GREENLAND – Gentle remediation of trace element contaminated land

BEST PRACTICE GUIDANCE FOR PRACTICAL APPLICATION OF GENTLE REMEDIATION OPTIONS (GRO)

December 2014.

GREENLAND: consortium lead scientists and contact points

- Markus Puschenreiter, University of Natural Resources and Life Sciences, Vienna (co-ordinator)
- Jaco Vangronsveld, Universiteit Hasselt
- Jurate Kumpiene, Luleå tekniska universitet
- Michel Mench, Institut National de la Recherche Agronomique
- Valerie Bert, Institut National de l'Environnement industriel et des Risques
- Andrew Cundy, University of Brighton
- Petra Kidd, Consejo Superior de Investigaciones Cientificas
- Giancarlo Renella, University of Florence
- Wolfgang Friesl-Hanl, Austrian Institute of Technology
- Grzegorz Siebielec, Instytut Uprawy Nawozenia I Glebooznawstwa – Panstwowy
- Rolf Herzig, Phytotech-Foundation
- Ingo Müller, Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie
- Jannis Dimitriou, Sveriges lantbruksuniversitet
- Xose Quiroga Troncosco, Tratamientos Ecológicos del Noroeste SL
- Patrick Lemaitre, Innoveox
- Anne Serani Loppinet, CNRS-ICMCB

Other contributors: Paul Bardos, Andrew Church, Jolien Janssen, Silke Neu, Nele Weyens, Nele Witters, Angela Sessitsch, Rodolphe Gaucher.

Contact points:

UK

Professor Andy Cundy

School of Environment and Technology, University of Brighton
Lewes Road, Brighton
BN2 4GJ, UK
Tel: + 44 1273 642270
A.Cundy@brighton.ac.uk

Project co-ordinator:

Dr. Markus Puschenreiter
Universität für Bodenkultur (BOKU); Department für Wald und Bodenwissenschaften
Peter Jordan Strasse 82
A-1190 Wien
Tel: ++43 1 47654 3126
markus.puschenreiter@boku.ac.at

The GREENLAND project is financially supported by the European Commission under the Seventh Framework Programmes for Research (FP7-KBBE-266124, Greenland).

Foreword:

This guidance document presents condensed results from the European Union Framework 7 GREENLAND project, a cross-European multi-partner project focussed on the use of gentle remediation options (GROs) as practical land remediation and risk management tools. GRO have been under-utilised as practical remediation strategies in the European contaminated land sector, despite their capability to provide rapid risk management and generate a range of additional economic, environmental and social benefits. This guide is intended to encourage wider consideration and use of GRO as an effective risk management strategy within Europe and in other geographic regions, and provides:

- a context and rationale for the practical application of Gentle Remediation Options as effective risk management strategies;
- examples of successful GRO application within the European contaminated land arena;
- an illustration of the potential wider economic, environmental and social benefits that may be realised during and following GRO application; and
- outline operating windows for GRO application.

In addition, we provide a series of technical appendices to support design and implementation of effective GRO strategies on a site-specific level. The guidance document is aimed at planners, consultants, regulators, practitioners, scientists, and other brownfields or contaminated land stakeholders, and is provided with an accompanying decision support tool (DST), in MS Excel format, which is intended to provide practical decision support when appraising various options for contaminated site management. The guidance document and the decision support tool are intended to act as decision support and information guides, not as decision making tools, and should not replace expert input – in common with many remediation strategies GRO are not “off-the-shelf” tools, and a site specific assessment and testing is required prior to implementation.

1. Definitions and context – what is GRO and how does it work?

1.1 GROs – a definition

Gentle Remediation Options (GRO) are risk management strategies or techniques for contaminated sites that result in a net gain (or at least no gross reduction) in soil functionality as well as risk management. These strategies and techniques have been successfully applied at sites containing a range of organic, inorganic and radioactive contaminants. This guidance document, following the EU Knowledge-Based Bio-Economy research programme GREENLAND, focuses on their application at trace element (including metal and metalloid) contaminated sites.

1.2 Context

Two broad concepts have emerged in contaminated land management over the past 30 years: the use of risk assessment to determine the seriousness of problems, and the use of risk management to mitigate problems found by risk assessment to be significant. For a risk to be present (see Figure 1) there needs to be a ***source*** (of hazardous contamination), one or more ***receptors*** (which could be adversely affected by the contamination) and one or more exposure ***pathways*** (linking the source to the receptors). Receptors might be human health, water resources, a built construction, or the wider environment. For example, in the UK this combination of a source-pathway-receptor is referred to as a *pollutant* or *contaminant linkage*. Requirements for land and groundwater remediation strictly depend on risk management needs, whether the intended use of the remediated land is for a "hard" end use such as a built development or a "soft" end use, where the soil remains unsealed, such as community parkland. Risk management focuses on breaking the contaminant linkage, either by controlling the source (*e.g.* removing or (bio)degrading the contamination); managing the pathway(s) (*e.g.* preventing labile contaminant pools and migration of contamination); protecting the receptor(s) (*e.g.* planning - institutional - controls to avoid sensitive land uses) or some combination of these components.

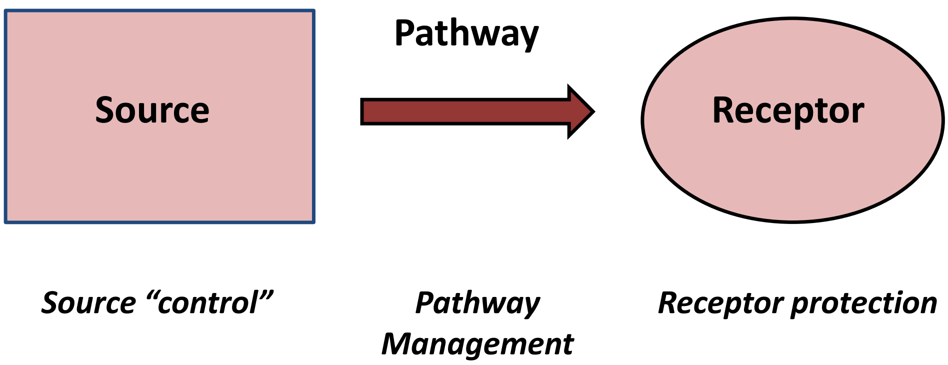


Figure 1: Contaminant Linkage and Risk Management Options (based on DEFRA 2012, after Cundy et al. 2013).

Conventional approaches to contaminated land risk management have focussed on containment, cover and removal to landfill (or "dig and dump"). However, since the late 1990s there has been a move towards treatment-based remediation strategies using *in situ* and *ex situ* treatment technologies (*e.g.* soil washing). More recently the concept of Gentle Remediation Options (GRO) has emerged. These are risk management strategies/techniques that result in a net gain (or at least no gross reduction) in soil functionality as well as risk management. Hence they have particular usefulness for either maintaining or restoring biologically productive soils. GROs encompass a number of technologies which include the use of plant (phyto-), fungal (myco-) or bacterial-based methods, with or without chemical additives, for reducing exposure of local receptors to contaminants by *in situ* stabilisation (using biological and / or chemical processes), or extraction, transformation or degradation of contaminants. GRO includes techniques such as *in situ* immobilisation/phytoexclusion, phytovolatilisation, phytostabilisation, rhizofiltration, rhizodegradation, phytodegradation/phytotransformation and phytoextraction (Table 1). A similar concept might also exist for groundwater, for example monitored natural attenuation might be considered a GRO. As a concept GROs are a development of an earlier idea called "extensive" technologies which sought to distinguish low input longer term remediation approaches from energy, resource and labour intensive strategies.

Table 1: List of definitions for Gentle Remediation Options used to remediate soils contaminated by either trace elements or mixed contamination (after Peuke and Rennenberg 2005, Mench et al 2010)**.**

GRO	Definition
Phytoextraction	The removal of metal(loid)s or organics from soils by accumulating them in the harvestable biomass of plants. When aided by use of soil amendments, this is termed aided phytoextraction.
Phytodegradation / phytotransformation	The use of plants (and associated microorganisms such as rhizosphere and endophytic bacteria) to uptake, store and degrade organic pollutants.
Rhizodegradation	The use of plant roots and rhizosphere microorganisms to degrade organic pollutants.
Rhizofiltration	The removal of pollutants from aqueous sources by plant roots and associated microorganisms.
Phytostabilisation	Reduction in the bioavailability of pollutants by immobilisation in root systems and / or living or dead biomass in the rhizosphere soil – creating a milieu which enables the growth of a vegetation cover. When aided by use of soil amendments, this is termed aided phytostabilisation.
Phytovolatilisation	Use of plants to remove pollutants from the growth matrix, transform them and disperse them (or their degradation products) into the atmosphere.
In situ immobilisation / phytoexclusion	Reduction in the bioavailability of pollutants by immobilizing or binding them to the soil matrix through the incorporation into the soil of organic or inorganic compounds, singly or in combination, to prevent the excessive uptake of essential elements and non-essential contaminants into the food chain. Phytoexclusion, the implementation of a stable vegetation cover using excluder plants which do not accumulate contaminants in the harvestable plant biomass can be combined with *in situ* immobilisation.

Intelligently applied GROs can provide: (a) rapid risk management via pathway control, through containment and stabilisation, coupled with a longer term removal or immobilisation/isolation of contaminants; and (b) a range of additional economic (*e.g.* biomass generation), social (*e.g.* leisure and recreation) and environmental (*e.g.* C sequestration, water filtration and drainage management, restoration of plant, microbial and animal communities) benefits (which are encompassed in the generic term "ecosystem services"). These are discussed further in sections 2 and 4 below.

2. Overview of current state of development and risk management capability.

Box 1: GRO: Technical Applicability.

GRO are primarily deployed on contaminated soils to remove the labile (or bioavailable) pool of inorganic contaminants (phytoextraction), remove or degrade organic contaminants (e.g. phytodegradation), protect water resources (e.g. rhizofiltration), or stabilise or immobilise contaminants in the subsurface (e.g. phytostabilisation, in situ immobilisation/phytoexclusion).

Despite widespread use of "green" technologies such as landscaping, application of green cover, and reedbeds and constructed wetlands in remediation or industrial/urban regeneration projects, the application of GROs as practical remedial solutions is still in its relative infancy, particularly for trace element-contaminated sites. The barriers to wider adoption, especially in Europe, arise both from the nature of GROs as remediation techniques, and market and stakeholder perceptions of uncertainties over whether these methods can achieve effective risk management in the long term.

The majority of remediation work in Europe has been carried out as a result of regulatory demand for critical risks and/or to stimulate the re-use or development of brownfield land. Hence, unsurprisingly, most funded remediation and brownfield regeneration projects are in or around urban environments, and brownfields re-use is strongly driven by economic factors. These projects are often constrained by pressure on time scale and relatively limited site areas. Both of these factors have tended to exclude consideration of GROs which are perceived as slow and more suited to large area problems.

The time taken before prescribed "total" concentration-based risk management targets such as soil quality thresholds are reached is also seen as a limitation for GROs. This has led to intensive discussions in particular about phytoextraction, which is perhaps the most well-known GRO, and which has been widely tested at demonstration scale. Phytoextraction has tended to be seen as a source management activity which seeks to gradually remove metal(loid)s from soil over time harvestable biomass. Phytoextraction has poor acceptance as a functional source management tool because contaminant removal may take decades (when the aim is to clean up to specific levels of total concentration) and there is some concern over the fate of and contaminant concentration in harvested biomass. Acceptance of other GROs related to phytostabilisation and *in situ* immobilisation is limited because source removal does not take place, and there is a perception that stabilisation or immobilisation is potentially reversible over time.

The constraints on acceptability of GROs are inevitable when remediation success is judged solely using generic soil concentration targets. While this target-led approach can be attractive to some because of its simplicity, its inherent conservatism may lead to over-designed risk management solutions, which are costly, invasive and may not be sustainable. A site-specific approach, that properly considers source and pathway interventions in a more comprehensive risk management strategy, allows a more targeted and hence likely more sustainable risk management solution. This also creates a better rationale for the deployment of plant- and microorganism-based GROs. GROs may then facilitate land regeneration in circumstances where the case for intervention is economically marginal by virtue of their lower cost and also, potentially, by their linkage to other project services such as biomass production, public green space provision, recovery of land values etc. GRO approaches can be tailored along pollutant linkages (Figure 2), for example:

- Source: gradual removal or immobilisation of source term
- Pathway: rapid reduction in flux of contaminants to receptors at significant risk
- Receptor: using vegetation to manage receptor access to the subsurface.

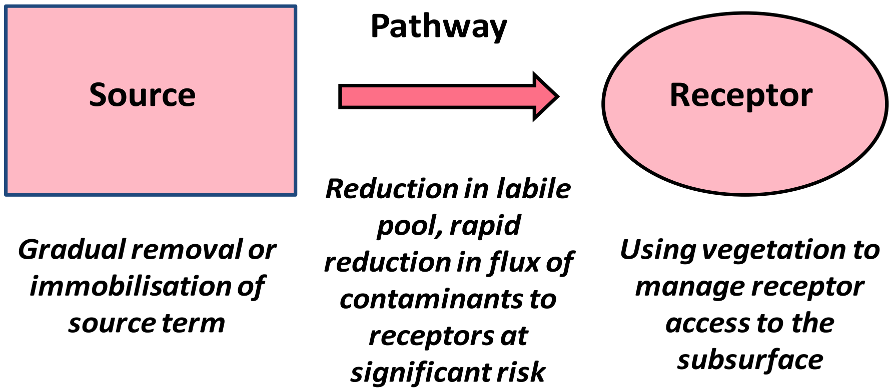


Figure 2: GRO-based risk management strategy, tailored along contaminant linkage model.

Examples of circumstances which do not favour existing treatment-based remediation solutions, but which may be highly amenable to this broader risk management approach using GRO, include:

- Large treatment areas, particularly where contamination may be causing concern but is not at strongly elevated levels
- Where biological functionality of the soil is required after site treatment
- Where other environmental services related to soil quality (*e.g.* biodiversity, carbon sequestration) are valued highly
- Where there is a need to restore marginal land to produce non-food crops and avoid major land use changes
- Where there are budgetary constraints
- Where there are deployment constraints for land remediation process plant (*e.g.* as a function of area and location).

Typically these constraints describe sites for which a “soft” end use is envisaged.

Intelligently applied GROs have been shown in a number of cases to provide rapid risk management via pathway control, through containment and stabilisation, coupled with a longer term removal or immobilisation of the contaminant source term. Large-scale, long duration, examples of GRO application at trace element contaminated sites across Europe are given in section 3 in the GREENLAND case / success stories. In North America, application of GRO is arguably more developed than in Europe with the US Interstate Technology & Regulatory Council listing 48 sites, largely within the USA, as hosting "full-scale" phytotechnology trials (as of 2007). GRO application generally in North America ranges from relatively small-scale phyto- and bio-remediation projects that are driven and implemented by the local community to larger "green-technology"-based remediation programmes at Superfund sites which involve tree planting, soft cover etc. GRO can be durable solutions as long as land use and land management practice does not undergo substantive change causing shifts in pH, Eh, plant cover etc., suggesting that some form of institutional or planning control may be required. The use of institutional controls over land use however is a key element of urban remediation using conventional technologies (*e.g.* limitation of use for food production), so any requirement for institutional control and management with GROs continues a long established precedent.

3. Case / success stories.

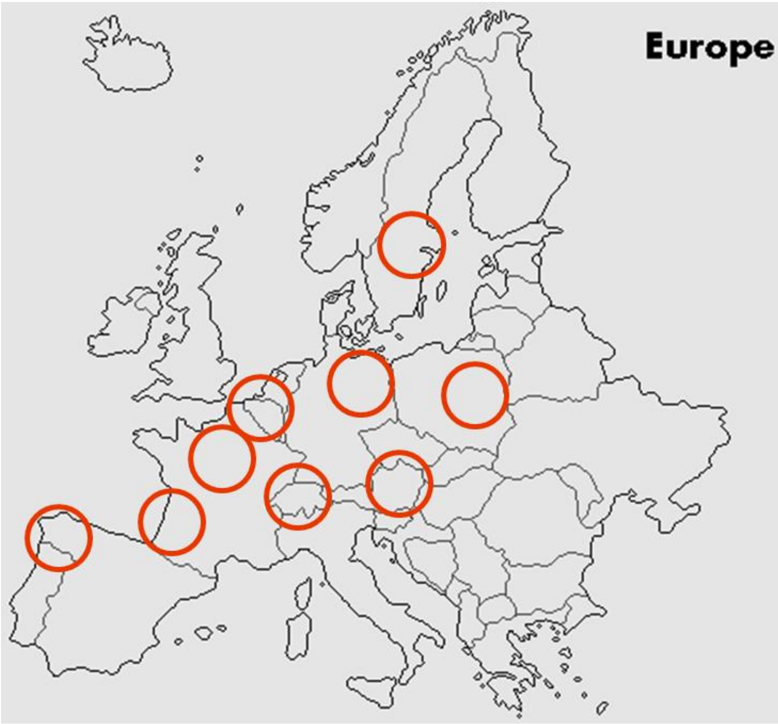


Figure 3: The GREENLAND project network of long-term (>5 year) GRO field experiments in Europe at trace element contaminated sites, covering a range of climatic, soil and contaminant types.

The GREENLAND site network (Figure 3) is a cross-European network of metal(loid) contaminated sites where phytomanagement efficiency has been tested for long (> 5 year) periods, under different contaminant types and loadings and soil and climatic conditions, with various plants and cultivars. Further details of three of these sites are given in the following pages, as examples of cases where application of phytoextraction, aided phytostabilisation, and *in situ* stabilisation / phytoexclusion phytomanagement strategies have led to demonstrable source removal, pathway management or receptor protection. Further examples are given in the technical appendices which accompany this guidance.

Example 1: Phytoextraction (DE)

Site name	Freiberg/Halsbrücke	GRO type	Phytoextraction / -stabilization
Location	Freiberg, Germany	Origin of soil contamination	Geogenic and smelter emissions over centuries
Site type	Contaminated arable land	Implementation of field trial	start: 2005 – 2019
Current land use	Short rotation coppice (SRC)	Lifetime	Up to now: 9 years
End land use	Arable land/ grassland/SRC	Surface area	Regional scale, 2 ha test site
Objective	Reduction of pollutant linkages, bioenergy production, reduce total and mobile TE		

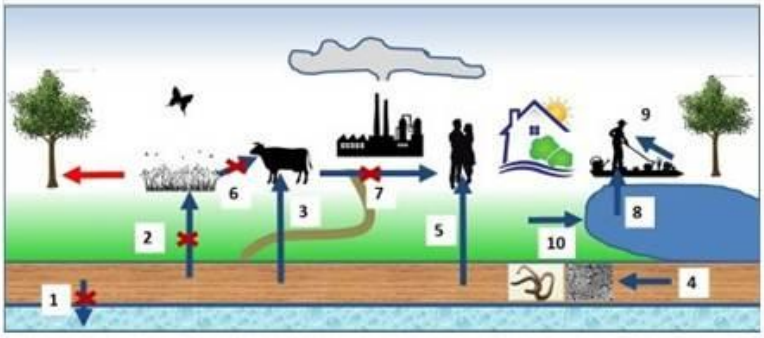
Soil characteristics	Initial values	After best GRO	Initial labile pool* mg/kg	Labile pool after best treatment$ mg/kg
pH	5.7	5.2		
Sand, silt, clay (%)	sandy loam			
Organic C (%)	1,4			
CEC	7.5			
As (mg/kg)	118	95.9	**(0.13) 0.03 ± 0.01	0.03 ± 0.01
Cd (mg/kg)	3.2	2.6	0.17 ± 0.06	0.17 ± 0.06
Cr (mg/kg	42.4		0.002 ± 0.001	< LOD
Cu (mg/kg)	24.3		n.d.	n.d.
Pb (mg/kg)	37.4		0.37 ± 0.11	0.37 ± 0.18
Zn (mg/kg)	179.5		1.7 ± 1.2	1.8 ± 1.0

* NH_4NO_3; $ after 8 years; ** adjacent arable land

Halsbrücke

Core stakeholder	Function	Remark	Main site operators
Farmer	Site owner and harvest logistics		LANDESAMT FÜR UMWELT, LANDWIRTSCHAFT UND GEOLOGIE; Freistaat SACHSEN
SMUL, LfULG	Saxon Ministry and its scientific authority	Scientific driven praxis field trial	

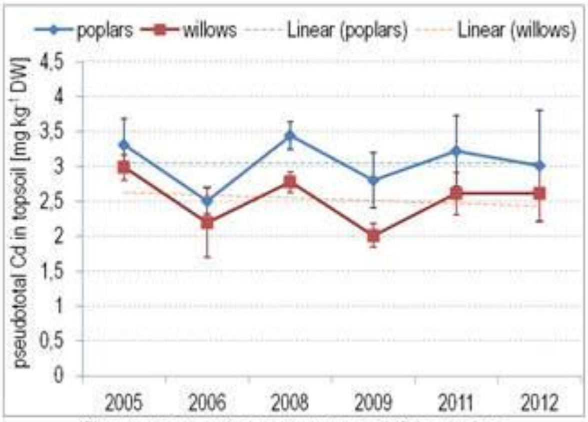
Conceptual model and relevant pollutant linkages



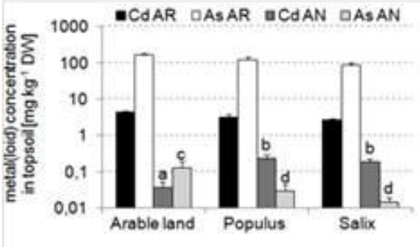
	Pollutant linkages	Description	Remediation changes
1	Soil to groundwater	leaching of mobile elements from soil solution	Reduction of seepage water
2	Soil to plants	metal accumulation in crops	Change of land use towards bioenergy (SRC)
3	Soil to animals	soil ingestion while feeding on pasture	Change of land use towards bioenergy (SRC)
4	Soil to microorganisms		Not investigated
5	Soil to humans	ingestion of soil particles by humans	Not relevant (metal bioaccessibility: not reduced)
6	Plants to animals	metal uptake through contaminated forage	Change of land use towards bioenergy (SRC)
7	Animals to humans	metal accumulation in animal products	Change of land use towards bioenergy (SRC)
8	Water to humans		Not investigated
9	Plants to humans	Relevant for arable land/food crops only	Not investigated

Remediation technology	Description
Pre-treatment	Conventional agricultural practice, fence was built to protect young trees from wildlife animals
In-situ stabilization	-
Phytoextraction/-stabilization	Selection of poplar and willow clones for low/ high element uptake, biomass production; herbicides used in the 1st year
Biomass management and use	Trees were cut and chaffed by a chartered specific wood harvester every 3rd year; biomass use: combustion plant → co-generation of heat and power
Biomonitoring, soil management	Every year analysis of total and labile elements in the soils, elements in plant tissue / wood chips, faunistic and floristic investigations in the first 4 years
Timescale for reaching the objective	Mitigation of transfer of TE into the food chain: immediately Complete phytoextraction referred to total concentration: more than 100 years (Cd)
Major hindrances	Weed control and protection against wildlife animals at the beginning, specific harvester to be rented, non-annual income generation (every 3rd year only), draught during the 1st year

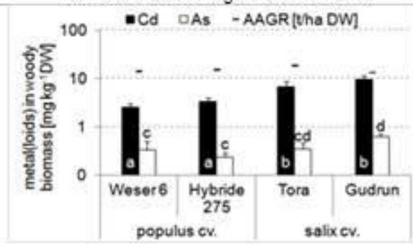
Specific achievements	Description
Reduction of total metal (Cd, Zn, Pb) pools in the soil	Compared to adjacent arable land mobile As could be reduced by ~ 90 %
Mitigate TE transfer into food or forage, bioenergy production	SRC with poplars and willows is a suitable alternative to conventional agriculture, average biomass production was 15 t/ha/DW per year



Changes in pseudo-total (aqua regia) Cd over time (data 2005 – 2009 from Dietzsch et al. 2011)



Changes in mobility of Cd and As due to land change use from conventional agriculture to SRC



Element uptake into wood of poplar and willow clones and biomass production (annual average growth rate)

Key progresses over time

3rd harvest in Feb. 2013

Plantation in summer 2013 – all poplar and willow trees recovered from 3rd harvest

Projected balance sheet	Implementation	(phyto)management	Financial returns
Cost/revenues	Grubbing, Plantation of cuttings: willow < poplar	Pesticides, fencing, charter fee for harvester, biomass logistics	Major factors: biomass production, price for wood chips, duration of management option (min. 5 – 6 years, Dietzsch 2011), management costs, subsidies
Phytomanaged area	2 ha	2 ha	
Uncertainty of upscaling	Medium; specific care during implementation (weed and pest control, fencing, irrigation where required)		
Influence of upscaling on the cost/revenues	High implementation costs, improvement of plant performance, harvest process, subsidies (Greening)		
Possibility to change the land use	Yes – need to remove tree roots		
Biomass use	Combustion plants (energy and heat production)		

For more information			
Contacts	State agency: LfULG	Dr. Ingo Müller	Ingo.mueller@smul.sachsen.de

Representativeness evidences: Low / • **Medium** / High

References

•**Neu** S. & I. Müller (2014 - oral presentation): Gentle remediation options (GRO) for the management of large-scale contaminated agricultural sites in Saxony, Germany. 4th International Conference on Managing Urban Land – Tailored and Sustainable Redevelopment towards Zero Brownfields, 14. – 16. Oktober, Frankfurt am Main.

•**Neu** S. & I. Müller (2013): Gentle remediation options (GRO) for the management of large-scale contaminated agricultural sites in Saxony, Germany. Practical examples from the EU-Projekt GREENLAND (FP7) (in german). Poster and manuscript in conference proceedings of 5th Saxon-Thuringian Soil protection days in Altenburg, Thuringia.

• Dietzsch (2011): Utilisation of contaminated soils (in German); Saxon State Office for Environment, Agriculture and Geology, Dresden.

https://publikationen.sachsen.de/bdb/artikel/14994/documents/17993

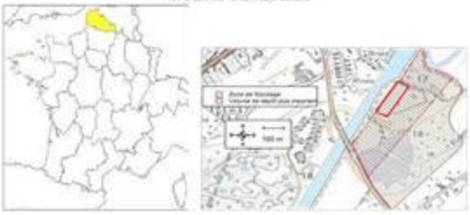
Example 2: Aided phytostabilisation (FR)

Site name	Fresnes-sur-Escaut	GRO type	Aided phytostabilization
Location	Fresnes-sur-Escaut, France	Origin of soil contamination	Emissions and ores of metal industry over decades
Site type	Contaminated sediment deposit site	Implementation of field trial	Start : 2011 – on going
Current land use	No use	Lifetime	6 years
End land use	No use	Surface area	1 ha
Objective	Reduction of pollutant linkages, forage/ bioenergy production, reduce mobile TE		

Soil characteristics	Initial values	After best GRO	Initial labile pool* mg/kg	Labile pool after best treatment§ mg/kg
pH	7.29 ± 0.06	8.05 ± 0.17		
Sand, silt, clay(%)	Silty sandy clay	Silty sandy clay		
Organic C (%)	15.3	3.6		
CEC (cmol+/kg)	23.5	19.4 ± 3.9		
As (mg/kg)	48 - 69	29 - 48	0.008	0.006 ± 0.000
Cd (mg/kg)	7 - 11	6 - 10	0.025	0.015 ± 0.002
Cr (mg/kg	93 - 90	78 - 96	0.009	0.008 ± 0.001
Cu (mg/kg)	95 - 118	79 - 105	0.394 ± 0.065	0.105 ± 0.013
Pb (mg/kg)	801 - 1327	647 - 1327	0.013 ± 0.006	0.038 ± 0.018
Zn (mg/kg)	7254 – 11047	6600 - 9844	15.23 ± 14.52	6.406 ± 1.040

* NH_4NO_3 ‡ after 2 years
For total metal concentrations minimum and maximum values, in dry weight

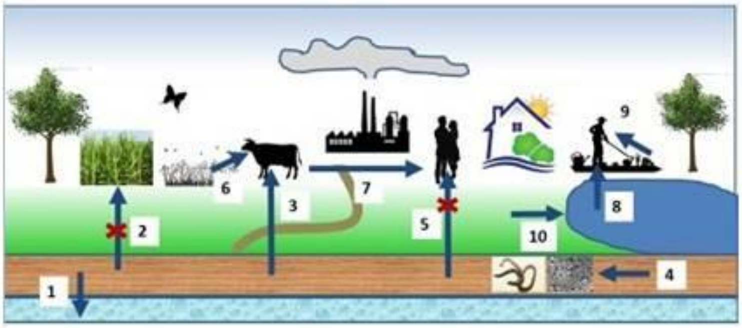
Fresnes-sur-Escaut



Core stakeholder	Function	Remark
Voies Navigables de France (VNF)	Site owner	
INERIS (Institut National de l'Environnement indutriel et des RISques)	Scientific monitoring	

Main site operators

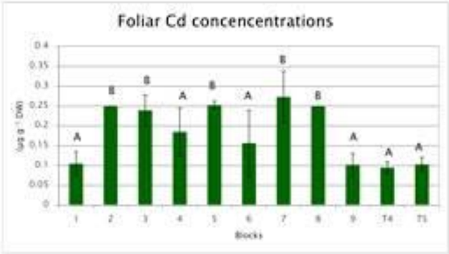
Conceptual model and relevant pollutant linkages



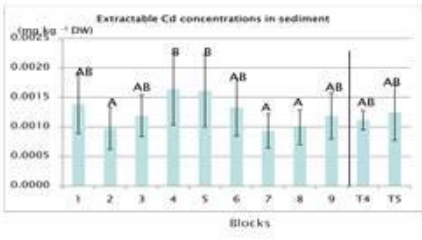
	Pollutant linkages	Initial status	Achievement
1	Soil to groundwater	Not relevant	
2	Soil to plants	metal accumulation in cover grass	uptake into cover grass reduced
3	Soil to animals		not investigated
4	Soil to microorganisms		not investigated
5	Soil to humans	Ingestion of soil and dust inhalation	100 % of soil covered by grass
6	Plants to animals		not investigated
7	Animals to humans		not investigated
8	Water to humans		not investigated
9	Plants to humans		not investigated

Remediation technology	Description
Pre-treatment	Removal of initial plant cover of which an invasive species (*Fallopia japonica*)
In-situ stabilization	Basic mineral amendment (Optiscor)
phytostabilization	Sowing of a commercial cultivar of grass (*Barchampsia cespitosa*) at high density
Biomass management and use	Lawn mowing twice a year, with no removal; specific removal of *Fallopia japonica* and composting
Biomonitoring, soil management	Once a year : grass and plant colonizers analysis : metal concentrations Once a year : analysis of pH and total and labile metal pool in the soil
Timescale for reaching the objective	A few weeks - 3 years
Major hindrances	Soil heterogeneity (metal pollution, sediment texture and structure)

Specific achievement	Description
Reduction of plant uptake	Foliar element concentration in cover grass has been reduced by 60 % (Zn); 20% (Cd).
Reduction of surface covered by invasive species	Reduction by 27% after 1 year monitoring



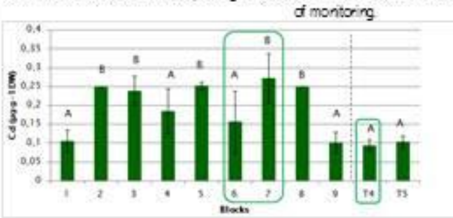
After 2 years of monitoring, foliar Cd concentrations in *Barchampsia cespitosa* approximate common values (0,05-0,2 mg kg^{-1}) found in grasses grown on uncontaminated soils (Kabata-Pendias, 2010).

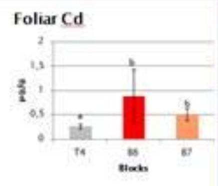


0.01M $Ca(NO_3)_2$ - extractable Cd concentrations in sediments. Cd mobility is rather low as extractable Cd concentrations represent around 0.015% of the total sediment Cd. After 2 years of monitoring, Cd is not significantly reduced by the alkaline mineral amendment (1-9 vs T4 and T5)

Key progresses over time

Foliar Cd concentrations in *Barchampsia cespitosa* at the beginning of the project (right) and after 1 year of monitoring (left). Despite the high Cd content in the sediment, the grass concentrate very few Cd in its foliage which makes it suitable for composting. A reduction in its Cd foliar concentration was measured after one year of monitoring.





Projected balance sheet	Implementation	(phyto)management	Biomass revenues
Cost/revenues	29 k€ *	4.69 k€	no
Phytomanaged area	1 ha	1 ha	
Uncertainty of upscaling	Medium (By far, efficiency of the cultivar *Barchampsia cespitosa* not tested on highly contaminated site)		
Influence of upscaling on the cost/revenues	High (due to the cost of implementation)		
Possibility to change the land use	No (no use)		
Biomass use	Compost		

*The implementation required the removal of initial plants, of which *Fallopia japonica* (specific removal)

For more information			
Contacts	INERIS VNF	Valérie BERT Marion DELPLANQUE	valerie.bert@ineris.fr marion.delplanque@vnf.fr

Representativeness evidences: Low / • **Medium** / High

References

ANDERSSON-SKÖLD Y, BARDOS P, CHALOT M, BERT V, CRUTU G, PHANTHAVONGSA P, DELPLANQUE M, TRACK T, CUNDY AB (2014). Developing and validating a practical decision support tool (DST) for biomass selection on marginal land. *Journal of Environmental Management 145: 113-121.*

BERT V, Hadj-Sahraoui A, Leyval C, Fontaine J, Ouvrard S (2012). Les phytotechnologies appliquées aux sites et sols pollués. Etat de l'art et guide de mise en oeuvre. Ed. EDP sciences. ISBN : 978-2-7598-0805-2

DELPLANQUE M, COLLET S, DEL GRATTA F, SCHNURIGER B, GAUCHER R, ROBINSON B, BERT V (2013). COMBUSTION OF *SALIX* USED FOR PHYTOEXTRACTION : THE FATE OF METALS AND VIABILITY OF THE PROCESSES, *BIOMASS AND BIOENERGY, 2013, 49: 160-170*

BERT V, LORS CH, PONGE JF, CARON L, BIAZ A, DAZY M, MASFARAUD JF. 2012. Metal immobilization and soil amendment efficiency at a contaminated sediment landfill site: A field study focusing on plants, springtails, and bacteria. Environmental Pollution 169: 1-11.

BERT V, SEUNTJENS P, DEJONGHE W, LACHEREZ S, THI THANH THUY H, VANDECASTEELE B (2009) Phytoremediation as a management option for contaminated sediments in tidal marshes, flood control areas and dredged sediment landfill sites. Environmental Science and Pollution Research 16:745–764.

KIDD P, MENCH M, ALVAREZ-LOPEZ V, BERT V, DIMITRIOU I, FRIESL-HANL W, HERZIG R, JANSSEN J O, KOLBAS A, MÜLLER I, NEU S, RENELLA G, RUTTENS A, VANGRONSVELD J, PUSCHENREITER M. Agronomic practices for improving gentle remediation of trace element-contaminated soils (Submitted).

KUMPIENE J, BERT V, DIMITRIOU I, ERIKSSON J, FRIESL-HANL W, GALAZKA R, HERZIG R, JANSSEN J, KIDD P, MENCH M, MÜLLER I, NEU S, OUSTRIERE N, PUSCHENREITER M, RENELLA G, ROUMIER P-H, SIEBIELEC G, VANGRONSVELD J, MANIER N (2014). Selecting chemical and ecotoxicological test batteries for risk assessment of trace element-contaminated soils (phyto)managed by gentle remediation options (GRO). *Science of the Total Environment, 496: 510-522*

MENCH M, LEPP N, BERT V, SCHWITZGUEBEL JP, GAWRONSKI S, SCHRÖDER P, VANGRONSVELD (2010) J. Successes and limitations of phytotechnologies at field scale: outcomes, assessment and outlook from COST Action 859 Journal of Soils and Sediments 10:1039–1070.

MENCH M, SCHWITZGUEBEL JP, SCHRÖDER P, BERT V, GAWRONSKI S, GUPTA S (2009) Assessment of successful experiments and limitations of phytotechnologies: I. Outcomes from COST Action 859 on contaminant uptake, detoxification and sequestration, and consequences for food safety. Environ Sci Pollut Res 16, 876-900.

Example 3: *In situ* stabilisation / phytoexclusion (AT)

Site name	Arnoldstein	GRO type	*In-situ* immobilisation / Phytoexclusion
Location	Arnoldstein, Austria	Origin of soil contamination	Pb/Zn smelter emissions (start: 1495 – closed:1992)
Site type	Contaminated arable land	Implementation of field trial	start: 2002 – end:2014
Current land use	Arable land	Lifetime	actual:13 years
End land use	Arable land	Contaminated surface area	2 km² (trial plots 500 m²)
Objective	To produce safe food crops and reduce pollutant linkages		

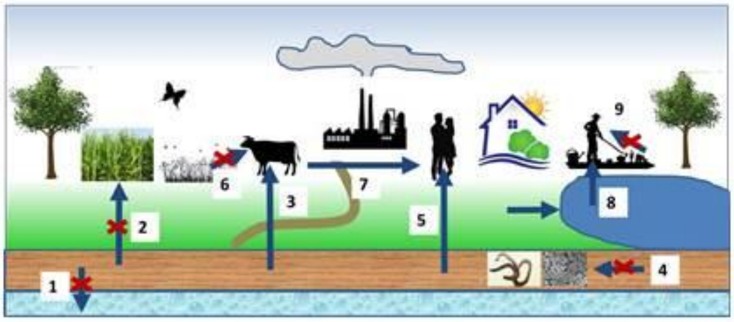
Soil characteristics	Initial values	After best GRO	Initial labile pool* mg/kg	Labile pool after best treatment$ mg/kg
pH	5	6.5		
Sand, silt, clay (%)	49 – 36 -15			
Organic C (%)	3			
CEC (mmol$_c$/kg)	50			
As (mg/kg)	32		0.025 ± 0.00	0.025 ± 0.00
Cd (mg/kg)	5		1.26 ± 0.04	0.28 ± 0.05
Cu (mg/kg)	58		0.10 ± 0.01	0.09 ± 0.01
Pb (mg/kg)	950		9.68 ± 0.47	0.96 ± 0.34
Zn	500		75.80 ± 2.95	10.05 ± 2.90

*1 M NH_4NO_3-extractable meta(loid)s in the control soil; $ in the treated soil after 7 years

Arnoldstein – arable land

Core stakeholder	Function	Remark	Main site operators
Farmers (Mr. Mitsche, Mr. Tschinderle)	Site owner and tenant		AIT AUSTRIAN INSTITUTE OF TECHNOLOGY TOMORROW TODAY
AIT and farmers	Site operator		
Dr. Wolfgang Friesl-Hanl	Scientist	Scientific driven	
Ministry of Agriculture, EU FP7	Funding organization	Operated by KPC	
Communities (Arnoldstein, Hohenthurn)	Communication		
Greenland partners	Scientific collaboration		

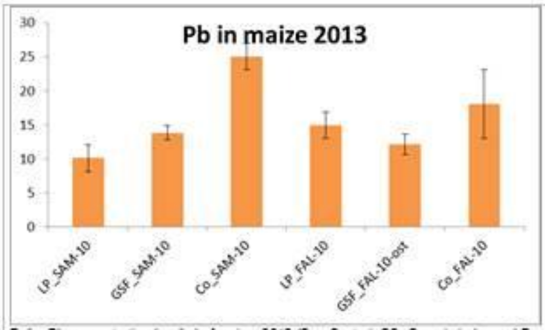
Conceptual model and relevant pollutant linkages



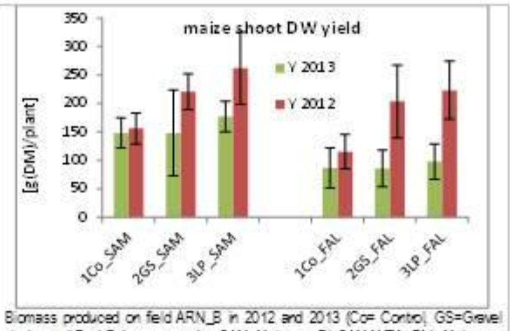
	Pollutant linkages	Initial status	Achievement
1	Soil to groundwater	Transfer of mobile metals to groundwater	Mobile element concentration reduced
2	Soil to plants	Metal accumulation in maize, barley and potato tubers	Uptake into crops reduced below threshold
3	Soil to animals	Biotest with terrestrial isopod *porcelio scaber*; (soil ingestion by cows while rearing on pasture was not investigated)$	Bio-accessibility could be reduced
4	Soil to microorganisms	Respiration curve of microbes are reduced	25% increase still after 10 years
5	Soil to humans		Not investigated
6	Plants to animals	Metal uptake through contaminated forage (e.g. maize silage)	Cd in maize below threshold of EC 2002
7	Animals to humans		Not investigated
8	Water to humans		Not investigated
9	Plants to humans	Metal uptake through contaminated potato tubers	Cd in potato tubers below threshold of EC 2001

Project execution	Description
Pre-treatment	Not necessary
In-situ immobilisation	Soil amendments: gravel sludge and iron bearing material; amount: 3 %(w/w) = 9 kg/m² = 90 t/ha
Phytoexclusion	Selection of Cd-excluding cultivars (barley, maize, potatoes) Conventional agricultural practices (organic farming principles)
Biomass management and use	Harvest: here shoot biomass in t DW/ha, annual analysis; biomass use
Biomonitoring, soil management	Every 2 years for labile metal pools in the soils.
Timescale for reaching the objective	Soil additives show immediately an effect, information for excluding cultivars has to be provided
Major hindrances	Cold and wet spring; dry summer

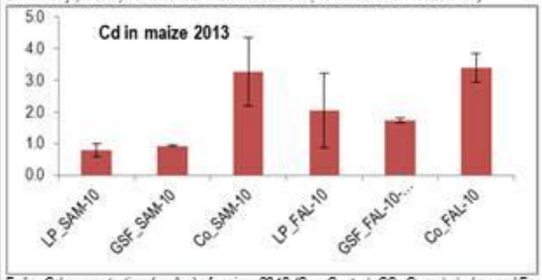
Specific achievements	Description
Reduction of labile metal (Cd, Zn, Pb) pools in the soil	1M NH_4NO_3-extractable Cd could be reduced by >80% Zn >90% and Pb >90%
Reduction of plant uptake	Cd uptake into barley could be reduced up to >75 % compared to accumulating cultivar. Uptake into maize silage was reduced up to 50%(Cd), 60%(Pb), 70%(Zn)



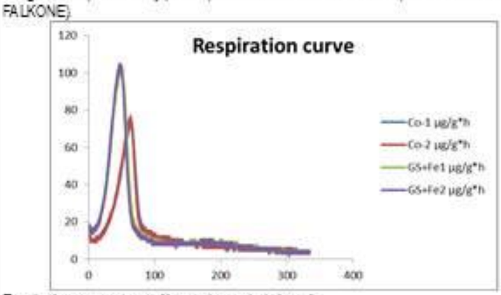
Foliar Pb concentration (mg/kg) of maize 2013 (Co= Control, GS=Gravel sludge and Fe, LP=Loamy powder, SAM=Maize cv. DieSAMANTA, FAL=Maize cv. FALCONE).



Biomass produced on field ARN_B in 2012 and 2013 (Co= Control, GS=Gravel sludge and Fe, LP=Loamy powder, SAM=Maize cv. DieSAMANTA, FAL=Maize cv. FALKONE).



Foliar Cd concentration (mg/kg) of maize 2013 (Co= Control, GS=Gravel sludge and Fe, LP=Loamy powder, SAM=Maize cv. DieSAMANTA, FAL=Maize cv. FALCONE).



Respiration curves: treated in purple, controls in red

Key progresses over time

Maize: July 28th 2011 (view to north)

Maize August 13th 2012 (view to north)

Summary:
Main pathways of metal transfer such as
soil to plants,
soil to groundwater,
plants to animals,
plants to humans
could be reduced by the treatments
***in-situ* immobilisation** in combination with **phytoexclusion**.

Projected balance sheet	Implementation	(phyto)management	Financial returns
Cost	If waste material – only transport and application; If product (€ 100,00 per ton) = € 9.000,00/ha)	Typical agriculture	Quality improvement, legal compliance
Phytomanaged area	500 m²		
Uncertainty of upscaling	Very low, biomass can be used, crops can be changed		
Post alternative land use	crop production		

For more information			
Contacts	AIT Austrian Institute of Technology GmbH	Dr. Wolfgang Friesl-Hanl	wolfgang.friesl-hanl@ait.ac.at

Representativeness evidences: Low / Medium / **High**

References

Friesl-Hanl W., M.H. Gerzabek , W.W. Wenzel , W.E.H. Blum. Industrial Waste: Soil Pollution. In Encyclopedia of Environmental Management. Taylor and Francis: NewYork, Published online: 01 May 2013; 1430-1433.

Friesl-Hanl W, Platzer K, Horak O, Gerzabek MH 2009 Immobilising of Cd, Pb, and Zn contaminated arable soils close to a former Pb/Zn smelter: a field study in Austria over 5 years. Environmental Geochemistry and Health 31(5):581-94

Friesl W., J. Friedl, K. Platzer, O. Horak, M. H. Gerzabek (2006): Remediation of contaminated soils in the vicinity of a former Pb/Zn smelter in Austria: Batch, Pot, and Field experiments; Environmental Pollution, 144 (1): 40-50.

Udovic M., Drobne D., Lestan D. (2013). An in vivo invertebrate bioassay of Pb, Zn and Cd stabilization in contaminated soil. Chemosphere 92: 1105–1110

4. Potential economic, environmental and social benefits.

GROs have potential to deliver a range of additional economic (*e.g.* biomass generation), social (*e.g.* leisure and recreation) and environmental (*e.g.* C sequestration, water filtration and drainage management, restoration of plant, microbial and animal communities) benefits (which are encompassed in the generic term "ecosystem services"), as well as risk management. These wider benefits have often been only superficially considered during remediation options appraisal in the past, but present a potentially very important wider value proposition for use of "soft" remediation strategies such as GRO. Benefits may be in the form of direct revenue generating opportunities (*e.g.* biomass revenues), an increase in natural or cultural capital in an area (*e.g.* soil and water improvement, provision of green infrastructure, amenity space etc.), or provision of tangible or intangible economic benefits (*e.g.* increase in property values, job generation etc.). While economic, social and environmental benefits will clearly be site and project specific, a number of more generic qualitative, semi-quantitative and fully quantitative tools and systems are available to enable identification and quantification of wider benefits arising from application of GRO. Within the GREENLAND decision support tool (DST), links to three matrices/modules are provided:

(a) The European Union FP7 HOMBRE project (grant 265097, www.zerobrownfields.eu) **Brownfield Opportunity Matrix** (BOM). This is an Excel-based qualitative screening tool to help decision makers identify which services they can obtain from "soft reuse" interventions (including GRO) at a site, and how these services interact. GREENLAND partners have collaborated with HOMBRE partners to populate the operating and opportunity windows for GRO within the Brownfield Opportunity Matrix. The matrix can be used to map the prospective range of opportunities that might be realised by a remediation or redevelopment project, and the project's consequent sources of value.

(b) The SURF **indicator sets on sustainability**, which outline the various headline indicators that should be considered during sustainability assessment in land remediation projects. These indicators provide a semi-quantitative ranking system based on key economic, environmental and social indicators. In the DST, the user is then referred on to more detailed, external web-based tools for semi-quantitative and quantitative assessment via Life Cycle Assessment (LCA) and Cost Benefit and Multi-Criteria Analysis (CBA/MCA)

(c) An outline **Cost-Calculator**, which has been developed within the GREENLAND project and incorporates user-entered cost data (including site preparation costs; plant and planting costs; site costs; biomass costs and revenues; and monitoring costs) to estimate the economic value proposition of GRO at a particular site. This module has been "calibrated" using data from the GREENLAND site network, which are used to test the cost calculator and give input examples to the user.

It is important to stress that alongside the more technical aspects of remediation, effective and sustained engagement strategies with a wide range of stakeholders will be required to ensure that the full potential benefits of GRO are realised and communicated. Additional support and guidance for stakeholder engagement, including **guidelines for stakeholder engagement** when applying GRO and criteria for the identification of different stakeholders profiles/categories, is provided in the Greenland project decision support tool and in Appendix 6.

5. Operating windows for GRO.

5.1 High-level (generic) operating windows – managing site risk for soft end-use.

Biologically productive soils include those used for agriculture, habitat, forestry, amenity, and landscaping, and therefore GROs will tend to be of most benefit where a "soft" end use of the land is intended. Conventionally regeneration of contaminated land for soft end use has involved the use of cover systems with revegetation and/or removal of contamination hot spots. Remediation (*i.e.* mitigation of the effects of contaminants using biological, chemical or physical treatment) has been largely restricted to returning smaller land areas to hard re-use as these treatments simply tend to cost too much for soft end uses.

There are many drivers for soft end uses of contaminated land. The site in question may simply not have a feasible alternative use for reasons of size, location, geotechnical or topographical reasons, or levels of economic activity, as a result of global shifts in land use and industrial change. There may be important urban renewal arguments for developing amenity land, particularly in areas of urban deprivation. In addition, there may also be opportunities for generating renewed economic activity, for example, through biomass production. Indeed, the EU Renewables Directive (DIRECTIVE 2009/28/EC) points out an enhanced sustainability value for biomass from marginal land, including contaminated land. The use of GROs can be highly compatible with biomass end use. This creates an important and expanding role for GROs, as an important part of the value proposition for the management of degraded land in the future might be an income from biomass-based GRO.

GROs therefore offer a cost effective treatment alternative for managing risks for soft end uses, rather than simply containing or transferring contamination. GROs should be attractive alternatives to conventional clean-up methods in these situations owing to their relatively low capital costs and the inherently aesthetic nature of planted or "green" sites. In addition, "greening" of contaminated or marginal land may have additional wider benefits in terms of educational and amenity value, C sequestration, resource deployment (i.e. for re-use of organic matter/compost and technosols) and providing a range of ecosystem services – see also section 4.

5.2 Detailed operating windows.

As discussed above, and illustrated by the case/success stories in section 3, GRO can be effectively used as part of a wider risk management strategy at contaminated sites, while promoting additional economic, environmental and social benefits. GRO can be implemented in a range of soil types and climates, across a range of site and contaminant types. As with other remediation strategies however they are not a simple "off-the-shelf" solution that can be applied to every site situation and type, and a site specific assessment and testing is required prior to implementation. Further details on GRO design and implementation are given in the technical appendices which accompany this guidance, but here we provide quick reference tables on GRO applicability, and a link to three MS Excel-based operating window matrices which allow the user to check the outline applicability of GRO (grouped as phytoextraction, phytostabilisation, and immobilisation/phytoexclusion) to a specific site, in terms of local soil pH, site plant toxicity, climate, soil type, and depth of contamination. The purpose of these tables and matrices is to highlight the potential applicability of GRO at a site, NOT to confirm that GRO will be a successful risk management tool at that site.

Further technical and design input and expertise will be required to effectively design and implement a GRO strategy that effectively manages contaminant risk, and delivers wider benefit. Contact points and further literature to support this is given in section 6, in the appendices, and on page 1 of this guidance.

Quick reference: Are GRO applicable to your site?

Key questions:	If YES, are GRO potentially applicable?
Does the site require immediate redevelopment?	**Unlikely** (except immobilisation / phytoexclusion which can show immediate positive effects)
Are your local regulatory guidelines based on total soil concentration values?	**Unlikely** for phytoextraction but **possibly** for some other GRO
Is the site under hard-standing, or has buildings under active use?	**Unlikely** (there is a need to remove the hard-standing or buildings and to establish a soil layer enabling plant growth).
Do you require biological functionality of the soil during and after site treatment?	**YES**
Is the treatment area large, and contaminants are present but not at strongly elevated levels?	**YES** (even where soil ecotoxicity is high, use of soil pretreatments and amendments may enable GRO application)
Are the contaminants of concern present at depths within 5 – 10m of the soil surface?	**YES** (depending on soil porosity, if contamination is present within 1m of the soil surface then treatment is possible by most plants. Deeper contamination may be addressed using trees, with interventions where necessary to promote deeper rooting).
Is the economic case for intervention and use of "hard" remediation strategies marginal?	**YES**
Are you redeveloping the site for soft end-use (biomass generation, urban parkland etc)?	**YES**

Quick reference: Which metal(loid) contaminants can GRO treat?

GRO Contaminant	Phytoextraction (stripping of bioavailable metal(loid))	Phytostabilisation (including aided phytostabilisation)	In situ immobilisation / phytoexclusion
Arsenic	✓✓*	✓**	✓**
Cadmium	✓✓	✓✓	✓✓
Chromium	-	✓	✓✓
Copper	✓✓	✓	✓✓
Lead	✓	✓	✓✓
Nickel	✓✓	✓✓	✓✓
Zinc	✓✓	✓	✓

Number of tick marks in the table represents degrees of confidence, using data from the GREENLAND site network. Supporting data can be found in the individual site descriptions in Appendix 7.
For Arsenic: * some hindrances if the soil is contaminated with Cu; **Aided phytostabilisation & in situ immobilisation : As sorption can reverse due to ageing and/or building of organic litter

Link to MS Excel-based operating window matrices allowing the user to check the outline applicability of GRO (grouped as phytoextraction, phytostabilisation, and immobilisation / phytoexclusion) to a specific site can be accessed via the GREENLAND project decision support tool (DST), downloadable from: http://www.greenland-project.eu/

6. Selected further information sources.

Phytoremediation for trace element contaminated sites: the Greenland project	http://www.greenland-project.eu/
ITRC Phytotechnologies guidance	http://www.itrcweb.org/Guidance/GetDocument?documentID=64
USEPA Phytotechnologies factsheet (including links to success stories)	http://www.epa.gov/tio/download/remed/phytotechnologies-factsheet.pdf
Application at US Superfund sites (USEPA, 2014)	http://www.epa.gov/superfund/accomp/news/phyto.htm
CLU-IN phytotechnologies overview	https://www.clu-in.org/techfocus/default.focus/sec/Phytotechnologies/cat/Overview/
Further examples of full-scale phytotechnology application	http://www.clu-in.org/products/phyto/search/phyto_list.cfm
Phytoremediation of Contaminated Soil and Ground Water at Hazardous Waste Sites	http://www.clu-in.org/download/remed/epa_540_s01_500.pdf
Phytoremediation of contaminated soils and groundwater: lessons from the field	http://www.au-plovdiv.bg/cntnr/fiziologia/statii/Vassilev/23.pdf
Willows for energy and phytoremediation in Sweden	http://www.fao.org/docrep/008/a0026e/a0026e11.htm
Stakeholder engagement guidance for GRO and case studies	http://www.ncbi.nlm.nih.gov/pubmed/23973957, http://www.greenland-project.eu/