URBAN SMS Soil Management Strategy

Handbook for measures enhancing soil function performance and compensating soil loss during urbanization process

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HANDBOOK FOR MEASURES ENHANCING SOIL FUNCTION PERFORMANCE AND COMPENSATING THE SOIL LOSS DURING URBANIZATION PROCESS

Final draft

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CONTENT

SUMMARY

Urban soils fulfill numerous functions ensuring balance in the urban ecosystem and quality of life for the human population. High quality soils, characterized by high water and heat capacity, high fertility and biological activity are very valuable due to their role for microclimate, biodiversity, flood prevention, dust reduction, filtering and buffering of contaminants or even keeping aesthetic functions of space and mental health of the population. Loss of soil or its transformation in urbanization process is practically irreversible. Therefore it is not possible to compensate loss of soil functions in the particular spot. However some compensation activities might be helpful to sustain performance of soil functions in the whole given area (e.g. city district) at the certain safe level. This Handbook presents a range of universal measures that can be used in a variety of urban environment to improve or sustain soil functions. These measures include recovery treatments bringing soil back to use, treatments improving soil function that are currently in use, and alternative measures without link to soil. The handbook is aimed to help in selection of the proper method of compensation when the problem is defined. The paper characterizes soil properties important for soil quality, functions, describe widely available soil treatments and other measures than can be applied in any area in order to enhance soil functions and presents a rough estimation of the effectiveness of these measures.

1. INTRODUCTION

The role of soils within urban space can not be limited to production function, strictly related to agricultural and forestry sectors, and being space for constructions. Urban soils fulfill numerous functions ensuring balance in the urban ecosystem and quality of life for the human population. Especially high quality soils, characterized by high water and heat capacity, high fertility and biological activity have high meaning including role for microclimate, biodiversity, flood prevention, dust reduction, filtering and buffering of contaminants or even keeping aesthetic functions of space and mental health of the population through creation of human-friendly areas.

We must be aware that loss of soil or its transformation in urbanization process is practically irreversible. Thus it is not possible to compensate loss of soil functions in the particular spot. T**he compensation measures mentioned in this report lead only to a partial compensation of the most important soil functions**. Additionally it must be kept in mind, that suitable areas for performing certain compensation actions are limited. **Therefore it is essential, to avoid or to minimize soil consumption as far as possible.**

When the soils are lost by sealing or degraded within urbanization process - the compensation activities are necessary to sustain performance of soil functions in the given area at the certain level (above threshold value). That level should allow avoidance of environmental risks and ensure life quality of population as a whole in all possible dimensions: social, environmental and economic.

There are various compensation definitions present in Central Europe cities. However, we propose the following compensation measure definition: **actions taken or instruments introduced in order to compensate/counterbalance soil loss or degradation during urbanization and to sustain/restore overall soils capacity to fulfill their functions in a given area**.

Review done within deliverable 6.1.1 of URBAN SMS project indicates that compensation of soil function loss varies among Central Europe cities both in terms of legal regulations, assessment and practice. In some locations the compensation is ambiguous element of soil protection framework whereas in other locations (e.g. Baden-Württemberg/ Germany) it comprises well defined assessment procedures and set of compensation alternatives. There is a broad frame of compensation policies in the partner cities. Many of existing instruments are of voluntary character. There are two main groups of measures:

1) direct measures including e.g. reuse of top soil excavated for reclamation of degraded land elsewhere or the removal of sealing, and 2) indirect measures, e.g. collecting fees for soil consumption that are used for environmental purposes.

Application of compensation measures might serve as a particular type of strategy of soil management – it would be a strategy for sustaining soil function performance in a certain area, rather then protection of soils against loss. The proposal for such a strategy is included in the Soil Manager Guide. An approach for assessment of compensation requirement in a given area as related to the given measure is for example the Stuttgart report "Compensation measures for encroachments on soil" (ahu AG, 13.10.2010) where the benefit of the measures is calculated with index-points based on the soil protection concept of Stuttgart. Such approaches, theoretically, might be framed as a formal tool.

This document focuses on measures that can be used in a variety of urban environment to improve or sustain soil functions. The handbook would help to select the proper method of compensation when the problem is defined. The subsequent sections characterize soil properties important for soil quality, functions, describe widely available soil treatments and other measures than can be applied in any area in order to enhance soil functions and presents a rough estimation of the effectiveness of these measures.

2. IMPORTANT SOIL FUNCTIONS TO BE PROTECTED

The soil is developed from parent rock material in a process of pedogenesis. Soil formation is an effect of combination of physical, chemical, biological and anthropogenic impacts. Pedogenesis is a very slow process, thus any soil loss or substantial transformation is practically irreversible. The soil is a basic element of terrestrial ecosystems, deciding on sustaining life on Earth. The main role of soil is biomass production and related processes of energy and matter cycling in the biosphere. In traditional understanding soil functions were limited to production of food and feed. Nowadays other functions of soil are appreciated as important for environmental quality both in rural and urban areas.

Production function related to **natural soil fertility**

Food production and therefore the food supply strongly depend on the availability of arable lands with soils of high fertility. Besides the supply of the still increasing world population, local food production opportunities should also be taken into account as beneficial for the local markets. Soil production potential (natural soil fertility) should be kept at high level, especially at peri-urban areas, even if their meaning as food reservoirs is currently lower.

Regulation of water balance (retention function)

Retention function is responsible for holding water in a soil profile and limiting risk of flood after torrential rains. Movement of contaminants and nutrients in profile of soil with high water holding capacity is slower since such soil reaches the full saturation much later.

Filter and buffer

Basic requirements for human health are unpolluted food and drinking water. Soils are able to filter particulate pollutants and to adsorb soluble pollutants by clay minerals and organic matter. Sorption and buffering function of soil retard migration of contaminants in the environment. Sorption of organic contaminants or heavy metals in soil protects ground and surface water against contamination.

Habitat (biodiversity) function

Habitat function is related to the role of soil in functioning of non-agricultural ecosystems that create the landscape picture and ensure **biodiversity** of landscape.

3. SOIL PROPERTIES IMPORTANT FOR SOIL QUALITY AND ABILITY TO PERFORM THE SOIL FUNCTIONS

3.1. ORGANIC MATTER

Soil organic matter (SOM) is a mixture of substances with complex structure and diverse properties. SOM is being constantly developed through transformation of plants and soil organisms decomposition products. Two main groups of soil organic substances are humic and fulvic acids. Their combination decides on properties of the SOM. Humic acids are characterized by the most complex structure and limited solubility in water. They have a high sorption ability and water retention capacity.

Fulvic acids have more simple structure and are soluble in water, thus they play a significant role in soil profile development process and contaminants migration. Fulvic acids are predominant in acidic soils.

Generally, the organic matter alters the soil sorption capacity for nutrients and contaminants. Sorption of metals and organic contaminants reduces their toxicity and environmental effects of contamination. Water retention in high organic matter soil is much greater than in soils with depleted organic matter. Soils rich in organic matter are more resistant to degradation processes.

3.2. PARTICLE SIZE DISTRIBUTION

This soil parameter describes share of different size fractions of soil particles (sand, silt, clay). It is an important criteria of soil classification in most countries. High percentage of coarse particles (gravel, sand) increases permeability and, in consequence, decreases water retention. Coarse soils are characterized by weak buffering capacity for pH change or contaminant input. Silt particles increase water retention and water movement to upper layers but increase susceptibility to erosion.

Clay particles (<0.002 mm) decrease soil permeability, increase water retention and sorption potential. Clay soils are generally more productive and more resistant to degradation, such as acidification or contamination.

3.3. SOIL pH

Soil pH is a parameter that has a strong impact on sorption capacity and availability of nutrients and heavy metals. In typical soils pH generally ranges from 4.0 to 8.5. In soils degraded by e.g. sulphur industry or presence of sulphides, pH may drop drastically (even below 3.0). Agricultural soils in climate with dominance of precipitation (downward movement of water) are subject of slow natural acidification processes related to leaching of basic cations. Application of some fertilizers, mostly introducing nitrogen as ammonia, also causes soil acidification.

Optimal pH for growing plants, biodiversity and proper organic matter and nutrient cycling is 5.5 to 7.2. Acidic pH of soil causes poor vegetation since few species are resistant to low pH, decrease in cation sorption, lower effectiveness of fertilizers, weaker soil structure, lower quality and amount of organic matter, resulting in progressive soil degradation.

Heavy metals in contaminated soils become more mobile in acidic environment and more available to food chain and living organisms.

3.4. SOIL CONTAMINATION

Anthropogenic pressure related to industrial and urban development, often without sufficient effort for waste management, has caused local soil contamination in most countries. Main groups of contaminants are organic compounds (e.g. PCB, Polycyclic Aromatic Hydrocarbons) and trace elements (e.g. cadmium, lead, mercury). Contamination with organic compounds is a result of such activities as refineries, industry producing chemicals, plastics, dyes, power plants. Organic contaminants in soil might limit microbial activity and cause risk for soil and other organisms. Soil contamination with trace metals mainly results from activity of smelters, tanneries, plant producing paints, cables, ceramics, power plants. Contamination with metals, depending on level of contamination and soil properties, may cause phytotoxicity (zinc, nickel), reduced microbiologically driven soil processes (zinc, mercury, copper), contamination of food chain (cadmium), health risk through dust inhalation (lead), etc. Soil contamination results in restrictions in use of such land, some land use types must be avoided.

4. ENCROACHMENTS AND TYPES OF COMPENSATION MEASURES

Encroachments on soils (actions that cause loss of soil functions) should only be considered for compensation if the loss is obvious and detectable. This applies mainly to the following types of encroachments:

Soil sealing: total loss of soil functions

Abrasion (Exploitation, road cut): loss of soil functions depends on percentage of remaining soil

Landfills: usually total loss, for closed landfills the performance depends on recultivation.

Compaction by construction activities (e.g. construction tracks): partial loss of functions.

Compensation measures are designed to restore or at least to improve soil functions. Compensation actions involve substantial resources, thus the improvement of soil functions has to be measurable and permanent.

The list of available measures includes:

- Removal of sealing
- Soil decontamination
- Recultivation/reclamation
- Removal of landfills
- Application of topsoil
- Re-Irrigation (restoration of natural biotop)
- Extensification of arable land use
- Depth loosening / Decompaction
- Erosion prevention
- Liming
- Green roofs

- Covering of physical structures

The amount of the needed compensation depends on the loss of soil functions caused by the investment. Therefore it is necessary to gather information on performance of soil before the encroachment and the possible performance after the encroachment. The difference between these two states corresponds to the compensation demand.

As already mentioned, the compensation measures described in the following sections can often ensure only partial compensation. To give a rough estimation of the reachable compensation effect of the single measures, it is compared with the total loss of a high quality soil. A high quality soil is here defined as a soil with at least 1 m depth, a loamy texture, a very low skeletal content and a pH-value in the neutral range (Soils like Luvisols, Phaeozems or Chernozems).

Example: an application of 20 - 25 cm topsoil (to enhance the performance of a soil with a lower quality), enables to reach a compensation effect equal approx. 20 - 25 % of value of high quality soil. That means: to fully compensate the total loss of 1 m² of high quality soil, a top soil application on 4 or 5 m² is needed.

5. DESCRIPTION OF MEASURES ENHANCING SOIL FUNCTIONS

5.1. SOIL RECOVERY TREATMENTS

5.1.1. Removal of sealing

Type of measure	**Removal of barriers and impermeable layers**
Description	Removal of such layers as e.g. asphalt covers, concrete layers and covers with removal of compacted areas in the subsoil, removal of foreign materials and subsequent profile restructuring.  *Photo: Schwenk; Substructure of sealed area*

	The effective connection with the natural subsoil must be completely restored. Only then can the soil function be fully resumed following the new soil restructuring. It is important here that the sealing, including the support layers, is removed and soil compaction (topsoil and subsoil) is reversed by deep tillage (e.g. ploughing). Effective recultivation (Chapter 3.1.3) is of great significance for the level of soil function restoration after removal of the sealing. Topsoil application might be needed.
Implementation notes	When the site is contaminated under the layer to be removed, the seal removal must not result in exposure of pollutants and the related risk. Where necessary, the pollution must be eliminated.
Benefits	The sealing removal restores soil functions in the site. If properly managed the treatment may substantially restore retention, filtering, biodiversity and landscape aesthetics functions through removal of impermeable layer and soil recultivation. Relating to the total loss of a high quality soil: Up to 80 % compensation (these values are only rough assessments of the compensation potential of the particular measures; real compensation will depend on properties of lost soil and quality of compensating intervention)
Disadvantages	High financial and technical outlay
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" BfN (2000): Restoration options for soil functions within the framework of impact regulation

5.1.2. Pollutant removal / Remediation of contaminated sites

There exist different methods for treatment of contaminated soils. Selection of the method may depend on many criteria such as type of contamination, contaminant content, soil properties, size of contaminated site, current and planned land use, available financial and technical resources, etc. The methods might be grouped into *in-situ* and *ex-situ* techniques. *In-situ* methods are performed on site without soil removal. Ex-situ methods involve excavation of the soil and its treatment in a different location in order to remove pollutants or to be safely stored. Such soil might be returned to the original site after cleaning or be replaced by other soil material.

Another division of the methods is based on contaminant fate as a result of the applied method – some methods are aimed at contaminants removal and, thus cleaning the soil, while the others only on reduction of contaminants availability to reduce the impact of contamination.

Remediation of soil contamination with organic compounds is usually aimed at contaminant removal from soil or its biodegradation to less toxic forms. Remediation of metal contaminated soils utilizes techniques of metal removal or metal stabilization (they still remain in soil but are immobilized).

Available methods include both biological and engineering techniques. Biological methods utilize ability of microorganisms or plants to accelerate biodegradation (microbes, plants), removal (plants) or stabilization of contaminants (plants). Biological methods might be applied both on site and *ex-situ*. Engineering methods involve technical and chemical means to remove contaminants (soil replacement, extraction of contaminants from soil, thermal soil treatment).

Any remediation action should be performed and supervised by experienced professionals – soil contamination creates a risk for human and the environment – such risk might be increased if the remediation fails or is done incorrectly. Furthermore, the soil remediation consumes substantial costs, regardless if public or private. Thus, the most proper method should be planned for particular sites.

5.1.2.1. Engineering techniques for removal of organic contaminants

Type of measure	**Engineering removal of organic contaminants**
Description	Removal of pollutants, generally by digging out polluted soil, followed by recultivation. The excavated soil is replaced by the clean soil material and is a subject of treatment aimed at removal of contaminant or safe landfilling.

Type of measure	Engineering removal of organic contaminants
	 *Photo: City of Stuttgart; Soil excavation of polluted material* The introduction of the new soil material is encompassed with the correct soil profile construction. The excavated polluted soil might be a subject of treatments in order to enhance degradation or removal of organic pollutants: a) Thermally induced desorption involves warming the soil material. Temperature increase leads to removal of volatile contaminants. b) Chemical oxidation is a method in which the soil is mixed with chemicals that cause degradation of contaminants. c) Thermal soil cleaning involves soil treatment with high temperatures (800-1200 ^{o}C) which leads to burning the contaminants. Theoretically the cleaned soil might be returned to the original site.
Implementation notes	Detailed assessment of the site is needed prior to remediation. Area of contamination must be precisely delineated, level of contaminant content, depth of pollution and soil properties analyzed. Correct precautionary measures are needed to limit pathways of contamination impact on human and environment during remediation process. The remediation should be done by experienced professionals.
Benefits	The soil functions, such as filter and buffer function, are restored. Exposure of human population and other living organisms to contamination reduced. Value of land increased. More land use types allowed on the cleaned site. The soil cleaning is relatively quickly achieved. Relative compensation of the total loss of a high quality soil: Up to

Type of measure	Engineering removal of organic contaminants
	30 % (only one soil function)
Disadvantages	High financial and technical outlay. Often lack of quality soil material for replacement of the excavated polluted soil. Thermal and chemical methods of soil cleaning destroy soil biological activity, soil structure, high temperature ashes soil organic matter and alters soil minerals. The cleaned soil material must be a subject of further costly treatment in order to restore their chemical, physical and biological properties.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB"

5.1.2.2. Bioremediation of organic contaminants

Type of measure	Bioremediation of organic contaminants
Description	Bioremediation of organic contaminants may be performed *ex situ* and *in situ*. In ***ex situ*** methods the excavated polluted soil is a subject of microbiological degradation of pollutants. Biodegradation in bioreactors is used for cleaning of soils contaminated with e.g. pesticides and PAH-s. Bioreactors ensure conditions most suitable for biodegradation process – pH, nutrient content, temperature oxygen content. Composting is a method in which the contaminated soil is mixed with straw, bark or manure. Composting process accelerates microbial activity including strains able to degrade the contaminants. ***In situ*** methods involve utilization of microorganisms for degradation of contaminants. Often specially selected strains are introduced to the soil. These microorganisms selectively use the organic contaminants as a source of carbon. Conditions favouring the degradation process are: pH optimal for microbial activity, high organic matter content, correct C:N ratio, availability of nutrients, soil aeration. Phytostimulation is a process of stimulation of microbial activity by root exudates in order to accelerate biodegradation process.
Implementation notes	Detailed assessment of the site is needed prior to remediation. Area of contamination must be precisely delineated, level of contaminant content, depth of pollution and soil properties analyzed. Correct precautionary measures are needed to limit pathways of contamination impact on human and environment during remediation process. The remediation should be done by experienced professionals.
Benefits	The soil functions, such as filter and buffer function, are restored after soil cleaning. Exposure of human population and other living

Type of measure	Bioremediation of organic contaminants
	organisms to contamination reduced. Value of land increased. More land use types allowed on the cleaned site. In situ bioremediation and phytostimulation are low-cost processes. Relative compensation of the total loss of a high quality soil: Up to 30 % (only one soil function)
Disadvantages	In situ bioremediation is a long-term process. Ex-situ bioremediation requires substantial financial resources.
References	Stuczynski T., G.Siebielec. B.Maliszewska-Kordybach, B.Smreczak, L.Gawrysiak. 2004. Guidelines for delineation of contaminated soils. GIOS (in polish) Maliszewska-Kordybach B. and B. Smreczak. 2003. Habitat function of agricultural soils as affected by heavy metals and polyclic aromatic hydrocarbons contamination. Environm. Internat. 28: 719-728 Colleran E. 1996. Uses of bacteria in bioremediation. Methods in Biotechnology 2: Bioremediation protocols.

5.1.2.3. Engineering techniques for removal of trace elements

Type of measure	Engineering removal of trace elements
Description	Removal of pollutants, generally by digging out polluted soil, followed by recultivation. The excavated site is filled with a clean soil material. The polluted soil is a subject of treatment aimed at removal of contaminant or safe landfilling. The excavated polluted soil material might be treated with extracting solutions (inorganic acids, complexing agents e.g. EDTA) in order to remove excess of metals from the soil. The procedure is repeated until the further metal removal is not effective. The soil might be also divided into particle size fractions by sieving. Metals are sorbed mainly on fine particles (clay) – removal of clay fraction removes most of metals from the soil material.
Implementation notes	Detailed assessment of the site is needed prior to remediation. Area of contamination must be precisely delineated. Contaminants content, depth of pollution and soil properties must be analyzed before and after the treatment. Correct precautionary measures are needed to limit pathways of contamination impact on human and the environment during remediation process. The remediation should be done by experienced professionals.
Benefits	The soil functions, such as filter and buffer function, are restored after soil replacement. Exposure of human population and other living organisms to contamination reduced. Value of land increased. More land use types allowed on the cleaned site. The soil cleaning is relatively quickly achieved.

Type of measure	Engineering removal of trace elements
	Relative compensation of the total loss of a high quality soil: Up to 30 % (only one soil function)
Disadvantages	High financial and technical outlay. Often lack of quality soil material for replacement of the excavated polluted soil. Chemical extractions negatively change other soil properties – acidify soil (extraction with acids), remove nutrients, destroy soil biological activity and soil structure. Soil sieving removes the clay fraction which is the most valuable in terms of soil productivity, buffering capacity and water retention. Thus, the cleaned soil is not fully valuable soil material and needs further treatment (mixing with other soils, composts, etc.) Such cleaned soil material must be a subject of further costly treatment before it is safely stored or returned to the site.
References	Stuczynski T., G.Siebielec. B.Maliszewska-Kordybach, B.Smreczak, L.Gawrysiak. 2004. Guidelines for delineation of contaminated soils. GIOS (in polish)

5.1.2.4. Biological methods for removal of trace elements - phytoextraction

Type of measure	Phytoextraction
Description	The method utilizes plants with natural ability to acquire and accumulate metals in their tissues. So called hyperaccumulators can potentially accumulate, depending on soil properties and soil metal content, over 1% of such metals as zinc or nickel and 0.1% of cadmium in plant dry matter. The plants are to be cropped mainly in monoculture, their biomass collected regularly, ashed and landfilled. Some metals might be potentially re-cycled from the ash. There are attempts to utilize regular plants with higher biomass (corn, willow). However in case of these plants the yearly metal removal is smaller. They are also not able to grow on highly contaminated soils due to lack of resistance to metals.

Type of measure	**Phytoextraction**
	 *Photo: R.Chaney; Nickel hyperaccumulating plants*
Implementation notes	Detailed assessment of the site is needed prior to remediation. Area of contamination must be precisely delineated. Contaminants content, depth of pollution and soil properties must be analyzed before the remediation. The remediation should be supervised by experienced professionals.
Benefits	Decrease in soil metal content. No destruction of soil properties. Potentially re-cycling of valuable metals (zinc, nickel). Alternative agricultural production, if connected to renewable biomass or fuel production, on post-industrial areas. Relative compensation of the total loss of a high quality soil: Up to 30 % (only one soil function)
Disadvantages	Very slow process (even 100 years to fully clean soil). Need for system of biomass treatment. Lack of plants able to accumulate some metals (e.g. lead). Problems with cultivation of hyperaccumulators (small size, weed control, often weak adaptation to climate conditions). Very rare practical and successful field applications so far (well documented is only field scale phytoextraction of nickel)
References	Chaney, R.L., S.L. Brown, Y.-M. Li, J.S. Angle, T.I. Stuczynski, W.L. Daniels, C.L. Henry, G. Siebielec, M. Malik, James A. Ryan and Harry Compton. 2001. Progress in Risk Assessment for Soil Metals, and In-situ Remediation and Phytoextraction of Metals from Hazardous Contaminated Soils. Proc. US-EPA Conf. “Phytoremediation: State of the Science.” May 1-2, 2000, Boston, MA

5.1.2.5. Inactivation (phytostabilization) of trace elements

Type of measure	**Phytostabilization**
Description	Phytostabilization is an alternative method for metal removal from soil. It involves soil treatment with materials that lower metals mobility through pH shift, metal precipitation or soil sorption capacity increase. Such materials as limestones, composts, phosphates, clay materials, iron oxide by-products have been tested as effective amendments. These materials are applied to topsoil as individual amendments or in combination, depending on soil properties and the metal present in soil. Subsequently the resistant plant species (mainly grasses) are seeded to cover the soil surface and to reduce erosion of contaminated soil and metals leaching to groundwater.  *Photo: Siebielec, Zinc, lead and cadmium contaminated smelter wasteland in Piekary, PL reclaimed through liming and biosolids application* The method do not lead to the soil cleaning but reduce environmental risk related to contamination with metals until resources for metals removal are gathered or more efficient methods are developed.
Implementation notes	Detailed assessment of the site is needed prior to remediation. Area of contamination must be precisely delineated. Contaminants content, depth of pollution and soil properties must be analyzed before the remediation. Such information is required for planning of effective soil amendments. The remediation should be performed by experienced professionals.
Benefits	The method reduces negative impact of soil contamination through reduction of metals mobility and availability to living organisms. No destruction of soil properties. Soil and landscape biodiversity are

Type of measure	Phytostabilization
	usually increased. Some soil amendments improve water retention potential. Buffer and filter function of soil is substantially improved. Low cost comparing to engineering methods. Relative compensation of the total loss of a high quality soil: Up to 30 % (only one soil function)
Disadvantages	The measure does not actually clean the soil but only reduces its environmental impact. In terms of metal content the soil is still contaminated.
References	Stuczynski T., G. Siebielec, W. Daniels, G. McCarty, R. Chaney. 2007. Biological aspects of metal waste reclamation with biosolids. Journal of Environmental Quality, 36: 1154-1162 Iskandar I. 2001. Environmental restoration of metals contaminated soils. Vangronsveld J., S. Cunningham. 1998. Metal-contaminated soils: In-situ inactivation and phytorestoration. Siebielec G., R.L. Chaney, U. Kukier. 2007. Liming to remediate Ni contaminated soils with diverse properties and a wide range of Ni concentration. Plant and Soil 299: 117-130

5.1.3. Soil recultivation/reclamation

Type of measure	**Recultivation/Reclamation**
Description	The measure is applied for lands with disturbed or destroyed soil profile, wastelands, barren lands, former landfills. Reclamation may convert land deemed as unproductive and unable to fulfil ecological functions into agricultural land. It is also used for stabilization of lands that are denuded being a subject for erosion. Reclamation creates hostile environment for seed germination and plant cover establishment. Soil profile and soil functions are restored through recultivation/reclamation. For this purpose, soil profiles are professionally constructed in order to obtain the highest possible function performance. The treatment involves establishment of well-draining soil layer with the depth of 1 to 2 m. A requirement is the removal of any compaction present in the substrate and removal of foreign materials. In addition, careful maintenance or post-utilisation of the soil is important (e.g. by sowing deep-rooting plants). Fertilization is needed for effective establishment of plant cover.  *Photo: Soil protection office of the Canton Bern (Swiss); Careful use of a digger when creating a soil profile (sub/topsoil) during recultivation* The recultivation generally occurs in combination with further measures, such as e.g.: ▪ Removal of seals (Chapter 3.1.1), Removal of pollutants (Chapter 3.1.2), Removal of landfills (Chapter 3.1.4)

Type of measure	**Recultivation/Reclamation**
Implementation notes	The measure is to be done by experienced professionals. Reclamation/recultivation requires topsoil material to be placed on the surface. Organic matter rich materials (e.g. composts, biosolids) might be needed for establishment of a top layer. Reclamation should be preceded by detail assessment of the site (in order to check for contamination, pH shift needs) and analysis of any applied materials (topsoil, organic materials – in order to learn nutrient status and avoid secondary contamination). Any reclamation/reculativation treatment, especially when it involves application of topsoil or organic by-products or wastes, must follow the national regulations.
Benefits	The impaired functions can be established/restored in the recultivated/reclaimed area. In short term the treatment may restore production, retention and buffering functions when performed correctly. In long term retention and biodiversity functions might be restored. Relative compensation of the total loss of a high quality soil: Up to 80 %
Disadvantages	Potential conflicts with nature protection goals. Requires soil material with certain quality to be applied on surface of land.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" Barnhisel R. et al. 2000. Reclamation of drastically disturbed lands. ASA,CSSA,SSSA

5.1.4. Removal of landfills

Type of measure	**Removal of landfills (near-natural and artificial)**
Description	The measure refers to lands from which heaps of slags, bricks, municipal waste deposits are removed. If the stored waste material is environmentally neutral, only removal of waste down to the original soil surface is needed, followed by land recultivation (chapter 3.1.3). Any compaction present must be reversed by depth loosening. The recultivation might involve organic matter application, liming, drainage, depending on needs. However, foreign materials might remain in the soil profile after removal of above ground layer of stored wastes. In such case, they must be removed.  *Photo: Lazar; Landfill of soil material with foreign materials* Correct disposal of the removed material is required. After the slag or waste heap is removed, soil-regenerating techniques (e.g. sowing deep-rooting plants) should be implemented.
Implementation notes	Detailed assessment of the site after removal of disposed wasted is needed in order to recognize potential contamination problems and needs for such treatments as liming or fertilisation. Removal of contaminated wastes requires, additionally, solving problems related to soil contamination (chapter 3.1.2).
Benefits	Restoration of original condition is possible. The measure improves retention, filtering/buffering and habitat functions. The soil function performance depend on quality of native soil material and the recultivation effectiveness. Natural cycles in the soil are reactivated. Relative compensation of the total loss of a high quality soil: Up to 80 %
Disadvantages	Limited amount of topsoil material that can be used to restore natural soil functions.

Type of measure	Removal of landfills (near-natural and artificial)
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" BfN (2000): Restoration options for soil functions within the framework of impact regulation

5.2. TREATMENTS IMPROVING SOIL FUNCTIONS

5.2.1 Application of topsoil

Type of measure	Topsoil application to soils
Description	Humus topsoil material is applied to soils with poor quality, after careful site and soil selection, in order to improve the soil functions. The depth of the applied topsoil layer should not exceed 25 cm. The quality of the material applied is essential for the gain in soil functions performance (in general, site-typical, unpolluted soil material with less than 10% foreign materials content must be used). Additionally, the correct application and profile structuring, as well as careful maintenance e.g. sowing soil-loosening plants are important.  *Photo: Güthler; Application of topsoil near the village of Möglingen (Baden-Württemberg)*
Implementation notes	Application of the measure is not suitable for high quality soils.

Type of measure	Topsoil application to soils
Benefits	The application of topsoil generally results in an improvement of such soil functions as production ability, water retention, buffering for pH change and contaminants. Particular improvement is achieved for low quality soils or soils degraded by erosion. Relative compensation of the total loss of a high quality soil: Up to 80 %
Disadvantages	Possible target conflicts with nature protection on very poor quality soils. There is often a lack of high quality topsoil in densely urbanized and industrialized areas
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation"

5.2.2. Re-irrigation

Type of measure	Re-irrigation
Description	Re-irrigation of originally hydromorphic soils such as e.g. gley or peat soils. The measure re-establishes native characteristics of the treated soil by stopping drainage process. Re-irrigation is achieved by e.g. closing drains, holding water in (existing) ditches, stopping dewatering or disposal of mine water. Careful site selection and assessment is important as the re-irrigation must be restricted to soils that were originally wet (hydromorphic soils, moors).  *Photo: Lazar; Re-irrigated high moor*

Type of measure	Re-irrigation
Implementation notes	No artificial creation of wetlands by compaction, introduction of clay materials or sealing of the subsoil with foil is recommended.
Benefits	Re-irrigation returns the original functions of wetland. Water retention function is restored. The measure creates a valuable ecological site. Specific and valuable habitat for some fauna and plant species, including rare species, is restored. Re-irrigation would usually increase or, at least, alter biodiversity. It may also improve aesthetics and cultural functions. Not comparable to loss of high quality soils. The measure applied to restore natural plan and animal habitats.
Disadvantages	In general, rare suitable areas are available. Filter and buffer functions are lost. There are changes in plant succession and fauna habitat. Production function is lost, however it was usually limited in a such site before the treatment.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) BfN (2000): Restoration options for soil functions within the framework of impact regulation

5.2.3. Extensification of land use

Type of measure	**Extensification of arable land use**
Description	**a) Extensification of intensive arable land utilisation:** Conservation tillage is introduced in intensively utilized arable lands. The soil structure, water storage capacity and the habitat conditions for soil organisms are improved by extensification of land use in combination with conservation soil tillage (direct sowing) and appropriate cover crops. Sowing of deep-rooting and fine-rooting plants that increase soil decompaction and humus enrichment in the topsoil.  *Photo: Hanspeter Frey, TerraTec Lindau ZH; Left: Intensively used arable land, Right: direct sowing* **b) Conversion of arable land into grassland or forest:** The measure is usually applied to low quality soils. The arable land is converted into grassland or forest. Forestation might be also distributed in a way that improves connectivity between forest complexes.
Implementation notes	-

Type of measure	Extensification of arable land use
Benefits	The extensive agricultural utilisation of land improves soil structure and physical soil characteristics – it may results in slight increase in water storage capacity and the natural soil fertility. Extensification of crop production provides better conditions for numerous animal species, especially birds. Forestation provides better structure of ecological corridors, it improves carbon sequestration process. Habitats for fauna and plant species are created, improving biodiversity and landscape diversity. Forestation improves water storage capacity of the area. It also reduces land susceptibility to erosion on slopes. Extensification reduces input of contaminants to soil such as pesticides. Relative compensation of the total loss of a high quality soil: Up to 20 %
Disadvantages	Long term process, no rapid improvement of soil functions. Limited area of application for justified forestation - only low quality soils.
Measure described in:	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" BfN (2000): Restoration options for soil functions within the framework of impact regulation

5.2.4. Soil decompaction

Type of measure	**Soil decompaction / depth loosening**
Description	Soil decompacting can be implemented either by the use of technical equipment (e.g. plowing, slackening tillage) or by sowing soil-loosening plants. Technical means are used for deep loosening in order to reduce compaction and improve soil permeability in the subsoil. The entire soil down to a depth of 60 cm can be decompacted. When such deep tillage is applied the topsoil should not be reversed. Cultivation and soil-protecting post-utilisation of the soil is necessary (e.g. by sowing deep-rooting plants).  *Photo: Heinz de Buhr (www.debuhrfirrel.de); Mechanical depth loosening of fallow land* A certain improvement of soil structure can be achieved without mechanical treatment, by sowing deep and fine-rooting plants as helping in soil decompaction. This measure should be combined with measures to activate biological soil activity (e.g. mulching) in order to improve soil aggregate stability. Target objects are soils with high compaction, i.e. after incorrect recultivation, former building sites, terminated dump sites, etc.
Implementation notes	Following decompaction measures, the soil is susceptible to recompaction. This must be avoided by careful maintenance (tillage, application of organic matter, plant residues) and soil-protecting post-utilisation (e.g. seeding deep-rooting plants). Soils with distinctly visible organic top layer must not be deeply plaughed with reversing of layers since the valuable organic matter is diluted in the soil profile.

Type of measure	**Soil decompaction / depth loosening**
Benefits	Deep tillage operations effectively remove compaction of subsoil. Sowing deep-rooting plants is a long-term measure, but it leaves the soil with its original horizon structure. Soil loosening provides, in long term, an improvement of soil water storage capacity, avoiding such effects as waterlogging. The treatment may also slightly improve filter/buffer function for pollutants since water movement through soil profile is improved and the water containing pollutants does not remain on soil surface nor flow to rivers. Relative compensation of the total loss of a high quality soil: Up to 20 %
Disadvantages	Improvement of most functions is a long-term process. Extensive post-utilisation of the soil must be ensured in order to avoid secondary compaction.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" BfN (2000): Restoration options for soil functions within the framework of impact regulation

5.2.5. Erosion prevention

Type of measure	Erosion prevention
Description	The measures prevent or reduce erosion processes that cause deflation of soil particles or washing away of soil material from a topsoil. Erosion increases risk for enrichments of surface waters with nutrients. a) Soft preventive measures. Such measures include conservation cropping systems with mulching, constant soil coverage, including winter period (after-crops). Aligning the ploughing direction perpendicular to the slope to reduce water erosion. Soils on sharp slopes (e.g. >12^{o}) shall be afforested. Some slopes should be covered with grasses. Run-off ditches should be covered with grasses. Some improvement might be obtained through proper crop rotation (e.g. with legumes). b) Engineering methods to reduce erosion. The measures involve proper management of gorges – filling and flattening, hardening of bottoms, canalization. Network of balks and borders might be implemented to reduce water erosion. Hedges might limit wind erosion.  *Photo: Mohr; Water erosion during cultivation of corn*
Implementation notes	Soils differ in susceptibility to erosion. Silty soils (loess) are especially sensitive to erosion. Soil typology and texture information is valuable when assessing erosion risk and prevention needs.

Type of measure	Erosion prevention
Benefits	The presented measures are particularly effective in erosion-prone steep locations or locations exposed to wind. The measures reduce soil degradation (loss of topsoil particles, humus, soil structure, nutrients) through erosion. Reduced erosion of soil particles limits risk of enrichment of surface waters with nutrients and contaminants. Implementation of permanent grassland or forestation may slightly improve water storage capacity of the area. Erosion prevention helps to keep buffer/filter potential on certain level. Relative compensation of the total loss of a high quality soil: Up to 20 % (stops the degradation process)
Disadvantages	The measures limit degradation process but generally do not improve soil functions, besides, in some cases, biodiversity, retention or landscape aesthetics.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" BfN (2000): Restoration options for soil functions within the framework of impact regulation Duer I., M.Fotyma, A.Madej. 2004 Codex of good agricultural practice. IUNG, Ministry of Agriculture, Warsaw (in polish)

5.2.6. Soil liming

Overview	Liming
Description	Liming is a soil treatment aimed at raising pH in acidic soils. Agricultural lime (calcium carbonate or magnesium carbonate – dolomite) or calcium oxide are applied on soil surface and mixed with soil, using plough or cultivator, in order to facilitate the reaction. Limestone is usually applied in autumn to let the lime to react with soil over winter. Some alkaline by-products can be used instead of limestone, e.g. wood ash, if safe for the environment. Liming might be applied to acidic arable soils, grasslands, green urban areas, post-industrial areas. Liming of acidic and metal contaminated soils should be obligatory and is most urgent. Liming of surfaces with natural vegetation should be avoided, if not contaminated, due to risk of its impact on plant succession. Peat soils generally are not limed to preserve their chemical and habitat characteristics. Liming of forest soils is especially justified in case of contaminated soils. In other cases the decision must be preceded by the site assessment since liming of forest might change conditions of

Overview	**Liming**
	plant growth and, thus, species structure.  *Photo: Manfred Lange; Badische Zeitung: Forest liming by a helicopter*
Implementation notes	Precise knowledge on the soil properties is necessary, including soil pH and buffering capacity. Some negative effects (release of nitrogen, changes in plant succession in natural areas) are possible, thus the measure should only be implemented in collaboration with the soil protection authorities. Calcium oxide can be applied only to clay soils with greater buffering capacity and should be immediately mixed with soil. Rate of lime needed for neutralization of soil acidity depends on soil pH and texture – heavier soils require greater doses of lime. Effective pH adjustment is possible only when correct lime rates are applied. The rate should be determined based on laboratory soil analysis na quality of liming material. Significant pH increase is gained usually 1-2 years after lime application, in case of calcium oxide the reaction time is shorter. Liming of soils above pH 6.0 is not necessary, if the soils are not contaminated. pH of soils contaminated with heavy metals should be adjusted to 7.0 to limit metals mobility.
Benefits	Liming improves filter and buffer function of highly acidic soils. It also improves soil productivity. The treatment stops degradation processes related to high acidity, improves microbial activity, soil

Overview	**Liming**
	organic matter quality and accumulation process, improves soil structure as a result of pH increase and Ca application. In soils contaminated with metals, increased soil pH reduces metals bioavailability and migration. Relative compensation of the total loss of a high quality soil: Up to 20 %
Disadvantages	Changes in natural plant succession possible. Liming may induce deficiency of micronutrients for crop plants.
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation" BfN (2000): Restoration options for soil functions within the framework of impact regulation Rengel Z. (2003). Handbook of soil acidity. New York, Marcel Dekker Inc.

5.3. MEASURES WITHOUT DIRECT LINK TO SOIL

5.3.1. Green roofs

Overview	**Green roofs**
Description	Application of topsoil material (no use of recycled building materials) with a minimum depth of 10 cm on a roof to be covered with grass mixture.  *Photo: Hübner; Green covering of roofs roofs on the new trade fair building of Baden-Württemberg (near Stuttgart)*

Overview	Green roofs
Implementation notes	Quality of soil material is crucial for establishment of dense grass cover. Fertilization and watering might be needed.
Benefits	Positive effects on temperatures resulting from precipitation water retention, improvement of air quality thanks to dust absorption, improvement of aesthetics. Relative compensation of the total loss of a high quality soil: Up to 10 %
Disadvantages	No effective link with the soil or subsoil. The green roofs may need regular soil replacements.
References	Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation"

5.3.2. Covering physical structures

Overview	Covering of physical structures
Description	Application of topsoil and subsoil material (no recycled building material or technogenic substrates) with a minimum thickness of 60 cm on physical structures to be covered by grasses.  *Photo: Orth; Covered underground garage with ventilation shaft* The measure is applied mainly for physical structures of which complete removal would be unreasonable, e.g. former military bunkers or munitions depots. The physical structures to be covered with soil can also be objects currently in use, for instance underground garages.

Overview	Covering of physical structures
Implementation notes	-
Benefits	The measure might regulate temperature extremes through absorbing heat by retained precipitation water. Improvement of air quality through dust and contaminants adsorption on plant leaves. Improvement of aesthetics. Relative compensation of the total loss of a high quality soil: Up to 50 %
Disadvantages	No effective connection with the soil or subsoil
References	LABO (2009): Guideline "Soil protection in environmental impact assessment as per BauGB" Eco-account regulation Baden-Württemberg (draft 14.11.2008) UM BW (2006): Working guideline "The ecological resource soil in nature protection law impact regulation"

6. SUMMARY OF RELATIONSHIPS BETWEEN THE MEASURES AND SOIL FUNCTIONS

The table below summarizes effects of the presented measures on performance of soil functions, outdoor air quality and temperature and human health. Sign “+” means positive effect, “-“ negative effect, “0” no clear effect.

Landscape **aesthetics** is generally improved by measures restoring the soil returned to use after removal of sealing or metal removal and recultivation. Green roofs or grass coverage of physical structures also definitely improve landscape exterior. **Health** provision function of land is improved mostly by remediation of soil contamination since the residents are less exposed to contaminants. Soil liming reduces contaminant content in urban dusts. Removal of landfills may in some cases reduce exposure of human population to harmful agents.

Recreation function is restored by a complex of measures that all together produce a healthier soil and, thus, healthier environment. Re-irrigation of wetlands might be in certain cases understood as a measure improving recreation function, through creating friendly zones for spending spare time. **Production** function, even if not basic in urban zones, is improved by many measures that increase soil fertility (topsoiling, liming, erosion prevention, decompaction) or recover the soil.

Compensation measures	Cultural	Human health	Recreation	Production	Biodiversity	Retention	Buffer/filter	Air quality	Temperature regulation
Soil recovery treatments									
Removal of sealing	+	0	0	+	+	+	+	0	+
Pollutant removal/soil remediation	+	+	0	+	+	0	+	+	0
Recultivation	+	0	0	+	+	+	+	0/+	0/+
Removal of landfills	+	0/+	0	0	+	+	+	0	+
Treatments improving soil functions									
Application of topsoil material	+	0	0	+	+	+	+	0	+
Re-irrigation	+	0	+	-	+	+	-	0	+
Extensification of land use	0	0	0	-	0	+	+	0	0
Soil decompaction	0	0	0	+	0/+	+	+	0	0/+
Erosion prevention	0/+	0/+	0	+	0/+	+	0/+	+	0
Soil liming	0	+	0	+	?	0	+	0	0
Measures without direct link to soil/subsoil									
Green roofs	+	0	0	0	0	0	0/+	+	+
Covering of physical structures	+	0	0	0	0	0	0/+	+	+

All soil recovery treatments, restoring soil profile, are beneficial for **biodiversity** of soil and landscape. Liming impact on biodiversity is questionable, the effect will be dependent on site characteristics. Liming with high lime rates may alter plant succession.

Soils with extreme properties (e.g. wet, dry or low nutrient availability) are often habitats for rare plant species. Re-irrigation might restore conditions for some uncommon species. Compensation actions on soils with valuable habitats of rare plant species should be avoided.

There is a wide range of measures improving water **retention** function of soil: the measures include topsoiling, erosion prevention, decompaction, forestation and soil recovery treatments such as recultivation and removal of sealing or landfill.

Buffer and filter function of soil is substantially improved by remediation treatments of contaminated soils as well as treatments improving soil sorption capacity (liming, topsoiling, humus application) or regulating water circulation (decompaction).

Air quality might be adjusted by measures reducing presence of contaminants and soil particles in air (contaminants removal or stabilization, erosion reduction). Green coverage of roofs and other surfaces improves air quality through enlargement of plant surface of dust adsorption. It might be improved also by growing creeping plants.

Measures increasing water storage capacity of land would be helpful in mitigation of **temperature** extremes in summer period. These measures would include, in some extent, green covers of roofs and other surfaces.

7. CASE EXAMPLES

7.1. IMPROVEMENT OF SOIL QUALITY IN MÖGLINGEN (BADEN - WÜRTTEMBERG) BY TOP SOIL APPLICATION

The soil function in the community of Möglingen was improved by the application of top soil on soils with low to medium soil quality. The high-quality soil material originated from building land. The top soil was removed in compliance with the local regulations and subsequently appropriately applied to the compensation area. The maximum application depth was 20 cm. Lucerne was sown as a deep rooting plant to bind together the newly applied top soil and the planted ground during post-utilisation.

Photo: Jaensch, Siegmar; Cultivation with Deep rooting plants (Lucerne) after top soil application

The water storage capacity and the natural soil fecundity were significantly increased, especially on the land with low soil quality. The filter-buffer functions of the soil were also increased (cf. Dengler, Güthler, Klumpp 2008).

REFERENCE: DENGLER, C./ GÜTHLER, M. / KLUMPP, M. (2008): Erfolgsbilanz einer naturschutzrechtlichen Ausgleichsmaßnahme. Oberbodenrecycling in Möglingen. In: BWGZ 24/2008 Se. 944 – 945.

7.2. PHYTOSTABILISATION OF ZINC AND LEAD SMELTER WASTES

A pilot reclamation of the site of decommissioned zinc and lead ore smelting plant located in Piekary Slaskie, Poland can serve as an example of contaminants inactivation technology. The disposed wastes, containing several percent of zinc and lead, become an environmental hazard through leaching and wind erosion (Stuczynski et al, 2007). The revegetation of such wastes is a challenging task because of zinc phytotoxicity. The wastes were treated in 1994 by application of municipal biosolids at the rate 300 dry tons per hectare (dry matter basis) combined with the incorporation of lime in an oxide and carbonate form. The fields were then seeded with mixture of local grass cultivars, previously tested for metal resistance. Assessment of metal solubility in subsequent years showed substantial decreases of Zn, Cd and Pb solubility as measured by water extraction. This was an effect of pH increase due to dissolution of applied limestone adsorption and occlusion of metals in the presence of organic matter and iron oxides. The used treatments created growing conditions suitable for grasses and allowed establishment of permanent plant cover which permanently reduced wind and run-off driven dispersal of pollutants.

Photo: Siebielec G., Stuczyński T., - smelter wasteland site reclaimed by using biosolids with lime and preselected grass mixture (untreated area in front of the reclaimed wasteland)

REFERENCES: Stuczynski T., G. Siebielec, W. Daniels, G. McCarty, R. Chaney. 2007. Biological aspects of metal waste reclamation with biosolids. Journal of Environmental Quality, 36: 1154-1162

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6.1.4 Guide for soil compensation

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