Guide for Application of Phytoremediation in Romania

"phytoremediation"
phyto = plant
remedium = to correct/to remove an evil

Phytoremediation is an innovative and cost effective remediation technique which uses plants to remove pollutants from the environment or to reduce their toxicity.

This guide was developed in the framework of the project "Capacity Building in Sustainable Environmental Techniques. The Application of Phytoremediation in Romania." The project was partially financed by the Flemish Government and was carried out between January and November 2009.

The guide is practical tool designed to promote phytoremediation among Romanian stakeholders (public institutions, NGOs, universities, research centres, SMEs, etc.) which are actively involved in the rehabilitation process of polluted areas from Romania.

What is phytoremediation?

The term "phytoremediation" consists of the Greek prefix *phyto* = plant, and the Latin root *remedium* = to correct/to remove an evil. Phytoremediation is defined as the use of green plants to remove pollutants from the environment or to reduce their toxicity. Phytoremediation is also referred to as bioremediation, botanical-bioremediation or Green Remediation.

Applications of phytoremediation

Phytoremediation may be applied wherever the soil or static water environment has become polluted or is suffering ongoing chronic pollution.

Examples where phytoremediation has been used successfully include the restoration of abandoned metal-mine workings, reducing the impact of sites where PCBs have been dumped during manufacturing and mitigation of on-going coal mine discharges.

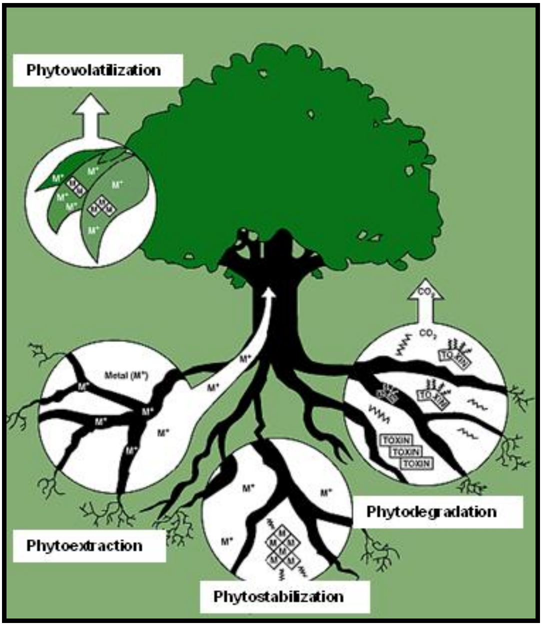
For what type of contaminants is phytoremediation suitable?

Contaminants that have been remediated in laboratory and/or field studies using phytoremediation techniques include:

- Heavy metals (Cd, Co, Pb, Cu, Ni, Se, Zn);
- Radionuclides (Cs, Sr, U);
- Chlorinated solvents (TCE, PCE);
- Petroleum hydrocarbons (BTEX);
- Nutrients (nitrate, ammonium, phosphate).

Types of phytoremediation

There is a wide variety of subcategories in the field of phytoremediation. The most common phytoremediation types are: phytoextraction, phytostabilization, rhizofiltration, phyto-degradation and phytovolatilization.

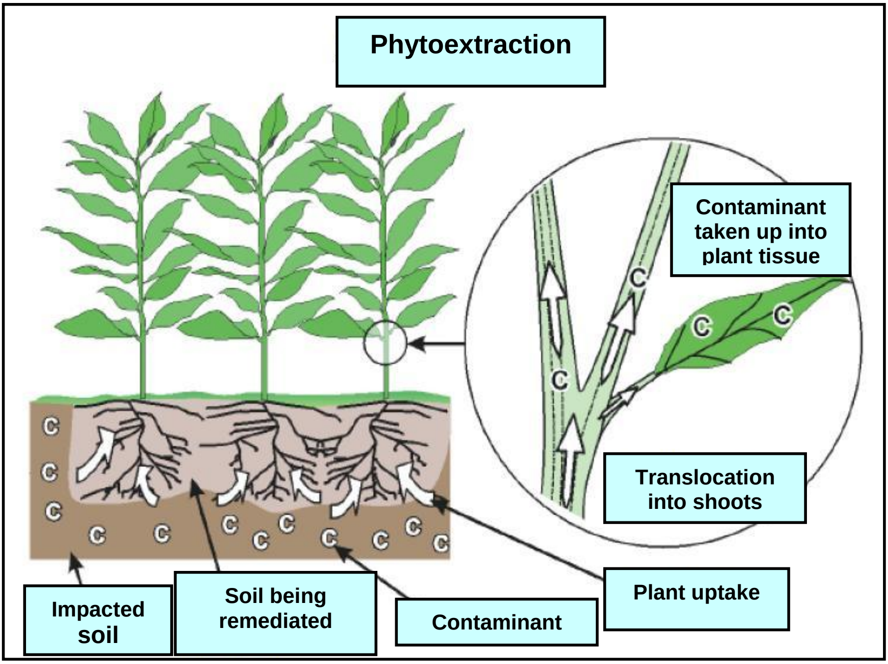


Phytoextraction

Phytoextraction (also referred as phytoaccumulation or phytomining) can be defined as a technique which uses plants to remove inorganic contaminants, especially metals, from contaminated soil. The process involves the removal of contaminants (metals, radionuclides, and certain organic compounds) from the environment by direct uptake into the plant tissue. Implementation of a phytoextraction application involves the planting of one or more species that are hyperaccumulators of the contaminants of concern.

Hyperaccumulators are plants which have the ability to tolerate and accumulate high concentrations of metals in their tissues.
In generally, all plants take up necessary nutrients, including metals, from the soil and water environments.

Hyperaccumulators take up a higher amount of metals than necessary for the nutrition and sometimes also metals that do not appear to be required for plant functioning.



The most hyperaccumulators known accumulate Ni, while others accumulate Cd, Co, Cu, Zn, but there are very few hyper-accumulators for Pb. The extraction of lead from contaminated soils can occur only by applying certain soil amendments. Encouraging is the fact that approximately 400 plant species from at least 45 plant families have been reported to hyper-accumulate metals (e.g. *Brassicaceae*, *Fabaceae*, *Euphorbiaceae*, *Asteraceae*, *Lamiaceae*, and *Scrophulariaceae*).

List of hyperaccumulators

Genus and species	Family
Cobalt	
Aeollanthus biformifolius	*Lamiaceae*
Crotalaria cobalticola	*Fabaceae*
Cyanotis longifolia	*Commenlinaceae*
Haumaniastrum homblei	*Lamiaceae*
Haumaniastrum robertii	*Lamiaceae*
Copper	
Aeollanthus biformifolius	*Lamiaceae*
Bulbostylis mucronata	*Cyperaceae*
Haumaniastrum katangense	*Laminaceae*
Ipomoea alpina	*Convolvulaceae*
Lidernia perennis	*Scrophulariaceae*
Nickel	
Alyssum argenteum	*Brassicaceae*
Bommueller baldacci tymphaea	*Brassicaceae*
Geissois pruinosa	*Cunoniaceae*
Peltaria emarginata	*Brassicaceae*
Psychotria douarrei	*Rubiaceae*
Thlaspi alpinum sylvium	*Brassicaceae*
Lead	
Armeria maritima halleri	*Plumbaginaceae*
Thlaspi alpestre	*Brassicaceae*
Thlaspi rotundifolium cepaeifolium	
Manganese	
Macadamia neurophylla	*Proteacea*
Maytenus bureauvianus	*Celastraceae*
Maytenus sebertiana	*Celastraceae*

Zinc	
Thlaspi alpestre	*Brassicaceae*
Thlaspi calaminare	*Brassicaceae*
Thlaspi caerulescens	*Brassicaceae*
Thlaspi tatraense	*Brassicaceae*

Allysum argentums (Copper)

Haumaniastrum homblei (Cobalt)

Festuca-rubra (Lead, Zinc)

Eichhornia crassipes (Zinc, Copper, Lead, Nickel)

Brassica juncea (Chromium 6+, Cadmium, Nickel, Zinc, Copper)

Populus (Cadmium, Nickel, Zinc)

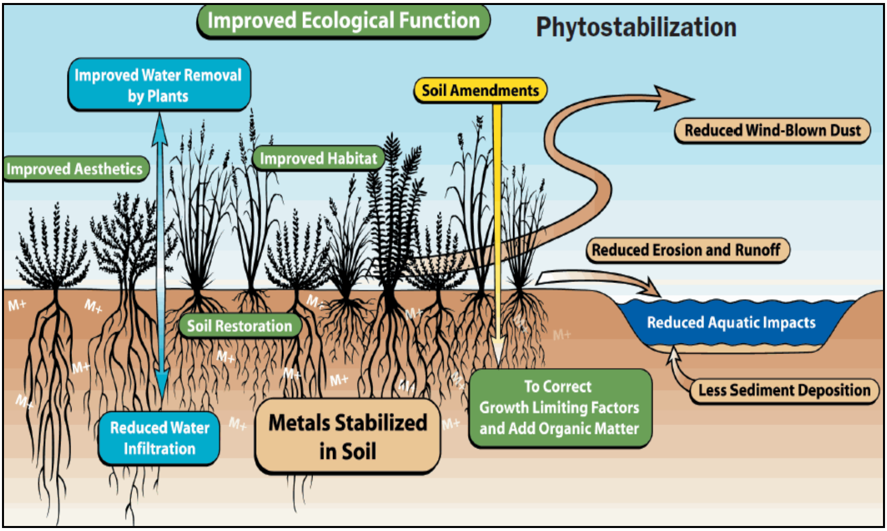
Thlaspi-alpestre (Zinc)

Willow (Cadmium, Zinc,

Phytostabilization

Phytostabilization is defined as the use of certain plant species to immobilize contaminants in the soil and groundwater through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone. This technology is very effective when rapid immobilization is needed to prevent migration of the pollution to the ground and surface water.

Phytostabilization is useful for the treatment of lead (Pb) as well as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Suitable plants for this technology are *Agrostis tenuis*, cv Parys for copper waste, *Agrostis tenuis*, cv Coginan for acid lead and zinc wastes, *Festuca rubra*, cv Merlin for calcareous lead and zinc wastes.

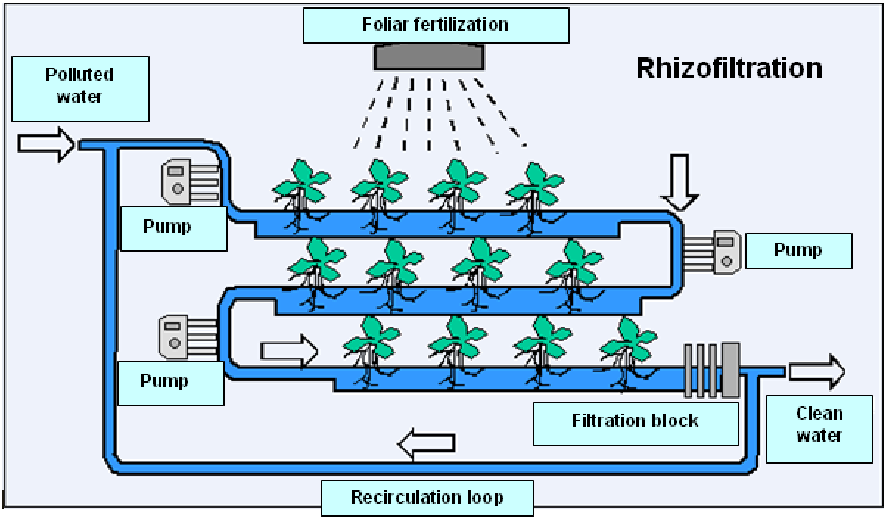


The advantages are the cost efficiency compared to other techniques (e.g. excavation, landfilling, and cement stabilization), the effective and durable immobilization of metals, the physical stabilization of the soil against wind erosion and metal percolation to the ground water, and the improvement of the landscape aesthetics. As compared to “hard” (“high impact”) remediation techniques, this technique does not destroy or remove soil organic matter, soil microorganisms, and soil texture and can be classified as a "soft" ("low impact") site rehabilitation technique, which can lastly serve as a standby process to reduce the impact of trace element-contaminated soil prior to the use of the most appropriate technologies for clean-up.

Some of the disadvantages are that the contaminant remains in the soil, the technique may not be appropriate at certain contaminated sites, e.g. due to the contamination with a combination of metals and organics, stabilization of the contaminants may be primarily due to extensive fertilization and soil amendments.

Rhizofiltration

Rhizofiltration, also referred as phytofiltration, is used to remediate surface and groundwater and is defined as the use of plants (terrestrial and aquatic) to absorb, concentrate and precipitate contaminants from polluted waters in their roots.
This technology may be used for Pb, Cd, Cu, Ni, Zn and Cr, these metals being primarily retained within the roots.



Best results were obtained with varieties of sunflower (*Helianthus annuus L*.), with Indian mustard (*Brassica juncea*), tobacco (*Nicotiana tabacum L*.), spinach (*Spinacia oleracea L*.) and corn (*Zea mays L*.). Especially sunflower and Indian mustard present a great ability to remove lead from water. Sunflower was also used in the remediation of radionuclide (Sr and Cs) from surface water near Chernobyl. Aquatic plants such as hyacinth (*Eichhornia crassipes*), pennywort (*Hydrocotyle umbellate*), duckweed (*Lemna minor*) and water velvet (*Azolla pinata*) have been also utilized for water purification, although their efficiency is low because of the small size and slow growing roots.

Phytodegradation

Also known as phytotransformation, phytodegradation is defined as the use of plants and associated microorganisms to degrade organic contaminants to less toxic or non-toxic compounds or to breakdown complex organic molecules into simple molecules. If pollutant molecules are small they may be used as metabolites by the plant, thus becoming incorporated into the plant tissues.

This technology can be applied for soil, surface and ground water remediation being accomplished in situ or ex situ in ponds or wetlands. Many different compounds and classes of compounds can be removed from the environment by this method, including solvents in groundwater, petroleum and aromatic compounds in soils, and volatile compounds in the air.

Phytovolatilization

Phytovolatilization involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere. This technology is defined as uptake and transpiration of a contaminant by plant, with release of the contaminant or a modified form of the contaminant to the atmosphere. 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.

This phytotechnique has been primarily used for the removal of mercury; the mercuric ion is transformed into less toxic elemental mercury.

Harvesting, disposal or use of plant material

Once plants have accumulated the contaminants, plant shoots can be harvested and roots removed, followed by disposal or subsequent processing methods, depending on the toxicity of the end products. The most commonly mentioned process is controlled incineration, which results in ash with a high metals content. Some technologies allow for extraction of metals from ash, but it is considered that they are quite expensive. Other methods of plant tissue treatment are currently under investigation: sun, heat and air drying, composting, pressing and compacting. When trees (poplar, willow, acacia) are used for phytoremediation these can be harvested and used for paper or energy production.

Estimates of phytoremediation costs versus costs of established technologies (USEPA, 2000)

Contaminant	Phytoremediation costs	Estimated cost using other technologies
Metals	€ 70/m³	€ 220/m³
Site contaminated with petroleum hydrocarbons	€ 50.000	€ 550.000
10 acres of lead contaminated land	€ 350.000	€ 8.000.000
Radionuclides in surface water	€ 0,4 to € 1 per 1000 liters	None listed
1 hectare to 15cm depth (various contaminants)	€ 1.700 to € 10.000	None listed

Advantages and limitations of phytoremediation

Advantages

- Amendable to a variety of organic and inorganic compounds;
- Expensive equipment or highly specialized personnel is not required;
- No disturbance of soil or environment;
- Improved landscape aesthetics;
- Reduced cost compared to traditional methods;
- Habitant creation – biodiversity;
- Green technology;
- Publicly accepted;
- Low secondary waste volume;
- Sun as energy source;
- Provide erosion control;
- Reduced spreading of contamination via air and water;
- In large scale applications the potential energy stored can be utilized to generate thermal energy.

Limitations

- Long remediation time required;
- Restricted to sites with medium and low contaminant concentrations;
- Climate dependent/variable;
- Seasonal effectiveness;
- Potential transfer of contaminants (to animals or air);
- Limited performance;
- Harvested plant biomass may be classified as hazardous waste, hence disposal should be proper;
- Introduction of non-native species may affect biodiversity;
- Consumption/utilization of contaminated plant biomass is a cause of concern.

Comparison of phytoremediation with classic remediation techniques

An evaluation of remediation techniques is in generally a very difficult process because of the multiplicity of factors that must be taken into account. The successful application of certain techniques depends on the site characteristics, type and level of contamination, time required, surrounding environment, future use of the land and others. The economical aspects are also of high importance and a cost-benefit analyze should be carried out prior choosing the best suitable remediation technique for a given site.

	Phyto-remediation	In situ techniques	Ex situ techniques
Technical evaluation			
Concentration reduction	+++	+++	++++
Risk reduction	+++	+++	+++++
Laboratory/pilot tests needed	+	++	+++++
Duration	+	++++(+)	+++++
Economical evaluation			
Costs	+++++	+++	++
Benefits	+++	+	+
Use of the site	+	+++	+++++
Ecological evaluation			
Impact on flora, fauna, soil biota	++++	++	++++
Landscape	+++++	++	+++

Note: +: least positive
+++++: most positive

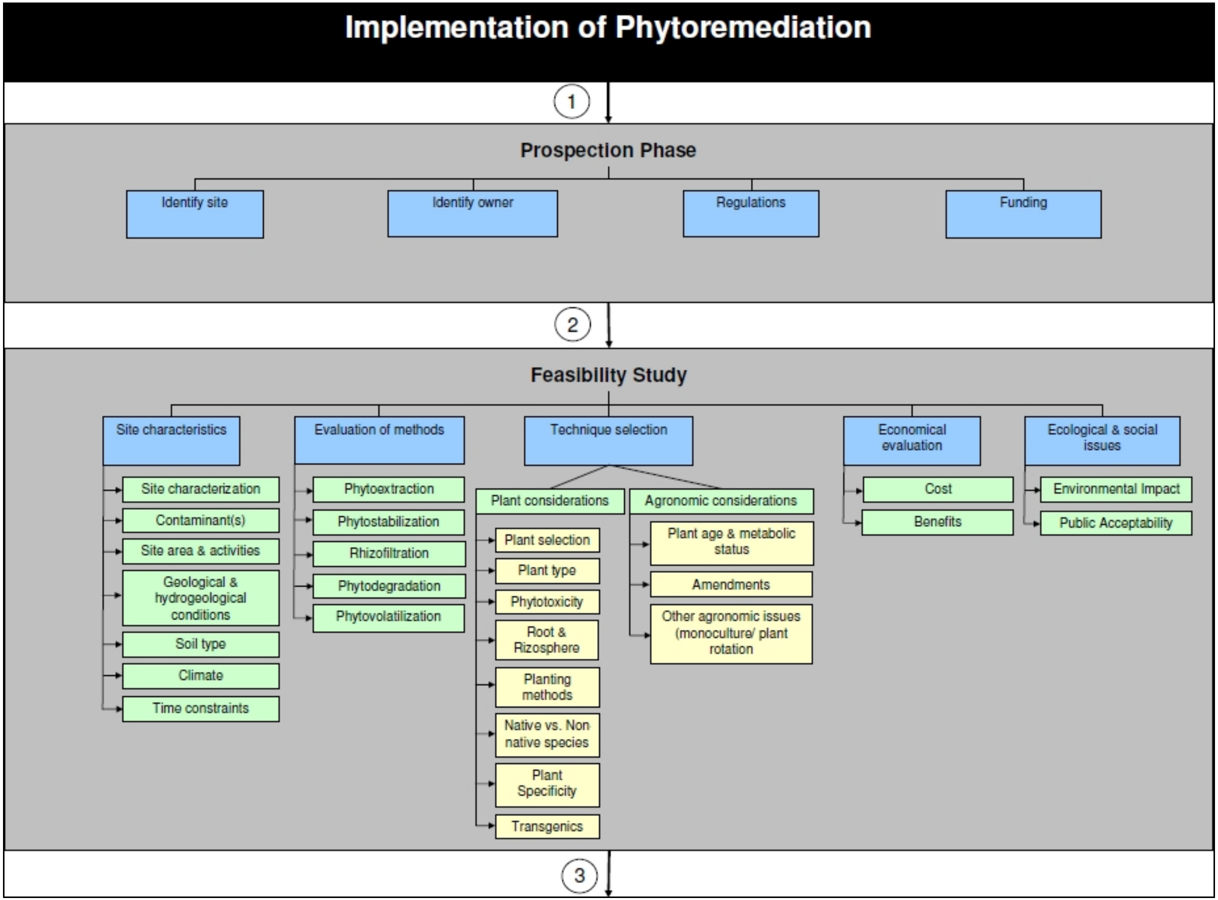
The evaluation presented in the table above is a general assumption based on literature study and represents only a brief approach of the compared remediation techniques. In many cases the score depends on several actors. For example, in case of phytoremediation several laboratory and pilot tests must be carried out prior to implementation, as long as in the case of classic remediation techniques, which are already established, tests are necessary only when dealing with innovations or improvements of these techniques.

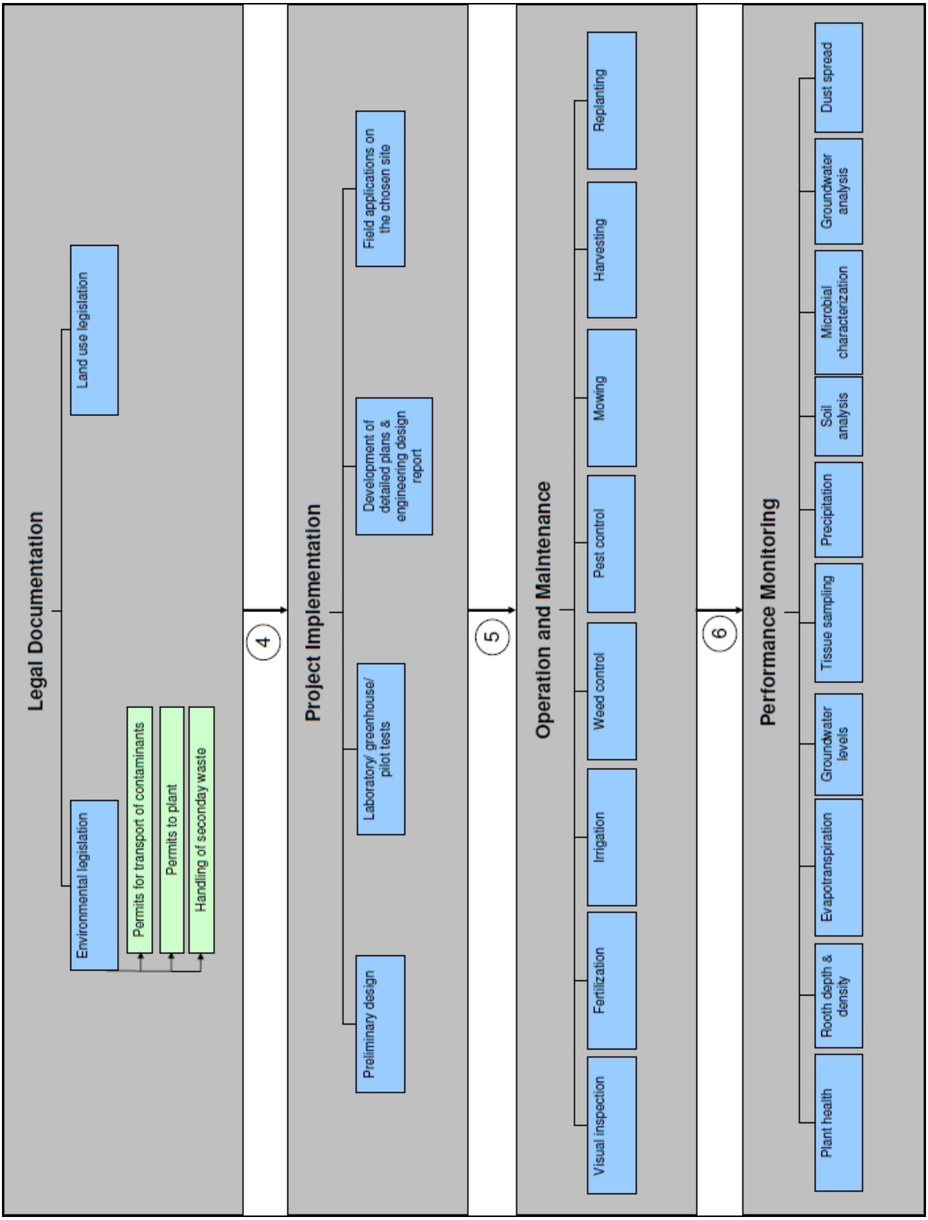
The evaluation of the costs for the described techniques points that phytoremediation is the less expensive method for remediation of contaminated sites, while the classic techniques, in situ as well as ex situ, require quite high financial efforts. For the economical evaluation is important to analyze which are the benefits when the site is restored, in terms of the future land use of the given site. For phytoremediation the results indicate a restricted use during the remediation process but economical benefits can be achieved for example by harvesting the trees used for phytoremediation and using them for energy production (bio fuels), paper manufacturing, furniture, etc.

Funding sources

Phytoremediation projects can be developed in the frame of national and international partnerships. The necessary funds for this type of projects can be obtained, for example, from the following sources:

- Eureka: http://www.eureka.be;
- Structural Funds: http://www.fonduri-structurale.ro;
- Environmental Fund: http://www.afm.ro;
- Ministry of Education, Research and Innovation: http://www.edu.ro.


Implementation of Phytoremediation
1
Prospection Phase
Identify site
Identify owner
Regulations
Funding
2
Feasibility Study
Site characteristics
Site characterization
Contaminant(s)
Site area & activities
Geological & hydrogeological conditions
Soil type
Climate
Time constraints
Evaluation of methods
Phytoextraction
Phytostabilization
Rhizofiltration
Phytodegradation
Phytovolatilization
Technique selection
Plant considerations
Plant selection
Plant type
Phytotoxicity
Root & Rizosphere
Planting methods
Native vs. Non native species
Plant Specificity
Transgenics
Agronomic considerations
Plant age & metabolic status
Amendments
Other agronomic issues (monoculture/ plant rotation
Economical evaluation
Cost
Benefits
Ecological & social issues
Environmental Impact
Public Acceptability
3


Legal Documentation
Environmental legislation
Permits for transport of contaminants
Permits to plant
Handling of seconday waste
Land use legislation
4
Project Implementation
Preliminary design
Laboratory/ greenhouse/ pilot tests
Development of detailed plans & engineering design report
Field applications on the chosen site
5
Operation and Maintenance
Visual inspection
Fertilization
Irrigation
Weed control
Pest control
Mowing
Harvesting
Replanting
6
Performance Monitoring
Plant health
Rooth depth & density
Evapotranspiration
Groundwater levels
Tissue sampling
Precipitation
Soil analysis
Microbial characterization
Groundwater analysis
Dust spread

References

- Ghosh, M. and Singh, S.P., A review on phytoremediation of heavy metals and utilization of its byproducts. - Applied Ecology and Environmental Research 3 (2005): 1-18.
- Miller, R.R., Phytoremediation. – GWRTAC Technology Overview Report (1996): 1-11.
- Henry, J.R., An overview of the phytoremediation of lead and mercury. - NNEMS for U.S. Environmental Protection Agency, Washington, DC (2000): 1-47.
- Bonaventura, C. and Johnson, F.M., Healthy environment for healthy people: Bioremediation today and tomorrow. Environmental Health Perspectives 105 (1997): 5-20.
- Green, C. and Hoffangle, A., Phytoremediation field studies database for chlorinated solvents, pesticides, explosives, and metals. – Report prepared for U.S. Environmental Protection Agency, Washington, DC (2004): 1-24.
- Vassilev, A., Schwitzguébel, J.-P., Thewys, T., Van der Leile, D., and Vangronsveld, J., The use of plants for remediation of metal-contaminated soils. The Scientific World Journal 4 (2004): 9-34.
- Salt, D.E., Blaylock, M., Kumar, N.P.B.A., Dushenkov, V., Ensley, B.D., Chet, I., and Raskin, I., Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. Biotechnology 13 (1995): 468-474.
- Dushenkov, V., Nanda Kumar, P.B.A., Motto, H., and Raskin, I., Rhizofiltration: The use of plants to remove heavy metals from aqueous streams. Environmental Science & Technology 29, No. 5 (1998): 1239-1245.

Web references

- http://arabidopsis.info/students/dom/mainpage.html
- http://www.biology-online.org/articles/phytoremediation-a-lecture/phytoextraction.html#
- http://quasimodo.versailles.inra.fr/inapg/phytoremed/nuls/comment.htm
- http://www.civil.northwestern.edu/EHE/HTML_KAG/Kimweb/MEOP/Section7.htm

Project partners

Romanian partners

EPA Maramures APM Maramures	EPA Suceava APM Suceava	APM Botosani EPA Botosani
Baia Mare Municipality	Maramures County Council	Gorj County Council
Baia Sprie Municipality	North University of Baia Mare	University Constantin Brancusi from Targu-Jiu
EPA Gorj APM Gorj	Baiut Municipality	Cavnic Municipality

Flemish partners

Ecorem nv	Hasselt University

FITS YOU

WITH THE SUPPORT OF
THE FLEMISH GOVERNMENT

Ecorem

Ecorem NV
Kontichsesteenweg 38, B - 2630 Aartselaar
Web: www.ecorem.be
Email: info@ecorem.be
Phone +32 (0) 38710900
Fax +32 (0) 38710901