…risk exists where I live – either I change my residence or the risk is not that bad'. Something comparable was found during an investigation in Great Britain where residents saw their own home as no more at risk or even less at risk than other homes in their direct neighbourhood. This behaviour is able to lead to an unrealistic optimism (CL:AIRE 2007b). Heuristics seems to be a process reducing emotional concern making people 'cognitively immune' to risk reduction arguments. People in that kind of process often believe that they know all about the risk and prevent themselves from any further information that could refute their belief in the low environmental risk. In communication during the risk assessment and option appraisal for remediation as well, that heuristics have to be seen as a type of knowledge by people, but from a scientific point of view such arguments are rather weak (Grasmück & Scholz 2005). Nevertheless they should be accepted as phenomenon and be integrated as much as possible in the process of decision making. Regarding to remediation the need of decontamination is positively related to risk perception and to thoughts about sustainability, and negatively with this dissonance-reducing heuristics (Grasmück & Scholz 2005). There is a need for a separate communication strategy to involve that part of people exposed to contamination that use that heuristic approaches. The second and often largest group usually stays emotionally uninvolved but open minded to "scientific" arguments and could be involved much easier. On the other hand, often a third group is observed being strongly emotionally concerned using arguments of environmental fears. Individual risk perception originated from soil contamination may cause fear of possible health effects (Hugo et al., 1999). Sometimes these health problems may arise indirectly from the psychological weight of contamination that means they have a psychosomatic origin (Hugo et al., 1999). The same aspect is pointed out by Matschonat et al. (2004) who found, that chronic stress is induced by the individual feeling of exposure rather than of the objective measurable exposition. This group is focussing on "individual worst-case-scenarios". Especially the danger for children is realized as threateningly and the contamination of private property can lead to social isolation of these inhabitants (Hugo et al., 1999). A similar ranking of fears arising from the awareness of a nearby soil contamination were also reported by the authors from the case study bulletin 8 (CL:AIRE 2007a). They posed that people initially concerned about their families health followed by concerns about their pets and finally their real property value.

Regarding risk exposure and perception as discussed above there doesn't exist a direct relation to the topic of gentle remediation but to remediation in general. Knowledge and perception of the risk is the first phase for affected people in the case of a contamination and is at first independent from the remediation strategy chosen later. But it can be read from the studies that a decision towards gentle remediation option which need a long time for remediation and work more at risk reduction than decontamination are asking for a well structured communication process to get public acceptance.

6.4.3.3 Communication and acceptance

People's acceptance to a certain remediation project including remediation itself and the site use after remediation strongly depends on the communication process with the people concerned. Communication is one of the most important facts for the realization and acceptance of a remediation project – and has to start within risk assessment Linacre et al. (2003). Communication is necessary from the very first detection of contamination up to the finalization of remediation. In a remediation project different aspects have to be communicated. Firstly the contamination problem itself has to be communicated. The second step is to communicate and to discuss the different remediation options in order to find the appropriate measure dependent on the concrete case and on people's acceptance. And finally it is important to explain all the performed actions and its effects during and after the remediation for preserving people's acceptance. In the next sections general aspects of communication as well as the special requirements on communication strategy and its effects on people's acceptance should be further examined. In general communication should contain all information about the contamination and remediation. In the following Table 26 it is tried to list the most important information:

Tab. 26: *Information about contamination and remediation which should be given to affected people during a remediation project*

Contamination	Remediation
Which substances cause the contamination?	Which technologies are available?
Which media are affected – soil, surface water, groundwater etc.?	What is the appropriate measure?
	How long is the remediation lasting?
How large is the contaminated area?	What can be achieved with the chosen method?
Who is affected by the contamination?	How the area can be used after remediation?
Which risks arises from the contamination for humans and environment?	How expensive is the remediation?

Besides the content of information itself there is the question on which communication strategy to choose. To transfer all the aspects caused by the contamination an open, clear and transparent communication strategy should be used generally (Kemp et al., 1998). That includes clear information on all facts, e.g. contaminants, their nature and their determination and risks. Furthermore it is absolutely necessary to identify and address public concerns and give the public the possibility to express its thoughts and concerns in order to build a trustful relation between the authorities and the public (Vangronsfeld & Cunningham 1998). Especially public information materials should contain clear and well presented information and should emphasis the value of independent endorsement in terms of preserving and building trust and credibility (Kemp et al., 1998). In this context, Vangronsfeld & Cunningham (1998) as well as Hesske et al. (1998) refer to an effective communication and education to still potential public concerns on the one hand and on the other hand generate acceptance to all the measures in respect to the contamination especially the remediation technology. The development of such risk communication strategies, improve the awareness of the overall approach and objectives of land contamination (Kemp et al., 1998). For authorities it is very important to start these activities as early as possible before specific site issues become a focus of local concern. In the next step public involvement should follow to avoid potential suspicion against authority's actions (Kemp et al., 1998). In the whole process 'trust' is one key factor for a successful performance of remediation (Kemp et al., 1998).

In the communication process all affected people like inhabitants, future land users, stakeholders and public agencies should be involved (Hesske et al., 1998). Hugo et al. (1999) point out, that participation of inhabitants in the remediation process from the very beginning can influence acceptance directly. In addition, an open and extensive information policy and introduction in the problem is decreasing uncertainty, supporting mutual understanding and increasing acceptance. Furthermore such information policy can form a basis for active participation of affected people in the planning process and develop a sustainable confidence in the measure. In this sense it seems useful if administration is willing to accept affected people as parties to deal of the same grade. That means each side, expert and public, has something valid to contribute and each side must respect the insights and intelligence of the other (Hugo et al., 1999).

Very important for the success of communication is the knowledge of affected people (Grasmück & Scholz, 2005; Matschonat et al., 2004). Grasmück & Scholz (2005) reported a great deal of variation in the knowledge of people from a case study in Switzerland although information was easily and similarly available for everyone. Further they found out that people were unaware of the influence of knowledge on their own risk perception and self-estimated knowledge and desire of further information seemed to vary independently of actual knowledge people had. People have a different need of further information. Depending on their own risk perception different arguments are necessary to explain the risk and to convince them of the need for remediation. For example Matschonat et al. (2004) investigated two different groups of people. The first group were residents living on a contaminated area, which was remediated. The residents had no knowledge about soils in general, but got detailed information on physical properties of soil and about the several aspects of remediation by the remediation company. Although these people could reproduce the correct information they were unable to integrate this knowledge in a comprehensive construct because of a lack of specific soil knowledge: the remediation residents felt at risk and expressed distrust against authorities and the remediation company. The second group were allotment holders, who collected soil knowledge because of their activities in their garden plots. These people could be characterized as self-confident because of their knowledge and they felt not unsettled by risk. But in the contrast to the first group this one could hardly be convinced that they aren't right in all their arguments. Often these people consider their knowledge to be right and don't accept expert's knowledge as to be better. In the case of a contamination such people may additionally use dissonance-reducing heuristics (Grasmück & Scholz 2005) and reject remediation especially if the contamination and their effects aren't obviously dangerous (Hugo et al., 1999). On the other hand in many contamination cases where public or residents are affected some people exist who are overanxious about the effects arising from the contamination. The communication with these people isn't easy too, because they could not be convinced with rational, empiric and scientific arguments and they get at panic situations very fast. It is very important to listen to their concerns and problems, to calm them down and to explain with easy understandable arguments that remediation is the best solution for all their fears.

The absolutely wrong way would be lacking communication and participation of affected people. It is clear that in the moment of intensified public concerns about a contamination an absence of appropriate information or the withholding of information can lead to a total breakdown of trust to those in charge, and lost trust is very difficult to recover (Kemp et al., 1998, CL:AIRE 2007b). Furthermore it can lead to an absent acceptance for remediation actions especially by missing transparency of remediation decisions and its reasons (Hugo et al., 1999). In relation to Kemp et al. (1998), Hugo et al. (1999) also determined an increase in lacking acceptance may occur by dissatisfaction and distrust to agencies and policy because of delayed decisions and measures. Additionally the restrictions caused by the contamination like healthy, psychological, social and economical disadvantages can be enhanced by remediation itself what may lead to resistance against remediation (Fig. 8) (Hugo et al., 1999).

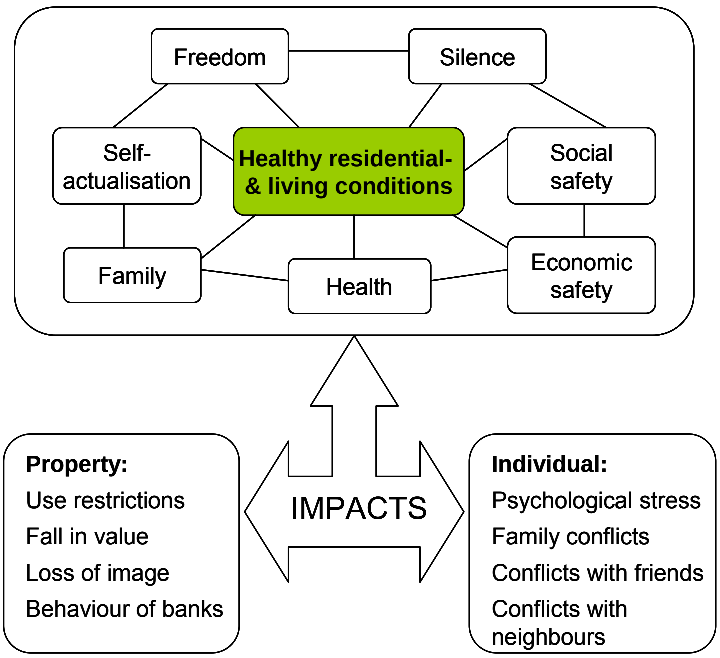


Fig. 8: *Effects of contamination to residents (modified from HUGO et al., 1999)*

The following examples from Great Britain and Germany will show the effects of different communication strategies. In the first example people in two contaminated areas (areas 'A' and 'B') where two different communication styles were practiced: In area 'A' residents were kept in distance and information was not shared, that means risk communication tend to be cautious, reactive and 'closed'. In the opposite in area 'B' residents were actively engaged in dialogues about potential risks, risk communication was proactive and 'open' and involved residents more substantively (CL:AIRE 2007b). Nevertheless residents of both areas were dissatisfied with their local councils in terms of their perceived style of communication, but dissatisfaction was stronger in 'A' than in 'B'. And overall residents were distrustful on how their local council is dealing with issues of contaminated land. Unfortunately such examples of poor practice and lack of professional risk communication like in area 'A' seems not to be uncommon within local government. If councils appeared to made more effort to be open with local residents and to engage them in discussion about the relevant issues, such distrust and dissatisfaction were significantly reduced. In general residents trusted their council far more if they were satisfied with its communication but less if they perceived to be at a relatively greater risk from contamination. The two most important predictors of residents' general trust in their councils were openness and shared interest (CL:AIRE 2007b).

The second example was from a contaminated area in Coventry where councils chose a very open and transparent communication strategy equally to the council in area 'B'. In the following, remediation of affected residents' gardens could be carried out without problems and finally residents were satisfied with the way the project was handled (CL:AIRE 2007a). Thirdly it is shown an example from the city of Leverkusen in Germany where Heisters & Welpmann (2008) queried people about a recreational park which is lying on a remediated waste heap. Most of the asked people (over 70 %) rated the park very positive and showed acceptance for the location. One argument for this great acceptance may be the open and continuing communication between the population and the authorities of Leverkusen and the liable company respectively.

To summarize these general aspects of communication and experiences from the examples it seems that acooperative style in terms of finding a consensus and a more informal behaviour without keeping to much at general guidelines but focus on the characteristics of the certain case are recommendations for policy, administration and engineers (Hugo et al., 1999). Some general aspects for communication were collected by Kemp et al. (1998) and could be extended by the findings of other authors:

- Quantitative information will be expected and should be provided in a transparent manner with all assumptions and uncertainties clarified.
- Not only the technical properties and problems of remediation should be emphasised (Hugo et al., 1999).
- It is important that public is allowed to express its thoughts and concerns in the communication process (Vangronsveld & Cunningham 1998).
- Explain terminology that would unfamiliar or confusing to non-experts.
- Do not trivialise land contamination risks by comparison with other risks.
- Public can be very well informed about scientific and technological aspects of remediation, due to this responsible persons should be aware of this fact (Glass 1999).
- Be aware that interested parties will focus on consequences rather than probabilities of harm from land contamination.
- Be aware that public perception of risk is contextual and will be influenced by factors such as the perceived effectiveness of land contamination practitioners and managers, independent of evidence and access to information.
- Present information clearly and using local contexts, but without distortion.
- Keep in mind of talking to different kind of people e.g. some using heuristics, some full of fears

A fundamental perspective to communication is captured by Paul Solvic in 1987 (cited by Kemp et al., 1998):

"Lay people sometimes lack certain information about hazards. However, their basic conceptualisation of risk is much richer than that of experts and reflects legitimate concerns that are typically omitted from expert risk assessments. As a result, risk communication and risk assessment efforts are destined to fail unless they are structured in a tow-way process. Each side, expert and public, has something valid to contribute. Each side must respect the insights and intelligence of the other."

Beside the facts of communication strategy a relation between communication, acceptance and the remediation technology exists. Generally the awareness of the contamination leads to a high acceptance and willingness to act regarding a possible remediation (Kemp et al., 1998). In dependence on the special contamination case various remediation technologies should be communicated in order to have different possibilities for action. I.e. dependent on acceptance and the different requirements of affected people the appropriate solution can be found.

Gentle remediation options are attractive and can be easily communicated to public as ecological and sustainable i.e. as 'green' technology (Vangronsveld & Cunningham 1998). The use of plants is generally considered to be an aesthetically pleasing means of remediation a contaminated site than use of heavy machinery which can involve noise, disruption, frequent worker activity and unsightliness. According to many reports from practitioners phytoremediation has already proven popular with interested public at field sites where it has been implemented (Glass 1999). Similar findings are reported from the study made by HESSKE et al. (1998) who found that affected people if they have the choice they clearly preferred gentle remediation options. This technology was seen as ecological and regarding the cost-benefit as more favourable. Especially the fact of sustainability met the agreement of the people because the soil is preserved as a living ecosystem as well as fertile soil for future generations. In this sense people had the feeling to support a sustainable environmental policy. Vice versa peoples' acceptance for phytorestoration can gain the acceptance for this technology by other stakeholders as well as influencing regulatory direction (Vangronsveld & Cunningham 1998).

Comparable results were found by a study from Janikowski et al., 2000. They compared different remediation actions for metal contaminated soils against different criteria e.g. time, cost or social acceptance. Additional these methods were assessed from two different perspectives, the land owners and the ecologists. The results show, that technologies with low economically and ecologically cost and with high public acceptance were preferred. Regardless of the perspective of assessment, the cultivation of non-edible plants (phytostabilisation) on contaminated soils was a preferred method. In the case of the ecologist perspective phytoextraction was the second most preferable option. Furthermore Janikowski et al. (2000) could show, that gentle remediation options have also a benefit in the macroscale perspective: remediation using commercial crops is consistent with the goals of environmental policy in Poland and helps to reduce greenhouse gases and increase the share of renewable energy in the primary energy balance. From the microscale point of view phytoremediation can be also applied because it can create additional job opportunities.

But beside phytorestorations' green image there exist some provisos. First, most regulators and decision makers have little or no experiences with phytoremediation and – if at all- the technology is accepted as an interim measure or is considered even to be 'better than nothing' (Vangronsveld & Cunningham 1998). Additionally, if only little specific skills exist on the decision making level there will be no one who is able to communicate all the aspects regarding gentle remediation to affected people. But especially in the case of phytorestoration it is necessary to explain the public on how phytorestoration works (Vangronsveld & Cunningham 1998). People have to be accurately informed about the efficacy of the technology but also about the additional potential risks, benefits and limitations (Glass 1999, Vangronsveld & Cunningham 1998). Moreover phytoremediation as an alternative method must be able to manage potential risks to acceptable levels. Only with this knowledge and the full understanding of technology people will accept and perceive phytorestoration as an appropriate measure (Vangronsveld & Cunningham 1998).

Secondly, phytorestoration is a time consuming measure with duration of remediation from several decades up to centuries (Vassilev et al., 2004, Pulford & Watson 2003, Robinson et al., 2003, Soriano & Fereres 2003). In this context Hesske et al. (1998) found that a remediation time of 5 to 10 years seems to be acceptable for affected people. Against this background an intensive communication over all the years of the remediation process is necessary in order to sustain peoples' trust and acceptance as well as to obtain a long-term solution. But it has to be stated that selecting an appropriate remedial strategy for a specific contaminated site is a process which has to involve the balancing of technical, social, economic and other policy issues (MARTIN & HERBERT 1998).

6.4.3.4 Conclusions

Beyond all the aspects of phytoremediation the main goal of any remediation action should be the stabilizing of the site in ecological, economical and social terms (Fig 9). Ecological stabilizing means in the best form the absolutely cleansing of the soil i.e. total elimination of the contaminants or obtaining concentration levels in the range of the natural background values.

Economical stabilization should aim at a reuse of the soil. In the case of non-urban sites this could be agricultural or forestry usage in terms of urban areas it may be used for housing, parks etc. Closely connected with ecological and economical stabilization is the social stabilization. On the one hand remediated sites which can be economically reused provide the possibility to its owners to earn their money from the use. On the other site users from remediated public areas like parks or children playgrounds feel certain because of successful remediation and the restored ecological status.

Pulford & Watson (2003):

‘Local authorities, private companies and other bodies involved with the remediation of contaminated land should be encouraged to use phytoremediation, especially if budgets are limited and the alternative is that no treatment is carried out. There is an opportunity to use these sites as demonstration and research areas.’

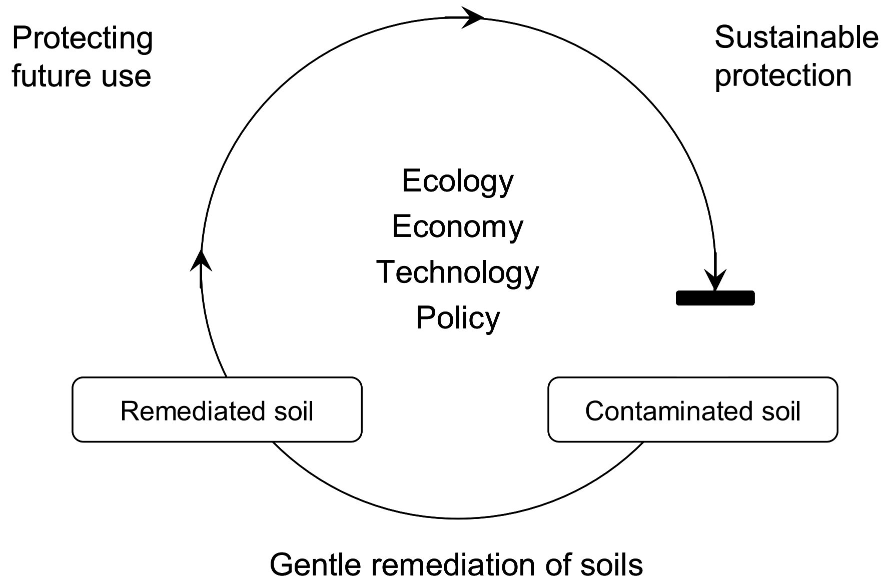


Fig. 9: *Concept for a gentle remediation of a polluted soil and a following sustainable use (HESSKE et al., 1998)*

6.4.4 Metal contaminated biomass for valorization purposes – a review and a case study

Bert V., Tack K., Vialletelle F., Magnié M-C., Cochet N., Schoefs O.

6.4.4.1 Introduction

Phytoextraction is a promising method to remediate soils and sediments contaminated with trace elements. By now, there is two main phytoextraction strategies. The first one uses high biomass crop species, generally not metal specific with low average metal concentrations. The second one uses metal hyperaccumulators. These plants are wild plants, generally with low biomass and able to accumulate in their

above ground parts one or two metals in very unusual quantity (e.g. >0.01% Cd and >1% Zn DW) (Baker and Brooks, 1989; Reeves et al., 2000).
Although the problem of metal contaminated biomass valorization following phytoextraction is crucial for the economic feasibility of the technology, its public acceptance and for convincing policy makers, it is poorly addressed (Sas-Nowosielska et al., 2004).
Processes to valorize uncontaminated non-food biomass exist. Biomass coming from agriculture, forest, gardens and parks are valorizable in bioproducts (biodegradable plastic, polymers,etc.), organic composts, furniture, feedstuff, raw material for chemistry (ink, resin,etc.), biofuels (biodiesel, bioethanol, etc.) or in bioenergy (heat and electricity) .
At present, there is no dedicated process of valorization for contaminated biomass. Indeed, very small amount of highly contaminated biomass is available for valorization. Metal content may be a limitation for valorization purposes and contaminated biomass has to fit with current regulations. As a consequence, combustion is by far the most important conversion route for biomass (Vassilev et al., 2004; Keller et al., 2005; Lewandowski et al., 2006).
The aim of this work is to address the following question: What to do with highly metal contaminated biomass coming from phytoextraction with hyperaccumulators and high biomass plants? To answer this question, a review of both literature and European or national regulations regarding biomass valorization possibilities was undertaken to see how and where contaminated biomass can fit in. In addition, preliminary experiments were performed with a Zn and Cd hyperaccumulating plant to test incineration and two pre-treatment steps. High incineration standard is presented as a feasible, economically acceptable and environmentally sound approach. Does it work with Zn and Cd hyperaccumulators? After harvest, several authors have proposed to pre-treat highly contaminated biomass in order to reduce its volume before incineration or disposal (Sas-Nowosielska et al., 2004). Our purpose is to pre-treat highly contaminated biomass using composting or leaching to reduce metal content or concentration and thus facilitate its valorization in existing processes.

6.4.4.2 Definitions

In literature, biomass is usually defined as renewable and organic plant material such as trees, grasses, agricultural crops, agricultural waste or other plant material. In recent literature, the term biomass is associated with the use of such plant material to produce energy or to convert it into gas or fuel (Lievens et al., 2008 a,b; Van Ginneken et al. 2007). Regarding European regulation, reference is made towards two EU biomass definitions. The first is the one mentioned in EU directive on Renewable Energy 2001/77/EC where biomass is defined as “the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste”. The second is the definition mentioned in EU directives on Large Combustion Plant 2001/80/EC and Waste Incineration 2000/76/EC where “biomass consists of those products that are completely or partly composed of vegetable agriculture or forestry materials that can be used as a fuel to utilise its energy content, as well as the waste materials that can be used as a fuel”.
To our knowledge, there is no regulation that defines the term “contaminated biomass”. For instance, in the Netherlands, the Dutch Government has set two lists, a “White list” with clean biomass and a “Yellow list” with contaminated biomass. The White list contains all the materials that are mentioned in EU directive 2001/80/EC and the Yellow list contains all other materials that contain biomass but are contaminated with other materials. The Yellow list contains examples but is not complete.
In literature, there is no clear definition of what is called “contaminated biomass”. Generally, it is stated by the authors that plant biomass is considered as a contaminated one if it accumulates abnormal concentrations of contaminants compared to averaged concentrations normally found in most of plant species (kabata-Pendias and Pendias, 1992) or if plant biomass accumulates contaminant concentrations that exceed feedstuff regulation.
Literature dealing with contaminated biomass is focused on hyperaccumulators like *Thlaspi caerulescens* or *Alyssum* sp., crop plants and biomass energy crops with annual important biomass like maize, sunflower, rape seed, wheat, poplar or willow trees.
It is interesting to note that energy crops (i.e. any crop purposely grown for energy, including annual and perennial crops, short rotation coppice, grasses such as *Miscanthus*, etc.) are not concerned by the Waste Incineration Directive because they are considered a fuel and not a waste.

6.4.4.3 Literature review

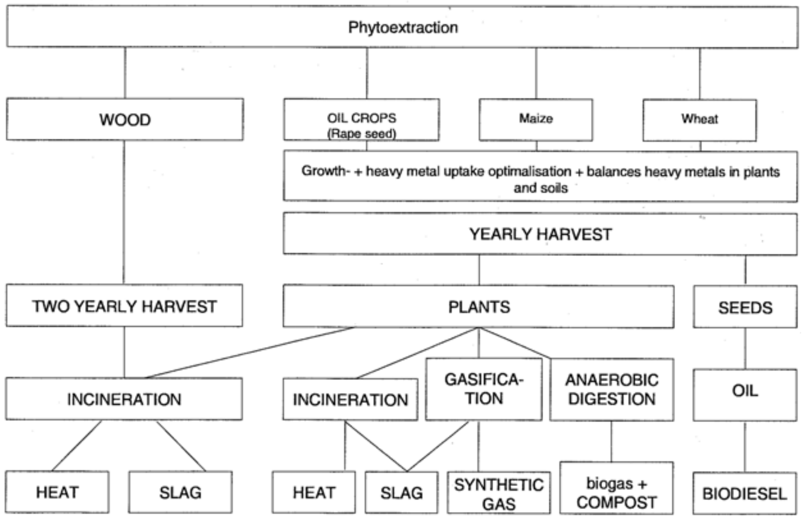


Fig 1. Representation of studied techniques to produce bioenergy from energy crops used in the remediation of soils contaminated with heavy metals

Fig 10: Representation of studied techniques to produce bioenergy from energy crops used in the remediation of soils contaminated with heavy metals.

Literature related to phytoextraction and cost recuperation through, for instance, recovery of metals or energy production from phytoextraction biomass is relatively recent and scarce. The most famous example is coming from Li *et al.* (2003) who reported the recovery of nickel (Ni), a valuable metal, from the ash of *Alyssum* biomass and the use of water extracts of Ni-rich *Alyssum* biomass as a replacement of a commercial Ni salt fertilizer. Chaney et al. (2008) have suggested to increase the commercial viability of phytoextraction by recovering energy during burn of *Alyssum* biomass.
Concerning metal contaminated biomass with Zn, Cd and Pb, studies have not reached such practical development and little information concerning valorization of such biomass is available. In a recent paper, Van Ginneken *et al.* (2007) give an overview of the different potential energy-recovery-techniques (incineration, gasification, anaerobic digestion and pure plant oil productionto valorize the bioenergy crops obtained in a case of phytoextraction (Fig. 10).

Keller *et al.* (2005) stated that contaminated plant parts cannot be recycled as green material and have to be disposed off in a safe manner. Incineration experiments performed on leaves of *T. caerulescens*, a Zn and Cd hyperaccumulating plant, have shown that incineration was a viable option for the treatment of the heavy metal-enriched plants, even if the authors indicated that the technique will have to be optimised. Keller *et al.* (2005) proposed to co-incinerate *T. caerulescens* leaves with other wastes because of the low amount of biomass that might be produced. In addition, authors suggested to recycle the bottom ash as fertiliser and to recover energy from the biomass to make an additional benefit. For instance, several authors assume combustion for the energetic use of Cd contaminated willow (*Salix* sp.) (Lewandowski *et al.*, 2006). Nevertheless, depending on the amount of metals in the biomass and the available combustion technique, measures like the installation of specific filters are required to ensure that metals during combustion are not emitted but are fixed in the fly ash . (*Lewandowski et al*., 2006). Giasson *et al.* (2004) performed an incineration experiment at laboratory scale with vegetation harvested after a phytorestoration experiment. The vegetation, a mixture of various non hyperaccumulating plants, accumulated 1880 mg kg^{-1} Zn DW, 21 mg kg^{-1} Cd DW and 18 mg kg^{-1} Pb DW. The aim of the study was to incinerate at low temperature metal contaminated biomass (500°C) to limit the metal volatilisation and concentrate metals in the ash residue. Results showed that Zn, Cd and Pb were highly concentrated in the ash residue (ash/plant tissue ratios: 7:1; 5:1 and 6:1 respectively for Zn, Cd and Pb). Authors concluded that it is possible to recover metals from ashes using chelates. In addition, they suggested that it should be possible to recover Zn in a Zn smelter as Zn concentration in the ashes (1.3%) are close to the lowest concentrations found in the main Zn ore used in Quebec (Sphalerite, 2%).
In their review, Sas-Nowosielska *et al.* (2004) suggested to pre-treat contaminated biomass to reduce the volume of plant material before incineration or deposition on land. Indeed, waste volume can be reduced by thermal, microbial, physical or chemical treatments using composting, compaction, leaching or pyrolysis.

Regarding composting, several studies were performed at laboratory scale with Pb contaminated biomass after EDTA induced phytoextraction (e.g. Garbisu and Alkorta, 2001; Hetland *et al.*, 2001). Authors concluded that composting can significantly reduce the volume of harvested biomass and that further investigations are needed to assess the effect of the presence of chelating agents in harvested material related to metals on composting process. Sas-Nowosielska *et al.* (2004) suggested that the chemical form of the metal within the leaves of harvested hyperaccumulators or within plant material in general should be considered as it may directly influence the obtained leachate (more or less enriched in metals). Composting, as a pre-treatment step, should decrease cost of transportation and cost of deposition. Authors pointed out that studies on composting were performed with no consideration to the agricultural properties of the final product and that contaminated decomposed biomass should be treated as harzardous material (Sas-Nowosielska *et al.*, 2004; Shilev *et al.* 2007). Giasson *et al.* (2004) performed a pilot scale composting experiment using $1m^3$ domestic composting equipment with vegetation harvested after a phytorestoration experiment. The vegetation, a mixture of various non hyperaccumulating plants, accumulated 1880 mg kg^{-1} Zn DW, 21 mg kg^{-1} Cd DW and 18 mg kg^{-1} Pb DW. The compost obtained from this vegetation presented the following values: 1272 mg kg^{-1} Zn, 10 mg kg^{-1} Cd and 17 mg kg^{-1} (DW). According to the Canadian Valorisation Guide of Fertilising residues (MDDEP, 2004), the authors concluded that the obtained compost could be used as an amendment for abandoned lands, golf, forest or to cover mining waste residues or coal wastes but not for agricultural purpose.

Compaction of harvested plant material was proposed by several authors for processing metal-rich phytoextraction residues (Salt *et al.*, 1995; Blaylock and Huang, 2000) but there was no literature on plant biomass compaction after phytoextraction. Compaction should use a container equipped with a press and a leachate collection system. Remaining contaminated biomass and leachates should be treated as hazardous wastes.

Since biomass usually contains high moisture content, and has low density, there are some difficulties of transportation, storage and usage of biomass without any pre-treatment (*Lievens et al.*, 2008a). In a recent paper, Lievens *et al*. (2008a) suggest that some thermal conversion methods such as pyrolysis, gasification and carbonization to produce fuel products or biological conversion to obtain methyl alcohol is more preferable to the direct combustion of biomass. Pyrolysis is a thermal degradation process of biomass using heat in the absence of oxygen, which results in the production of char (solid), bio-oil and tar (liquid) and fuel gas products. Lievens *et al.* (2008a) performed fast pyrolysis of birch and sunflower contaminated with metals (Cd_{birch} = 4.4 $\pm$ 0.5 mg kg^{-1} DW; $Cd_{sunflower}$ = 8.4 $\pm$ 2.2 mg kg^{-1} DW; Zn_{birch} = 1344 $\pm$ 7 mg kg^{-1} DW, $Zn_{sunflower}$ = 653 $\pm$ 110 mg kg^{-1} DW) in a lab scale reactor to concentrate metal in the ash/char fraction and to study metal distribution in the products streams at different pyrolysis temperatures. The authors concluded that at low temperature (673 K) metal contaminated biomass is not only reduced in weight and volume, but also concentrate the metals in the ash/char fraction which is interesting for recovery. The authors noticed that Cd compounds are more susceptible to volatilisation at low pyrolysis temperatures than Zn compounds and that Cd and Zn volatilization is dependent on the type of biomass under thermal treatment. In addition, the authors concluded that pyrolysis has a potential for metal enrichment in the metal free non- and condensable organic fractions, making these fractions suitable for both fuel and chemical stock applications. In an other paper, Lievens *et al.* (2008b) characterised liquid and gaseous fractions to investigate the future valorisation of these fractions. The authors concluded that pyrolysis should be conducted at 673 K to minimise the heavy metal concentration in the non and condensable pyrolysis fractions. Additionally, at lower temperatures, the pyrolysis process energy imput is most likely lower and the sulphur and nitrogen content in metal contaminated birch and consequently their pyrolysis products is lower with respect to other fossil fuels, making them less polluting than e.g. coke and charcoal.

Regarding leaching, the use of leaching to extract metals from harvested biomass has been described by several authors (Salt *et al.*, 1995; Hetland *et al.*, 2001). Hetland *et al.* (2001) assessed chelation extraction with EDTA and ADA as a technique for the recovery of Pb from harvested biomass. They showed that at a pH of 4.5 and a 1:4.76 molar ratio of Pb to EDTA, it is possible to extract 98.5% of the Pb present in the biomass using 2 sequential batch extractions. In their opinion, this technique would be very attractive if Pb could be efficiently and cost-effectively separated from the chelating agent and the chelating agent could be recycled.

In their paper, Van Ginneken *et al.* (2007) discussed the possibilities to produce biodiesel from heavy metal contaminated rape seed (*Brassica napus*) using non-catalytic transesterification in supercritical methanol. After harvesting rape seed from a contaminated site, the seeds may be further processed to obtain the rape seed oil. The authors suggest that one of the major advantages of using the non-catalysed supercritical methanol process over the more conventional base-catalysed process is that purification of glycerol and fatty acid methyl esters becomes much simpler and can make the production of biodiesel much more attractive. They also suggest that, since the excess methanol can be easily recycled, and virtually no waste products are produced, this method can be regarded as a good example of green chemistry. However, the authors concluded that a crucial question remains unanswered about the content of heavy metals in biodiesel obtained from the oil of contaminated rape seed. In particular, the authors cited a study performed on accumulation and distribution of Cd, Cu and Pb in plant organs and in the oil of rape seed (Angelova *et al.*, 2005) showing the although the metal concentrations were the lowest in the seeds, the concentrations of Cd, Cu et Pb in the rape seed oil were higher than the accepted maximum permissible concentrations for human consumption.

6.4.4.4 Regulation review

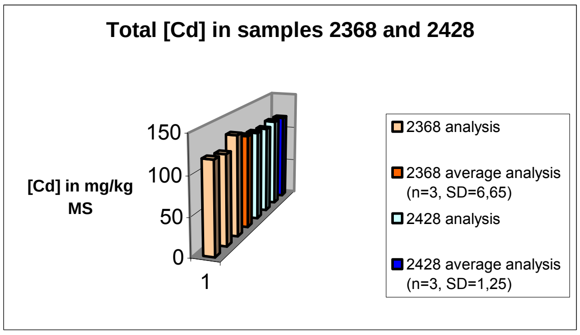
As shown previously, there is no definition and no current regulation that specify contaminated biomass. The reason why may be the absence of metal contaminated biomass on the market. As a consequence, regulators have not being faced to this case yet. Thus, in absence of specific regulation, the first question could be whether or not contaminated biomass is a waste (according to the Waste Directive (2008/12/EC)). A waste means any substance or object in the categories set out in Annex 1 of the Waste Directive which the holder discards or intends or is required to discard. Alternatively, could contaminated biomass be considered as a fuel and not as a waste if the plants were purposely grown for energy? In this case, the Waste Incineration Directive would not apply. Whatever the status of contaminated biomass, requirements under Integrated Pollution, Prevention and Control (IPPC) have to be reached as well as eligibility criteria and relevant emissions regulations under Waste Framework Directive, Waste Incineration Directive, Large Combustion Plant Directive or Renewable Energy Directive.

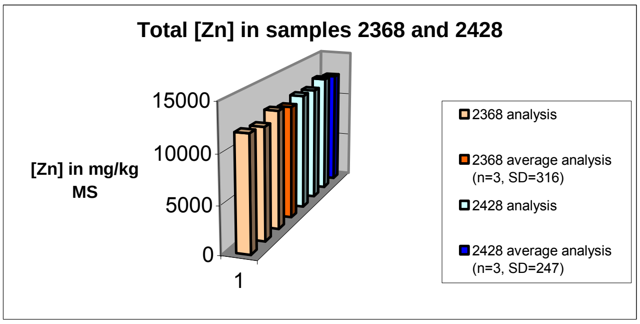
6.4.4.5 Second part: Experimental work

a) Material and Methods

Plant material: *Arabidopsis halleri* is one of the two existing hyperaccumulators of Zn and Cd (Huguet et al., 2007; Bert et al., 2003). Fifty kg of fresh aerial parts of *A. halleri* were harvested on a highly metal contaminated soil (Auby, Bois des Asturies, France) in April 2008. At the time of harvest, *A. halleri* was not flowering. The concentrations measured in the aerial plant parts were as follow: 122 mg kg^{-1} Cd DW (0.12%), 12,015 mg kg^{-1} Zn DW (1.2%) and 60 mg kg^{-1} Pb DW (sample called 2368 in Fig. 11 and in leaching experiments). Plant material was divided in 3 samples and used as fresh or dried material in pre-treatment experiments (leaching and composting).

In July 2008, when A. halleri was flowering, a second harvest was performed to look at the influence of the development stage on pre-treatment efficiency (leaching). This plant material was used to test incineration. Measured concentrations were similar to the previous ones (119 mg kg^{-1} Cd DW, 12,542 mg kg^{-1} Zn DW and 73 mg kg^{-1} Pb DW) (sample called 2428 in Fig. 11 and in leaching experiments).





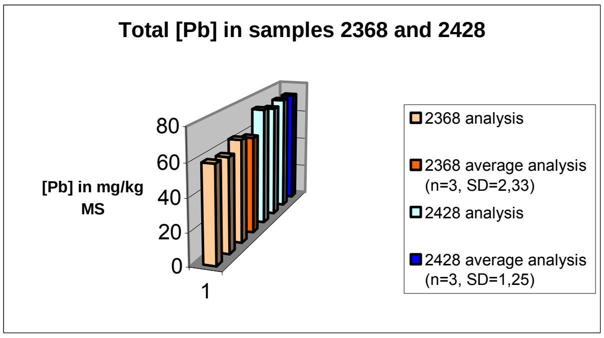


Fig 11: Cd, Pb, Zn concentrations analysed in the plant samples before experiments (three acid mineralisations for each sample, followed by ICP-AES analysis)

Conditions and experimental design for incineration: Incineration was carried out on A. halleri to study its behaviour during the process. The main goals were to estimate the content of the metals in the gaseous emissions and in the residue after the thermal decomposition. The metal concentration found in the emissions could be compared to the regulation values for incineration (Directive 2000/76/CE). These values are applied for measurement performed by the authorities annually for these waste incinerators. During this measurement campaign, gases are periodically sampled at a given time between 30 min and 8 hours. The results took into account correspond to an average of different measurements. Results must be lower than 0.05 mg.Nm-3 for Cd and lower than 0.5 mg.Nm-3 for Pb according to annex V of the European Directive. Zn is not regulated due to its lower toxicity compared to the one of Cd.

To assess the metal concentration in these emissions, a tubular oven, also called tubular calorimeter, was used to model the incineration process in laboratory.
Some investigations performed at INERIS have shown that it is particularly relevant to use this kind of apparatus to reproduce conditions of combustion in incinerator. Until now, it is the only method that allows to the pollutants emitted during combustion at a given temperature. More commonly, this calorimeter is used to simulate fires on materials with the objectives to analyse the combustion gas as described in the following French standards NF X 70-100-1 and NF X 70-100-2.
According to theses ones, the combustion process was performed at 800°C under a controlled air atmosphere with a discharge equal to 2 L.min-1. All the parameters of the tubular oven are predetermined :

- tube in silica,
- the internal diameter of the oven (□) is equal to 40 mm,
- the homogeneous heating length is equal to 600 mm.

The combustion was performed during 20 minutes . A blank of combustion was also performed during the same time, before combustion of the sample.

The combustion assay was performed on *A. halleri*. The sample was dried and crushed before the introduction in the oven to have an homogeneous sample. 1 g of the sample was used for the combustion assay.

The gaseous emissions were trapped into adsorption solutions which were a mixture HNO3/H2O2 (50/50, v/v). The goal was to dissolve metals from the gas phase into the liquid phase. Three vials with 100 mL of the adsorption solution were put in series at the outlet of the tube to be sure to trap the maximum of the metals.

Next, the Cd, Pb and Zn analyses were performed for the adsorption solutions and for residues by ICP/OES (Inductively Coupled Plasma / Optical Emission Spectrometry).

Conditions and experimental design for leaching: In parallel to the composting tests, leaching experiments were carried out as an alternative way for a pre-treatment before valorisation of the contaminated biomass. As no study has been found in the literature concerning leaching of Zn and Cd polluted plants, the trials have been run following existing procedures used for polluted inorganic materials (e.g. bottom ashes, fly ashes and APC residues) and also according to the experience of INERTEC in the treatment of waste and polluted soils.

The objectives of these experiments were on one hand to assess the possibility of extracting metals contained in the plants by leaching and on the other hand to obtain the characteristics of the plants after leaching, regarding a further valorisation. The experiments were performed with two dried polluted samples of Arabidopsis halleri (samples 2368 and 2428). Leaching tests were conducted with classical laboratory equipment: each sample of polluted plant was put in a balloon in which a leaching solution was added (ratio liquid/solid of 15), the whole being agitated during 24 hours.
Five different leaching solutions were tested for the first sample 2368:

- Water at 20°C,
- Water at 60°C,
- *Aqua regia*,
- EDTA / ammonia pH of 7,
- EDTA / ammonia pH of 10.

Due to insufficient available quantities of sample “2428”, only three leaching solutions were selected and tested for that sample (no significant difference observed in the previous results between water at 20°C - water at 60°C and EDTA / ammonia pH of 7 - EDTA / ammonia pH of 10):

- Water at 20°C,
- *Aqua regia*,
- EDTA / ammonia pH of 7.

After these leaching tests, the residues of the sample 2428 were kept and another battery of identical leaching tests was performed.

Conditions and experimental design for composting: During composting process, microorganisms break down organic matter and produce carbon dioxide, water, heat and humic substances. Three phases may be distinguished: the mesophilic or moderate-temperature phase (10 to 42°C), the thermophilic or high temperature phase (42 to 70°C), and finally a cooling and maturation phase (under 30°C). Mesophilic microorganisms (Bacteria and fungi coming from the soil) rapidly break down the soluble and readily degradable compounds. During the thermophilic phase (cellulolytic fungi, and bacteria of the genus Bacillus mainly) the breakdown of proteins, fats and complex carbohydrates take place.

The essential parameters to be controlled during the composting process are: particle size, aeration, moisture content and temperature.
The experimental device included plastic boxes equipped with an exhaust pipe in the bottom, and surrounded with insulating polypropylene. 5 kg of roughly cut plants were set up in each box. Leachates were recovered in plastic bags.
Two main parameters were tested on the composting of Arabidopis halleri at laboratory scale: the carbon content of plants at the beginning of the process, and the method of watering.
Of the many elements required for microbial decomposition, carbon and nitrogen are the most important. The ideal C/N ratio for composting is generally considered to be around 30. At lower ratios, nitrogen will be supplied in excess and will be lost as ammonia gas, causing undesirable odors. Higher ratios mean that there is not sufficient nitrogen for optimal growth of the microbial populations, so the compost will remain relatively cool and degradation will proceed at a slow rate.

In our case, the C/N value of contaminated biomass is very low, around 12. In order to test the impact of this parameter on the composting process, the carbon content was increased by sawdust addition in the boxes N°1 and 4. After 0,6 kg sawdust addition, the ration reached C/N = 35. In the boxes N°2 and 3, no sawdust was added (C/N = 12).

The moisture content was maintained inside the boxes by tap water addition (boxes N°1 and 2) or by recycling of the leachates as it is a usual procedure in composting facilities (boxes N°3 and 4).

Aeration inside the boxes was carried out by manually stirring the plants once a week.

Moisture content of the compost must be controlled and maintained up to 60%. Watering was provided with tap water or with leachates.

Measurements: 9 sampling in each box were carried out along the composting assays (67 days), and each sampling was made in triplicate.
Before each sampling, the boxes were weighted.

The C/N ratio of the biomass was determined at the beginning and at the end of the assay (Total carbon and nitrogen content were performed by combustion analysis by the Laboratoire departemental d'analyses de l'Aisne).
Moisture content of the compost was measured on samples (2g) dried at 105°C to constant weight.
Room temperature and compost temperature were continuously measured by Pt100 probes set in tubes filled with water and placed in the room and inside the boxes.

b) Results

Incineration

Results for emissions: The results obtained by ICP/OES, in $\mu g.L^{-1}$, were expressed by taking into account the sample mass and the right total volume of each adsorption vial.

The results (Table 27) here after take into account the sum of metals measured in the 3 successive vials.

Table 27 : Comparison between the results of this work and the values from the European Directive (2000/76/CE)

Metals	Regulation values	Results of this work
Cd	0.05 $mg.Nm^{-3}$	0.53 $mg.Nm^{-3}$
Zn	No value	1.10 $mg.Nm^{-3}$
Pb	0.5 $mg.Nm^{-3}$	0.26 $mg.Nm^{-3}$

The result obtained for Cd is more than 10 times upper to the regulation value whereas the one of Pb is lower.

Table 28 : Quantity of each metal in the 3 vials put in series (µg).

	Cd	Pb	Zn
Vial 1	10.7	4.80	24.1
Vial 2	7.15	4.31	13.2
Vial 3	1.78	1.18	4.69

Moreover, regarding the quantity (µg) found for each metal in each adsorption vial (Table 28), it seems that if a fourth vial would have been used, the 3 metals would have been measured in it. Thus, the total concentration measured in the emissions would have been greatest.

Results for residue: For the residue, results are expressed in mg or g of metal per kg of residue. The concentration of the metals measured in the dry matter of *A. halleri* are also reported in the Table 29.

Table 29 : *Comparison between the metal concentration in the plant before the combustion and in the residue after the combustion.*

Metals	After flowering step (DM)	Residue
Cd	119 mg kg^{-1}	2.6 mg.kg^{-1}
Zn	12.5 g. kg^{-1}	58 g. kg^{-1}
Pb	73 mg kg^{-1}	168 mg.kg^{-1}

Cd concentration is lower in the residue than in the plant before incineration. .The most part of Cd initially contained in the plant was extracted during the combustion and volatilised in the emissions as shown by the results on emissions.. On the contrary, Zn and Pb were concentrated in the residue during the process mostly due to the thermal decomposition of the organic matter in CO_2.

Leaching

The results of the leaching experiments are presented in the following Table 30 for the first stage sample (2368) and Table 31 for the second stage sample (2428). The French limit values for agricultural spreading and composting are added in order to compare the values.

Table 30: First stage sample 2368 – results of the leaching tests (1x24 hours)

		H_2O		HCl/HNO_3		EDTA		French regulation	
	Metal concentrations in plant material before leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	Spreading	Composting
	mg/kg DM	%	mg/kg RDM	%	mg/kg RDM	%	mg/kg RDM	mg/kg DM	mg/kg DM
Cd	**120**	*9*	**218**	*58*	**101**	*85*	**36**	**20**	**3**
Pb	**60**	*19*	**97**	*15*	**102**	*68*	**38**	**800**	**180**
Zn	**12 000**	*71*	**6 909**	*89*	**2 691**	*90*	**2 284**	**3 000**	**600**

Table31: *Second stage sample 2428 – results of the leaching tests (1x24 hours):*

		H_2O		HCl/HNO_3		EDTA		French regulation	
	Metal concentrations in plant material before leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	% of initial metal concentration leached	Metal concentrations in the plant residue after leaching	Spreading	Composting
	mg/kg DM	**%**	mg/kg RDM	%	mg/kg RDM	%	mg/kg RDM	mg/kg DM	mg/kg DM
Cd	**119**	***25***	**178**	*75*	**60**	*52*	**115**	**20**	**3**
Pb	**73**	***23***	**112**	*31*	**101**	*65*	**51**	**800**	**180**
Zn	**12 542**	***55***	**11 221**	*74*	**6 417**	*73*	**6 868**	**3 000**	**600**

The leachates analysis show that leaching allows the extraction of important quantities of cadmium, lead and zinc, but with different efficiencies according to the leaching solution used:

- Water is not efficient for extracting cadmium and lead,
- *Aqua regia* is rather efficient for extracting cadmium and zinc,
- Leaching with EDTA allows satisfying extraction for cadmium, lead and zinc.

Moreover, an average reduction of 50% weight has been observed for the two samples tested, which explains the fact that the concentration in the residues may be higher than in initial samples.

When comparing the concentrations remaining in the residue after leaching and the French regulation thresholds (agricultural spreading and composting), it appears that the results obtained are exceeding French limit values for cadmium and zinc: valorization of the residue (obtained after leaching) by agricultural spreading or composting is then not conceivable if considered as a final treatment, but may be interesting if considered as a pre-treatment.

Composting

- The activity of microorganisms (fungi and bacteria) during the biodegradation of the plants leads to a high weight loss due to carbon dioxide and water production (evaporation and leachates). The evolution of the total fresh weight shows the reduction of the weight for each box (Fig. 12) and after 67 days composting at laboratory scale, we observed 80% (average value) loss of biomass weight whatever the boxes and the conditions.

- The metal contents in each box (Cd, Zn, Cu, Pb, expressed in mg) have been determined for each box at day 0, 38, 54, and 67. These values have been calculated from the statement:

Metal content in the box (mg) = Biomass fresh weight (g) * Biomass dry matter (%) * metal concentration (μg/g DM) / 1000. The evolution of the Cd content is given as an example on Fig. 12:

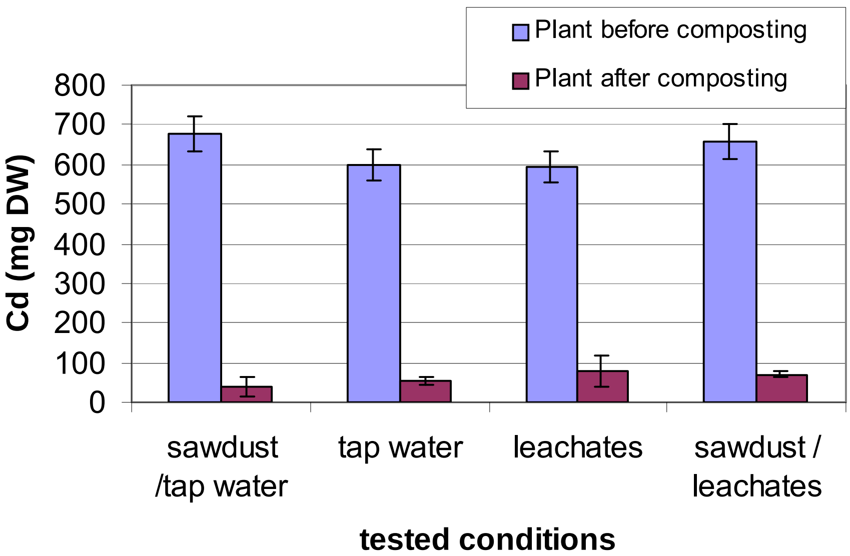


Fig 12: Cadmium content (mg) in fresh plants in each box before and after 67 days composting, related to tested conditions (average ± SD, n=3)

The reduction of the metals content in the biomass is quite clear at the beginning of the process, between day 0 and day 38 (data not shown). In each box, the plants have lost a large amount of metals which have been transferred in the liquid phase and eliminated in the leachates.(data not shown).

Table 32: Metal contents expressed in each box before composting (value in brackets) and after composting, related to tested conditions. The results (averages ± SD, n=3) are expressed in mg and the remaining metal contents after composting are expressed in % related to the initial plant metal content, i.e. before composting.

Plant metal contents (mg)				
Metals	**Sawdust + tap water** **Box 1**	**Tap water** **Box 2**	**Leachates** **Box 3**	**Sawdust + leachates** **Box 4**
Zn	(66 417±2275) 5 959±1070 *9%*	(58 800±2014) 8 175±2393 *14%*	(58 200±1993) 15 462±3297 *27%*	(64 404±2206) 5 981±398 *9%*
Cd	(664±46) 39±23 *6%*	(588±40) 54±10 *9%*	(582±40) 78±40 *13%*	(644±44) 69±7 *11%*
Pb	(332±17) 23±13 *7%*	(294±15) 18±2 *6%*	(291±15) 40±10 *14%*	(322±17) 29±2 *9%*

At laboratory scale, metal contents were greatly reduced by composting. The remaining metal contents appeared very low (6% for Cd in box 1; Table 32).

Comparing the evolution of the metal contents in the different boxes and at that preliminary state of our assays, it's not possible to show any influence of the C/N ratio on the metal content reduction in the plants.

- At the end of the process, the metal concentrations in the different produced composts (mg/kg DM in the plants after composting) were compared with the concentrations determined before composting and the regulation values for organic amendments (NFU 44-051, 2006) in Table 33.

Whatever the tested conditions, metals were concentrated during the composting process in the composted biomass due to mass reduction of the initial contaminated plants. Consequently, the concentrations of Cd and Zn in the composted biomass exceeded the French regulation values and it is not possible to use the composts produced during these assays as organic amendments.

Table 33: Comparison between regulation values for organic amendments (NFU 44-051, 2006) and the concentrations of metal in the produced composts (average values expressed in mg/kg DM ± SD, n=3 in the plants after 67 days composting)

Metals mg/kg DM	Plant metal concentrations before composting	**Regulation values**	**Sawdust + tap water Box 1**	**Tap water Box 2**	**Leachates Box 3**	**Sawdust + leachates Box 4**
Zn	12 000 ± 387	**600**	**12379** ± 2199	**31974** ± 9295	**33412** ± 7058	**10400** ± 672
Cd	120 ± 2	**3**	**82** ± 49	**210** ± 39	**168** ± 86	**120** ± 12
Pb	60 ± 3	**180**	**47** ± 27	**72** ± 8	**86** ± 22	**50** ± 4

c) Discussion

Incineration: The different behaviours observed for the 3 metals during the combustion could be partly explained, by their melting and boiling points (Table 34) even if these metals are not in a pure form but in a vegetal matrix. Indeed, for Cd melting and boiling temperatures are both lesser than the combustion temperature used in the experiment. Thus, it seems that this element is essentially in the gas phase. At 800°C, the boiling points are not reached for Pb and Zn. That can explain why theses elements stayed in the residue. Incineration conditions such as O2 excess, residence time, presence of chelating agent may have also influenced the obtained results.

Table 34: Melting and boiling points for Cd, Pb and Zn.

Metals	Melting point (°C)	Boiling point (°C)
Cd	312	767
Zn	419	907
Pb	327	1749

The important decrease of the Cd amount in the residue can suggest that a combustion performed at a temperature higher than 800°C and/or during a longest heating period would allow to totally eliminate Cd in the residue.

Leaching: The tests run have mainly shown that the extraction of metals (Cd, Pb, Zn) by leaching is possible, but that, regarding the French regulation, the residue obtained contains too high quantities of Zn and Cd to be used directly for composting or agricultural spreading.

Composting: From the results obtained with these preliminary assays, we can conclude that it is possible to get compost from highly contaminated A. halleri. However, compared to organics, trace elements are not biodegradable during the composting process, being concentrated due to mass reduction of the original materials. Even if Cd and Zn contents are clearly reduced in the composted biomass and partly eliminated with the leachates (results not shown), the obtained compost is not valorizable for agricultural purpose.

The main impact of the composting process on the contaminated biomass is the drastic reduction of the biomass weight and volume. Consequently, with lower cost transportation to the hazardous wastes disposal, composting may be a pre-treatment step before incineration or other final disposal.

d) Conclusion

It is stated by several authors that phytoextraction, a developing technology, could be a viable option to decontaminate trace element contaminated sites when the biomass produced during the phytoextraction process could be economically valorised in the form of bioenergy or any other form that could produced economical benefit (Vassilev et al., 2004; Van Ginneken et al., 2007; Chaney et al., 2008).

The aim of the review and the experimental study was to address the following question: What to do with the metal contaminated biomass after harvest? From the literature review, we can conclude that, so far, the only phytoextraction development that includes valorization of biomass in a commercial way is reached for nickel phytoextraction by Alyssum hyperaccumulator species (Chaney et al., 2007). For other trace elements, particularly Zn and Cd, biomass valorization is an unsolved problem. It has to be noted that a lot of researches are ongoing and should give technological answers in the near future. However, these researches will have to answer the crucial question of distribution and concentrations of trace elements in the products that will be valorized in a commercial way in order to fit with current regulations. Concerning this last point, the literature review clearly shows that authors never or extremely rarely take into account legal and economic aspects whereas regulation and cost are main keys for the feasibility and applicability of a process.

The regulation review clearly showed that nothing exist related to contaminated biomass. Because regulators have not been faced to this case yet, there is no specific regulation or article. As a result, for valorization purposes, it may be advisable for developers to discuss at an early stage their valorization process with a regulator, e.g. their Environment Agency, to develop a technically rigorous, not too costly and suitable method.

Our results show that composting or leaching may be helpful to pre-treat contaminated biomass before incineration in hazardous waste plant. In addition, our results may suggest that the ash residue enriched in metals would be placed in a hazardous landfill if the ash meets the criteria and in particular the TOC criterium. In such a case, ash can be, for instance, stabilised. Regarding recovery or valorisation, it should be possible to recycle metals from contaminated biomass, residues from incineration and pyrolysis or leachates. Further developments are needed on these aspects to improve the separation of the metals from the waste.

6.4.4.6 Research needs and reasons of hindrance

If biomass coming from gentle remediation option like phytostabilisation or assisted phytostabilisation is not considered as an hazardous waste, based on the Hazardous waste Directive, such biomass are valorizable in bioproducts, organic composts, furniture, feedstuff, raw material for chemistry or in bioenergy. Regarding (highly) contaminated biomass which is considered as an hazardous waste, limited options are available : incineration (including pyrolysis or any thermal treatment) and pre-treatment before incineration (e.g. composting or leaching). Further research needs and developments are related to the improvement of the processes to avoid ash-related problems during biomass incineration (e.g. slagging, deposit formation, corrosion) or to separate metals from incineration residues and leachates from pre-treated biomass. This last point should increase the possibilities for a sustainable ash utilisation, disposal and recovery options. Is it possible to separate Zn and Cd from bottom and cyclone fly ashes to get " usable ash " with low amounts of TE ? from leachates to minimise the cost of treatment and deposition? Is it possible to separate Zn from Cd related to the potential recovery of each metal? Is it economically profitable for industrials to do such separation? Very few studies are performed with metal contaminated biomass ([hyper]accumulators) and if such studies exist very few are performed at the field scale whereas phytoextraction, as a management option for a TEC site, should generate a large amount of contaminated biomass (tons/ha). Consequently there is a big need for field scale experiment and large amount of contaminated biomass to test the different options taking into account regulations and potential profits. Behaviour of metals during processes are not well known, transfers of metals from the contaminated biomass to leachates are not well known, etc. Needs for basic research are also important to improve further technologies.

6.4.5 Economic assessment of eco-technological choices: some theoretical problems and new perspectives

Jollivet P.

Proceeding to socio-economic assessment of eco-technological options such as gentle remediation faces immediately the question of the value of environmental & societal assets and services[1]. Presently, this issue is - from a theoretical standpoint - far from being solved (not to mention methodological aspects). We aim in this section at presenting the state of the research in economics concerning main clues and emerging answers to this key issue for public policy for sustainable development and remediation.

Ecological catastrophe increase GDP: the lack of valuation of environmental & societal assets in present accounting systems and conceptual frameworks

In the present public accounting framework of most countries, environmental catastrophes increase GDP[2] (main economic indicator of the wealth of nations). This counter-intuitive evidence has two main origins:

- in public accounting, there is no category as environmental asset : an environmental destruction can not have a debit counterpart in public accounting;

- the remediation actions processed by companies and institutions constitute an economic activity which is valued by public (and private) accounting ;

Consequently, and at least in a short run, the more environmental devastation, the more economic growth, as measured by common GDP-like indicators.

Similar counter-intuitive mechanism may appear concerning the economic valuation of social impacts of environmental damages[3], such as the impact of air pollution on health: at least in a short term, large scale damage to health in society may contribute to economic growth in GDP since public health is not accounted as an asset in public accounting (GDP) when the remediation to health damages (cure) is valued in accounting as an economic activity generating added value.

These concerns are relevant not only at the macro level – for public choice - but also at the micro-economic level – for private choice -. Except some quite recent legal initiatives concerning Social and Environmental

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[1] In the application and methodological side, the Cost/Benefits method of Socio-Economic Analysis critically faces this problem of valuation (and monetization) [see section on Socio-economic impact analysis in this Sumatec research]

[2] Dominique Meda, 1999, "Au-delà du PIB" Flammarion.

[3] Marc et Marque-Luisa Miringoff, 1999, The Social Health of the Nation, Oxford University Press.

Responsibility of companies, or Corporate Social Responsibility (CRS)[4], firms don't keep track in their balance sheet of anything like the environmental capital or health capital they own.

These theoretical and accounting fundamental problems of economic valuation make the issue of socio-economic impact assessment of eco-technological options very uneasy with traditional concepts, indicators and associated tools.

Valuation of public environmental goods via remediation costs approach: interest and limits

Some interesting concepts are however traditionally used in economics (notably in environmental economics and public economics) to try to bypass these concerns: public goods[5] and public assets, and valuation via remediation costs.

The first idea is to considerer that the environment needs to be analyzed in most cases as a public (local or global) or collective good[6] : its economic governance (optimal allocation of environmental resources, notably) can *not* be mainly operated via market mechanisms and private agents preferences, but rather by some public bodies representing a collective utility. Indeed, the services provided to the collectivity by a forest (quality of air via C02 capture for ex., or even benefit to public health via jogging) can not be efficiently valued, exploited and "commercialized" by a private "entrepreneur" to customers in a "pure market".

Consequently, private socio-economic assessment of environmental service or asset may lead to appropriate private choice, but will generally lead to inefficient and unsatisfactory collective choices.

The second idea consists in assessing that since it's impossible (or very uneasy or too costly) to valuing most environmental services and assets (being a collective good) via market prices one can try to base economic calculus on the costs of re-production of the damaged original environmental good. Since the value of "pure air" can not be found in a marketplace, an alternative is to estimate it through the costing of production of "pure air" from "un-pure air". We are getting close to the issue of remediation of contaminated environment and socio-economic assessment. Since it's not possible to valuating the service provided by the (clean) ground (an environmental asset), let's estimate it by costing the remediation of contaminated ground to on "original" clean status. This will ultimately enable us to value the production of "negative goods" (as pollution generated by private agents) and possibly set up public regulating mechanisms (as ecological tax) for better governing environmental assets and services.

But this perspective – as seductive as it mean seem – faces important theoretical and practical limits:

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[4] For a comprehensive presentation, see Commission Green Paper, 2001, "Promoting a European Framework for Corporate Social Responsibility".

[5] Paul A. Samuelson (1954) . "The Pure Theory of Public Expenditure". Review of Economics and Statistics, 36 (4): 387–389. doi:10.2307/1925895.

[6] Taking the example of the quality of air, we can say that this type of environmental good is a collective good since it is :

- a non-divisible good (the quality of air is the same for all in a given neighborhood),

- a non-exclusive good (in a given place, no inhabitant can be excluded from it's use);

- and a non-rival good (breathing the local air does not prevent any other inhabitant from breathing it also).

1) the value theory, in economics, demonstrates that results from valuation based on costs of production of goods, on one side, and valuation based on utility of goods (or use value) on another side, may deeply diverge. For example, the decontamination of a desert land may be costly (there have a high value based on costs) but present little utility for the (inexistent) local population of humans (there have a little value based on utility). These kind of tension may be quite strong in a decision making process for a local elective public delegate (“What if my electors don’t care … that much?”);

2) the re-production of the original environmental good (full remediation) may be either unfeasible in the present state of knowledge, or may require outrageously high of even infinite costs. This is the case for eco-technological options such as nuclear power (since it does have virtues as far as CO2 emission is concerned): the cost of decontamination for low to medium intensity radioactive residues in the World (including nuclear sites to be dismantled) was recently evaluated to 1000 billion Euros[7]. But highly radioactive residues can not being treated in the present state of knowledge. Consequently, the collective cost (or social cost) of nuclear option can not be valued, and rational economic assessment of this technological option can not be done.

   The other classical argument of non-reversibility (non economical reproducibility to an initial environmental or ecological status) deals with biodiversity: we can not re-produce a species which disappeared, whatever the amount of money we invest in it. A current illustration of a associated issue comes with OGM dissemination: it is not possible to assert this eco-technological option via a valuation based on the cost of re-production of an initial ecological/environmental status since the dissemination process is mainly irreversible.
   This last problem finds very practical economical and societal expressions with the current debate on who should pay (OGM seeds users or OGM-free seeds users) for the subsequent costs of control of non presence of OGM in products due to the recent OGM agricultural allowance in Europe?

3) some costs of re-production of environmental goods/assets have to be accounted for during a long period of time (decades from bio-decontamination of soil from trace elements; and millions of years for some radioactive residues). Economic calculus requires the use of an *actualization* parameter, traditionally expressing the “preference for the present” of individuals. But also, nowadays, this parameter ought to include the respect of the needs of future generations, as stated by the Brundland report.
   Consequently, it happens that depending on the weight we attribute to this parameter (the relative value we give to the future) results of economic calculation differ drastically: the sensitivity of this valuation model to the actualization parameter is very high in case of quite long term. To express it differently, if the term of the period of assessment is long, the result of the economic calculation will likely to be negative (option refused) if we give a value to the actualization parameter close to null (high valuation of the future).
   If we value (economically) a little bit the future, most eco-technological options generation social costs (as contaminating radioactive residues) in a quite long term are likely to be refused within a economic calculation framework, the *social cost* of long period remediation of contaminated environment being likely to result extremely high.

Toward new concepts and indicators : positive externalities, intangible assets and “pollen” economies

Even though those concepts and associated methods of valuation are interesting, they don’t provide a conceptual framework of *endogenous* ecological development: environment is still approached mainly as a cost factor constraining the economic development of nations.

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[7] LE MONDE, 01.10.08, « 1 000 milliards de dollars pour traiter l'héritage nucléaire », quoting Michele Laraia from International Atomic Energy Agency (IAEA).

Three main concepts provide some renewal of economic though toward such a endogenous sustainable growth framework[8]: endogenizing *positive* externalities, valuing intangible assets, and developing a “pollen economies” framework[9].

The major conceptual shift in political economics of the environment during the past two decades lies in the concept of endogenizing negative externalities (such as pollution). It did provide some progress at the nationwide level (such as “ecological” tax policies) as much as the micro-level (eco-conception of processes and products by firms). But this approach is lacking capacities in valuing the *positive* contribution of the environment to the economy and to the wealth of nations in general, that is needed to go toward “green growth”.

Positive externalities, intangible assets & the economics of opinion: reputation capital, image capital and the Erika trial

A new perspective is opened via the concept of endogenizing positive (environmental) externalities[10],. It theoretically allows the valuing of environmental assets through the environmental services it provides to the economy. But how to value those positive externalities, if not via the estimation of the cost of re-producing it when destroyed ? One way is to refer to the concept of intangible assets, associated to environmental assets.

The recent case of the Erika trial[11] is quite expressive to this respect. After a decade of procedures, a French high court of justice stated some month ago an historical verdict concerning socio-economic valuation of environmental assets and services[12]. Different bodies were condemned to pay an amount of about 200 million Euros to local institutions and associations in the name of two motives :

- about 1 million for financial reparation of the *cost* of remediation of damages to the environment (traditional approach of negative externalities);
- about 199 millions for reparation to the damages caused to the *image and the reputation* of the local territories, paid to different local representatives of organisms taking care of the local environment.

This second motive constitute an incarnation of a the new approach we mentioned : the positive externalities of environmental assets to the local economy (services procured by protected ecological area for instant) are valued via its positive effects on the intangible assets of “image” “reputation” of the territory. The Erika catastrophe did have a social (or collective) cost associated to damages to the environment in the form of destroying positive external effects of the environment to the image and the reputation of the local territories: this damaged image affected the “real” economy such as the seasonal tourist frequentation or the real estate local market.

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[8] Yann Moulier Boutang, 2006, *L’irruption de l’écologie ou le grand chiasme de l’économie politique*, Multitudes - 1 (no 24)| ISSN 0292-0107

[9] Yann Moulier Boutang , 2008, Le capitalisme cognitif : La Nouvelle Grande Transformation, edition Amsterdam.

[10] Yann Moulier Boutang , 1997, *La revanche des externalités, Globalisation des économies, externalités, mobilité, transformation de l'économie et de l'intervention publique*, Futur Antérieur 39-40 : septembre.

[11] From the name of the Erika tanker that devastated the Brittany coasts with heavy fuel. We refer here to the January 2008 sentence, which was appealed.

[12] Le Monde , 18 janvier 2008, *Le " préjudice écologique " fait son entrée dans le droit français*.

New indicators of wealth & value for state governance and firm strategies

This trial case may be thought as anecdotic if it was not getting along with current important transformation in firms strategies on value creation and some state governance initiatives in alternative indicators of wealth. Firms are more and more focused on the valuing of their intangible assets, such as their image and reputation *vis-à-vis* their stakeholders[13]. Pursuing it's own private utility (or interest), the firm is more and more endogenizing in its value creation strategy the care that its stakeholders show toward environmental assets[14].

In parallel, some governmental bodies[15], in the perspective of stimulating growth through a more environmental based economy, are taking initiative towards the setting up of new indicators of wealth [16] [17], including some environmental and societal assets.

Conclusion.

There still is much research to be done and socio-economic changes to impulse in order to be capable of rigorously valuing and governing environmental assets and services, and to proceed to proper socio-eco assessment of eco-technological options. But the current world financial crisis, which is connected to a crisis in social valuation of the future, may allow some ecological "new deal".

6.4.6 Socio-economic aspects of gentle remediation

Brignon J-M., Rouïl L., Gombert D

6.4.6.1 INTRODUCTION

The WP4 of the SUMATECS project has the objective to study some aspects that are closely related to the remediation process, but that were previously only partly covered by research projects. These aspects include the potential socio-economic impacts on the local population, this being linked to the principal question on the sustainability of the remediation process and its target.

This report aims at reviewing some existing socio-economic studies of remediation projects, and proposing a general methodological framework for such socio-economic assessments. Moreover, an illustration of the

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[13] About 50% of the stock capitalization of the CAC 40 companies in France are constituted by what financial analyst call the *goodwill* of the firms, i.e. an expression of its intangible capital or asset). In, *Ce que nous révèle la financiarisation sur l'économie*, A. Rebiscoul, Philippe Lentschener et Yann Moulier-Boutang, 11 juillet 2006, Le Figaro.

[14] Pascal Jollivet, 2008, *L'éthique est-elle rentable ?* in proceedings of the OI2 conference, UTC, France.

[15] The French government publicized mid 2008 the order of a study on « New indicators of Wealth » for a greener growth to two major economists : J. Stieglitz and A. Sen.

[16] Sometime refered as « Green GDP » for instance.

[17] Gadrey J. (2007) Les nouveaux indicateurs de richesse, La découverte, Second actualized edition.

practical difficulties of socio-economic assessments in this context is shown, with the help of a case study of the "La Combe du Saut" remediation project in France.

6.4.6.2 STATE OF THE ART FOR SOCIO-ECONOMIC ASSESSMENT (SEA) IN PHYTOREMEDIATION

Socio-Economic Assessment can been seen as a Decision Tool among others, such as Multi-Criteria Decision theories. Some scientific papers have been published on these other theoretical frameworks for supporting decision-making in phytoremediation projects (See the use of Multi-criteria utility functions by Scholtz et al.). Such frameworks are quite similar to SEA in that they rely on an assessment of the impacts and benefits of phytoremediation, and the use of a decision technique to make an overall appraisal of the pros and cons of different alternatives. They have the advantage of making easier the assessment and decision-making process using qualitative impact descriptions of phtoremediation projects in terms of human health, environment, economy…

SEA has long been employed to assist decision making in environmental policy, for instance in the management of chemical substances. For instance, SEA will be pivotal in the implementation of the new and ambitious European regulation concerning the authorisation of chemicals (REACH). When addressing phytoremediation in relation to its economic implications, it seems that few studies exist, and that most of them quite narrowly consider only the financial value as being part of the socio-economic value and sustainability of the projects (see Banuelos for instance). Robinson et al. take into account the cost of inaction (reputation, loss of income from tourism,…) but again only in a financial perspective.

As a consequence, it seems that appraisals and decisions regarding the economic impact of contamination sites and the socio-economic benefits of rehabiliation projects are not generally taken on transparent and rational basis (OFEPF). However, Vassilev et al. acknowledge the importance of the social or welfare point of view for benefits and costs. But in practice they are difficult to evaluate, and studies for the valuation of reduced human health, environmental and landscape damage near contaminated sites are lacking.

Lewandowski et al., review the approaches for the assessment of the economic value of the phytoremediation in the context of rehabilitation of Cadmium contaminated agricultural land. They also carry out a very detailed and complete economic assessment of a phytoremediation case study in Germany. The main conclusion is that Willingness To Pay methods are not adequate phytoremediation valuation tools, compared to hedonic pricing or substitution costs assessment.

Many authors agree that the generally longer time-period that is necessary for reaching environmental targets through phytoremediation techniques, compared to traditional techniques, is a critical point for the cost-effectiveness. That is why, as a decision support tool and to compare with the more traditional remediation methods, a cost-benefit analysis over a relevant period is appropriate Therefore, the results of cost effectiveness or cost benefit studies of phytotechnologies can be dependant on the choice for interest and depreciation rates.

6.4.6.3 PROPOSED FRAMEWORK FOR SOCIO-ECONOMIC ASSESSMENT

In this section we briefly present a possible general framework for conducting a socio-economic assessment of a phytoremediation project. This method is presented in a series of steps, and for each step, some explanations and specific recommendations for the context of phytoremediation are given.

The major steps of the proposed method are the following :

Step 1 :	Define the Aims and Scope of the SEA (scenarios, timeframe, geographical boundaries)

Step 2 :	Assessment of the environmental and health impacts of the project in for various scenarios

Step 3 :	Assessment of the economic impacts of the project for various scenarios

Step 4 :	Use the assessments to weight the positive and negative consequences of one or several scenarios

Step 5 :	Conclude on the SEA, describing also the uncertainties or unknowns of the assessment

Step 1 : AIMS AND SCOPE OF THE SEA

Discussion of aims and frameworks of the SEA

The general aim is to have captured in a single assessment of phytoremediation scenarios all « market » and all « non-market » consequences of these scenarios :

- impacts on human health (all possible causes and exposure pathways leading to mortality and morbidity, …) and the environment (ecosystems health, landscape, biodiversity, climate change, ….), along the whole chain (including valorisation of biomaterials)
- impacts on the economy in terms of financial costs and financial benefits of the remediation actions along the whole chain (including valorisation of biomaterials)

The aims of the SEA has to be clearly stated in terms of the kind of answer that is expected from the assessment :

- a "Go /no go" assessment for a phytoremediation scenario ?
- a comparison of different options for a phytoremediation project so as to select the « best » option from the overall socio-economic point of view ?

The economic analysis perspective has also to be clarified, in relation with the aims of the analysis. Basically three options are possible :

1) Cost Benefit Analysis (CBA) : CBA provides a framework for comparing the full societal costs and benefits of different remediation (and non-remediation) actions. The nature of the analysis may range from one which is mainly qualitative to one which is fully quantitative (and monetised).

CBA can indicate whether or not a particular remediation project is 'justified' in the sense that the benefits to society outweigh the costs to society.

2) Multi-Criteria Analysis : MCA describes any structured approach used to determine overall preferences among alternative options, where the options have several types of impacts and/or accomplish several objectives. Different environmental and social indicators may be developed side by side with economic costs and

benefits and MCA provides techniques for comparing and ranking different outcomes, even though a variety of indictors are used. Explicit recognition is given to the fact that a variety of both monetary and non-monetary objectives may influence policy decisions. MCA is in practice very similar to « qualitative » CBA.

3) Cost-Effectiveness Analysis (CEA) is widely used to determine the least cost means of achieving pre-set targets or goals, with these targets defined by government guidelines or legislation. A CEA is often defined in terms of finding the minimum cost of meeting a specified physical outcome. A clear and quantifiable target has therefore to be set to the remediation project

A main drawback of CEA is that non-market impacts are not taken into account.

If quantitative targets for the project are set, then there can be a variety of technical options packages that achieve (at least) 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, using Cost-Effectiveness Analysis.

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’.

If setting targets, they should be of course verifiable. If they are related to real impact (for instance in terms of reduced human exposure to a particular set of substances), then they have the advantage of being adapted to socio-economic analysis.

When undertaking an SEA, the aim and the economic analysis perspective have to be transparently and explicitly declared. Generally phytoremediation is embedded in a multi-component remediation project. If phytorehabilitation has to be assessed in terms of costs/benefits, an assessment of the impacts and benefits of the phytorehabiliation part of the project has to be carried out separately, or it has to be possible to isolate in the assessment the results that refer only to the phytoremediation part. This has to be well planned from the very beginning, and this assessment of the phytoremediation component must use the same criteria as those used for the whole project.

There are also two possible ways to use SEA regarding time :

- Ex-ante comparison :

Compare benefits associated with environmental objectives with projected cost of the rehabilitation activities projected.

Ex-ante studies are especially useful to choose between different rehabilitation alternatives. For instance SEA can be used to carry out a CEA of different alternatives that all comply with rehabilitation objectives. Ex-ante SEA can also be used to set the objectives, so as to maximise the “value for money” delivered by the rehabilitation.

- Ex-post comparison :

Compare benefits associated with the actual environmental improvements with the actual costs of the carried out rehabilitation activities.

Definition of a “reference” scenario

It is generally difficult, not to say impossible, to assess the socio-economic impacts of a project in absolute terms, without defining a reference scenario against which the socio-economic changes will be assessed.

It is important to define precisely this reference scenario, which can take different aspects, for instance :

- a ‘no action’ scenario in which a contaminated site is left without taking action.

- A non-phyto remediation scenario, against which one wants to see whether a phyto remediation alternative brings overall socio-economic improvements

Definition of the alternative(s) scenario(s)

The alternative(s) scenario(s) will consist in the technical description of a package of phyto and/or non-phyto remediation actions. Each variation in the package or in its application (timeframe, relative importance of dosage of different techniques) will be specific to a unique scenario. One should not make confusion between these technical scenarios and the environmental/human health improvement targets that may exist or not for the remediation project. Of particular importance for remediation projects is to have for any scenario a precise and complete description of the life cycle of the materials involved. The final valorisation and destination of plants in phytoremediation options has to be precisely described, because all significant impact along their lifecycle should be mentioned and assessed as far as possible.

The reference scenario and the alternative scenarios must all explore the same issues and types of outcomes in order to be comparable and the SEA to be consistent. For instance, in the case of an alternative scenario considering phytoremediation, the valorisation of plants used for phytoremediation and the associated benefits (revenue from selling the plants, etc….) will be taken into account. Symmetrically a reference scenario without phytoremediation would need to assess whether the « lost » revenue from the plants valorisation is locally compensated by another production for local actors.

Set out the time and geographical boundaries of the SEA

Because of the slow dynamics of pollutants in soils, underground water, and due to the long-term consequences of exposure of humans and ecosystems to these pollutants, the time horizon of environmental and health impacts is often very long (one generation or longer). This is even more important in phytoremediation that is a often a very long soil cleaning process compared to “traditional” engineering techniques.
As a consequence, the socio-economic analysis could have to consider very long time horizons. In order to ensure that benefits and risks of an option are compared fairly on a equal basis, the same time horizon for any impact should be used, or the difference should be justified (if an impact does not occur after a certain period).
The same issue arises for the geographical scope : not all impacts need to be considered in the same area obviously, an this area can vary from one scenario to another, but choices must be explicit and transparent so that fair comparisons between different scenarios can be made.

Steps 2 and 3 : ANALYSIS OF THE IMPACTS

Environmental impacts

Two main challenges are related to environmental impacts :

1 identifying significant impacts without setting aside one forgotten but important impact
2 assessing the impacts.
Generally, at least a qualitative description of exposure pathways should be possible, and exposure to pollutants can be assessed, and in some cases even risks estimates can be computed. However, due to the lack of knowledge of how risks translate into actual impacts, impact assessment will not always be possible. Therefore, the original aim of SEA which is to compare predicted environmental impacts with predicted benefits of scenarios will have to be degraded into a comparison of an indicator of impact and benefits.

Furthermore, some impacts are by definition qualitative (landscape for instance), therefore assessing impacts will remain most of the time a qualitative work, or will be expressed in terms of increased/decreased exposure to pollutants, or concentration of pollutants in different media.

An additional challenge is to conduct this work along the life cycle of recovered accumulating crops, and to have a integrated vision of impacts along this lifecycle.

Human Health impacts

The same remarks formulated above for environmental impacts are also valid for human health impacts.

Valuation of Environmental and Human Health impacts

If the economic analysis framework adopted for the SEA is that of CBA or MCA, then expressing the environmental and human health impacts in monetary terms will be useful.

There should be no confusion between :

- on one side, the economic impacts (on employment, income for different stakeholders and groups,…). See 3.2.4.
- on the other side the monetary value of health and environmental impacts

Both can be expressed in monetary units, so can be said in common language to be “economic”, but they are of different nature. There are techniques to express impacts in monetary units, and they are called by environmental economists ‘valuation techniques”. Their aim is to assign a value to “non-market” goods such as “a good health”, “a less contaminated underground aquifer”… Their use can make easier the comparison of impacts with socio-economic benefits of the remediation project, and they are interesting in that some of these techniques will require the consultation and the involvement of stakeholders. However, they should be used with caution to avoid misinterpretation. If valuation techniques are used to monetarise some of the impacts, it is extremely important that the other impacts that cannot be monetised (because of lack of data for instance) are not forgotten in the analysis. A presentation and a discussion of the relative merits of several valuation techniques in the context of phytoremediation projects will be found in Lewandowski et al. An example of the use of Willingness To Pay techniques is given in Younger et al.

A cautious approach is recommended when using valuation techniques : their limitations and assumptions have to be understood before drawing conclusions Especially for WTP techniques, monetary values are not very robust, and they are strongly influenced by local perception of people.

Economic impacts

Both economic benefits and costs need to be taken into account at this stage, and each of them on all targets groups, and on society as a whole.

Expressing things as benefits in the following illustration, some specific examples can be given for phytoremediation projects (this section based on Lewandowski et al) :

For the group paying for the phytoremediation (either public or private body), the benefit can be an avoided cost compared to traditional remediation, because phytoremediation is a cheaper method.

In case that farmland is contaminated, the benefit for farmers can be the future revenue associated with the valorisation of accumulating crops, and the future crops grown after decontamination. More generally, the decontamination can change the value of land (phyto techniques being used or not), and this is can be an important part of the benefits of a rehabilitation project.

On the cost side, significant examples are the following :

Cost for public bodies or industry associated with the further life cycle of the accumulating crop (for example, if incinerated, additional air treatment could be needed). More generally, cost can consist in process adaptation or new process in an industry using the bioaccumulating crops. The distinction between investment costs and operation costs has to be clear, because they are not handled in the same way if further economic calculations are carried out, such as depreciation.

Social and wider economic impacts

Some macroeconomic benefits (employment, added value in the area) could be expected in the geographical scope of the SEA, for instance if research and development on remediation, net commercial activity around the valorisation of the accumulating crop is created by the project.

Impact on employment and local added value could be assessed quantitatively. For important projects that may have large scale impacts, the use of macroeconomic models is possible, but this will probably be an exceptional case.

Other examples could be

- impact on consumers if for instance the phytoremediation projects changes consumption patterns
- impact on job satisfaction
- impacts on quality of life created by the project (losses and gains in the “utility” of some goods or services associated with the project)

These effects will generally be assessed qualitatively.

Steps 4 and 5 : COMPARING NEGATIVE IMPACTS AND BENEFITS

Finally the SEA ends generally with the comparison of positive and negative consequences of the scenarios using Cost Benefits Analysis, or the ranking of different scenarios using Multi-Criteria-Analysis or Cost Efficiency Analysis.

At this final stage, it is important to keep in mind and present transparently all the key assumptions that have been made from the beginning (setting the aim and the scope) and at each stage. Of major importance are especially :

- the list of impacts considered and discarded, and the rationale behind this choice
- the main assumptions made for simplifying the calculations of impacts
- what is left out of the scope of the assessment because there is a lack of knowledge.

For some key assumptions, it may be necessary to undertake an uncertainty analysis.

Finally it is useful to present a list of data sources, the data collection approach, and the organisations and stakeholders consulted.

6.4.6.4 ILLUSTRATION WITH THE “LA COMBE DU SAUT” REHABILITATION PROJECT

In this section of the report, one remediation project in France is taken as a case study to illustrate some key points and practical difficulties of undertaking a socio-economic assessment.

No SEA has been carried out in the project. The purpose here is not at all to point out at supposed caveats in the studies carried out for this project, but to use the context and existing studies around the project as a support to show what kind of additional studies and considerations undertaking an SEA would require in this framework.

Presentation of La Combe du Site Case Study

“La Combe du Saut” is a site in France on which two centuries of mining and metals industry caused soil contamination, most notably by Arsenic. The French ADEME undertook rehabilitation of the site, with different techniques, including phytostabilisation. A general description of the site, the environmental issues, the remediation actions undertaken and the results of these actions can be found in a synthesis report of the European project “DIFPOLMINE” (ADEME, 2007). We use this site as a case study to illustrate a proposal for template for socio-economic analysis of phytoremediation projects. The background material comes from the numerous studies carried out by BURGEAP and IRH in this LIFE project.This report ends with some comments and conclusions on the feasibility, the main methodological and data issues and gaps regarding socio-economic analysis of phytoremediation projects.

The aim and scope of the SEA

Generally phytoremediation is embedded in a remediation project. If phytorehabilitation has to be assessed in terms of costs and benefits, an assessment of the impacts and benefits of the phytorehabiliation part of the project has to be carried out. This has to be well planned from the very beginning, and this assessment must use the same criteria as those used for the whole project.

In the case of la Combe du Saut, a separate assessment of the effects of phytostabilisation has not been carried out. Such a task would probably have been difficult, because the decrease in contamination would have been to be apportioned between various rehabilitation techniques that were simultaneously used. The reports of the project describe the state of the site before the rehabilitation, the objectives of the rehabilitation, and the results of the rehabilitation project.

In this case, three scenarios would have been considered in a SEA :

- A baseline scenario corresponding to the state of the environment at cessation of industrial activities in 2004.
- An ex-ante rehabilitation scenario corresponding the environmental objectives and associated planned rehabilitation measures
- An ex-post rehabilitation scenario, corresponding to actually implemented measures and monitored improvements

The La Combe du Saut report shows that, even if ex-ante environmental objectives have been set, only an ex-post assessment was carried out. For that reason, only a baseline and an ex-post rehabilitation scenario are referred to later in this section.

The rehabilitation objectives are formulated as follows :

- to limit peak concentration of As in the river below 100 µg/l,
- to reduce the arsenic discharged yearly below 0.35 tons/year,
- to limit As concentration in run off water to 1 mg/l

and consequently to limit the production of polluted sediments and the requirement for water treatment of run-off water from the site.

Some remarks on these objectives :

- They are expressed on As, but As is one of many contaminants of the site (metals)

- Health impacts have been studied but are not defining the objectives or only very indirectly
- The objective could be related to an estimate of reduction exposure for population and ecosystems, but this work was not undertaken

Different sets of possible objectives were considered at the beginning of the project but no SEA-like study was carried out to choose the options (only some qualitative consideration of financial costs, and their implicit comparison to benefits).

Time and geographical boundaries of the SEA

The choice for the time horizon and the geographical scope for consideration of the impacts is not discussed in the available reports. For human exposure, there is an implicit assumption that around 10km distance scope is relevant. Health impacts are computed for an exposure of 10 years for adults, and 6 years for children.

Definition of the “baseline” scenario (before remediation)

<u>What has been done :</u>

The human environment comprises dispersed settlements constituted of hamlets of several houses and of villages of several hundred inhabitants located approximately five kilometres from the site. The main agricultural uses are viticulture on the plateaux and irrigated crops (vegetable gardens and market gardening) in the valley. The remaining area is occupied by scrubland and forests.
Several surveys were conducted with the nearby population. They revealed that there are several use points for ground water (traditional wells) and surface water (the Orbiel): for irrigation, watering of livestock, recreational activities (swimming pools) and even, on occasion, for human consumption. A study investigated the present heath impacts of the contamination, and these are presented in additional number of lung and skin cancers. Non-cancer risks were found to be non significant. Another study investigated the pollutant flows coming from the site, and the peak concentration in the river flowing to the site in case of a typical intense rain event : Peak As concentration : Additional flow for a typical storm rainfall event leads to the estimate of 1 770 µg/l peak concentration. Annual As flows from the site have been assessed, including surface runoff, subsurface runoff and flows as well as water infiltration from lagoons. The total yearly As flow before rehabilitation is estimated to be of around 2 tonnes.

<u>Examples of additional studies for an SEA :</u>

Study giving an estimation of impacts of other aspects of the contamination before remediation : landscape, economic and tourist attractivity of the area.

Scenario 2 after remediation

<u>What has been done :</u>

The remediation is carried out via the following techniques and steps :

- «Clean soil cover»: the polluted material is left in place, but covered with clean soil and then vegetation.
- «Partial excavation»: a part of the polluted material is excavated, transported and treated. The treatment may consist in washing the materials, stabilising the pollution or storing them within a confined perimeter. After excavation, some residual pollution will remain on the surface; this is not compatible with all uses, but can be managed in several ways:

- Direct revegetation with the addition of soil additives that immobilise the trace elements, where needed, and the selection of appropriate plants; this is the «phytostabilization» scenario applied in the context of the Difpolmine project.
  It involves the spreading and blending of steel shot at a percentage of 1% by weight in 15 cm of soil, followed by hydraulic seeding of selected plants.

  The phytoremediation is here a phytostabilization. Some qualitative objectives for phytoremediation are given : The phytostabilization protocol is designed to strengthen the cohesion of the soil, increase infiltration to the detriment of runoff (which will consequently contribute to a decrease in erosion in view of the specific nature of the problem).

  These objectives contribute to the objectives for the whole project. Their scope is wider than the objectives assigned to the whole project, in the sense that they serve the objectives but also bring additional benefits.

<u>Examples of additional studies for an SEA :</u>

A more complete description of changes (relatively to the baseline scenario) caused by the rehabilitation, that can have an impact on the environment, on human health, or have socio-economic impacts :

- how the landscape is modified
- how the future monitoring and maintenance of the phytostabilisation installations will create activity
- how the phytostabilisation could possibly later lead to phytoremediation when the concentrations of pollutants in the soil have decreased, and describe the valorisation of the biomaterials

6.4.6.5 ANALYSIS OF THE IMPACTS

Environmental impacts

<u>What has been done :</u>

The project did not really undertake an environmental assessment further than the assessment of metals concentration in water flows after remediation.

Some qualitative indications are given on the impact on landscape but there is no real assessment.

<u>Examples of additional studies for an SEA :</u>

If feasible, the reduction on metal flows and concentrations could have been expressed as an equivalent in exposure reduction to metals of water ecosystems. An indication of how the magnitude of the reduction of exposure varies within main areas under study would have been useful.

The end of the life cycle of the plants used for phytostabilisation could have been described, to give an indication whether some variations in exposure of ecosystems later in the life cycle could occur due to the contamination of these plants.

About landscape, one might argue that the benefit for landscape cannot be attributed to phytostabilisation, because any plantation independently from phytostabilisation purposes, would have improved the situation. Is it fair to apportion this benefit to the phytoremediation ?

Some issues such as long term productivity of soil could also have been investigated.

Human Health risks

What has been done :

No human health objectives were given to the project. An evaluation of exposure or impact before remediation was carried out, but not of the changes in exposure or impact after remediation.

However the evaluation made before remediation was used to qualitatively try to maximise the health benefits of the remediation actions, by targeting most important endpoints and exposure routes.

Examples of additional studies for an SEA :

An assessment of changes in human exposure to pollutants after remediation would have been key in the SEA, to objectively compare the costs of remediation with the main benefits.

To make such comparisons possible, effects need to be assessed in comparable terms before and after remediation. For instance, for inhalation exposure, if the As content of dusts coming from the contaminated site is express in flux before remediation and in concentration in PM after, no comparison is possible.

An additional issue is how to apportion the effect of phytoremediation among the whole remediation techniques package. Some hypothesis on the extent to which exposure reduction is attributable to phyto techniques has to be made somehow.

Social and Economic impacts

What has been done :

The cost of the whole remediation and of the phytostabilisation have been computed (total cost = 11 M€; phytostabilisation cost = 500 000 €)

The cost have been analysed to show that, compared to confinement in some areas of the site, phytostabilisation is competitive in financial terms.

Distinction between investment costs and operation costs has been made.

Examples of additional studies for an SEA :

Only financial costs have been assessed in the project. An SEA requires moreover, even in a qualitative manner, some assessment of the social and economic impacts. Some examples that seem relevant for this project include :

- amount of employment generated by the project, during the rehabilitation, and during the monitoring of the site. More generally, impact on the economic attractiveness of the region, including tourism.
- impact of quality of life.

6.4.6.6 FINAL COMMENTS

The examination of the La Combe du Saut project helps to underline some key points that should be kept in mind if an SEA of a project is to be made.

General recommendations

Decide whether ex-post / ex-ante analysis will be undertaken

Define which framework between CBA or CEA (or other) will be used

Impact assessment

As far as possible, try to assess at least qualitatively all impacts, especially in terms of changes before and after remediation.

Assess impact before and after remediation with the same metrics.

If some impacts are not assessed, it should be make clear in the analysis.

Comparison of costs and benefits

Assess not only financial costs of remediation, but also economic and social costs borne by other stakeholders. When presenting the results of the comparison between benefits and impacts of remediation, list all key assumptions and simplifications, and deliver the results of uncertainty analysis, even if inconclusive (for instance, in the Case of La Combe du Saut, the result of the uncertainty analysis of the health impacts was that it was not even possible to determine whether the result could be under or overestimated, nor any order of magnitude of the uncertainty).

Reasons for hindrance :

- Prediction of the impacts in the alternative scenarios is very difficult in practice : At best, only risk estimates often possible
- Assessment of socio-economic benefits of ecosystems improvement will often remain qualitative (lack of information on value) => impacts on human health might be overweighted.
- Timeframe issues : difficult to assess long-term impacts, difficult to handle long-term economic assessments; imeframe can be even much longer for phytoremediation and economic assessment much more problematic
  => research based on case study needed !
- Lack of guidance :
  Gneral guidance by COM on SEA available
  Other SEA guidance docs useful (REACH, IPPC)
  → Need for specific guidance

6.4.7 Current perception of gentle remediation options

Bernd Marschner, Ingo Müller, Rita Haag, Rosel Stolz

6.4.7.1 Objectives, background and methodology

Although numerous studies applying gentle remediation technologies have been conducted and published in the past 20 years, not much of this knowledge has been adapted in practice. Since the reasons for this are unclear, the objective of this activity was to interview experts dealing with trace element contaminated sites about their experience and opinions regarding gentle remediation options. Due to time and budget restrictions, it was decided to perform this survey with questionnaires sent out to selected stakeholders and experts in all the countries involved in SUMATECS. The questionnaire was developed in late 2007 and sent to some key respondents in three SUMATECS countries. Based on their comments and suggestions, it was revised in early 2008.

The final version of the questionnaire contains 20 questions to gather personal opinions reflecting the current knowledge of the gentle remediation methods within the above mentioned groups and additional questions to review the current experience among professionals and experts. Most questions provide either multiple choice answers or evaluations on ordinal scales, with a few open questions for opinions, suggestions or references to specific case studies or information sources (Appendix on CD-ROM). It was translated into the native languages of SUMATECS countries to involve non-English speakers. The questionnaires were sent out in March 2008 to key respondents first and later also to COST 859 action and ICOBTE / ISTEB members. The recipients of the national mailings were also contacted by telephone, in some cases repeatedly, in order to increase the response rate.

Altogether 130 answered questionnaires (Tab. 31) were collected by the national SUMATECS members and translated into English for further central evaluation at the Ruhr-University Bochum.

6.4.7.2 Origin, position and experience of respondents

Overall, most respondents are employees in public administrations 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.

For the countries with at least 5 returned questionnaires, the position of the respondents is depicted in Fig. 12, clearly showing that there were large differences between the countries.

Tab. 35: *Number of questionnaires sent out and returned in the SUMATECS countries and received from other countries*

country	# sent out	# returned
Austria (AT)	50	8
Belgium (BE)	*	5
Czech Republic (CZ)	88	29
France (FR)	56	15
Germany (DE)	107	32
Italy (IT)	50	4
Sweden (SE)	60	21
United Kingdom (UK)	18	6

Netherlands	-	1
Spain	-	2
Portugal	-	3
Finland	-	1
Israel	-	1
Vietnam	-	1
Ukraine	-	1
total	**~ 430**	**130**

When asked about their handling of issues regarding trace element contaminated sites, the majority of the respondents (65%) are dealing with this at least once a month, about 12% even daily. Only 14% have very little practical experience with such sites.

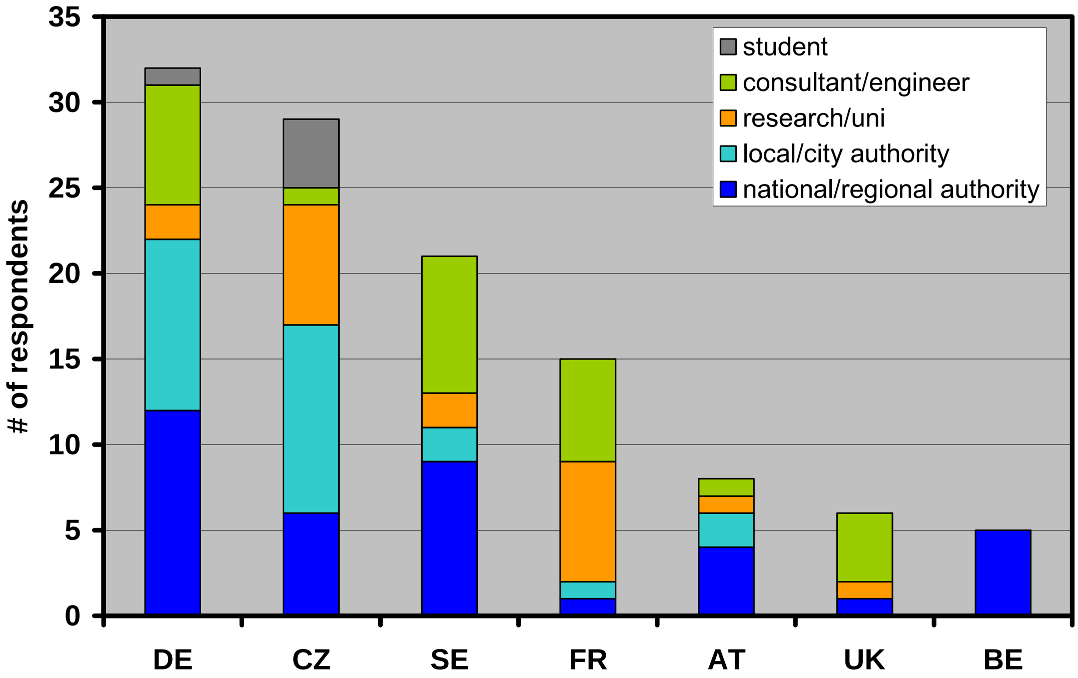


Fig. 13: Origin and position of the questionnaire respondents from the countries involved in SUMATECS.

Regarding their experience with gentle remediation technologies, the respondents marked the following answers:

Answer	%
Yes, I know about them and have planned / decided / operated on them	22
Yes, I know about them but have only limited practical experience	28
Yes, I know them but only theoretically, I have never chosen or used them	37
I know too little to decide on them / use them	12
I am not aware of them	1

So, roughly 50% of the respondents are familiar with gentle remediation options themselves, while the other half had no practical experience with them. When differentiating between the different professional groups, it becomes clear that the scientists in universities and research institutions have the most experience with gentle remediation options (Fig. 14). Employees in the local authorities who generally are directly involved in the decision making process for remediation options have a comparably low knowledge about these "alternative" technologies.

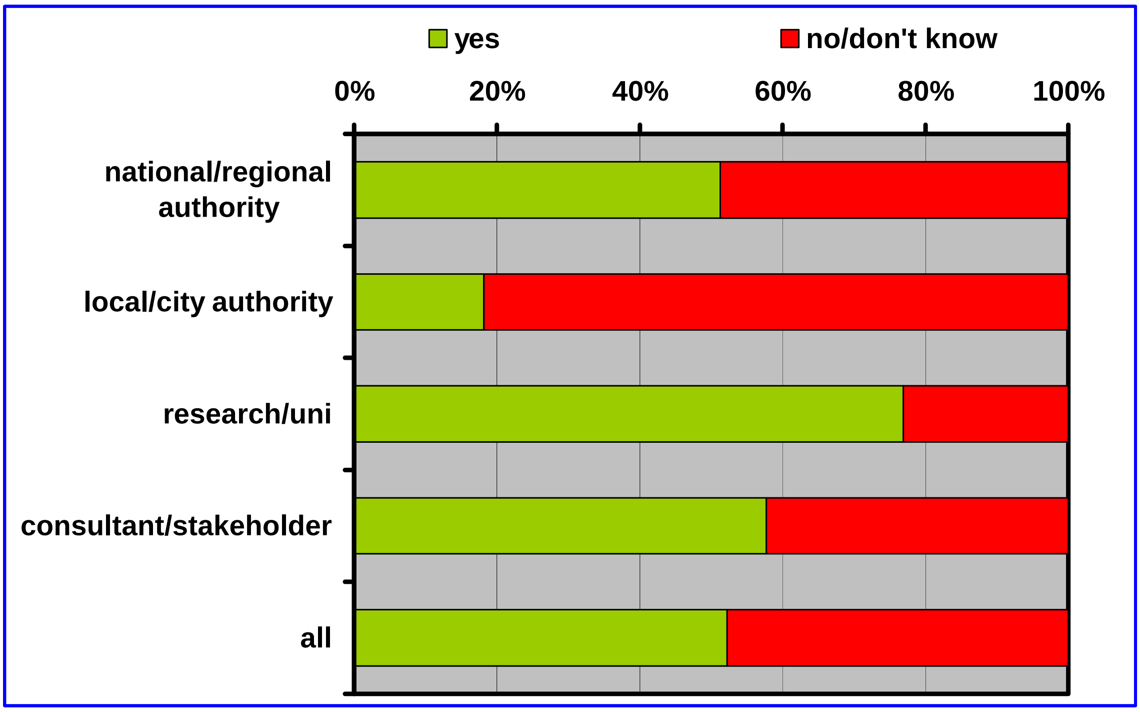


Fig. 14: *Answers to the question: "Are you familiar with “gentle” remediation options such as phytoremediation or immobilization?". All responses with at least some practical experience were summed under "yes", the remaining responses as "no/don't know".*

6.4.7.3 Evaluation of gentle remediation options

Before evaluating any specific remediation options, the interviewees were asked to rate factors according to their relevance in the process of choosing a particular remediation technology (Tab. 32). Clearly, the removal, reduction or controls of risks are considered as key factors for the remediation of contaminated sites. In this context, the extent and impact of the contamination are also considered to be of great importance, since they determine the risks for human health or the environment. Interestingly, the reduction or removal of the contaminant are not among the top most important factors, as they only are found on ranks 9 and 11. Instead, the impact of the remediation technology and the site suitability after remediation are considered more important. The factor "costs" is also only found at rank 8. Even less importance is assigned to such "soft" factors like public or private needs, social aspects, public pressure or urban planning issues. Even time constraints regarding the duration of the measure or longer-term commitments for aftercare are of relatively little importance when selecting among different remediation technologies.

The 10 most important factors were identified similarly among the professional groups. However, there were some interesting differences in ranking (Tab. 33). Local authorities who need to look for practical remediation solutions see the most important factor in reducing and controlling risks, while the national authorities, consultants and scientists primarily aim at actually removing risks. Scientists put more emphasis on impact and extent of the contamination and on the available remediation technology, while consultants and engineers regard the impact of a contamination as much more relevant than its extent or location.

Tab. 36: *Importance of factors for their relevance in choosing a remediation technology on a scale 1 (key factor) to 5 (unimportant factor). Mean values of all responses (n = 139)*

Factor	Mean
Reduction & control of risks	1.5
Removal of risks	1.6
Impact of contamination	1.6
Contamination extent/concentration level	1.8
Impact of remediation	1.8
Suitability for site use after remediation	1.8
Remediation technology/feasibility	1.8
Costs	1.9
Reduction & Control of contamination	1.9
Contaminant location	1.9
Removal of contamination	2.2
Burden of aftercare	2.4
Public needs	2.6
Spatial planning issue	2.6
Time needed for remediation	2.7
Private needs	2.8
Social aspects	2.8
Public fears/pressure	3.2
Possibility to choose or change site end use during remediation process	3.3
Site usability during remediation	3.4

Tab. 37: *Ranking of factors according to their importance rated by different professional groups. Ranking is based on mean rating values.*

Factor	**nat/reg autho.**	**local autho.**	**consult. & engineer.**	**uni & res. inst.**
Reduction & control of risks	2	1	2	9
Removal of risks	1	3	1	1
Impact of contamination	3	4	3	2
Contamination extent	6	8	10	3
Impact of remediation	4	5	5	5
Site use suitab. after remediation	5	2	4	6
Remediation technology/feasibility	7	9	7	4
Costs	8	10	6	10
Reduct./control of contamination	9	6	8	7
Contaminant location	10	7	9	8

When asked to rate the degree of site disturbance on a scale of 1-5 for different remediation technologies, the respondents gave the following average evaluation which can be grouped into three subsets (Tab. 38). Interestingly, restrictive measures such as change of crop type or land use are evaluated similarly as phytostabilisation or phytoextraction, while enhanced phytoextraction that involves the addition of acid or complexing agents is regarded as more "gentle" than on-site immobilization. On the other hand, all technologies involving soil washing or soil removal are clearly evaluated as being most disturbing.

Tab. 38: *Rating of remediation technologies according to their degree of site disturbance on a scale 1 ("gentle") to 5 ("aggressive"). Mean values of all responses (n = 139).*

remediation technologies	**rating**
Phytoextraction	1.4
Crop type change	1.6
Phytostabilisation	1.6
Land use change	1.7
Soil use restriction	2.0
Aided phytostabilisation	2.1
pH optimization	2.1

Enhanced phytoextraction	2.2
Contaminant immobilization on-site	2.7
Covering with clean soil	2.8
Soil grain size separation on-site	3.7
Contaminant immob. off-site	3.8
Soil washing on-site	3.8
Soil grain size separation off-site	4.1
Soil washing off-site	4.2
Soil excavation	4.8

When asked, if they consider a remediation option useful that enhances contaminant fixation in soil to reduce the risk of transfer into plants, groundwater and the risk on human health, i.e. on-site immobilization, the majority of the respondents viewed this positively, with an average of 2.0 on a scale of 1 to 5. Interestingly, there were some distinct differences between the home countries and the positions of the respondents.

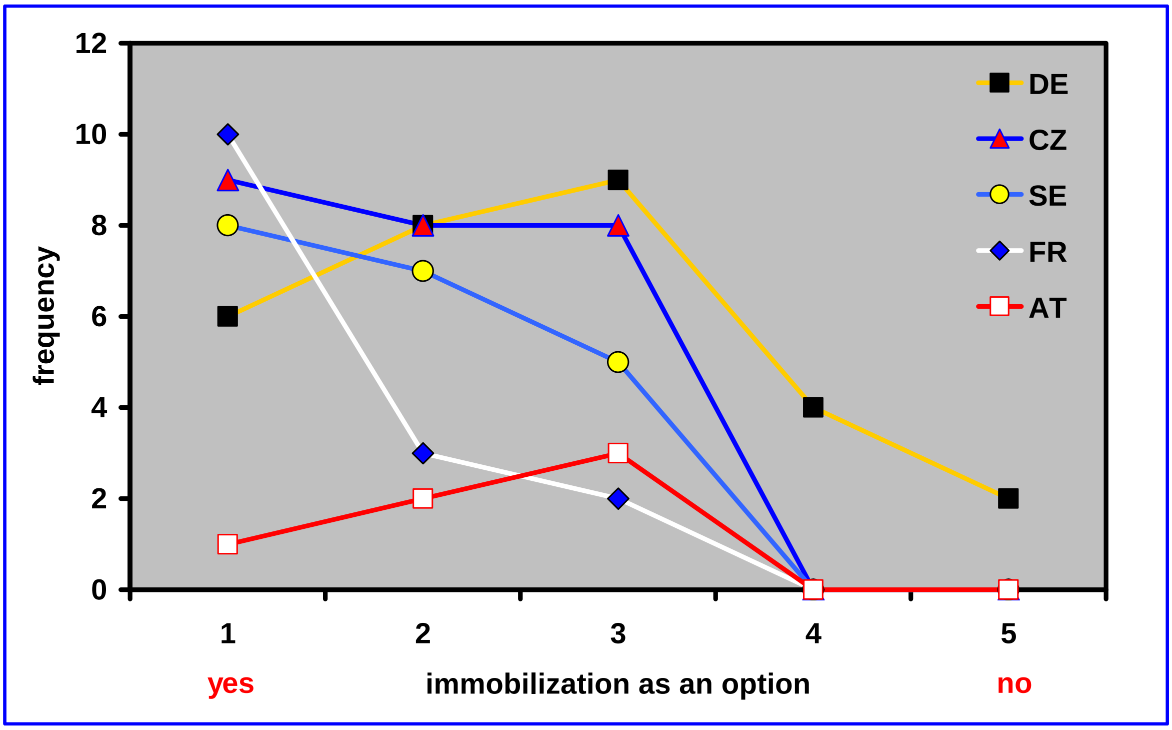


Fig. 15: *Evaluation of on-site immobilization as an option for the remediation of trace element contaminated sites by respondents grouped according to their country of origin.*

The respondents from Germany and Austria were more sceptical about this option than the respondents from France, Czech Republic and Sweden (Fig. 15). Among the 31 respondents from Germany, 20% even considered this as an option with no or very little practical use.

When grouping the respondents according to their professional position, there appears a very distinct differentiation between the representatives from national or regional authorities and the other groups (Fig. 16). Clearly, respondents working in administrations where they are more likely involved in developing guidelines for site remediation are more hesitant about this technology than consultants and practitioners in the local authorities or scientists.

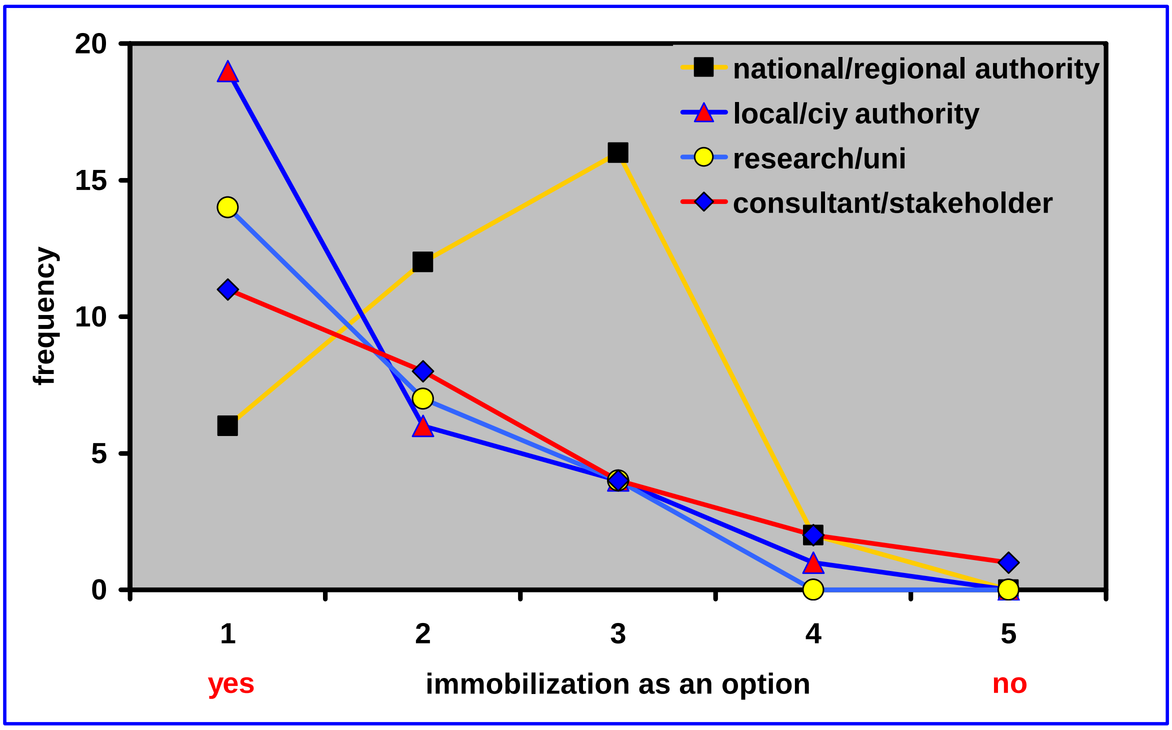


Fig. 16: *Evaluation of on-site immobilization as an option for the remediation of trace element contaminated sites by respondents grouped according to their professional position.*

When asked about their evaluation of specific aspects of gentle remediation options ("g.r.o."), a distinct differentiation was found (Tab. 39). Almost all respondents agreed with the statement that gentle remediation options need a long time. Aspects regarding the low negative impacts on the environment and soil functions and the ability to reduce or remove risks were also rated very positively. Much less agreement was given to the statements that these options are well accepted or easy to perform. The more negative evaluation about contaminant removal is not surprising, since this isn't the objective of most of these technologies. But a negative impact on economic aspects is apparently expected to a large degree.

In order to investigate if respondents who have applied or supervised these technologies before, will evaluate them differently than non-experts, the responses of those who reported to have experience in dealing with g.r.o. were compared with the others. The two groups were of about equal size, each containing about 60 respondents.

Tab. 39: *Mean rating of statements regarding gentle remediation options (g.r.o.)*
[yes = 1; sometimes = 0.5; no = 0]

statement	**rating**
g.r.o. generally need long time for remediation	0.98
g.r.o. were a contribution to a sustainable management strategy	0.87
g.r.o. have no/small negative impact on soil functions	0.87
g.r.o. were able to reduce or even remove risks	0.86
g.r.o. have no/small neg. impact on the environment	0.86
g.r.o. have a positive impact on cost-benefit-balance	0.83
g.r.o. are in general well accepted in the public	0.66
g.r.o. were simple to install and perform	0.63
g.r.o. were able to reduce or even remove contamination	0.50
g.r.o. have no/small neg. impact on economic aspects	0.47

In a first step, the numbers of "yes", "sometimes" and "no" were expressed in percent of total answers for each statement and for each of the two subgroups separately. As a next step, the percentages of "no" were subtracted from the percentages of "yes" to obtain a value expressing the "degree of affirmation". As a final step, the difference in "degree of affirmation" between the two groups was calculated for each statement. A positive value of i.e. 20% then implies that a statement was affirmed by 20% more "experts" than by "non-experts". The results of this calculation are presented in Fig. 17.

Clearly, respondents with experience in gentle remediation technologies evaluate them more positively than the "non-experts" whose more sceptical evaluation is apparently largely based on lack of experience. The more positive evaluation by the experts is most pronounced for the statements concerning impacts on soil functions and public acceptance. Especially the more positive response to the latter statement is of interest since this ranks fairly low in the overall evaluation (Tab. 39). The only statement, with which the "experts" disagree more than the "non-experts" concerns the long duration of gentle remediation technologies. Possibly, the "non-experts" mainly consider phytoextraction as a gentle option, because the other technologies involving contaminant immobilization or site stabilization are less well known.

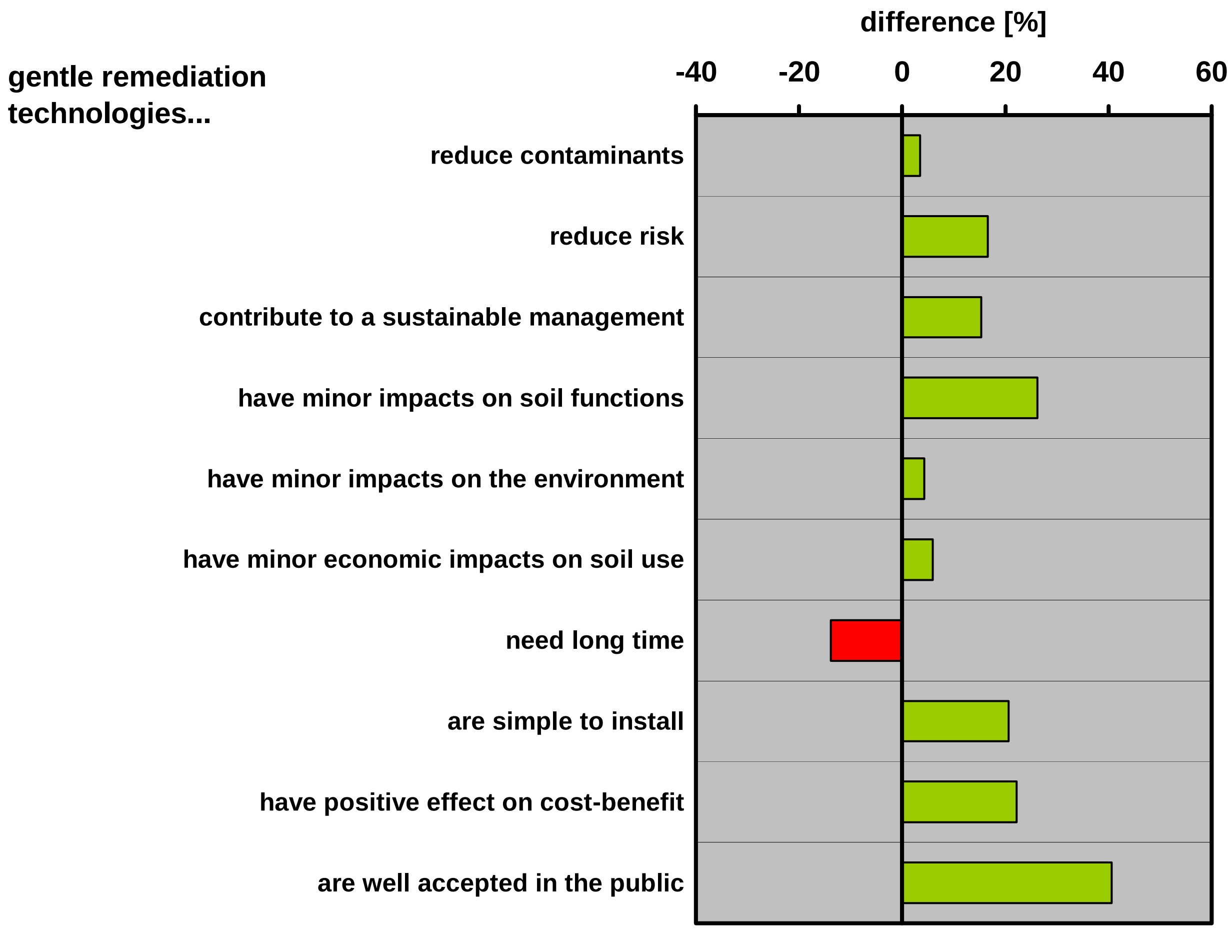


Fig. 17: *Differences in the evaluation of gentle remediation technologies between "experts" and "non-experts". Positive differences reflect a surplus of affirmative answers by the "experts" compared to the "non-experts"*

In the open answers to the question of "pros" and "cons" of gentle remediation technologies, many respondents listed similar aspects as listed in the previous statements (Tab. 40). Overall, many more negative aspects were listed than positive ones (36 vs. 23). Among the positive aspects it was additionally pointed out that these technologies can be applied to large-scale areas, where other technologies involving soil removal or covering are generally not feasible. It was also pointed out that public acceptance can be higher because these technologies produce less noise and exhausts. The need for long-term monitoring and the restricted applicability to only a few cases of contaminated sites were the most frequently stated negative aspects. Here, the lack of knowledge about successful case studies was also stated as a major problem in evaluating these technologies.

Tab. 40: *Positive and negative aspects of gentle remediation technologies as reflected in the open answers from the respondents. The answers were grouped into several categories and some selected specific answers are included. The numbers in parentheses refer to the number of answers that fall into that category.*

positive	**negative**

maintain ecological soil functions (5): non-invasive, maintains soil structure & ecological functions of soil **costs (4):** often low cost, long term solution, low energy consumption **sustainability (4)**: can be highly sustainable, long term solution **suitability for large-scale treatment (3)** possibility to treat large areas; lower amounts of direct wastes, perfect solutions for sites that are not used intensely **public acceptance (2):** wide public acceptance, little noise and exhausts **reduce risks (2):** can reduce risks on the sites that wait for use choice **energy production with biomass (2)** **easy to apply (1):** pH modification can be applied by non professionals	**long-term monitoring necessary (10)** **not applicable to all metals/sites (10):** 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. **duration of measure (8):** not compatible with current administrative procedures **lack of knowledge and practical experience (5):** I don't know any successful project working with phytoextraction. There are few well documented references. **costs (2):** Higher costs of preliminary stages (lab/field). Is it economically feasible? **usability during remediation (1):** During process, people should be kept aware that the site is still polluted

One specific aspect of plant-based gentle remediation technologies is the option to utilize the phytomass for energy production or other purposes that would provides some revenues for the site owner ("biomass valorisation"). When asked, if this could be a relevant land use for gently remediated sites, over 50% answered "yes", however, about 20% would consider this only as a temporary option. Only 7% would not consider it at all, but overall, almost 40% knew nothing or only very little about this land-use option. In this context, one respondent remarked about this question "… quite thought provoking!".

Among the professional groups, the representatives from national, regional and local authorities were best informed about biomass valorisation, while over 45 % of the scientists and consultants had only limited knowledge about it (Fig. 18). Among the local authorities who are generally responsible for approving and implementing remediation measures, over 60% would consider this option as an end use, while consultants and engineers are much more in favour of it as a temporary solution. These large differences can possibly be attributed to the opposing economic interests of these two groups.

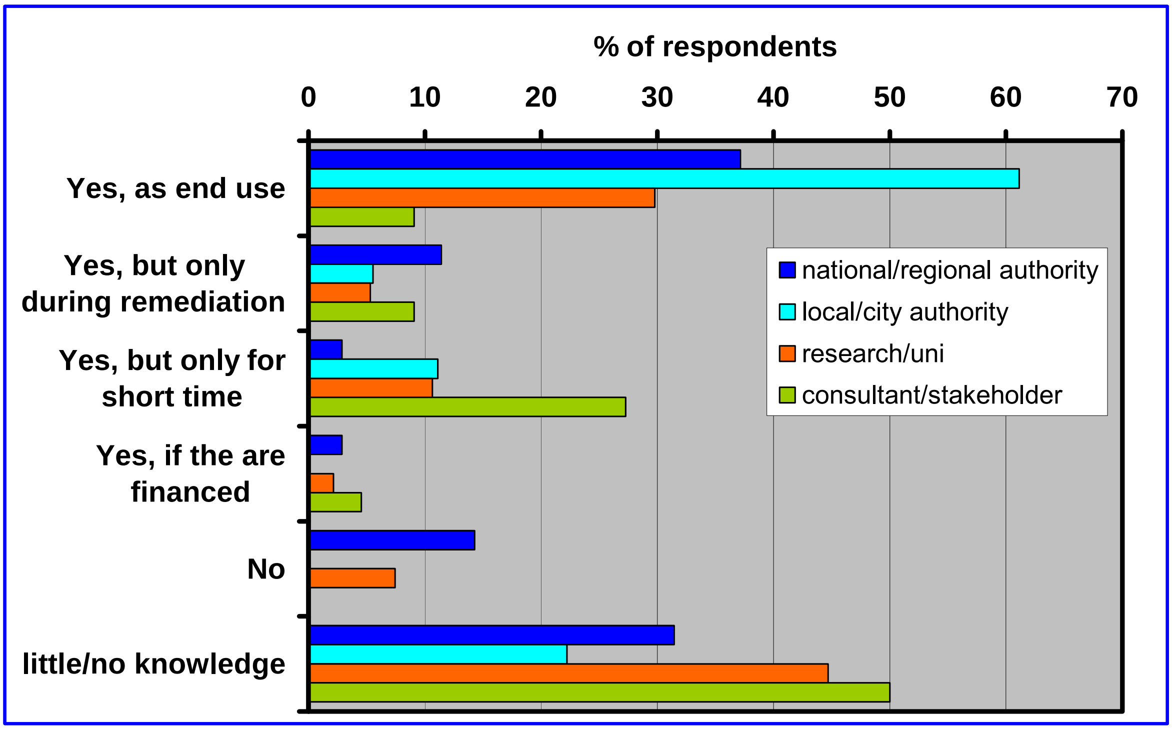


Fig. 18: *Answers to the question "Do you think that biomass production and its valorisation (e.g. industrial crops, crops for bio fuel, energy production or gas production through pyrolysis) might be a relevant land use at gently remediated sites?" grouped by professional position of the respondents.*

In the past, various decision support tools have been developed for assessing risks and selecting remediation technologies for contaminated sites. However, when asked if they are aware of such tools, only 22% answered "yes". The French respondents were among the best informed (54%) while only one out of 26 Czech respondents, knew about such a tool. Among the professional groups, there was some differentiation. The representatives from local authorities knew least, while consultants and engineers were among the best informed (Fig. 19).

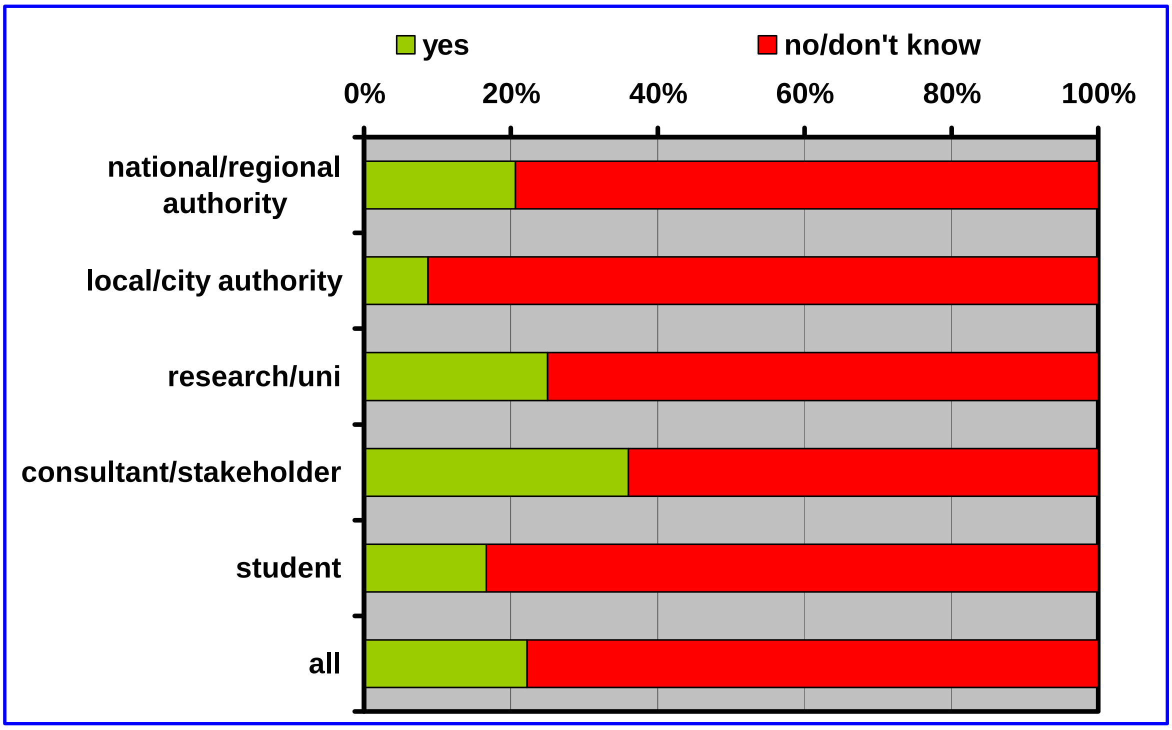


***Fig. 19:** Answers to the question " Are you aware of any decision support tools that can be used to select appropriate remediation or management strategies for TECS sites?" grouped by professional position of the respondents.*

6.4.7.4 Identification of obstacles in applying gentle remediation options

Since one of the main objectives of this survey was to determine, why gentle remediation options are not more widely used, this issue was addressed in two questions. When asked, if they would like to see a more widespread use of these technologies, less than 5% marked "5" on a scale of 1 to 5, stating that they believe that these technologies are not very useful and their use must not be extended. Over 65 % marked either "1" or "2", meaning that they are tools which are under-used at present. Interestingly, no differences were found between "experts" and non-experts" regarding this assessment.

However, among the professional groups, scientists from universities and research institutions were the strongest supporters of an increased use of gentle remediation technologies (Fig. 20). Representatives from authorities were more reserved, especially those associated with national or regional institutions, which is evident from the fact that only members from this group considered them not useful at all.

The interviewees were then asked for their ideas, how to increase the acceptance and implementation of gentle remediation technologies. The answers fell into 4 distinct groups:

- More communication and information about techniques required (34 x):
- Convince decision makers of feasibility and advantages of g.r.o. (15 x):
- Successful pilot projects are required in order to show the methods' performance (14 x)
- Financial support of techniques (6 x):

Clearly, a lack of knowledge or information about these technologies among the decision makers is seen as the most important obstacle in their wider application. To this end, many respondents expressed a need for "success stories", i.e. case studies or pilot project that applied gentle remediation technologies at the field scale and achieved risk reduction.

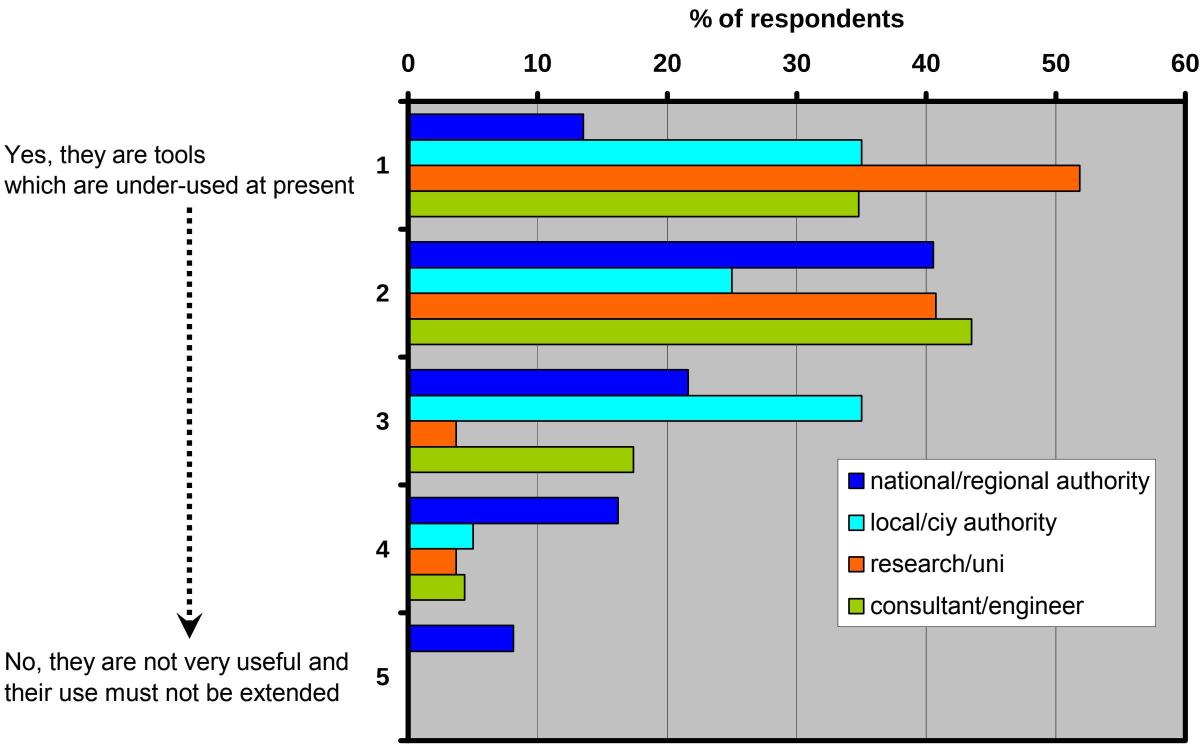


Fig. 20: *Answers to the question "Do you think that gentle remediation options should be more widely used?" grouped by professional position of the respondents.*

6.4.7.5 Summary

From this survey, the main results can be summarized as follows:

- Gentle remediation technologies are known to most respondents but rarely applied.
- Regulators are more sceptical than scientists and consultants.
- The disadvantages of gentle remediation technologies are seen in the need for long-term monitoring and the limited applicability regarding contamination and land use.
- Dealing with gentle remediation technologies improves knowledge and acceptance.
- Lack of knowledge, experience and convincing pilot projects are considered to be the main obstacle for more general application of gentle remediation technologies.

When evaluating and interpreting these results it needs to be considered, that due to the methodology and small sample size they may not be representative for the general perceptions and opinions of stakeholders, administrators and scientists who are involved with trace element contaminated sites. On the one hand, the interviewees were selected by the national SUMATECS participants according to their personal criteria and contacts. On the other hand, it can be assumed, that questionnaires were preferentially returned by respondents with some experience or at least interest in the subject. So, there will be some bias towards experts with previous experience in gentle remediation options and towards open-minded respondents.

Still, we consider this survey to be a valuable and helpful contribution to the assessment of perceptions and opinions of decision makers and scientists dealing with trace element contaminated sites. It has become quite evident, that the majority of the respondents consider gentle remediation options to be relatively cost-effective technologies with low environmental impacts, but scepticism remains regarding the effective and long-term risk reduction through these approaches. This scepticism is largely based on the poor availability of data from convincing field-trials or pilot projects applying these technologies. This data compiled in this report will hopefully alleviate this deficit.

6.5 Sustainable management strategies for trace element contaminated soils and surrounding environments: evaluation and development (WP5)

Mench M., Soularue JP., Raspail F., Jaunatre R., Vangronsveld J., Ruttens A., Adriaensen K., Kumpiene J., Renella G., Müller I., Schoefs O., Bert V., Magnié M-C., Tlustos P.

Keywords:
Bioimmobilisation, Human health, In situ stabilisation, Land contamination, Management, Option appraisal, Phytoextraction, Phytostabilisation, Phytovolatilisation, Receptor, Remediation, Rhizodegradation, Rhizofiltration, Risk assessment, Stakeholder,

6.5.1 AIMS

Who is this WP aimed at*?*

Scientists, developers, consultants, local authority planning, environmental protection departments, soil remediation departments, companies, students and citizens, and in general anyone else involved in the management of trace element-contaminated soils (TECS) (soils being contaminated by trace elements either only present or in combination with organics which is a frequent case study).

What is the aim of this WP?

Main question/Goal

According to danger and risk assessment, can a TECS at a site be sustainably managed with gentle remediation option(s) where required, to satisfy both the technical objectives (to the extent that all potential unacceptable risks are completely removed? and if possible that a beneficial socio-economic impact is generated?) and the management objectives

- No: in this case, are there alternative (or additional actions for) risk reduction or risk control actions?

- Yes: which strategy and standards are acceptable?

One successful method to implement new technologies is to provide tools useful to regulators, industry, technology vendors and public stakeholders. This report was developed:

- to aid interested parties (authorities, regulators, site owners, appraiser, and stakeholders) in evaluating gentle remediation for TECS;

- to provide information that can be used to determine if phytoremediation and other gentle remediation options have the ability to be effective at a given site where soil is contaminated with trace elements.

WP phases

A. Review information on management strategies for TECS and their surroundings (from bench scale through field scale to catchment's scale) especially in Europe and worldwide similar climatic areas; take contact with networks, authorities, environment agencies, consultants, companies, and anyone else having reported on TECS sustainable management, and summarise valid criteria;

Information is classified:

What we know?

Where are the gaps within and lacks of knowledge?

What would be relevant to know?

What is not relevant or what is not immediately essential to take decision?

- To take contact with past (Clarinet) and existing network and to inform the audience about their works.

B. Evaluate the cost-efficiency, sustainability, certainty and accuracy of management strategies stock-listed, with emphasis on those demonstrated at field/catchment's scale with biomass disposal adding land value; report on current pro's & con's;

C. Set out priorities for action and research to meet current and future needs and for reducing delay between the availability of management strategy and its implementation at adequate sites;

D. Start with partners to assess/develop most relevant strategies with adequate (phyto)remediations (WP2), relevant tests for efficiency/sustainability (WP3), decision tools (WP6), biomass valorisation (WP2, WP4), and other deliverables at a field scale remediation platform (e.g. 10 ha with past pollution from wood treatment industry, field experiments managed by INRA BIOGECO in Gironde, France) or other appropriate sites.

- To submit a draft within the project to the WP6 and information to the WP7 which reflect the state-of-the art and the good strategies according to the types of sites.

- To inform the audience of the type of information available, researches and strategy development required in order to sustainably manage TECS through a chapter and web pages within the consortium report and web site.

What issues does this WP address?

The main issues of concern related to the annexe 4 of Snowman project during the sustainable management of TECS, and wider environmental issues related to surrounding environments of TECS, including water, animal and human health.

This WP concentrates on:

- the sustainable strategies, and in particular option appraisal and implementation of the remediation.

- Compliance of strategies with regulatory regimes enforced by Environment Agencies.

The WP is linked with a database collecting data from demonstration pilots at contaminated sites (see http://w3.pierroton.inra.fr:8000/users/welcome). **Co, V, and Sb, and radionuclides are out of the WP scope**.

Why is this WP required?

Many information are available at laboratory and field scales on natural attenuation, gentle (bio)remediation techniques, on risk assessment tools, on environmental and socio-economic aspects and impacts, etc. However, available technical reports and publications frequently either do not fully address sustainability of options, especially in long-term experiment or at catchment's scale, or do not contain sufficient information to demonstrate how the risks can be sustainably mitigated and how TECS are sustainably managed. This generally results in a large delay between the availability of one management option and its implementation at adequate site.

6.5.2 Operational summary

The WP5 aims at "According to danger and risk assessment, can a TECS at a site be sustainably managed with gentle remediation option(s) where required to satisfy both the technical objectives (to the extent that all potential unacceptable risks are completely removed and if possible that a beneficial socio-economic return is generated) and the management objectives"? Which strategy and standards are acceptable? When it is not possible, are there alternative or additional actions for risk reduction or risk control actions?

The work of WP5 was running based on 3 main phases.

Phase 1.

a) The WP5 has reviewed information on management strategies for TECS and their surroundings, from bench scale through field scale to catchment's scale, especially in Europe and worldwide similar climatic areas. The review has started with the collection of the official and grey literature on management procedures for contaminated lands, and especially TECS. After description of the Context and a section on Definitions & Background, major steps have been identified such as: Setting of a conceptual model, Risk assessment (generic and detailed) including uncertainty and risk communication, Option appraisal, Remediation strategy, and Implementation of remediation strategy. For option appraisal, site-specific factors determining the appropriate remediation options, i.e. nature of the conceptual scheme and risk management, treatable contaminants and materials, remedial options, location, overall strategy and implementation, and general criteria related to site and contaminants are addressed. Criteria related to technical basis, legal, commercial and financial factors affecting the decision-making process such as engaging with stakeholders, feasible remediation options, etc are also taking in account.

b) A non exhaustive list of gentle remediations has been identified (in collaboration with WP4): Phytoextraction, Aided phytoextraction with chemicals, Aided phytoextraction with bioaugmentation, Phytomining, Phytostabilisation (with and without microbial association), Aided phytostabilisation, Phytovolatilisation, Rhizofiltration, Rhizodegradation, Bio-immobilisation, (physicochemical) in situ stabilisation, Natural attenuation, and Landfarming.

c) Detailed evaluation of gentle remediation options is included in the main report and also one detailed report is written for several gentle options. Satisfaction of remediation and management objectives are reviewed as well as information needed on the characteristics of gentle remediation options. Most advanced detailed reports are those on phytoextraction and aided phytoextraction, phytostabilisation and aided phytostabilisation, and in situ stabilisation.

d) Besides, we have promoted contact with networks, authorities, environment agencies, consultants, companies, and anyone else having reported on TECS sustainable management, and summarised valid criteria (still on going).

For enhancing such contacts, collecting information, and promoting the SUMATECS programme, we have participated and gave lectures within the following international conferences:

- 1st International Conference for Environment and Natural Resources, Environmental Protection for Urban and Industrial Zones to International Integration, March 17th - 18th, 2008, Ho Chi Minh-City, Vietnam.

Mench M, Aulen M, Bes C. 2008. Traits, and Cu translocation to shoots of poplar cuttings (*Populus nigra*, *P. deltoides, and P. trichocarpa x P.deltoides*).

Mench M., Bes C. 2008. Assessment of Cu stabilisation in a wood preservative treatment site.

Mench M, Jaunatre R, Julien F, Bes C 2008. Plant communities at a wood preservative treatment site and soil phytotoxicity.

Mench M, Gasté H, Aulen M, Taberly J 2008. Metallicolous and non-metallicolous plant responses to increasing Cu exposure.

Mench M, Bes C, Jaunatre R, Aulen M, Gasté H, Julien F, Taberly J, Guinberteau J, Garcia S, Gawronski S 2008. Phytoremediation of metal-contaminated soils: field trials at a wood treatment site.

Mench M, Puschenreiter M, Ruttens A, Kumpiene J, Müller I, Cundy A, Friesl-Hanl W, Renella G, Tlustos P, Bert V, Marschner B. 2008. SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project.

Mench M, Winkel B, Baize D, Bodet JM 2008. French bread wheat cultivars differ in grain Cd concentrations.

- Contaminants and nutrients: availability, accumulation/exclusion and plant-microbia-soil interactions, COST Action 859, Working group 1, Smolenice, May 22 -24, Slovakia.

Mench M., Gasté H., Bes C. 2008. Phenotypic traits of metallicolous and non-metallicolous *Agrostis capillaris* exposed to Cu. COST 859 – Meeting of WG1 - Contaminants and nutrients: availability, accumulation/exclusion and plant-microbia-soil interactions, D. Liskova, A. Lux, M. Martinka (Eds.), Smolenice, May 22 -24, 2008. ISBN 978-80-969950-0-4. p.19.

- Genes and proteins involved in limiting steps of phytoextraction and degradation of pollutants, Workshop of Working group 2, COST Action 859, Phytotechnologies to promote sustainable land use and improve food safety, 5 – 6 June 2008 Verona, Italy.

Bes C, Bedon F, Mench M, Lalanne C, Plomion C, 2008. Soluble proteins involved in copper tolerance in metallicolous *Agrostis capillaris*. Genes and proteins involved in limiting steps of phytoextraction and degradation of pollutants, A. Furini et al. (eds.), WG2 COST859, University of Verona, 5 – 6 June 2008, Verona, Italy. p. 21-22.

- Challenges on improving quality and safety of food crops, COST Action 859, Working group 3, Lillehammer, Norway, September 1-3, 2008.

Mench M, Winkel B, Baize D, Bodet JM 2008. French bread wheat cultivars differ in grain Zn concentrations.

- S U M A T E C S, Sustainable Management of Trace Element Contaminated Soils, Workshop and final meeting Dresden 2008, September 18th -19th 2008, Development Bank of Saxony, Dresden

Mench M, Tlustos P, Vangronsveld J, Adriaensen K, Kumpiene J, Renella G, Müller I, Schoefs O, Bert V, Magnié MC 2008 How to implement gentle remediation into sustainable management strategies? How to implement gentle remediation into sustainable management strategies?

- Phytotechnologies in practice – biomass production, agricultural methods, legacy, legal and economic aspects, COST Action 859, Working group 4, Integration and application of Phytotechnologies, October 14-17, 2008, INERIS, Verneuil en Halatte, France.

Bes C, Jaunatre R, Hego E, Kechit F, François J, Mench M. 2008. Aided phytostabilisation of a Cu contaminated soil. pp. 30-31.

Carrier M, Mench M, Loppinet-Serani A, Cansell F, Aymonier C, Marias F, Mercadier J. 2008. Valorisation of phytoremediation biomasses with supercritical water. pp. 51-52.

Marschner B, Haag R, Muller I, Bert V, Mench M, Magnié MC, Cundy A, Renella G, Kumpiene J. 2008. Current perception of gentle remediation options for contaminated sites – results from a survey in Europe. p. 97

Mench M, Bes C, Negim O, Jaunatre R. 2008. Phytostabilisation at a wood preservative site: Cu leaching and plant responses. pp. 89-90.

- SoilRem 2008, the 3rd International Conference on Soil Pollution and Remediation, Luo Y M et al (Eds.), October 18-21, 2008, Nanjing, P.R. China.

Mench M, Puschenreiter M, Ruttens A, Kumpiene J, Müller I, Cundy A, Friesl-Hanl W, Renella G, Tlustos P, Bert V, Marschner B. 2008. SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project. pp. 40-41.

- 5th International Phytotechnologies Conference, October 22-25, 2008, Nanjing, P.R. China.

Mench M, Gaste H, Bes C. 2008. Phenotypic traits of metallicolous and non-metallicolous *Agrostis capillaris* exposed to Cu. pp. 55-56.

Discussions with international experts during the Conferences:

Dr. D.M. Antosiewicz (Univ of Warsaw, PL), Dr. M. Aarts (Wageningen, NL), Dr. G. Banuelos (USDA, USA), Dr. J.G. Burken (Missouri University of Science & technology, USA), Dr J. Japenga (Wageningen, NL), Dr. S. Gupta (Agroscope ART, Zurich, CH), Pr. S. Gawronski (Univ of Life Sciences, Warsaw, PL), Pr. Y.M. Luo (Institute Soil Science, Nanjing, RP China), Pr. N. Marmiroli (Univ of Parma, Italy), Dr. L. Newman (Univ South Carolina, USA), Pr. Steve McGrath (IARC, Rothamstedt, UK), Dr. Steve Rock (US EPA, USA), Dr. J.P. Schwitzguébel (EPFL, CH), Dr. J Song (Institute Soil Science, Nanjing, RP China), Pr. T. Vaneck (Lab Plant Biotechnologies, Prague, CZ), Dr. D. Van der Lelie (BNL, Brokhaven, USA), Pr J Verkleij (UVA, Amsterdam, NL), Dr. J. Yang (Lincoln Univ of Missouri, USA), Dr. F.J. Zhao (IARC, Rothamstedt, UK), Pr. Q.T. Wu (Canton University, RP China), Etc.

We have taken contact with past/present framework (Clarinet, Cost859, ISTEB, Claire, Environment Canada, US EPA Clu-in) to collect formulated scientifically valid criteria for sustainable management of TECS.

A second part of the questionnaire has been established to collect detailed information on the management strategy (data interpretation still ongoing with Pr B. Marschner et al of WP4).

Phase 2.

We have developed a software for managing a database dedicated on experiments carried (from bench scale to field experiments) on the management of TECS with gentle remediation options. After the analysis and the definition of templates for loading the digital data from each experiment, we have worked of the web navigation and the server. This database is currently filled by WP5 members and other partners.

The database is at: http://w3.pierroton.inra.fr:8000/users/welcome (the link must be written in your web navigator). We have written a notice containing all the information for loading data in the database and distribute this notice to all SUMATECS partners. (see notice attached). This is a **living database** that everybody can consult. This database has an advantage compare to the other ones, as it contains information with data on the phytoremediation options. Currently partners have loaded information for 11 sites with a demonstration experiment. Other information will be load in the forthcoming months, before to put the database in production. This database will be maintained alive by the UMR BIOGECO in the following years (Mench, Raspail, Labbé, Soularue). More information will be collected with the help of the Sumatecs partners.

Phase 3.

We have carried the three steps of a sustainable management strategy, *i.e.* Risk assessment, option appraisal, implementation on site, at a Cu-contaminated site (contamination source: washing of treated timbers). This site surface is 6ha. Selections of sustainable strategy (minimizing the risks, produce plants such as wood and sunflower for biofuels) and of feasible options (aided phytostabilisation, phytoextraction) have been done. Phytostabilisation, aided phytostabilisation with and without associated microbes (mycorhiza), in situ stabilisation, and aided phytoextraction passed the tests of option appraisal. Biostimulation of phytostabilisation with endophytes is currently tested. Several remediation options, aided phytostabilisation, phytostabilisation, and aided phytoextraction have been implemented (in general the field experiment was 150 m², with replicated plots).

Communications and diffusion:

- See the lectures at the Conferences mentioned above.

16 lectures have been given during the course of the SUMATECS programme.

- The UMR BIOGECO INRA 1202 has organized the second workshop of Sumatecs (12-15 March 2008), at the Bordeaux 1 University in Talence, France.

6.5.3 Context

Soil contamination by trace elements (TEs) is a global problem with ramifications to human, animal and environmental health. Acute or chronic exposure in excess to TEs can cause DNA damage, and their carcinogenic effects in animals and humans are probably caused by their mutagenic ability (Knasmuller et al. 1998; Baudouin et al. 2002). Exposure to high levels of TEs has been linked to adverse effects on human health and wildlife (Padmavathiamma and Li, 2007). Lead poisoning in children causes neurological damage leading to reduced intelligence, loss of short term memory, learning disabilities and coordination problems. The effects of arsenic include cardiovascular problems, skin cancer and other skin effects, peripheral neuropathy (WHO 1997) and kidney damage. Cadmium accumulates in the kidneys and is implicated in a range of kidney diseases (WHO 1997). The principal health risks associated with mercury are damage to the nervous system, with such symptoms as uncontrollable shaking, muscle wasting, partial blindness, and deformities in children exposed in the womb (WHO 1997).

Soil pollution by TEs is particular because many TEs persist in soil much longer than in other compartments of the biosphere (Lasat 2002). Annual worldwide release of metals reached 22,000 t (metric ton) for cadmium, 939,000 t for copper, 783,000 t for lead and 1,350,000 t for zinc (Singh et al. 2003).

Hg: increased burning of coal-naturally contaminated with mercury is leading to increase releases to the air in some parts of the world (e.g. in China) from where it can spread around the globe. The soaring gold price would also increase Hg pollution locally and world-wide.

<u>Sources of TEs in soils</u> include metalliferous mining and smelting, acid mine drainages from mine tailings, metallurgical industries, manufacturing emissions, recycling of organic matters such as sewage sludges, pig slurries, and urban composts, warfare and military training, waste disposal sites, agricultural fertilizers and pesticides, ground-transportation (e.g. tread ware, engines, lubricants, brake abrasion, tire abrasion, exhaust emissions, corrosion are sources associated with highway traffic, de-icing) and electronic industries (Alloway 1995; Adriano, 2001; Padmavathiamma and Li, 2007). European Union has a considerable legacy of soils affected by TE contamination arising from past land use, industrial activities (mining, smelting, manufacturing emissions), recycling of organic matter (sewage sludges, wastewaters) and diffuse sources (applications of fertilisers, slurries). The European Environment Agency reported that although there may not be severe widespread soil contamination with TEs in Europe, there are many localized areas where intense TE contamination is known to exist (hot spots) (EEA 2000). Fig. 21 shows the location of zones with high probability of soil contamination through industrial activities (pink spots). The EEA report repeatedly notes the lack of available and coherent scientific data on TECS: 'there is no harmonized monitoring of local soil contamination in Europe and many countries do not yet have national inventories'. The map was made by using the location of areas of heavy industry as a proxy data set *(*Van Ginneken et al 2007*).* The areas where the probability of occurrence of local contamination is high are located in North-West Europe, from Nord-Pas de Calais in France to the

Rhein- Ruhr region in Germany, across Belgium and the Netherlands. Other areas include the Saar region in Germany, northern Italy, north of the river Po, from Milan to Padua; the region located at the corner of Poland, the Czech Republic and the Slovak Republic, with Krakow and Katowice at its centre, and the areas around all major urban agglomerations in Europe. Total anthropogenic emissions of Pb in European countries in 2004 were 5 580 tons. In the most pollution-loaded areas of such countries as Belgium, Germany, Portugal, Poland, Greece, etc. deposition fluxes often exceed 2 kg/km^2/y. For anthropogenic Cd, total deposition is estimated at 181 tons. The highest anthropogenic depositions were obtained for the FYR of Macedonia, followed by Slovakia, Bulgaria and Poland.

EMEP Status Report 2/06, 2006 Heavy Metals: Transboundary Pollution of the Environment. *Joint MSC-E & CCC Report*, 79 p.

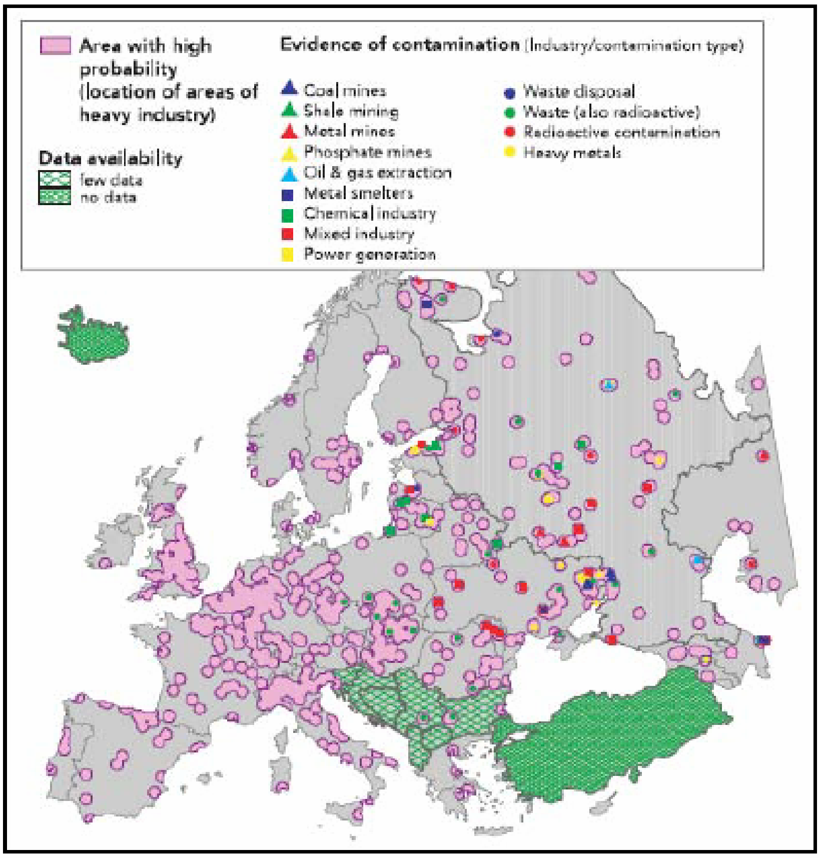


Fig 21. Probable problem areas of local contamination in Europe (EEA, 2000)

TECS often presents a risk to a range of receptors including humans, ecosystems, biodiversity, water quality, and property including crops and animals. Current and future use of the soil may be adversely affected. Uncertainty of such potential risks may inhibit the development or redevelopment of land, and may contribute to long-term dereliction and increasing pressure to develop greenfield land.

Technical obstacles as well as potentially large costs mean that it is often neither feasible nor realistic to think in terms of total clean-up of past damage. Instead, the goal is to find solutions that identify and deal with risks from contamination in a sustainable way (Environment agency 2007). Therefore, the management of contaminated sites has been changed markedly over 30 years. It has moved from a cost-centred approach in the mid-1970s, through the technology feasibility studies of the mid-1980s, the risk-based approaches of the mid-1990s and into a new millennium where environmental decisions must be ‘socially-robust’ within a context of sustainable development (Urban Task Force, 1999; ESRC Global Environmental Change Programme, 2000; Pollard et al. 2001). All these efforts were to ensure management and/or remediation is affordable, feasible, effective and latterly, sustainable. For "new" contamination, the principle (in UK) is that deterioration of the environment needs to be avoided. This principle underlies the approach in regimes aimed at controlling potentially polluting activities, such as Pollution Prevention and Control (PPC). When land contamination is caused as a result of a breach in permit conditions, the land should be restored to a satisfactory state – taken as the state before issuing the permit.

A conceptual framework for sustainable management of TECS is considered a part of the wider conceptual framework "Risk-based land management". Current solutions can be characterised by several goals ("*suitability for use*"):

- ***fitness for use***: reducing human health risks and ecological risks as necessary to achieve/permit the safe (re)use of soil, restore soil quality and (multi)functions;

- ***protection of the environment***: preventing the pollutant dispersion to surroundings; preventing of negative environmental impact of remediation;

- ***reduction of aftercare***: sustainable solutions minimise the burden of aftercares.

The successful management of land contamination whether at the site, regional or national scale, relies on applying a large and multidisciplinary knowledge base that straddles the natural, physical, engineering and social sciences within a practical, commercial, regulatory and often community context (Pollard et al., 2001a). There is no universal best solution. Decision-makers must be able:

- to synthesise and apply this knowledge (WP4, 6)

- to work in a modern decision-making environment with an emphasis on 'process', wider participation and deliberation (WP7).

Table 41. Trace elements and toxicity risks for the food chain (Chaney 1980)

Group 1	Group 2	Group 3	Group 4
Low solubility	Low translocation	Phytotoxic	High risks
	in edible plant parts		for animals & Human beings
Ag	As*	B	Cd
Cr(III)	Hg	Cu	Co
Sn	Pb	Mn	Mo
Ti		Mo	Se
Y			As in rice grain/Asia
Zr			*(except the problem of rice grain)

In response to contaminated soils and risks (Table 41), a variety of physicochemical remediation methods has been adopted, including solidification, electrokinetics and encapsulation (Mulligan *et al*. 2001, Clarinet 2002). In many cases, these strategies have resulted in criticisms in regards to their high cost, energy intensiveness, site destructiveness, associated logistical problems and growing degree of public dissatisfaction (Rulkens *et al*. 1998). The implementation of alternative, gentle strategies that address these concerns is critical in effectively removing metallic trace elements from soil or the risk(s) for exposed receptors (Kachenko et al). Phytoremediation is the name given to a set of technologies that use plants (or plant-microbe associations) to remediate contaminated sites. Phytoremediation uses living plants and associated microorganisms for *in situ* and *ex situ* remediation of contaminated soil, sludges, sediments and ground water through contaminant removal, degradation or stabilization. Phytoremediation can be used to remediate various contaminants including metals and non-metals, pesticides, solvents, explosives, petroleum hydrocarbons, polycyclic aromatic hydrocarbons and landfill leachates. Phytoremediation has been used for point and nonpoint source hazardous waste control. It is mostly described in literature for metals (Ag, Cr, Co, Cd, Cu, Hg, Mn, Mo, Ni, Pb, Ni, Zn), metalloids (As, Se), radionuclides (Sr, Cs, Pu, U) and non-metals (B). Works on In situ immobilisation (in situ stabilisation) is the mixing of amendments into the soil to reduce the labile pool of contaminant(s) for biological action (bioavailability) and for migration (mobility).

6.5.4 Definitions/Background

<u>Conceptual model:</u> represents the characteristics of the site in diagrammatic or written form that shows the possible relationships between contaminants, pathways and receptors. The term pollutant linkage is used to describe a particular combination of contaminant–pathway–receptor.

<u>Contaminated site (*can be adapted to contaminated soil*)</u>

• The CSMWG* *(*Contaminated Site Management Working Group in Canada)* defines a contaminated site as

A site at which substances occur at concentrations:

1. *above background levels and pose, or are likely to pose, an immediate or long-term hazard to human health or the environment; or*
2. *exceed levels specified in policies and regulations.*

For the purpose of this definition:

- Background levels refer to the ambient levels of a contaminant in the local area of the site under consideration.
- The above definition is intended to include sites which are contaminated but are being properly managed and sites that are known or suspected of being contaminated but have yet to be addressed.
- The definition is not intended to include sites only covered by debris, or simply "aesthetically" unpleasant. Heat, sound, and vibration are excluded as "contaminants".

<u>Soil manager</u>: can be the owner or a user or a local/national authority. The area may be large, including different past, current or future land uses.

<u>Degradation</u>: Many human activities degrade the natural capital of soil by using renewable resources faster than nature can renew

A key variable is the rate at which we transform the soil to meets our needs and wants.

<u>Environmental setting of the land</u>: the surrounding and underlying water environment, on-site and nearby ecosystems.

<u>Land contamination</u> in its broadest sense describes a general spectrum of site and soil conditions. It can include areas with elevated levels of naturally occurring substances, as well as specific sites that have been occupied by former industrial uses, which may have left a legacy of contamination from operational activities or from waste

disposal. It can also include areas of land in which substances are present as a result of direct or indirect events, such as accidents, spillages, aerial deposition or migration (Environment agency, 2007)

Management:

A set of activities involving decisions about assessment, remediation, soil/land use restrictions, monitoring, spatial planning, aftercare, and other issues (Vegter 2001)

Natural capital is not fixed and has changed in response to environmental changes. It is the sum of natural resources and natural services.

Pollutant linkage (in the context of contaminated soil/land) (adapted from Environment agency, 2007)

there are 3 essential elements to any risk:

• A contaminant – a substance that is in excess in the soil compared to pedological background and has the potential to cause harm or to cause contamination of other receptor media (water, air, receptors, etc);

• A receptor – in general terms, something that could be adversely affected by a contaminant, such as people, an ecological system, property, or a water body (here we made a distinction between (biological) receptors and receptor media (water, air, soil, etc.);

• A pathway – a route or means by which a receptor can be exposed to, or affected by, a contaminant.

Each of these elements can exist independently, but they create a risk only where they are linked together, so that a particular contaminant affects a particular receptor through a particular pathway. This kind of linked combination of contaminant–pathway–receptor is described as a pollutant linkage.

On any individual site, there may be only a single pollutant linkage or there may be several. Different pollutant linkages may be related, for example, the same contaminant may be linked to two or more distinct types of receptor by different pathways, or different contaminants and/or pathways may affect the same receptor. Not all receptors will be relevant in every context, and new pollutant linkages may be created by changes over time. Each pollutant linkage needs to be separately identified, understood and dealt with if appropriate.

Soil degradation leads us to search for solutions. These ones involve some conflicts which require us to make trade-offs or compromises

Soil quality includes such factors as organic matter content, the biotic activity of the soil fauna, soil structure and water infiltrability, porosity and pore-size distribution, cation-exchange capacity, pH, concentration of potentially toxic elements, the presence of any nutrient imbalance, etc.

Sustainable management:

- Finding a balance between meeting the needs of our current generation while conserving natural resources and protecting the environment for the benefit of future generations (www.abc.net.au/learn/silentflood/glossary.htm).

- Development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (UN, 1987)

The concept of sustainable development gained international governmental recognition at the United Nation's Earth Summit conference in Rio de Janeiro in 1992 (Clarinet 2002). Underpinning all of these approaches are three basic elements to sustainable development: economic growth, environmental protection and social progress.

Adapted to TECS:

- Maintenance of soils to meet current and future ecological, economic, and social needs (https://www.uwsp.edu/natres/nres743/Glossary.htm).

- Managing an unrenewable resource, such as soils, to meet the needs of the present without compromising the ability of future generations to meet their needs (www.wipapercouncil.org/fun7.htm)

Sustainable contaminated soil management is an issue within the wider sustainable contaminated land management which is more and more based in Europe on the principles of risk management (Vegter 2001)

The Strategy: defines the problem, sets out the priorities for action and states the outcomes that people seek. It describes what we can do to assist soil & land users directly to improve land use practices, and what we can do by improving the support systems which underpin land management practice

Remediation options/technologies: applying treatment based remedial approaches which destroy contaminants, extract them as some kind of concentrate or stabilise /detoxify them (NATHANAIL et al 2001; Clarinet 2002).

Receptor: the entity that could be adversely affected by the contamination (e.g. humans, insects, microbes, etc.).

Risk:

- describes the adverse environmental effects of contaminants (human and ecosystem health, aquatic environment, water resources, soil and groundwater quality, etc) (Vegter 2001)

- a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence (Environment agency, 2007).

- in ecotoxicology defines as the PEC/PNEC ratio

    - Predicted Exposure Concentration

    - Predicted Non Effective Concentration

    - When PEC/PNEC >1 there is a risk

C.E. 2003: European Commission. Technical guidance document in support of Commission Directive 93/67/EEC on risk assessment for new notified substances, Commission Regulation (EC) N° 1488/94 on risk assessment for existing substances ; Directive 98/8/EC of the European Parliament and of the council concerning the placing of biocidal products on the market.

Risk management: all the processes involved in identifying, assessing and judging risks, taking actions to mitigate or anticipate them, and monitoring and reviewing progress

Sustainability: ability of earth's various systems to survive and adapt to changing environmental conditions indefinitely (Ward and Dubos, 2007)

Countries are using different definitions and approaches to measure sustainability, and the principle of investigating sustainability is so far not implemented in any regulatory framework in Europe. United Kingdom is defining sustainable development as consisting of (Clarinet 2002):

- Social progress, which encompasses the needs of everyone;

- Effective protection of the environment;

- Prudent use of natural resources;

- Maintenance of high and stable levels of economic growth and employment.

"*Developing a sustainable management strategy for TECS*":

The Sustainable Management Strategy for TECS sets out how the option or combination of options, either including remediation or not, selected for each relevant contaminant linkage (including human health), will be put into place at the site in order that soil managing can meet current and future ecological, economic, and social needs (including human health).

It should provide a clear picture of how relevant pollutant linkages will be remediated (if necessary) and the remedial works verified. Practical issues such as zoning and phasing of remediation and proposals for obtaining the appropriate environmental licences, permits, discharge consents, etc. should be addressed within the Remediation Strategy.

The purpose of a Management Strategy for TECS: is to enable soil & land users, and those who provide support and services to soil & land users, to work together more effectively, especially to maintain soils capable to meet current and future ecological, economic, and social needs (including human health).

Tolerance to trace elements in plants may be defined as the ability to survive in a soil that is toxic to other plants and is manifested by an interaction between a genotype and its environment (McNair *et al.* 2000).

6.5.5 Procedures for the Management of Land Contamination

Definition: The Model Procedures provides a technical framework for applying a risk management process to land affected by contamination.

Context:

A risk based decision-making process for remediation is the norm across most EU member states (CLARINET and NICOLE, 1998). In this process, risk assessment and the subsequent step of risk management are intimately related elements that form the basis for a fitness-for-use option to land affected by contamination. Risk assessment was the focus of CARACAS, the Concerted Action, which was a forerunner of CLARINET (Ferguson et al 1998, Ferguson & Kasamas, 1999).

The policy framework differs, e.g. some European countries (e.g. Portugal, Greece, and Hungary), had not implemented Risk Based Land Management (RBLM) for decision-making (before 2002). There are large differences in economic framework, i.e. for supporting innovative technology implementation, sustainable remediation solutions, or remediation of derelict land or brownfields (Clarinet 2002).

In the United States (US), arsenic is the 2nd most common inorganic constituent after Pb on the US EPA National Priority List, which comprises in excess of 2000 contaminated sites that pose environmental health risks (Davis et al., 2001).

Davis A, D. Sherwin, R. Ditmars, K.A. Hoenke 2001. An analysis of soil arsenic records of decision. *Environ Sci Technol* 35, 2401–2406

International Projects:

- EURODEMO - Final Conference. Towards Innovative Remediation in Europe – Chances and Perspectives. Conference of the Federal Environment Agency on 6-7 November 2007 in the Urania in Vienna. www.eurodemo.info/events/final-conference-2007

EURODEMO and PROMOTE are projects funded by the European Commission, DG Research within the 6th Framework Programme. EURODEMO is a contact point for Europe regarding information on innovative remediation demonstrations in the field of soil and groundwater remediation. (http://www.eurodemo.info/)

PROMOTE develops an ETV system for monitoring and remediation technologies in soil-groundwater systems. With a European ETV system technology vendors can more easily get acceptance for their technologies on a national and European level, and technology users have more security regarding the performance of new technologies.

- ENVASSO (ENVironmental ASsessment of Soil for mOnitoring) An EU directive for the protection of European Soils is in the final stage of publication. Overall aim of the new EU soil policy is to conserve European soils on a long term basis. The new directive defines eight key soil threats (surface sealing, soil contamination, landslides, compaction, loss of biodiversity, salinisation, erosion, loss of organic matter and demands the monitoring and assessment of their state. ENVASSO is developing adequate soil monitoring and assessment strategies for all soil threats in order to allow the assessment of “good soil status”. The University of Cranfield (UK) is in charge of the project which in total includes 30 expert institutions as project partners. The Austrian Environment Agency is responsible for the definition of indicators, thresholds and targets related to all eight soil threats. (http://www.envasso.com/)

- CABERNET (The Concerted Action on Brownfield and Economic Regeneration Network) is a multidisciplinary network comprising of 8 expert stakeholder groups that aims to facilitate new practical solutions for urban brownfields. Its vision is to: 'Enhance rehabilitation of brownfield sites, within the context of sustainable development of European cities, by the provision of an intellectual framework for coordinated research and development of tools

- INCORE (Integrated Concept for Groundwater Remediation -INCORE; -Localisation and identification of groundwater contamination- (Contract N° EVK1-CT-1999-00017, 2001) http://www.ietu.katowice.pl/5pr/Incore_eng.html

- CLARINET (Contaminated Land Rehabilitation Network for Environmental Technologies) was a Concerted Action within the Environment & Climate Programme of the European Commission DG Research, and was co-ordinated by Umweltbundesamt, the Austrian Environment Agency. The project started on 1.7.1998 and finished on 30.6.2001. It brings together the combined knowledge of academics, government experts, consultants, industrial land owners and technology developers. It provided a thematic network on interdisciplinary research, integrating technological, societal and economical aspects for contaminated land management. Overall, 16 European Countries were participating in this project with various types of stakeholders.

- CARACAS (Concerted Action for Risk Assessment for Contaminated Sites in Europe) was a Concerted Action initiative within the Environment and Climate Programme of the European Commission DG XII. 16 European Countries were participating in the CARACAS project with scientists from national environmental authorities and research organisations. It has co-ordinated research initiatives on contaminated land risk assessment in Europe and identifies priority research tasks for future R&D programmes (http://www.umweltbundesamt.at/en/umweltschutz/altlasten/projekte1/international1/caracas/caracas_researchneeds/).

- EUGRIS is a web portal offering information and services on topics related to soil and water. it operates as a community of collaborating projects, people and organisations who co-operate to supply information for the benefit of everyone and also to promote themselves and disseminate their work. (http://www.eugris.info/). EPP Publications with Land Quality Management and r3 Environmental Technology have released an update to the Contaminated Land Management: Ready Reference' (Title: Contaminated Land Management: Ready Reference Authors: Judith Nathanail, Paul Nathanail, Land Quality Management Ltd and Paul Bardos, R3 Environmental Management Ltd, 2007)

- CL:AIRE (Contaminated Land: Applications in Real Environments): is a respected independent not-for-profit organisation established in 1999 to stimulate the regeneration of contaminated land in the UK by raising awareness of, and confidence in, practical and sustainable remediation technologies. CL:AIRE’s aim is to build a portfolio of these technology demonstration and research projects using different technology providers demonstrating under different conditions to show successes as much as lessons learnt, so that a thorough understanding of the application of a technology can be achieved.

http://www.claire.co.uk/index.php?option=com_content&task=view&id=40&Itemid=32

European Network of Excellence in Biological Management of Environmental Pollution (BIOPOL)',

'Risk Management of Human Exposure to Chemicals (MANAG EXPOSURE)',

Components:

Primary procedures are at the top of a hierarchy of documents, which increases in complexity and technical detail at each decreasing tier. They are to be supported by supporting secondary model procedures and technical guidance/reports. Taken together this comprehensive package of guidance will constitute a complete decision support system, linking individual decision support tools (UK, FR, DE, SW, BE-Flanders, etc)

Model procedures can include such components

• Risk assessment – establishing whether unacceptable risks exist and, if so, what further action needs to be taken in relation to the site;

• Options appraisal – evaluating feasible remediation options and determining the most appropriate remediation strategy for the site;

• Implementation – carrying out the remediation strategy and demonstrating that it is, and will continue to be, effective.

Phases

- The process is phased, with scope for iteration within individual components (e.g. UK, DE, AT, FR, SE, BE, etc)

or

- the process in not phased.

UK: The framework focuses on individual sites, although it can also be used in the context of managing a portfolio of sites.

The Ecological Risk Assessment (ERA) Framework for contaminated soils has been developed by the Environment Agency in collaboration with DEFRA, Natural England, Welsh Assembly Government, the Countryside Council for Wales, local authorities and industry. It aims to provide a structured approach for assessing the risks to ecology from chemical contamination in soils that is requirement under Part 2A (Contaminated Land) of the Environmental Protection Act 1990. It sets out the three-tiered risk assessment process that has been designed to:

• establish whether pollutant linkages between the contamination and the designated ecological receptors are likely to exist;

• gather sufficient information for making decisions regarding whether harm to those receptors is, or could, occur.

The risk assessment is preceded by a desk study that reviews information about the site and nature of the contamination to assess whether pollutant linkages are feasible.

Tier 1 of the risk assessment is a screening step based on a comparison of chemical analyses of site soils with a soil screening value (SSV) for the contaminant of concern.

Tier 2 uses a choice of tools (ecological surveys and biological testing) to provide evidence for harm to the receptors.

Tier 3 seeks to attribute the harm to the chemical contamination.

The ERA framework is supported by further guidance documents – both for the desk study (how to develop a Conceptual Site Model) and at each tier. The series includes guidance on:

• the use of soil screening values;

• how and when to perform ecological surveys and biological tests;

• Standard Operating Procedures for bioassays;

• how to consider cause–effect attribution.

The ERA framework and guidance documents make reference to the Statutory Guidance as necessary. The ERA framework is intended to structure decision-making and, as such, does notseek to provide criteria on which determinations of contaminated land can be made. These decisions remain with the relevant regulator. However, the ERA framework can also be used in contexts other than Part 2A (Contaminated Land) such as within conservation regulations, and planning and pollution control.

Ashton D, Benstead R, Bradford P, Whitehouse P 2008 An ecological risk assessment framework for contaminants in soil. Science report SC070009/SR1, Environment agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD, UK.

http://publications.environment-agency.gov.uk/epages/eapublications.storefront/4942e62c00e6b5f4273fc0a8029606a4/Product/View/SCHO0908BOOZ&2DE&2DE#

Table 42: Some national procedures for the management of land contamination

Country	Title	Abbreviation
AT	Austrian Standards (ÖNORM) S 2085 to 2089	ÖNORM S 2085 to 2089
UK	Model Procedures for the Management of Land Contamination	CLR11[1]
FR	Circulaire Politique nationale de gestion des sites et sols pollués	8 février 2007
DE	Bundesbodenschutzgesetz" - Federal Soil Protection Act	
	(Act on Protection against Harmful Changes to Soil and on Rehabilitation of Contaminated Sites, 1998)	
BE	Order of the Flemish Government establishing the Flemish regulation	Vlarebo (June 1, 2008)
	on soil remediation and soil protection	
	Region Wallonne: décret Lutgen	Decree project (November 18, 2008)
SW	To select remediation measures: A guideline from generic to measurable remediation aims”	

[1] Not directly applicable to site surrender reports prepared for sites permitted under IPPC (Integrated Pollution Prevention Control) or for decisions about the surrender of waste management licences,

Table 43: Overall option in dealing with past land contamination

	Conceptual scheme	**Option**	**Deciding action/remediation**
AT		Risk management*	Suitable for use option**
FR	Pollutant linkages	Risk management*	Suitable for use option**
UK:	Pollutant linkages	Risk management*	Suitable for use option**
Flanders	Remediation objectives	Risk management	Suitable for use option
	& remediation objectives	& remediation standards exceeded	
Walloon	Remediation objectives	standard and action values	Remediation targets
Finland	Pollutant linkages	Risk management*	Suitable for use option**

CH:	requiring remediation. registration, assessment and remediation of polluted sites.

* "all the processes involved in identifying, assessing and judging risks, taking actions to mitigate or anticipate them, and monitoring and reviewing progress"

** there are "unacceptable risks to human health and the environment" in relation to the use of the land and its environmental setting.

Austria

Austrian legislation does not provide any tools for decision making. Therefore the Austrian Standards Institute produced a sequence of guidelines to assist the management of contaminated sites (numbered ÖNORM S 2085 to ÖNORM S 2090). The ÖNORM S 2085 (July 1st, 1998) illustrates a tiered approach of procedures and activities for the management of contaminated sites using a flow diagram (see below). This provides a general guide for dealing with investigation, assessment and remediation of contaminated land incorporating a number of standards dealing with subsets of the contaminated land problems. The flow diagram provides the framework for decision making; the integration of the various steps is provided by the progressive nature outlined in the flow diagram. A general outline for risk assessments is set by ÖNORM S 2088 part 1 and part 2, which also define guideline values for contaminated land related to the protection of groundwater resources as well as the safe use of land.

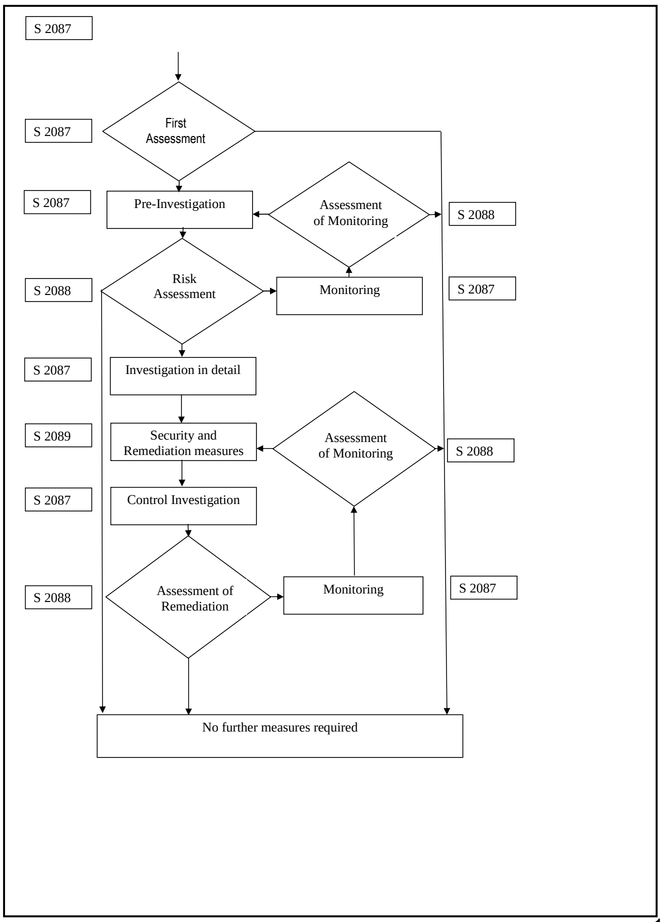
The Austrian Standards (ÖNORM) describe the remediation procedure. According to the Umweltbundesamt, the praxis differ sometimes (mostly) from these standards:

Basic standard ÖNORM S 2085: „ Contaminated sites – procedure of the work on contaminated sites and old wastes" (see flowchart)

ÖNORM S 2087: "Identification and investigation of (suspected) contaminated sites.

ÖNORM S 2088-1: for Groundwater, S 2088-2: for Soil: "Contaminated Sites – Risk assessment for polluted soil concerning impacts on surface environments", S 2088-3: for Air

ÖNORM S 2089: "Remediation of contaminated sites – Methods for security and decontamination"



In Austria, substances posing a threat to human health and the environment are - and had been handled at about 80.000 sites (51 081 sites are old deposits and industrial sites; http://www.umweltbundesamt.at/en/umweltschutz/altlasten/statistik/). About 2.039 sites are suspected and would need remediation. 35 sites are in the priority class I. 78 sites have a remediation in progress and 88 have been remediated. Taking the present legal policy into account, the estimated total expenses for safeguarding and remediation of the contaminated sites are at about 4.4 Mrd. Euro. The largest project is the implementation of the Law for the Clean-up of Contaminated Sites (ALSAG). The registration, assessment and support with the order and control of investigations of contaminated sites are carried out on behalf of the Federal Ministry for Agriculture and Forestry, Environment and Water Management. Since 1996 the Umweltbundesamt (the Austrian Federal Environment Agency) has been the main partner of the European Environment Agency in the field of contaminated sites.

Fig. 22 : Basic standard ÖNORM S 2085: „ Contaminated sites –procedure of the work on contaminated sites and old wastes"

There is an Austrian Association for Management of Contaminated Sites" (AAMCS) http://www.altlastenmanagement.at

BE:

Flanders: OVAM stands for Openbare Afvalstoffenmaatschappij voor het Vlaams Gewest (Public Waste Agency of Flanders) and is responsible for waste management and soil remediation in Flanders (http://www.ovam.be/jahia/Jahia/pid/973?lang=en). In the course of 2007, OVAM worked to develop implementation decrees for the new soil remediation and protection decree. As a result, the Flemish Government approved the accompanying implementation decree on 14 December 2007. This new Vlarebo entered into force on 1 June 2008. Concerning soil data management, over the past 11 years, 26,990 plots were studied and some 19,588 plots were included in the register of polluted plots. In 2007, OVAM opened 138 new dossiers for soil remediation and removal of waste products for a total cost price of 29 million Euros. The scope of such interventions varies widely. Both small cleanups for innocent private owners as well as projects concerning hundreds of plots are carried out.

The delivery of soil certificates: since October 1, 1996, a soil certificate must be required during each soil transfer. If a soil is registered in the register of the polluted soils, this mention is reproduced on the soil certificate. In the contrary case, the soil certificate is virgin.

The follow-up of the descriptive and indicative studies of soil. The indicative study of soil gives precise details on the soil pollution at a site. According to pollution and moment of its appearance (new or historical), it is necessary to manage and remediate the soil and risks. The first stage of a soil cleansing is the descriptive study of this soil. It is checked how the noted pollution was already propagated and how this propagation will evolve/move. In addition, the risks of pollution are checked. In the case of a historical pollution, this one involves an inscription in the register of the polluted soils.

The assessment of the projects of soil cleansing: checking of the exhaustiveness and the admissibility of the introduced projects of cleansing, request of the councils necessary and control of the publication of the project, establishment of a certificate of conformity or request for addition and/or modification.

The follow-up and the control of the soil remediation and management. If monitoring and control are still necessary after implementation, those are also the follow-up object. To finish, OVAM delivers a final certificate establishing the results of work.

The Flemish Vlarebo procedure is available at http://www.ovam.be/jahia/Jahia/cache/offonce/pid/176?actionReq=actionPubDetail&fileItem=1755.

The Soil Remediation Decree (Vlabero, June 1st 2008) incorporated the procedures of remediation including the following 5 phases:

1. Exploratory study (historical investigation and soil sampling);

2. Descriptive soil survey (risk analysis and limitation of the pollution);

3. Remediation project (studying alternatives for remediation following the BATNEEC principle);

4. Remediation works;

5. Aftercare and follow up.

A soil remediation project shall contain at least the following information:

1° a non-technical summary of the soil remediation project;

2° the following identification data:

a) the identification of the land that requires remediation included in the soil remediation project;

b) the identification of the plots of land on which soil remediation works are necessary, including the coordinates of their owner and user and, if applicable, the coordinates of the association of co-owners;

3° the following specific information in case of:

a) a phased soil remediation project: the motivation for drawing up a phased soil remediation project;

b) additions or changes to the soil remediation project: the additions or changes to the soil remediation project;

c) a new soil remediation project: the motivation for drawing up a new soil remediation project;

4° an overview of the state of the contamination and any measures and pilot projects implemented:

a) the results of the relevant exploratory and descriptive soil surveys, descriptive soil surveys or sediment surveys which have been declared in conformity and updated if necessary;

b) the results of the other measures mentioned in chapter VI of title III of the Soil Decree, taken where necessary, insofar as they have an impact on the soil remediation project.

c) the results of any pilot projects carried out;

5° the following information on the treatment of the soil contamination and the possible aftercare:

a) concerning the technical possibilities to treat the soil contamination;

1) the different technical possibilities to treat the soil contamination and the results of any research done into the feasibility of those technical possibilities;

2) an estimate of the costs of those technical possibilities;

3) an indication of the impact of those technical possibilities on the environment and of the results they will help to achieve, taking into account the provisions of articles 10 or 21 of the Soil Decree and any limitations they may entail for the future use of the contaminated land;
4) an evaluation of the relevant technical possibilities considered with a view to proposing the way in which pollutants or parts of the soil or the buildings and structures erected on it removed best available technique as referred to in article 48;
b) the measures proposed by the person drawing up the soil remediation project in accordance with articles 10 or 21 of the Soil Decree, and the periods within which those measures will be implemented;
c) the compatibility of the potential use of the contaminated land after soil remediation with the current or temporarily assigned use;

d) the limitations which will apply during or after the execution of the soil remediation by virtue of article 72 of the Soil Decree;

e) temporarily or definitively will be treated or processed;
f) the description of the measures which will be taken to ensure both environmental safety and work safety during the execution of the soil remediation works;

g) the repercussions of the soil remediation works on adjacent plots;
h) the activities on adjacent plots insofar as they can have an impact on the soil remediation;

i) the possible aftercare and the period during which it will apply;

6° the following data on possible activities which are under a licence obligation in the framework of the soil remediation works:

a) if the execution of the soil remediation works comprises activities which are under a licence obligation by virtue of the Environmental Licence Decree or the decree of 18 May 1999 on the organisation of town and country planning: the relevant data on those activities which are under a licence obligation;

b) if the execution of the soil remediation works implies the operation or modification of an installation for which an environmental impact assessment report or a regional safety report is required under the applicable legislation: the corresponding relevant data.

A risk management plan shall contain at least the following information:

1° a non-technical summary of the risk management plan;

2° the following identification data:

a) the identification of the land to which the risk management refers;

b) the identification of the land on which works are necessary to carry out the risk management, including the coordinates of their owner and user and, if applicable, the coordinates of the association of co-owners;

3° the following specific information in case of:

b) additions or changes to the risk management plan: the additions or changes to the risk management plan;

b) a new risk management plan: the motivation for drawing up a new risk management plan;

4° an overview of the state of contamination and other preconditions:

a) the results of the relevant exploratory and descriptive soil surveys, descriptive soil surveys or sediment surveys which have been declared in conformity and updated if necessary;

b) the results of the other measures mentioned in chapter VI of title III of the Soil Decree, taken where necessary, insofar as they have an impact on the risk management plan;

c) the results of any pilot projects carried out;

5° the following information regarding the management of the risks arising from the soil contamination and their follow-up:

a) where the risk management measures are concerned:

1) an evaluation of the different relevant technical possibilities to manage the risks arising from the soil contamination and the results of any research done into the feasibility of those technical possibilities;

2) the risk management measures proposed by the party drawing up the plan to manage the risks arising from the soil contamination;

3) an estimate of the costs of the risk management measures;

4) the periods within which the risk management measures will be taken;

5) if appropriate, a proposal for a maximum duration of the risk management measures;

6) the repercussions of the application of the risk management measures on adjacent plots and the environment;

b) the objectives of the risk management plan;

d) the limitations which will apply during the risk management by virtue of article 72 of the Soil Decree;

d) the way in which the pollutants or parts of the soil or the buildings and structures erected on it removed temporarily or definitively will be treated or processed;

e) the description of the measures which will be taken to ensure both environmental safety and work safety during the application of the risk management measures;

f) the activities on adjacent plots insofar as they can have an impact on the risk management;

g) where the follow-up of the risk management is concerned:

1) a description of the measures the person drawing up the plan proposes to take in order to follow up the effectiveness of the risk management measures, and a proposal for the periodicity of the follow-up reports on the implementation of those measures;

2) a decision schedule indicating the manner in which the risks arising from the soil contamination will be monitored and which measures will be taken based on the results of that monitoring;

3) possible gaps with respect to the soil contamination and a plan to fill those gaps;

6° the following data on possible activities in the framework of the risk management which are subject to a licence obligation:

a) if the execution of the risk management measures comprises activities which are under a licence obligation by virtue of the Environmental Licence Decree or the decree of 18 May 1999 on the organisation of town and country planning: the relevant data on those activities;

b) if the execution of the risk management measures implies the operation or modification of an installation for which an environmental impact assessment report or a regional safety report is required under the applicable legislation: the corresponding relevant data.

Table 44: The target values for soil quality, mentioned in article 3 of the order of the Flemish Government establishing the Flemish regulation on soil remediation and soil protection are listed in the table below.

	Solid phase of the soil (mg/kg dry matter)	**Groundwater** (µg/l)
METALS AND METALLOIDS ([1])		
Arsenic	16	5
Cadmium	0.7	1
Chromium (III)	62	10
Copper	20	20
Mercury	0.1	0.05

Lead				31		5
Nickel				16		10
Zinc				77		60
	(mg/kg dry matter)					**Groundwater** (µg/l)
Land-use type	I	II		IV	V	I,II,III,IV,V
METALS AND METALLOIDS						
Arsenic	58	58	103	267	267	20
	2	2	6	9.5	30	5
Chromium (III) (2)	130	130	240	560	880	50
Copper	120	120	197	500	500	100
Mercury	2.9	2.9	4.8	4.8	11	1
Lead	200	200	560	735	1250	20
Nickel	93	93	95	530	530	40

Zinc	333	333	333	1000	1250	500

[1]In order to be able to take into account the characteristics of the soil when verifying metal and metalloid concentrations in the solid phase of the soil against the target values for soil quality, the target values for soil quality shall be converted to the measured clay and organic material contents in the sample to be verified, except for cadmium and mercury (see formula in the Flemish directive).

I: forest & natural areas, II: Rural area, III: Residential area, IV: Recreation area

Article 1. The soil remediation standards, mentioned in articles 47, 161, §2, 3° and 164 of the order of the Flemish Government establishing the Flemish regulation on soil remediation and soil protection are listed in the table below.

A distinction is made between Historical Soil Pollution (pre 29/10/95) and New Soil Pollution (post 28/10/95).

Région Wallonne: décret Lutgen (http://lutgen.wallonie.be/spip/spip.php?article586). Two major criteria will govern from now on the cleansing: a pollution will be defined as news if it is posterior at April 30, 2007, goes back to coming into effect of the European directive on the environmental responsibility. In addition, the degree of pollution according to values known as “of threshold, intervention or threat” is detailed in an appendix of the decree which specifies the various substances tolerated on very low levels in the soil (metals, hydrocarbons…). If the soil concentration exceeds the soil remediation standards, the owner must clean the soil.

Denmark: The Danish EPA guidelines no. 6/1998 ‘Remediation of Contaminated Sites’provide a step by step description in the form of a flow diagram. Decision support is provided on how to conduct a risk assessment. The procedures are PC based using Microsoft Excel.

About 40,000 sites are contaminated in Denmark because they have had petrol gas stations, dry cleaners or other polluting industries located on them. The Danish EPA is responsible for drawing up guidelines for remediation, so that contaminated sites do not cause danger to human health or contaminate our drinking water. Municipalities manage the regulations on movement of soil and contact with the public, while the regions are responsible for remediation etc. of contaminated soil. (http://www.mst.dk/English/Soil+and+Waste/). On 1 January 2003, a total of 14.000 sites had been listed/ registered by the regional authorities. 7.213 sites were listed at knowledge level 2 (established soil contamination, referred to as V2 in the following), and 5.810 sites were listed at knowledge level 1 (knowledge of activities that may have caused soil contamination, referred to as V1 in the following). In addition, the local authorities have reported a total of 1,433 sites to the counties, but the counties have not yet decided on relevant listing for these sites. The Danish EPA sets criteria for when the soil can be characterised as contaminated, along with principles for how soil contamination is to be investigated and remedied. Focus is on the large, cost-intensive soil contamination cases such as Cheminova and Kærgaard Plantage. The total amount of soil cleaned up and deposited in connection with remediation of listed properties or in order to avoid listing, was estimated at 631,000 tonnes.

Contaminated Sites Council to the Minister for the Environment. Annual report 2002. Depotrådet. Redegørelse om jordforurening 2002. Danish: http://www.mst.dk/udgiv/Publikationer/2003/87-7614-083-0/pdf/87-7614-084-9.PDF.

Finland: In 2004 Finland's environmental administration was aware of more than 20,000 sites where the soil could be contaminated. Around 10 000 sites located less than 100 metres from residential, groundwater or surface water areas, or less than 200 metres from a source of water supply, are potentially contaminated. The volume of contaminated soils annually restored in Finland amounts to more than 500 000 tons. The number of sites at which restoration is undertaken has clearly increased during the last few years. In the early 1990s, some 10 to 20 sites were annually restored while today the annual number is around 400. The most common remediation method for contaminated sites is mass exchange: the contaminated soil is replaced by clean soil. Three main principles are applied in soil protection work: 1. The multiple functions of soils must be sustained.

2Irreversible damage must be minimised.3 Non-renewable resources must be used providently. Policy instruments in soil protection include legislation, land use planning, EIA (Environmental Impact Assessment), environmental permit procedures and official supervision and monitoring. There are no specific laws on soil protection in Finland, but soils are protected and their sustainable use is ensured through legislation controlling the various activities that affect soils. According to the Land Use and Building Act, planners must be aware of any contamination wherever land use changes are planned. The Environmental Protection Act prohibits the pollution of the soil or groundwater, and obliges polluters to notify the environmental authorities of any soil contamination, and also take responsibility for cleaning up any contaminated soil.

The environmental authorities classify sites into four categories:

Sites requiring assessment

Such sites are known by the authorities to have been used for activities involving substances that can harm the environment, and that may also have entered the soil. Even if soils have not always been contaminated in such cases, it is important that such risks are considered when changes in land use or building are planned, and also accounted for in the sale or rental of such properties.

Sites which must be investigated or remediated as necessary

In such sites, wastes or other substances are known to have reduced soil quality, creating potential health risks or damage to the environment. Such contamination may also reduce the amenity value of sites.

Sites where no remedial action is needed

Such areas include sites where soils have been cleaned up according to the authorities' requirements, as well as sites where detailed surveys have shown that soils are not significantly contaminated. In some of these sites certain forms

of land use and development may still be limited.

Operative sites

Environmentally hazardous substances are handled or stored at the site. As soon as operations are concluded or altered the state of the soil shall be examined where necessary.

See http://www.miljo.fi/download.asp?contentid=67296&lan=en

A Council of State Decision is under preparation (based on the Environmental Protection Act, 2000) which identifies that either guideline values or risk assessment can be used in the management of contaminated sites. No specific flow diagram or equivalent is provided. There are no official decision support systems. An earlier guide to risk assessment of contaminated soils presented a simple conceptual decision model. This model has essentially the same elements as those followed by the US EPA and ASTM.

Pirre (Eco-efficient risk management of contaminated soil and groundwater) (www.environment.fi/syke/pirre)

DE (Germany) All German procedures could be traced back to the "Bundesbodenschutzgesetz" - Federal Soil Protection Act (Act on Protection against Harmful Changes to Soil and on Rehabilitation of Contaminated Sites, 1998) and its statutory ordinance "Bundesbodenschutzverordnung" (1999) giving regulations for both risk assessment and the decision about counter-measures like remediation or safeguarding and restriction measures. For whole Germany, there is a standard sequence of assessment steps given, which is obligatory but not very detailed.

The flow diagram involves three steps:

1. Identification and Historical data collection

2. Investigation and Risk Assessment

3. Remediation and Monitoring

The decision about remediation options is part of a standard sequence:

1) Are there any indications for a risk / harmful soil change? Yes - continue / No - exit procedure

2) The local authorities have to perform an exploratory investigation. The results of this investigation are mainly tested by comparison with the German trigger and action values representing some kind of "realistic worst case standard presumptions" concerning land use, exposure, bioavailability, affected population etc. If this step confirms that there is a risk / harmful soil change --> Yes, continue procedure / No --> exit procedure

3) Is it possible to implement "simple" measures? Yes --> Install those measures / No --> Continue procedure

4) The one who is "responsible" (may be the owner, the user, the polluter or an authority) performs a detailed assessment. At the end of this step it must be clear, if there is an enlarged risk level / a harmful soil change or not. Yes, it is --> Continue / No, it is not --> exit

5) The responsible one / the authority performs an assessment for remediation. At the end of this investigation step it comes to the decision about which remediation option will be the best for the site

6) The responsible one / the authority builds up a conceptual scheme, call remediation plan. In this step the whole remediation is planned and the technical details were fixed.

7) Install and perform remediation, if necessary implement monitoring

8) Control remediation, if all has run smoothly you are ready with the job

The procedure can differ from the standard procedure if changes can be justified the changes.

Sub-procedure for remediation assessment and remediation plan (5 and 6):

(given by part 8 of the "Saxon handbook of contaminated sites remediation", a compendium of 9 large books:

http://www.lfug.smul.sachsen.de/de/wu/umwelt/lfug/lfug-internet/veroeffentlichungen_2287.html

All these parts are meant as a helping hand for local authorities and the responsible ones, a reliable guide given by experts for a recommended course of action. But they are not meant as mandatory regulations which you have to obey strictly. Usually these steps were performed by experts or done with help of experts:

1) final risk assessment, identification of remediation issues and targets

2) Preparation and evaluation of basic data

3) additional site investigation, zoning, pre-tests

4) pre-selection of possible remediation options

5) build up remediation scenarios

6) technical & environmental evaluation and cost estimation

7) cost-benefit-analysis

8) specification of remediation targets, may be re-running the procedure from step 4

9) final suggestion of an ideal remediation option for the site

10) decision on remediation

11) Build up a conceptual scheme / remediation plan --> continue at step 6 of the general procedure mentioned above

There are several handbooks, reports and recommendations concerning step 4 (pre-selection of options). Some of them created as a kind of small decision tool systems like ATRIUM (http://www.lfug.smul.sachsen.de/de/wu/umwelt/lfug/lfug-internet/abfall-altlasten_8434.html).

Greece:

There is no specific legislation dealing with contaminated land and thus there are no flow diagrams for the procedures dealing with contaminated land. There are more clearly specified procedures in respect of municipal and hazardous wastes management, aspects of which are closely related to contaminated land. To date there is no decision support system for risk management.

Ireland

Ireland does not have legislation dealing specifically with contaminated land. A risk based approach is used in the assessment of contaminated land, but it is not part of the legislative framework.

Italy APAT (Agenzia per la protezione dell'ambiente e per i servizi tecnici) Manuale per le indagini ambientali nei siti contaminati (Handbook for environmental assessment at contaminated sites) Manuali e linee guida 43/2006, Dipartimento Difesa del Suolo, Servizio Tecnologie del Sito e Siti Contaminati, Roma, Italy, ISBN 88-448-0234-1. www.apat.gov.it

This publication draft the topics legacies to the contaminated sites, in particular the assessments to determine the characteristics of environmental matrices such as soils, sub-soils and groundwaters. It is in relation with the publication of the European directive on groundwaters and the European directive proposal for the soil protection.

Other publication available:

APAT - Centro Tematico Nazionale Territorio e Suolo [2004]: Proposta di guida tecnica sui metodi di campionamento dei suoli contaminati. Rassegna e confronto delle metodologie esistenti in ambito nazionale e internazionale

APAT - Centro Tematico Nazionale Territorio e Suolo [2003]: Proposta di guida tecnica sui metodi di analisi dei suoli contaminati.

Carlon et al (2008) proposed the following solutions to support the formulation of remediation plans for contaminated land:

1. in the hazard assessment, it supports the selection of Contaminants of Concern (CoC) with consideration of both their average concentration and peak concentrations, i.e. hot spots;

2. in the exposure assessment, it applies geostatistic interpolation methods for mapping the distribution of contaminant concentration;

3. in the risk characterisation, it provides a zoning of the site based on the risk posed by multiple substances and allows the interrogation of risk distribution vector maps about most relevant CoC and exposure pathways;

4. in the uncertainty analysis, it applies the Monte Carlo probabilistic calculation of the risk and generates maps of the uncertainty associated to Risk Factor estimates;

5. in the risk reduction phase, it supports the formulation of remediation plans according to a stepwise spatial allocation of remediation interventions and an on-time simulation of risk reduction performances.

Netherland:

There is a complex set of flow diagrams available for a variety of questions relating to

contaminated land management, but these have common threads:

- Is the site a potential risk?
- Is remediation urgent? – based human toxicology, ecotoxicology or rate of dispersal of material

Remedial objectives

Current approaches are driven by risk assessment rather than by the need to remove contaminated material (which characterised some earlier approaches).

A range of decision support tools are available commercially such as REC (see Section 5.4) and SUS (Saneringsurgentiesystematiek - system for environmental prioritisation of clean-up)

Norway

A flow diagram summarises contaminated land management processes. Its steps are as follows:

1. Problem Description;
2. Investigation and Risk Analysis;
3. Implementation of remedial measures; and
4. Terminating the Case.

Between each of these steps there is a control and decision-making phase which determines whether it is possible to progress through to the following step. There are decision support systems available in Norwegian.

Norwegian Pollution Control Authority. Guidelines for the risk assessment of contaminated sites TA-1691/1999; 1999.

Portugal:

There is no specific legislation on contaminated land. However, there is a programme to produce legislation on contaminated land towards the end of 2001. There is no risk assessment decision support system. When necessary the criteria employed in the Canadian and USEPA systems are used.

Spain:

There is legislation on waste (Waste Act, April 1998) that includes a chapter for contaminated soil. This legislation states the framework policy providing the basis for soil contamination management in Spain. At the moment this legislation is being developed in more detail. The flow diagram and the decision support tools will be developed in near future.

There is legislation on waste (the Catalan Waste Act, July 1993) which defines the responsibilities for soil remediation, but the management of contaminated soil was not specifically regulated. A flow diagram has been developed as a technical guideline; it summarises the process of dealing with contaminated land and involves five steps:

1. potentially affected sites;
2. soil suspected of contamination;
3. affected sites;
4. contaminated sites;
5. remediated site and monitoring of sites.

In each of these steps there is an assessment and a tool to help with the decision making process to determine whether it is necessary to progress through to the subsequent step.

In Spain, the Royal Decree 9/2005 governing contaminated soils and the Madrid Regional Law 2/2002 of Environmental Control provides for assessments of the environmental impact of a number of activities and projects, including those of regeneration of the contaminated sites (Lobo et al with R Millan 2007 Sede)

Switzerland: (Clarinet, decision tools, 1992): There are four main stages in contaminated site management:

1 Registering of sites;

2 Preliminary investigation (does the site need remediation? A basic risk evaluation);

3 Detailed investigation (detailed risk assessment, definition of remediation goals, definition of delays to be expected); and

4 Planning and realisation of remediation including monitoring of the site.

There is a computer based decision support system for the registration of sites and to support the initial decision on the necessity of an initial investigation. Development work is underway for later stages in the process, involving considerably more detailed information. This focuses in particular on the link between soil and land as a source of pollution through the unsaturated zone into groundwater. The model will follow the broad outline of the SISIM model produced by Germany.

No particular procedures are used or are available to stakeholders. Generally a remediation project is presented on behalf of the problem holder by consultants. It must deliver complete and understandable decision bases for the definitive establishment of remediation objectives and deadlines. The regulatory authority must approve these proposals. The minimum requirements are set in environmental legislation, there is a great deal of flexibility on how and over what timescales for remediation above these minimum standards, taking account of costs and acceptable environmental impacts.

Cost–benefit analysis plays a significant role. Other techniques may also be used depending upon size, significance and cost implications for a given site. The current directive on remediation projects highlights the issues and evaluations that have to be dealt with in the remedial design project prior to approval by the competent authority.

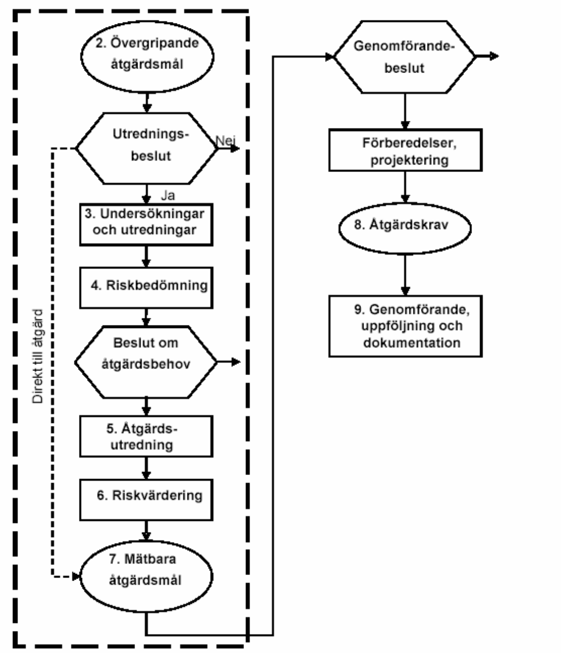
The primary factors driving decision-making for risk management are:
- Risk based remediation objectives;
- Cost effectiveness;
- Environmental merit/ sustainability;
- Planned redevelopment; v. feasibility;
- Time required and time available;

- Space and other site-specific constraints.

Sweden: Swedish Environmental Protection Agency has released in 2008 a report draft “To select remediation measures: A guideline from generic to measurable remediation aims” (*Att välja efterbehandlingsåtgärd: En vägledning från övergripande till mätbara åtgärdsmål,* in Swedish). The draft contains guidance how to, in a suitable way, select measures to handle contaminated areas and materials. Schematic presentation (flow diagrams, Fig 23) and more detailed description of a selection of various handling alternatives and phases composing a remediation project are given.

http://www.naturvardsverket.se/upload/30_global_meny/02_aktuellt/Remisser/vagledningsmaterial_om_fororenade_omraden/Att_valja_ebhatgard_remissversion_2007-10-19.pdf
http://www.naturvardsverket.se/upload/30_global_meny/02_aktuellt/Remisser/Sammanstallning_av_remissvar/Synpunkter_pa_vagledningsmaterial_om_fororenade_omraden/Att_valja_EBH_atgard_remissvar2008_allman_niva.pdf

The report is intended for a broad range of stakeholders, media (soil, sediment, water, etc) and situations (constructions, pumping of water, dredging of sediments, etc).



Figur 1.1.Schematisk bild av olika moment som ingår i ett efterbehandlingsprojekt. Den streckade rutan visar vilka moment som bidrar till åtgärdsvalet. Siffrorna anger i vilket kapitel i vägledningen som respektive moment beskrivs.

Fig 23. Flow diagram of a selection of various handling alternatives and phases composing a remediation project in Sweden.

Remediation and Monitoring

Documents that are used as support tools on deciding whether a site requires to be remediated are provided by Swedish Environmental Protection Agency (SEPA) in form of guidelines. Generic guideline values for contaminated sites, developed in 1996 and revised in 2008, are used as a main starting point for deciding on necessity of remedial measures. SEPA also provides guidance and calculation tools for estimation of site specific values and how to perform risk assessment of a contaminated site in generic as well as in-deep level.

USA: see Federal Remediation Technologies Roundtable Decision Support Tools (DSTs) Matrix at http://www.frtr.gov/decisionsupport/

DSTs are interactive software tools used by decision-makers to help answer questions, solve problems, and support or refute conclusions. They can be incorporated into a structured decision-making process for environment site clean-up. DSTs often support multiple functions, such as data acquisition, spatial data management, modeling, and cost estimating. The Federal Remediation Technologies Roundtable matrix is a table that provides general information about each DST, such as the types of files that may be imported to, or exported from, the DST, the characteristics of applicable sites (contaminants and media) and the functions it performs. All DSTs that were evaluated are free to the public.

For risk assessment see: http://www.frtr.gov/decisionsupport/FunctionalGroups/risk_assessment.htm

Table 45: Presentation of the model procedure

	FR	UK	DE
Overview	+		
Components			
Conceptual scheme	+		+
Risk assessment	+	+	+
Options appraisal	+	+	
Identification of feasible remediation options	+	+	
Detailed evaluation of options		+	+
Zoning/pre-test			+
Developing the remediation strategy/			+
Build up remediation scenario	+		+
Implementation	+	+	
Preparation of the plan		+	+
Design, implementation, verification		+	+
Cost-benefit analysis			+
Long-term monitoring maintenance		+	+
Framework(s)	+	+	+
Phases within components	+	+	+
Scope for iteration	+	+	+
Possible response options*		+	
Formalisation of the outputs**	+	+	
Supporting information	+		
Information map	+		
References	+		
Glossary	+		

* flexibility for a particular set of conditions or findings to optimise time and financial resources

** written records and reports

Table 46: Availability of framework(s) for the (national) model procedures

UK: Yes (including flowcharts) FR: not really framework and flowcharts but specific tools for each procedure parts, standard sequence DE: standard sequence BE- Flanders: standard sequence SW: standard sequence and flowcharts AT: standard sequence and flowcharts

Table 47: Risk assessment

	FR	UK	DE
Stages	2	3	2
Conceptual model	+	+	
Desk study			
Collection of historical information	+	+	+
Visual inspection	+	+	+
Intrusive site investigation			
Taking samples			+
Monitoring equipment			
Evaluation criteria			
Absolute standards			
Realistic worst case standard presumptions			+
Recommended limit values			
Guideline values			+
Mandatory values in media			
Guidelines			
Compliance with Mcerts*			
Decision records			
*Mcerts: Monitoring certification scheme			

Stage 1 – Preliminary risk assessment: • What the context and objectives are for the risk assessment
• What the outline conceptual model is for the site
• What potential unacceptable risks can be identified?
• What further action is appropriate?

Stage 2 – Generic quantitative assessment: • What pollutant linkages can be evaluated using generic assessment criteria
• Whether there are unacceptable risks associated with these pollutant linkages
• What further action is appropriate?
Stage 3 – Detailed quantitative risk assessment:
• What tools and criteria are appropriate for estimating and evaluating the risk
• Whether there are unacceptable risks associated
• What further action is appropriate?

The conceptual model

An important thread throughout the overall process of risk assessment is the need to formulate and develop a conceptual model for the site, which supports the identification and assessment of pollutant linkages.

Development of the conceptual model forms the main part of preliminary risk assessment, and the model is subsequently refined or revised as more information and understanding is obtained through the risk assessment process.

Each tier of risk assessment requires decisions to be made on the basis of information about the site – for example, the type, extent, location and behaviour of potential contaminants, physical conditions on or around the site and the characteristics of the people and the environment potentially affected by contaminants on the site. Information used in risk assessment may also be essential in informing decisions about possible solutions for managing the contaminated soils.

Examples of conceptual schemes

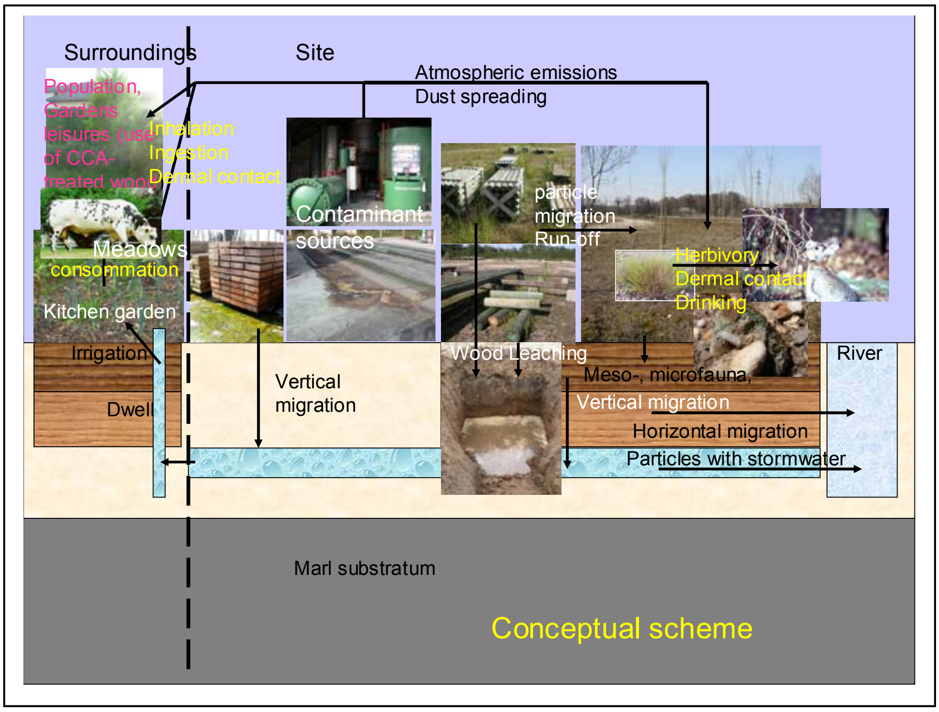


Fig 23. Conceptual model used at the UMR BIOGECO remediation platform.

Europe:

France: The model procedure is available at http://www.sites-pollues.ecologie.gouv.fr/

UK: The Model Procedures for the Management of Land Contamination, CLR 11, have been developed to provide the technical framework for applying a risk management process when dealing with land affected by contamination. The process involves identifying, making decisions on, and taking appropriate action to deal with land contamination in a way that is consistent with government policies and legislation within the UK. The technical approach is designed to be applicable to a range of non-regulatory and regulatory contexts:

(1) Development or redevelopment of land under the planning regime;
(2) Regulatory intervention under Part IIA of the Environment Protection Act 1990 or Part III of the Waste & Contaminated Land (Northern Ireland) Order 1997;
(3) Voluntary investigation and remediation; and
(4) Managing potential liabilities of those responsible for individual sites or a portfolio of sites.
The Model Procedures consist of three parts – the Procedures, Supporting Information and the Information Map. These provide a hierarchy of information in which Part 1 sets out the framework of the risk management process, Part 2 provides further technical detail to support the process and Part 3 contains sources of further information and guidance. These Procedures are intended to assist all those involved in dealing with land contamination, including landowners, developers, professional advisors, regulatory bodies and financial providers. The document is available at: Model Procedures for the Management of Land Contamination)

USA:

IRTC: Within the Superfund Amendments and Reauthorization Act (SARA) of 1986, Congress essentially translated into law EPA's policy to use other environmental laws to guide response actions. SARA added CERCLA Section 121(d), which stipulates that the remedial standard or level of control for each hazardous substance, pollutant, or contaminant be at least that of any applicable or relevant and appropriate requirement (ARAR) under federal or state environmental law. For example, Clean Water Act restrictions can be applicable to hazardous substances discharged into surface water from a Superfund site. Regulations codified in the National Contingency Plan govern the identification of ARARs and require compliance with ARARs throughout the Superfund response process, including during certain removal actions. All remediation technologies used at Superfund sites are subject to ARARs. Regulators must evaluate the proposed phytoremediation application and determine if it meets Federal and State environmental statutes, regulations and other requirements that pertain to the site.

6.5.6 Risk assessment

6.5.6.1 Definitions

Hazard identification – establishing contaminant sources
Hazard assessment – analysing the potential for unacceptable risks (what pathways and receptors could be present, what pollutant linkages could result and what could the effects be)
Risk estimation – predicting the magnitude and probability of the possible consequences (what degree of harm or pollution might result and to what receptors, and how likely is it) that may arise as a result of a hazard
Risk assessment - establishing whether unacceptable risks exist and, if so, what further action needs to be taken in relation to the site;
Risk evaluation – deciding whether a risk is unacceptable

Preliminary risk assessment
Define the context & objectives of the risk assessment
Define the broad characteristics of the site & the scope of the conceptual model
Identify & collect the information needed on potential contaminants, pathways, receptors & other relevant characteristics of the site & its setting
Outline conceptual model & identify possible pollutant linkages

Generic quantitative risk assessment
The purpose is to establish whether generic assessment criteria and assumptions are appropriate for assessing the risks and, if so, to apply them to establish whether there are actual or potential unacceptable risks. It also determines whether further detailed assessment is required.

See some handbooks:
ASTM [1996] - Standard Practice for environmental site assessment: Transaction screen process. E1527-97
ASTM [1997] - Standard Practice for environmental site assessment: Phase I environmental site assessment process. E1527-97
Moreover, the implementation of this methodology was fully
supported by an easy-to-use software developed in the popular

ECS (European Chemical Bureau). European Commission Technical Guidance Document on Risk Assessment. European Commission Joint Research Centre. EUR; 2003. p. 20418.
ISO [2005]: Soil quality - Sampling - Part 5: Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination. INTERNATIONAL STANDARD 10381-5 First edition 2005-10-01
USEPA (United States Environmental Protection Agency). Integrated Risk Information System (IRIS), database on line; 2002. Washington DC, http://www.epa.gov/iris/.
Carlon C, Critto A, Ramieri E, Marcomini A. 2007 DESYRE: decision support system for the rehabilitation of contaminated megasites. Integr Environ Assess Manag 3, 211–22.
Carlon C, Pizzol L, Critto A, Marcomini A. 2008 A spatial risk assessment methodology to support the remediation of contaminated land. Environment International 34, 397–411

Detailed quantitative risk assessment

The *purpose* is to establish and use more detailed site-specific information and criteria to decide whether there are unacceptable risks. It may be used as the sole method for quantitative assessment of risks, or it may be used to refine earlier assessments using generic assessment criteria.

For local scale and soil contaminants, four software packages, HHRA-GIS (Morra et al., 2006), HIRET (Bien et al., 2004), NORISC (http://www.norisc.com/) and SADA(http://www.tiem.utk.edu/~sada/help/) respectively, have been developed to assess the spatial distribution of human health risk (Carlon et al 2008). In HHRAGIS and HIRET, the human health risk assessment was implemented in a widespread Geographical Information System (GIS) platform to generate human health risk assessment maps as a function of soil contamination and land uses. NORISC (Network Oriented Risk assessment by In situ Screening of Contaminated sites) and SADA (Spatial Analysis and Decision Assistance, 2005) are more comprehensive GIS-based software packages that include modules for sampling, risk assessment and selection of remediation techniques.
While HHRA-GIS and HIRET do not provide an operational link between the risk assessment and the selection of remediation techniques, SADA and NORISC offer decision support modules for the selection of remediation techniques. However, these modules can be applied only to the peak concentrations, i.e. they were not designed for planning remediation interventions over large sites.

6.5.6.2 Deciding whether the level of risk justifies remediation.

Without a pollutant linkage, there is not a risk – even if a contaminant is present. But even where there is a pollutant linkage, and therefore some measure of risk, the question still needs to be asked as to whether the level of risk justifies remediation.

In UK, the answer depends on the context (Environment agency 2007). Government policy for dealing with past land contamination focuses on taking action where there are “unacceptable risks to human health and the environment” in relation to the use of the land and its environmental setting – the “suitable for use approach” [1]. Part IIA of the Environmental Protection Act (EPA) 1990 considers risk in relation to the current use of the land and defined receptors. In planning and development control, the aim is to ensure that there are no unacceptable risks to the receptors accounting for the proposed new use [5].

The question of whether risk is unacceptable in any particular case involves not only scientific and technical assessments of the particular circumstances (what is the level of risk represented by the circumstances of the site?), but also appropriate criteria to judge the risk (exactly what risk would be unacceptable?).
UK: The acceptability or significance of risk, including socio-economic aspects, is considered in general terms in the Guidelines for Environmental Risk Assessment and Management [4]. Decision-makers need to establish appropriate criteria for use in the specific context of land contamination.
Italy: For the purpose of supporting the formulation and comparison of remediation plans for large contaminated sites, also called megasites, a SDSS software called DESYRE was developed (Carlon et al., 2007). In DESYRE, outcomes of spatial risk assessment are the basis for the selection and allocation of remediation technologies and the creation of remediation plans. In a final module, each remediation plan is characterised by indicators

Uncertainty
In some cases, assessing land contamination involves direct observation of the effects or consequences of the existence of a hazard. This could take the form of visible contaminants leaching into water, or the observation of morbidity or death in livestock or crops. However, in very many cases, risk assessments will have to be based on a prediction of the risk. This relies on an understanding of how risks might arise, the characteristics of the site as determined through sampling, analysis and other investigations, and the use of models or other tools to estimate risk. All of these introduce uncertainty, as understanding of the risks may be incomplete, modelling may

produce an imperfect representation of the real world, and sampling, analysis and other investigations may not provide an accurate reflection of the true or relevant characteristics of the site.
Risk-based decision making offers the opportunity to formalise the management of these different uncertainties. Statistical techniques can frequently be used to evaluate the scale of uncertainties, and sensitivity analysis used within risk assessment can allow evaluation of the potential significance of inherent uncertainties in the process to any final decision. In some cases, further information can be collected, and the calculations refined to reduce the levels of uncertainty.

Most remediation work has been initiated for one or more of the following reasons (Clarinet 2002):

• To protect human health and the environment. In most countries, legislation requires the remediation of land, which poses 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 recent spillage of substances from a process or during transport. Groundwater protection has in many countries become an important driver for remediation projects.
• To enable redevelopment. Remediation 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 “repair“ problems. In some cases remediation work must be retrofitted to a newly developed site.
• To limit potential liabilities. Remediation can take place as an investment to increase the potential value of land. Owners may perceive that a particular site could potentially have an environmental impact, which might leave them liable to third party actions.

An important topic in the field of risk and decision analysis is the way in which expert judgments are aggregated or integrated into a single judgment; for instance, regarding the uncertain effects of technology application in complex environments (Scholz and Hansmann 2007). Various methods are suggested:
- deliberative, multiple-step procedures, in which experts first identify, categorize, and define risk rankings. Following this, laypersons or experts judge health, safety, or performance risks, with these then being aggregated by statistical or group decision processes.
- a representation of continuous uncertainty measures, e.g., different quantiles for certain events as a risk measure of critical infrastructures.
Delicate issues in this context are the procedures of aggregating individual judgments and the role of self-confidence ratings as selection criteria for incorporating or weighting the individual expert judgments.
different conceptions of expertise and experts.
(1) expert judgments of the *components* on which decision are based
(2) expert judgments of how to *structure* the decision task.

individual risk or uncertainty judgments are measured
the individual judgments are aggregated in a *group* decision (e.g., by means of a consensus building procedure)

Sources of uncertainty for the phytoremediation options. The performance of the plant depends on the concentration of the pollutant, the soil conditions, the interactions of different contaminants, the climate conditions (in particular rainfall, wind, and temperature), the plant species, the agricultural practices (including fertilizers, the soil parameters, the additives that mobilise or immobilise the contaminants), and the interactions among all these variables. These are the situational or *exogenous sources of uncertainty*.

A plant species can be considered a technology variant. In general, there is uncertainty about the performance of a certain plant and its subspecies as even individual plants of one and the same species may show considerable variation in their ability to extract contaminants. These are *endogenous sources of uncertainty* of technology application. There is also uncertainty with respect to long-term and sequential applicability as it is often unclear in which way a treatment will affect follow-up treatments with the same or with different technologies.

The connection between confidence and the validity of expert judgment was investigated. Scholz and Hansmann (2007) introduced a formative consensus building procedure (FCB) that generates probability statements on the performance of technologies, and compared different algorithms for the statistical aggregation of individual judgments. The case study refers to an expert panel of 10 environmental scientists assessing the performance of a soil cleanup with phytoextraction. The panel members first provided individual statements on the effectiveness of a phytoremediation. Such statements can support policymakers, answering the questions concerning the expected performance of the new technology in contaminated areas. Their study reviews (1) the steps of the FCB, (2) the constraints of technology application (contaminants, soil structure, etc.), (3) the measurement of expert knowledge, (4) the statistical averaging and the discursive agreement procedures, and (5) the boundaries of application for the FCB method. The quantitative statement oriented part of FCB generates terms such as: "The probability that the concentration of soil contamination will be reduced by at least 50% is 0.8." The data suggest that taking the median of the individual expert estimates provides the most accurate aggregated estimate. The discursive agreement procedure of FCB appears suitable for deriving politically relevant singular statements rather than for obtaining comprehensive information about uncertainties as represented by probability distributions.

Decisions on soil remediation are one of the most difficult management issues of municipal and state agencies. Scholz and Schnabel (2006) have presented a method for decision making among the remediation alternatives. Soil washing, phytoremediation, and no remediation were considered. Multi-criteria utility functions including (a) the cost of remediation (b) the impact on human health and agricultural productivity, and (c) the economic gain after remediation were constructed using probability density functions representing contamination for all site coordinates. The probability of different types of (i) correct decisions such as a hit or a true rejection and (ii) erroneous decisions such as a false alarm or miss were examined. The decision theoretic model is applied to a case study on TECS. It reveals the non-linear structure of multi-criteria-decision making. The case study shows that the geostatistical uncertainties of the log-normal distributed soil contamination must be taken into account: When uncertainties are not considered and the utilities are assessed according to the estimated value for a spatial unit, only few (N=26) spatial units result where the utility score of the alternative soil washing are higher than the utility score to the no remediation alternative. However, when taking into account geostatistical uncertainties of the log-normal soil distribution this number is about ten times greater (N=237). Furthermore, the use of 'maximizing expected utility' as decision rule is critical in that it may lead to a high probability of misses.

6.5.6.3 Costs and benefits

At several stages of the risk management process, judgements have to be made about the relative costs and benefits of particular courses of action or decisions. This "cost–benefit analysis" is an inherent part of the management of environmental risks in a sustainable way, and is a formal component of particular stages of regulatory regimes. It allows for the structured and transparent balance of the costs (usually, but not always, in financial terms) against benefits, which can be wide-ranging depending on the context – for example, enhanced health and environmental protection, increased commercial confidence in the condition of the land or simply greater certainty in ultimate decision making.
The scope and particular criteria for any cost–benefit analysis will depend on the context.

The replacement of a traditional crop in favour of a phytoremediating culture, is not a neutral operation (Thewys 2006). Apart from physical constraints - like not fitting in the crop rotation - the social acceptability of introducing a phytoremediating crop depends on the condition that the present value of the gross labour income (the total revenue diminished by the non-labour variable costs) earned on the area to be cleaned up and calculated over a sufficient long period, is at least not decreased. Phytoextraction will be implemented only if it is a financially attractive long-term option. When a farmer considers to introduce (if any) phytoremediating crop, his decision making can be assisted by the device called 'cost-benefit analysis' in which the timely evolution of costs and benefits of phytoremediation can be taken up. The outcome is than summarized by the net present value of the result. Assuming a predefined time period for the study, a cost-benefit approach could distinguish the following items (Vassilev et.al., 2004):
1. The cost of the phytoremediation action, capital and operational costs will be strongly connected with the pollutant removal performance of the remediation crop, the soil conditions, the difference between the initial and the target level of pollution, etc. All these items will also determine the length of the remediation period.
2. The loss of the income that the soil is still generating even in its polluted situation.
3. The eventual income through the valorisation of the biomass. This can be considered as 'recovering' some of the costs of phytoremediation.
4. The regained income of the soil after reclamation, determined by its functional use for which the reclamation target is decisive.

6.5.6.4 Risk communication

Managing the risks from land contamination is not simply a matter for the land owner or occupier, the officials engaged in the regulatory process and technical and/or legal advisors and contractors who may also be involved in a professional capacity. The actual or potential presence of contamination may have direct or indirect consequences for a much broader constituency of people and organisations, including neighbouring property owners and the local community. These stakeholders may have legitimate concerns about the level of risk posed by a site, whether or not the risk is unacceptable and how best it should be reduced or controlled. Communicating information about the risks associated with land contamination to parties not directly involved in a project is not necessarily straightforward. This is particularly the case when anxieties about the land may be at odds with technical or scientific assessments, or when there are major differences of opinion between the different groups about the best way of proceeding. Therefore, a formal 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 a number of ways of developing and delivering risk communication strategies at a site-specific level

An agreed strategy presented in non-technical language is necessary for genuine communication with all concerned parties in order to gain public and stakeholder confidence in the approach adopted. A publication from the Environment Agency entitled 'Consensus Building for Sustainable Development' (Sustainable Development Series Publication SD12) provides guidance on how this is done. (Clarinet decision tools 2002)

6.5.6.5 Guidance

UK: Communicating Understanding of Contaminated Land contains further guidance on how best to approach this issue.

Flanders: Comments from Dries et al (OVAM) (http://www.ovam.be/jahia/Jahia/pid/994)
If a company is confronted with a soil investigation indicating that its soil has been contaminated, most companies are quite willing to manage this problem. An environmental consultant is contacted to conduct a risk assessment out to see if and how soon remediation is necessary and to work out a remediation plan. Only very seldom, the company in question will communicate relevant information to its neighbours in an early stage of the process. This can cause very serious frictions and even endanger the objective management of the soil remediation. Risk communication is as important as risk assessment.

One example: The register of polluted soils in Flanders: The implementation of the Flemish soil remediation decree implied that the government made a list of risk-activities. When a property is transferred on which such a risk-activity was or is still carried out, the party transferring the property is obliged to carry out a soil-investigation before the transfer. Next to that, the regulation implies that the controllers of several risk-activities must carry out a soil investigation on a regular basis. Depending on the risk posed by the activity, such an investigation has to be carried out every five, ten or twenty years. The reports of these investigations must be sent to the OVAM within 30 days after completion of the report. If the investigation proves that a soil is polluted, OVAM puts the data concerning the soil into the register of polluted soils.

In accordance to European regulation, the Flemish government has dictated that the register of polluted soils is open to public.
This means that any interested party gets access to the data. A first form of access is the soil certificate. When a ground is put into the soil register, the owner and the user of the ground get a soil certificate from OVAM. This soil certificate gives a good indication of the degree of pollution. A copy of this certificate is sent to the local authorities of the community where the property is situated. The local authorities are obliged to give any interested party access to their copies of soil certificates. Next to that, any interested party can ask the OVAM for a certificate for any property located in Flanders. A second access to information is the right of any party to consult the entire file OVAM has on this specific ground. Any interested party only needs to send a prior notice in written in order to have access to the files, which may be consulted (and even copied) at the OVAM offices thereafter.

Communication

Let's suppose you have a company and you know the site on which it is located, is polluted. The question what you are going to do with that information, is very relevant. Do you inform your neighbourhood, local authorities, etc.? Or do you start an extensive risk assessment to find out if the contamination really poses a threat without telling anyone?
The second option looks the most interesting. Why would you tell your neighbours that you have a problem that may impact them? Keeping quiet is definitely the easiest way to avoid any embarrassing questions you might encounter when you spread the information.
You have to be aware, though, that even telling nothing about the problem is a definite choice you make; a choice that can cause major problems and that should be very well studied and motivated. Let's suppose that one of your neighbours suspects you have an environmental problem, and wants to

find out if anything is wrong. He can very easily contact the local authorities, to consult the content of the soil certificate regarding your property. If he sees the certificate indicates that the ground is severely polluted, he can write a letter to OVAM, asking for access into the files. Looking at the report, he finds out the situation is quite serious. He also finds out that the report is already a few years old, so the company has been aware of the problem for some years, but they never told anybody, nor did anything about it as far as he knows.
Then you have a serious problem. Before you know it, you're confronted with the most provoking questions such as: "How bad is it in reality?", "How does the pollution effect on the neighbourhood?", "Are our children in danger?", "Why haven't you done anything yet to solve the problem?"…
Things can even get worse: your neighbour can go to the local press; the questions they pose are even more persistent and within a day, you're front-page news. Improvising an answer on the spot can be quite exciting, especially in front of the camera of a local TV-crew. A classical answer telling "No comment" really gets things going, because your neighbours think it must be really very bad, if you don't even want to answer a serious question. Then the gossip train starts, and you have a major problem, because there's almost nothing you can do about gossip: people start making imaginations and always think the worst of such a situation. Getting this right afterwards often proves to be almost impossible.

3 Case studies in Flanders to underline the importance of good communication. Union Minière is quite well aware of the fact that its property is probably very polluted. When the soil remediation decree is published, they decide to carry out a very big soil investigation on all their grounds. They find out that not only their grounds but also the adjacent properties are polluted. They make a contract with the government indicating that they will perform all necessary actions, within a limited span of time. After that, they set up a communication plan. All the information they have on the contamination is given to the public. The company organises information sessions with the local authorities, the local doctors, the press and the neighbours. They also stress that they have agreed to start a remediation in the very near future. Attention is also paid to the fact that the firm is modernising and investing in its industrial sites, and that a lot of employment is guaranteed.

In spite of the pollution situation they affected, the media comments were very positive and stressed that Union Minière was actively managing the situation and the firm was investing in its industrial activity in the region.
In the beginning of the '90s, a company acquired a petrochemical factory, with a very heavy environmental "debt". The new owner started investing very heavily in the installations to reduce the emissions and starts a very big soil investigation. A voluntary soil investigation showed a severe soil pollution, and they contacted the government and started planning the remediation. They didn't inform the public at all. During a warm summer, fishes died in a nearby lake. High concentrations of PAH's were found in the water, in the soil around the lake and in a few private gardens. It was quite obvious that the pollution was caused by the nearby-located facility. A local journalist wrote an article about the problem, and the very next day the pollution was national news. Confronted with the press, the firm answered "No comment". During the three next weeks, the wildest articles appeared in the media. Quite a bit of attention was paid to the carcinogenity of benzo(a)pyrene and to the health of the children living in the neighbourhood which might be affected. When the company tried to explain that they had already invested heavily to solve the emission problem and that they had remediation plans for the soil, they were not believed. Their reactions got very little press coverage. Even though the pollution was far less problematic than in the previous example, the company got a "black" label.
A soil investigation was carried out on a non-ferrous metallurgy facility in order to fulfil its periodical investigation duty. They found out the groundwater was very polluted with chlorinated solvents. They thought the chance was quite high that also the groundwater under the houses in the neighbourhood would be polluted. They organised an information session for the neighbourhood explaining the problem they faced and asking the people permission to investigate the groundwater on their premises. Even though they told the people that they may have a pretty serious problem, the neighbours were reassured by the active approach. Not one negative article was published in the press.

Conclusion In most cases, it may be very interesting to spread the news of a contamination by yourself. This active approach of risk communication assures third parties of your willingness to reduce your liability at the minimum. It's quite evident that this communication has to be planned and prepared very cautiously. An information session which is not well prepared, can lead to improvised answers and misunderstandings and can be as dangerous as not telling anything. If you try to handle the problem without telling anything to anyone, third parties become anxious when they find out you have "hidden" your problems and you may be "labelled" for quite a long period, which also affects your relationship with your clients, your suppliers, your insurer, the authorities and even financial institutions or stockholders.

6.5.7 Options appraisal

6.5.7.1 Action/definitions:

Evaluating feasible remediation options and determining the most appropriate particular option or remediation strategy for the site;

- A remediation option is a means of reducing or controlling the health or environmental risks associated with a particular pollutant linkage.
- A remediation strategy is a plan that involves one or more remediation options to reduce or control the risks from all the relevant pollutant linkages associated with the site.

Planned land use, time available for remediation, developers knowledge and understanding and the money available for development, are powerful controlling the remediation solutions (Clarinet 2002)

UK: Options appraisal is the 2nd stage of the overall process of risk management in the Model Procedures. It comes into play only if risk assessment demonstrates unacceptable risks are associated with a site and these need to be managed. As options appraisal proceeds, it focuses primarily on those pollutant linkages (relevant pollutant linkages, RPLs) that have been shown through risk assessment to represent unacceptable risks (given the legal and commercial context) and where a decision has been made to undertake remediation. The role of options appraisal is to establish, taking all the circumstances of the site into account, which options (either singly or in combination) offer the best overall approach to remediation for the site as a whole.

USA:

- The FRTR reference guide provides a "yellow pages" of remediation technologies. It is intended to be used to screen and evaluate candidate cleanup technologies for contaminated installations and waste sites in order to assist remedial project managers (RPMs) in selecting a remedial alternative. To reduce data collection efforts and to focus the remedial evaluation steps, information on widely used and presumptive remedies is provided. Figure 24 illustrates the trend toward reduction in the degree of site characterization through screening and the use of presumptive remedies.

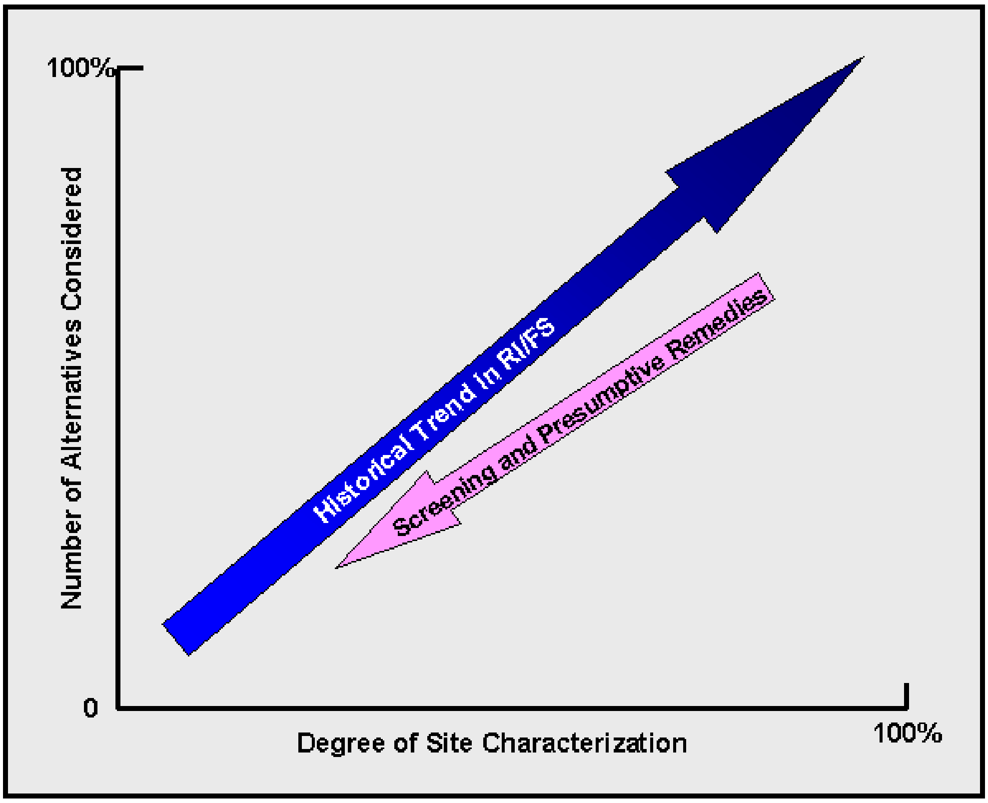


Figure 1-1 Reduction of Data Needs by Screening and Presumptive Remedies

Figure 24: Degree of site characterisation vs. number of alternatives considered (http://www.frtr.gov/matrix2/section1/figur_1_1.gif).

This guide enables the reader to:

Screen for possible treatment technologies.
Distinguish between emerging and mature technologies.
Assign a relative probability of success based on available performance data, field use, and engineering judgment.
This document reviews and compiles the unique features of several U.S. Government documents into one compendium document. Information on widely used and presumptive remedies is provided in order to minimize the amount of remediation resources used in obtaining site characterization data and/or evaluation of every possible remedial alternative. Presumptive remedies are preferred technologies for common categories of sites established by the U.S. Environmental Protection Agency (EPA), based on historical patterns of remedy selection and EPA's scientific and engineering evaluation of performance data on technology implementation. Commercially available innovative technologies are also included.
In situ biological treatment technologies reviewed are bioventing, enhanced biodegradation, and phytoremediation (http://www.frtr.gov/matrix2/section4/4-3.html).
FRTR (2002) (federal remediation technologies roundtable) Remediation technologies screening matrix and reference guide. Van Deuren J, Lloyd T, Chhetry S, Liou R, Peck J. http://www.frtr.gov/matrix2/section1/toc.html

- A matrix for selecting remediation process is available at
http://www.frtr.gov/decisionsupport/FunctionalGroups/remedialprocessselection.htm

- EPA's Office of Superfund Remediation and Technology Innovation has developed a Green Remediation web site. The site explains the basic principles and objectives of green remediation, and outlines best practices for reducing the environmental footprint of contaminated site cleanup projects. The site describes details on green remediation best practices, and serve as a clearinghouse for technical materials, decision-making tools, site-specific case studies illustrating green remediation implementation efforts, and information on green remediation related events and new information products. See : http://www.clu-in.org/greenremediation/. Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites outlines the principles of green remediation and describes opportunities to reduce the footprint of cleanup activities throughout the life of a project (http://www.clu-in.org/download/remed/Green-Remediation-Primer.pdf).

- SMARTe is a Web-based information source and decision support tool. The purpose of SMARTe is to aid stakeholders in identifying, applying, and integrating tools and technologies to facilitate the revitalization of potentially contaminated sites in the United States. SMARTe is intended to be a Web-based system that can be updated as new tools, technologies, and approaches become available for revitalization. (http://www.smarte.org/smarte/home/index.xml).
- The CLU-IN web site provides information about characterization and treatment technologies for the hazardous waste remediation community. It offers technology selection tools and describes programs, organizations, publications for federal and state personnel, consulting engineers, technology developers and vendors, remediation contractors, researchers, community groups, and individual citizens. (http://www.clu-in.org/)

Main stages (**based on UK procedure**)
1 Identifying feasible remediation options for each relevant pollutant linkage;
2 Carrying out a detailed evaluation of feasible remediation options to identify the most appropriate option for any particular linkage;
3 Producing a remediation strategy that addresses all relevant pollutant linkages, where appropriate by combining remediation options.

Once a remediation strategy has been identified and agreed, the process of risk management continues with the detailed planning and design work needed to implement the strategy in practical terms and show that it has been effective.

Stage 1
• What site-specific remediation and other objectives should apply to options appraisal
• Which remediation options should be taken forward for more detailed evaluation

Stage 2
• Which remediation option(s) is most appropriate for each relevant pollutant linkage
• Which options, (if any) need to be combined

Stage 3
• How, in broad terms, the remediation strategy is to be implemented

• Whether the remediation strategy will meet all site-specific objectives

During options appraisal, each relevant pollutant linkage is considered on an individual basis in the first instance, and the most appropriate remediation option is identified using a set of formal evaluation criteria. If only one pollutant linkage has to be considered, or if a single remediation option will deal satisfactorily with all the relevant pollutant linkages, that remediation option forms the basis of the remediation strategy for the site as a whole. Where more than one relevant pollutant linkage exists, it may be possible to combine remediation options to produce the remediation strategy or to identify a different option.

Objectives will be linked to the:
• Degree to which risks need to be reduced or controlled;
• Time within which the remediation strategy is required to take effect;
• Practicability of implementing and, where

Remediation options can be defined in accordance to the type of treatment processes taking place, such as (Clarinet 2002):

- Biological
- Chemical/Physical
- Solidification/stabilisation (S/S)
- Thermal

Remediation options are also referring to where the action is taking place:

- On site
  - In situ
  - Ex situ
- Off site
  - Ex situ

The <u>principal advantages</u> of *ex situ* technologies versus *in situ* technologies are:
 Clean up operations on site are fast;
 Liability discussions can be limited;
 Practical operational experiences are available for the technologies;
 Process optimisation and final results can be easily controlled;
 Nearly independent of geology, can better deal with soil heterogeneity.
Principle <u>disadvantages</u> include:
 Working labour and surrounding environment are likely to be exposed to higher concentrations of the contaminants;
 Not easily applicable to contaminants located deep in the soil;
 Difficult to use when existing infrastructure is complex or need special precautions;
 Can have extensive negative influence on a natural environment;
 Can be very costly since larger volumes of soil often need to be treated. It is often difficult to limit the volumes of soil to be removed due to time constraints.
 Negative side effects (non-core issues) can be extensive.

Metal-contaminated soil can be remediated by chemical, physical or biological techniques (McEldowney et al. 1993). Chemical and physical treatments irreversibly affect soil properties, destroy biodiversity and may render the soil useless as a medium for plant growth.

In situ techniques in general can be considered most suitable when:
 The contaminants are located deep in the ground;
 Both soil and groundwater need to be treated;
 Large volumes are contaminated;
 The contaminated volume contains coarse types of soil;
 Treatment time is not so important;
 Minimum site disturbance is required (some gentle remediation options can deal with the contaminants without affecting the soil fertility)

The principal advantages of *in situ* treatment include:
 Working labour and environment are in some cases less exposed to the contamination than when *ex situ* techniques are used;
 Not In My Back Yard (NIMBY) discussions are reduced;
 The costs for excavation, transport, and landfilling / off site treatment are reduced or avoided;
 Risk of accidental spillage causing environmental pollution during transport is removed.

The principal disadvantages of *in situ* treatment include:
 Typically they are of longer duration than *ex situ* processes;
 Techniques may require greater knowledge of the ground environment (geology) than techniques following excavation;
 Process containment, optimisation and control is difficult compared with ex situ *option*s;
 Techniques are limited by the accessibility of contamination in the soil;
 Concern for residual liability is higher;
 Concern on feasibility of completeness is higher.

Clarinet (2002) stated that ex situ technologies were by far the most widely applied remediation solution in Europe, and that in situ technologies are in the early stage of implementation, and a number of constraints must be resolved before they are readily implemented. Assuming that a remedial option can be adequately monitored and controlled, there is an increasing desire to promote in situ over ex situ solutions and on site solutions over solutions based on removal off site. There are often conflicting pressures affecting whether or not an on-site or off-site option is taken. In some cases stakeholders may express a preference for a solution based on removing materials off site. This may be related to concerns over residual liabilities, which in turn are related to concerns over the duration, feasibility or completeness of on site solutions. Conversely, removal of materials off site may be problematic because of the transportation and related problems, or because excavation is not considered technically or economically feasible. Offering previously validated solutions and developing an appropriate verification strategy for the sites in question are key steps in dealing with these concerns.

Technologies are often being referred to as:
• Emerging technology (E);
• Some field applications, but not widely used (FA);
• Widely used (WU).
Emerging technologies have only been applied in laboratory- or pilot scale/demonstration plants. A technology, which has been used in some field applications for solving a particular problem, or addressing a specific type of matrix, could be emerging when it comes to another application.

Clarinet (2002) summarized the degree of implementation of gentle remediation options in Europe (for trace elements or mixed contamination):

Civil engineering techniques widely applied technologies throughout Europe:
• Cover systems (WU); Vertical barriers (WU).
• Barriers beneath buildings (WU); Gas Barriers in the ground (WU); Monitoring systems and gas alarms (WU).
In situ technologies
• Bioventing (WU);
• Redox amendments for in situ bioremediation (WU); in situ oxidation (WU);
• Electro-remediation (FA);
• Phytoremediation, (E);
• Monitored Natural Attenuation (MNA) (WU).
The following group of technologies are predominantly ex situ technologies:
• ex situ bioremediation (WU);
• Stabilisation (WU);
• ex situ groundwater treatment

Risk management is based on breaking the pollutant linkage(s). This can be done by:
 Reducing or modifying the source;

 Managing or breaking the pathway;
 Modifying the exposure to the receptor.

Table 48 categories of gentle remediation options identified:

Gentle options	Process	Type
Phytoextraction		Biological
Aided phytoextraction with chemicals		Biological
Aided phytoextraction with bioaugmentation		Biological
Phytomining		Biological
Phytostabilisation		Biological
Aided phytostabilisation		Biological
Phytovolatilisation		Biological
Rhizofiltration		Biological
Rhizodegradation		Biological
Bio-immobilisation		Biological
(physicochemical) in situ stabilisation	Mixing of amendments into the soil to reduce mobility of contaminants	Physicochemical
Natural attenuation	Monitored use of naturally occurring in situ processes to remediate contamination without enhancement (so-called monitored natural attenuation, MNA)	Biological & Physicochemical
Landfarming	Cultivation of surface soils (typically 0-50 cm) to stimulate biodegradation. Can include the addition of various amendments (e.g. fertiliser)	Biologica

Other gentle options that can be combined in the strategy in case of mixed contamination (Table 49).

Table 49: Other gentle options that can be combined in the strategy in case of mixed contamination.

Technology	**Description**	**Type**
Biopiles	Excavated soil is built into a heap within which is a network of perforated pipes to aerate the soil.	Bio
Bioreactors	Soil (dry or slurried) is treated in a enclosed reaction vessel to which nutrients, air water and microbes are added as necessary. Bioreactors are also used to treat groundwater.	Bio
Biological treatment beds	shallow cultivation, where contaminated soil is cultivated in a contained treatment bed on a specially prepared area of a contaminated site	Bio
Bioremediation	Remediation by altering *in situ* conditions, typically by *in situ* flushing (see below) to optimise biodegradation rate. Examples include the addition of nutrients, oxygen, etc.	Bio
Bioventing	Movement of air or other gas through soil to stimulate biological destruction of contaminants, possibly in combination with their removal in the gas phase (c.f., soil vapour extraction)	Bio & phys

Biological treatments exploit one or more basic processes to treat contaminated soil and/or water; either *ex situ* or in situ:

(a) Degradation. Aerobic and anaerobic biochemical decomposition of a compound through the action of soil microorganisms (bacteria, fungi and actinomycetes);
(b) Transformation. Biochemical conversion of a contaminant to a less toxic and/or less mobile form;
(c) Accumulation. Accumulation of organic and inorganic contaminants within plant or algal tissues;
(d) Mobilisation. Biochemical mediated mobilisation of contaminants into a solution that is then separated from the contaminated soil and the contaminants recycled, treated, or disposed of.
(e) Immobilisation. Transformation of a compound less mobile and bioavailable in a given matrix.

In most cases the indigenous microflora is already competent (i.e. capable of carrying out the desired biodegradations), but is limited by environmental factors. Hence typically, biostimulation only is required.

Ex situ application of biological processes allows better process control, in particular the breaking down of ground into small particles, for example by cultivation, grading or conversion into a slurry. This overcomes one of the major limitations of *in situ* processes, which is ensuring the accessibility of the contaminant to the treatment.

Passive amendments for enhanced bioremediation (Clarinet 2002)
Changes in in situ redox conditions are affected when using materials that release oxygen (creates oxidizing /aerobic conditions) or that stimulates microbial removal of oxygen (creates anaerobic conditions). These materials are added to the subsurface to treat contaminated groundwater or soil in place. The desired effect is to enhance aerobic or anaerobic bioremediation, respectively. Aerobic bioremediation converts many organic contaminants to carbon dioxide, water and microbial cell mass. Anaerobic bioremediation is typically used for solvent contamination through dehalorespiration. The redox control amendments can be placed into the subsurface by injection of fluids, or a powder and water mix (slurries), as a direct mass reduction treatment or as a barrier containment approach.

Chemical treatments in gentle remediation options degrade, immobilise or concentrate potentially toxic compounds in contaminated soil or water by:
(a) Oxidation. Includes addition of chemicals donating electrons to the contaminant.
(b) Reduction. Includes addition of chemicals accepting electrons from the contaminant.
(c) Immobilisation. Precipitating as insoluble complexes, by adsorbing to a solid matrix, or by amending soil conditions; reduces the mobility of contaminants.
(d) Substitution. Replacement of functional groups of a contaminant.
(e) Hydrolysis includes addition of chemicals leading to hydrolysis (degradation) of the compounds.

6.5.7.2 Site-specific factors determining the appropriate remediation options:

One objective is to draw aside the inappropriate options and to only select options which need detailed evaluation. In complement of the technical criteria the user will have to get information about the existence of operators and their industrial references compared to the applications considered;
A preliminary selection can be made on site and contaminant parameters and on technical basis. It is mentioned again that in situ options limited the cost induced by soil excavation, and transport. Some gentle remediation options are also feasible ex situ on site.
Mobile unit to treat the soil can be used to reduce transport cost, but the soil volume to be treated must be sufficient.

From a broader perspective remediation processes will achieve core objectives by:
- Helping to conserve land as a resource;
- Preventing the spread of pollution to air and water;
- Reducing the pressure for development on green field sites.

There are a number of factors/criteria that need to be considered in selecting an effective remediation solution (Table 50).

Table 50: factors/criteria that need to be considered in selecting an effective remediation solution.

General criteria related to site and contaminants	
nature of the conceptual scheme and risk management	Conceptual scheme, contamination types & sources, pollutant linkages source control: remedial action either to remove, or modify the source of contamination properties of pathways, receptors
Treatable contaminants and materials	Contaminant (s) Concentration range Phase distribution Source and age Labile pool for biological action and migration lateral and vertical distribution of pollutants and affected media Soil & site characteristics limiting the option feasibility - physicochemical fertility - soil/contamination heterogeneity - soil volume possibility to excavate the soil, and volume of soil to excavate
Remedial options	Type of treatment applicability ability to grow plant species on the contaminated soil development of root system feasibility to satisfy the technical objectives regarding a pollutant linkage possibility to change root exposure and accumulation responses to fertilisation Legal & commercial context views of key stakeholders the costs and benefits of using any particular option potential conflicts between different objectives of the remediation strategy and remediation options
Location	Where the action takes place (e.g.: *in situ* or ex situ , on site or off site); Accessibility, topography, wider environmental setting, existence of buildings and other structures
Overall strategy	current or intended use of the site Degree to which risks need to be reduced or controlled Time within which the remediation strategy is required to take effect; Integrated / 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) Legal & commercial context views of key stakeholders
Implementation	**Practicability** of implementing and, where appropriate, maintaining the strategy Site management Planning remedial operations Verification of performance/Technical **effectiveness** of the strategy in reducing or controlling risks; Monitoring process performance and environmental effects **Durability** of the strategy Sustainability of the strategy Public acceptability and neighbourhood relationships (risk communication and risk perception) Strategies for adaptation in response to changed or unexpected circumstances, - i.e. flexibility Aftercare Cost of the strategy Benefits/side-effects/failures of the strategy

	Legal, financial and commercial context

6.5.7.3 General criteria related to site and contaminants

- nature of the conceptual scheme and risk management

risk management

source control: remedial action either to remove, or modify the source of contamination

- type of contamination (i.e. for TECS only or combined with organics, so-called mixed contamination)

. Source and age

. Studying the historical activities of the site generally provides a good indication of potential sources and types of contaminants likely to be found on site.

. Contaminant properties and chemical structure affecting treatment include not just the chemical types present, but also their concentration range, their phase distribution, and their origin. Identification of contaminants must be determined on a site-by-site basis.

.Typical contaminants found related to past activities on a site (Table 51):

Table 51: Typical contaminants found related to past activities on a site.

Past activities conducted on the site	**Typical contaminants**
Agriculture	VOCs, arsenic, copper, carbon tetrachloride, ethylene dibromide and methylene chloride, pesticides, insecticides, herbicides, grain fumigants
Automobile refinishing and repair	Some metals, metal dust and metal sludges, various organic compounds, solvents, paints and paint sludges, scrap metal, waste oils, acids and alkalis
Battery recycling and disposal	Heavy metals (Pb, Cd, Ni, As, Cu, Hg, Cr, At, etc.) and metals, and acids
Chloro-alkalis manufacturing	Chlorine compounds, mercury
Coal gasification	PAHs, BTEX, creosote, phenolics, sulphur compounds, chloride compounds, cyanide, aluminium, iron, lead, nickel, chromium, arsenic
Cosmetic manufacturing	Heavy metals, dusts, different type of solvents, acids
Dry cleaning activities	Chlorinated aliphatics, such as chloroform and tetrachloroethane, various solvents, spot removers, fluorocarbon, perchloroethylene and its dechlorination break down products
Dye facilities	2-naphthylamine, 4-aminobiphenyl, benzedrine and other organic solvents, aromatics, phosphates, sulphates, nitrites, chromium, zinc

Past activities conducted on the site	**Typical contaminants**
Electroplating operations	Metals such as cadmium, chromium, copper and nickel, cyanide, chlorofluorcarbons and other solvents
Glass manufacturing	Arsenic and lead, acids and alkalis
Herbicide manufacturing and use	Dioxin, metals, herbicides (dangerous halogenated organic compounds and others)
Hospitals	Formaldehyde, radionuclides, photographic chemicals, solvents, mercury, ethylene oxide, chemotherapy chemicals, pathogens
Incinerators	Dioxins, various municipal and industrial waste, ash and slags with dangerous compounds, ordnance compounds, metals, sulphuric acid and waste from cleaning gas system
Landfills- municipal and industrial	Metals, VOCs, PCBs, ammonia, methane, household products and all kind of detergents, pesticides, diversified wastes, hydrogen sulphide, batteries, medicines, photo-chemicals, acids and alkalis
Leather treatment and manufacturing	BTEX and other solvents, paints and dyes, chromium and sludges with chromium
Machine shops/metal fabrication	Metals, VOCs, dioxins, beryllium, degreasing agents, solvents, waste oils, metal wastes
Marine maintenance industry	Solvents, paints, cyanide, acids, VOC emissions, heavy metal sludges, degreasers, waste oils, acids and alkalis
Munitions manufacturing	Lead, explosives, copper, antimony, mercury, unexploded ordnance (UXO), sludges with heavy metals and solvents
Paint/ink manufacturing	Meatls (such as chromium, cadmium, lead, and zinc), VOCs, chloroform, ethylbenzene, other solvents, paints, inks, waste paints and sludges
Pesticide manufacturing	VOCs, arsenic, copper, pesticides, insecticides, herbicides, fungicides, xylene, chlorinated organic compounds, solvents, acids and alkalis
Petroleum refining and use	Petroleum hydrocarbons, PAH's, BTEX, fuels, oil and grease, acids, sludges with hydrocarbons and dangerous substances
Pharmaceutical manufacturing	Heavy metals (essentially lead), various organic chemicals, organic solvents
Photographic manufacturing and uses	Silver, bromide, methylene chloride, solvents, photographic products and residues from this industry

Past activities conducted on the site	**Typical contaminants**
Plastic manufacturing	Polymers, phthalates, cadmium, solvents, resins, chemical additives, acids and alkalis, oils, waste additives and sludges with dangerous substances
Printing industry	Silver, solvents, acids, waste oils, inks and dyes, toner, photographic chemicals, waste etching solutions, contaminated sludges
Railroad yards	Petroleum hydrocarbons, VOCs, PAH's, BTEX, solvents, fuels, oil, and grease, lead, PCBs
Research and educational institutions	Inorganic acids, organic solvents, metals and metal dust, photographic waste, waste oil, paint, heavy metals, pesticides
Scrap metal operations	Various metals and heavy metals (such as Pb and Ni), PCBs, PCT, dioxin, transformers, oil filters, asbestos, brake and antifreezing fluids, explosive components
Semiconductor manufacturing	Metals, VOCs, carbontetrachloride, degreasing agents, solvents, phosphoric acid??
Smelter operations / mining activities	Metals and heavy metals (such as Pb, Cu and As), dust, ash, slag, metal sludges, mineral oils, acids and alkalis
Underground storage tanks	Solvents, metals, POLs, BTEX, gasoline, diesel fuel
Wood pulp and paper manufacturing	Chlorinated organic compounds, dioxins, furans, chloroform, acid resins, mineral oils
Wood preserving	Creosote, PCP, arsenic, chromium, copper, zinc, PCBs, PAHs, beryllium, dioxin, wood preservatives, solvents, mineral oils
Inorganic chemical processes	Acids and alkalis, solutions and sludges with heavy metals, wastes with asbestos, solutions and slags with dangerous substances
Organic chemical processes	General organic chemicals (halogenated and not halogenated solvents, washing liquids, mother liquors)

- the type, amount, lateral and vertical distribution of pollutants and affected media,

The labile pool for biological action (so-called here bioavailability) can be estimated with various methods (Table 52 and 53)

- single chemical extraction (the extractive solution must be adapted to the investigated TE)
- isotopic methods (kinetic of isotopic dilution, data reported for Cd, Ni, Cu, Zn, Tl etc)
- collection of soil pore water with moister sampler
- percolation and lixiviation tests
- battery of biological tests (see WP3)

Table 52: Orientation on the basis of Zn content and labile pool

	Total Zn content		
Labile pool (mobility) (extractable with H_2O)	Low < 600 mg/kg	Medium 600-1400 mg/kg	High > 1400 mg/kg
Low <1 mg/kg	Phytostabilisation No remediation	Phytoextraction mobile element	Other option Phytostabilisation Phytoextraction mobile element
Medium > 1mg/kg < 6 mg/kg	Phytostabilisation Phytoextraction mobile element Phytoextraction total element	Phytostabilisation Phytoextraction mobile element	Other option Phytostabilisation Phytoextraction mobile element
High	Phytostabilisation	Phytostabilisation	Stand-by phytoremediation

> 6 mg/kg	Phytoextraction mobile element Phytoextraction total element	Phytoextraction mobile element Phytoextraction total element	or phytoremediation after physicochemical options Phytostabilisation Phytoextraction mobile element

Ademe (2003)

Table 53: Orientation on the basis of Cd content and labile pool

	Total Cd content		
Labile pool (mobility) (extractable with H_2O)	Low < 2 mg/kg	Medium 2-8 mg/kg	High > 8 mg/kg
Low <0.01 mg/kg	Phytostabilisation No remediation	Phytoextraction mobile element	Other option Phytostabilisation Phytoextraction mobile element
Medium > 0.01mg/kg < 0.05 mg/kg	Phytostabilisation Phytoextraction mobile element Phytoextraction total element	Phytostabilisation Phytoextraction mobile element	Other option Phytostabilisation Phytoextraction mobile element
High > 0.05 mg/kg	Phytostabilisation Phytoextraction mobile element Phytoextraction total element	Phytostabilisation Phytoextraction mobile element Phytoextraction total element	Stand-by phytoremediation or phytoremediation after physicochemical options Phytostabilisation Phytoextraction mobile element

Ademe (2003)

Pb: When Zn labile pool is low, *T. caerulescens* is taking more Pb and Cd.

- possibility to excavate the soil, and volume of soil to excavate.

Table 54: Soil & site characteristics limiting the option feasibility

	Soil and/or contamination heterogeneity	Location of contaminants	Soil volume	Elapsed time since soil contamination		
Phytoextraction	😐	☹				
Aided phytoextraction	😐	☹				
Phytomining	😐	☹				
Phytostabilisation	😐	☹				
Aided phytostabilisation	😐	☹				
(physicochemical) in-situ stabilisation	😐	😐	😐			
Bio-immobilisation	😐	☹	😐			
Phytovolatilisation	😐	☹				
Rhizodegradation	😐	☹	😐			
Rhizofiltration	😐					

6.5.7.4 Selection based on the ability to grow plant species on the contaminated soil.

Orientation tests are mainly used especially to investigate the feasibility to grow trace element-tolerant, either accumulator, hyperaccumulator or excluder plants in the conditions to satisfy the remediation and management objectives:
- to reduce root exposure to trace elements and/or accumulation in aerial plant parts (
- to increase trace element accumulation in root system

- to enhance root exposure to trace elements and accumulation in aerial plant parts
- to reduce trace element migration to the groundwater

Step 1. Analyse of soil (chemical and physical) fertility
Step 2. Selection of appropriate plant species
- tolerant, excluders
- tolerant, accumulator & high biomass
- tolerant, hyperaccumulator
- germination and growth tests

the standardized tests used are NF X31-201 (1982) with 3 plant species belonging from Poacea, Brassiccacea, and Leguminosae (plants can be *Lolium multiflorum* (raygrass), *Brassica napus* (rape), and *Trifolium pratense* (red clover), for Compositae *Achillea millefolium* (yarrow). Test are carried out in Petri dishes with 20 seeds place in dark at 22°C and daily weighted and watered at 80% WHC. Germinated seeds are daily count over a 14-day period. Tests must be performed with and without soil fertilisation (especially after the preliminary tests with *Lolium perenne*, various amount are tested; day/night 16h/8h 24°C/16°C, 70% WHC, an uncontaminated, agricultural soil with the same soil texture is included in the test as control).

- development of root system

Step 3. Plant responses to agricultural practices
- fertilisation: behaviour of nutrients
- plant responses
Step 4. Changes in trace element labile pool for biological action (bioavailability) and for migration with water (mobility)
- response to soil amendment/microbe incorporation
- response to nutrient supply
Step 5. Trace element fluxes
- lixiviation
- migration with particles
- offtakes through the crops

Driving forces for phytostabilisation

Step 1 Topic: implementation of a vegetation cover on a contaminated soil - characterisation of soil fertility: pH, soil texture, organic matter, organic carbon, total N, potential mineral N, C/N, total P, available P (e.g. Olsen method, kinetic of isotopic dilution), exchangeable cations, CEC, micronutrients. - physical parameters: water holding capacity, wilting point, structural stability, porosity, available water - soil phytotoxicity: germination and growth tests with selected plant species (e.g. excluders)

Step 2 Topic: response to agricultural practices - investigation of the behaviour of fertilising element in the soil (labile pool for biological action and water migration) - effect of nutrient supplies (N, P, K, S, micronutrients, etc) on plant growth

Step 3 Topic: response to soil treatment aiming to reduce soil phytotoxicity - investigation of the amendment incorporation: lime, alkaline materials, organic matters, aluminosilicates, phosphates, Fe, Mn, Al – oxides, etc. - amendment effects on plant nutrition

Driving forces for phytoextraction are:

- installation of accumulator/hyperaccumulator plant on the soil
- soil exploration by the roots;

- contaminant labile pool in the soil for biological action (bioavailability) and for water migration (mobility)
- trace element uptake by plants

Step 1
Topic: implementation of a vegetation cover on a contaminated soil
- characterisation of soil fertility: pH, soil texture, organic matter, organic carbon, total N, potential mineral N, C/N, total P, available P (e.g. Olsen method, kinetic of isotopic dilution), exchangeable cations, CEC, micronutrients.
- physical parameters: water holding capacity, wilting point, structural stability, porosity, available water
- soil phytotoxicity: germination and growth tests with selected plant species (e.g. excluders)

additional information:
- tests for trace element mobility: single extraction, kinetic of isotopic dilution,
- tests for trace element bioavailability: microbiological tests, plants tests

- effect of nutrient supplies (N, P, K, S, micronutrients, etc) on plant growth and TE uptake

Step 2
Topic: response of the root system and phytotoxicity
- effect of the nature, intensity, and localisation of the contaminant(s) on the root growth, ability of root system to colonize the most contaminated zones in the soil: plant tests in rhizotron (root architecture and biomass, localisation)
- rhizospheric pH

Step 3
Topic: response to agricultural practices
- investigation of the behaviour of fertilising element in the soil (labile pool for biological action and water migration)

-

- nature of the relevant pollutant linkages: feasibility to satisfy the technical objectives regarding a pollutant linkage

 There are large differences in prioritisation of protection of groundwater, very much dependent on the degree of utilisation of groundwater, e.g. in countries like Norway, where only 15% of the groundwater resource is utilised for water supply, remediation is rarely initiated to protect the groundwater (Clarinet 2002)

Table 55: Feasibility to satisfy the remediation technical objectives:

Feasibility to satisfy the remediation technical objectives	Reduce migration to the groundwater	Reduce animal/human being exposure through soil ingestion	Reduce animal exposure through herbivory	Reduce animal/human being exposure through dermal contact	Reduce plant exposure and phytotoxicity	Reduce microorganism exposure and toxicity to microbes
Phytoextraction	☹ long term	😐	☹	😐		?
Aided phytoextraction	☹		☹	😐	☹	☹
Phytomining	☹ long term	😐	☹	😐		?
Phytostabilisation	☹ long term	☹	😐	☹	😐	😐
Aided phytostabilisation	😐 or ☹	☹	😐	☹	😐	😐
(physicochemical) in-situ stabilisation	😐 or ☹	☹	😐	☹	😐	😐
Bio-immobilisation	?	☹	😐	?	😐	😐
Phytovolatilisation	?		☹	?		
Rhizodegradation	?					
Rhizofiltration			☹			
Feasibility to satisfy the remediation technical objectives	Reduce contamination through the food					

	chain (quality of foodstuff or feedstuff)					
Phytoextraction	😐					
Aided phytoextraction	☹					
Phytomining	😐					
Phytostabilisation	😐					
Aided phytostabilisation	😐					
(physicochemical) in-situ stabilisation	😐					
Bio-immobilisation	?					
Phytovolatilisation	😐					
Rhizodegradation	?					
Rhizofiltration	😐					

- the physical status of contaminants (Table 56), i.e. distribution between solid, liquid and gaz phases, mainly presents in the solid phase, equilibrium between solid and water liquid phases, equilibrium between solid and gaz phases, mainly present in non aqueous liquid phases, status not sufficiently defined)

Table 56: Influence of physical status of contaminants.

	equilibrium between solid, liquid and gaz phases	mainly presents in the solid phase	equilibrium between solid and water liquid phases	equilibrium between solid and gaz phases	mainly present in non aqueous liquid phases	status not sufficiently defined
Phytoextraction	☹	😐	☺	☹	☹	😐
Aided phytoextraction	☹	😐	☺	☹	☹	😐
Phytomining	☹	😐	☺	☹	☹	😐
Phytostabilisation	😐	😐	☺	😐	😐	😐
Aided phytostabilisation	😐	😐	☺	😐	😐	😐
(physicochemical) in-situ stabilisation	😐	😐	☺	☹	😐	😐
Bio-immobilisation	😐	☹	☺	😐	☹	😐
Phytovolatilisation						
Rhizodegradation	☺	😐	☺	☺	☺	😐
Rhizofiltration						

☹: option is not appropriated; 😐: option may be appropriated; ☺: option is appropriated.

- properties of pathways (especially soil properties, but also receptors)

The soil preparation is very important for several options with plant implementation. Physical and chemical soil properties must be appropriated to the plant used to satisfy the technical remediation objectives. For options with plant cultures, general constraints for plant cultivation must be satisfied (climatic conditions, water and nutrient supply, harvesting method, etc; *see detailed information*) For aided phytoextraction and aided phytostabilisation, in general soil amendments should react with the soil for a minimum time before to cultivate the plant. Rhizofiltration is relevant to treat liquid effluents from other treatment.

Table 57: Factors limiting feasibility.

Feasibility may be limited by	Soil texture	Soil organic matter	Soil water content	Carbonates content in Soil	Macronutrients (N, P) in soil	Soil salinity
Phytoextraction	☹		☹	☹	☹	☹
Aided phytoextraction	☹		☹	☹	☹	☹
Phytomining	☹		☹	☹	☹	☹
Phytostabilisation	☹		☹	😐		☹
Aided phytostabilisation	☹		☹	😐		☹

(physicochemical) in-situ stabilisation	☹		☹			☹
Bio-immobilisation	☹		☹	😐		☹
Phytovolatilisation	☹		☹		☹	☹
Rhizodegradation	☹	😐	☹	☺	☹	☹
Rhizofiltration						☹

Feasibility may be limited by	Soil operationally	Physical & chemical fertility of soil	Water permeability of the soil	Air permeability of the soil	Soil microbial activity	
Phytoextraction	☹	☹	☹			
Aided phytoextraction	☹	☹	☹			
Phytomining	☹	☹	☹			
Phytostabilisation	☹	☹	☹			
Aided phytostabilisation	☹	☹	☹			
(physicochemical) in-situ stabilisation	☹		☹			
Bio-immobilisation	☹	☹	☹	☹	☹	
Phytovolatilisation	☹	☹	☹			
Rhizodegradation	☹	☹	☹	☹	☹	
Rhizofiltration			☹			

- Site characteristics: its size, location, accessibility (especially in case of mobile system), topography and wider environmental setting, and the existence (or proposed construction) of buildings and other structures.

- current or intended use of the site also needs to be taken into account to ensure that remediation does not compromise soil functions, including geotechnical properties.

6.5.7.5 Criteria related to technical basis

- applicability: in situ on site, ex situ on site, ex situ on another site

- Legal & commercial context

- views of key stakeholders

- the costs and benefits of using any particular option.

Potential benefits

- Restoration of landscape "value"
- Restoration of ecological functions
- Improvement of soil fertility (e.g. for some biological remediation techniques)
- Recycling of materials

- potential conflicts between different objectives of the remediation strategy and remediation options

- Step(s) of option dismantling:

dismantling of unit treatment
treatment of wastes: effluents, plant biomass
implementation of the final land use

Criteria that should be addressed for each remediation option/remediation strategy

• Degree to which risks need to be reduced or controlled;

• Time within which the remediation strategy is required to take effect;

• **Practicability** of implementing and, where appropriate, maintaining the strategy;

• Technical **effectiveness** of the strategy in reducing or controlling risks;

• **Durability** of the strategy (i.e., will it provide a robust solution over the design life?);

• Sustainability of the strategy (i.e., how well it meets other environmental objectives, for example on the use of energy and other material resources, and avoids or minimises adverse **environmental impacts** in off-site locations, such as a landfill, or on other environmental compartments, such as air and water);

• Cost of the strategy (bearing in mind that the person who makes the decision about remediation may not be the person who has to pay);

• Benefits of the strategy – all remediation strategies should deliver direct benefits (the reduction or control of unacceptable risks) – but many have merits that extend well beyond the boundaries of the site; for example, remediation may enhance the amenity or ecological value of an area or contribute towards improved economic activity by removing blight or encouraging regeneration;

• Legal, financial and commercial context within which the site is being handled including the specific legal requirements that remediation has to comply with, and the views of stakeholders on how unacceptable risks should be managed.

The selection and evaluation process has to be able to balance all these factors so the necessary decisions can be made, bearing in mind that regulatory approval will often be the key driver.

Flow chart Ademe Orientation tests

According to preliminary tests (germination, plant growth, fertilisation supply), plants for phytoextraction or phytostabilisation can be established. In contrast, if the results are negative, additional steps are necessary to restore soil physico-chemical quality (through mainly soil amendment and restoration of nutrient balances)

Remediation objectives relate directly to the need to address pollutant linkages by one or more means. This may be achieved by decreasing contaminant mass, concentration, mobility or toxicity; by effective containment of the contaminant; or through the management of the receptor or pathway.

Remediation criteria provide a measure (usually, but not necessarily, expressed in quantitative terms) against which compliance with remediation objectives can be measured. Examples of quantitative measures include:
• Guideline values (e.g., soil guideline values, drinking water standards);
• Site-specific assessment criteria developed from detailed quantitative risk assessment;
• Engineering-based criteria (e.g., the thickness and permeability of a cover system).

a long-term monitoring programme to track changes in the behaviour and movement of pollutants.

Legal, commercial and financial factors affecting the decision-making process.
Although a number of techniques have been developed to remove metals from contaminated soils, many sites remain contaminated because economic and environmental costs to clean up those sites with the available technologies are too high.

Engaging with stakeholders
To identify the stakeholders who have an interest in the scope, conduct and outcome of a particular risk management project is a context part.

Stakeholders can include a wide range of individuals and organisations, such as land owners/problem holders, founders, purchasers, occupiers/site users, workers, visitors, regulators/regulatory authorities, planning authorities advisors, neighbouring property owners (tenants, dwellers)/local residents and/or occupiers and the wider public (Campaigning organisations and local pressure groups), consultants, contractors, and possibly researchers.

Meaningful dialogue with all stakeholders is a key to the successful outcome of risk management projects and is essential in relation to regulators who have specific statutory duties and powers for health and environmental protection in this area. It is important, therefore, that managers understand, and comply with, the specific legal requirements that may apply to a particular project and that they also observe good practice in terms of both formal and informal liaison and information sharing.

Clarinet (2002): Stakeholders will have their own perspective, priorities, concerns and ambitions regarding a site. The most appropriate remedial actions will offer a balance between meeting as many of their needs as possible, in particular risk management and achieving sustainable development, without unfairly disadvantaging any individual stakeholder. 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 of 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 of a decision is important in helping to achieve sustainable development. Arguments and decisions need to be communicated in a balanced form to all stakeholders. 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. Unsurprisingly once these remedial objectives are set it may be hard to renegotiate them.

- Landowners may define a project (and hence the technology employed) as cost effective, if negative equity relating to the land was eliminated at a cost of less than the negative value. Conversely, they may seek to employ specific technologies that delivered “cleaner” land than was required by the regulator, in order to maximise the value of that land. It depends entirely on whether the land is a liability or an opportunity and it 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 is 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 landowner’s position as it reflects a superficially similar set of constraints. Regulators are obliged to make decisions that are 1) legal (same rules as landowners), 2) in the best interests of their shareholders (the public), and 3) to ensure environmental protection. “Best interests” begs the questions: whose interests, which interest, 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 action that delivers 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.

6.5.7.6 Feasible remediation options

Definition: 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 in dealing with a 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;
- Cost; and
- Acceptability of the solution to stakeholders who may have expressed preferences for a favoured solution or have different perceptions and expertise.

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 furthering the cause of sustainable development.

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

- Basic approach
- Efficiency
- Advantages
- Possible limitations, potential side effects and failures
- (Specific) information requirements
- treatability studies (laboratory or field scale trials)
- possibility to combine with other options
- decision record

Partial conclusions

The reduction of contaminant concentration leads to a proportional reduction of the risk. The allocation of one remediation technology usually has different effects on various categories of contaminants present at the site. For this reason the prediction of the effects on each risk zone, and the subsequent changing of the risk zoning, is beyond the capability of the expert, while even a rough simulation model can be very supportive for this scope (Carlon et al, 2008). One example in Italy showed the performance rates of remediation options at Porto Marghera, Italy.

Table 58:

Performance rates (% of contaminant concentration reduction expected from the application of common remediation technologies to individual inorganic chemicals (indicated as elements)) applied in the case study of Porto Marghera and categories of organic contaminants: Non-halogenated Volatile Organic Compounds (NH-VOC), Halogenated Volatile Organic Compounds (H-VOC), Non-halogenated Semivolatile Organic Compounds (NH-SVOC), Halogenated Semivolatile Organic Compounds (H-SVOC), Fuels

Technology	As	Cr	Cu	Cd	Hg	Ni	Pb	Zn	NH-VOCs	H-VOCs	NH-SVOCs	H-SVOCs	Fuels
Bioventing	–	–	–	–	–	–	–	–	90	–	85	–	88
Enhanced bioremediation	–	–	–	–	–	–	–	–	90	–	85	–	88
Natural attenuation	–	–	–	–	–	–	–	–	90	80	70	–	90
Phytoremediation	0	38	0	0	42	0	0	98	90	80	70	80	90
Soil vapour extraction	–	–	–	–	–	–	–	–	99	96	95	90	92
Solidification/stabilisation in situ	90	90	90	60	90	91	75	60	80	0	70	0	–
Thermally enhanced soil vapour extraction	–	–	–	–	–	–	–	–	75	90	70	99	75
Biopile	–	–	–	–	–	–	–	–	85	85	79	75	79
Composting	–	–	–	–	–	–	–	–	95	95	86	40	85
Landfarming	–	–	–	–	–	–	–	–	90	85	57	60	57
Separation	0	0	0	0	0	0	0	0	–	–	0	0	0
Soil washing	96	93	88	80	80	93	92	98	90	85	93	98	93
Solidification/stabilisation ex situ	99	99	98	–	98	96	98	97	–	–	–	96	–
Incineration	–	–	–	–	–	–	–	–	99	99	93	93	95
Thermal desorption	–	–	–	–	–	–	–	–	99	99	80	99	80
Landfill cap	100	100	100	100	100	100	100	100	100	100	100	100	100

6.5.8 Remediation strategy

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, soil and water, and reducing the pressure for development on Greenfield sites.

Combined or strategic approaches have become increasingly used as means of dealing with contamination problems, particularly as a means of reducing costs and facilitating in situ treatments. This section outlines some of the most important of these approaches:

□ Process integration

 Active containment / in situ treatment zones

 Extensive approaches

In frequent cases, using only one remediation option may not be sufficient to deal with all the problems of the site; more than one pollutant linkage may need to be addressed, or the most appropriate remediation option for one linkage may not be the most appropriate for another. In these cases, the remediation strategy may consist of one or more appropriate remediation options. Such a combined approach may be considered a treatment train.

Complex contamination problems often require the combination of different remediation options to deal with either different contaminated areas on the site or for a specific material, carrying complex mixtures of contamination.

Process integration is the combined use of two or more remediation options. The main objective is to enhance treatment by extending the potential application of individual methods beyond that where they would normally be used as a single, stand-alone treatment.

Process integration tends to be used to describe specific technology linkages being used to resolve a specific contamination / material mixture. On almost all sites a variety of remedial operations may be going on in parallel, for example on different sections of a site, which require careful management to achieve best effectiveness along with minimum cost and environmental impact. It may be useful to distinguish this latter activity as an implementation issue: managing operations.

6.5.8.1 Active containment/ in situ treatment zones

Treatment zones aim to improve in situ remediation by treating contamination in a smaller more clearly defined and better optimised surface or sub-surface volume to address typical limitations of in situ remediation, ensuring contaminant availability and accessibility. Treatment zones employ groundwater as a "carrier" for the contamination. Active containment is a special case of an in situ treatment zone with the aim of treating migrating contaminants, usually dissolved in groundwater or in the vapour phase, where the source cannot be treated (for example for reasons of cost). Active containment targets treatment of contaminants in the plume/pathway rather than the source. Active containment deals with migrating contaminants. At its most elegant active containment does not contain the carrier fluid (i.e. groundwater), but contains the contamination by destroying it or removing it from the groundwater. (case studies of pumping groundwater associated with a TECS and treating by rhizofiltration/rhizodegradation

6.5.8.2 Extensive approaches

Many remedial treatments operate over the shorter term and require relatively high cost and energy inputs. These are referred to as "intensive" treatment technologies. Extensive options operate over a longer period with low maintenance, cost, and energy requirements. Examples in current use include phytoremediation and monitored natural attenuation.

Phytoremediation: is the term used for a process that use specific plants, i.e. hyperaccumulation, extract/accumulate or enhance degradation. The technique is mostly applied to treatment of surface soil contaminated with trace elements, soils but some demonstration projects with treatment of organic contaminants have been carried out as well (i.e. Batelle Europe, hydrocarbons; Limburgs Univ, Belgium, BTEX).

Potential obstacles to large-scale application of phytoremediation technologies include the time required for remediation, the pollutants levels tolerated by the plants used, and the fact that only the bioavailable fraction of the contaminants are removed, while regulations often still are based on the total amount. Another obstacle is the problem of how to dispose of the plants which have accumulated high concentrations of contaminants in their tissue and are themselves hazardous materials. These problems are addressed when considering harvesting and disposal. Research is studying ashing the vegetation and recycling of the ash through a metal smelter. VAN DER LELIE *et al* reported results from nine successful field projects in Europe (2001).

Monitored natural attenuation is the combination of all the naturally occurring processes that act without human intervention or enhancement, and is used with the objective of managing risks posed by contamination in soil and groundwater. Natural attenuation comprises a series of naturally occurring processes that can be shown to be protective of critical receptors. The processes include biodegradation, sorption, dispersion, dilution, volatilisation, chemical and biological stabilisation, transformation or destruction of contaminants. A high standard of site characterisation and considerable monitoring is required to document the loss of contaminant and demonstrate an adequate understanding of the processes causing that contaminant loss. This is necessary in order to develop and maintain confidence that natural attenuation will continue to protect critical receptors. Natural attenuation is sometimes wrongly viewed as acceptance of a “do-nothing” approach. Monitoring and recording are essential and MNA is often combined with *in situ* techniques to speed up the natural processes. Monitoring and detailed site characterisation is essential. Furthermore natural processes can be enhanced or can act in parallel with other technologies, for example, source removal can be coupled with MNA of dissolved contaminants.

To ensure that a remediation strategy consisting of more than one remediation option works effectively in practice requires even more care during planning and detailed design. For example, it may be necessary to zone the site and phase remediation work in such a way that different remediation options can be implemented without interruption, delay or error. It may be both practicable and cost-effective to combine certain components of different options leaving others to proceed independently.

The appraiser also collects information on the broad characteristics of different remediation options to decide which are most likely to satisfy site-specific objectives. It may be necessary to collect additional site information to complete this stage of options appraisal and to review and, if necessary, amend site specific objectives to ensure that feasible options can be identified.

6.5.8.3 Detailed evaluation of options

The *purpose* of this stage of options appraisal is to decide, for each relevant pollutant linkage, which of the feasible remediation options is the most appropriate given the specific circumstances of the site.

The *most appropriate remediation option* will be defined by the evaluation criteria in any particular case, but is likely to be that which is best able to meet site-specific objectives.

6.5.8.4 Developing the remediation strategy

The *purpose* of this stage of options appraisal is to develop a remediation strategy capable of practical implementation on the site and to describe in broad terms the characteristics of that strategy.

• How the site should be packaged or zoned to accommodate different types or phases of remediation;

• How the remediation strategy is to be verified to demonstrate that site-specific objectives have been met; and

• Whether and how preparatory work (such as baseline monitoring or the creation of access routes) should be factored into the early stages of remediation design.

decisions

• How, in broad terms, the remediation strategy is to be implemented and what practical issues may be involved.

• Whether the proposed remediation strategy continues to meet all specified remediation, management and other technical objectives and is acceptable on cost–benefit grounds.

Methods for investigating the environmental sustainability of remediation options

(Clarinet 2002)

Approaches to assessing the wider impacts of individual elements of sustainability (e.g. wider environmental effects) are under development in several countries.

- Clarinet (2002) stated a truly integrated approach has yet to be found

- There is some way to go before an international consensus can be reached in the way that agreement has emerged about the principles of risk assessment and risk management. This is hardly surprising given the complex interplay of economic, environmental and social factors that affect and are affected by a remediation project.

Austria. There are no provisions to consider environmental impacts, wider environmental effects and sustainability issues of remediation options. In an integrated pollution control context, the environmental impacts of the remediation system during and after the works are considered in decision making and remediation planning, verification and evaluation. The best available technology must be used to ensure that the problem is not simply 'passed on'. The guidelines for public funding postulate an overall target of remediating contaminated sites at the maximum wider environmental effects subject to acceptable expense. Therefore it is necessary to perform a study on the remediation options and to evaluate environmental impacts and broad economic consequences. However it is done on a case by case basis without general valid provisions. As a consequence remediation goals, costs and feasibility remain the important drivers for decisions on the general solution design. Other sustainability issues like community, political, and social concerns are not considered at an operational basis.

BE Flanders In an integrated pollution control context, decision making and remediation planning, verification and evaluation are considered in the Vlabero decree. Post remediation costs and risks are considered.

Denmark, the Danish Railroad Systems AS (supported by EU's Life Programme & Danish EPA) has developed a method into a computer model for investigating the environmental sustainability of different remediation technologies applied in a clean up project and suitable for optimising the environmental and economic aspects when selecting remediation strategy (Deigaard, 2000).

The total environmental costs and benefits, including any potential negative or positive side effects of remediation solutions were included as decision parameters, together with management criteria, such as time, finances and function. When side effects of remediation technologies are taken into consideration, the decision of technical solution has demonstrated that this often becomes different than initially anticipated. The LIFE approach has been applied in several Danish projects, and in one Norwegian project. The most important environmental aspects considered are: climate gas emission, acidification (acid rain), ecotoxicity, persistence (human and ecotoxicity on a regional scale), and waste production. All phases in a clean up project is included; mobilisation, operation and demobilisation.

Finland

In the application of the permit for remedial activity (Environmental permit or notification) measures for the protection of remediation workers as well as plans for the post-remediation site monitoring have to be presented. If the authority considers these measures to be inadequate, specific requirements can be set in the final permit. Remediation is considered to be completed only after a supervisor has stated this in a separate decision.

The main objective of the generic target values given for soil is to maintain the multifunctionality of the site. In this sense, sustainability is considered in soil protection. Target values can be exceeded if the risk assessment process demonstrates that there is no significant risk to humans or the environment (animals, plants, cultural environment, countryside). Sustainability is a general aspect of decision making so that only solutions that are acceptable in the long run are normally accepted. Economic aspects play an important role, especially in residential areas. Community, political and social concerns are taken into account as well as the BATNEEC principle.

FR: The Ministry of Ecology and Sustainable Development is responsible for defining public policy concerning contaminated soil, whether the contamination is of natural or human origin and whether linked to a listed facility or otherwise. Earlier processes called Simplified Risk Assessment and Detailed Risk Assessment have been abrogated. Updated information in English can be found in the French pages of EUGRIS, the Portal for Soil and Water Management in Europe (www.eugris.info).

All draft ministerial texts, new management tools and consultation methods and timelines can be found at www.sites-pollues.ecologie.gouv.fr. 5 directives have been published (8 february 2007):
- Instructions on the actions imposed by the Administration to the owners or holders of polluted or potentially polluted sites; Methods and tools for the implementation of the policy.
- General circular for the local government authority (préfet): methods of management and refitting of the polluted sites;
- Interdepartmental circular on the establishment of building accommodating sensitive populations (kindergarten, schools, etc), recommending to avoid their construction on the old industrial sites;
- New device for the management of the polluted soils and sites applicable to the facilities classified for environmental protection:

Prevention of the soil pollution - Chain responsibilities and actions to be carried out in the event of failure of the persons in charge.

Directives to the local government authority (préfets) for fixing, the covering and the restitution of the consignment.

2 main types of management situations: (see http://www.sites-pollues.ecologie.gouv.fr/welcome.asp to download the English version)
- the option of "Media Quality Assessment" : to make sure that the environment status is compatible with already fixed present land uses (can be implemented to appreciate the acceptability of the impacts in the surroundings of an classified facility under operation)

- The management strategy (Management Plan): to act on the site status, by treatment or depollution options, and on the land uses which can be selected or adapted (used for projects with changes in soil uses on polluted sites, classified or not facility, required for classified facility at the time of the discontinuance of business and the repairing for a use similar or not with that of the last working period.

Germany. The Federal Soil Protection Ordinance requires the assessment of environmental impacts. It is not specified how these must be undertaken. Sustainability issues are not mentioned specifically.

Greece. The government co-operates with experts from Greek Universities, national Institutes and scientific Chambers and Associations, together with some private environmental consultancies with significant relevant experience.

Ireland: The environmental impacts are dealt with by ongoing monitoring as agreed between the authorities and developers and are specified in the licence conditions for a particular site. There are no formal procedures in place, however consideration is given to the above during site specific analysis.

Italy: Sustainability issues and environmental merit are not considered under present legislation, but these issues are promoted by following BATNEEC principles and by stated limitations on landfill use. However practice may contradict these principles, as compliance with fixed limit values appears to prevail over promotion of sustainable and risk-based solutions.

The Netherlands: A decision support system weighing the various remediation techniques is being or was used. The term “environmental merit” is used to describe the non-core environmental effects. This enables objective mutual comparison of the different remediation technologies, their contribution to risk reduction, environmental merit and costs. The costs and benefits for the environment are weighed as well. A remediation technology can be chosen using the following strategy: primary risk assessment, take the time (considering natural processes in the ground), use “the self cleaning” capacity of the soil (investigate if it is sufficient), stimulate natural processes (investigating the possibility), intensive in situ remediation if necessary (investigate the possibility), and quantifying financial risk of a remediation alternative.

(Clarinet decision tools 2002) Sustainability was addressed only in terms of the ‘costs’ of remediation and specifically with respect to the choice of remediation procedure. The remediation procedure involved two approaches; the total remediation and return of multifunctionality; alternatively an ICM (Isolate-Control-Monitor) approach. The ICM approach was allowed if the total remediation would result in environmental problems, was technically not feasible, or was too costly. Following recent changes the policy allows more flexibility and will consider the relative environmental merits of the remediation procedures and the remediated site, allowing for a lower degree of remediation if the impact of the remediation procedures will be ‘environmentally costly’. Applications of current and future versions of REC will increase; in addition political considerations may be important.

UK: Groundwork, a federation of more than 40 local Trusts in England, Wales and Northern Ireland, established in 1981, was dedicated to improving the local environment and the quality of life in local communities. A large scale, ecological-informed and community-led programme of land regeneration (Changing Places) was initiated in 1995 on the basis of a grant of £22.1 million from the Millenium Commission’s project: “Revitalising Our Cities”. During the last 5 years of the 20th century, tracts of neglected industrial areas have been transformed into parklands and conservation areas, play areas and wildlife sanctuaries, urban commons and community spaces. The major difference from the British approach compared to the Danish and Dutch was the community involvement. The communities involved prioritised the following aspects

- Nature: building diversity;
- People: developing a network of friends;
- Art: Functional and celebratory;
- Learning: developing ownership and responsibility;
- History: Proud pasts, optimistic futures;
- Regeneration: people, places, prosperity.

6.5.8.5 Definition and approach used for "sustainable development"

Norway

Sustainable development requires a broad-based approach, which encompasses both on assessment of environmental problems and possible remedial measures:

Economic dimensions,

Technological dimensions,

Social and cultural dimensions

UK

Sustainable development consists of:

- 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.

Switzerland

Sustainability is mentioned in the ordinance on contaminated sites in various ways. Long-term effective and sustainable remediation means that after no more than one or two generations, the remediated site can be safely left to posterity without any further measures. Similar requirements apply for containment procedures. In establishing securing measures for sites, attention must additionally be paid to long term maintenance, monitoring, overhauling and seizure of the requisite financial means. Negative environmental impact at polluted sites that have been secured can only be prevented as long as the securing measures function.

If the remediation efforts to achieve the remediation goals would result in more harm to the environment then alternative remediation approaches would be considered.

Wider economic merits such as effects on the regional economic redevelopment are only rarely driving forces.

Community, political and social concerns do not feature greatly in decision-making.

The approach is based on Life Cycle Analysis in which environmental burden and environmental merit are quantified based on mass and energy flows yielding and overall environmental merit. The Swiss Agency for the Environment, Forests and Landscape leads the consideration of sustainability for the remediation of contaminated sites.

There are relatively few commercial organisations with expertise in dealing with the identification and remediation of contaminated sites.

6.5.9 Implementation of the Remediation Strategy

There are three main stages in the implementation process:

1 Preparing the implementation plan;

2 Design, implementation and verification of remediation;

3 Long-term monitoring and maintenance.

Needs for the implementation plan (preparation & preparatory works, responsibilities/supervision)

- implementation is to prepare the implementation plan such that the remediation strategy can be put into place in an effective and orderly manner.

• Who will undertake each aspect of implementation of the remediation strategy (including verification, monitoring, maintenance, health and safety and environmental protection measures) and what competencies are required;

• What regulatory permits or licences are likely to be required;

• What form of contract and technical specifications will be used to deliver the remediation strategy;

• Timescales for completion of different activities, including any subsequent long-term monitoring activities.

Specific needs

Verification

Quality assurance needs. What thinks should be recorded

Are there constructions or other works to be carried out on site that must be combined with the remediation activities?

Possibility to react to the monitoring data in a timely manner

Long-term monitoring and maintenance

Maintenance need monitoring to achieve or demonstrate on-going effectiveness (early warning of adverse trends) reactive maintenance occurs to deal with unexpected events (e.g., vandalism);

Stage 1

• Define the remediation strategy that forms the basis of the implementation plan for remediation

• Who will be responsible for all aspects of the work

• What regulatory permits & licences are required

• What form of contract & technical specifications will be used

• Timescale for completion of remediation

Stage 2

• The final form of the design

• The procurement strategy

• That remediation has achieved its objectives as evidenced by a verification report

• Whether any long-term monitoring & maintenance is required

Stage 3

• How remediation has performed in relation to agreed remediation objectives

• Whether there is a need for further monitoring & maintenance

A verification plan is a document that sets out the requirements for gathering data to demonstrate that remediation meets the remediation objectives and remediation criteria. It includes sampling and testing criteria, and identifies all those records that should be retained to demonstrate compliance within the specification (e.g., field monitoring data, analytical data, level surveys above and below capping layers).

A verification report provides a complete record of all remediation activities on site and the data collected as identified in the verification plan to support compliance with agreed remediation objectives and criteria. It also includes a description of the work (as-built drawings) and details of any unexpected conditions (e.g., contamination) found during remediation and how they were dealt with.

Typical licences, permissions or permits that may be required include:

• Planning permission

• Waste management licence

• Mobile plant licence

• Site licence

• PPC permit

• Abstraction licence

• Groundwater authorisation

• Discharge consent

• Trade effluent consent

Role of the regulatory authorities to “approve” remediation, implementation,

• Assessment of reaction/degradation rates of contaminants in soil and/or groundwater

• Monitoring operating parameters (e.g. pH, dissolved oxygen, flow rates) and treatment conditions

• Representative measurement of the physical properties (permeability, strength, thickness,

level, etc.) of a clay cap or stabilised materials

• Regular monitoring of pollutant concentrations and geochemical properties in groundwater to demonstrate the effectiveness of active treatments and/or natural attenuation

attainment of remediation objectives over an agreed period of time may be the trigger to cease monitoring activities.

The Clarinet (2002) review of the implementation of remediation technology and ongoing pilot scale and demonstration programmes show gaps in knowledge, and that R&D throughout Europe in this area still is needed, both on a local scale and in the international scene, and in short, the following items have been identified:

 Comparable cost figures;

 QA/QC systems for performance and total emission;

 Comparable output (demonstration plants);

 Harmonised approaches including wider environmental issues for sustainable technology evaluation;

- Integration of technologies for solving the variety of problems occurring on one site;
- Integration of the planning-, investigation-, remediation- and aftercare process;
- Long-term experiences from pathway/ exposure control technologies;
- Decision making on "clean" remediated soil (soil function);
- For some countries, risk based decision making approaches need implementation;
- Further development of more cost/effective technologies;
- Further development of integrated technologies solving mixed problems.
- Developing remediation goals based on bioavailable fraction of contaminants rather than total concentration

for phytoremediation

- Control of enhanced leaching of TEs as a result of addition of chelating agents to stimulate TE solubility and uptake in plants in phytoextraction schemes.
- Use of plants to affect longterm stabilisation, while at the same time yielding revenue.
- Identification and/or construction of fast growing hyperaccumulators able to effectively translocate contaminants from roots to leaves.
- Environmental risks connected with bioavailability of TEs accumulated in plants

6.5.10 Detailed evaluation of gentle remediation options

6.5.10.1 Phytoremediation options

IRTC : Phytoremediation, a technology using plants to remediate or stabilize contaminants in soil, groundwater, or sediments, has received a great deal of attention from regulators, consultants, responsible parties, and stakeholders. Phytoremediation has become an attractive alternative to other clean up technologies due to its relatively low cost potential effectiveness and the inherently aesthetic nature of using plants to clean up contaminated sites.

Several comprehensive reviews have been written, summarizing many important aspects of this plant based technology (Salt et al. 1995, 1998; Chaney et al. 1997; Raskin et al. 1997; Chaudhry et al. 1998; Wenzel et al. 1999; Meagher 2000; Navari-Izzo and Quartacci 2001; Lasat 2002; McGrath et al. 2002; McGrath and Zhao 2003; McIntyre 2003; Singh et al. 2003; Garbisu and Alkorta 2001; Prasad and Freitas 2003; Alkorta et al. 2004; Ghosh and Singh 2005; Pilon-Smits 2005; Padmavathiamma and Li 2007; Shah and Nongkynrih, 2007).

Plants termed 'accumulators' concentrate metals in aboveground biomass regardless of the metal concentration in which they are growing (Kachenko et al 2007). Such properties have been found in ferns, for example *P. vittata* and *Pytyrogramma calomelanos* for arsenic (As) (Ma *et al*. 2001; Francesconi *et al*. 2002). Conversely, plants termed 'excluders' maintain low concentrations of metals in aboveground biomass, compared with their substrate, up to a certain threshold before the mechanism breaks down.

Last, plants termed 'indicators' are those in which the metal concentration in the aboveground biomass reflects the substrate concentration, and are often used in mineral prospecting (Nkoane *et al*. 2005).

6.5.10.2 Categories of Phytoremediation

Depending on the contaminants, the site conditions, the level of clean-up required, and the types of plants, phytoremediation technologies can be used for containment (phytostabilization) or removal (phytoextraction and phytovolatilization) purposes (Thangavel and Subhuram 2004). The four different plant-based technologies of phytoremediation, each having a different mechanism of action for remediating metal-polluted soil, sediment, or water:

(1) phytostabilization, where plants stabilize, rather than remove contaminants by plant roots metal retention; (2) phytofiltration, involving plants to clean various aquatic environments; (3) phytovolatilization, utilizing plants to extract certain metals from soil and then release them into the atmosphere by volatilization; and (4) phytoextraction, in which plants absorb metals from soil and translocate them to harvestable shoots where they accumulate.

Phytostabilization is most effective for fine-textured soils with high organic-matter content, but it is suitable for treating a wide range of sites where large areas are subject to surface contamination (Cunningham et al. 1997; Berti and Cunningham 2000).

The US EPA's *Phytoremediation Resource Guide* defined six types of phytoremediation (IRTC)

Table 58: Different mechanisms of phytoremediation (Ghosh and Singh 2005)

Process	Mechanisms	Contaminant
Phytofiltration	Rhizosphere accumulation	Organics, Inorganic
Phytostabilisation	Complexation	Inorganic
Phytoextraction	Hyper accumulation	Inorganic
Phytovolatilization	Volatilisation by leaves	Organics,Inorganic

Phytoextraction (Phytoaccumulation): refers to the uptake and translocation of contaminants (e.g. trace elements) in the soil by plant roots into the aboveground portions of the plants.

The aim of phytoextraction is reducing the concentration of TEs in contaminated soils to regulatory levels within a reasonable time frame.

Certain plants called hyperaccumulators absorb unusually large amounts of metals in comparison to other plants and the ambient metals concentration. These plants are selected and planted at a site based on the type of metals present and other site conditions. After the plants have been allowed to grow for several weeks or months, they are harvested. Landfilling, incineration and composting are options to dispose of or recycle the metals, although this depends upon the results of the Toxicity Characteristic Leaching Procedure (TCLP) and cost. The planting and harvesting of plants may be repeated as necessary to bring soil contaminant levels down to allowable limits. A plan may be required to deal with the plant waste. Testing of the plant tissue, leaves, roots, etc., will determine if the plant tissue is a hazardous waste. Regulators will play a role in determining the testing method and requirements for the ultimate disposal of the plant waste.

Phytostabilisation uses certain plant species to immobilise contaminants in the soil and groundwater through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone and physical stabilisation of soils (IRTC).

This process reduces the labile pool of contaminants for biological action (ecological receptors, human health) and/or prevents contaminant migration to the groundwater, the soil solution or air.

This technique can re-establish a vegetative cover at sites where natural vegetation is lacking due to high TE concentrations (Tordoff et al. 2000). Species tolerant to trace element may be used to restore vegetation to such sites, thereby decreasing the potential migration of contamination through wind erosion, transport of exposed surface soils and leaching of soil contamination to groundwater.

The schematic mechanism of phytostabilization is illustrated in Fig. 25 (Padmavathiamma and Li 2007).

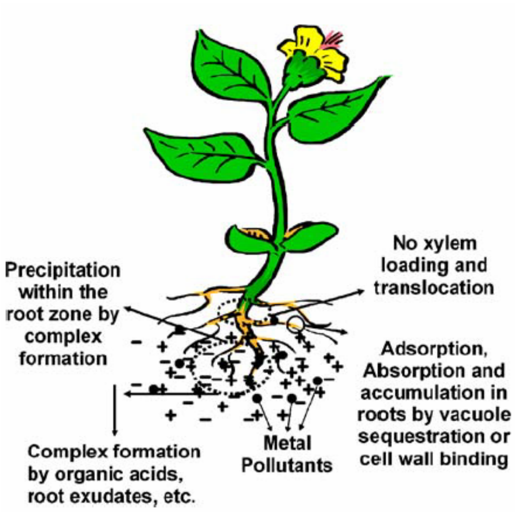


Fig. 25: The schematic mechanism of phytostabilization.

Phytovolatilization is 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.

Phytovolatilization occurs as growing trees and other plants take up water and the organic and inorganic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

Rhizodegradation (also called 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. Microorganisms (yeast, fungi, and/or bacteria) consume and degrade or transform organic substances for use as nutrient substances. In the case of TECS contaminants can be organic chemical species of trace elements, or can be organic compounds mixed with trace elements

Certain microorganisms can degrade organic substances such as fuels or solvents that are hazardous to humans and receptors and convert them into harmless products through biodegradation. Natural substances released by the plant roots—such as sugars, alcohols, proteins and acids—contain organic carbon that act as nutrient sources for soil microorganisms, and the additional nutrients stimulate their activity. Rhizodegradation is aided by the way plants loosen the soil and transport oxygen and water to the area. The plants also enhance biodegradation by other mechanisms such as breaking apart clods and transporting atmospheric oxygen to the root zone.

(can be combined with other phytoremediation options)

Rhizofiltration 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. The plants are raised in greenhouses hydroponically (with their roots in water rather than in soil). Once a large root system has been developed, contaminated water is diverted and brought in contact with the plants or the plants are moved and floated in the contaminated water. The plants are harvested and disposed as the roots become saturated with contaminants.

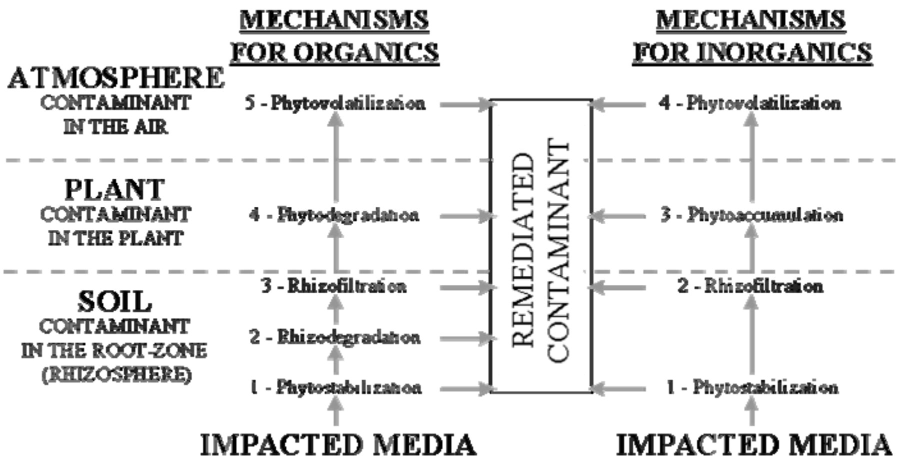


Figure 26 Contaminant Fates in the Soil-Plant-Atmosphere Continuum.

6.5.10.3 CONTAMINANTS

Contaminants that have been remediated in laboratory and/or field studies using phytoremediation or plant-assisted bioremediation include:

• Trace elements (As, Cd, Cr(VI), Pb, Co, Cu, Pb, Ni, Se, Zn, Tl)

• Radionuclides (Cs, Sr, Ur)

• Chlorinated solvents (TCE, PCE)

• Petroleum hydrocarbons (BTEX)

• Polychlorinated biphenyls (PCBs)

• Polynuclear aromatic hydrocarbons (PAHs)

• Chlorinated pesticides

• Organophosphate insecticides (e.g., parathion)

• Explosives (TNT, DNT, TNB, RDX, HMX)

• Nutrients (nitrate, ammonium, phosphate)

• Surfactants.

Table 59: Types of Phytoremediation for Inorganic Constituents (IRTC)

Type of Phytoremediation	*Process Involved*	*Contaminant Treated**
1 - Phytostabilization	Plants control pH, soil gases, redox conditions, inputs of root materials and aggregation in rhizosphere soil to	Proven for trace elements in mine tailing ponds

	immobilize contaminants. Humification of some organic compounds and a simultaneous co-precipitation of trace elements (especially cations) is expected	
2 - Rhizofiltration	Compounds taken up or sorbed by roots (or sorbed to algae and bacteria)	Trace elements
3 - Phytoextraction	Trace elements and organic chemicals taken up by the plant with water, or by membrane transporters, sorption and other mechanisms.	Nickel, zinc, lead, chromium, cadmium, selenium, other trace elements.
4 - Phytovolatilization	Trace elements are taken up, changed in volatile chemical species, and transpired.	Mercury and selenium

Trace elements are very often present with organic contaminants in TECS. Therefore some effects of phytoremediation options on organic compounds are expected (Table 60)

Table 60: Types of Phytoremediation for Organic Constituents

Type of Phytoremediation	*Process Involved*	*Contaminant Treated**
1 - Phytostabilization	Plants control pH, soil gases, and redox conditions in soil to immobilize contaminants. Humification of some organic compounds is expected.	Expected for phenols, chlorinated solvents (tetrachloromethane and trichloromethane) and hydrophobic organic compounds
2 - Rhizodegradation, (phytostimulation, rhizosphere bioremediation, or plant-assisted bioremediation	Rhizodeposition (plant exudates, root necrosis, and other processes) provide organic carbon and nutrients to spur soil bacteria growth by two or more orders of magnitude. Exudates stimulate degradation by mycorrhizal fungi and microbes. Live roots can pump oxygen to aerobes and dead roots may support anaerobes.	Polyaromatic hydrocarbons, BTEX, and other petroleum hydrocarbons, perchlorate, atrazine, alachlor, polychlorinated biphenyl (PCB), and other organic compounds
3 - Rhizofiltration	Compounds taken up or sorbed by roots (or sorbed to algae and	Hydrophobic organic chemicals

	bacteria)	
4 - Phytodegradation	Aquatic and terrestrial plants take up, store, and biochemically degrade selected organic compounds to harmless byproducts, products used to create new plant biomass, or byproducts that are further broken down by microbes and other processes to less harmful products. Reductive and oxidative enzymes may be used in series in different parts of the plant.	Munitions (TNT, DNT, HMX, nitrobenzene, picric acid, nitrotoluene), atrazine, halogenated compounds (tetrachloromethane, trichloromethane, hexachloroethane, carbon tetrachloride, TCE, tetrachloroethane, dichloroethane), DDT and other chlorine and phosphorus based pesticides, phenols, and nitrites.
5 - Phytovolatilization	Organic compounds are taken up, kept or changed in volatile compounds and transpired. Some recalcitrant organic compounds are more easily degraded in the atmosphere (photodegradation).	Chlorinated solvents (tetrachloromethane and trichloromethane), organic VOC's, BTEX, MTBE

Phytoextraction

Table 61: Matrix of phytoextraction options according the ways to control or reduce unacceptable risks.

	Remove or treat the (source) of pollutant(s);	Remove or modify the pathway(s);	Remove or modify the behaviour of receptor(s).	Ex-situ basis	In-situ basis	Relevant pollutant linkage(s)
Phytoextraction with tolerant, accumulator, herbaceous plant with high biomass	Cd, Ni					Soil-soil solution-root
Phytoextraction with tolerant, accumulator, ligneous plant with high biomass						Soil-soil solution-root Soil-soil solution-groundwater
Phytoextraction with tolerant accumulator plant with (high) biomass useable for energy/biofuel or	Cd, Ni, Zn					Soil-soil solution-root

industrial raw material						
Phytoextraction with plant mutant (higher tolerance, and accumulation)	Cu, Pb, Zn					Soil-soil solution-root
Phytoextraction with tolerant, hyperaccumulator plants	As, Cd, Ni					Soil-soil solution-root
Phytoextraction with plant-microbe association						
Phytoextraction with GMO plant (or GMO organism)						
Combination of phytoextraction and chemical mobilisation						
Combination of phytoextraction and chemical immobilisation						

Phytoextraction is a plant based technology for the removal of contaminants from soil and water ; Root uptake TEs in the soil solution of contaminated soils, and after translocation plants accumulate TEs in their crop tissues (generally above-ground plant parts, tubers) and then the metal-enriched biomass is harvested for remediation,

6.5.10.4 Rhizospheric processes

The current knowledge on how root exudates, as well as organic acids and synthetic chelator amendments, might hasten both the phytoextraction of metals from soil and their translocation to shoots is explored.

Role of root exudates in metal phytoextraction (do Nascimento and Xing 2006)

Notwithstanding the fate of exudates in the rhizosphere, and the nature of reactions involved in phytoextraction and transport of metals by plants being not yet fully understood, it is recognized that they contribute significantly to the accumulation of TEs in plants.

Direct effects: Chemical compounds likely to occur in the rhizosphere are clearly associated with increase of TEs uptake from soil and their translocation to shoots (Mench & Martin, 1991; Salt et al., 1995; Krishnamurti et al., 1997; Lin et al., 2003; Wenzel et al., 2003).

Low molecular-weight organic acids are probably important exudates in natural phytoextraction systems. They influence the acquisition of metals by either forming complexes with metal ions or decreasing the pH around the roots and altering soil characteristics. Despite the fact that metals uptake may be increased due to decreasing pH (Brown et al., 1994), it is clear that the complexing capacity of organic acids, rather than their capacity to decrease pH, is the main factor related to mobilization of metals in soil and their accumulation in plants (Bernal et al., 1994; McGrath et al., 1997; Gupta et al., 2000; Quartacci et al., 2005).

The fact that plants can benefit from organic acid exudation in a number of ways has aroused interest of genetic engineering to increase organic acid exudation in crop and pasture species (Ryan et al., 2001). These authors sustain that large changes in organic acid production can be achieved in yeast and bacteria by inactivating or overexpressing specific genes whose products are involved in organic acid biosynthesis. These studies with microorganisms may be helpful in determining which enzymes could be successfully manipulated to alter organic acids biosynthesis and organic acid exudation in plants (ferritin: iron chlorosis)

Advance on the knowledge of genetic control of root exudation would be used to hasten the ability of plants in extracting metals from soil. Once specific root exudates related to increasing uptake of metals from soil are identified, plants could be genetically engineered aiming at higher exudation of such natural biodegradable compounds.

Some plants release specific metal-chelating or reducing compounds into the rhizosphere to aid the absorption of Fe and Zn when availability of these micronutrients is low (Marschner, 1995). Other environmental stimuli have also been associated with root exudation of organic acids, including anoxia (Marschner, 1995) and exposure to Al (Ma, 2000; Piñeros et al., 2002). It is thought that metal accumulators may enhance metal solubility by releasing chelators from the roots. However, only a few reports on the involvement of specific exudates in the uptake and accumulation of potentially toxic metals by plants are known so far. In addition, the exudation rates and chemical composition of exudates of hyperaccumulator species are unclear.

Salt et al. (2000) were unable to identify any high-affinity Ni-chelator compound in the rhizosphere of the Ni hyperaccumulator Thlaspi goesingense. In contrast, they found that Ni-chelators histidine and citrate accumulated in the root exudates of the non-hyperaccumulator Thlaspi arvense exposed to Ni. Such findings led the authors to suggest that the release of these exudates by T. arvense may be a strategy to reduce Ni uptake and toxicity, but exudate releasing is not involved in the hyperaccumulation of Ni by T. goesingense. Persans et al. (1999) also established that Ni hyperaccumulation in T. goesingense is not determined by the overproduction of histidine in response to Ni. Since at non-toxic Ni concentrations, both plant species translocate Ni to shoots at equivalent rates (Krämer et al., 1997), the existence of a more efficient translocation mechanism in T. goesingense does not seem to explain the capability of this species in accumulating Ni. Krämer et al. (2000) provided evidence that free histidine may be also involved in shuttling Ni across the cytoplasm into the vacuole in T. goesingense, which could be responsible for Ni tolerance and accumulation. Krämer et al. (1996) have already reported a 36-fold increase in the concentration of free histidine in the xylem exudates of the Ni hyperaccumulator Alyssum lesbiacum after exposure to Ni, suggesting that histidine could be involved in the transport and storage of Ni in such species. Kerkeb & Krämer (2003) recently provided further evidence that histidine enhances the release of Ni from roots into the xylem, not only in A. lesbiacum but also in the non-hyperaccumulator B. juncea. Salt et al. (2000) identified Zn-histidine complexes in the roots of the Zn hyperaccumulator Thlaspi caerulescens, but Knight et al. (1997), McGrath et al. (1997) and Zhao et al. (2001) did not detect any specific exudate related to accumulation of Zn by this species.

Not only the role that rhizosphere exudates play in accumulation of Ni and Zn is not fully understood, but there is also a lack of information on the role of root exudation in metal phytoextraction for most of the environmentally-relevant metals. As a matter of fact, there is no conclusive evidence so far that hyperaccumulators exude specific chelators in the rhizosphere to enhance metal uptake. Therefore, the release of specific chelators associated with enhanced metal uptake and translocation needs more intensive research. Indeed, increasing root uptake is the first step to successful removal of metals from soils. Insights into the understanding of these processes and the compounds involved are essential to boost phytoextraction technology.

Indirect effects of root exudates: on microbial activity, rhizosphere physical properties and root growth dynamics may also influence ion solubility and uptake (Marschner, 1995; Walker et al., 2003). For instance, microorganisms have been shown to mobilize Zn for hyperaccumulation by Thlaspi caerulescens (Whiting et al., 2001) via dissolution of Zn from the non-labile phase in soil.

Genetic manipulation of plant rhizosphere to enhance metal solubility may thus be a good way, and may not only make phytoremediation more efficient but also overcome environmental constraints associated with chemically-assisted phytoextraction.

This extraction process depends on the ability of selected plants to grow and accumulate metals under the specific climatic and soil conditions of the site being remediated.

Two options based on long-term continuous extraction are used to reach this goal:

- the use of plants with exceptional, natural metal-accumulating capacity, the so-called hyperaccumulators, and

- the utilization of high-biomass crop plants, such as corn, barley, peas, oats, rice, and Indian mustard (Huang et al., 1997; Salt et al., 1998; Lombi et al., 2001; Chen et al., 2004).

If TE availability is not adequate for sufficient plant uptake, chelates or acidifying agents may be added to the soil to liberate them (Cunningham and Ow 1996; Huang et al. 1997; Lasat et al. 1998): so-called chelate-aided phytoextraction or chelate-assisted phytoextraction or a chemically enhanced method of phytoextraction

Microorganisms can also be used

6.5.10.5 Phytoextraction with tolerant, accumulator plants with high aerial biomass

The use of chemical amendments to enhance metal phytoextraction and accumulation (do Nascimento)

Labile TE pool for biological action and migration are both dependent on soil characteristics and are strongly influenced by pH and the degree of complexation with soluble ligands (Kaschl et al., 2002). Metals exist in soil in various pools: in solution as ionic or organically complexed species; on exchange sites of reactive soil components; complexed with organic matter; occluded in Fe, Al, and Mn oxides and hydroxides; entrapped in primary and secondary minerals (Shuman, 1985; Mann & Ritchie, 1993). Most metals in soils exist in unavailable forms, thus soil conditions have to be altered to elicit phytoextraction since the phenomenon, depends on a relatively abundant source of soluble metal to enable significant metal uptake and translocation to shoots. Metals such as Pb and Cr have their extraction rate limited by their inherently low solubility. In such a case, organic compounds can be utilized as amendments to enhance phytoextraction. Such substances can complex and chelate metal ions, therefore modifying the availability of metals in soils. Ethylenediaminetetraacetate (EDTA) has been successfully utilized to enhance phytoextraction of Pb and other metals from contaminated soils (Cunninghan & Ow, 1996; Blaylock et al., 1997; Chen et al., 2004). Huang et al. (1997) showed that EDTA was the most efficient chelator for inducing the accumulation of Pb in pea plants shoots (Figure 2), a naturally Pb excluder. Blaylock et al. (1997) demonstrated that the ability of soil-applied EDTA to increase metal uptake in a multi-contaminated soil is not limited to Pb, since EDTA was also efficient in increasing Cd, Cu, Ni, and Zn concentrations in shoots of B. juncea. Several chelating agents, such as EDTA (ethylene diamine tetra acetic acid), EGTA (ethylene glycol-O,O□Œ-bis-[2-amino-ethyl]-N,N, N□Œ,N□Œ,-tetra acetic acid), EDDHA (ethylenediamine di o-hyroxyphenylacetic acid), EDDS (ethylene diamine disuccinate) and citric acid, have been found to enhance phytoextraction by mobilizing metals and increasing metal accumulation (Tandy et al. 2006; Cooper et al. 1999). Successful phytoextraction depends not only on metal concentration in shoots but also on high biomass production. Thus, maintaining plants capable of accumulating metals as long as possible is desirable in phytoextraction. Citrate and gallic acid were as effective as EDTA at enhancing removal of Cd, Zn, Cu, and Ni from soil, as a result of the higher biomass production of plants treated with citrate and gallic acid, in comparison to EDTA-treated plants (Nascimento et al., 2006). Some biodegradable synthetic chelators, such as ethylenediaminedissuccinate (EDDS) and methylglycinediacetate (MGDA), have been evaluated as EDTA alternatives (Groman et al., 2003; Tamura et al., 2005). Although to date these chelators have not been extensively studied, they show promise for environmentally safe phytoextraction, especially for Pb-contaminated soils. Coating natural organic acids to maintain a stead concentration of metal-organic acids complexes in soil solution, as done to EDTA by Li et al. (2005), could be an alternative. Fast biodegradation rather than the low organic acid ability to solubilize metals may be the main reason for unsuccessful phytoextraction (Krishnamurti et al., 1997; Nascimento et al., 2006). The slow release of organic acids from coated materials could provide a sustained uptake rate while decreasing the rapid disappearance of metal-organic acid complexes from the soil solution by buffering the solution for chelators. Together with a high extraction rate by roots, the success of chemically-aided phytoextraction depends on substantial increases in the transfer of metals to shoots.

Background Mechanisms

The understanding of the physiological mechanisms involved in accumulation of metals in shoots is still incipient. Metals themselves can damage plant membranes (Marschner, 1995), and as a result high concentrations of Pb (Kumar et al., 1995), and Cd (Salt et al., 1995) alone might induce elevated accumulation of these metals in plants. Cd toxicity might cause the breakdown of physiological barriers for the accumulation of metals in shoots due to the dramatic effect of toxic concentrations of Cd in nutrient solution on Cd concentration in xylem sap (Salt et al., 1995). Vassil et al. (1998) speculated that synthetic chelates can destroy physiological barriers in roots that control the uptake and translocation of metals, for instance, by removal of Zn and Ca from the plasma membrane. Regardless the exact mechanism involved, metal-EDTA complexes are absorbed by plants and transported to shoots via the xylem (Epstein et al., 1999; Collins et al., 2001).

The mechanism of metal accumulation in *Phaseolus vulgaris* induced by EDTA depends upon the nature of the studied metal (Sarret et al., 2001). Regarding Zn, no difference occurred between plants grown in Zn-EDTA and $Zn(SO)_4$ solutions. In both cases, Zn predominantly precipitated as Zn phosphate in roots and leaves. In contrast, cerussite was the major form of Pb in the absence of EDTA, whereas in the presence of EDTA, part of the Pb present in the leaves was complexed as Pb-EDTA. Thereforemetal-EDTA complexes in soil solution can be totally (Zn) or partially (Pb) dissociated when absorbed by *P. vulgaris* (Sarret et al. 2001). As the concentrations of both Pb and Zn in the shoots were much higher in plants grown in EDTA solution, the translocation of Zn from roots to shoots in *P. vulgaris* does not seem to be dependent on EDTA complexation.

Pb: Indian mustard exposed to Pb and EDTA in nutrient solution accumulated 11,000 mg kg^{-1} Pb in dry shoot tissue (Vassil et al., 1998).

Blaylock (2000) described two successful field demonstrations of the use of EDTA-assisted phytoextraction of Pb by Indian mustard.

Amending the soil with the biodegradable chelator MGDA resulted in a 5-fold increase in the Pb shoot concentration of common buckwheat (Tamura et al. 2005).

The increase in the phytoextraction of Pb by shoots of Z. mays L. was more pronounced than the increase of Pb in the soil solution with combined application of EDTA and EDDS (Luo et al. 2006). Although EDTA was, in general, more effective in soil metal solubilization, EDDS, less harmful to the environment, was more efficient in inducing metal accumulation in B. decumbens shoots (Santos et al. 2006).

Cd/Zn/Ni

Addition of synthetic chelators increase the translocation not only of Pb but also of Cd, Zn, Cu and Ni (Blaylock et al., 1997). However, unsuccessful cases have also been reported. Ebbs & Kochian (1998) showed that EDTA increased the concentration of Zn in shoots of Indian mustard to a lesser degree than the values reported by Blaylock et al. (1997). The contradiction can be attributed to differences in metal solubility in soils. Blaylock et al. (1997) spiked the soil tested with $ZnCO_3$, which may be more easily solubilized by EDTA than Zn present in the aged-contaminated soil used by Ebbs & Kochian (1998).

Lombi et al. (2001) concluded that EDTA increased metal mobility in soil and uptake by roots, but did not substantially increase the transfer of metals (Cd, Zn, Pb, Cu) to corn shoots. They suggested that EDTA was far more efficient in overcoming the diffusion limitation of metals to the root surface than the barrier of root to shoot translocation.

6.5.10.6 Limiting factors

Synthetic chelators such as EDTA are barely degradable by microorganisms and can pose a threat to the environment by metal leaching to groundwater (Sun et al., 2001; Wenzel et al., 2003; Madrid et al., 2003; Chen et al., 2004), and adverse effects on soil microbiota (Welper & Brummer, 1997; Bouwman et al., 2005).

EDTA toxicity and drastic plant growth reduction in Indian mustard grown on a metal multicontaminated soil was reported (Nascimento et al., 2006).

Chemically-enhanced phytoextraction has faced serious limitations when applied to multi-contaminated sites with more bioavailable metals. Metals such as Cd, Zn, and Cu may cause severe toxicity to plants even before chelators are added to soil (Sun et al., 2001; Lombi et al., 2001; Marchiol et al., 2004; Wu et al., 2004). Such an inhibition of plant growth limits phytoextraction success. Lombi et al. (2001) suggested that phytoextraction of Zn and Cd by T. caerulescens is constrained by Cu toxicity. Ebbs & Kochian (1997) observed that the removal of Zn and Cu from soil solution by Brassica species was reduced in the presence of both metals, as compared to single metal treatments. The chelator enhancement seems to be plant- and metal-specific, and might be inhibited when multiple metals are present.

Side effects of the addition of chelate to the soil microbial community are usually neglected. It has been reported (Wu et al. 1999) that many synthetic chelators capable of inducing phytoextraction might form chemically and microbiologically stable complexes with heavy metals, threatening soil quality and groundwater contamination.

The chelator inputs in soil and time of application during the vegetation course are keys factors.

The amount of TEs made soluble by synthetic chelators usually exceeds by far the plant's uptake capacity. Attempts were made to minimize this by applying the chelator at the time of maximum crop biomass (Salt et al., 1998). But this may not be the optimal period. It should match with the installation and growth of the root system and the root uptake which can be maximum during the highest growth rate of the aerial biomass or on the whole vegetation development

High labile TEs pool for migration implies risks related to groundwater pollution when such chelators are applied under field conditions. Chen et al. (2004) reported high mobility of EDTA-chelated metals in soils columns after water application, equivalent to 158 mm of rainfall precipitation within 2 days. Amounts of Pb, Cu, Zn, and Cd in the leachates increased dozens of times after addition of 5 mmol kg^{-}

[1]. In a lysimeter study under field condition using another synthetic chelator (EDGA), Römkens et al. (2002) observed that dissolved Cu and Cd remained mobile in soil and leaching prone.

Even if suitable irrigation strategies are implemented as proposed (Blaylock et al., 1997; Madrid et al., 2003), the potential of metals leaching in synthetic chelator-treated soil is still high during seasons of intense rainfall. Using 1 week-old seedlings, Li et al. (2005) registered that turning EDTA into a slow-release compound through coating of the EDTA granules with silicates could reduce the risk of metal leaching.

there is a potential risk of leaching of metals to groundwater, and a lack of reported detailed studies regarding the persistence of metal-chelating agent complexes in contaminated soils (Lombi et al. 2001a,b).

EDTA can persist towards biological degradation and the most stable metal-EDTA complexes (i.e. chelates of Cu^{2+}, Co^{2+}, Zn^{2+}, and Pb^{2+}) have to dissociate prior utilization by bacteria (Satroutdinov et al. 2000). Consequently, metal-EDTA complexes may be found in soil pore water up to five months after EDTA application (Lombi et al., 2001). This slow degradation rate and high persistence increase the leaching risk associated with EDTA application in field conditions. Such effects must be weighed against its use in phytoextraction.

The use of root-produced agents which are naturally degradable by microorganisms is preferable. Such an approach sounds better to the public acceptance of phytoextraction technology. Unfortunately, the effectiveness of natural organic acids on metals mobilization and subsequent plant uptake is low compared to synthetic chelators, especially in the case of Pb phytoextraction (Salt et al., 1995; Gupta et al., 2000; Lombi et al., 2001; Wu et al., 2003; Kos & Lestan, 2004). The efficiency of organic acids released by roots to mobilize metals from soil seems to depend upon the rate of biodegradation (Krishnamurti et al., 1997; Renella et al., 2004). The biodegradation process is under control of the soil's microbial community, which is also not fully understood (Ryan et al., 2001), but the process of consumption of organic acids by microorganisms is probably an important process in reducing their effectiveness in complexing metals around the plant roots. Low effectiveness of phytoextraction using natural organic acids has been reported due to rapid mineralization when small doses are applied (Romkens et al., 2002; Meers et al., 2004). Higher doses may be toxic to plants (Turgut et al., 2004), resulting in impaired phytoextraction. Thus, it might be necessary to add organic acids several times to maintain an optimal concentration of soluble metals during the phytoextraction process. Krishnamurti et al. (1997) observed that Cd release from soils increased initially up to a reaction period of 2 h and then slowly decreased with time; increasing amounts of Cd were released from the soils with renewal of organic acids every two hours.

Exceptional results of metal phytoextraction have been reported, especially on Pb accumulation (Huang et al., 1997; Blaylock et al., 1997; Vassil et al., 1998). However, results from soils artificially contaminated with a single metal do not address the "real life" multicontaminated soils. For instance, 70% of all metal-contaminated Superfund sites in The United States involve two or more metals (Forstner, 1995).

These results highlight the importance of the kinetics of metal release from low molecular weight organic acids and their degradation rate.

6.5.10.7 Phytoextraction with tolerant, hyperaccumulator plants

Certain plants, called hyperaccumulators, absorb unusually large amounts of TEs compared to other plants and translocate them into the aboveground tissues to levels far exceeding the concentration of TEs in the medium (Baker and Brooks, 1989).

The concept of hyperaccumulation has been extended to a plant growing in its natural habitat in which those metal concentrations have been recorded in the dry matter of *any* aboveground tissue. This detailed definition includes plants that accumulate metals in aerial tissues other than leaves, which might be useful to phytoextraction as well, and disqualify any species that hyperaccumulates metals under artificial conditions, such as massive addition of metals to soil or nutrient solution (Reeves & Baker, 2000).

Natural metal hyperaccumulators can accumulate and tolerate greater metal concentrations in shoots than those usually found in non-accumulators, without visible symptoms. Examples of commonly reported hyperaccumulators are given in Tables . According to Baker and Brooks (1989), hyperaccumulators should have a metal accumulation exceeding a threshold value of shoot metal concentration of 1% (Zn, Mn), 0.1% (Ni, Co, Cr, Cu, Pb and Al), 0.01% (Cd and Se) or 0.001% (Hg) of the dry weight shoot biomass.

Plants

Over 400 hyperaccumulator plants have been reported, including members of the Asteraceae, Brassicaceae, Caryophyllaceae, Cyperaceae, Cunouniaceae, Fabaceae, Flacourtiaceae, Lamiaceae, Poaceae, Violaceae, and Euphobiaceae. (Reeves & Baker, 2000). The vast majority of the species discovered so far being Ni hyperaccumulators. Plant species that can accumulate Cd, Pb, Zn, Co and Cu are much less numerous (McGrath et al., 2001). Environment Canada has released a database “Phytorem” which contains a worldwide inventory of more than 750 terrestrial and aquatic plants, both wild and cultivated species and varieties, of potential value for phytoremediation.

Table 62: Examples of hyperaccumulators and their bioaccumulation potential.

Table 7 Examples of hyperaccumulators and their bioaccumulation potential

Plant species	Metal	Content (mg kg^{-1})	Reference
T. caerulescens	Zn	39,600 (shoots)	Reeves and Brooks (1983)
T. caerulescens	Cd	1,800	Baker and Walker (1989)
Ipomea alpine	Cu	12,300	Baker and Walker (1989)
Sebertia acuminate	Ni	25% by wt. dried sap	Jaffre et al. (1976)
Haumaniastrum robertii	Co	10,200	Brooks (1998)
A. racemosus	Se	14,900	Beath et al. (1937)
P. vittata	As	27,000	Wang et al. 2002
Berkheya coddii	Ni	5,500	Robinson et al. 1997
Iberis intermedia	Ti	3,070	Leblanc et al. 1999

These plants are selected and planted at a site based on the metals present and site conditions. After they have grown for several weeks or months, the plants are harvested. Planting and harvesting may be repeated to reduce contaminant levels to allowable limits (Kumar et al. 1995). The time required for remediation depends on the type and extent of metal contamination, the duration of the growing season, and the efficiency of metal removal by plants, but it normally ranges from 1 to 20 years (Kumar et al. 1995; Blaylock and Huang 2000). This technique is suitable for remediating large areas of land contaminated at shallow depths with low to moderate levels of metal-contaminants (Kumar et al. 1995; Blaylock and Huang 2000).

As The brake fern *Pteris vittata* has the great ability in accumulating arsenic (Ma et al., 2001).

This species can accumulate up to 95% of the As taken up from soil in its shoots. Because this enormous translocation, P. vittata shoot concentrations of As can reach up to 23,000 µg g^{-1}.

Cd/Zn Ebbs et al. (1997) reported that B. juncea, while having one-third the concentration of Zn in its tissue, is more effective at removing Zn from soil than Thlaspi caerulescens, a known hyperaccumulator of Zn. The advantage is due primarily to the fact that B. juncea produces ten-times more biomass than T. caerulescens.

Basic et al. (2006a,b) investigated the parameters influencing the Cd concentration in plants, as well as the biological implications of Cd hyperaccumulation in nine natural populations of T. caerulescens. Cd concentrations in the plant were positively correlated with plant Zn, Fe and Cu concentrations. The physiological and/or molecular mechanisms for uptake, transport and/or accumulation of these four heavy metals interact with each other. They specified a measure of Cd hyperaccumulation capacity by populations and showed that T. caerulescens plants originating from populations with high Cd hyperaccumulation capacity had better growth, by developing more and bigger leaves, taller stems, and produced more fruits and heavier seeds.

Pb Common buckwheat (*Fagopyrum esculentum* Moench) can naturally accumulated up to 4,200 µg g^{-1} of Pb in the shoot(Tamura et al. 2005). Common buckwheat is the first known Pb hyperaccumulator species with high biomass productivity.

Se The efficacy of genetically altered plants for phytoremediation has been successfully tested under actual field conditions (Bañuelos et al., 2005), utilizing three transgenic Indian mustard lines overexpressing genes that encode the enzymes adenosine triphosphate sulfurylase (*APS*), -glutamylcysteine synthetase (g- *ECS*), and gluthathione synthetase (*GS*), respectively. The three transgenic lines accumulated substantially larger amounts of Se in their shoots than the wild type. The APS transgenic line accumulated 4.3-fold more Se in its shoots than wild type, while ECS and GS lines accumulated 2.8-fold and 2.3-fold more Se than wild type, respectively

6.5.10.8 Successful Factors for Phytoextraction of Metals & Metalloids

As a plant-based technology, the success of phytoextraction is inherently dependent on several plant characteristics, the two most important being the ability to accumulate large quantities of biomass rapidly and the capacity to accumulate large quantities of environmentally important metals in the shoot tissue (Kumar et al. 1995; Cunningham and Ow 1996; McGrath 1998; Pilon-Smits 2005). Effective phytoextraction requires both plant genetic ability and the development of optimal agronomic practices, including :

(1) soil management practices to improve the efficiency of phytoextraction, and

(2) crop management practices to develop a commercial cropping system.

Plants for phytoextraction should be able to grow outside their area of collection, have profuse root systems and be able to transport metals to their shoots.They should have high metal tolerance, be able to accumulate several metals in large amounts, exhibit high biomass production and fast growth, resist diseases and pests, and be unattractive to animals, minimizing the risk of transferring metals to higher trophic levels of the terrestrial food chain (Thangavel and Subhuram 2004).

6.5.10.9 Plant biology background

The precise relationship between metal hyperaccumulation and tolerance is still a subject of debate. For some authors, there is no correlation between these traits (Baker & Walker, 1990; Baker et al., 1994), while others suggest that hyperaccumulators possess a high degree of tolerance to metals (Reeves & Brooks, 1983; Chaney et al., 1997). Macnair et al. (2000) compiled a number of studies in which the accumulation of metals by tolerant and non-tolerant clones of species had been compared, and concluded that there is no pattern regarding tolerance and accumulation. Both shoot and root concentrations are equally variable even when only one particular metal is considered. However, at least in some cases, it is clear that increased tolerance leads to greater accumulation of metals. For instance, Cd tolerance appears to be the most important criterion in developing lines of *T. caerulescens* with great phytoextraction potential (Roosens et al., 2003). As a matter of fact, it is plausible to consider that to cope with high concentrations of metals in their tissues, plants must also hypertolerate the metals that they accumulate.Internal tolerance to metals is thought to be based on several mechanisms rather than one alone, and the lack of a comprehensive understanding of this complex metal homeostatic network in plants remains a major bottleneck in the development of phytoextraction technologies (Hirschi et al., 2000; Krämer, 2003). Compartmentation in the vacuole and chelation in the cytoplasm are among the most significant mechanisms proposed to be related to metal accumulation by plants. Subcellular compartmentation in the vacuole is also a mechanism of Zn tolerance used by the Zn hyperaccumulator *T. caerulescens* (Vázquez et al., 1994; Küpper et al., 1999) and probably by *Arabidopsis halleri* (Neumann & Zur-Nieden, 2001). In the leaves of the latter species, Zn is predominantly complexed to malate (Sarret et al., 2002). As this acid seems to be the most abundant organic acid in vacuoles of *T. caerulescens* (Tolra et al., 1996), it is supposed to be related to metal chelation and accumulation in this species as well. However, as pointed out by Sarret et al. (2002), the mere presence of malate, or another organic acid, does not guarantee high metal accumulation rates in shoots. This is rather dependent on both the location of malate (vacuolar or cytoplasmic) and the quantity of metal transmembrane transporters. For instance, Ni hyperaccumulation in *T. goesingense* is achieved by an efficient system that pumps Ni into the vacuole of shoot cells (Krämer et al., 2000). Such a vacuolar sequestration of Zn seems to be driven by a member of the cation diffusion facilitator family (T*g*MTP1), constitutively-expressed in *T. goesingense*. Similar constitutively enhanced expression by cation diffusion facilitators has also been observed for *T. caerulescens* and *A. halleri* (Assunção et al., 2001; Becher et al., 2004).

Chelation and sequestration of metals by particular ligands are also mechanisms used by plants to deal with metal stress. The two best-characterized metal-binding ligands in plant cells are the phytochelatins (PCs) and metallothioneins (MTs) (Grill et al., 1988; Cobbett, 2000; Cobbett & Goldsbrough, 2002). Both ligands are widely distributed in plants and form stable complexes with metals in the cytosol which can be subsequently sequestered into the vacuole (Zenk, 1996; Goldsbrough, 2000). Many physiological and genetic studies indicate that PCs and MTs are critical for metal tolerance and accumulation in plants (Howden & Cobbett, 1992; Zhu et al., 1999; Schmöger et al., 2000; Inouhe et al., 2000; Hartley-Whitaker et al., 2001; Van Hoof et al., 2001). A comprehensive review of PCs and MTs and their characteristics is found in Cobbett & Goldsbrough (2002).

Naturally hyperaccumulating plants do not overproduce phytochelatin as part of their mechanism against toxic metals. This appears to be an inducible rather than a constitutive mechanism, observed especially in metal non-tolerant plants (Freeman et al., 2005). Instead, hyperaccumulator plants rely on constitutive mechanisms including enhanced vacuolar compartmentation. However, overproduction of phytochelatin has played an important role in the attempts to genetically transform high biomass plants into efficient phytoremediators. For example, transgenic seedlings of *Brassica juncea* overexpressing γ-glutamylcysteine synthetase (γ- *ECS*), had higher concentrations of PCs than wild genotype seedlings (Zhu et al., 1999). As a consequence, the transgenic plants accumulated more Cd than the wild genotype and possessed shoot Cd concentrations 40% to 90% higher. Gisbert et al. (2003) demonstrated that the overexpression of a wheat gene encoding phytochelatin synthase in *Nicotiana glauca* (shrub tobacco) markedly increased the species tolerance to Pb and

Cd. The transformed plants accumulated twice as more Pb than the wild type when grown in a mining contaminated soil. Dhankher et al. (2002) combined the γ-glutamylcysteine synthetase (g- *ECS*) expression with a leaf-specific arsenate reductase (*arsC*), thereby avoiding diminution of the root pool of arsenate (oxidized form) which could move to the leaf. This enabled the transformed *Arabidopsis thaliana* plants to transport arsenate to aboveground parts where it was reduced to arsenite and sequestered in thiol-peptide complexes, such as PCs and MTs. As a result, As concentrations in shoots were three-fold higher than those of the wild type. This substantial increase in As accumulation, however, is not impressive compared to the high ability of *P. vittata* in concentrating As in the shoots. Insights into the effects of root exudates on As, as well as on environmentally important metals (Pb, Cd, Ni, Zn, Cu) are urgently necessary and will have a dramatic impact on the feasibility of phytoextraction, either by using wild or transgenic plants.

Metal transport from the cytosol to the vacuole is considered an important mechanism of both metal tolerance and accumulation in plants. For this reason, much work has been dedicated to investigating subcellular localization of metals in hyperaccumulators (Vázquez et al., 1992; 1994; Küpper et al., 1999; 2000; Hirschi et al., 2000; Krämer et al., 2000; Sarret et al., 2002). Krämer et al. (2000) isolated vacuoles from Ni-tolerant *T*. *goesingense* and Ni-sensitive *T. arvense* aiming directly to address the role of vacuolar Ni storage in Ni tolerance. They found that *T*. *goesingense* accumulated two-fold more Ni in the vacuole than *T. arvense*. Since protoplast and apoplast Ni contents were similar in both species, vacuolar compartmentalization in *T*. *goesingense* seems to play a major role in Ni-accumulation and tolerance. Lasat & Kochian (2000) proposed a model to explain the higher accumulation of Zn by *T. caerulescens* compared to *T. arvense* (Figure 4). According to their model, several altered transport systems account for the Zn hyperaccumulation in *T. caerulescens*. The first step is the higher capacity for Zn influx across the root cell plasma membrane in *T. caerulescens*. Following its entry in the cytoplasm, Zn is sequestered in the vacuole of *T. arvense* and made unavailable for translocation to the shoot, since the rate of vacuolar Zn efflux is significantly smaller in *T. arvense* at similar amounts of Zn accumulated in the root cells of the two *Thlaspi* species. In *T. caerulescens*, on the other hand, symplasmic Zn is readily available for loading into the xylem and subsequent long-distance transport to the shoot. As a consequence, *T. caerulescens* accumulated about five-fold higher concentrations of Zn in the xylem sap compared to *T. arvense*.

Feasability:

Phytoextraction is applicable only to sites containing low to moderate levels of metal pollution, because plant growth is not sustained in heavily polluted soils. The land should be relatively free of obstacles, such as fallen trees or boulders, and have an acceptable topography to allow normal cultivation practices, utilizing agricultural equipment. Selected plants should be easy to establish and care for, grow quickly, have dense canopies and root systems, and be tolerant of metal contaminants and other site conditions which may limit plant growth.

Liu et al. (2006) conducted a survey of Mn mine tailing soils and eight plants growing on Mn mine tailings. The concentrations of soil Mn, Pb, and Cd and the metal enrichment traits of these eight plants were analyzed. It was found that Poa pratensis, Gnaphalium affine, Pteris vittata, Conyza Canadensis and Phytolacca acinosa possessed specially good metal-enrichment and metal-tolerant traits. In spite of the high concentration of Mn in P. pratensis, its lifecycle was too short, and its shoots were too difficult to collect for it to be suitable for soil remediation.

The effectiveness of phytoextraction of heavy metals in soils also depends on the availability of metals for plant uptake (Li et al. 2000). The rates of redistribution of metals and their binding intensity are affected by the metal species, loading levels, aging and soil properties (Han et al. 2003). Generally, the solubility of metal fractions is in the order: exchangeable > carbonate specifically adsorbed > Fe–Mn oxide > organic sulfide > residual (Li and Thornton 2001). Ammonium nutrition of higher plants results in rhizosphere acidification due to proton excretion by root cells. Ammonium-fed sunflowers induced a strong acidification of the solution and, compared to the nitrate-fed sunflowers, a small modification in mineral nutrition and different Cd partitioning between root and shoot. Moreover, ammonium nutrition was found to induce a great mobilisation of a sparingly soluble form of cadmium ($CdCO_3$) (Zaccheo et al. 2006).

A lipid-transfer protein isolated from a domestic cultivar of brewer's barley grain, Hordeum vulgare has the affinity to bind Co (II) and Pb (II), but not Cd (II), Cu (II), Zn (II) or Cr (III). This suggests a new possible role of barley lipid-transfer protein for phytoextraction (Gorjanovic et al. 2006).

The slow desorption of metals in soils has been a major impediment to the successful phytoextraction of metal contaminated sites. Except for Hg, metal uptake into roots occurs from the aqueous phase. In soil, easily mobile metals such as Zn and Cd occur primarily as soluble or exchangeable, readily bioavailable form. Cu and Mo predominate in inorganically bound and exchangeable fractions. Slightly mobile metals such as Ni and Cr are mainly bound in silicates (residual fraction). Soluble, exchangeable and chelated species of trace elements are the most mobile components in soils, facilitating their migration and phytoavailability (Williams et al. 2006). Other species such as Pb occur as insoluble precipitates (phosphates, carbonates and hydroxyl-oxides) which are largely unavailable for plant uptake

(Pitchel et al. 1999). Understanding the mechanisms of rhizosphere interaction, uptake, transport and sequestration of metals in hyperaccumulator plants will lead to designing novel transgenic plants with improved remediation traits (Eapen and D'Souza 2005). Moreover, the selection and testing of multiple hyperaccumulator plants could enhance the rate of phytoremediation, giving this process a promise one for bioremediation of environmental contamination (Suresh and Ravishankar 2004). Some of the recent reports on phytoextraction are summarized in Table 9. Phytoremediation has been combined with electrokinetic remediation, applying a constant voltage of 30 V across the soil. The combination of both techniques could represent a very promising approach to the decontamination of metal polluted soils (O'Connor et al. 2003).

6.5.10.10 Handling of Hazardous Plant Biomass after Phytoremediation

Phytoextraction involves repeated cropping of plants in contaminated soil until the metal concentration drops to an acceptable level. Each crop is removed from the site. This leads to accumulation of huge quantities of hazardous biomass, which must be stored or disposed appropriately to minimize environmental risk. After harvesting, the methods of disposal of contaminated plants include approved secure landfills, surface impoundments, deep well injection, ocean dumping or incineration. The waste volume can be reduced by thermal, microbial, physical or chemical means. In one study, the dry weight of B. juncea for induced phytoextraction of lead amounted to 6 tons/ha containing 10,000–15,000 mg/kg metal on a dry weight basis (Blaylock et al. 1997). Composting and compaction can provide post-harvest treatment (Raskin et al. 1997 and Kumar et al. 1995). Even though composting can significantly reduce the volume of the harvested biomass, metal-contaminated biomass still requires treatment prior to disposal. In the case of compaction, care should be taken to collect and dispose of the leachate. A conventional and promising route to utilize biomass produced by phytoremediation is through thermo-chemical conversion processes such as combustion, gasification and pyrolysis. If phytoextraction could be combined with biomass generation and its commercial utilization as an energy source, then it could be turned into a profitable operation, with the residual ash available to be used as an ore (Brooks 1998; Comis 1996; Cunningham and Ow 1996). Phytomining includes the generation of revenue by extracting soluble metals produced by the plant biomass ash, also known as bio-ore. With some metals like Ni, Zn, Cu, etc., the value of reclaimed metal may provide an additional incentive for phytoremediation (Chaney et al. 1997, Watanabe 1997, Thangavel and Subhuram 2004).

Phytoremediation is still in its research and development phase, with many technical issues needing to be addressed. Phytoremediation is an interdisciplinary technology that can benefit from many different approaches. Results already obtained have indicated that some plants can be effective in toxic metal remediation. The processes that affect metal availability, metal uptake, translocation, chelation, degradation, and volatilization need to be investigated in detail.

Better knowledge of these biochemical mechanisms may lead to:

(1) Identification of novel genes and the subsequent development of transgenic plants with superior remediation capacities;

(2) Better understanding of the ecological interactions involved (e.g. plant-microbe interactions);

(3) Appreciation of the effect of the remediation process on ecological interactions; and

(4) Knowledge of the entry and movement of the pollutant in the ecosystem. In addition to being desirable from a fundamental biological perspective, findings will help improve risk assessment during the design of remediation plans, as well as alleviation of risks associated with the remediation. It is important that public awareness of this technology be considered, with clear and precise information made available to the general public to enhance its acceptability as a global sustainable technology. So far, most phytoremediation experiments have taken place on a laboratory scale, with plants grown in hydroponic settings fed heavy metal diets. Both agronomic management practices and plant genetic abilities need to be optimized to develop commercially useful practice.

Table 63: Examples of hyperaccumulators and their accumulation characteristics.

Table 8 Examples of hyperaccumulators and their accumulation characteristics

Plant species	Metal	Results	Reference
Pistia stratiotes	Ag, Cd, Cr, Cu, Hg, Ni, Pb and Zn	All elements accumulated mainly in the root system.	Odjegba and Fasidi 2004
Spartina plants	Hg	Organic Hg was absorbed and transformed into an inorganic form (Hg^{+}, Hg^{2+}) and accumulated in roots	Tian et al. 2004
H. annuus	Pb	Pb concentrated in the leaf and stem indicating the prerequisites of a hyperaccumulator plant	Boonyapookana et al. 2005
H. indicus	Pb	Heavy metal mainly accumulated in roots and shoots	Chandra Sekhar et al. 2005
Sesbania drummondii	Pb	Pb accumulated as lead acetate in roots and leaves, although lead sulfate and sulfide were also detected in leaves, whereas lead sulfide was detected in root samples. Lead nitrate in the nutrient solution biotransformed to lead acetate and sulfate in its tissues. Complexation with acetate and sulfate may be a lead detoxification strategy in this plant species	Sharma et al. 2004
Lemna gibba	As	A preliminary bioindicator for As transfer from substrate to plants. Used for As phytoremediation of mine tailing waters because of its high accumulation capacity	Mkandawire and Dudel 2005
P. vittata, P. cretica, P. longifolia and *P. umbrosa*	As	Suitable for phytoremediation in the moderately contaminated soils	Caille et al. 2004
Alyssum	Ni	Majority of Ni is stored either in the leaf epidermal cell vacuoles, or in the basal portions of the numerous stellate trichomes. The metal concentration in the trichome basal compartment was the highest ever reported for healthy vascular plant tissue, approximately 15–20% dry weight	Broadhurst et al. 2004
Solanum nigrum and *C. Canadensis*	Cd	High concentration of Cd accumulated. Tolerant to combined action of Cd, Pb, Cu and Zn	Wei et al. 2004
T. caerulescens	Cd	High Cd-accumulating capability, acquiring Cd from the same soil pools as non-accumulating species.	Schwartz et al. 2003
Arabis gemmifera	Cd and Zn	Hyperaccumulator of Cd and Zn, with phytoextraction capacities almost equal to *T. caerulescens*	Kubota and Takenaka 2003
Sedum alfredii Hance	Cd	Mined ecotype had a greater ability to tolerate, transport, and accumulate Cd, compared to non-mined ecotype	Xiong et al. 2004
Stanleya pinnata	Se	Adapted to semi-arid western U. S. soils and environments. Uptake, metabolism and volatilization of Se	Parker et al. 2003
Austromyrtus bidwilli. P. acinosa Roxb	Mn	Australian native hyperaccumulator of Mn, grows rapidly, has substantial biomass, wide distribution and a broad ecological amplitude	Bidwell et al. 2002; Xue et al. 2004

Table 64: Recent reports on phytoextraction.

Table 9 Recent reports on phytoextraction

Metal	Plant studied	Method of Phytoremediation	Results	Reference
Cd, Zn	*T. caerulescens*	PE-C	Physiological and molecular mechanisms for uptake, transport and accumulation of four heavy metals Cd, Fe, Cu and Zn interact with each other. T. caerulescens plants originating from populations with high Cd hyperaccumulation capacity had better growth. Revegetation of metal polluted soils with T. caerulescens could help activate their biochemical and microbial functionality. Different soils had various responses to acidification. A different optimum pH may exist for phytoextraction.	Basic et al. 2006a,b; Keller et al. 2006; Hammer et al. 2006; Hernandez-Allica et al. (2006); Wang et al. (2006)
Mn	*G. affine* D. Don *C. canadensis* (L.) Cronq	PE-C	*G. affine* and *C. canadensis* had excessive accumulation of Mn and could be useful in phytoremediation. The perennial herb *P. acinosa* Roxb. (Phytolaccaceae), which occurs in Southern China, was found to be a new manganese hyperaccumulator.	Liu et al. 2006; Xue et al. 2004
Cu	*Elsholtzia splendens*, and *Trifolium repens*	PE-CA	Application of glucose or citric acid significantly increased the extractable Cu concentration in planted and unplanted soils. Concentrations of Cu in the shoots of *E. splendens* were 2.6, 1.9 and 2.9 times of those of *T. repens* under no chelate, citric acid and glucose treatments, respectively.	Chen et al. 2006
Pb, As, Pb, Cu, Zn, Cd	Carrot, Lettuce and Tomato. Euphorbia, Verbascum. and Astragalus	PE-C	Except for carrot roots, concentration less than ICP-OES detectable limits. Plants with high metal intake abilities escalate mobility of metals and increase contaminations on surface and subsurface.	Pendergrass and Butcher (2006); Sagiroglu et al. (2006)
Cu, Zn, Pb	Sunflower	PE-CA	Synthetic Chelating agents did not increase the uptake of heavy metals for equal soluble concentrations in the presence and absence of chelates. Proper use of soil amendments increased the phytoextraction of Zn, Cu, Pb, Cd from contaminated soils	Tandy et al. 2006; Clemente et al. 2006; Chen et al. 2006
Cu and Fe	*Athyrium vokoscense*	PE and PM	1 g Cu and 0.1 g Fe recovered from 500 g soil. Removal rates of Cu and Fe in the contaminated soil were 82 and 95% respectively. Application of (NLMWOA (Natural Low Molecular Weight Organic Acids) increased the extraction of Cu, with no enhancement of lead phytoextraction.	Kobayashi et al. 2005; Evangelou et al. 2006
Se	*A. bisulcatus* and *B. juncea*	PE	There was a substantial improvement in Se accumulation (4 to 9 times increase) in transgenic plants.	LeDuc et al. 2006

Metal	Plant studied	Method of Phytoremediation	Results	Reference
Cd	*B. napus* and *B. juncea*	PE	Lipid changes in *B. juncea*, the well-known Cd-hyperaccumulator species, revealed greater stability of its cellular membranes to cadmium-stress compared to a Cd-sensitive specie, *B. napus*. An increase in cadmium content varying from 16 to 74%, compared to the non-inoculated control, was observed in rape plants cultivated in soil treated with 100 mg Cd kg^{-1} (as $CdCl_2$) and inoculated with the cadmium-resistance bacterial strains from heavy metal-polluted soils.	Quartacci et al. 2006; Belimov et al. 2005; Nouairi et al. 2006; Sheng and Xia 2006

PE PhytoExtraction. *CA* Chelate Assisted. *C* Continuous. *PM* Phytomining

6.5.10.11 Phytostabilisation

Phytostabilisation is not intended to remove metal contaminants from a site, but rather to stabilize them by accumulation in roots or precipitation within root zones, reducing the risk to human health and the environment. It is applied in situations where there are potential human health impacts, and exposure to substances of concern can be reduced to acceptable levels by containment. The disruption to site activities may be less than with more intrusive soil remediation technologies. Kachenko et al Phytostabilisation is a versatile technique and has been successfully applied in the containment of trace elements in mine spoils, metalliferous waste and smelters (Smith and Bradshaw 1979; Pierzynski *et al*. 2002; Stoltz and Greger 2002). Thorough planning is essential for successful revegetation, including physical and chemical analyses, bioassays and field trials. The main approaches to revegetation are summarized in Table .

TE-tolerant species may be used to restore vegetation to such sites, thereby decreasing the potential migration of contaminants through wind, transport of exposed surface soils, leaching of soil and contamination of groundwater (Stoltz and Greger, 2002). Characteristics of plants appropriate for phytostabilisation at a particular site include: tolerance to high levels of the contaminant(s) of concern; high production of root biomass able to immobilize these contaminants through uptake, precipitation, or reduction; and retention of applicable contaminants in roots, as opposed to transfer to shoots, to avoid special handling and disposal of shoots.

Yoon et al. (2006) evaluated the potential of 36 plants (17 species) growing on a contaminated site and found that plants with a high bio-concentration factor (BCF, metal concentration ratio of plant roots to soil) and low translocation factor (TF, metal concentration ratio of plant shoots to roots) have the potential for phytostabilization (Fig. 2a–e). The lack of appreciable metals in shoot tissue also eliminates the necessity to treat harvested shoot residue as a hazardous waste (Flathman and Lanza 1998).

In a field study, mine wastes containing copper, lead, and zinc were stabilized by grasses (Agrostis tenuis cv. Goginan for acid lead and zinc mine wastes, Agrostis tenuis cv. Parys for copper mine wastes, and Festuca rubra cv. Merlin for calcareous lead and zinc mine wastes) (Smith and Bradshaw 1992). The research of Smith and Bradshaw (1992) led to the development of two cultivars of Agrostis tenuis Sibth and one of Festuca rubra L which are now commercially available for phytostabilizing Pb-, Zn-, and Cu-contaminated soils.

Two plant species, Hyparrhenia hirta and Zygophyllum fabago, that have naturally colonized some parts of mine tailings in South-East Spain, have been reported to tolerate high metal concentrations in their rhizospheres. These plant species do not take up high concentrations of metals, providing a good tool to achieve surface stabilization of tailings with low risk of affecting the food chain (Conesa et al. 2006).

Plants were identified as hyper tolerant which can be used for phytostabilization (Boularbah et al. 2006).

Phytostabilization efforts in the Mediterranean region were improved by using mixtures including local metallicolous legume and grass species (Frérot et al. 2006). It is better to identify the plants spontaneously colonizing the contaminated site, since they are more ecologically adapted than introduced species. Recent research results on phytostabilisation are summarized in Table 4.

6.5.10.12 Aided phytostabilisation

One way to facilitate such immobilisation is by altering the physicochemical properties of the metal-soil complex by introducing a multipurpose anion, such as phosphate, that enhances metal adsorption via. anion-induced negative charge and metal precipitation (Bolan et al. 2003). Addition of humified organic matter (O.M.) such as compost, together with lime to raise soil pH (Kuo et al. 1985), is a common practice for immobilizing heavy metals and improving soil conditions, to facilitate re-vegetation of contaminated soils (Williamson and Johnson 1981). Soil acidification, due to the oxidation of metallic sulphides in the soil, increases heavy metal bioavailability; but liming can control soil acidification; also, organic materials generally promoted fixation of heavy metals in non-available soil fractions, with Cu bioavailability being particularly affected by organic treatments (Clemente et al. 2003). The production of sulphate by sulphide oxidation increased solubility of Zn and Mn, and therefore their concentrations in plant-available (DTPA-extractable) fractions. However, the bioavailability of Cu did not decrease with either soil pH increase or with lime, indicating that the organic treatments might have had a significant effect. Revegetation of mine tailings usually requires amendments of phosphorus, even though phosphate addition can mobilize arsenic (As) from the tailings. Leachates and uptakes of As were found to be higher with an organic fertilizer amendment than superphosphate, particularly in combination with barley (Mains et al. 2006b). Active phytoremediation followed by natural attenuation, was effective for remediation of the pyrite-polluted soil (Clemente et al. 2006).

Suitability

Phytostabilization is most effective for fine-textured soils with high organic-matter content, but it is suitable for treating a wide range of sites where large areas are subject to surface contamination (Cunningham et al. 1997; Berti and Cunningham 2000).

Advantages

Phytostabilization has advantages over other soil-remediation practices in that it is less expensive, easier to implement, and preferable aesthetically. (Berti and Cunningham 2000; Schnoor 2000). When decontamination strategies are impractical because of the extent of the contaminated area or the lack of adequate funding, phytostabilization is advantageous (Berti and Cunningham 2000). It may also serve as an interim strategy to reduce risk at sites where complications delay the selection of the most appropriate technique

limitations

Some highly contaminated sites are not suitable for phytostabilization, because plant growth and survival is impossible (Berti and Cunningham 2000).

Table 65: Matrix of phytostabilisation options according the ways to control or reduce unacceptable risks

	Remove or treat the (source) of pollutant(s);	Remove or modify the pathway(s);	Remove or modify the behaviour of receptor(s).	Ex-situ basis	In-situ basis	Relevant pollutant linkage(s)
Phytostabilisation with tolerant, excluder, herbaceous plant		As, Cu				Soil-soil solution-root
Phytostabilisation with tolerant, excluder, ligneous plant		As Cu				Soil-soil solution-root Soil-soil solution-groundwater
Phytostabilisation with tolerant excluder plant with useable						Soil-soil solution-root

biomass						
Phytostabilisation with plant mutant (higher tolerance, and exclusion)						Soil-soil solution-root
Phytostabilisation with GMO plant						Soil-soil solution-root
Phytostabilisation with plant-microbe association						
Combination of phytostabilisation and chemical in situ immobilisation						
Plant cultivation with tolerant, excluder, plant cultivar						

Table 66: Options to revegetation and problems encountered.

Soil Characteristics	Reclamation technique	Problems encountered
Low toxicity – Total metal content <0.1%	Amelioration and direct seeding with grasses and legumes. Seed or transplant ecologically adapted native species. Apply lime, organic matter and fertilizers as necessary	Medium or long-term maintenance program. Expertise required on the characteristics of native flora. Grazing must be strictly monitored and excluded in some situations
High toxicity – Total metal content >0.1%	Amelioration and direct seeding with metal tolerant and salt tolerant (saline) ecotypes. Apply lime, organic matter and fertilizers as necessary. Amelioration with 10–50 cm of innocuous mineral waste and organic material and seeding with grasses and legumes. Apply lime and fertilizer if necessary	Commitment to regular management. Expertise required for the selection of tolerant ecotypes. Grazing management not possible. Regression will occur if depths of amendment are shallow or if upward movement of metals occurs. Availability and transport costs limiting
Extreme toxicity	Isolation; surface treatment with 30–100 cm of innocuous barrier material and surface banding with 10–30 cm of rooting medium. Apply lime and fertilizer if necessary.	High cost and potential limitation of material availability

6.5.10.13 In situ immobilisation

Table 67: Examples for in situ immobilisation

Plant species	Metal	Treatments	Results	Limitations	Reference
Horedeum vulgare, Lupinus angustifolius, Secale cereale	As	Different P amendment products (organic and inorganic)	P amendment of <3 gm^{-2} caused As leaching of 0.5 mg l^{-1} from unplanted lysimeters and up to 0.9 mg l^{-1} on average in planted lysimeters. Arsenic accumulated in plant biomass to 126 mg/kg in shoots and 469 mg/kg in roots.	Variable species – amendment combinations produced differences in the amount of As leached and uptake.	Mains et al. 2006a,b
Lolium italicum and *Festuca arundinaceae*	Pb and Zn	Compost at two rates (10%, and 30% v/v)	The concentration of Pb and Zn in aerial parts and in roots of *L. italicum* and *F. arundinacea* decreased more than five times in presence of compost. Pb content decreased from 218 to 32 mg/kg in shoot and 7,232 to 1,196 mg/kg in root. Zn decreased from 4,190 to 624 mg/kg in shoot and 7,120 to 1,993 mg/kg in root.	The level of contaminants in aerial parts of plants was still too high to be grazed by herbivores.	Rizzi et al. 2004
B. juncea	Cd	Soil amendments – liming materials, phosphate compounds and biosolids	Phosphate immobilized Cd, thereby reducing the phytotoxicity of Cd. The tissue metal concentration of Cd, Cu and Cr(VI) with biosolids application was 253, 157 and 12.4 mg/kg. (i.e. a decrease over nil amendment.)		Bolan et al. 2003
B. juncea	Zn, Cu, Mn, Fe, Pb and Cd	organic amendments (cow manure and compost) and lime	Active phytoremediation followed by natural attenuation, was effective for remediation of pyrite-polluted soil. Soil concentration decreased from: 363 to 166 mg/kg for Zn, 36 to 31 mg/kg for Cu, 1.94 to 1.48 mg/kg for Pb, 1.6 to 0.86 mg/kg for Cd, 679 to 303 mg/kg for Fe and 245 to 120 mg/kg for Mn. Available As concentration in soil decreased from 2.5–13.5 mg/kg after the first crop to 0.5–2.6 mg/kg after the second.	Bioavailability of Cu did not decrease with either soil pH increase or with lime.	Clemente et al. 2003; Clemente et al. 2006
Anthyllis vulneraria, Festuca arvernensis, Koeleria vallesiana, Armeria arenaria.	Zn, Cd and Pb	Local metallicolous legume and grass species.	Festuca and Koeleria in co-culture with Anthyllis showed a decreased concentration of heavy metals (Zn Pb Cd) in their leaves compared with monocultures. For Festuca, decreases of 2885 to	Armeria, one of the plants used in the study reduced the recruitment of Anthyllis seedlings.	Frérot et al. 2006

			1469 mg/kg for Zn, 1002 to 376 mg/kg for Pb and 19 to 8 mg/kg for Cd were reported. For Koeleria, a decrease of 3,514 to 2,786 mg/kg for Zn, 1,960 to 1,477 mg/kg for Pb and 34 to 26 mg/kg for Cd were reported.		
H. hirta and *Z. fabago*	Pb, Zn and Cu	Characterization of soil and plant samples from a mine tailing located in South-East Spain for further phytostabilisation research	*H. hirta* accumulated around 150 mg kg^{-1} Pb in both shoots and roots. Zn concentration was 750 mg kg^{-1} in *Z. fabago* shoots.	The plant species, *H. hirta* and *Z. fabago*, colonize only parts of the tailings with low electrical conductivity	Conesa et al. 2006

6.5.10.14 Rhizofiltration

Rhizofiltration is the use of plant roots or seedlings (blastofiltration) to absorb or adsorb pollutants, mainly metals, from water and aqueous waste streams (Prasad and Freitas 2003). Plant roots or seedlings grown in aerated water absorb, precipitate and concentrate metals from polluted effluents (Dushenkov and Kapulnik 2000; Elless et al. 2005). Mechanisms involved in biosorption include chemisorption, complexation, ion exchange, micro precipitation, hydroxide condensation onto the biosurface, and surface adsorption (Gardea-Torresdey et al.

2004).

Plants

Rhizofiltration uses terrestrial plants instead of aquatic plants because the former feature much larger fibrous root systems covered with root hairs with extremely large surface areas. Metal pollutants in industrial-process water and in groundwater are most commonly removed by precipitation or flocculation, followed by sedimentation and disposal of the resulting sludge (Ensley 2000). The process involves raising plants hydroponically and transplanting them into metal-polluted waters where plants absorb and concentrate the metals in their roots and shoots (Dushenkov et al. 1995; Salt et al. 1995; Flathman and Lanza 1998; Zhu et al. 1999). Root exudates and changes in rhizosphere pH may also cause metals to precipitate onto root surfaces. As they become saturated with the metal contaminants, roots or whole plants are harvested for disposal (Flathman and Lanza 1998; Zhu et al. 1999). Dushenkov et al. (1995), Salt et al. (1995), and Flathman and Lanza (1998) contend that plants for phytoremediation should accumulate metals only in the roots. Dushenkov et al. (1995) explain that the translocation of metals to shoots would decrease the efficiency of rhizofiltration by increasing the amount of contaminated plant residue needing disposal. However, Zhu et al. (1999) suggest that the efficiency of the process can be increased by using plants with a heightened ability to absorb and translocate metals. Several aquatic species have the ability to remove heavy metals from water, including water hyacinth (Eichhornia crassipes, Kay et al. 1984; Zhu et al. 1999), pennywort (Hydrocotyle umbellata L., Dierberg et al. 1987), and duckweed (Lemna minor L., Mo et al. 1989). However, these plants have limited potential for rhizofiltration because they are not efficient in removing metals as a result of their small, slow growing roots (Dushenkov et al. 1995). The high water content of aquatic plants complicates their drying, composting, or incineration. In spite of limitations, Zhu et al. (1999) indicated that water hyacinth is effective in removing trace elements in waste streams. Sunflower (Helianthus annus L.) and Indian mustard (Brassica juncea Czern.) are the most promising terrestrial candidates for removing metals from water. The roots of Indian mustard are effective in capturing Cd, Cr, Cu, Ni, Pb, and Zn (Dushenkov et al. 1995), whereas sunflower removes Pb (Dushenkov et al. 1995), U (Dushenkov et al. 1997a), 137Cs, and 90Sr (Dushenkov et al. 1997b) from hydroponic solutions. A novel rhizofiltration technology has been proposed by Sekhar et al. (2004) for removal and recovery of lead (Pb) from wastewaters. This technology uses plant based biomaterial from the bark of the plant commonly called Indian sarsaparilla (Hemidesmus indicus). The target of their research was polluted surface water and groundwater at industrially contaminated sites. Cassava waste biomass was also effective in removing two divalent metal ions, Cd (II) and Zn (II), from aqueous solutions (Horsfall and Abia 2003). Modification of the cassava waste biomass by treating it with thioglycollic acid resulted in increased adsorption rates for Cd, Cu, and Zn (Abia et al. 2003). Several species of Sargassum biomass (non living brown algae) were effective biosorbents for heavy metals such as Cd and Cu (Davis et al. 2000). Plants used for rhizofiltration should be able to accumulate and tolerate significant amounts of the target metals, in conjunction with easy handling, low maintenance costs, and a minimum of secondary waste requiring disposal. It is also desirable for plants to produce significant amounts of root biomass or root surface area (Dushenkov and Kapulnik 2000).

Table 68: Examples for rhizofiltration.

Plant species	Metal	Treatments	Results	Reference
B. juncea, H. annuus	Cu, Cd, Cr, Ni, Pb, and Zn	Roots of hydroponically grown terrestrial plants used to remove toxic elements from aqueous solutions	Roots of B, juncea concentrated these metals 131–563-fold (on a DW basis) above initial solution concentrations. The recoveries of heavy metals were 45 % for Cd, 55% for Zn, 50% for Cr, 45% for Ni, 97% for Cu and 100 % for Pb.	Dushenkov et al. 1995
Sunflower plants	U	Rhizofiltration of U in water by roots of sunflower plants	U concentration in water reduced from 21–874 ug/l to <20 ug/l by rhizofiltration	Dushenkov et al. 1997a,b
Water Hyacinth	As, Cd Cr, Cu, Ni, and Se	The abilities of water hyacinth to take up and translocate six trace elements – As, Cd, Cr, Cu, Ni, and Se were studied under controlled conditions	The highest levels of Cd in shoots and roots were 371 and 6,103 mg/kg dry wt., and those of Cr were 119 and 3,951 mg/kg dry wt., Cadmium, Cr, Cu, Ni, and As were more highly accumulated in roots, whereas Se accumulated more in shoots.	Zhu et al. 1999
Duckweed	Hg	Effects of pH, copper and humic acid	Duckweed strongly absorbed Hg from water and after 3 days contained 2,000 ppm of Hg by weight	Mo et al. 1989
Duckweed (*Lemna minor* L.) and water velvet (*Azolla pinnata*).	Fe and Cu	Solutions enriched with 1·0, 2·0, 4·0, and 8·0 ppm of these 2 metal ions, renewed every 2 days over a 14-day test period.	When duckweed was kept in a solution containing Cu alone at 8·0 ppm level, the value of the metal concentration factor (i.e. the ratio of metals in the plant to the growth media) after 14 days was 51. However, in the presence of an equal concentration of Fe the value of this factor was 27, indicating the influence of Fe on the uptake rate of Cu.	Jain et al. 1989

6.5.10.15 Phytovolatilization

Some metal contaminants such as As, Hg, and Se may exist as gaseous species in the environment. Researchers have sought naturally-occurring or genetically-modified plants capable of absorbing elemental forms of these metals from the soil, biologically converting them to gaseous species within the plant, and releasing them into the atmosphere. This process is called phytovolatilization.

Volatilization of Se from plant tissues may provide a mechanism of selenium detoxification. As early as 1894, Hofmeister proposed that selenium in animals is detoxified by releasing volatile dimethyl selenide from the lungs, based on the fact that the odour of dimethyl telluride was detected in the breath of dogs injected with sodium tellurite. Using the same logic, it was suggested that the garlicky odour of plants that accumulate selenium may indicate release of volatile selenium compounds. This is the most controversial of phytoremediation technologies. Hg and Se are toxic (Suszcynsky and Shann 1995), and there is doubt about whether the volatilization of these elements into the atmosphere is desirable or safe (Watanabe 1997). The volatile selenium compound released from the selenium accumulator Astragalus racemosus was identified as dimethyl diselenide (Evans et al. 1968). Selenium released from alfalfa, a selenium nonaccumulator, was different from the accumulator species and was identified as dimethyl selenide. Lewis et al. (1966) showed that both selenium nonaccumulator and accumulator species volatilize selenium. Selenium phytovolatilisation has received the most attention to date (Lewis et al. 1966; Terry et al. 1992; Banuelos et al. 1993; McGrath 1998) because this element is a serious problem in many parts of the world where there are Se-rich soil (Brooks 1998). According to Brooks (1998), the release of volatile Se compounds from higher plants was first reported by Lewis et al. (1966). Terry et al. (1992) report that members of the Brassicaceae are capable of releasing up to 40 g Se ha-1 day -1 as various gaseous compounds. Some aquatic plants, such ascattail (Typha latifolia L.), have potential for Se phytoremediation (Pilon-Smits et al. 1999).

Volatile Se compounds such as dimethylselenide are 1/600 to 1/500 as toxic as inorganic forms of Se found in soil (DeSouza et al. 2000). The volatilization of Se and Hg is also a permanent site solution, because the inorganic forms of these elements are removed, and gaseous species are not likely to redeposit at or near the site (Atkinson et al. 1990; Heaton et al. 1998). Furthermore, sites that utilize this technique may not require much management after the original planting. This remediation method has the added benefits of minimal site disturbance, less erosion, and no need to dispose of contaminated plant material (Heaton et al. 1998). Heaton et al. (1998) suggest that the transfer of Hg (O) to the atmosphere would not contribute significantly to the atmospheric pool. This technique appears to be a promising tool for remediating Se- and Hg- contaminated soils.

Volatilization of arsenic as dimethylarsenite has also been postulated as a resistance mechanism in marine algae. However, it is not known whether terrestrial plants also volatilize arsenic in significant quantities. Studies on arsenic uptake and distribution in higher plants indicate that arsenic predominantly accumulates in roots and that only small quantities are transported to shoots. However, plants may enhance the biotransformation of arsenic by rhizospheric bacteria, thus increasing the rates of volatilization (Salt et al. 1998).

Unlike other remediation techniques, once contaminants have been removed via volatilization, there is a loss of control over their migration to other areas. Some authors suggest that the addition to atmospheric levels through phytovolatilization would not contribute significantly to the atmospheric pool, since the contaminants are likely to be subject to more effective or rapid natural degradation processes such as photodegradation (Azaizeh et al. 1997). However, phytovolatilization should be avoided for sites near population centres and at places with unique meteorological conditions that promote the rapid deposition of volatile compounds (Heaton et al. 1998). Hence the consequences of releasing the metals to the atmosphere need to be considered carefully before adopting this method as a remediation tool.

6.5.11 Factors to consider when selecting site specific evaluation criteria

6.5.11.1 Explanatory Note

Detailed evaluation criteria are used to test the ability of each feasible remediation option to meet specific remediation, management and ‘other’ technical objectives. Since objectives are determined on a site- specific basis, it follows that detailed evaluation criteria should also be specific to the site, although many will be common to most sites.

Note that the statutory guidance to Part IIA of EPA 1990 (Chapter C, DETR Circular 02/2000) sets out very specific criteria for the identification of Best Practicable Technique for the determination of appropriate remediation requirements which may not include all the factors relevant in a wider context.

6.5.11.2 Typical factors and criteria

To satisfy remediation objectives

Effectiveness (see WP2)

• Extent to which the method will reduce and control the risks associated with the pollutant to an acceptable level within an appropriate timescale and how practicable it will be to verify that objectives have been met.

We can use the database and classify the options for each trace element

To satisfy management objectives

Management objectives should aim to define reasonably precisely the specific desired outcomes of remediation, or ways in which it is to be carried out. ‘Other’ technical objectives are usually defined by wider technical goals (e.g., to produce a particular form of development) or the need to avoid practical problems, such as disruption to ongoing site activities.

Examples of management objectives

• To produce a remediation strategy that can be agreed with all key stakeholders

• To meet all regulatory requirements relevant to the installation or operation of remediation options

• To avoid unacceptable health and safety and environmental impacts during remediation

• To minimise long-term liabilities

• To avoid long-term monitoring or maintenance obligations

• To carry out remediation using in-house contractors or external contractors only on a competitive tendering basis

• To carry out remediation in accordance with good technical practice

• To achieve successful remediation within a particular timescale and budget

- to improve biodiversity in particular zones

Stakeholder views

(People, organisations, neighbouring property owners and the local community

Stakeholder concerns with the technology must be addressed before a phytoremediation system is installed (IRTC).

- The toxicity and bioavailability of biodegradation products is not always known
- Mobilization of degradation by-products in groundwater or bio-accumulating in the food chain
- The lack of research to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products manufactured by plants do not contribute toxic or harmful chemicals into the food chain
- Scientists need to establish whether contaminants that collect in the leaves and wood of trees are released when the leaves fall in the autumn or when firewood or mulch from the trees is used
- Harvested plants may require disposal as hazardous waste
- The depth of the contaminants limits treatment. The treatment zone is determined by plant root depth. In most cases, it is limited to shallow soils, streams, and groundwater
- Pumping the water out of the ground and using it to irrigate plantations of trees may treat contaminated groundwater that is too deep to be reached by plant roots but raises concerns with the fate and transport of the contaminant
- Generally, the use of phytoremediation is limited to sites with lower contaminant concentrations and contamination in shallow soils, streams, and groundwater. However, researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground
- The success of phytoremediation may be seasonal, depending on location. Other climatic factors will also influence its effectiveness
- If contaminant concentrations are too high, plants may die
- Some phytoremediation transfers contamination across media, (e.g., from soil to air)
- Phytoremediation is not effective for strongly sorbed contaminants such as PCBs
- Phytoremediation requires a large surface area of land for remediation
- Animals may damage the plants and create a need to replant

• Extent to which the method satisfies the requirements of key stakeholders

Preservation of the top soil

Phytoremediation preserves the top soil and reduces the amount of hazardous materials generated during cleanup (Ensley, 2000).

Reduction of the amount of hazardous materials generated during cleanup

Phytoremediation reduces the amount of hazardous materials generated during cleanup (Ensley, 2000).

Operational requirements • Practicability of installing and operating the method, including site access, storage, support services, etc., and the potential for effective integration with other remediation methods where appropriate

Commercial availability

• Number, identity and geographic location of potential commercial suppliers and expertise

Track record

• Extent of any evidence of successful application of the method in similar circumstances elsewhere

Permissions

• Feasibility of obtaining all relevant permissions and approvals to install and operate the method within the required timescale

Owing to strict quarantine regulations on import of planting material suitable for phytoremediation; consequently one must screened native species

Health and safety risks • Effectiveness in protecting those who carry out remediation or other site personnel and others (including members of the public) who might be affected by remediation

Environmental impact

• Nature and extent of potential effects on the quality of the environment on or close to the site and in a wider context

The wider consequences of a particular remedial project are site-specific in their nature.

The relative significance that attaches to any particular wider effect of remediation will itself vary at a local, regional and / or national level, for example as a result of cultural differences, differences in population density, use of resources etc.

Potential impacts

- Traffic
- Emissions (e.g. volatile organic compounds)
- Noise, dust, odour
- Loss of soil and groundwater function
- Use of material resources (e.g. Aggregates) and energy
- Use of landfill resources
- Waste production
- Accidents on personnel and machinery
- Physical surroundings

Long-term obligations

• Extent to which those who undertake remediation action are able and willing to assume responsibility for any post-remediation maintenance and monitoring, including any long-term obligations

Durability over time

• Extent to which the method is effective in reducing or controlling risks on completion of remediation and for a defined period thereafter

Cost

• Extent to which particular options are reasonable and affordable, given the available resources

To satisfy 'other' technical objectives

Compatibility • Extent to which remediation options are compatible with related construction or infrastructure works or other site operations

6.5.11.3 Information needed on the characteristics of gentle remediation options (*see detailed reports for each option*)

Information on the characteristics of remediation options is available from a variety of sources, including the technical literature and material produced by technology suppliers. Information from independent sources can be extremely useful, especially when the remediation option is highly proprietary in nature.

At the beginning of detailed evaluation, appraisers should have information on the following characteristics for all the remediation options being considered.

6.5.11.4 Applicability of the method to particular pollutant(s) in soil and groundwater

(groundwater is taken here as a receptor media in connection with TECS) Use on gentle remediation options can have impacts on the groundwater (IRTC). Site characterization will determine if contaminants in the soil and/or groundwater are within root depth range of the plants or trees to be used (Typically this is 3-6 m below ground surface (bgs)). Site characterization will determine the physical properties and nutrient requirements of the soil.

Are technologies only applicable to sites with low to moderate soil contamination over large areas, and to sites with large volumes of groundwater with low levels of contamination that have to be cleaned to low (strict) standards?

If there are hotspots (e.g zones toxic to or not suitable for plants, animals, etc), it must be determined if they can be economically treated or removed. Removal of phytotoxic hotspots will make phytoremediation an option to "polish" the site and remove the remaining contamination.

If the groundwater is to be pumped to the surface and then applied to the plants (some form of irrigation) or input in a constructed wetland (rhizofiltration, rhizodégradation), state regulations may be reviewed. There may be restrictions on the use of contaminated water for irrigation. Transpiration of metals such as mercury or organic contaminants must be evaluated to determine if the process creates a hazard to human health or the environment. Hydraulic control is a form of containment. Groundwater contaminant plume control may be achieved through water consumption in plants that increase evaporation and transpiration from a site. Trees and other plants can be used as inexpensive solar pumps that use the energy of the sun to raise contaminated water to the surface. These plants may also have enzymes or other factors capable of reacting with, and in many plants completely degrading, some organic compounds (e.g. munitions and chlorinated solvents). In case of TECS with mixed contamination (trace elements & organic compounds): plant growth in the rhizosphere increases organic carbon, bacteria and mycorrhizal fungi, all factors that encourage the degradation of organic chemicals. The addition of plant root systems creates an ecology that is suitable for bioremediation and rhizodegradation. Oxygen, water and carbon transport mechanism can vary among plant species. Plants supply oxygen to the root zone and root turnover is a key mechanism that adds organic carbon. Oxygen pumped to the root zone by the plant ensures aerobic transformations.

6.5.11.5 Scientific basis of the method (e.g., engineering-based; physical, chemical or biological process-based)

Plant biomass production and plant elemental uptake are two key factors for successful application of phytoextraction and aided phytoextraction (Reeves and Baker, 2000).

(Miller 1996)

Phytoremediation options based on certain natural processes carried out by plants including:

• (aided) Phytoextraction: Uptake of metals and certain organic compounds (i.e., moderately water soluble, log Kow=0.5 to 3, such as BTEX) from soil and water;

• (aided) Phytoextraction, (aided) Phytostabilisation: Accumulation or processing of these chemicals in plant parts,

• Phytovolatisation Accumulation or processing of these chemicals via, metabolization, volatilization

• Rhizodegradation: Use of enzymes to breakdown complex organic molecules into simpler molecules (ultimately CO_2 and water); mineralization (transformation into CO_2 and water);

• Rhizodegradation, Phytostabilisation: Increasing the carbon and oxygen content of soil around roots (and so promoting microbial/ fungal activity) through release of chemicals (exudates) and decay of root tissue;

• Capture of groundwater (even contaminated groundwater) and utilization for plant processes.

6.5.11.6 Mode of operation (e.g., ex-situ or in-situ)

Greenhouse or pilot field studies of selected plants are recommended to determine the ability of candidate plant species to survive in the contaminated environment and their potential efficiency to satisfy the remediation objectives. The plant that reacts best and will be the most effective for phytoremediation is based upon a number of different requirements.

6.5.11.7 Time to achieve technical effectiveness

Phytoremediation may take longer than traditional methods to reach final cleanup levels. Site characterization data should allow phytoremediation designers to estimate the cleanup time.

6.5.11.8 Operational requirements (e.g., working space, support services, plant and equipment needs)

The design of a phytoremediation system varies according to the contaminants, the conditions at the site, the level of clean-up required and the plants used (Phytoremediation Technology Evaluation, Schnoor) (IRTC). A thorough site characterization and risk assessment should provide the needed data to design any type of remediation system.

The contaminant source may need to be removed, especially to avoid contaminant migration to the media (here TECS) under remediation.

Phytoextraction has different design requirements than phytostabilization or rhizodegradation.

- Nevertheless, it is possible to specify a few design considerations that are a part of most phytoremediation options. Site characterization, identification of relevant pollution likages, and risk assessment data will provide the information required for the designer to develop a properly functioning system.

6.5.11.9 Information needs (e.g., in relation to the nature of pollutant and properties of affected materials)

The design considerations include:

- Contaminant levels
- Plant selection
- Treatability
- Irrigation, agronomic inputs (P, N, K, salinity, Zinc etc.) and maintenance
- Groundwater capture zone and transpiration rate
- Contaminant uptake rate and clean-up time required

a) Contaminant Levels

During the site characterization phase, the concentration level and the chemical species/speciation of the contaminants of concern will be established. High levels of contaminants may eliminate phytoremediation (other remediation options) as a treatment option. Plants are not able to treat all contaminants.

b) Plant Selection (just starting after checking the IRTC site, most information not relevant)

Plants are selected according to the application and the contaminants of concern.

The requirements for rhizodegradation of organic compounds at sites where they are mixed with trace elements may be not relevant with requirement for phytoextraction or phytostabilisation

For phytotransformation of organic compounds, the design requirements listed by the US EPA are: that vegetation is fast growing and hardy, easy to plant and maintain, utilizes a large quantity of water by evapotranspiration and transforms the contaminants of concern to non-toxic or less toxic products. Many did not match with conditions at TECS

In temperate climates, phreatophytes (e.g., hybrid poplar, willow, cottonwood, aspen) are often selected because of fast growth, a deep rooting ability down to the level of groundwater, large transpiration rates, and the fact that they are native throughout most of the country.

A screening test or knowledge from the literature of plant attributes will aid the design engineer in the selection of plants.

Pb: Plants used in phytoextraction include sunflowers and Indian mustard for lead;

Zn, Cd *Thlaspi* spp. (Pennycress)

Cu: sunflowers .

constructed wetlands : Aquatic plants are used in applications. The two categories of aquatic plants used are emergent and submerged species. Emergent vegetation transpires water and is easier to harvest if required. Submerged species do not transpire water but provide more biomass for the uptake and sorption of contaminants.

c) Treatability

Treatability or plant screening studies are recommended prior to designing a phytoremediation system. If the decision tree flowcharts indicate phytoremediation is an applicable technology for a site, contact a plant scientist to assist in the treatability studies. Treatability studies assure concerned parties that the phytoremediation system will achieve the desired results. Toxicity and transformation data are obtained in treatability studies. Treatability studies assess the fate of the contaminants in the plant system. Different concentrations of contaminant are tested with proposed plant species.

d) Irrigation, Agronomic Inputs and Maintenance

Irrigation of the plants ensures a vigorous start to the system even in drought. Hydrologic modeling may be required to estimate the rate of percolation to groundwater during irrigation conditions. Irrigation should be withdrawn if the area receives sufficient rainfall to sustain the plants. Agronomic inputs include the nutrients necessary for vigorous growth of vegetation and rhizosphere microbes. The soil must be analyzed and then items such as nitrogen, potassium, phosphorous, aged manure, sewage sludge compost, straw and/or mulch are added as required to ensure the success of the plants. Maintenance of the phytoremediation system may include adding fertilizer, agents to bind metals to the soil or chelates to assure plant uptake of the contaminants. Replanting may be required due to drought, disease, insects or animals killing off plants.

e) Groundwater Capture Zone and Transpiration Rate

For applications involving groundwater remediation a capture zone calculation can be used to estimate whether the phytoremediation pump (trees) can be effective at entraining the plume of contaminants. The goal is to create a water table depression where contaminants will flow to the vegetation for uptake and treatment. Organic contaminants are not taken up at the same concentration as in the soil or groundwater. Membranes at the root surface reduce the uptake rate of the contaminant.

f) Contaminant Uptake Rate and Clean-up Time Required

How to estimate the uptake rate of contaminants?

- a model has been developed for willow (see phytoextraction report)

- an on line model is available at www.nottingham.ac.uk/environmental-modelling with plants such as Thlaspi caerulescens, willow, and maize+chelate, especially for sludged soils. The PASS decision aid is a predictive model of 3 phytoremediation systems, freely available to interested parties (http://www.nottingham.ac.uk/environmental-modelling/PASS%20DA.htm)

- The Ground-Water Remediation Technologies Analysis Center (GWRTAC) Technology Evaluation Report *Phytoremediation*, by Jerald L. Schnoor, (www.gwrtac.org) describes how to determine the contaminant uptake rate and clean-up time.

Limitations of the method (e.g., related to soil type, presence of inhibiting substances or conditions)

- The site characterization process is important in determining if the contaminants of concern fit within the boundaries of phytoremediation technology.

- Contaminants in the soil and/or groundwater are not within root depth range of the plants or trees to be used. In this case, contaminants cannot be intercepted by the root system.

- Physical properties and nutrient requirements of the soil may not be in favour of the plant establishment.

- High concentrations of hazardous materials can be toxic to plants

- It can transfer contamination across media, e.g., from soil to air. The accumulation of contaminants/waste in the plants may present a problem with contaminants entering the food chain (e.g. herbivory) or cause the plants to become a waste disposal issue. The relative concentrations of contaminants in the plant tissue must be determined. Proper harvest and disposal methods must be developed and approved by regulatory agencies.

- It involves the same mass transfer limitations as other biotreatments.

- It may be seasonal, depending on location.

- It is often not effective for strongly sorbed (e.g., Phytoextraction vs. Cu, Pb).

- It is often in the demonstration stage.

- It is unfamiliar to regulators.

Track record (e.g., whether established or innovative method)

Permissions (for installation and operation of the method)

• In some countries waste licence is needed to treat contaminated soil on site, making time constraints a problem for on site treatment technologies (Clarinet 2002)

Health and safety risks

Potential environmental impacts

Remediation activities themselves have their own environmental, social and economic impacts. On a project-by-project basis, the negative impacts of remediation should not exceed the benefits of the project.

If the undesirable impacts of the remediation process exceed the desired benefits of the core objectives, the core objectives may need to be re-evaluated. If proper risk management procedures have been followed, along with a thorough cost benefit analysis and stakeholder consultation, the risks of such a situation arising should be minimised, depending on the remediation approach selected.

Durability (e.g., on installation and over time)

USA: a matrix is available for modelling long term maintenance and monitoring at http://www.frtr.gov/decisionsupport/FunctionalGroups/lt_monitoring_optimization.htm

6.5.11.10 COSTS

There is a constant pressure for reducing remediation costs, both to improve the economics of brownfield re-use for "hard applications" such as housing or commerce; and for "softer" uses such as nonfood agriculture and recreation. Cost effectiveness is not just a product of reducing remediation costs, but also of finding remediation approaches that provide an additional enhancement to the value of the land (Clarinet 2002). The environmental costs involve the work process throughout the whole life cycle of the remediation. The work process includes the consumption of materials, fuel and energy consumption (including emissions to air, soil and water), and effects on man (noise, odour), as well as waste and accidental issues. The highest cost reducing potential can be achieved by reducing the volume of soil needing treatment and by increasing the proportion of materials to be recycled and reused. Experienced and professional project management, relevant and adequate site investigations, improved knowledge of the performance and efficiency of remediation processes can significantly enhance the accuracy of forecasting remediation costs (Clarinet 2002). There are two additional 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, and the potential for its treatment, disposal, recovery, recycling and reuse. The second is the designated land-use of a remediated site; this has a profound effect on site values and hence the options available for remediation (Clarinet 2002).

• The economic framework differs, e. g. differences in landfill taxes in the countries

The cost figures for the same technology varies several orders of magnitude, illustrating differences in clean-up projects, but also illustrating the lack of availability of the technologies in some countries, and the size of a commercial remediation marked in other countries.

Prior to investigation, some authors had the general feeling that in situ technologies would be cheaper than ex situ technologies, but the Clarinet (2002) investigations showed that this was not always the case. In situ technologies are mostly applied in projects where ex situ technologies were not so easy implemented, e.g. difficult clean-up projects (beneath existing buildings etc.). Some cost figures for gentle technologies were summarised by Clarinet (2002):

Predominantly ex situ option

• Bioremediation: 20-40 Euros/t, assuming that:

- Low cost figures are referring to composting, and

- High cost figures are referring to bioslurry or reactor treatment system

• Stabilisation/solidification 80-150 Euros/t

Solidification / stabilisation £30-60/m3 in Clarinet (2002) cited by *Nathanail (2000)*

In situ technologies:

• 20-60 Euros/t depending on technology and application at site. Many remedial treatments operate over the shorter term and require relatively high cost and energy inputs. These are referred to as "intensive" treatment technologies. Extensive technologies operate over a longer period with low maintenance, cost, and energy requirements. Examples in current use include phytoremediation and monitored natural attenuation (MNA).

Table 69: Costs of different remediation technologies (Glass, 1999).

Table 1 Cost of different remediation technologies (Glass 1999)

Process	Cost (US$/ton)	Other factors
Vitrification	75–425	Long-term monitoring
Land filling	100–500	Transport/excavation/ monitoring
Chemical treatment	100–500	Recycling of contaminants
Electrokinetics	20–200	Monitoring
Phytoextraction	5–40	Disposal of phytomass

Among the listed remediation technologies, phytoextraction is one of the lowest cost techniques for contaminated soil remediation.

According to Ensley (2000), the estimated expenses incurred in the remediation of a site contaminated with Pb using the conventional excavation-landfill approach most commonly practiced in the United States are approximately $150-$350 t-1. Taking into account such a high demand of economic resources, methods of environmental restoration of metal-polluted soils using a plant-based technology have attracted increasing interest in the last two decades. In this context, phytoremediation has been developed as a cost effective and environmentally friendly remediation method of contaminated soils. Remediation of contaminated soils using plants may cost in the order of US$ 20-80 t-1 (Ensley, 2000) or US$ 0.25 M ha-1 (Cunningham & Berti, 2000), which makes it an economically attractive approach to decontaminate soils polluted by heavy metals. Phytoremediation for metal-contaminated soils represents a market opportunity of approximately US$1 billion per year (Glass, 2000) in the USA alone; the U.S. phytoremediation market currently comprises only 0.5% of the total remediation market, equivalent to circa US$ 100-150 million per year (Pilon-Smits, 2005). Thus, there is a large repressed demand for such technology. Because of its relatively low costs, phytoremediation poses a viable approach to cleaning up soils in developing countries as well, where funds available for environmental restoration are scarce.

The estimated costs of disposal of plant material containing “hazardous” concentrations of TEs to landfill sites are around 200 euros per tonne. (Istriteanu et al 2006 Sintra)

Table 70: USA: Cost of phytoremediation according to FRTR (http://www.frtr.gov/matrix2/section4/4-3.html)

RACER PARAMETERS	Scenario A	Scenario B	Scenario C	Scenario D
	Small site		Large Site	
	Easy	Difficult	Easy	Difficult
COST PER SQUARE FOOT	$2	$7	$0.42	$1
COST PER CUBIC FOOT	$18	$66	$4	$14
COST PER CUBIC METER	$626	$2,322	$147	$483
COST PER CUBIC YARD	$479	$1,775	$112	$369

6.5.11.11 Phytoextraction with rape or willows

One case study applies to a large area cross bordering the eastern part of Flanders and the Netherlands in which diffuse TE pollution forms a heritage from the historical zinc smelters in the region. The area surface is so vast that traditional techniques are far too costly to be considered. A cost-benefit analysis is useful in deciding which phytoremediation crops are most fitted from the point of view of their impact on agricultural income. For the larger part the actual income comes from diary cattle rearing. The cattle feeding (roughage), mostly maize, forms the most important land use. In switching this land use towards phytoremediation accumulator crops the income of the land use would change. As a reference for this change the present value of the actual labour income of the average farm (36 ha) earned by cultivating roughage (grassland and maize) is used. Two alternative phytoremediation crops are considered: (i) rape (brassica nappus), and (ii) willow (salix spp.) in 'short rotation forestry'. The choice for rape is motivated by the possibility of using its biomass as a source of renewable energy like bio-diesel. With the purpose to create the value added as much as possible on the farm itself, we opt for the production of pure plant oil (PPO) by the farmer to be used as fuel (with a price of € 0,50/lit.) for his own tractor(s) equipped for such an application. In the phytoremediation scenario, the yearly cultivation scheme then looks as follows: 8 ha of rape (in 4 year rotation); 4 ha of willow (whole period, with harvest every 4th year); 24 ha of roughage (to continue the cattle rearing). Remark that the lost produce of the surface of roughage substituted by rape and willow (12 ha), is compensated by external buying, so that the cattle population can stay the same. The reclamation activity aims at removing on average 1,9 kg Cd/ha (depth of 30 cm). The net present value (NPV) over a period of 40 years of the gross labour income resulting from the mentioned phytoremediation cultivation scheme is 4,5% higher than the NPV of continuing the actual land occupation, that is 36 ha only for roughage – as if no soil reclamation would have been necessary. If the farmer would sell the PPO as a fuel for cars to a distribution network (at a price of € 0,65/lit.), the NPV then would be 11,7% higher. Increasing the ratio of willow versus rape from 4 ha/8 ha to 8 ha/12 ha (and thus also increasing the phytoremediation surface) remarkably shortens the calculated remediation period from 38 to 21 years (willow has a relative higher uptake performance), but the NPV is now only 2% (instead of 4,5%) higher than the reference (the biomass of willow has less profitable applications than the biomass of rape). (Thewys 2006 Sintra).

Table 71:

Cost heading	Example
Site preparation	Provision of hardstanding, access roads, site security, accommodation for remediation personnel
Regulatory approvals	Application for licenses and approvals to install and/or operate the method
Project management costs	For management and supervision of remediation
Equipment	Materials handling and processing plant, pumping wells and associated equipment
Mobilisation and start-up	Transport and assembly of plant, equipment and materials, calibration of equipment and other preoperational checks
Maintenance	Plant modification, repair and long-term performance
Demobilisation	Disassembly of plant and equipment, decontamination measures
Financing	Working capital, interest, depreciation, insurance, taxes, contingency
Labour costs	Salary and expenses
Consumables	Sampling equipment, construction materials, replacement parts
Utilities	Power, water, telecommunications
Health and safety measures	Protective clothing and equipment, project-specific training, independent audit
Environmental protection measures	Containment of dusts, vapours, noise, effluents and similar emissions and associated monitoring procedures (e.g. ambient air quality, discharge of effluents)
Waste disposal	Solid and liquid waste arisings, pollution-control residues
Analytical support	For verification purposes during, on completion and over the long-term if required, to support healthand safety and environmental protection needs

Table 72:

Aspect	***Total possible score***	***Method***
Effectiveness in achieving remediation objectives within appropriate timescale		

and practicability of verification		40
Stakeholder requirements		40
Operational requirements		5
Commercial availability of technique		5
Track record of use		5
Permissions for installation and/or operation		5
Timescale for implementation	5	
Health and safety impacts		5
Environmental impacts	5	
Long-term monitoring and maintenance implications		5
Durability over time		40
Compatibility with other site works		5
Score for all technical attributes		165

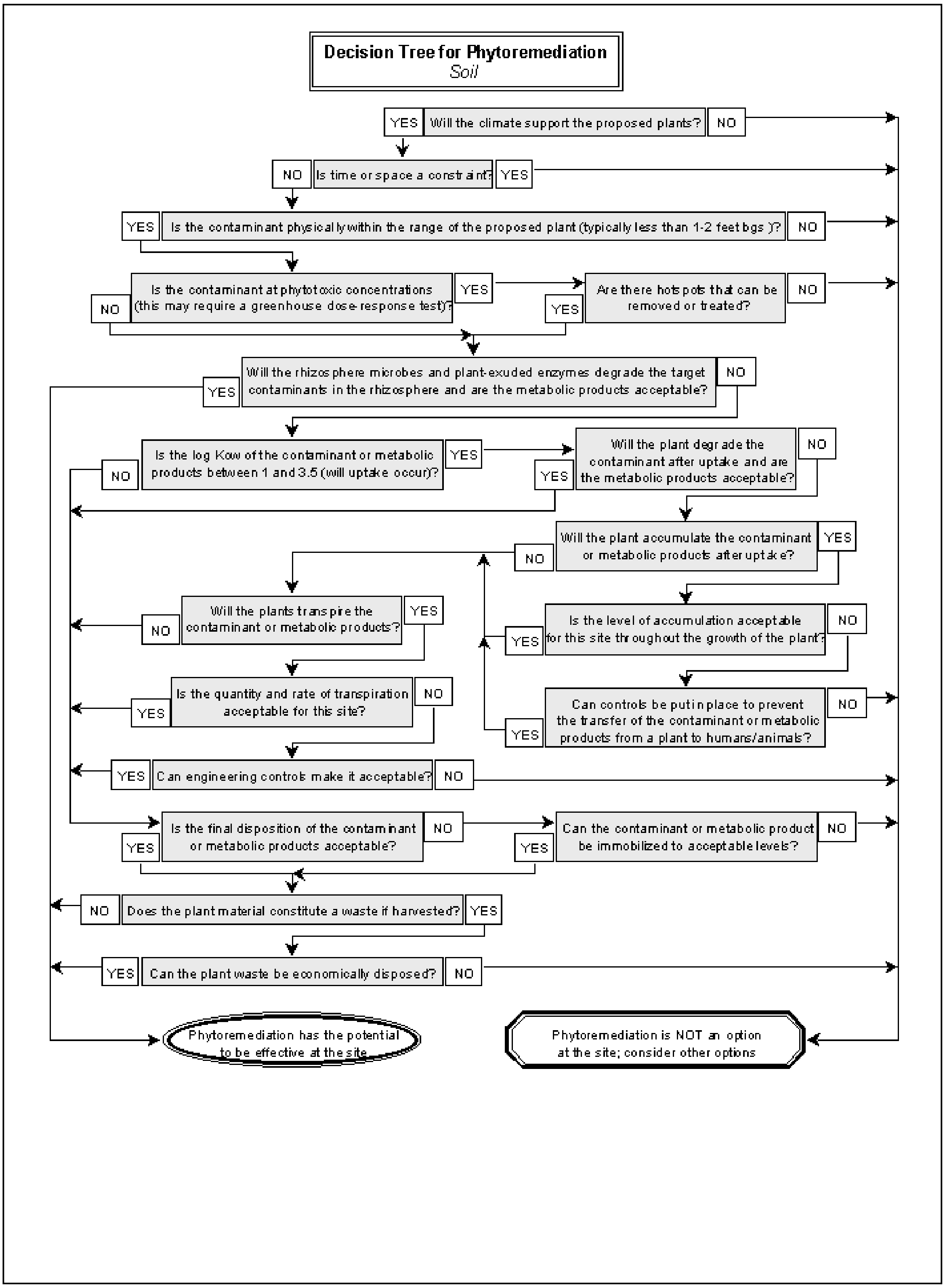

Decision Tree for Phytoremediation
Soil
Will the climate support the proposed plants?
YES
NO
Is time or space a constraint?
NO
YES
Is the contaminant physically within the range of the proposed plant (typically less than 1-2 feet bgs)?
YES
NO
Is the contaminant at phytotoxic concentrations (this may require a greenhouse dose-response test)?
NO
YES
Are there hot spots that can be removed or treated?
YES
NO
Will the rhizosphere microbes and plant-exuded enzymes degrade the target contaminants in the rhizosphere and are the metabolic products acceptable?
YES
NO
Is the log Kow of the contaminant or metabolic products between 1 and 3.5 (will uptake occur)?
NO
YES
Will the plant degrade the contaminant after uptake and are the metabolic products acceptable?
YES
NO
Will the plant accumulate the contaminant or metabolic products after uptake?
NO
YES
Will the plants transpire the contaminant or metabolic products?
NO
YES
Is the level of accumulation acceptable for this site throughout the growth of the plant?
YES
NO
Is the quantity and rate of transpiration acceptable for this site?
YES
NO
Can controls be put in place to prevent the transfer of the contaminant or metabolic products from a plant to humans/animals?
YES
NO
Can engineering controls make it acceptable?
YES
NO
Is the final disposition of the contaminant or metabolic products acceptable?
YES
NO
Can the contaminant or metabolic product be immobilized to acceptable levels?
YES
NO
Does the plant material constitute a waste if harvested?
NO
YES
Can the plant waste be economically disposed?
YES
NO
Phytoremediation has the potential to be effective at the site
Phytoremediation is NOT an option at the site; consider other options

Fig. 28: Decision tree for phytoremediation of TECS (source IRTC, USA)

6.5.11.12 Pilot case studies

A range of pilot scale studies and demonstration programmes are ongoing in Europe. Some of the programs are internationally oriented with partners from outside Europe (see detailed information on gentle remediations and in the Sumatecs database)

6.5.11.13 International programmes

In the international programme "NATO/CCMS pilot study" a broad range of countries have been and are demonstrating different technologies. The study covers a broad range of technologies such as remediation of gasoline, phenol, tar, BTEX, metals etc. in different media. Final demonstrations included 15 different technologies from 10 different countries. The earlier phases have been reported both in paper (EPA/542/R-98/002) and electronic format (http://www.nato.int/ccms/pilot-studies/pilot007/).

USA, Canada: several experiments for metals and metalloids are listed by CLU-in database

Table 73: Implementation of remediation experiments according to CLU-In database

	Phytoextraction	Phytostabilisation		Phytoremediation
As	9	7	17	USA, Canada
Cd	10	8	15	USA, Poland, Korea, Switzerland, Australia
Cr	4		6	USA
Co	1		1	Canada
Cu	7		11	Canada, Korea, USA
Hg	3	2	5	USA
Ni		1	2	USA, Australia
Pb	16	9	23	USA, Poland, Korea, Switzerland, Australia
Sb	1		1	Minnesota
Se	1		2	USA
Tl	2		2	USA
V	1		1	USA
Zn	9	6	13	USA, Poland, Korea, Switzerland, Australia

Québec province : Révi-Sols et ClimatSol are two programme for funding the remediation and land management of urban industrial bronwfields (M. BEAULIEU - Ministère du Développement Durable, de l'Environnement et des Parcs - Québec (télécharger la présentation)

6.5.12 Advancing the use of green remediation practices

6.5.12.1 USA:

To achieve green remediation goals, EPA's Office of Solid Waste and Emergency Response is working with private and public partners to (http://cluin.org/greenremediation/):

- Document the state of best management practices,
- Identify opportunities for improvement,
- Establish a community of practitioners, and
- Develop mechanisms and tools facilitating the use of green practices

The Superfund Innovative Technology Evaluation (SITE) Program attempted to demonstrate and evaluate the efficacy and cost of phytoremediation in the field at sites in Oregon, Utah, Texas, and Ohio.

Remediation Technology Demonstration Project Profiles: EPA has developed this Web site (http://www.clu-in.org/products/demos/) to summarize timely information about selected on-going and completed remediation technology demonstration projects. Remediation technology demonstration projects are new technologies or new applications of existing technologies that are under development and are being tested at the demonstration or field scale before they are used in full-scale cleanups. Projects for this Web site are collected using information from technical journals and conference proceedings, as well as information obtained from technology vendors and site managers. The project profiles contain information about relevant site background, the types of contaminants and media treated, the technology used, the duration of demonstration, project size, location, cost, monitoring and performance results, as well as points of contacts and references. This Web site can be used as a networking tool (each profile lists a contact) to identify past solutions and lessons learned that would apply to new sites with similar contaminants and climate.

As of August 2008, the Web site included information on 292 field-scale remediation technology demonstration projects. Projects address cleanup technologies for soil and groundwater that have been used in the U.S. or Canada. The database does not include projects that involve only site characterization technologies or computer modeling, however. As further information is obtained, EPA plans to update and expand this Web site with new remediation technology demonstration project profiles and updated information about existing project profiles.

In the past, EPA has tracked field-scale demonstration projects and has published two editions of a report titled “Innovative Remediation Technologies: Field-Scale Demonstration Projects in North America,” most recently in June 2000. In addition, EPA publishes a monthly Technology Innovation News Survey (TINS) that includes limited information about technology demonstrations and feasibility studies, as well as about market and commercialization, cleanup, research, and general topics.

6.5.12.2 European programmes

- A decision support system to assess the potential of phytoremediation in the management of metals polluted soils and sediments: Phyto-DSS was developed to meet the main objective of the EU supported project PhytoDec (contract number EVK1-CT-1999-0024), that was carried out by scientific institutes in The Netherlands, Italy, France, Spain and Poland. The project ended in August 2004. Project objectives and work plan can be downloaded from the PhytoDec website that will be installed in October 2001 (www.phytodec.nl).

Phytoremediation schemes were focusing at the removal of the metals from the soil after crop uptake (phyto-extraction, potentially applicable at moderately polluted sites) and at the physical and chemical stabilisation of heavy metal through direct and indirect root action (phytostabilisation, potentially applicable at heavily polluted sites).

- The TUP (Technology Development Programme) programme sponsored by the Danish EPA;

- ADEME in France, “Tests of polluted soil treatment and technology development” (1998-2003), “Phytoremediation of contaminated soils at a wood treatment facility (2006–2009)

- The Dutch NOBIS programme (SKB);

- The German VEGAS programme;

- The British CLAIRE and exSite programmes;

- The Swedish Coldrem programme.

See http://www.eugris.info/displayresource.asp?Cat=document&ResourceID=5760

In Europe, research on phytoremediation of contaminated soils and waste water as well as protection of foods is coordinated by *COST Actions*. Special mention should be given to COST action 837 *Plant biotechnology for the removal of organic pollutants and toxic metals from waste water and contaminated sites* (duration: from 1999 to 2003) (COS99) and COST action 859 *Phytotechnologies for promoting sustainable land use and improving food safety* (duration: from 2004 to 2009) (COS04). (see http://w3.gre.ac.uk/cost859/)

Belgium

Pilot scale experiments for soft remediation techniques for TECS: 50% funding by EFRO, 50% by the OVAM. Three techniques were tested in pilot scale: immobilisation, phyto-extraction and bio-extraction.

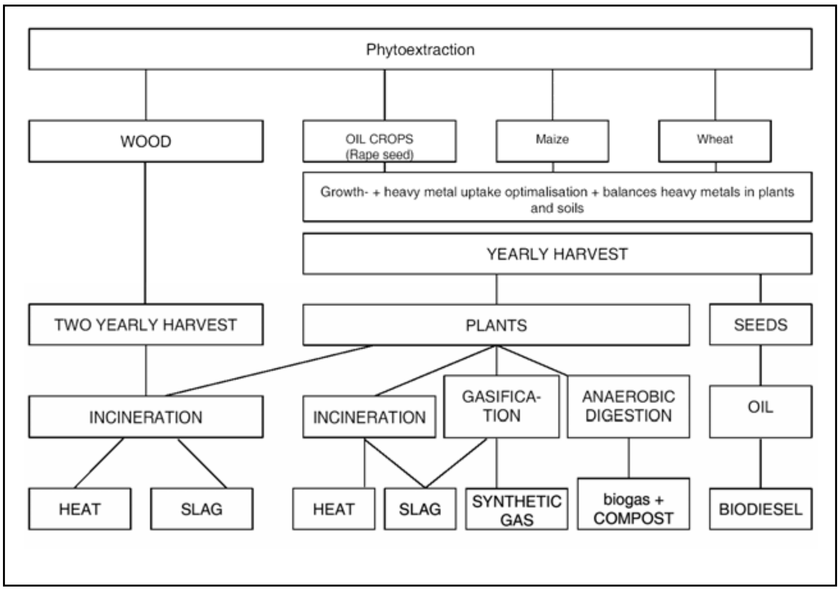


Fig. 29: Representation of studied techniques to produce bioenergy from energy crops used in the remediation of soils contaminated with metals (Van Ginneken et al 2007).

France

Previous French policy on treatment and rehabilitation of polluted sites has been presented in the CARACAS publication Risk Assessment for Contaminated Sites in Europe

The French Ministry of Environment published in 1996 the last register of contaminated sites, which need a remediation action in France, which is available on: http:// www.environnement.gouv.fr/basol/. This register is completed by statistical information about treatment technologies applied in these sites. Due to the number of concerned sites and due to emergent technologies, it can be considered that these data are probably quite different today. It can be noticed that in some cases, a combination of several treatments has been used.

The Ademe (2003) French programme proposed an inventory of tests in order to choose an appropriate remediation technology. For this purpose eight different technologies and eight different types of contaminated materials have been selected for studies.

the French company ATE has published a guide to identify available techniques, according to the contamination (pollutants and soil properties) and even according to activity at the origin of the pollution.

One national procedure published in 2007.

Phytorem

Phytorestore

IRH-Environnement

One large As-contaminated site has been managed using phytostabilisation (Difpolmine La Combe de Sault) http://www.difpolmine.org/servlet/KBaseShow?m=3&cid=10169&catid=10171&sort=-1

UK: The guiding principle in the United Kingdom is 'fit for purpose'. The planning and development control system will consider the intended future use of a development together with the wider environmental questions.

In practice, most remediation is secured voluntarily or through the Town and Country Planning system. Specific conditions may be attached to planning approval to require the implementation of an remedial design or construction measures necessary, either to ensure that the planned development and surroundings are safe in terms of any risks presented by land contamination, and/or, to prevent the development itself from causing unacceptable risks (for example by introducing a susceptible receptor, or a pathway linking an existing source with a receptor).

CLAIRE was a UK programme for demonstrating both remediation research and commercial scale technologies on contaminated sites throughout the UK. Established in 1999, it has approved 9 projects as of January 2001. In additional 8 to 10 projects are expected to approve over 2001.

RP5 Stabilisation of metal contaminants using phosphate derived from bonemeal.

See BIowise, LINK, NERC

Phytoremediation using SRC, near Glasgow, *WRC et al* Cr and metals

The Public Register of Contaminated Land http://www.castlepoint.gov.uk/Category.asp?cat=1056

Germany: The enforcement of contaminated site remediation which generally includes the steps

(a) registration

(b) remedial investigation

(c) risk assessment and

(d) remediation is with the 16 Federal States (Laender) of Germany. The Federal Soil Protection Act (FSAP), which has been enacted on March 1st, 1999, includes precaution issues as well as remediation of contaminated soils and sites.

The two terms "harmful changes in the soil" and "contaminated sites" in the FSAP cover all burdens of the soil, which cause hazards for human beings and the environment.

Nation-wide are more than 300.000 of suspected contaminated sites registered by the Leander.

According to the definitions of the FSAP remediation are measures

(1) for the removal or reduction of contaminants (decontamination measures)

(2) which prevent or reduce the spreading out of contaminants on a long term basic without removing contaminants (safeguarding measures)

(3) for the removal or reduction of harmful changes of the physical, chemical and biological nature of the soil.

The decision on whether to use prevention or decontamination measures for remediation is a complex procedure determined by a multitude of factors (remedial investigation).

For more information see http:/www.bmu.de or www.umweltbundesamt.de.

The most comprehensive overview on remediation technologies is provided by an electronic databank system, which has been developed under the contract of the Federal Environmental Agency from 1996 to March 2000. The databank TERESA 2.1

(GERMAN acronym for Register on Contaminated Land Remediation Technologies includes detailed information on approx. 110 companies in Germany who are offering services in the field of contaminated land clean up.

http://www.umweltdaten.de/altlast/web1/start.htm (Environmental Federal Agency) http://home.snafu.de/itva/ (Engineer-technical Association for Soil Remediation, ITVA e.V.)

http://www.iws.uni-stuttgart.de/vegas/uebersicht.html VEGAS

http://www.lfu.baden-wuerttemberg.de/lfu/abt5/altlasten/index.html (AlfaWeb)

From October 2003 to December 2005, the initiative, *Networks for Renewable Energy Research*, conducted by the German Federal Ministry of Education and Research (BMBF), has funded the network, *Renewable Energy from Biomass Obtained by Phytoextraction from Contaminated Soils*. As the name of the initiative implies, attention is focused on two problem fields which are of vital importance to the societies of industrial nations: the supply of *energy* as well as safeguarding or remediation of *soil* as a resource, for instance, as a basis for food production and drinking water supply.
Areas from which a serious hazard has originated have been or are being remediated on demand. However, the methods applied for the purpose (physical, chemical, thermal treatment) are often very expensive and can even impair or destroy the soil functions as a basis for plant, animal, and human life, as well as for agriculture or forestry as defined by the German Federal Law Relating to Soil Conservation (BBodSchG).

In the interdisciplinary *Network Energy from PhytoRemediation (NEPR)*, which was established by the funding initiative, these aspects are combined for the first time in an interdisciplinary and integral approach. The objectives of the network are to assess the feasibility of soil decontamination by plants with subsequent use of the resulting biomass as a source of energy and to determine which contaminated sites, plants, and energetic processes can be combined in this case.
For this purpose, some forty scientists have studied and evaluated the state of the art in the fields of phytoremediation and utilisation of biomass as an energy source over a period of two years. The experts in the fields of genetic engineering, process engineering, forestry, economics, biology, soil science, remediation of contaminated sites, ecology, chemistry, and agriculture are employed in industry, politics, society, and science. Within the network, they concentrate their professional competence and experience in a unique way. In six meetings and several intensifying specialist excursions, the results have been prepared and presented to a broad public in the course of a concluding symposium. These results are likewise presented in *chapter 2* and *chapter 3* of this volume. A discussion of the interfaces between the two major topics, *heat and power generation* and *soil remediation*, indicates that an isolated consideration yields only partial results which are not satisfactory: For developing sustainable solution concepts, the network approach must be considered in a more comprehensive manner which includes the individual systems as component parts, as discussed in *chapter 4*. In the prognosis given in *chapter 5*, the methodical procedure developed in the network is described in detail. Finally, the research requirement defined in the network is considered with the use of examples in *chapter 6*.

References

(BUN02) Bundesregierung (Hg.): Perspektiven für Deutschland, Berlin 2002
(COS99) http://lbewww.epfl.ch/COST837
(COS04) http://www.gre.ac.uk/cost859

Greece

Innovative technologies developed by Greek Universities and Research Organisations, are summarised in Table 74.

Table 74: Innovative technologies developed by Greek Universities and Research Organisations.

Technology	**Type of contaminants treated**	**Development stage**	**Details of application**	Result/**experience/ limitations**
In situ chemical stabilisation	Heavy metals	Pilot scale, 1000m² treated in-situ to a depth of 0.4m	Stabilisers tested: phosphates, biological sludge, fly ash, compost	Reduction of Pb, Zn, Cd solubilty by 60 to 95%. Reduction of phytotoxicity, development of vegetation on treated soils. Costs ~15-60 Euro/m³, depending on materials availability

Italy

A review has been presented by Comino and Marocco (2007). Phytotechnologies evaluation with multicriteria analysis

Nowadays phytoremediation is a well-known technique that presents some advantages: sustainability, environmentally friendly, low cost technology. In order to investigate the economical benefits of a wetland system we wanted to understand its feasibility starting from comparing the most common wastewater treatments in terms of cost-benefits analysis. Phytotechnologies are low-cost and environmentally friendly technologies, so that their efficiency is getting higher thanks to the several efforts and studies by a lot of scientific teams in Europe. They target extraction, degradation or fixation of the pollutants of contaminated soils and water around formers, mines, slag dumps from coal-fuelled power plants and are expected to play a major role especially in the restoration of former industrial areas. Thanks to their wide employment possibility and efficiency in the land use management a single-criterion, approach (such as cost-benefit analysis) was not considered enough, especially where significant environmental and social impacts cannot be assigned monetary values. For this purpose a Multi-Criteria Analysis (MCA) was developed in order to allows decision makers t include a full range of social, environmental, technical, economic and financial criteria. In a situation where multiple criteria are involved confusion can arise if a logical, well-structured decision-making process is not followed. For each waste water treatment technique the MCA defines criteria (in order to identify the studied ratings), attributes (to measure the studied ratings) and rules. The second step aims to compare the different techniques based on each criterion in order to find the priorities among the different alternatives, and then every criterion has to be weighted. In a Multi-Criteria Evaluation (MCE), an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective (Eastman et al., 1995). Decisions about the allocation of land typically involve the evaluation of multiple criteria according to several, often conflicting-objectives. The advantage of MCE is that it provides a flexible way of dealing with qualitative multi-dimensional environmental effects of decisions (Munda, 1995). Although a variety of techniques exists for the development of weights for the criteria, one of the most promising would developed by Saaty (1977): it is a comparison method where the decision-maker is asked to give the relative importance to the criteria by comparing them two by two. Then the priorities between the criteria is calculated according to the following alternative but equivalent procedures:

1) Calculating the priorities using an approximation method starting from the Saaty's matrix of pairwise comparison between the criteria;

2) Calculating the priorities using the exact method based on the idea of consistency. If the matrix is consistent all its

powers give the same priority or dominance pattern.

When the matrix is consistent, the normalized sum of each row tells us how much each element dominates the others in relative terms. The sum of the entries in each column tells us how much each element is dominated by other elements. To derive the priorities from the matrix we add the numbers in each row and divide each of the results by their total sum to obtain the normalized scores. The operation is repeated until results are stabilized. This methodology is tested on a case history in order to verify it's applicability.

Eastman J.R., Jin W., Kyem P.A.K., Toledano J., 1995. *Raster procedures for multicriteria/ multiobjective decisions*. Photogrammetry and Remote Sensing. 61(5); 539-547

Munda G., 1995 *Multicriteria Evaluation in a Fuzzy Environment*. Physica-Verlag Heidelberg, Germania.

Saaty T.,1999 *Decision making for leaders: The analytic hierarchy process for decisions in a complex world*. RWS Publications University of Pittsburgh, 322 Mervis Hall

Ireland

Phytoremediation – research work is undertaken to evaluate the effectiveness of phytoremediation to enhance natural degradation rates of hydrocarbonsand provide mechanisms for the remediation of metals from soils and shallow groundwater.

Geotechnical and Environmental Services, Consultant, Phyto-remediation for heavy metals and some organics

Portugal

Portuguese legislation (EC Directive 86/278/CEE from June 12th).

The Netherlands

There are three basic categories: not serious (decontamination not required), serious (decontamination required in due course), serious and urgent (decontamination required in the near future).

Prognoses relating to the costs of soil pollution indicate figures in the order of 45 billion €. gives an overview of the most important groups of pollution cases with figures for the category "serious and urgent". Around 60,000 cases are involved the costs of which amount to almost 30 billion €. Estimates for "serious" cases number is more than 26,000. It is thought that the costs of these cases, including the costs of the serious and the urgent diffuse cases of soil pollution, could be as high as 20 billion €.

NOBIS (Nederlandse Onderzoeksprogramma Biologische In situ Sanering) has focused on cost efficient remediation technologies in relation to location-specific circumstances. A new Dutch programme called "soil knowledge development and transfer" will use the same approach. Outcomes from NOBIS:

Take the time Natural processes in the soil are slow. This implies that the time factor is of vital importance for biological remediation options. Therefore, it is important to take the time in order to be able to use the advantages of in situ degradation. Taking the time means attacking a contaminated situation at an early stage, so that, when another application for the soil arises some years later, the location is suitable for that new purpose. Taking the time also implies that the in situ degradation process is in progress while the (new) company activities continue as usual.

Use the self cleaning capacity of the soil. All sorts of biological degradation processes take place in the soil. Generally, it is worthwhile to investigate whether the natural degradation process *as such* will be sufficient to obtain an acceptable risk reduction over time [11]. A number of factors play a role in this assessment, including the natural 'rate of disappearance' of the contaminants, the geochemical characterisation in relation to the degradation products, the capacity (potential) of the soil to remove a certain quantity of contaminants over a period of time, the 'global' modelling of the geohydrology, the compound behaviour to obtain an overall impression of the location and to determine the dominant processes [11].

Stimulate natural process A high return on investments can be obtained by stimulating the biological degradation processes that are already present. Limited injection of nutrients, oxygen, other electron acceptors or donors and a subtle control of the groundwater flow may be sufficient to stimulate the degradation processes to such an extent that the requirements for acceptable risk reduction will be met. This less intensive remediation can sometimes be combined with control measures that have already been taken or will be taken anyway. As mentioned before, the time factor is very important in this approach. The term within which the risk reduction will have to be realised will usually have to be weighed against the technological interventions.

Intensive remediation if necessary Despite all efforts, the previously described line of thought may lead to the conclusion that the stimulation of natural degradation will not sufficiently reduce the observed risks. In that case, a more intensive approach is required [12].

Stichting Kennisontwikkeling en kennisoverdracht Bodem (SKB), PO Box 420, 2800 GOUDA, The Netherlands, tel +31 (0)182 540690; E-mail: skb@cur.nl. This foundation has a large knowledge on the developments in in situ soil decontamination methods in the Netherlands.

Executive Organization for the Manual of Soil Decontamination Methods project. Within the scope of the project, method descriptions have been drawn up for all soil decontamination methods in operation or in development in the Netherlands, and practical evaluations have been performed on a very large scale for determination of the mechanisms and performance,

under practical conditions, of the methods used. Executive organization: BOdemBeheer bv, PO Box 25, 3998 ZR SCHALKWIJK, The Netherlands; E-mail: j.gun@tip.nl

The Service Centrum Grond (SCG) has a large amount of knowledge and experience concerning the treatability of soil. The SCG is the organ which, on the basis of the above-mentioned ban on dumping of cleanable soil, issues the statements to the effect that the soil cannot be cleaned. In addition, it assists the government departments in matters such as tendering procedures, cost/quality assessment and cleaning specifications. It also plays a part in the quality assurance in soil research, decontamination and the quality of the removed soil.

NV SCG, PO Box 19, 3990 DA HOUTEN, The Netherlands; E-mail: info@scg.nl

VEGAS, was founded in 1995. At this facility, remediation methods are tested in large-scale tanks ranging from 30 – 790 m3. The main research projects are methods for hydraulic remediation techniques, treatment of non-aqueous liquids in the vadose zone, remediation of PAHs and reductive contaminant transformation.

DK: The Danish TUP programme for development of technology, soil and groundwater contamination started 1996 in Denmark. The technology programme has focused mainly on remedial technologies for chlorinated solvents and oil, heavy metals and petroleum contaminations.

Sweden: Swedish EPA (http://www.environ.se). The Swedish Environmental Protection Agency (Swedish EPA) has estimated the number of contaminated sites in Sweden to approximately 22 000.

The Swedish EPA has published a range of reports and guidelines about methodology for environmental investigation of soil, inventories of contaminated sites andsampling and analysis for risk classification and remediation performance.

The program, Soil Remediation in a Cold Climate, Coldrem, (http://wwwnt.umu.se/coldrem) is directed towards remediation in a cold climate of soil contaminated with organic pollutants and metals.

Switzerland: Dr. R. Herzig : commercial GALVASWISS decontamination experiment (Vilnius 2007)

Spain: An amount of 287 industrial sites potentially contaminated are shown in the second step of the Operative Program on Contaminated Soils.

EIADES is a Research Program, integrated by eight Research groups from the Madrid Region, five Industrial partners and associated teams from different Spanish Regions and other European countries (www.eiades.org). The objective of the EIADES program is focused on the development of new scientific tools to accomplish these challenges. A methodology to assess the environmental impact of industrial activities on soils and the remediation projects themselves according to the risk

analysis techniques applying last generation scientific development) PRA Probabilistic Risk Assessment, Biotch-DTA, biotechnology-based –Direct- Toxicity Assessment) in relation to the characteristics of the Comunidad de Madrid will be developed. The application of different remediation strategies such as electrokinetic, bioremediation and phytoremediation, is being developed in relation to the size and type of contaminant, metals or organic compounds, characteristics of the ecosystem and the future use of the soil. With the aim to evaluate the efficiency of the remediation processes, an ecotoxicological analysis system is carrying out to quantify the ecosystem remediation in terms of cost/benefit

(Lobo et al 2007 Sede)

IMIDRA-El Encín” (A2- km 38,2). E28800-Alcalá de Henares, Madrid (Spain), carmen.lobo@madrid.org;

6.5.13 SUMATECS databasis - A short introduction to the “input information” part

Soularue J.P., Mench M., Raspail F.
in collaboration with Kerdraon L. and Labbé T. for network interface

The web interface of the Sumatecs database allows the input of whole and accurate information on studies and publications dealing with gentle remediation technologies for trace element contaminated soils (TECS). This document describes an easy procedure for the creation of a complete new entry.

Web site: http://w3.pierroton.inra.fr:8000/users/welcome

We consider that an entry is composed by a site associated to one or several publication(s)/reference(s) associated to one or several project(s). Within the frame of these projects, studies which include experiments containing experimental datasets are realised.

6.5.13.1 Site map

This map describes the “input information” part (Fig. 30).

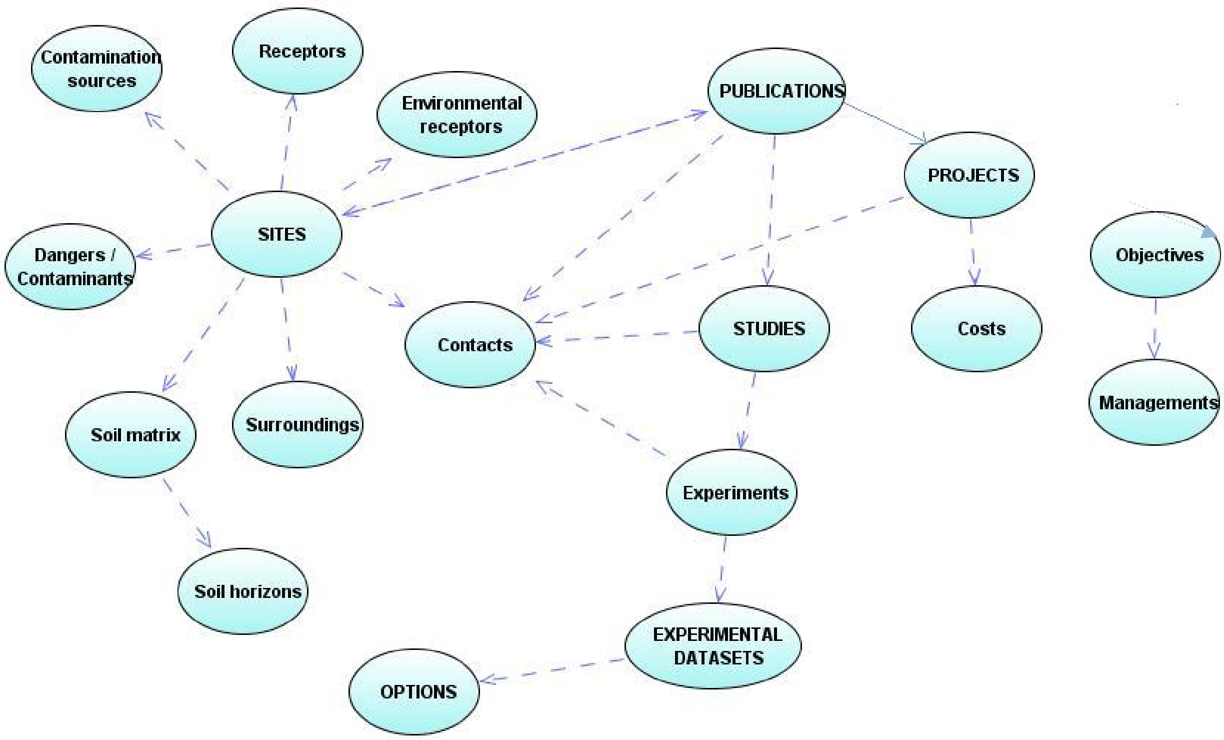


Fig. 30: “input information” part of the database.

6.5.13.2 Creation of new entries

The proposed procedure includes the following steps :

1. Site creation
2. Associated elements creation (surroundings, contaminants, receptors, references, etc…) via site details screen
3. Publication/source details : input of associated projects and studies
4. Projects details : objectives, costs and management options
5. Input of experimental datasets.

a) Site creation

After having passed the authentication step, the easiest way is to start to create a new "site" (this is the location label where the studies are taking place) (Fig. 31).

Fig. 31: How to create a new "site".

This link leads us to the following page containing a list of all sites already created (Fig 32):

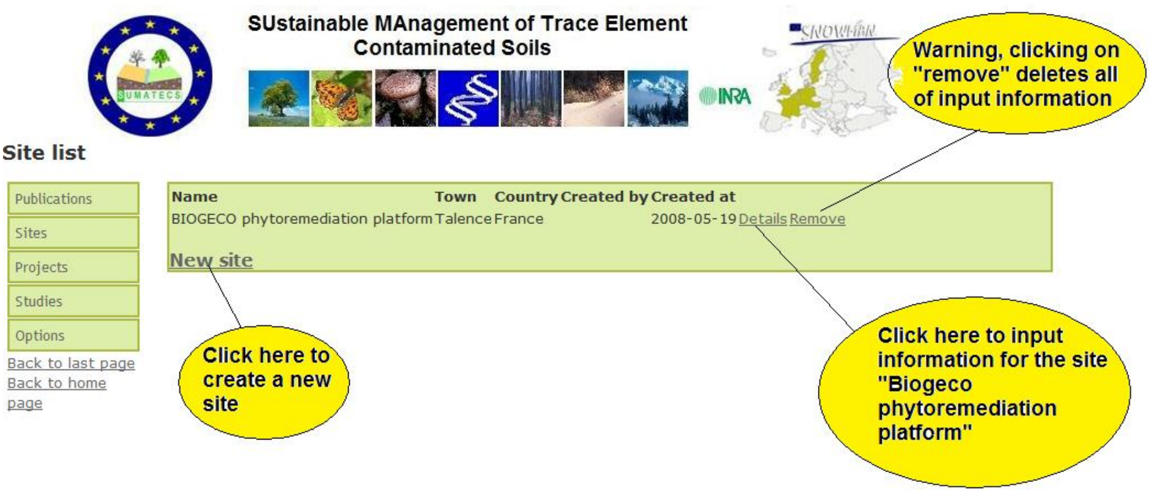


Fig. 32: Page showing the list of all sites.

The menu on the left is an access to other lists. Notice the presence of the two links below the menu.

For the creation of a new site, click on "New site", and the following screen appears (Fig. 33):

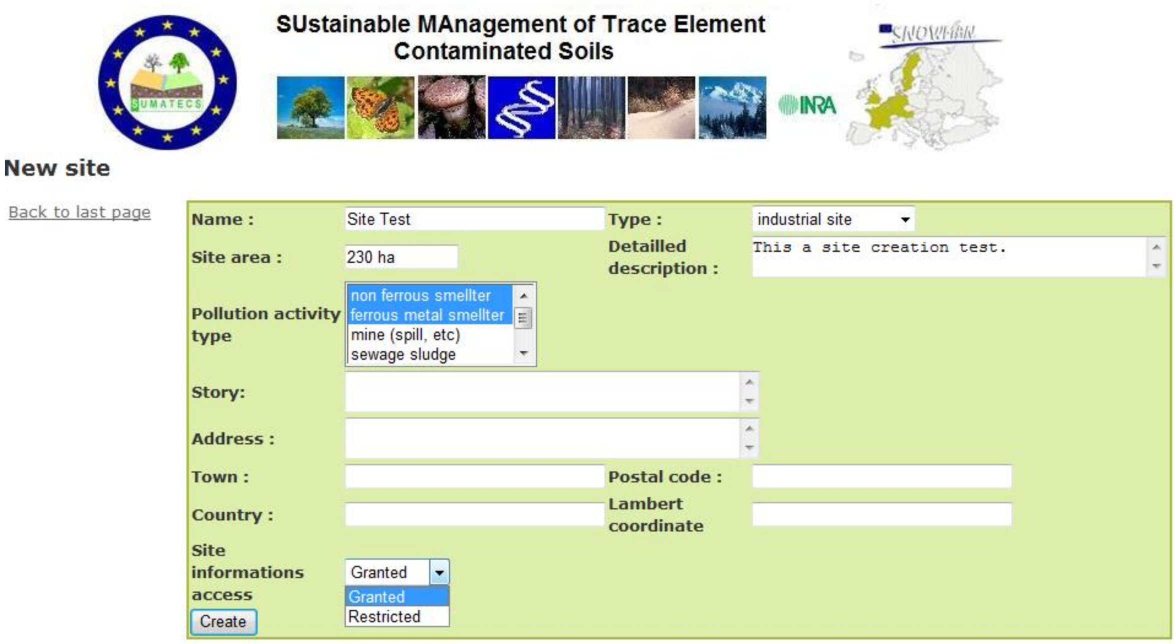


Fig. 33: Screen to create a new "site".

After having filled all of the fields, click on "Create". The corresponding screen site details will appears.

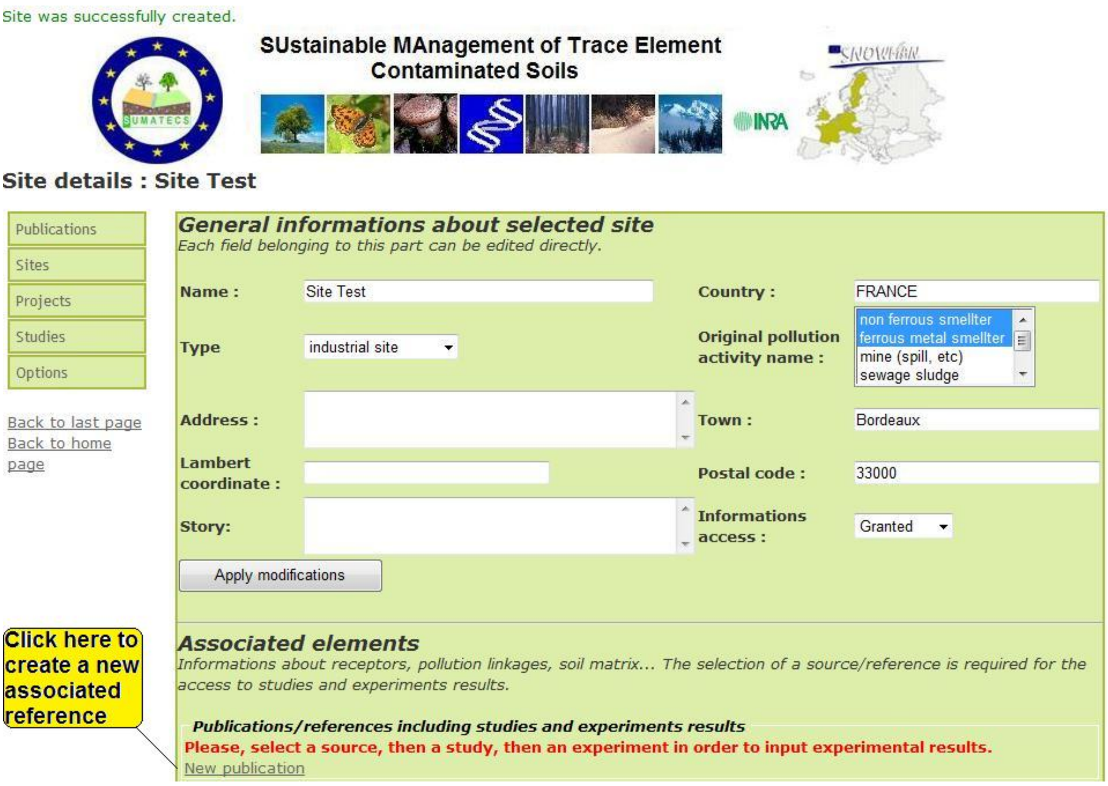
b) "Site details" screen : information related to the created site.

The "site details" screen divides in two parts. The first is for modifying the information input during the site creation. The second is for creating the associated elements: publications, contacts, contaminants/dangers, receptors, contaminations sources etc…

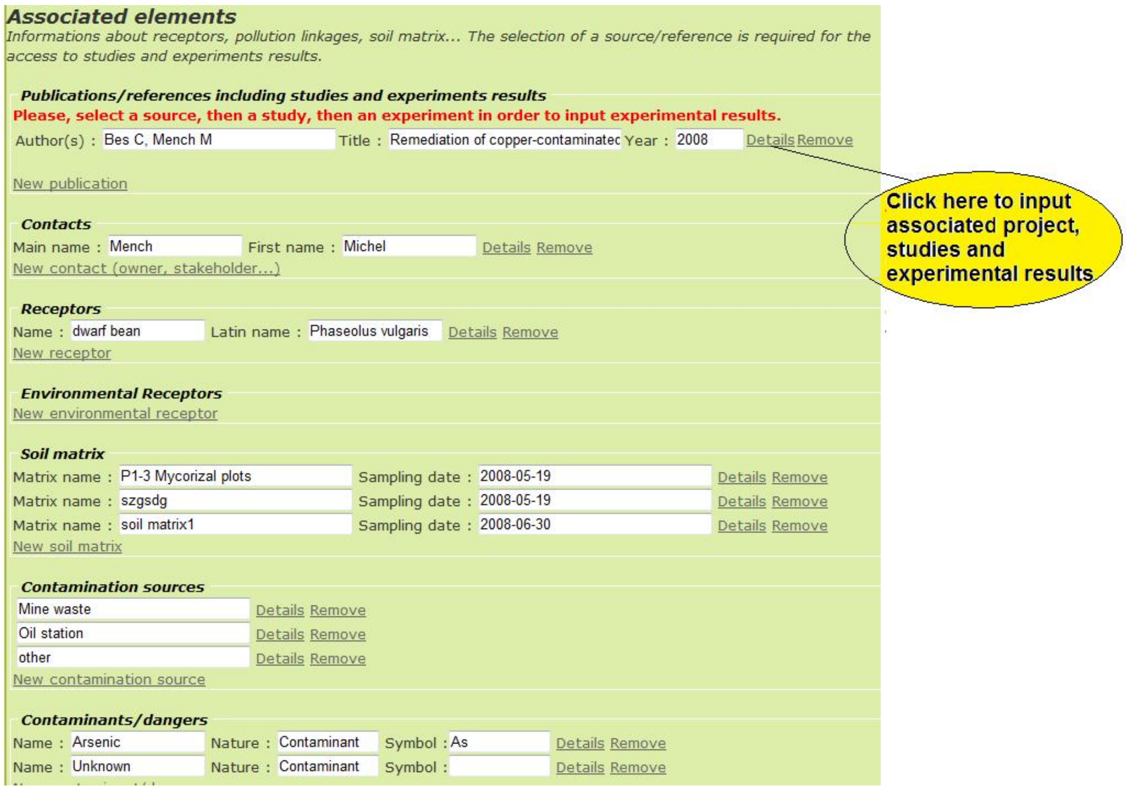
It is possible to indicate here the pollutant linkages. For example, if you want to indicate that a biological receptor is exposed to a specific contaminant, you must first create the contaminant then when you create the receptor you can select the contaminant appearing on the screen.

In all screens of the web interface, the link "details" can be use to modify or enter additional information on the corresponding item. Some elements can only be accessed via this kind of link. For example, when you click on "details" in the site list page you can enter then information about receptor for this site.

Here is the "site details" screen (**Fig. 34**):



Here is an example for creating several elements in the current site (**Fig 35**):



c) Publication/source details

Associated projects and studies must be input from the publications/sources details page.

WARNING. It is possible to create a new site on this page. If you create a new site here, the current active site will be this new site, you will be also redirected to the site detail page of this new site. In fact you can begin the creation of a new entry by the creation of a new reference/publication, then you associate a new site to the created publication etc, etc…

Don't forget that you can browse across sites, publications, options, projects and studies list by using the menu on the left.

d) Project details : objectives, costs, management options

When publication details are displayed, a new project can be created. The details of this project give the possibility to enter information on costs and objectives. To enter information on management options click on details of a created objective.

e) Experimental datasets creation

After having created a study:

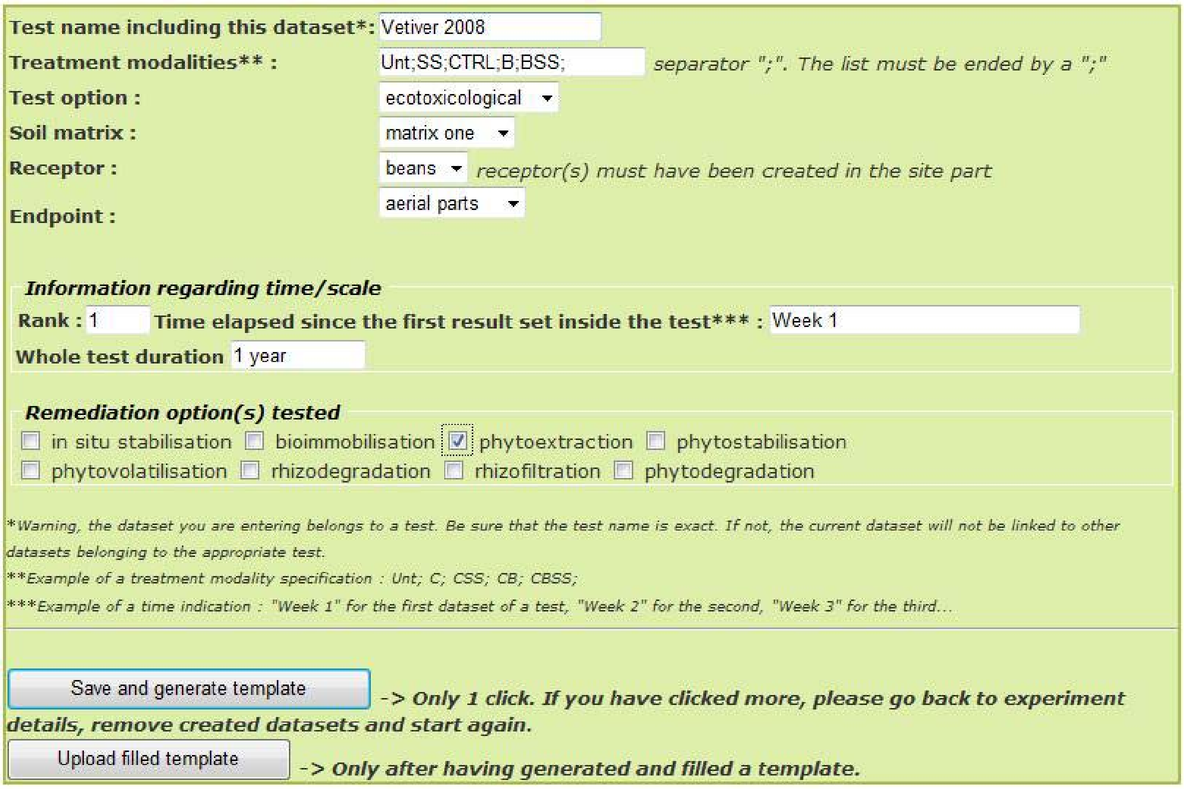
1. Click on study "details".
2. Click on "new experiment".
3. Click on the link "details" near the created experiment.
4. You can now create experimental tests.

A test belongs to one of the 6 defined categories. Depending on the kind of test you want and the information you have to input, the program generates the structure of excel templates. Because it is difficult to represent and use more than 2 dimensions in an automatically generated excel grid, we introduced the concept of datasets.

A test is made up of one to several datasets. A datasets corresponds to an excel template filled and recorded and associated to few additional information about time scale, remediation option used and test type.

Here is an example of the creation of a whole "concentration test" made up of two datasets.

4.1 click on "new concentration dataset", the following screen appears (**Fig. 36**) :



Here we specify that the dataset we are creating belongs to the test "Vetiver 2008". We specify therafter the type of the test option. The soil matrix and the receptor that can be selected during the creation of experimental datasets must have been created in the site part.

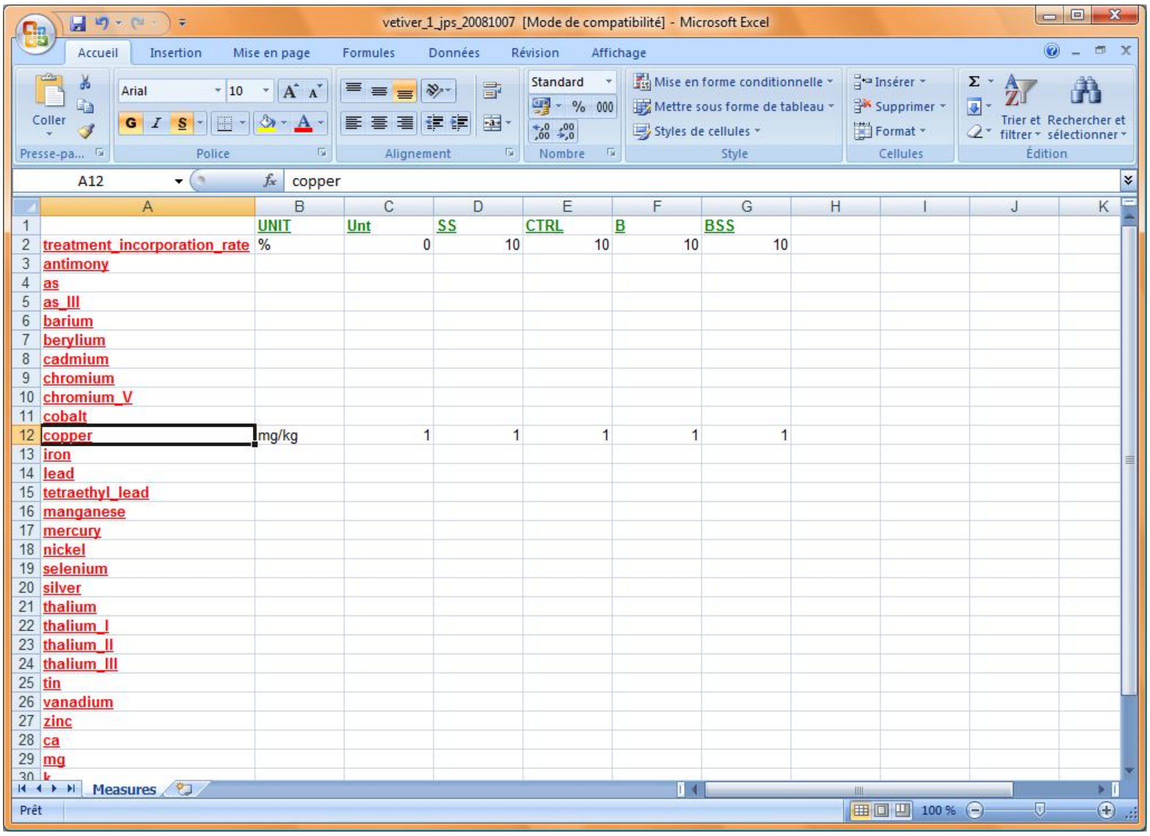
The part "information regarding time/scale" is useful to :

- specify the rank of this dataset in the whole test;
- date this experimental dataset by using the first dataset as reference;
- specify the duration of the whole test.

In this example we indicated that it is the first dataset we are entering for the test "Vetiver 2008". The measures we want to enter in the excel template have been recorded the first week of the test. We specified also that the total duration of the test is one year.

4.2 After having selected one or more remediation option(s), click **only one time** on "save and generate template".

4.3 Click on “open” button of the appearing box indicating that an excel file has been downloaded. If Excel is installed the following screen appears (**Fig. 37**):



In green are the treatment modalities we specified before. In red are the trace elements that we have to input the concentrations measured. The first line, “treatment incorporation rate” must be used to specify the treatment incorporation rate in case of in situ immobilization and aided phytostabilisation options (% of soil amendment by air-dried soil for example as Unit) or for chelating agents applied in chemical aided phytoextraction..

IMPORTANT: If you want to input other values for an additional parameter (letter in red element) not listed in the generated template just add it at the end of the proposed list and input unit and values (but always write using small case letters).

4.4 Save the excel file on your computer (in a temporary file dedicated to the Sumatecs databasis).

WARNING 1 : the file name must corresponds to the model : ***TestName_DatasetRank_LoginName_DateYYYYMMDD***

In our example, considering that my login is “jps : vetiver2008_1_jps_20081007

WARNING 2 : the format of the file must be Excel97-2003. If not, an error will occur during the upload step.

4.5 Close Excel

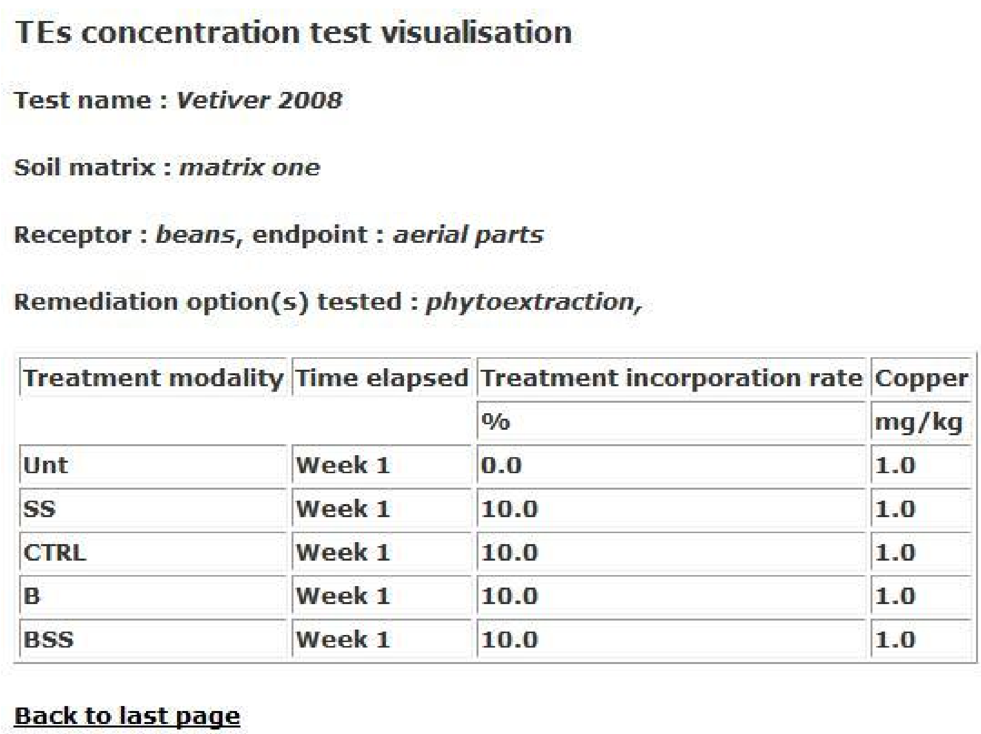
4.6 Click on “upload filled template”.

4.7 Use the “parcourir” (browse) button to find the file you saved before and click on “upload”. On experiment details screen, the created dataset appears (**Fig. 38)**.

<u>Only one dataset with the same test name and the same rank</u> :

If you have clicked more than one time on the “save and generate template” button, there is more than one dataset here with the same test name and the same rank. In this case, you must remove all of these datasets and restart the creation of template.

4.8 Clicking on the view link displays all the results of the test. At the moment, we have only one dataset for the test “Vetiver 2008”, clicking on view also produces (**Fig. 39**):



TEs concentration test visualisation

Test name : ***Vetiver 2008***

Soil matrix : ***matrix one***

Receptor : ***beans,*** **endpoint :** ***aerial parts***

Remediation option(s) tested : ***phytoextraction,***

Treatment modality	Time elapsed	Treatment incorporation rate	Copper
		%	mg/kg
Unt	Week 1	0.0	1.0
SS	Week 1	10.0	1.0
CTRL	Week 1	10.0	1.0
B	Week 1	10.0	1.0
BSS	Week 1	10.0	1.0

<u>Back to last page</u>

4.9 Creation of the second dataset associated to the test “Vetiver 2008”. Click on “new concentration dataset”, then enter the same test name “Vetiver 2008”. Because we want to input measures realised in the same conditions but at a different moment, we will enter the same treatment modalities (in the same order!! Very important), matrix, receptor, endpoint, test options and remediation option. Of course, depending on your goal you can modify the endpoint or other… **<u>But the test name and the treatment modalities must be the same for all of the linked datasets.</u>**

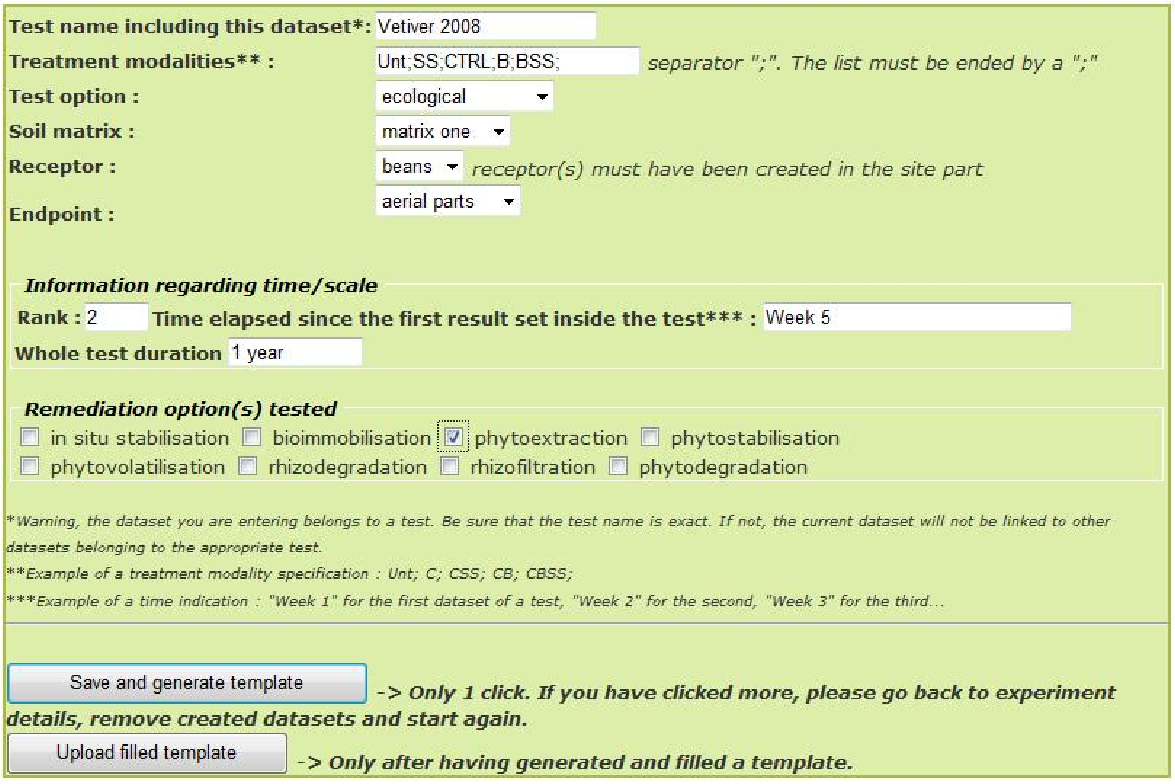


Fig. 40.

4.10 After having clicked on "save and generate template", filled and saved the excel file and uploaded the file we see the two lines in the experiment details screen (**Fig. 41**):

4.11 Now, if we click on View we can see the following test summary (Fig. 42):

TEs concentration test visualisation

Test name : *Vetiver 2008*

Soil matrix : *matrix one*

Receptor : *beans*, endpoint : *aerial parts*

Remediation option(s) tested : *phytoextraction,*

Treatment modality	Time elapsed	Treatment incorporation rate	Copper
		%	mg/kg
Unt	Week 1	0.0	1.0
SS	Week 1	10.0	1.0
CTRL	Week 1	10.0	1.0
B	Week 1	10.0	1.0
BSS	Week 1	10.0	1.0
Unt	Week 5	0.0	1.0
SS	Week 5	10.0	1.0
CTRL	Week 5	10.0	1.0
B	Week 5	10.0	0.97
BSS	Week 5	10.0	0.56

Back to last page

Note : the test duration doesn't appear on this summary. This information appears in the visualization part (welcome page > research information in Sumatecs database).

6.5.13.3 Information research

After having created a new entry in the input part, it is necessary to go to the visualization part to validate that the information set is coherent and readable.

6.6 Decision Tool Systems for the Selection of Gentle Remediation Approaches

Cundy A., Onwubuya K., Teasdale P., Mikhalovsky S., Puschenreiter M., Waite S., Tlustoš P., Kumpiene J.

6.6.1 Background.

It is clear from the work carried out and reported under Work Packages 2 – 4 of SUMATECS, and from the general trade and academic literature, that a number of (gentle) *in-situ* remediation options are available (WP 2), in addition to an array of more aggressive remediation methods such as pump and treat, soil vapour extraction, soil washing etc. Some form of decision support is therefore beneficial, to allow the user to make an informed decision on which is the most suitable technique(s) for the particular site requiring remediation or management. Site management and/or remediation should also be affordable, feasible, effective & sustainable, factors which also need to be built in to the decision support process (e.g. CLARINET 2002; Pollard et al 2004). A range of systems and tools have been proposed to support decision making within the contaminated land arena (e.g. CLARINET 2002). It is clear, however, that there are considerable differences in the decision support process between different EU member states, and more generally (within the context of the SUMATECS project) the adoption and promotion of gentle remediation technologies within and between member states. Hence, in line with the general aims of the SUMATECS project (specifically, to derive or recommend decision support systems and remediation scenarios for gentle remediation techniques), this work package (WP) critically reviews available decision support tools in terms of their fitness for purpose for the application of gentle remediation technologies, identifies gaps in current knowledge, and recommends areas for further research and development in decision support for gentle remediation options.

6.6.2 Scope of the study

WP6 (Development of a decision tool system as a basis for selecting the most applicable remediation option) aims to review and classify existing decision support tools, assess whether current tools are fit for purpose (with specific reference to gentle remediation options), identify input parameters required for a workable decision support tool, and identify knowledge gaps for input into WP7. The work package has the following **specific objectives:**

1. Search and review available information on decision-support tools (DSTs) for the application of gentle remediation technologies;
2. Examine whether current decision-support tools are fit for purpose in each of the SNOWMAN member states;
3. Identify whether a universal decision-support tool for gentle remediation technologies is feasible or desirable;
4. Identify input parameters / site knowledge (e.g. depth and type of contamination, local geology, depth to groundwater) needed for a workable decision-support tool;
5. Systemize the reviewed information and identify knowledge gaps for input into WP7.

6. In terms of project structure, WP6 draws on information generated during WPs 2-4, running in parallel with (and exchanging information with) WP5.

The above objectives were addressed using three main methods:

(1) Via a literature review and critical analysis of existing decision support systems, in terms of their application to "gentle" remediation technologies

(2) Via focussed discussions with regulators and other stakeholders (individually; at international meetings (specifically, during and following presentation of WP6 at a special session on Green Remediation at the 2008 CONSOIL meeting, Milan, Bardos et al 2008); and at an international expert workshop held in Dresden in September 2008 by the SUMATECS project).

(3) Via circulation and analysis of a project questionnaire, to assess stakeholder opinions and needs. This questionnaire is discussed elsewhere in the SUMATECS final report, but (relevant to WP6) contained a section specific to decision support tools (cf. figure 4), with a series of closed (i.e. yes/no) and open questions to assess stakeholder awareness of DSTs, their fitness for purpose, and desired features of DSTs.

The final deliverables for WP6, specifically:

D6.1 Summarised overview and critical analysis of existing decision support tools (within the framework of recent legislative and technological developments) for input into WP7.

D6.2. Guidelines on range of input parameters required to adequately inform decision-making on the use of gentle remediation technologies.

are incorporated into the following report.

6.6.3 Structure of the report

The report begins with an overview of the role of decision support in contaminated land assessment, remediation and management, and then undertakes a critical review of existing decision support tools. Stakeholder feedback (via the project questionnaire and focussed discussion sessions) is then discussed and evaluated, and conclusions and recommendations for further action / research are made in the final section of the report.

6.6.4 Decision support tools (DSTs) for contaminated land assessment and remediation

Historically, a range of generic decision making approaches have been made available for the management of land contamination (CLARINET 2002). The techniques include: Life Cycle Analysis (LCA), Multi-Criteria Analysis (MCA), Cost Effectiveness Analysis (CEA) and Cost Benefit Analysis (CBA). These techniques have varied methods of implementation, are used at various stages of the decision making process, and have been adopted in the development of a range of DSTs. For the purpose of this review, MCA and LCA will be considered primarily. These two tools are the most widely recognised instruments implemented in collecting detailed information on environmental decision support aspects and have been widely used in industrial ecology and environmental systems analysis (Hermann et al, 2007).

6.6.4.1 Multi Criteria Analysis (MCA)

The remediation and development of contaminated land has become a multi-stakeholder issue. This increase in interest has necessitated the development of Multi Criteria Analysis (MCA). MCA is a decision-making tool used in environmental systems analysis to evaluate a problem by giving an order of preference for multiple alternatives on the basis of several criteria that may have different units (Hermann et al, 2007). Its techniques can be used to identify a single most preferred option, to rank options, to short-list a limited number of options for subsequent detailed appraisals, or simply to distinguish acceptable from non-acceptable possibilities (DTRL multicriteria manual). MCA encapsulates a variety of decision-making processes that require different criteria on which to establish a decision. The main purpose of MCA is to compare and rank alternative options and to evaluate their consequences (in this case environmental consequences) according to the criteria established (Zopounidis et al, 2002). It achieves this by assessing information in a consistent way, where the different factors are weighted by means of a score. It involves identifying the decision requirement and criteria of the various processes, scoring, weighting, establishing an overall result, scrutinising the result and undertaking sensitivity analysis tests. MCA relies heavily on the judgement of the decision making team, which includes the stakeholders and experts, and it is therefore conceivable that results may be biased. Dedicated consultations and debate are necessary in order to reduce the subjectivity of this form of analysis. This subjective mode of decision-making is believed to be the main disadvantage of MCA (Hermann et al, 2007). The outcome of the weighting procedure is therefore often determined by whom it includes as much as by the choice of weighting methods (Hobbs and Meier, 2000).

MCA, however, has been recommended in the development of DSTs to provide a formal structure for the joint consideration of environmental, technological and economic factors relevant to evaluating and selecting amongst management alternatives and for organising the involvement of stakeholders in the decisional process (Kiker et al, 2005 and Carlon et al, 2006). It is favoured because of its transparency, rigorous structure and its intense evaluation of options. It can also be used in the combination of monetary and non-monetary values in the decision making process. A common and popular type of MCA is Multicriteria decision analysis (MCDA) which is also known as multi attribute decision analysis (MADA). As described above, this form of MCA is suited for use in the combination of monetary and non-monetary values in a bid to reach a decision. It is a way of looking at complex problems that are characterised by any mixture of monetary and non-monetary objectives, of breaking the problem into more manageable parts to allow data and judgments to be brought to bear on the different parts, and then reassembling the different parts to provide a more coherent picture to the decision makers (DTLR multicriteria manual). For example, MCDA is the approach used in the DESYRE DSS (decision support system for the rehabilitation of contaminated megasites, Carlon et al, 2006).The implementation of the MCDA involves, but is not limited to the following:

- Establishing the context which includes identification of the various stakeholders and key players.
- Indication of the various options to be appraised.
- Identifying the criteria that would be used to assess the various options identified above
- Analysis of the various options and award scores based on the criteria
- Assign weights for the criteria based on their relative importance to the decision making process
- Combine the weights and the values in order to achieve overall significance
- Study the results
- Carry out a sensitivity analysis test to ensure that all necessary areas / parameters / options have been appropriately considered.

6.6.4.2 Life Cycle Analysis

Life Cycle Analysis (LCA) is a tool that identifies and quantifies the emissions and resources used at all stages of a product's or an activity's life cycle. It has been defined as the 'compilation and evaluation of the inputs, outputs, and the potential environmental impacts of a product system throughout its life cycle (ISO 1997)". In other words it employs the 'cradle to grave' approach as described in the manufacturing sector. It previously became popular in the manufacturing industry but its use has been expanded into a range of other areas, including the management of contaminated land. According to Blanc et al, 2004, LCA is gaining widespread acceptance in the field of support systems for environmental decision-making. The present era and interest in sustainable development has necessitated the need for the development and use of such a tool in remediation options appraisal. Implementation of LCA would indicate the best possible option that does not compromise sustainability. In recent years several examples have been published on the use of LCA in site remediation: Bayer and Finkel (2006) assess LCA in active and passive groundwater remediation technologies; Volkwein et al, (1999) use LCA to complement risk assessment of the primary impacts and, with this aim in view, compare the results of LCA before and after remediation; Diamond et al, 1999 and Page et al 1999 both deal with similar methods using generic remediation options and case studies. The application of LCA to land remediation offers the opportunity to make relatively objective comparisons between several available approaches. Some remediation techniques are energy-hungry (e.g. steam enhanced processes) for a short period of time (eg dual phase vacuum extraction) whilst others consume less energy per unit time but are required for a long duration eg enhanced monitored natural attenuation, or pump and treat, which could run for several years or decades. A reasonable balance needs to be attained whereby priority is given to the more sustainable technique. LCA initiates the comparison of such diverse techniques taking into consideration the needs of various stakeholders.

LCA is commonly used in the UK with a recent publication by Defra endorsing its use (Defra 2006a). It is also popular in other parts of Europe and has been incorporated into some decision support tools including Dutch ABC. LCA can be a complex and resource hungry process and therefore can only find acceptance if used by a competent decision support tool. The key elements of an LCA are;

- Goal and scope definition
- Life Cycle Inventory Analysis
- Life Cycle Impact Assessment
- Life Cycle Interpretation
- Reporting; and
- Critical Review

6.6.4.3 Cost Benefit Analysis (CBA)

CBA is the assessment of all costs and benefits that are involved in various available options. It is a framework for comparing the monetary value of a project with the monetary value of its cost. The terms cost and benefit is not used solely in the financial context. Cost can be defined as anything that can reduce ones well-being whilst the definition of benefit is anything that has the capability of increasing human well-being.

The application of CBA requires mainly financial/monetary input and therefore needs a great deal of expertise for implementation. Difficulties may arise when considering aspects which may not have an immediately obvious or easily quantifiable monetary value (e.g. an ecosystem, social acceptability of a remediation option etc). The results from a CBA can form a major input for MCA.

6.6.4.4 Cost Effectiveness Analysis (CEA)

The significant difference between CBA and CEA is that the benefits of a project, in the case of CEA, are not monetised. In the context of management of contaminated land once remediation objectives have been agreed, CEA provides a framework for deciding the least cost option to deliver the required remediation standard; it is a relatively simple balance of costs of measure, versus its effectiveness and whether it meets the remediation objectives of the site. As for CBA above, the results from CEA can form a major input for MCA.

6.6.4.5 Critical review of existing decision support tools

Presently, relatively few countries have a fully developed methodology/system for decision making in contaminated land management. Considerable improvement is necessary for considering sustainability issues more systematically in decision making procedures as presently a large majority of projects favour conventional and often non-sustainable technical solutions for contaminated land remediation (EURODEMO 2005). Arguable, significantly more emphasis is currently placed on the financial implications of the technique, cost saving and profit margins than on potential environmental impacts, socio-economic implications and stakeholder involvement. The key drivers of remediation in most European countries are; (i) risk management (ii) core stakeholders (project drivers), (iii) timescale and (iv) technical suitability/feasibility. By comparison, stakeholder satisfaction, cost effectiveness and sustainability are given significantly less consideration in current practices as indicated in figure 21 below (CLARINET 2002).

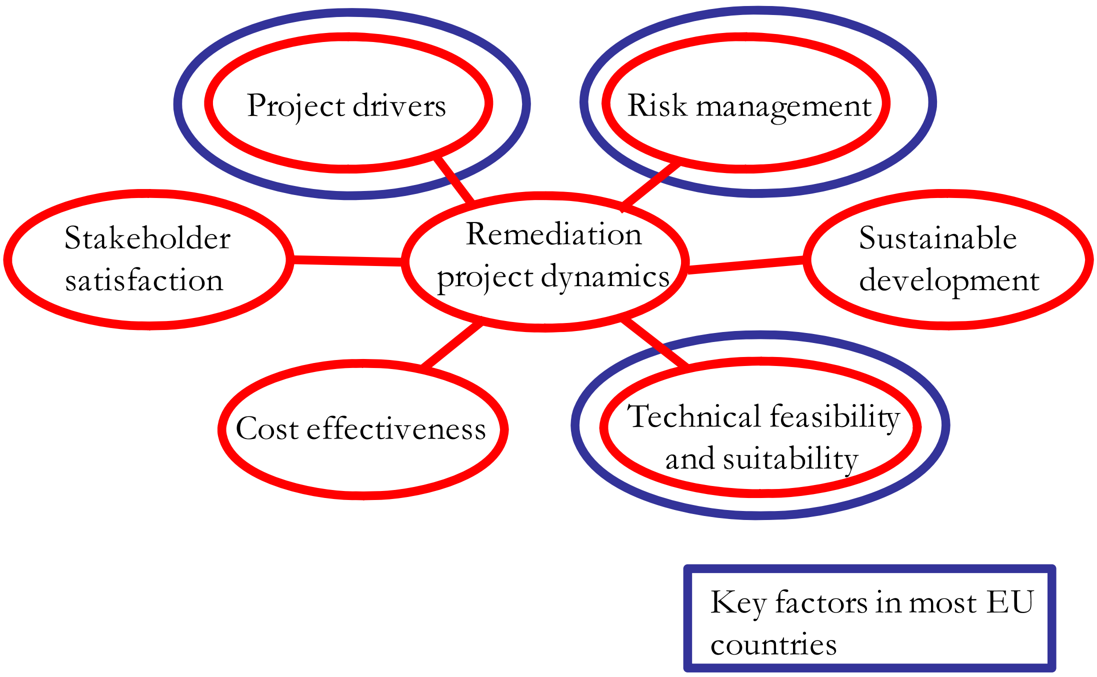


Figure 43. Key factors in decision making in remediation technology selection (CLARINET, 2002)

6.6.4.6 Decision support tools in the UK

Initiated in 2004, the Environment Agency has developed a guidance document / strategy entitled Model Procedures for the management of contaminated land, also referred to as Contaminated Land Report 11 (CLR11). This document encapsulates procedural guidance for the whole life cycle of the management of contaminated sites. It consists of three main stages;

- Risk assessment

- Options appraisal to include the evaluation and selection of remediation options and their suitability for the site

- Implementation of the remediation strategy and subsequent aftercare of the site in the form of a post-monitoring strategy to evaluate technology efficiency.

CLR11 borders on the requirement of the statutory contaminated land regime in the UK (Part IIA of the Environmental Protection Act 1995, and the associated guidance – Defra Circular 01/2006 (Defra 2006b)),

and proposes a tiered remedial approach to decision making. Tiers within the options appraisal stage (i.e. the stage most relevant to the selection of gentle remediation technologies) are indicated below:

Tier 1: Identification of feasible remediation options

According to CLR11, a feasible remediation option is one that is likely to meet defined, site-specific objectives relating to both pollutant linkages and the wider management context for the site as a whole. In this stage the procedures offers two tools for utilisation by decision makers:

Tool 1 involves a simple set of tables or decision support matrices which relate at a generic level, the applicability of different remediation methods to environmental media (soil/water), and the nature of the pollutant. At this stage a suitable technique is chosen that is relevant to the identified pollutant linkage.

Tool 2 is a link to further information on remediation options in order to assess the technical basis of the remediation techniques. There are several sources used for this assessment but three major ones are outlined below:

- Environment Agency Remedial Treatment Data Sheets;

- CIRIA, Remedial Treatment of Contaminated Land series reports (now supplemented by CIRIA C622 – 'Selection of remedial treatments for contaminated land – a guide of good practice')

- Two web-based sources in EUGRIS (the European Groundwater and Contamination Land Information Systems) and CL:AIRE (Contaminated Land: Applications in Real Environments)

This stage drives the decision maker to develop a series of selection criteria and CLR 11 refers to four decision making tools in this tage;

Tool 1 – Carries out a Multi Criteria Analysis

Tool 2 – Collects Cost information on the remediation options

Tool 3 – Combines the information from the above in a qualitative Cost Effectiveness Analysis

Tool 4 – Examines how the remedial treatment methods can be combined.

CLR11 also reflects the need for the consideration of the environmental impacts of remediation to satisfy management objectives. This considers the nature and extent of potential effects on the quality of the environment in a wider and generic context .The Model procedure theoretically considers both aggressive and gentle techniques without bias, although notably there is little detail given on the range of available gentle remediation options, with only the generic term “landfarming” being listed in the decision support tables / matrices in Tool 1 of the Identification of Feasible Remediation Options tier (described above) .

On a technological level, the UK only has one DST framework called the WRATE model but this focuses on waste management rather than remediation option appraisal. There was little information available as regards this technique. However there is a potential for the WRATE model to be developed as an appropriate tool for decision making in remediation.

6.6.4.7 Decision support systems/tools in Germany

Similar to the UK, Germany also has guidance documentation used for decision making in contaminated land management. The procedure involves the following stages:

- Goal and process: reduction of contaminant exceedances by a certain percentage. This is similar to the risk assessment stage of the CLR 11 for the UK.
- Project mobilisation; includes determination of the various stakeholders, technical experts and financial obligations
- Discretionary measures/activities to include site investigations, preliminary tests etc
- Development of remediation scenarios
- Technical assessment of remedial options
- Cost estimation
- Cost Benefit Analysis (economic, technical and ecological issues are considered)
- Specification of remediation objectives
- Remediation proposal
- Decision for remediation (made by authorities working under the auspices of the German government)

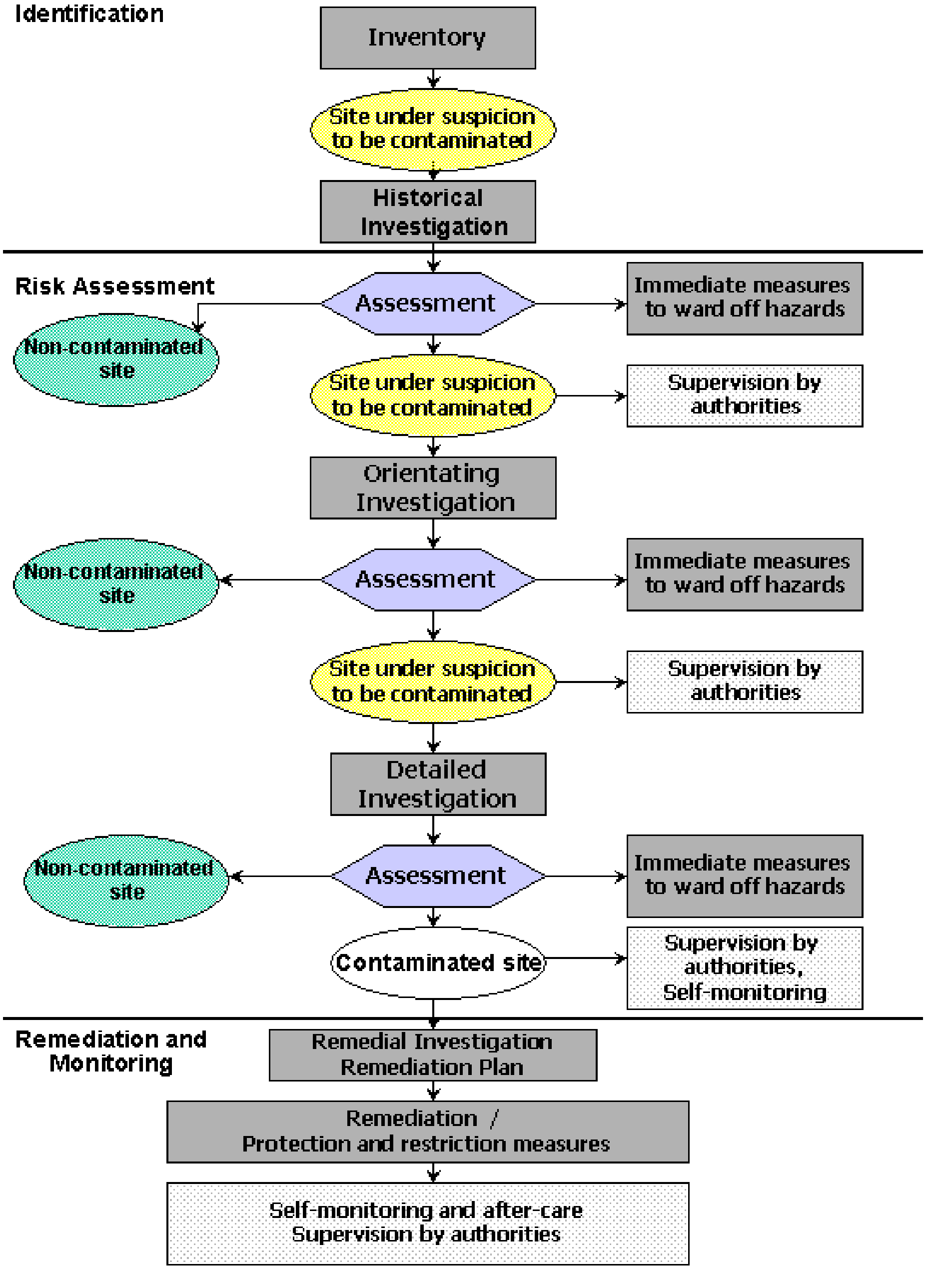


Figure 44. Flow chart for contaminated land management in Germany. From www.eugris.com

From the above outlined procedure it can be deduced that there is no explicit consideration of the environmental impact of the proposed remedial technique and the specific incorporation of gentle remediation technologies (or indeed sustainability issues) is minimal.

A review of software tools for remediation decision support has indicated that a number of such tools have been developed in Germany (see table 36). These tools include PRESTO (PREselection of treatment options), CARO (cost analysis of remediation options), ROCO (rough cost estimation tool) and the Sinsheim model. An appraisal of these tools shows that they mainly deal with aggressive remediation techniques and serve as technical efficiency tools focussing primarily on cost estimation. Cost does constitute an element of the decision making process but cannot serve the purposes of a sustainable DST without considering issues bordering on sustainability. The Sinsheim model, however, quantifies and evaluates the environmental impacts of remediation processes. It utilises a streamlined LCA as described in earlier sections, and produces a summary of LCA results which allows comparison of different remediation processes. A decision can therefore be reached on the best possible technique that is environment-friendly. This DST does not include other core objectives of the remediation process: costs, socio-economic factors etc. The model is very advanced in that is utilises the application of a full LCA on assessment of feasible remediation techniques and therefore could serve as a model for an efficient DST if all other missing aspects are included. As noted above, it is not developed specifically for use on gentle remediation techniques but also encompasses aggressive techniques.

6.6.4.8 Decision support systems/tools in the Netherlands

ROSA and BOSS are two software based DSTs that originate from the Netherlands. ROSA is used for the evaluation of remediation alternatives in line with interpretations of the National soil protection legislation. Information regarding this software is not widely available and therefore its preferred remedial technique (aggressive or gentle) cannot be ascertained. BOSS is a web-based expert system which is available at present only in Dutch. It targets both aggressive and gentle remediation techniques but does not undertake detailed analysis of the wider environmental impacts of the remediation activity.

6.6.4.9 Decision support systems/tools in Italy

DESYRE (Decision Support System for the Requalification of Contaminated sites) is an advanced, Italian-developed GIS-based decision support system, formulated to address the contaminated land management of megasites. The developers of DESYRE have included in their conceptual design and development the main aspects pertaining to a remediation process: analysis of social and economic benefits and constraints, site characterisation, risk assessment, selection of best available technologies, creation of sets of technologies to be applied, analysis of individual risk and comparison of different remediation scenarios. These highlighted aspects of the tool have been encompassed into 6 interconnected modules which comprise: site characterisation, risk, socio-economic, technological analysis, residual risk analysis and decision making. DESYRE consists of a two step methodology for the selection of appropriate remediation technique whereby the first step provides for the selection of feasible technologies, which are then ranked in the second step where there is an integration of environmental and technological databases, using MCDA to produce a ranking.

This highly sophisticated GIS-based, integrated DST deals with a range of decisions from risk assessment to selection of remediation strategy. Environmental impacts are considered along with socio-economic effects which is very uncommon in most of the existing DSTs. The technological module holds a database of more than 60 types of treatment technologies described in terms of contaminant type, commercial availability, application modalities and different site specific parameters (Carlon et al, 2006). This range of remediation technologies includes both gentle and aggressive techniques.

DESYRE however does not include LCA of its remediation techniques and its utilisation of MCDA analysis has been found to be subjective (Hermann et al, 2007) with a tendency to be biased.

6.6.5 Relevant decision support systems/tools developed by EU sponsored programmes

PhytoDSS is a DST developed under EU framework funding and could be described as probably the only available tool that focuses specifically on gentle remediation technologies. Its main technology of focus is phytoremediation, which is further divided into phytoextraction and phytostabilisation. In this definition, phytoextraction involves the uptake of selected contaminants by plants, with the contaminants being stored in the above-ground biomass which is eventually harvested and disposed. This process results in eventual site cleanup through physical extraction. The process of phytostabilisation, on the other hand, immobilises the contaminants (mainly heavy metals) through re-vegetation and some input of chemical immobilisation.

With these factors taken into consideration, a DST was developed to assess the viability of using vegetation, via phytoextraction and phytostabilisation, as a means of abatement whilst weighing cost effectiveness against environmental impacts in comparison with other remediation techniques. For its implementation PhytoDSS uses the REC model (described below) as basis for decision support.

REC (Risk reduction, environmental merits and cost) was developed as part of the NOBIS programme (a previous Dutch national research programme on bioremediation). The primary aim of the programme was to bring risk reduction, environmental merits and cost, which had been individually studied and integrated into decision making, into contaminated land management due to changes in the Dutch legislation. REC does not consider other factors such as legal, political and social factors which might impact on remediation choice. ABC (Assessment, benefits and Costs) on the other hand could be deemed as a modern version of REC. It consists of three modules

- Assessment: This stage appraises the feasibility of different remediation options. There are about 27 techniques in the database of this technique.

- Benefits: This module utilises LCA to assess each remediation technique. This outlines the advantages and disadvantages of remediation into potential environmental impact factors such as: resource, energy input, emissions, hazardous and non-hazardous waste production.

- Costs: The range cost bracket for each technique is highlighted at this level.

The ABC considers both gentle and aggressive remediation techniques which are outlined in its database.

The above (and other selected) techniques are summarised and evaluated, in terms of how they address the key criteria of risk, cost, sustainability, and socio-economic factors, and their suitability to gentle remediation technologies, in Table 75.

Table 75: Overview of selected decision support tools across Europe

				Criteria addressed			
Tools	**Principle**	**Country of origin**	**Target techniques**	**Risk Assessment**	**Cost**	**Sustainability (environmental impacts)**	**Socio-economic factors**
REC (Risk Reduction, Environmental Merit and Costs) (Phyto DSS)	Multi Criteria analysis and Life Cycle Analysis	EC funded project	Gentle remediation (Phytoremediation)	Yes	Yes	Yes	No
ABC (Assessment, Benefits and Costs)	Life Cycle Analysis	EC funded project	Aggressive and gentle techniques	Yes	Yes	Yes	No
PRESTO (PREselection of Treatment Options)	Not applicable does not serve as an assessment tool	Germany	Aggressive and gentle techniques	No	No	No	No
CARO (Cost Analysis of remediation options)	Assesses the overall cost of remediation techniques	Germany	Aggressive and gentle techniques	No	Yes	No	No
ROCO (Rough Cost Estimation Tool)	Assesses the rough cost of specific remediation techniques such as dig and dump/pump and treat	Germany	Aggressive techniques	No	Yes	No	No
ROSA	Approach based on balance between cost, environmental	The Netherlands	Not indicated	Yes	Yes	No	No

	compartments versus risk reduction and reduction in liabilities						
DESYRE (Decision Support System for rehabilitation of Contaminated Sites	Multi criteria decision analysis (MCDA)	Italy	Aggressive and gentle techniques	Yes	Yes	Yes	Yes
SPEAR(Sustainable Project Appraisal Routine)	Multi criteria assessment	Private development	Aggressive and gentle techniques	No	No	Yes	Yes
BOSS	Not provided (all in Dutch language)	Netherlands	Aggressive and gentle techniques	No	No	No	No
DARTS (Decision Aid for Remediation Technology Selection)	Multi criteria analysis	Italy	Aggressive and gentle techniques	No	Yes	Yes	Yes
The Sinsheim Model	Life Cycle analysis	Germany	Aggressive Techniques	No	No	Yes	No

An overview of the various DSTs across the European Union indicates that the only widely-available DST that focuses specifically on gentle remediation techniques is PhytoDSS under the platform of REC, and this DST considers only phytoremediation as a technique. There are a range of other DSTs that are potentially suitable to the decision support of gentle remediation technologies, of which DESYRE in particular has wide coverage of risk, cost, environmental and socio-economic factors. In terms of national decision support frameworks, the UK's CLR11 framework (and similar systems used or under development in Germany, Austria, France and elsewhere) provides a systematic and practical tool for decision support over the whole assessment and remediation process, although there is a relative lack of information on gentle remediation approaches in comparison with more aggressive technologies.

The uptake of the various tools that are currently available, and their fitness for purpose as seen by the contaminated land community, is examined in the next section.

6.6.6 Stakeholder feedback

As noted previously, a questionnaire survey was carried out by the SUMATECS group to gather stakeholder opinions on gentle remediation options, and assess reasons for hindrance in their uptake. Questionnaire sections specifically focussed on decision support tools and systems are shown in Figure 45. Responses were received from over 10 European countries with 124 participants from a variety of disciplines within the environmental sector and outside stakeholders. The primary aim of the questionnaire was to ascertain the general awareness of gentle remediation techniques and the application of fit-for-purpose DSTs in contaminated land management. Specifically, in terms of DSTs, the questionnaire was designed to gather responses on whether current DSTs are felt to be fit-for-purpose, and to ascertain from relevant stakeholders what input parameters / site knowledge (e.g. depth and type of contamination, local geology, depth to groundwater) are needed for a workable decision-support tool. The target participants of the survey included university/research institutions, regional authority/government, environmental consultancies, remediation contractors, and other key stakeholders (land owners, investors, and pressure groups).

16) Are you aware of any decision support tools* that can be used to select appropriate remediation or management strategies for TECS sites?

Yes ☐	No ☐	Don't know ☐

If yes,

(a) Please list some of these tools below.

(b) Are these tools fit for purpose?

Yes ☐	No ☐	Don't know ☐

(c) Are these tools suitable for the application of gentle remediation techniques?

Yes ☐	No ☐	Don't know ☐

(d) What improvements could be made to these tools (please list)

If no,

(a) Do you think that such a decision support tool would be useful?

Yes ☐	No ☐	Don't know ☐

(b) Please list the features that such a decision support tool should have.

Figure 45: Page from questionnaire survey related to decision support tools.

From the DST-specific responses to the questionnaire, the survey indicated that more than half of the participants (58%) were not aware of any DSTs that can be used to select appropriate remediation or management strategies for contaminated land (see Figure 47 below).

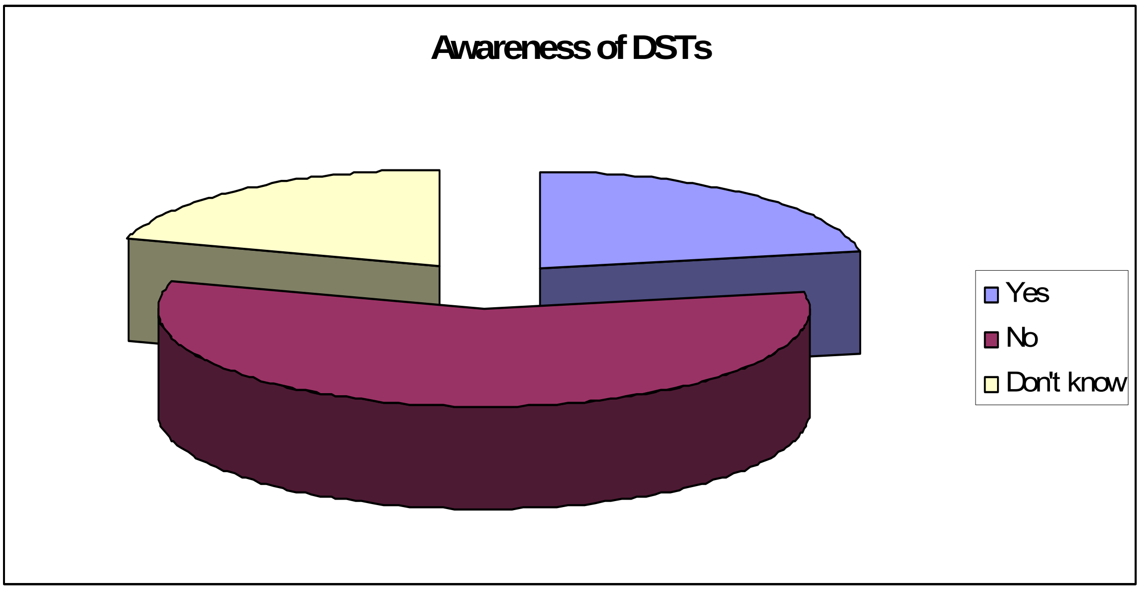


Figure 47: Participants' awareness of existing decision support tools, in response to the question "Are you aware of any decision support tools that can be used to select appropriate remediation or management strategies for TECS sites?"

22 % of our participants with knowledge of existing tools gave an indication of the various tools available for use; however most of the tools listed were consistent with traditional (national) guidance documents, and indicated a general lack of awareness amongst the contaminated land community of many of the advanced tools developed and listed in Table 75. The tools suggested includes: ADEME guideline, Swedish EPA report, Pirtu, DARTS, NSOIL (Dutch tool), THERESA 3.0. There is overwhelming evidence available from the questionnaire survey that shows that the knowledge of DSTs in the management of contaminated land is minimal and there is insufficient technical know-how regarding the utilisation of DSTs. It can be considered as a greenhorn technology in remediation options appraisal. Over 61% of our participants were indecisive as to whether the DSTs available were fit for purpose (which is unsurprising considering the percentage that are not aware of the existence and uses of DSTs) and 30% believed they are. On a similar note, 80% also could not indicate whether available DSTs were suitable for the application of gentle remediation techniques. This imbalance in the response suggests that a fraction of practitioners are aware of DSTs but there is still a shortage of knowledge in the field and therefore a proper tool has not been consistently adopted and utilised to cater for decision-support needs. Several comments from a variety of participants have included suggestions that existing tools are too general and not sufficiently precise, and training and skill enhancement in DSTs is required for decision makers. However, an overwhelming 72% believe that a DST that targets choosing remediation techniques would be useful particularly if it is specific for gentle remediation options. Features that should be included in a practical DST were listed by survey respondents as including (quotes are italicized):

- *It must support decision making at sites with mixed contamination and integrate both ecological and physiochemical traits.*
- *It should combine various contaminants and levels of contaminants, various types of soils, climates and plants, surface and deep water parameters, ecosystem sensitivity and various types of remediation techniques.*
- *It should implement a multi-criteria approach.*
- *It should be pragmatic and detailed.*
- *It should implement cost-benefit analysis to assess socio-economic factors*
- *DSTs should support the communication between all involved persons and should not give a fixed general solution* (i.e. tools should encourage dialogue between and informed decision making by users, rather than providing a proscriptive solution)
- *It should be simple and comprehensible for practical application*
- *There should be clear definition of categories for a transparent classification of assessing the site with a practicable manual for possibilities of techniques and management*
- *Tools should include consideration of feasibility, costs and application range*

- *Tools should be practicable for smooth execution and coherence*

These suggestions mirror those raised during focused discussions with regulators, practitioners and other stakeholders. These suggestions, and further points highlighted during stakeholder discussions, are considered in the discussion and recommendations section below.

6.6.7 Discussion and recommendations

Despite the multitude of tools that have been developed, the results from the questionnaire survey indicate a lack of stakeholder knowledge of decision support tools that can be used to support gentle remediation (and indeed other remediation) approaches. Many of the stakeholders surveyed are likely to be using DSTs in the course of their work via national guidelines (e.g. CLR-11 in the UK), but are not aware that these guidelines form a DST system. Generally, tools developed or applied need to be easy to use (a tiered approach, in line with several national guidelines, is arguably the simplest and most valid approach), and should incorporate sustainability and socio-economic measures (via life cycle analysis, Cost Benefit Analysis or similar). The inclusion of sustainability measures, and / or life cycle or cost benefit analysis (particularly where ecosystem services or the value of restoring or preserving soil function is included as a monetary benefit), coupled with recent moves in promoting sustainability in contaminated land management (e.g. Bardos et al 2008) could arguably benefit the adoption of gentle remediation technologies, although it should be noted that not all gentle remediation options can be considered sustainable, particularly where regular addition of fertilisers, chemical complexing agents etc. is required during the remediation process. The potential use of gentle remediation technologies as part of integrated site solutions, at large, heterogeneous or mixed contaminant sites should also be considered more widely e.g. where gentle remediation options are applied in combination with other methods, using a zoned approach.

Given:

(a) the lack of stakeholder knowledge on gentle remediation-orientated DSTs,
(b) comments received from stakeholders via the project questionnaire and during focussed discussions, and
(c) the large number of existing (competing) DSTs which operate as “stand alone”, specific tools, many of which only examine some aspects of the remediation process,

we recommend that, rather than producing more tools of high complexity and detail that may suffer similar problems of lack of stakeholder uptake, gentle remediation (and decision support which focuses on gentle remediation) is more strongly incorporated into existing, well-established (national) DSTs / decision-frameworks, to promote more widespread use and uptake. The recommended form of a gentle remediation-focused DST is that it should take the form of a simple checklist or decision matrix, integrated (where possible) into existing national framework guidelines / DSTs as a tier, probably at the options appraisal stage (following the initial risk and site assessment stage). This decision matrix or checklist should clearly state (based on current knowledge and field trials) the capabilities of gentle remediation options in broad terms, allowing a decision to be made on their potential use, and then should refer the user to a bundled information package on gentle remediation options (an outline structure of this tool is shown in figure 48). Longer term work undertaken during and following the SUMATECS project at the University of Brighton (in collaboration with the UK Environment Agency) is examining the production of a gentle remediation-focused decision support “tier” that can be operated as part of existing national decision support tools / frameworks (initially for CLR-11, the UK Environment Agency’s Model Procedures for the Management of Land Contamination, and subsequently for other national decision support frameworks).

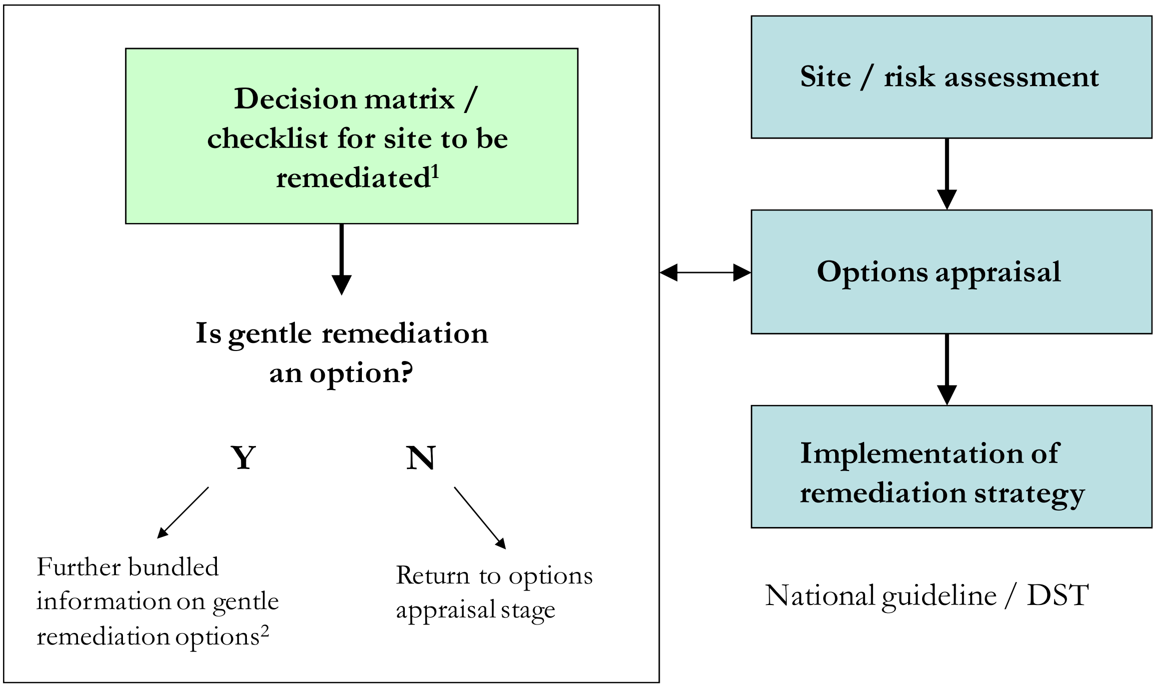


Figure 48: Recommended form of gentle remediation-focussed DST – diagrammatic outline.

Notes: [1] Decision matrix / checklist should be clear and straightforward to use, e.g. a spreadsheet or tick box, including consideration of level of contamination, main pollutant linkages, type of contaminants, timescales for remediation, depth of contamination, and other evaluation or exclusion criteria.. [2] Bundled information could include the EUGRIS website, the SUMATECS database (developed under WP5), and / or a list of case studies showing the field application of gentle remediation options.

Note that there are other possible insertion points of the gentle remediation decision support tier, at the site / risk assessment and the implementation stages e.g. to examine questions such as "Should we implement gentle remediation technologies" and "Will the proposed remediation scheme be approved by the relevant regulatory authority"?

6.6.8 Main reasons for hindrance.

Lack of stakeholder knowledge on DSTs generally, and specifically those which can be used to support the selection and application of gentle remediation technologies.

Existing tools are too general, contain insufficient detail on the range of gentle remediation options, or alternatively are too complicated, for regular or widespread use by decision makers in selecting and applying gentle remediation technologies.

6.7 Future Research Needs (WP7)

Friesl-Hanl W., Adriaensen K., Kumpiene J., Müller M., Mench M., Cundy A., Puschenreiter M.

6.7.1 Introduction

Research activities are the most appropriate tools for improvements in all technical or socio-economic fields (e.g. development of methods, techniques, systems, processes or models). To guide the implementation of research activities in the fields of utmost importance is a necessary assistance for optimal use of resources. The compilation of research needs in the field of Trace Element Contaminated Sites (TECS) and their management will be an output of SUMATECS.

Research Needs for the Management of Contaminated Sites (including TECS) in former conduced projects are summarized in the following.

6.7.2 Research needs defined by previous projects

CARACAS (*Concerted Action on Risk Assessment for Contaminated Sites*): The focus of CARACAS was in the development of risk assessment of contaminated sites.

CLARINET (*Contaminated Land Rehabilitation Network for Environmental Technologies in Europe*): The overall objective of CLARINET was to identify the means, by which management of contaminated land can be applied effectively in a sustainable manner (a) to ensure the safe (re-)use of these lands; (b) to abate caused water pollution; (c) to maintain the functionality of soil and (ground-)water ecosystems.

NICOLE (*Network for Industrially Contaminated Land in Europe*): The overall objectives of NICOLE are (a) the exchange and dissemination of knowledge and ideas about contaminated land; (b) identifying research needs for management of contaminated sites; (c) the collaboration with other networks concerning this topic.

SENSPOL (*Sensors for Monitoring Water Pollution from Contaminated Land, Landfills and Sediments*): The network aims to enhance the development of sensors for monitoring environmental pollutants in water, contaminated soil and sediments.

ETCA (*Environmental Technologies Concerted Action*): The tasks of ETCA include achieving the aim of the EU with regard to sustainability of industrial growth, preservation of the environment and improving the competitiveness of European enterprises.

CABERNET (*Concerted Action on Brownfield and Economic Regeneration Network*): The Network's aim is to enhance the rehabilitation of brownfield sites within the context of sustainable development, by sharing experiences from across Europe, providing new tools and management strategies and a framework for coordinated research activities.

Research needs defined by these projects:

In the following working fields research needs were summarized:

<u>Site characterisation:</u>

- robust and rapid low-cost techniques for investigation of potentially contaminated sites
- improved methods for estimating the accuracy and variability of the whole sampling and analytical process
- methods that yield information at spatial scales relevant for exposure assessment
- characterisation by biosensors and bioassays
- methods to assess migration of groundwater contamination
- methods to assess the natural potential of soil to reduce contaminants to acceptable risk levels and to monitor the process

- the interaction and general fate of contaminant mixtures
- detection of non-aqueous phase liquids and the prediction of their fate

Bioavailability of contaminants in soil and groundwater

- to study the interaction between organisms (soil fauna, bacteria, plants) and their chemical environment
- time dependence (ageing) of bioavailability
- cost effective procedures for estimating bioavailable fractions in the environment.

Fitness for Use - Human health risks

- validation of human exposure pathways
- availability of contaminants within the human body
- availability of contaminants in the soil as compared to the availability in the animal experiments underlying most toxicological reference values.
- "Fitness for use" focuses on the relationship between soil and groundwater quality and human land use and natural ecosystems. This provides two starting points for research: 1) The nature of contaminated land: the fate, transport, biodegradation and long term behaviour of soil pollutants. 2) Fitness for use: understanding the demands on soil quality and risk acceptability for various form of land use.

Ecological risk assessment

- impact of a site on its environment
- ecological recovery at the site
- changes in community structure caused by pollution-induced tolerance versus classical ecotoxicological endpoints
- biomagnification and adverse effects on food chains
- ecological soil quality requirements related to human land use.

Risk perception and communication

- Risk perception of contaminated land
- Development of communication strategies: how to communicate the results of risk assessments and the choice of solutions to those potentially at risk and to other interested parties.
- A focused research effort with international co-ordination is needed.
- to provide a high quality base for peer review to stimulate co-operation and harmonisation to avoid duplication of research at the national level

Remediation Technologies

- Processes of natural attenuation
- Low-energy approaches
- cost-effective remedial technologies
- Monitoring of remediation

Decision-making Tools

- Research should provide a variety of decision-making tools for managing and solving contaminated land problems
- Decision-making tools can take various forms such as sampling protocols, transport models, tiered risk assessment frameworks and soil screening values

Brown fields

- Establishment of multidisciplinary and multi-stakeholder “research platforms”
- Establishment of a multinational, multi-stakeholder and multidisciplinary research and development and knowledge transfer platform

Context of SUMATECS to former projects

The topics of these former projects were much broader than in SUMATECS which focused only on the gentle remediation options (GRO). In principle the development of GRO has been suggested by former projects, thus SUMATECS can be seen as one answer to these requirements. However, also a lot of new questions were raised by SUMATECS. Especially on risk assessment and the new techniques determining the risk (e.g. bacterial biosensors, whole cell biosensors) much more research activities should be spent . Of course GRO-specific research needs were added by SUMATECS, but in principle all other aspects that have been raised before are still valid for sustainable management of TECS as well.

6.7.3 Reasons for hindrance defined by SUMATECS

The application rate of “gentle” remediation techniques (e.g. phytoextraction, immobilisation) is still quite limited. Of course there is still a lot of research activities needed to fill the knowledge gaps (see below), but it should be noted that the limited applicability of these techniques is also caused by socio-economic and technical reasons of hindrance.

6.7.3.1 Socio-economic reasons

Lack of stakeholder knowledge on decision support tools (DSTs) generally, and specifically those which can be used to support the selection and application of gentle remediation technologies.

The output of the SUMATECS questionnaire action stresses on the following topics:

- More communication and information about techniques is required.
- Convince decision makers of feasibility and advantages of gentle remediation options.
- Successful pilot projects are required in order to show the methods' performance.
- Financial support of techniques is required.
- The need for long-term monitoring can be deterrent (vs. dump and forget).
- Limited applicability to few cases with moderate contamination that would not be considered for conventional techniques, such as dig & dump.
-

6.7.3.2 Technical reasons

The practical application of phytoextraction is still limited because of the long time that is required to remediate a soil with this technique (up to several decades). Additionally, it seems to be difficult to assess long-term impacts as well as long-term economic assessments.

In the field of immobilisation the remaining contaminants on site can be seen as a “time bomb” which may be dangerous in the future if it is not possible to show a sustainable immobilising performance of certain amendments.

As it is technically and scientifically almost not possible to valuate the benefits of gentle remediation (in most cases only in qualitative terms because of a lack of knowledge on value) the advantages of GRO are not always visible.

The possible risk for human health may be often overestimated due to a lack of a proper risk-based approach and risk assessment.

The lack of guidance through the whole process of GRO application is evident.

Existing decision tools are too general, contain insufficient detail on the range of gentle remediation options, or alternatively are too complicated, for regular or widespread use by decision makers in selecting and applying gentle remediation technologies.

The use of GRO for certain sites or at least for certain parts of contaminated sites following the concept of zoning and phasing is not present enough in decision maker minds.

6.7.4 Research Needs defined by SUMATECS

6.7.4.1 General Remarks

The complexity of the topic of “contaminated site remediation” requires a multidisciplinary research.
Legal frameworks in several countries should be adopted for the possibility of the application of “gentle” remediation techniques.
The implementation and demonstration of “field experiments” and “pilot projects” is one of the most urging needs, to show stakeholders (administration, remediation companies etc.) the proper use of these techniques.
Further helpful means for appropriate application of “gentle” remediation technologies are dissemination and collaboration with other networks (e.g. NICOLE, EURODEMO+ etc.). The information about and even involvement of decision maker in “pilot projects would be an important and necessary step forward applying GRO.

6.7.4.2 Remediation Technologies

If we are to use high biomass crops’ plant species for metal phytoextraction, investigations must be directed towards the search for metal-tolerant high biomass cultivars. Efforts are being made to develop traditional crop plants with ‘hyperaccumulator tendencies’. One proposed strategy, as yet unsuccessful, is to cross hyperaccumulators with high biomass relatives (Cunningham et al., 1995). The engineering of transgenic plants suitable for phytoextraction will probably require a change in the expression levels of several genes. Beyond a certain number of genes, this could render transgenic approaches impractical (Kramer and Chardonnens, 2001). In the transgenic approach, only Hg has been demonstrated to work in the field (Heaton et al., 2003) but public acceptance has been difficult because Hg0 is volatilized at the soil surface and will eventually be re-deposited.

The bottle neck in phytoextraction is the availability of metals to plants rather than the maximal amount of metal that a plant can extract (Hernandez-Allica et al., 2008; Robinson et al., 2003; Van Nevel et al., 2007). New insights are needed in enhancing bioavailability of the contaminants (→WP 3) and in the same time optimizing the plant’s ability to take up and store the contaminants while avoiding environmental risks (→WP4).

Agronomists should focus on improving the biomass production of phytoextraction crops through e.g. use of fertilizers, lengthening of the growth season, crop rotation… But also the efficiency of phytostabilization can be further increased by optimizing agronomic practices, such as irrigation, fertilization, planting and harvest time and the timing of amendment application.

Application techniques for amendments should be better adapted to the land use; e.g. on arable land, the avoidance of dust generation can be focused on or on grassland, application of amendment could be developed that not destroy the vegetation cover.

In the field of "immobilisation" research is needed for interactions of amendments with nutrients such as Mn or P, and not targeted contaminants such as As when combined with Pb contamination.

More fundamental research is still needed to better exploit the metabolic diversity of the plants themselves, but also to better understand the complex interactions between contaminants, soil, plant roots and micro-organisms (bacteria and mycorrhiza) in the rhizosphere.

The development of pilot scale experimental systems to study long-term behaviour are addressed as future goals to fill gaps in current research

6.7.4.3 Bioavailability

In the case of bioavailability/bioaccessibility for humans, toxicological values need to be derived from internal dose, whereas most of them are currently determined from external dose.

As far as the microbial biosensensors are concerned, little is known about the bioavailability of chemical species that are of low potential physiological activity (e.g. insoluble). There is also little information on the kinetics of the bioreporter responses, i.e. on the mode of re-supply after metal uptake during phytoextraction.

Whole cell biosensors provide information on the bioavailability of various analytes in soil. This information, based on genetic responses selected during microbial evolution can not be extrapolated with single chemical methods. Particularly important is to study the ecological interactions in the soil and the rhizosphere, based on the use of microbial biosensors.

In terms of stability of the gene fusions and of the specificity of the signal production, the majority of cellular biosensors constructed in the last decade, modifying soil microorganisms, are ready to provide information on the metabolic processes occurring in soil and rhizosphere and on the bioavailability of trace elements in polluted and remediated soils. Recent advances of genetic and metabolic engineering techniques and technology for detection of the signals, more sensitive and specific whole cell biosensors will be likely available in a near future. Notwithstanding such progresses, it should be born in mind that the study of the soil remains the most problematic application of the cellular biosensors, due to the possible presence of unknown potential stimulating or inhibitory soil borne compounds. More experimental data are needed to link the responses of the whole cell biosensors to the variations of the metal mobility in remediated TECS and to the restoration of soil functions.

Moreover, rigorous standardization of the procedures of use of the cellular biosensors across various soil types and extended comparisons of their responses with results of the chemical analyses are advisable prior to suggesting their use to asses the efficiency of the remediation measures, in soil protection policy, and before the adoption of the tests based on the cellular biosensors in the environmental legislation.

The effect of multi-element contamination should also be in the focus in the field of risk assessment and/or determination of bioavailability and/or bioaccessibility.

6.7.4.4 Effects of remediation on the environment /

The review of positive and negative effects of GRO on soil biological parameters conducted within SUMATECS reveals a need for systematic studies on the short- and long-term. For evaluating and assessing the results of GRO general and site-specific sensitive biological indicators for the restoration of soil functions have to be identified.

Gentle remediation options deliver positive (at least no negative) impact on environment. That thesis has to be proven in a quantitative manner. The key difficulty in applying such a quantitative approach to assessing remedial options is in assigning a monetary value to either environmental impacts or benefits, particularly when comparing approaches.

There are a number of economic modelling tools, but there is little or no experience in their application to the issues relevant to land remediation.

- o Definition what is exactly meant by socio-economic impacts of phytoremediation, so far it is an vague term, that may lead to misunderstandings

If more time and money would be available

- o Further study of literature according to find more papers about socio-economic aspects as well as more papers where case studies especially in the field are described
- o Systematic search of performed field tests with gentle remediation methods e.g. in databases

Field tests on pilot scale – what should be done regarding socio-economic aspects of phytoremediation?

- o Field tests should not investigate the remediation process itself only but also socio-economic aspects
- o Separate research to socio-economic aspects in the case of phytoremediation comparable to e.g. SCHOLZ & SCHNABEL (2006), WEBER et al. (2001) or THEWYS & CLAUW (2003)

Attendance of practical remediation projects – accompanying with questionnaires and discussions with affected people, stakeholders, administration, engineers.

6.7.4.5 Effects of gentle remediation technologies on soil biological activities

- Systematic studies on the short- and long-term effects of gentle remediation technologies on soil biological parameters.
- Delineation of amendment effects of improving general soil physico-chemical parameters from reducing metal toxicity to soil organisms and their activity.
- Identification of general and site-specific sensitive biological indicators for the restoration of soil functions.
- Determination of the long-term stability of organic amendments and the sustainability of such measures for the remediation of trace element contaminated sites.
- Functionality measurement and ecological and epidemiological studies of old (1950s-1980s) remediated soils

6.7.4.6 Socio-economy

There still is much research to be done and socio-economic changes to impulse in order to be capable of rigorously valuing and governing environmental assets and services, and to proceed to proper socio-eco assessment of eco-technological options. But the current world financial crisis, which is connected to a crisis in social valuation of the future, may allow some ecological “new deal”.

6.7.4.7 Biomass valorisation

Regarding (highly) contaminated biomass for which the current regulatory status is unknown, i.e. a waste or not a waste, limited options are suggested in the literature: incineration (including pyrolysis or any thermal treatment) and pre-treatment before incineration (e.g. composting or leaching). Further research needs and developments are related to the improvement of the processes to avoid ash-related problems during biomass incineration (e.g. slagging, deposit formation, corrosion) or to separate metals from incineration residues and leachates from pre-treated biomass. This last point should increase the possibilities for a sustainable ash utilisation, disposal and recovery options.

Several authors suggested to produce fuel or oil from highly contaminated biomass. Further research needs must focus on trace elements in the final products that will be valorized in a commercial way in order to fit with current regulation.

Is it possible to separate Zn and Cd from bottom and cyclone fly ashes to get "usable ash" with low amounts of TE? Is it possible to minimise the cost of treatment and deposition from leachates? Is it possible to separate Zn from Cd related to the potential recovery of each metal? Is it economically profitable for industrials to do such separation?

Very few studies are performed with metal contaminated biomass ([hyper]accumulators) and if such studies exist very few are performed at the field scale whereas phytoextraction, as a management option for a TEC site, should generate a large amount of contaminated biomass (tons/ha). Consequently there is a big need for field scale experiment and large amount of contaminated biomass to test the different options taking into account regulations and potential profits.

Behaviour of metals during processes are not well known, transfers of metals from the contaminated biomass to leachates are not well known, etc. Further research is needed to improve technology development.

6.7.4.8 Management of TECS

Regarding the management of TECS we compiled the following important topics.

- Comparable cost figures of different techniques are needed and methods have to be developed providing this data.
- Quality Assurance and Quality Control systems for performance and total emission have to be adopted for GRO.
- Comparable output should be gained at demonstration plants.
- Harmonised approaches including wider environmental issues for sustainable technology evaluation would be useful.
- Integration of technologies for solving the variety of problems occurring on one site;
- Integration of the planning-, investigation-, remediation- and aftercare process;
- Long-term experiences from pathway/ exposure control technologies;
- Modelling of time scale for completion of the various activities
- Modelling of time scale for monitoring and residual risk assessment
- Decision making on “clean” remediated soil (soil function);
- For some countries, risk based decision making approaches need implementation;
- Further development of more cost/effective technologies;
- Further development of integrated technologies solving mixed problems.

6.7.4.9 Decision Support Tools

Decision support tools need to be easy to use (a tiered approach, in line with several national guidelines, is arguably the simplest and most valid approach), incorporate sustainability and socio-economic measures (via life cycle assessment, Cost Benefit Analysis or similar), and consider the potential use of gentle remediation technologies as part of integrated site solutions i.e. in combination with other methods, using a zoned approach?

There is a need for gentle remediation, and for decision support which focuses on gentle remediation options, to be more strongly incorporated into existing, well-established (national) DSTs / decision-frameworks, to promote their widespread use and uptake.

The potential impact of forthcoming legislative changes on the decision support process, and on use of gentle remediation options generally (particularly the proposed Soil Framework Directive and its emphasis on consideration of maintaining soil function), needs to be monitored.

The recommended form of a gentle remediation-focused DST is that it should take the form of a simple checklist or decision matrix, integrated (where possible) into existing national framework guidelines / DSTs as a tier, probably at the options appraisal stage (following the initial risk and site assessment stage). This decision matrix or checklist should clearly state (based on current knowledge and field trials) the capabilities of gentle remediation options in broad terms, allowing a decision to be made on their potential use, and then should refer the user to a bundled information package on gentle remediation options.

6.7.5 Priorities of Research Topics from SUMATECS viewpoint

The above compilation of research needs in different topics gives an overview about important research topics. The most urgent topics which have to be solved in the near future are pointed out here.

- There is a need for large-scale field demonstration projects for all gentle remediation techniques: immobilisation, phytostabilisation, phytoextraction - including biomass valorisation. Since it should be practical applications following topics should be covered: risk assessment, options appraisal, remediation and residual risk and post-remediation site use. The evaluation of the sustainability of any of the gentle remediation options should be included.

- Based on the practical application the following specified needs arise for the whole procedure, from the site characterisation, to risk assessment, option appraisal, decision for any technique as well as the approval of the sustainability.

- Improvements of the risk assessment using appropriate techniques such as microbial biosensors as well as whole cell biosensors are still needed. The development of a tool box (selected tests in a set kit) is suggested which where able to compare sites (e.g. EU wide) as well as risks.

- A financial valuation of soil functions must be implemented (new systems should be developed) in order to allow the financial comparison of various remediation options. It can be suggested doing this in terms of monetary values or at least in intangible values. This can and should lead to a broader awareness of the positive and necessary soil functions for all living systems.

- Further, there is a need to minimize potential negative impacts of gentle remediation techniques (e.g., negative effects on soil microbes).

- Development of simple checklists or decision matrices providing a good basis for decision makers integrating gentle remediation-focused decision support tool in existing DST should be enforced.

7 Anticipated use and especially application of results

The results of the SUMATECS project should be regarded as a guideline for future research activities. Chapter 6.7 summarises the main reasons why gentle remediation options are not more widely used and what are the most important research needs in order to overcome these reasons for hindrance. We recommend that the results of SUMATECS should be used for planning of forthcoming scientific work, including both basic and applied research activities, focusing both on the gentle remediation technology itself, but also on the related aspects.

Most parts of this report will be published in SCI journals. Furthermore, SUMATECS has already been presented at many confrences (see chapter 8) and will be shown at a number of forthcoming scientific meetings.

However, this report is also highly relevant for stakeholders and policy makers (e.g., the funding agencies of SNOWMAN) involved in the management of trace element contaminated sites (TECS). For them, this report will provide a sound basis for future decisions how to implement gentle remediation options on TECS.

This report shows clearly, that some gentle remediation options are closer to practical application than others. Nevertheless, for all these options much more research is necessary to answer all remaining questions that are listed in chapter 6.7. In the end, gentle remediation options will (when ready for application) provide an environmentally friendly, socially accepted and cost-efficient alternative to “hard” technologies and thus help to improve the environment.

8 Realised or planned publication of project results

8.1 Realised publications:

Mench M, Puschenreiter M, Ruttens A, Kumpiene J, Müller I, Cundy A, Friesl-Hanl W, Renella G, Tlustos P, Bert V, Marschner B (2008) SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project. 1st International Conference for Environment and Natural Resources, Environmental Protection for Urban and Industrial Zones to International Integration, March 17th - 18th, 2008, Ho Chi Minh-Ville, Vietnam, Poster

Puschenreiter M and the SUMATECS Team (2008) Sustainable management of trace element contaminated soils – Development of a decision tool system and its evaluation for practical application - the SUMATECS project. Geophysical Research Abstracts Vol 10, EGU2008-A-00000, 2008, EGU General Assembly, Vienna, April 13-18; Poster.

Ruttens A, Mench M, Kumpiene J, Müller I, Cundy A, Friesl-Hanl W, Renella G, Tlustos P, Bert V, Marschner B and Puschenreiter M (2008) SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project. ConSoil 2008, 3-6 June 2008, Milano, Italy, Poster.

Puschenreiter M (2008) SUMATECS – Nachhaltiges Management mit Schwermetallen und Spurenelementen kontaminierter Böden. BOKU Insight (Universität für Bodenkultur Wien), 1 / March 2008, 12-13.

Puschenreiter M, Ruttens A, Kumpiene J, Müller I, Mench M, Cundy A, Friesl-Hanl W7, Renella G, Tlustoš P, Bert V (2008) Sustainable management of trace element contaminated soils - The SUMATECS project. EUROSOIL, August 25-29, Vienna; oral presentation (2008-A-759).

Friesl-Hanl W and Puschenreiter M (2008) SUMATECS – Nachhaltiges Management von schwermetallkontaminierten Böden. Jahrestagung der österreichischen Bodenkundlichen Gesellschaft, June 12-13, Gmunden, Austria, accepted for Poster (in German).

Friesl-Hanl W und Puschenreiter M (2007): – Nachhaltiges Management von mit Schwermetallen und Spurenelementen kontaminierten Böden – SUMATECS (SUstainable MAnagement of Trace Element Contaminated Soils). In: Newsletter of the Austrian Assossiation for Management of Old Wastes (ÖVA)(06/2007) (in German).

Cundy A: Invited presentation on decision support tools and gentle remediationtechnologies in special session on "Green remediation" at CONSOIL 2008, Milan, June 2008. Audience included conference delegates, plus USEPA staff and other stakeholders in the US and the Far East via a web-link /web-conference facility on the USEPA / CLU-IN website. The presentation slides were made available through the CLU-IN website, and a paper onthe special session was published in the CONSOIL 2008 proceedings: Bardos P., Andersson-Skold Y., Blom S., Keuning S., Pachon C., Track T.,Wagelmans M., Cundy A., McDaniel P., and Mahoney M. (2008) Brownfields, bioenergy and biofeedstocks, and green remediation. In: Proceedings ofthe 10th International UFZ-Deltares / TNO conference on Soil:Watersystems (CONSOIL), Special Sessions, pp 3-10, Milan, Italy. ISBN:978-3-00-024598-5.

Cundy A: "Towards sustainable methods of contaminated land remediation and site regeneration". University of Brighton Sustainable Development Research Forum conference, 17/7 - 18/7/08. Oral presentation.

Mench M., Puschenreiter M., Ruttens A., Kumpiene J., Müller I., Cundy A., Friesl-Hanl W., Renella G., Tlustos P., Bert V. Marschner B. (2008) SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project. SOILREM 2008, October 18-21 2008, Nanjing, P.R. China, oral presentation.

Mench M., Puschenreiter M., Ruttens A., Kumpiene J., Müller I., Cundy A., Friesl-Hanl W., Renella G., Tlustos P., Bert V. Marschner B. (2008) SUMATECS – SUstainable MAnagement of Trace Element Contaminated Soils: a SNOWMAN-ERANET funded project. 5th International Phytotechnology Conference, October 18-21 2008, Nanjing, P.R. China, oral presentation.

Further publication at conferences:

- 1st International Conference for Environment and Natural Resources, Environmental Protection for Urban and Industrial Zones to International Integration, March 17th - 18th, 2008, Ho Chi Minh-City, Vietnam.

Mench M, Aulen M, Bes C. 2008. Traits, and Cu translocation to shoots of poplar cuttings (Populus nigra, P. deltoides, and P. trichocarpa x P.deltoides).
Mench M., Bes C. 2008. Assessment of Cu stabilisation in a wood preservative treatment site.
Mench M, Jaunatre R, Julien F, Bes C 2008. Plant communities at a wood preservative treatment site and soil phytotoxicity.
Mench M, Gasté H, Aulen M, Taberly J 2008. Metallicolous and non-metallicolous plant responses to increasing Cu exposure.
Mench M, Bes C, Jaunatre R, Aulen M, Gasté H, Julien F, Taberly J, Guinberteau J, Garcia S, Gawronski S 2008. Phytoremediation of metal-contaminated soils: field trials at a wood treatment site.
Mench M, Winkel B, Baize D, Bodet JM 2008. French bread wheat cultivars differ in grain Cd concentrations.

- Contaminants and nutrients: availability, accumulation/exclusion and plant-microbia-soil interactions, COST Action 859, Working group 1, Smolenice, May 22 -24, Slovakia.

Mench M., Gasté H., Bes C. 2008. Phenotypic traits of metallicolous and non-metallicolous Agrostis capillaris exposed to Cu. COST 859 – Meeting of WG1 - Contaminants and nutrients: availability, accumulation/exclusion and plant-microbia-soil interactions, D. Liskova, A. Lux, M. Martinka (Eds.), Smolenice, May 22 -24, 2008. ISBN 978-80-969950-0-4. p.19.
- Genes and proteins involved in limiting steps of phytoextraction and degradation of pollutants, Workshop of Working group 2, COST Action 859, Phytotechnologies to promote sustainable land use and improve food safety, 5 – 6 June 2008 Verona, Italy.
Bes C, Bedon F, Mench M, Lalanne C, Plomion C, 2008. Soluble proteins involved in copper tolerance in metallicolous Agrostis capillaris. Genes and proteins involved in limiting steps of phytoextraction and degradation of pollutants, A. Furini et al. (eds.), WG2 COST859, University of Verona, 5 – 6 June 2008, Verona, Italy. p. 21-22.

- Challenges on improving quality and safety of food crops, COST Action 859, Working group 3, Lillehammer, Norway, September 1-3, 2008.

Mench M, Winkel B, Baize D, Bodet JM 2008. French bread wheat cultivars differ in grain Zn concentrations.

- Phytotechnologies in practice – biomass production, agricultural methods, legacy, legal and economic aspects, COST Action 859, Working group 4, Integration and application of Phytotechnologies, October 14-17, 2008, INERIS, Verneuil en Halatte, France.

Bes C, Jaunatre R, Hego E, Kechit F, François J, Mench M. 2008. Aided phytostabilisation of a Cu contaminated soil. pp. 30-31.
Carrier M, Mench M, Loppinet-Serani A, Cansell F, Aymonier C, Marias F, Mercadier J. 2008. Valorisation of phytoremediation biomasses with supercritical water. pp. 51-52.
Marschner B, Haag R, Muller I, Bert V, Mench M, Magnié MC, Cundy A, Renella G, Kumpiene J. 2008. Current perception of gentle remediation options for contaminated sites – results from a survey in Europe. p. 97
Mench M, Bes C, Negim O, Jaunatre R. 2008. Phytostabilisation at a wood preservative site: Cu leaching and plant responses. pp. 89-90.

- 5th International Phytotechnologies Conference, October 22-25, 2008, Nanjing, P.R. China.

Mench M, Gaste H, Bes C. 2008. Phenotypic traits of metallicolous and non-metallicolous Agrostis capillaris exposed to Cu. pp. 55-56.

8.2 Planned publications:

Puschenreiter M, Adriaensen K, Ruttens A, Kumpiene J, Marschner B, Müller I, Mench M, Cundy A, Friesl-Hanl W, Renella G, Tlustoš P, Bert V (2008) Sustainable management of trace element contaminated soils - The SUMATECS project. 10th International Conference on the Biogeochemistry of Trace Elements (ICOBTE), Chihuahua, Mexico, July 13-16 2009.

SUMATECS Team: Review of impacts or failures from „gentle“ methods for remediation of soils.

8.3 Dissemination to students:

All SUMATECS members have presented all or specific aspects of SUMATECS in lectures held at their home insitutions.

8.4 General presentation about SUMATECS

Müller I (2007): Presenting the SUMATECS project using the publicity poster, homepage and project information sheet at the Saxon Soil Round Table (Anual Federal States ministry and authoritieś meeting) on Dec. 13th 2007

Müller I (2008): Presenting the SUMATECS project (project information sheet, homepage) to 140 German ministries, authorities, engineers, consultancies, universities and stakeholders involved in TECS problems (along with the questionnaire action).

Müller I (2008): Presenting the SUMATECS project (project information sheet, homepage) within the Saxon Soil Conservation Letter (Sächsischer Bodenschutzbrief); Saxon State Agency for Environment and Geology (ed.), Dresden, April 2008

Mench M: Letter to COST 859 members, including the questionaire.

Puschenreiter M: Weltbodentag, Klosterneuburg, Austria, December 5 2007.

Kumpiene J: Kalmar ECO-TECH -07: International Conference on Technologies for Waste and Wastewater Treatment, Remediation of Contaminated Sites and Emissions Related to Climate. 26-28 November 2007, Kalmar, Sweden

Kumpiene J: Spring meeting of Swedish national network “Cleaner Soil”, Luleå, 31 march – 1 April, 2008.

Müller I (2008): Presenting SUMATECS project during a lecture at the Technical University Dresden on June 4th 2008.

The Sumatecs poster will be also presented at COST Action 859: Working Group 1 meeting (Plant uptake/exclusion and translocation of nutrients and contaminants) “CONTAMINANTS AND NUTRIENTS: AVAILABILITY, ACCUMULATION/EXCLUSION AND PLANT-MICROBIA-SOIL INTERACTIONS”, 22-24 May 2008, Smolenice (Slovakia)

8.5 Sumatecs website:

www.rhizo.at/Sumatecs

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Links /Information on line/ Web site

- CLAIRE: Contaminated Land: Application In Real Environment http://www.claire.co.uk

- Environment agency

http://www.environment-agency.gov.uk/subjects/landquality/113813/881475/?version=1&lang=_e

- ITRC (Interstate Technology and Regulatory Cooperation)

http://www.itrcweb.org/webphyto/EnvDept/PHYTO/wwwphyto/View_Document_Online/view_document_online.htm

- Land Contamination and Reclamation http://www.btinternet.com/~epppublications/

- Remediation.co.uk http://www.remediation.co.uk

- Environment Canada

- aboutREMEDIATION.com - A Wealth of Knowledge
- Phytorem and Phytopet - Selecting Plants for Site Decontamination
- Selecting the Right Sorbent for Oil Spill Response

- PHYTOREM has been developed by Environment Canada and its partners as a worldwide interactive electronic database of more than 700 plants, lichens, algae, fungi, and bryophytes with a demonstrated capacity to tolerate, accumulate, or hyperaccumulate a range of 19 different metals.

Division, Cominco, Royal Military College, University of Saskatchewan, Department of National Defence, and Natural Resources Canada.

http://www.clu-in.org/products/tins/display.cfm?id=72994597

http://ncrweb.ncr.ec.gc.ca/etad/default.asp?lang=En&n=BF9A6F73-1

- US EPA

http://cluin.org/databases/#Phytotechnology_Project_Profiles

EPA has developed this Web site to summarize timely information about selected full-, field- and large greenhouse-scale applications of phytotechnology. Phytotechnology is an emerging technology that uses various types of plants to degrade, extract, contain, or immobilize contaminants in soil and water. Projects for this Web site are collected using information from technical journals, conference proceedings as well as information obtained from technology vendors and site managers. The project profiles contain information about relevant site background, the types of contaminants treated, type of vegetation used, phytotechnology mechanisms, planting date, project size, location, cost, monitoring and performance results, as well as points of contact and references. This Web site can be used as a networking tool (each profile has a contact) to provide past solutions and lessons learned to new sites with similar contaminants and climate.

http://cluin.org/products/phyto/search/phyto_search.cfm

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10 List of Abbreviations

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie; www2.ademe.fr
AMF	Arbuscular Mycorrhizal fungi
ASTM	American Society for Testing and Materials
ATP	Adenosintriphosphate
BATNEEC	Best Available Techniques Not Entailing Excessive Cost
BCF	Bioconcentration Factor
BCR	Community Bureau of Reference of the European Commission
BCS	Bioavailable Contaminant Stripping
BURGEAP	Environmental Engineering Company; www.burgeap.fr
CABERNET	Concerted Action on Brownfield and Economic Regeneration Network
CAC 40	Continuous Assisted Quotation
CARACAS	Concerted Action on Risk Assessment for Contaminated Sites
CBA	Cost Benefit Analysis
CCE	Calcium-Carbonate-Equivalent
CEA	Cost Effectiveness Analysis
CEC	Cation Exchange Capacity
CFU	Colony Forming Units
CLAIRE	Contaminated Land: Applications In Reas Environments
CLARINET	Contaminated Land Rehabilitation Network for Environmental Technologies in Europe
CLR-11	Model procedures for the management of land contamination (2004); http://www.eugris.info/DisplayResource.asp?ResourceID=4823
COST Action	European Cooperation in the field of Scientific and Technical Research
CSMWG	Contaminated Site Management Working Group in Canada
CSR	Corporate Social Responsibility
DARTS	Decision Aid for Remediation Technology Selection
DGT	Diffusive Gradients in Thin films
DIFPOLMINE	Diffuse Pollution From Minining Activities (LIFE Project; www.difpolmine.org)

DIN	Deutsche Industrie Norm
DOM	Dissolved Organic Matter
DST	Desicion Support Tool
DTPA	Diethylenetriaminepentaacetic Acid
DW	Dry Weight
EDDHA	Ethylenediamine-N,N'-bis(2-hydroxyphenylacetic acid)
EDDS	Ethylenediaminedisuccinic Acid
EDTA	Ethylenediaminetetraacetic Acid
EEA	European Environmental Agency
EEC	European Economic Community
ERA NET	European Research Area Network
ETCA	Environmental Technologies Concerted Action
EUGRIS	European Groundwater and Contaminated Land Information System
EURODEMO	European Co-ordination Action for Demonstration of Efficient Soil and Groundwater Remediation
GDP	Gross Domestic Product
GMO, OGM	Genetically Modified Organism
GRO	Gentle Remediation Options
IAEA	International Atomic Energy Agency
ICOBTE	Inteternational Conference on Biogeochemistry of Trace Elements
ICP-AES	Inductivle Coupled Plasma - Atomic Emision Spectrocopy
IPPC	Integrated Pollution Prevention and Control
IRH	IRH Environnement, Tolouse, France
ISO	International Standord Organisation
ISTEB	International Society of Trace Element Biogeochemistry
L/S	Liquid to Solid ratio
LCA	Life Cycle Assessment
LIFE	LIFE Environment, http://ec.europa.eu/environment/life/
LMWOA	Low Molecular Weight Organic Acids and amino acids
MCA	Multi Criteria Analysis
MVDA	Multivariate Data Analyses
NICOLE	Network for Industrially Contaminated Land in Europe

NTA	Nitrilotriacetic Acid
OECD	Organisation for Economic Co-operation and Development
PBET	Physiologically Based Extraction Test
PEC/PNEC	Predicted Environmental Concentration / Predicted No-Effect Concentration
PGPR	Plant Growth Promoting Rhizobacteria
PhytoDSS	Phytoremediation Decision Support System; http://www.ito.ethz.ch/people/robinson/PhytoDSS/Phyto-DSS.html
PRF	Pulverised Refuse Fines
QA/QC	Quality Assurance / Quality Control
RBLM	Risk-Based Land Management
REACH	Registration, Evaluation, Authorisation and Restriction of Chemical substances
Rhizon SMS	Soil Moister Sampler
ROTAS	Rapid On-site Toxicity Audit System
SCI journals	Science Citation Index Journals
SEA	Socio-Economic Assessment
SENSPOL	Sensors for Monitoring Water Pollution from Contaminated Land, Landfills and Sediments
SNOWMAN	Sustainable maNagement of sOil and groundWater under the pressure of soil pollution and soil contaMinAtioN
SUMATECS	SUstainable MAnagement of Trace Element Contaminated Soils
SWOT	Strengths, Weaknesses, Opportunities, Threats
TE	Trace Element
TECS	Trace Element Contaminated Soils
TOC	Total Organic Carbon
UK	United Kingdom
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation
WP	Work Package
WTP	Willingness To Pay techniques
WWS	Water Treatments Sludge
List of abbreviations of SUMATECS partner institutions	
ARC	Austrian Research Centers GmbH – ARC, Austria
BOKU	University of Natural Resources and Applied Life Sciences, Austria

HAU	Hasselt University, Belgium
LTU	Luleå University of Technology, Sweden
LfUG	Saxon State Agency for Environment and Geology, Germany
RUB	Ruhr-University Bochum, Germany
INRA	Institut National de la Recherche Agronomique, France
INERIS	Institut National de l'Environnement industriel et des RISques
INERTEC	INERTEC, constructeur de solutions environnementales; www.inertec.fr
UTC	Université de Technologie de Compiègne, France
UoB	University of Brighton, UK
CULS	Czech University of Life Sciences Prague, Czech Republic
UniFi	University of Florence, Italy

The SNOWMAN partners are:

Austria

Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft (BMLFUW)

http://www.lebensministerium.at/

Belgium (Flanders)

Openbare Vlaamse Afvalstoffenmaatschappij (OVAM)

http://www.ovam.be

France

Agence De l'Environnement et de la Maîtrise de l'Energie (ADEME)

http://www.ademe.fr

Germany

Umweltbundesamt (UBA)

http://www.umweltbundesamt.de

Netherlands

Stichting Kennisontwikkeling en Kennisoverdracht Bodem (SKB)

http://www.skbodem.nl/

Sweden

Naturvårdsverket (SEPA, Swedish Environment Protection Agency)

http://www.naturvardsverket.se/

United Kingdom

The Environment Agency of England and Wales

http://www.environment-agency.gov.uk/