Exploring the Opportunities for Using Gentle Remediation Options at the Lindholmen Southern Sector in Gothenburg

Master's thesis in Infrastructure and Environmental Engineering

LUCIJA PRSA GAZILJ

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

MASTER’S THESIS ACEX30

Exploring the Opportunities for Using Gentle Remediation Options at the Lindholmen Southern Sector in Gothenburg

Master’s Thesis in the Master’s Programme Infrastructure and Environmental Engineering

LUCIJA PRSA GAZILJ

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Research Group Engineering Geology
CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2023

Exploring the Opportunities for Using Gentle Remediation Options at the Lindholmen Southern Sector in Gothenburg

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

LUCIJA PRSA GAZILJ

Examensarbete ACEX30
Institutionen för arkitektur och samhällsbyggnadsteknik
Chalmers tekniska högskola, 2023

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Engineering Geology
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover: Lindholmen area
Photo Source: *Göteborgs Stad* *GOkart 3.10.5 (goteborg.se)*

Department of Architecture and Civil Engineering
Göteborg, Sweden, 2023

Exploring the Opportunities for Using Gentle Remediation Options at the Lindholmen Southern Sector in Gothenburg

Master's thesis in the Master's Programme Infrastructure and Environmental Engineering

LUCIJA PRSA GAZILJ

Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Research Group Engineering Geology
Chalmers University of Technology

ABSTRACT

Gentle Remediation Options (GRO) are low-cost and low-impact but sometimestime-consuming methods to deal with elevated levels of soil contamination. GRO rely on amendments, plant-, fungi-, and bacteria-based methods and form a subset of nature-based solutions (NBS). The aim of this thesis is to explore the opportunities for using GRO at the Lindholmen 6:9 property (a former shipyard area) that is currently sitting idle awaiting redevelopment for another 10-20 years. The specific objectives to reach this aim are to: i) identify potential soil contaminants at the Lindholmen 6:9 property based on investigation of previous uses of the area; ii) identify potential GRO strategies to deal with these soil contaminants at the Lindholmen 6:9 property; iii) delimit an area of interest and identify GRO strategies of interest for the stakeholder; and iv) review literature on effectiveness of relevant plant species for these strategies of interest. A retrospective study of orthophotos of the property, a review of previous site investigations, a consultation with the Shipyard Historical Association, a review of the Industry list for surveying of contaminated sites, stakeholder consultation and a literature review were used to reach the objectives. The study results suggest phytoextraction and phyto- and rhizodegradation for the removal of identified primary potential contaminants from soils at the delineated area of interest of the Lindholmen 6:9 property – lead as a representative of heavy metals and aliphatic hydrocarbons together with polycyclic aromatic hydrocarbons (PAHs) as organic contaminants, respectively. The identified candidate species for the area of interest are grasses such as ryegrass *Lolium perenne, Sorghum Bicolor, Pennisetum sinese,* alfalfa *Medicago sativa* as well as tree species poplar (*Populus nigra, Populus deltoides)* and willow (*Salix matsudana, Salix schwerinii, Salix viminalis, Salix smithiana, Salix purpurea*). Lead can however be very difficult to phytoextract as its bioavailability is usually low in the historically contaminated soils. An alternative strategy aimed at reducing mobility of contaminants in soils with help of stabilising plants (phytostabilisation) and/or immobilising soil amendments (chemical stabilisation/immobilisation) could potentially be considered for managing of this contaminant.. Further research is needed to assess the possibility of retaining parking lots in the area of interest during "gentle remediation". Soil sampling and analysis is recommended in accordance with a sampling plan developed in this study. Laboratory or (and) pilot field experiments are necessary to test the effectiveness of the candidate plant species for site-specific conditions before a full-scale field trial.

Key words: phytoremediation, gentle remediation options, nature- based solutions, contaminated soil, contaminated sites

Contents

Preface

This study aimed to investigate the possibilities of using Gentle Remediation Options, as a potential alternative to the traditional method of excavation and dispossal of contaminanted masses, at the Lindholmen Southern Sector in Gothenburg, Sweden, which is currently sitting idle and awaiting redevelopment. The study encompasses the identification of potential contaminants on the Lindholmen 6:9 property as well as the determination of potentially suitable phytoremediation technologies to manage these contaminants and finally a review of the literature on the effectiveness of the strategies in interest.

The work is carried out at the Department of Architecture and Civil Engineering, Division of Geology and Geotechnics, Research Group Engineering Geology at the Chalmers University of Technology, Sweden. Since the property in question is owned by Älvstanden Utveckling AB, this work has been compiled as a colaboration between Chalmers University of Technology and Älvstranden Utveckling AB. Accordingly, I would like to thank my supervisor Yevheniya Volchko, who was always available for my questions and concerns and always provided support and advice. Thank you Jenja! Big thanks to my examiner Jenny Norrman as well, who greatly contributed to this work with her expert advice and knowledge. To Annette Vejen Tellevi from Älvstanden Utveckling, who made my stay in Älvstranden very pleasant and also provided me with expert advice.

Finally, to my family, who is always there for me. Thank you!

Göteborg, June 2023

Lucija Prsa Gazilj

1 Introduction

Chapter 1 presents an introduction to the thesis, considering the background, aim and objectives, as well as limitations of the study. In addition, an outline of the thesis is presented.

1.1 Background to the study

The Lindholmen Southern Sector in Gothenburg, that is the property Lindholmen 6:9, owned by Älvstranden Utveckling AB, has undergone a transformation from an old industrial area when the last shipyard closed in 1976 (Shipyard Historical Association, no date), into a new residential and educational area (Göteborgs Stad, 2022). During this transformation, which is still ongoing (Göteborgs Stad, 2022), new properties were built, and several surveys of inherited contamination were carried out. As a result, some contaminated areas of this property have already been investigated and remediated. However, the traditional method of excavation and disposal of contaminated masses was used, which can be seen as a quick, yet high-cost and invasive solution (Rosén et al., 2015). Since Älvstranden Utveckling AB has the authority regarding the development of this property that sit idle for some time and its sustainable remediation in the long run, Gentle Remediation Options (GRO), with advantages such as low cost and low impact, but time-consuming, can be a potential alternative to the traditional remediation method for the site. The GRO's sustainability is reflected in their reliance on methods based on amendments, plants, fungi and bacteria, which form a subset of Nature-Based Solutions (NBS). In order to cope with the increased levels of soil contamination, organic and inorganics substances, in sustainable way, application of GRO could potentially be beneficial to the remainder of this property.
This thesis work is expected to:

- contribute to better understanding of the opportunities for using GRO at the Lindholmen 6:9 property as well as to
- support long-term strategic management of this property.

1.2 Aim and objectives

The aim of this thesis is to explore the opportunities for using GRO at the Lindholmen 6:9 property that is currently sitting idle awaiting redevelopment 10-20 years. In order to achieve the aim, the objectives of this thesis are to:

- identify potential soil contaminants at the Lindholmen 6:9 property based on investigation of previous uses of the area;
- identify potential GRO strategies to deal with these soil contaminants at the Lindholmen 6:9 property;
- delimit area of interest and identify GRO strategies of interest for the stakeholder; and
- review literature on effectiveness of relevant plant species for these strategies of interest.

1.3 Limitations

The study is limited to only those soil contaminants that have already been detected at the Lindholmen 6:9 property or are expected to be detected based on inventory of the past activities at this property. Regarding the latter, the study is limited to potential primary industry-specific soil contaminants only specified in Industry List for

Surveying of Contaminated Sites (SEPA, 2020). Furthermore, the studies of GRO are limited to only (enhanced) phytoremediation techniques that are suitable for managing for the detected and expected soil contaminants. Finally, the review of the literature on the effectiveness of the selected phytoremediation is limited to the Scopus database only. In this study, the term 'effectiveness' is used to describe the percentage of soil contaminant reduction achieved with help of GRO over a certain period of time.

1.4 Thesis outline

The thesis is structured in 7 Chapters. Following Introduction, Chapter 2 provides theoretical background on the Swedish guideline value model for soils together with the general information about the Gentle Remediation Options (GRO) for soils, taking into account GRO strategies and the GRO framework (Drenning et al., 2022). Moreover, general information about Grass reinforcement protection mesh is presented. Chapter 3 describes the property in question in terms of general information, geology, previous use/activities at the site as well as conducted site investigations and subsequent remedial actions. The information about Industry List for Surveying of Contaminated Sites (SEPA, 2020) alongside other methods used in this thesis are presented in Chapter 4. The obtained results from the study site which include the identification of potential contaminants at the site, potential phytoremediation strategies for managing those contaminants and their effectiveness can be seen in Chapter 5. The following chapters 6 and 7 present the discussion and the conclusions, respectively, with further recommendations.

2 Theoretical background

General information about Swedish EPA guideline value model for soils, Gentle remediations options (GRO) for soil contamination as well as the Generic risk management and communication framework for GRO are presented in this Chapter. Besides this, the definition and basic information about Grass reinforcement protection mesh are provided as well.

2.1 Swedish EPA guideline value model for soils

The Swedish Environmental Protection Agency (SEPA) has developed a model for obtaining guideline contaminant concentration values for contaminated soils (SEPA, 2009). The proposed soil guideline values set the level of protection against health and environmental effects based on land use classification into sensitive (KM) and less sensitive (MKM) (SEPA, 2009). Examples of the latter are industry, offices, roads, while sensitive land uses include residential areas, playgrounds, etc. (SEPA, 2009). Furthermore, the four risk/protection objects are included in the model; people living on or visiting the site/human health, soil environment, groundwater and surface water. The exposure pathways of the human health to the contaminated areas encompasses ingestion of soil, inhalation of dust and vapours (if volatile contaminants), dermal contact for the less sensitive land use scenario and intake of vegetables and groundwater as drinking water source as additional exposure pathways for the sensitive land use scenario (SEPA, 2009; Drenning et al., 2022). The generic soil guideline values for soil environment protection represent the protection for living organisms in soil, which are based on the 75th (sensitive land use) and 50th (less sensitive land use) percentiles of a statistical distribution of species sensitivity to each contaminant (SEPA, 2009.; Drenning et al., 2022). Furthermore, 50% of the drinking water standards represent the corresponding soil guideline value for groundwater protection based on the default hydraulic model parameters (SEPA, 2009.; Drenning et al., 2022). Generic soil guideline values for surface water protection depend on the type of contaminant. 75th and 90th percentile of natural background concentrations of metals in Swedish lakes, 75th and 90th percentile of average concentrations of PCB and Dioxins in inflow to the Baltic Sea, concentrations of other organic contaminants in Dutch and EU Water Framework Directive are considered to find corresponding generic soil guideline values based on default hydraulic model parameters (SEPA, 2009; Drenning et al., 2022). The final generic soil guideline value is determined as the lowest estimated soil guideline value among the risk-protection objects (human health, the soil ecosystem, groundwater, and surface water) (SEPA, 2009).

2.2 Gentle remediation options (GRO) for soil contamination

2.2.1 GRO as subset of nature-based solutions

Nature-based solutions (NBS) are defined as "actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature" (IUCN, 2020). The definition of the Gentle Remediation Options (GRO) includes risk management strategies or technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving effective risk management (Cundy et al., 2016, 2013). As can be seen in Figure 1, GRO relies on the intrinsic ability of plants (phytoremediation), soil microorganisms (bioremediation) and soil fauna (vermiremediation) to remediate the soil.

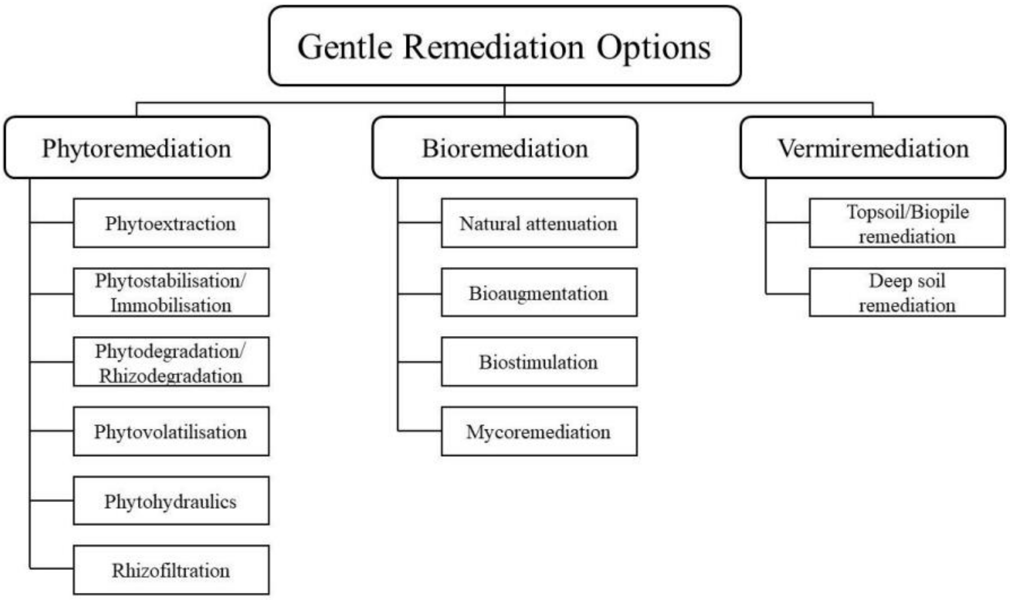


Figure 1. Gentle remediation options – categories and mechanisms (Drenning , 2021 modified from Lacalle et al., 2020).

Bioremediation is a remediation technology which utilises soil microorganisms to degrade, stabilise or reduce the bioavailability of organic contaminants. Furthermore, vermiremediation is defined as remediation technology which utilises earthworms to remove or stabilise soil contaminants (Drenning, 2021 adapted from (Bardos et al., 2020; Cundy et al., 2016; GREENLAND, 2014; OVAM, 2019)). Phytoremediation relies on plants in combination with soil living microorganisms (and sometimes soil amendments) to manage either organic or inorganic, or both types of contaminants (Drenning e, 2021). Various mechanisms of this GRO are described and presented in Table 1, Section 2.2.2. In addition to the phytoremediation mechanisms or strategies shown in Figure 1, chemical stabilisation or immobilisation with stabilising/immobilising soil amendments is mentioned under the phytoremediation strategies. The amendment-induced stabilisation/immobilisation mechanism itself, often targeting the trace elements (metals and metalloids) has been investigated for decades, where the use of stabilising/immobilising soil amendments causes chemical changes in the soil and consequently enhances soil properties as well as reduces trace element mobility, bioavailability and toxicity (Kumpiene et al., 2019). Organic matter, iron oxides, phosphates, ashes, and recently biochar are most often used as such soil amendments, alone or in combination with each other and/or with lime (Kumpiene et al., 2019). Special caution should however be given to the use of organic matter as it also can mobilise contaminants (Kumpiene et al., 2019; Drenning, 2021). Although it is included in Figure 1 under the phytoremediation strategies, chemical stabilisation/immobilisation is described as possible standalone GRO strategy in Kumpiene et al. (2019) and Drenning et al. (2022). However, it should be noted that both studies point out that chemical stabilisation/immobilisation with help of soil amendments is very seldom used without excluding or stabilising plants (Kumpiene et al., 2019; Drenning, 2021). Moreover, these two studies report that some plant species and the associated microbes have positive effects on immobilisation of contaminants in the root zone, but some can, on the contrary, increase contaminant mobility. After being mixed into a soil matrix, stabilisation/immobilisation effects of soil amendments are immediate, while stabilisation/immobilisation effects of stabilising plants are postponed due to development of a root system, e.g. occurrence of these effects can be observed in ca 3-4 months for gras species and ca 3-4 years for tree species (Drenning, 2021).

GRO strategies, or low input remediation technologies, can be seen as an alternative to traditional remediation (e.g., excavation and disposal) for large and marginal land with no exploitation and time pressures, with an emphasis on sustainability, as they are well aligned with the objectives of sustainable remediation and risk-based land management (Bardos et al., 2020). Moreover, the traditional methods can deteriorate the existing soil ecosystem and its necessary functions, or even eliminate them at contaminates sites (FAO et al., 2020; Gerhardt et al., 2017; Swartjes, 2011). On the contrary, GRO strategies can positively influence ecological functions of the soil in terms of improving them and consequently producing ecosystem services crucial for human wellbeing, such as biomass production, flood mitigation, decrease in urban heat islands, amenity and recreation, habitat for animals and microorganisms, and carbon sequestration (Burges et al., 2018; Cundy et al., 2016; Garbisu et al., 2020).

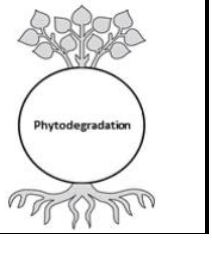
However, uncertainty and scepticism still exist for considering the application of GRO strategies in practice. The main reasons for the latter, which need to better be addressed, include poor knowledge on various risk mitigation mechanisms (usually solely phytoextraction is a widely known mechanism), the required risk reduction for an envisioned land use, and the (uncertain) time perspective associated with the risk mitigation mechanisms (Drenning et al., 2022). Also, there is a need of policies'shift towards setting remediation goals for reducing the risks to acceptable levels (risk-free approach) instead of completely removing or destructing contaminants in soils (contaminant-free approach) (Swartjes, 2011). One of the possible solutions to the increased applicability of the GRO strategies in practice is a phytomanagement approach, combining GRO with beneficial green land use and profit-making operations to gradually reduce the risks, restore ecosystem services and generate a profit (e.g. production of energy crops) (Burges et al., 2018; Cundy et al., 2016; Gerhardt et al., 2017; GREENLAND, 2014; Robinson et al., 2009).

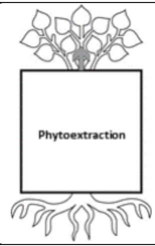
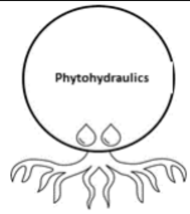
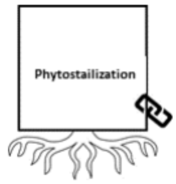
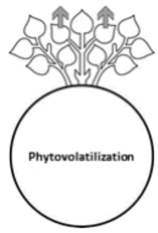
2.2.2 Phytoremediation

Phytoremediation is based on the technologies that utilize plants together with their microorganisms in order to capture, remove, convert or degrade contaminants in the soil, (ground) water and sediment (OVAM, 2019). The main difference among other biological remediation technologies and phytoremediation is that the latter, in order to remove or stabilize contaminants from the environment, applies collaboration between living microorganisms and living plants (OVAM, 2019). Phytoremediation can be applied both to remediate low to moderate concentrations of inorganic and organic contaminants, as well as a complementary method for remaining contamination after removal of source zones (hot spots) with traditional remediation (e.g. excavation, multi-phase extraction). Furthermore, it can be applicable for the avoidance of contaminants infiltration into groundwater or reduction of the fertilizers and pesticides leaching into rivers. Moreover, it could help to control the spreading of diffuse contaminants and finally to provide an active form of controlled natural attenuation (OVAM, 2019). Contaminants that can be removed or stabilized by phytoremediation are metals and organic contaminants such as volatile water-soluble components, polycyclic hydrocarbons, mineral oil and explosive residues (OVAM, 2019). Phytoremediation mechanisms include phytodegradation, phytoextraction, phytohydraulics, phytostabilization, phytovolatilization and rhizodegradation (see Table 1).

Phytoremediation can be categorized into ‘standard’ and ‘enhanced’, where the former includes the utilization of plants and their naturally occurring associated microorganisms whereas the latter implies: 1) bioaugmentation, that is by introducing a species to the site, which implies the enrichment of microbes within the plant itself, or the enrichment of microbes in the rhizosphere (enhanced phyto/rhizodegradation); and/or 2) biostimulation, where already existing microbes are stimulated with the help of soil amendments rich in nutrients (enhanced phyto/rhizodegradation) (OVAM, 2019). Furthermore, soil amendments can be used either 1) to stimulate dissolving of contaminants from the soil matrix and thus enhance phytoextraction with chelating agents (enhanced phytoextraction), or 2) to immobilise contaminants in the soil and thus enhance phytostabilisation with stabilising/immobilising agents (soil amendments) (chemical stabilisation/immobilisation). Chelating agents (synthetic aminopolycarboxylic acids, ethylene-diamine-tetraacetic acid (EDTA), hydroxyethylene-diamine-triacetic acid (HEDTA), ethylene-diamine-dihydroxyphenylacetic acid, etc.) or acidifying agents (such as ammonium fertilizers, organic and mineral acids, and elemental sulfur) (Prasad and Freitas, 2003; Evangelou et al., 2007) can increase the solubility of metals in the soil and improve metal availability for uptake in plants, thereby reducing the duration of phytoextraction (Santa-Cruz et al., 2022). By contrast, stabilising/immobilising agents such as biochars, in combination with stabilising plants, can have an “instant” effect on reducing the mobility and thus bioavailability of contaminants, both organic and inorganic (Denyes et al., 2016, 2013; Friesl-Hanl et al., 2017 by 1) amendment-induced various sorption processes as e.g. adsorption to mineral surfaces, formation of stable complexes with organic ligands, surface precipitation and ion exchange (Kumpiene et al, 2008; Drenning, 2021), and 2) by plant-(and associated microbe-) induced processes such as e.g. speciation and immobilization of contaminants, precipitation and immobilization of the contaminants by root exudates, biosorption into microbial cells and accumulation into or adsorption onto plant roots (Bolan et al., 2011; Drenning, 2021).
Table 1 presents the summary definitions of the phytoremediation mechanisms or strategies together with the remediation goals of each mechanism and the corresponding symbols for these mechanisms.

Table 1. Presentation of phytoremediation mechanisms. Table and symbols after OVAM, 2019.

Mechanisms	**Description**	**Remediation goal**	**Symbol**
Phytodegradation	Process in which plants and their associated microorganisms absorb and degrade contaminants in plant tissues through metabolic processes or enzymatic activity.	Remediation by degradation	

Phytoextraction	Process in which plants and their associated microorganisms absorb contaminants and fix them in plant tissue.	Remediation by removal of plants that have taken up the contamination	
Phytohydraulics	Process in which plants and their microorganisms absorb and transpire water and thereby influence the groundwater level and the direction and speed of the groundwater flow.	Containment by controlling hydrology	
Phytostabilization	Process in which plants and their microorganisms fix certain contaminants in the rhizosphere or in the roots	Reduction of spreading of contaminants into the groundwater or the atmosphere	
Phytovolatilization	Process in which plants take up the contaminants and transport them to the leaves of the plant. The volatile contaminants are subsequently excreted by evaporation	Remediation by transpiration of plant	
Rhizodegradation	Process in which contaminants are degraded in the rhizophere by a combination of plant enzymes and microorganisms in the rhizophere	Remediation by degradation	

Furthermore, the type of contaminant must be known and taken into account, together with the possible bottlenecks for the choice of the phytoremediation technology and relevant mechanisms (OVAM, 2019). Moreover, the effectiveness of phytotechnology will be influenced by the proper selection of the appropriate plant for a specific contamination, soil type and climate zone (OVAM, 2019). Figure 2 shows the relative necessary time for remediation as well as the suitability of phytoremediation mechanisms for different contaminants, for more details see OVAM (2019) and Drenning et al. (2022).

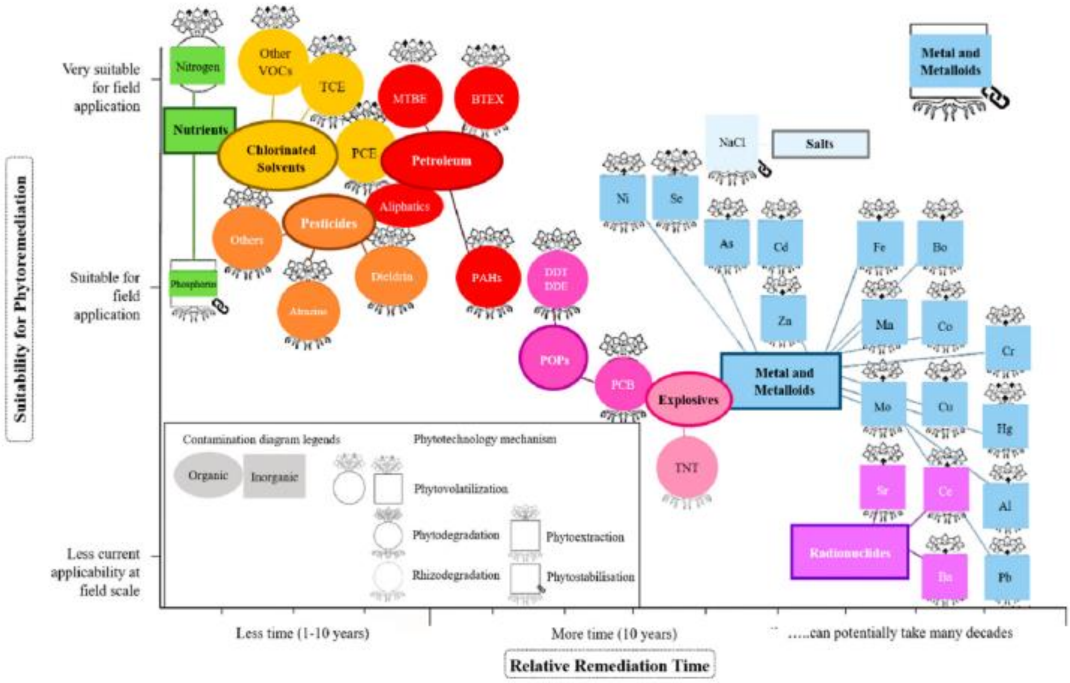


Figure 2. Relative remediation time for source removal (relevant only for extraction, degradation and volatilisation) of groups of contaminants and applicability of the phytotechnology mechanisms. Colours correspond to contaminant grouping. From Drenning et al. (2022) after OVAM (2019) and Kennen and Kirkwood (2015).

2.2.3 The generic risk management and communication framework for GRO

In order to consider and encourage the application of GRO strategies, a risk management framework for GRO has been developed (Drenning et al., 2022), which indicates the connection between risk mitigation mechanisms, risk/protection objects and GRO strategies (limited to phytoremediation including enhanced phytostabilisation) (Figure 3). According to Drenning et al. (2022), there are three main risk mitigation mechanisms which can be connected to GRO: 1) bioavailability and solubility reduction with help of immobilising soil amendments (chemical stabilisation/immobilisation) and plants stabilising contaminants in their root zone (phytostabilisation), 2) source removal – contaminant uptake in the aboveground plant tissue (phytoextraction), uptake and degradation in plant tissue (phytodegradation) or degradation in the plat root zone (rhizodegradation), uptake and volatilisation from plant leaves (phytovolatilization), and 3) secondary effects by vegetation cover for plant-based GRO. Relative risk reduction time has been assigned to each GRO strategy, where colours and time categories are in accordance with Figure 2 and Figure 3 (Drenning et al., 2022). It should be noted that while in Figure 2, the estimation of the 'relative remediation time' is based on the estimated time of full source removal, where only extraction or degradation are taken into account, Figure 3 also includes complementary risk reduction strategies of chemical stabilisation/immobilisation, (enhanced) phytostabilisation, rhizofiltration and vegetation cover are included as well (Drenning et al., 2022).

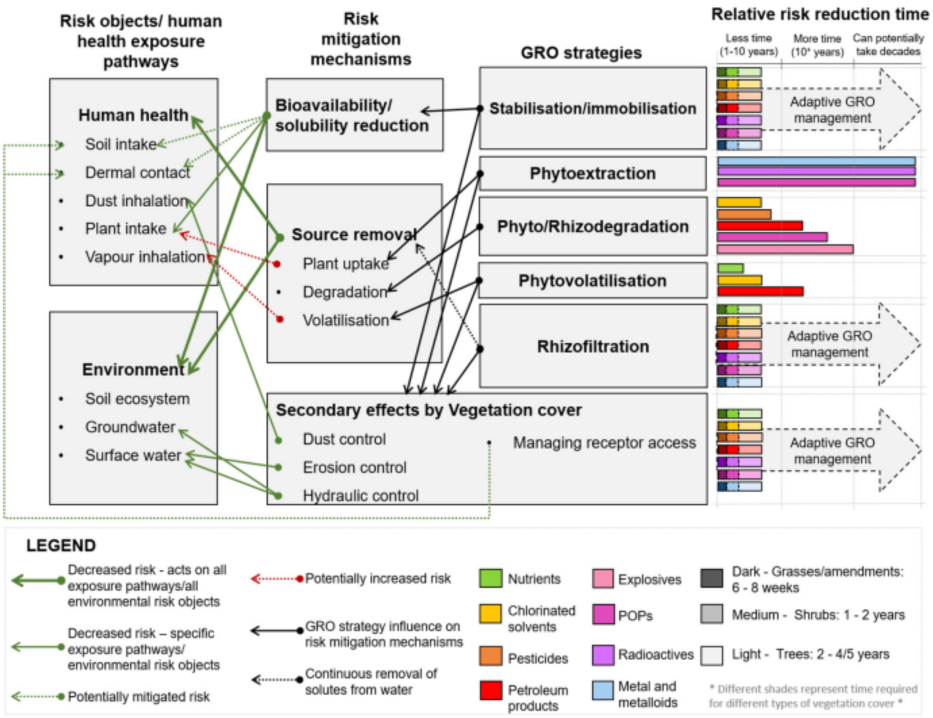


Figure 3. The generic risk management and communication framework for GRO with columns for Risk objects, Risk mitigation mechanisms, GRO strategies and a bar chart depicting relative risk reduction time for each GRO strategy. After Drenning et al., 2022.

The purpose of this framework is to support remediation contractors, decision-makers, regulatory bodies and other stakeholders involved in contaminated sites on selecting and communicating the selection results to stakeholders (Drenning et al., 2022). Furthermore, as a tool, this framework can be applied in the early stages of a brownfield redevelopment project for 1) communication of risk mitigation mechanisms by GRO and their associated timeframes, and 2) identifying opportunities for GRO implementation at specific sites preceding necessary site-specific risk assessments (Drenning et al., 2022). Moreover, it can be utilized in other countries for education and informing stakeholders (Drenning et al., 2022).

2.3 Grass reinforcement protection mesh

Grass reinforcement protection mesh is a thick plastic mesh which serves as reinforcement and stabilization of the grass from damage caused by traffic, that is, pedestrians and vehicles. In this way, the grass, which is prone to wear, could be protected (Typar, no date). It is mostly used to transform grassed areas into car parks. When it comes to installing the grass reinforcement protection mesh, it is easy and quick, without damaging the grass and without the need for a foundation layer. Once the installation is complete, grass growth will not be disturbed and stunted. The grass and the mesh will interlace, creating a natural looking and feeling grass surface, which at the same time, can cope with the pressure from vehicles, small and large, or foot traffic (Green-tech, no date). The mesh often comes in three different sizes: 14.5mm, 13mm and 10 mm thick. In case of heavier traffic, heavy duty grass reinforcement mesh would be more appropriate, whereas in the area with occasional traffic, turf reinforcement mesh would be more suitable (Green-tech, no date). Such meshes are suitable for overspill parking, cycle paths with occasional maintenance vehicle access and regular residential parking (Green-tech, no date). Some examples of grass reinforcement mesh are shown below.

Figure 4. Grass reinforcement protection mesh, Green-tech (https://www.green-tech.co.uk/ground-reinforcement/grass-and-turf-reinforcement-mesh/grass-protecta-medium-13mm); Ultimate one online (https://www.ultimate-one.co.uk/grass-reinforcement-mesh-2mx20m-145mm-thick-2kgsqm-heavy-p-813?osCsid=48b72d28c5pq9jqlfl4n83qm83)

3 Study site

This Chapter describe the property in question including general information, site geology, historic uses and previous site investigations and remedial actions.

3.1 Site description

The Lindholmen area in Gothenburg, Sweden was characterized by shipbuilding, shipyard work and industry back to 1850-1970-ies, while today it is shaped by companies, educational and research institutions (Shipyard Historical Association, no date, Göteborgs Stad, 2022). The area is located along Norra Älvstranden, where the southern border is represented by Göta älv, while in the north it borders Rambergsstaden, Eriksberg in the west and Kvillebäcken in the east according to the area classification, that is, the divisions on the primary areas “primärområden” (Göteborg Stad, no date), see Figure 5. The Lindholmen area is marked in blue, while the Lindholmen 6:9 property is in red in Figure 5. The area of the subjected property is around 90 943 m2 (Eniro's property map).

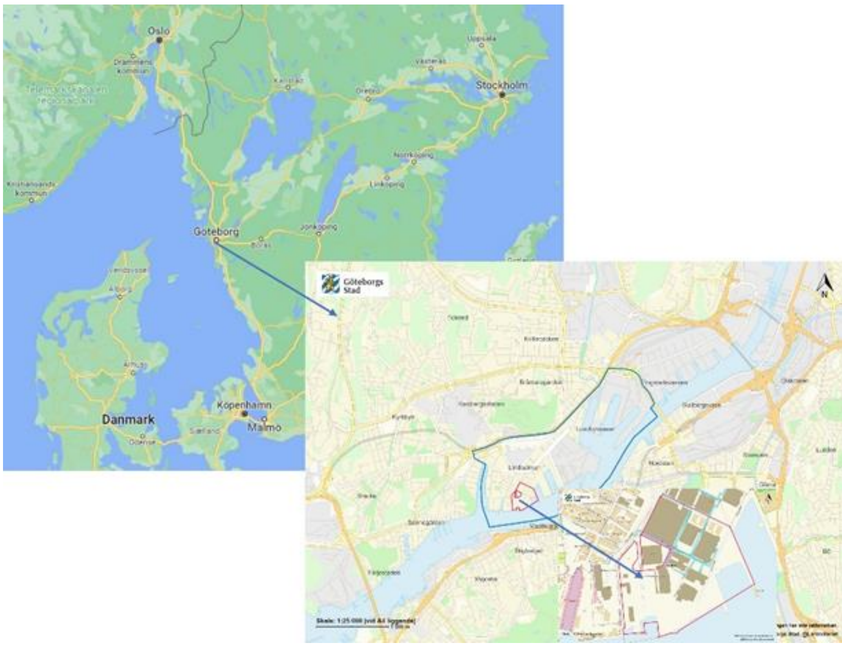


Figure 5. Location of the Lindholmen area and property 6:9 (Google maps https://www.google.se/maps, Göteborgs Stad [GOkart 3.10.5 (goteborg.se)](goteborg.se))

Furthermore, in Figure 6 below it is possible to see the current appearance of the Lindholmen 6:9 property, where the property in question is delimited with a red line. The area marked with a blue line is at the moment sitting idle in the coming 10-20 years. As seen in Figure 6, most of this area consists of the asphalt surface, where the southern part, except the buildings marked in yellow, serves as a parking lot. However, there are future plans to redevelop the blue-marked area which include the demolition of the yellow-marked buildings above the car park. A new residential area will be built here, while the buildings in the western part (kindergarten at the moment) will be demolished due to the plans to build the Lindholmen-Linnéplatsen tunnel, i.e. Lindholmsforbindelsen (interview with an architect from Älvstranden Utveckling AB) in the future.

Figure 6. Lindholmen property 6:9 (Göteborgs Stad GOkart 3.10.5 (goteborg.se))

The area of the Lindholmen property 6:9 consists mainly of the filling material at the surface, followed by postglacial clay and clay-silt on the east (Figure 7), underlined by bedrock of granite and granitoid (Figure 8).

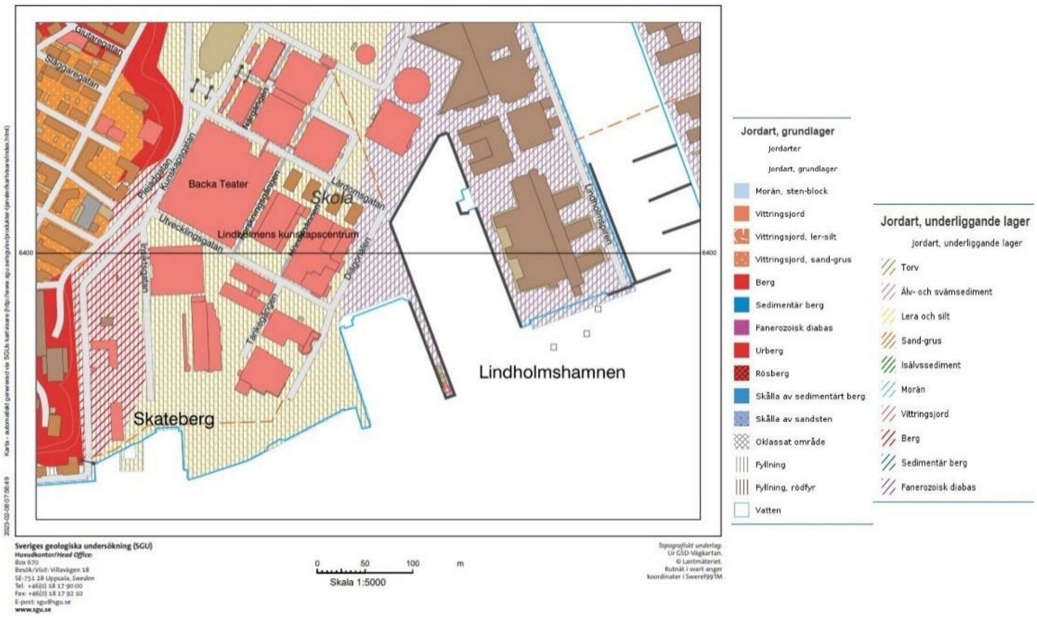


Figure 7. Geology of the Lindholmen property 6:9 (SGU, Kartvisaren Jordarter 1:25 000-1:100 000 (sgu.se))

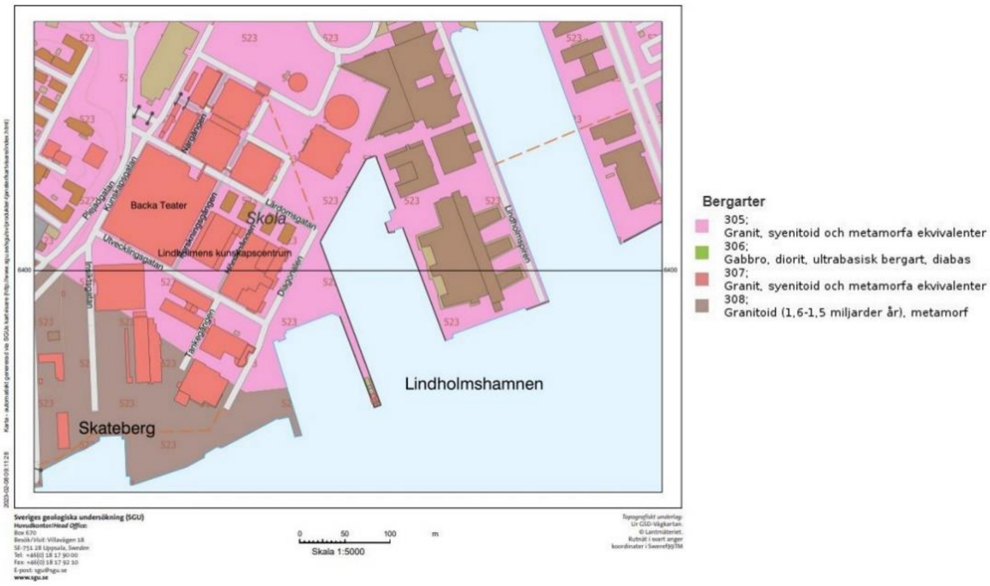


Figure 8. Bedrock of the Lindholmen property 6:9 (SGU, [Kartvisaren Jordarter 1:25 000-1:100 000 (sgu.se)](sgu.se))

The previous site investigations (Sweco, 2014; Sweco, 2016; Kodeda Konsulter AB, 2016) confirm the division of the stratigraphic units as shown in Figure 7 and Figure 8. The asphalt layer is relatively thin, 0.05 m, and is estimated as bituminous asphalt (Sweco, 2016). Below asphalt, in some sampling points, a bearing layer of stone, gravel and sand was encountered, 0.05-0.2 m. An organic soil layer was found, 0-0.3 m, underneath the vegetation cover (grass). Underneath a bearing layer of stone, gravel and sand, as well as the organic soil layer, a light brown layer of sand, about 1 m, was detected in some sampling locations. The stratigraphic unit of filling in general varies between 1.5-3.5 m and mainly consist of stone, gravel and sand, with brick, concrete and wood elements included (Sweco, 2016).

3.2 Historic use of the site

At the property Lindholmen 6:9, which is delimited with a red line in Figure 5-14, was the Lindholmen shipyard, that is, Lindholmen mekaniska verkstad. It started to operate in 1845 (Stadsbyggnadskontoret, 1986). In the beginning, the shipyard was mainly engaged in the construction of wooden ships, but later it produced iron and armoured ships (Sweco, 2020). The first ship was built in 1848, however the actual business began when the Motala Verkstad became the owner of the shipyard in 1858 (Sweco, 2016). At the end of 1920s, the operation was almost entirely suspended, with a new beginning in 1933 when Johnson's group took over. Furthermore, in 1970, the Lindholmen's shipyard was taken over by Broströmskoncernen, which merged Eriksbergs Mekaniska Verkstad and the Lindholmen's shipyard in 1971 (Sweco, 2016). In 1976, the Lindholmen's shipyard ceased operations (Shipyard Historical Association, no date).
In Figure 9 and 10 it is possible to see a comparison of the Lindholmen property in 1942 and 1970. It can be noticed that at some point between 1942 and 1970, the various workshops such as sheet metal workshop, assembly hall/installation hall, machine workshop were built, see Figure 9, 10, 16 and 18. Furthermore, the harbor basins were filled.

Figure 9. The Lindholmen property 6:9 during 1942 (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)]())

Figure 10. The Lindholmen property 6:9 during 1970 (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)]())

Furthermore, Figure 11 shows the property in question in 2019 with the marked location for the formerly open harbor basins (blue delineation) and pile beds areas (white delineation).

Figure 11. The Lindholmen property 6:9 during 2019 with the marked location for the former open harbor basins (blue delineation) and pile beds areas (white delineation) (Sweco, 2020)

During the 1990s, the transformation from the old industrial/workshop buildings to the gymnasium premises occurred (Sweco, 2020). The temporarily school was built, delineated with a yellow line in Figure 12 to the left presenting an orthophoto from 1998. However, it was later demolished as can be seen in Figure 12 to the right presenting an orthophoto from 2019.

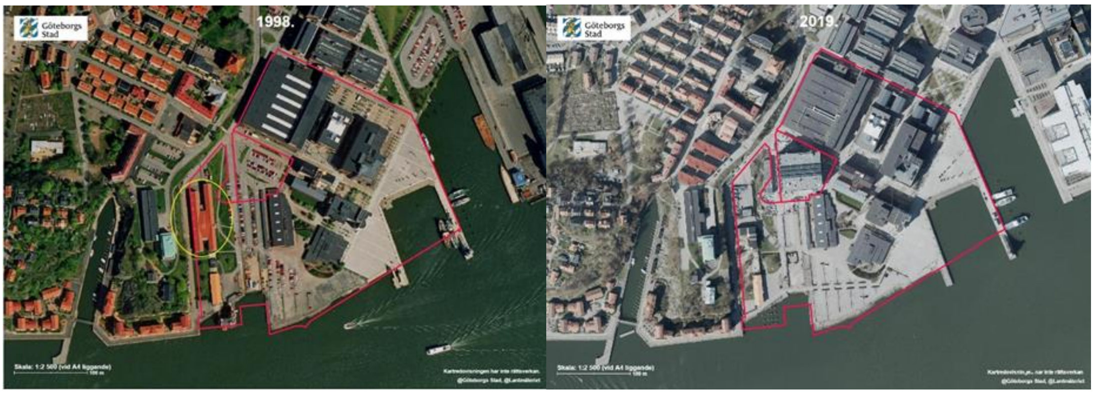


Figure 12. The Lindholmen property 6:9 in 1998 and 2019 (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)](goteborg.se))

The Lindholmen 6:9 property did not change significantly within the time period from 1998 to 2019 (Figure 12). "Urban Cribs" as a temporarily student housing, Lindholmsgymnasiet as well as a preschool with an associated yard (Sweco, 2020) were built (Figure 13). It should be noted that a subdivision of the property Lindholmen 6:9 took place to construct Lindholmsgymnasiet which is now a separate property Lindholmen 6:13.

Figure 13. New buildings marked in yellow (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)](goteborg.se))

The existing future plans for the Lindholm area include 2700 new homes and 3500 workplaces along with the new school for approximately 500 students in grades 4–9 to be completed by 2027 (Göteborgs Stad, 2022).

3.3 Previous site investigations and remedial actions

Based on the previous use of the location as a former shipyard and activities related to the shipyard, it is possible to anticipate the presence of contaminants in the soil related to the above-mentioned activity. According to Sweco (2012), the examples of past activities present in the area were: casting, welding, sheet metal processing and painting. Consequently, the contamination of the area is related to the residual products in the form of turning chips, sheet metal scrap, slag, coal, blast sand, plastic, brick, wood, etc. Moreover, contaminants such as heavy metals, aliphatic and aromatic hydrocarbons as well as polycyclic aromatic hydrocarbons (PAHs) can be expected in the soil, as a result of the above-mentioned activities (Kodeda Konsulter AB, 2016). Furthermore, residues of fuel oil, waste oil and hydraulic oil have also been identified (Sweco, 2012).
Before the construction of Lindholmsgymnasiet, Urban Cribs and Förskola vid Lindholmen at the Lindholmen property 6:9, see Figure 13 and 14, soil investigations were conducted in these areas (marked in yellow in Figure 14).

Figure 14. Investigated and remediated areas (yellow) at the property Lindholmen 6:9 (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)](goteborg.se))

The analyzed soil contaminant concentrations were compared to the SEPAs generic soil guideline values for both less sensitive (MKM) and sensitive (KM) land uses. Furthermore, the recommended Sweden's waste concentration limits for classification of contaminated masses as hazardous waste (farligt avfall - FA) (Avfall Sverige, 2007) were considered together with the site-specific guideline values applicable to soils divided into 2 layers: the surface soil <0.7 m and a deep soil >0.7 m (Sweco, 2012). The site-specific guideline values were developed for residential land use (KM) (Sweco, 2012). These values were compared to the detected contaminant concentrations values in the soils at the Urban Cribs (temporary student houses) (Kodeda Konsulter AB, 2016) and the Förskola (kindergarten) area (Sweco, 2014). However, the contaminant concentration values obtained in the soil investigation within the Lindholmsgymnasiet area (Sweco, 2016) were compared to site-specific soil guidelines for office, commercial and industrial land use (MKM) (Sweco, 2012).
Table A1 in Appendix A compiles the detected contaminants at the property according to the site investigation reports (Sweco, 2014; Sweco, 2016; Kodeda Konsulter AB, 2016). Accordingly, these reports reported the following detected contaminants that exceeded the above-mentioned soil guideline values in the investigated areas of the Lindholmen 6:9 property;are:

- Metals: Arsenic, Barium, Cadmium, Cobalt, Copper, Lead, Mercury and Zinc;
- Aliphatic and Aromatic Hydrocarbons;
- PAHs;
- BTEX: benzene.

4 Method

This Chapter provides information on how the study was conducted. An overview of the working process and methods used is presented in Figure 15.

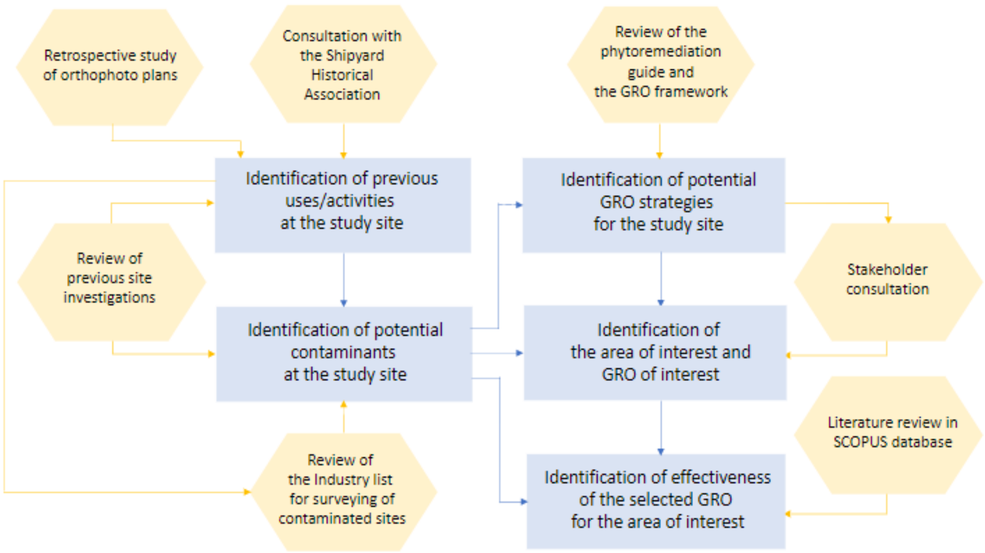


Figure 15. An overview of the working process and methods. The blue rectangles represent the objectives of the thesis, while the yellow hexagons represent the methods used to reach these objectives.

4.1 Identification of previous uses/activities at the study site

In order to meet the objective of identifying previously present uses/activities at the study site, a review of the available site investigation reports on the property in question was carried out. Among others, Sweco's " Historical inventory and overview assessment of additional costs for handling of contaminated land during development within the properties Lindholmen 6:9, 6:11 and 6:13" from 2020 was studied. The same contains retrospective orthophoto plans with the presented situation of the property in question from the 1930-ies to the current state as well as the inventory of the buildings within the property, determined according to the activities carried out in them. However, the majority of plans are extracted from an online database, Go kart (Göteborg stad GOkart 3.10.5 (goteborg.se)), which was also used to examine the situation at the study site to identify previous activities. Finally, the activities that could take place in this study, were checked with members of the Gothenburg Shipyard Association (Varvshistoriska Föreningen Göteborg), on 2023-02-15 and 2023-04-12, by interviewing the members of this association who have a good knowledge of past activities at shipyards. On the basis of the above presented methods, the identification of the previous activities at the study site was performed.

4.2 Identification of potential contaminants

Furthermore, the objective of identifying potential contaminants at the Lindholmen property 6:9 was carried out in two steps. First, a review of the available site investigation reports at the study site was performed. Associated with the reports' revision of the site investigation available documents, the aforementioned Sweco's report from 2020 was taken into account to connect the previous use of the site with the possible contaminants. Second, the activities inside these buildings were connected to the Industry List for Surveying of Contaminated Sites (SEPA, 2020). The latter includes a list of industries whose activities may contribute to soil contamination (SEPA, no date). It consists of industry name, industry comment, industry class, industry-specific contaminants and other comments and other related contaminants (SEPA, 2020). Based on the situation at the property from 1942 and 1970, and interviews of the members of the association stated above and their expert judgment of past activities in buildings, as well as data in the Industry List for Surveying of Contaminated Sites (SEPA, 2020), identification of potential soil contaminants at the study site was carried out.

4.3 Identification of potential phytoremediation strategies

After identifying potential contaminants at the Lindholmen property 6:9, a review of the Phytoremediation Guide – Code of Good Practice (OVAM, 2019) and A risk management framework for Gentle Remediation Options (GRO) (Drenning et al., 2022) was carried out in order to meet the objective of determining potentially suitable phytoremediation strategies to manage the identified contaminants.

4.4 Identification of the area of interest and phytoremediation strategies of interest

Consultations with the stakeholder, the architect from Älvstranden Utveckling and a study visit to the Lindholmen 6:9 property were caried out on 30-03-2023, with the aim of defining and delimiting the area of interest for sampling and potential phytoremediation.

4.5 Identification of effectiveness of the selected phytoremediation strategies

After defining both potential phytoremediation strategies of interest for the stakeholder as well as area of interest, a scoping literature review on effectiveness of the selected phytoremediation was performed in SCOPUS database (2023-03-20) to fulfil the objective of identifying effectiveness of the specific plant species for phytoremediation strategies of interest.
The literature review was conducted using following search strings:

- phytodegradation AND organic AND contaminants;
- phytoextraction AND heavy AND metals.

5 Results

The results of this study are summarized and presented in this Chapter.

5.1 Potential soil contaminants at the site and the area of interest

The historical uses of the site in the time period between 1942 and 1970 are presented in Table 2 and Figures 16, 17, 18, 19 together with the potential soil contamination as a consequence of these activities at the Lindholmen 6:9 property.

Table 2. Historical uses at the site in the time period between 1942 and 1970 and the potential soil contamination as a result of those uses, based on the Industry List for Surveying of Contaminated Sites (SEPA, 2020) and expert knowledge and an interview with the Gothenburg Shipyard Historical Association (Varvhistoriska föreningen Göteborg). The chemical congeners within the contaminant group: Aliphatic hydrocarbons (Hexane, Octane), PAHs (Anthracene, Naphthalene, Benzo(a)pyrene) and Chlorinated aliphatics (Tri- and Tetrachloroethene, Dichloroethane).

Historical uses at the Lindholmen 6:9 property	Industrial use in the Industry List for Surveying of Contaminated Sites	Potential primary industry-specific soil contaminant	Comment
Sheds	--	--	It is not known what kind of material has been stored there. Further investigation is needed.
Office	--	--	No soil contaminants are expected to result from this historical use.
Power plant	Transformer station	Aliphatic hydrocarbons, Polychlorinated biphenyls (PCBs)	
Carpentry and sheet metal workshop	Surface treatment of wood Engineering industry - without halogenated solvents	Aliphatic hydrocarbons, Polychlorinated aliphatic hydrocarbons (PAHs)	
Templates storage	--	--	Wood was the most used material. No soil contaminants are expected to result from this historical use. However, further investigation is needed because it is possible that other things besides wooden templates were stored there.
Workshop where the frame was bent	Engineering industry - without halogenated solvents Surface treatment of metals mechanical/physical processes	Aliphatic hydrocarbons, PAHs	

Tool storage	--	--	It is not known what kind of material has been stored there. Further investigation is needed.
Eternite shed	-	Asbestos	Because the historical use is specific, asbestos is defined as a potential contaminant, even though no relevant matching was found in the Industry List (SEPA, 2020). It was pointed out by the Gothenburg Shipyard Historical Association that asbestos was used here mainly for isolation around pipes.
Copper workshop	Surface treatment of metals mechanical/physical processes	Aliphatic hydrocarbons (Hexane, Octane)	
Boiler workshop	Engineering industry - without halogenated solvents	Aliphatic hydrocarbons, PAHs	
Blacksmith workshop	Iron and light metal foundry Surface treatment of metals mechanical/physical processes	Pb, PAHs, Aliphatic hydrocarbons	
Machine workshop	Engineering industry- with halogenated solvents	Chlorinated aliphatics Aliphatic hydrocarbons, PAHs	
Carpentry workshop	Surface treatment of wood	Aliphatic hydrocarbons, PAHs	
Workshop for raising and maintaining a complex system of sails and rigging	--	--	No relevant information about this activity/use was found. Further investigation is needed.
Transformer station	Transformer station	Aliphatic hydrocarbons, PCBs	
Wood storage	--	--	It is not known what kind of material has been stored there. Further investigation is needed.
Combustion room	Incinerator	Aliphatic hydrocarbons, PAHs	
Sheet metal workshop	Engineering industry - without halogenated solvents	Aliphatic hydrocarbons, PAHs	
Assembly Hall/Installation Hall	Engineering industry - without halogenated solvents	Aliphatic hydrocarbons, PAHs	
Welding workshop	Engineering industry - without halogenated solvents	Aliphatic hydrocarbons, PAHs	
Lunchroom	--	--	No soil contaminants are expected to result from this historical use.

Operational building	Engineering industry - with halogenated solvents	Chlorinated aliphatics, Aliphatic hydrocarbons, PAHs	
Personnel Building	--	--	No soil contaminants are expected to result from this historical use.
TRF	--	--	There is no relevant information about this activity/use or about what this abbreviation means. Further investigation is needed.
Pipe storage	--	--	It is not known what kind of material has been stored there. Further investigation is needed.

In Figure 16, it is possible to see the identified activities on the Lindholmen 6:9 property during 1942, while in figure 17, potential contamination as a consequence of previous activities is shown.

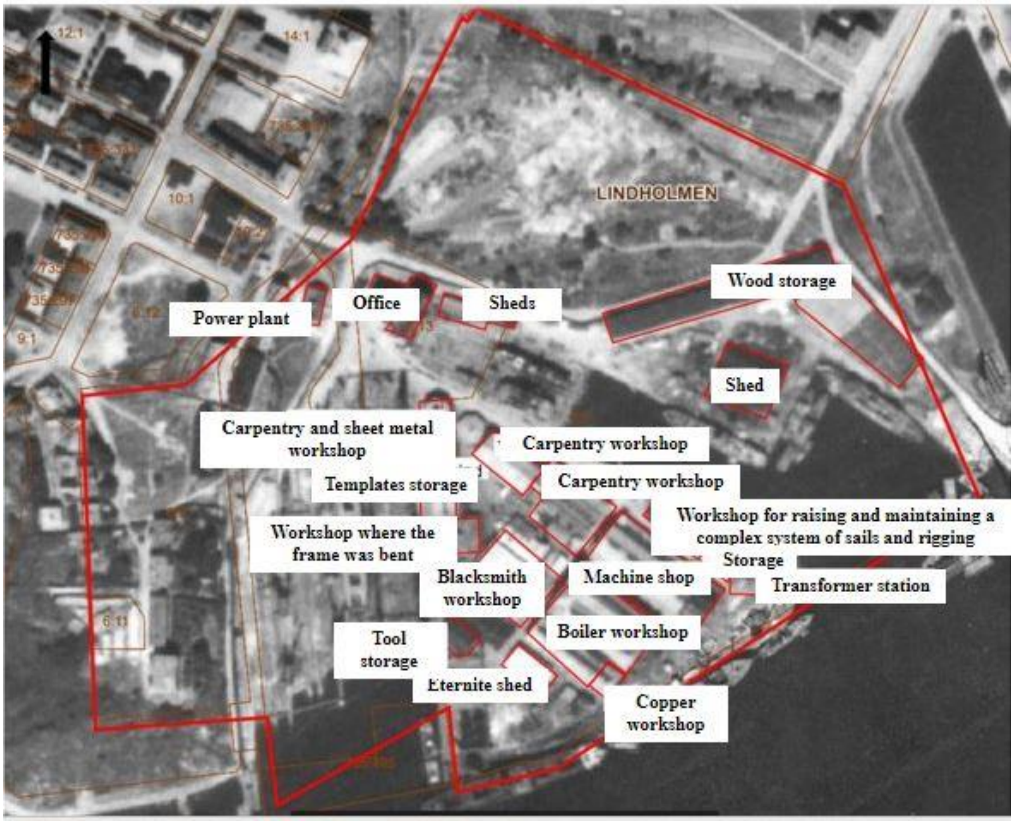


Figure 16. Historical site uses in 1942 at the Lindholmen 6:9 property (Sweco, 2020)

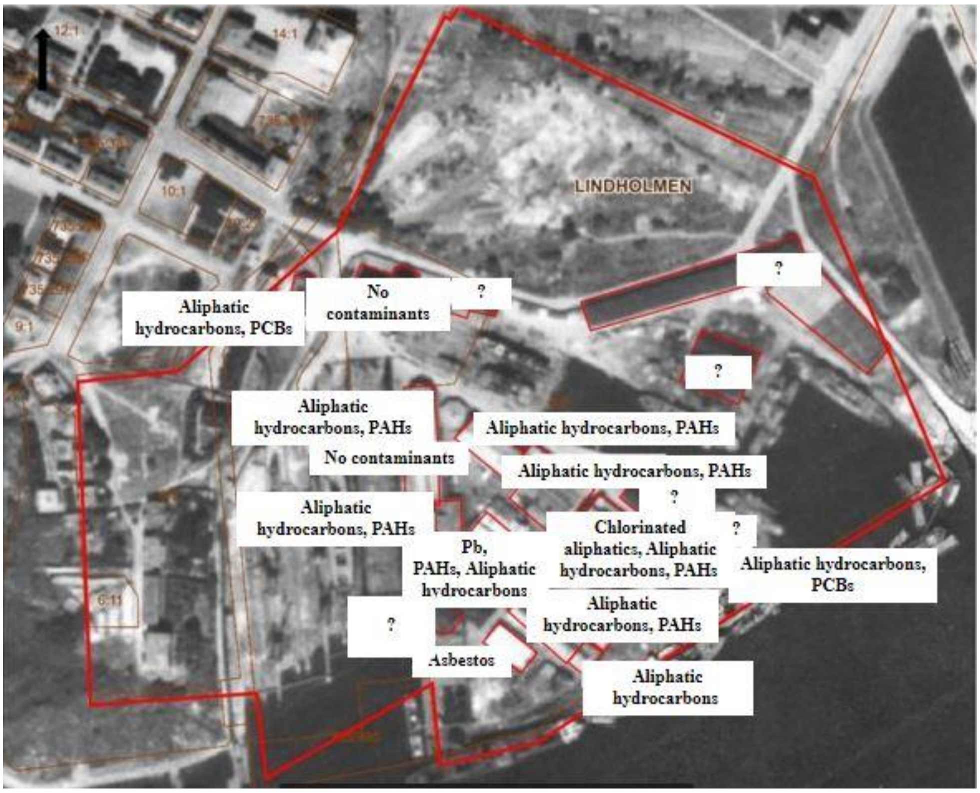


Figure 17. Potential contamination in 1942 at the Lindholmen 6:9 property, based on the Industry List for Surveying of Contaminated Sites (after SEPA (2020) and Sweco (2020).

Figure 18 and 19 represent the situation on the Lindholmen *6:9* property in 1970 with the same sequence of previous use and subsequent contamination.

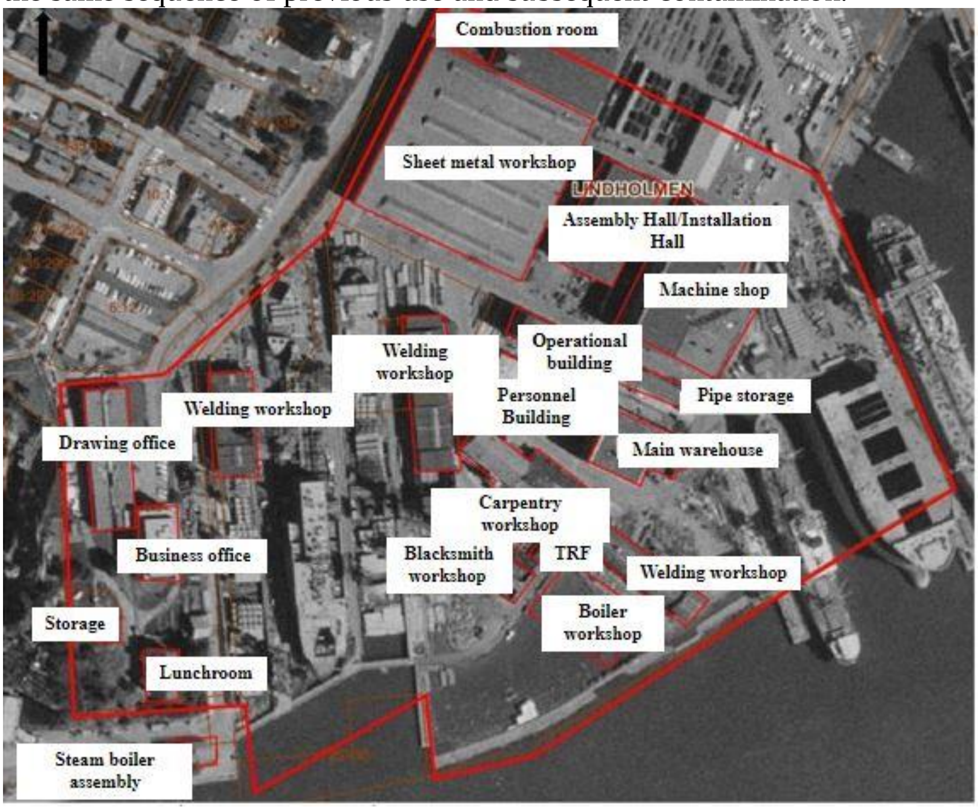


Figure 18. Historical site uses in 1970 at the Lindholmen property, (Sweco, 2020)

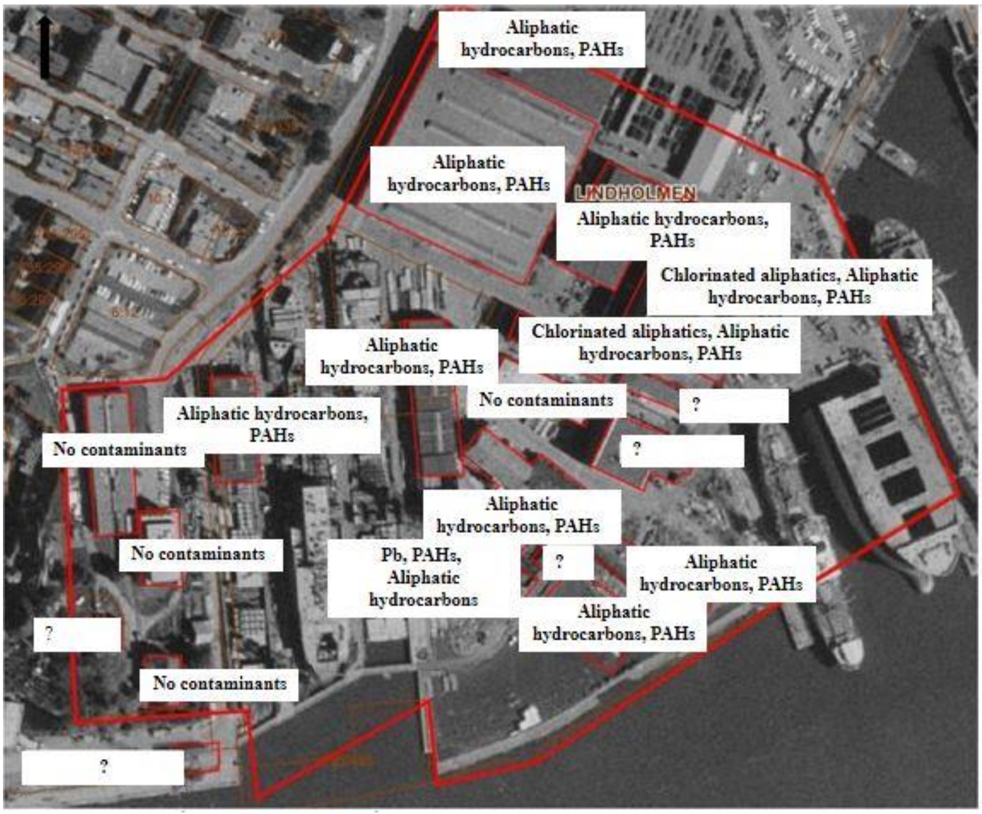


Figure 19. Potential contamination in 1970 at the Lindholmen property 6:9, based on the Industry List for Surveying of Contaminated Sites (after SEPA (2020) and Sweco (2020)).

Furthermore, according to the identified potential contaminants and current land uses as well as future land uses of the Lindholmen 6:9 property, the areas of most interest (marked in yellow) for the stakeholder was identified for potential application of the GRO strategies (Figure 20).

Figure 20. The areas of most interest (marked in yellow) for potential application of the GRO strategies at the Lindholmen 6:9 property (Göteborgs Stad [GOkart 3.10.5 (goteborg.se)](goteborg.se)

5.2 Identification of potential GRO strategies for the study site and area of interest

The GRO framework was used to identify potential GRO srategies for inorganic (heavy metals) and organic contaminants expected at the study site, taking into account sensitive land use, as the area is planned to be transformed into residential housing (Section 3.1). The risk objects for this land use, the relevant GRO strategies and their mechanisms to address the above mentioned contaminants are highlighted in Figure 21. As can be seen, relevant GRO strategies encompass phytoextraction to manage inorganic contaminants, phyto/rhizodegradation for management of organic contaminants as well as chemical stabilization/immobilisation with immobilising soil amendments to adress both inorganic and organic contaminants.

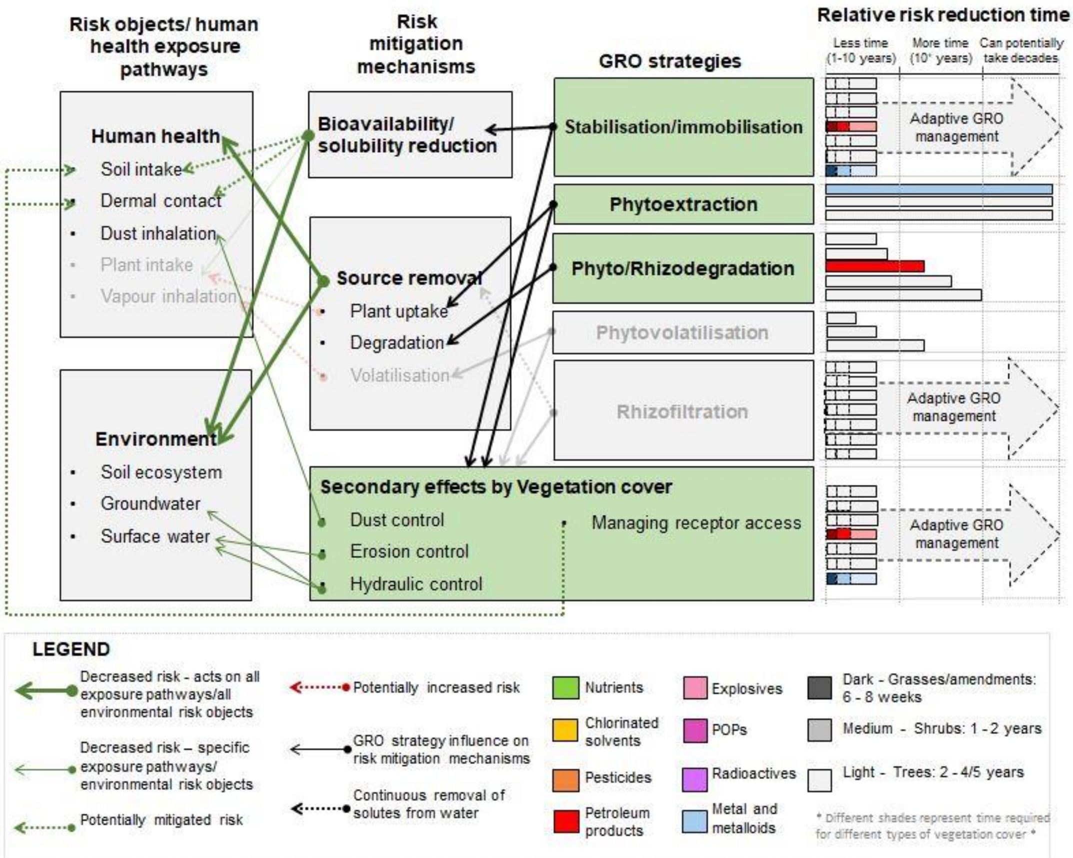


Figure 21. Application of the GRO framework for the Lindholmen property 6:9, modified after Drenning et al. (2022)

As can be seen in Figure 21, phytoextraction of metals at the site can take several decades while phyto/rhizodegradation of organics at the site can take less time. More immediate effects on risks posed by soil contaminants can be achieved using the GRO strategy aiming at stabilising/immobilising contaminants in soils with help of immobililising soil amendments (chemical stabilisation/immobilisation) and/or stabilising plant species (phytostabilisation) – contaminants are left in soil but their availability to biological receptors is reduced. After being mixed into a soil matrix, availability of contaminants to biological receptors is reduced immediately. Stabilisation/immobilisation effects of stabilising plants are postponed in time that can take ca 3-4 months for gras species and ca 3-4 years for tree species to get a developed root system. Furthermore, amendments can be mixed into soil matrix and address contaminants across the whole contaminated soil profile, while stabilising/immobilising effects of plant species are limited to their rooting depth.

Table 3 includes potential primary soil contaminants, i.e., industry-specific contaminants together with identified contaminants based on previous site investigations at the Lindholmen 6:9 property, see Section 3.3. and Table A1 in Appendix A, and accordingly potential phytoremediation strategies for managing these contaminants.

*Table 3. Potential phytoremediation strategies for the identified potential contaminates in the soil at the Lindholmen 6:9 property in Table 2 and Table A1 in Appendix A, based on Phytoremediation Guide (OVAM, 2019) and GRO framework (Drenning et al., 2022). Rows shadowed in grey refer to the areas of interest at the Lindholmen 6:9 property. *Applicable for groundwater contamination.*

Potential primary industry-specific soil contaminants expected at the site and the detected soil contaminants	Potential phytoremediation strategies	Comment
Aliphatic and aromatic hydrocarbons	Phytodegradation Rhizodegradation *Phytohydraulics	Based on the Industry List for Surveying of Contaminated Sites (SEPA, 2020) Aliphatic hydrocarbons were identified as Potential primary industry-specific soil contaminants. However, according to previously conducted site investigations, the concentration of aromatic hydrocarbons was also over the soil guidelines. Therefore, they were taken into account despite being found in different locations outside the area of interest. The same applies for inorganic contaminants presented in the table.
BTEX: benzene	Rhizodegradation Phytodegradation *Phytohydraulics	
Chlorinated aliphatic hydrocarbons	Phytodegradation Rhizodegradation Phytostabilization	
PAHs	Phytodegradation Rhizodegradation Phytostabilization/ Stabilization Phytovolatilization	
Arsenic	Phytostabilization/ stabilization Phytoextraction *Phytohydraulic	
Barium	Phytoextraction	
Cadmium	Phytostabilization/ stabilization Phytoextraction	
Cobalt	Phytostabilization/ stabilization Phytoextraction	

Copper	Phytostabilization/ stabilization Phytoextraction	
Lead	Phytostabilization/ stabilization Phytoextraction	However, there is a warning in OVAM (2019) that lead has usually low bioavailability in soils and its phytoextraction can be infeasible.
Mercury	Phytoextraction Phytovolatilization	
Zinc	Phytoextraction	

5.3 Effectiveness of the selected phytoremediation strategies for the area of interest

Table 4 present the effectiveness of the selected phytoremediation strategies for potential organic contaminants at the area of interest of the Lindholmen 6:9 property. Although many studies compiled in Table 4 specify reduction of contaminant concentrations in soils with help of different plant species, the used phytoremediation mechanisms (rhizodegradation, phytodegradation) are often not specified (Macci et al., 2013; Hou et al., 2015; Baruah et al., 2016; Salehi et al., 2020; Rostami et al., 2017; Hou et al., 2019; Dai et al., 2020). Furthermore, although many studies compiled in Table 6 specify reduction of metal concentrations in pot experiments with a spiked soils (Zou et al., 2023; Chen et al., 2023; Salehi et al., 2020), availability of metals in spiked soils, and thus their extraction effectiveness, can significantly differ from historically contaminated soils (OVAM, 2019; Liang et al., 2014;Törneman et al., 2009).

*Table 4. Effectiveness of the selected phytoremediation strategies for potential organic contaminants at the area of interest of the Lindholmen 6:9 property. All data are presented without manipulation as reported in the articles unless other is specified. Two rows describing a short summary of one study are either shadowed or not to distinguish between the presented studies. * The authors do not specify the used phytoremediation mechanism but only report the reduction of contaminant concentrations in soils. **Carbon ranges are not specified in the study.*

<table>
<tr><th>Soil contaminants</th><th>Applied strategies</th><th>Soil characterization</th><th>Plants/amendments used</th><th>Scale</th><th>Time frame</th><th colspan="2">Initial contaminant concentrations</th><th>Final contaminant concentrations</th><th>Effectiveness</th><th>Reference</th></tr>
<tr><td rowspan="2">Sum of all aliphatic hydrocarbon compounds with chain lengths from C10–C50 and PAHs</td><td rowspan="2">Rhizodegradation</td><td rowspan="2">Not specified</td><td rowspan="2">Willow trees/cuttings: Salix purpurea cultivar Fish Creek</td><td rowspan="2">Greenhouse experiment</td><td rowspan="2">6 months</td><td>C10-C50 mgkg $^{-1}$</td><td>C-NP: 1,546±635
C-P: 912±402</td><td>C-NP: 438±104
C-P: 447± 167</td><td>C-NP: 62±36 %
C-P: 46±23 %</td><td rowspan="2">Yergeau et al. (2014)</td></tr>
<tr><td>PAHs mgkg $^{-1}$</td><td>C-NP: 59.6±31.6
C-P: 60.3±37.8</td><td>C-NP: 8.3±4.1
C-P: 8.7±5.9</td><td>C-NP: 85±5
C-P: 83±11</td></tr>
<tr><td colspan="11">Willow cuttings were planted in the pots containing contaminated and non-contaminated soils, where C-NP stands for contaminated not planted and C-P for contaminated planted. Results presented above are mean ± st.dev. provided in the article.</td></tr>
<tr><td rowspan="2">**TPHs and PAHs</td><td rowspan="2">*Phytoremediation</td><td rowspan="2">Clay loam soil, 34.1% clay, 22.6% sand, 43.2% silt, pH: 8.34±0.29 EC (dS/m): 0.36±0.05 TOC (%): 1.15±0.11, TN (%): 0.07±0.01, TP (mg kg $^{-1}$): 529±84.14, WSC (mg kg $^{-1}$):226.75±125.45 $NH4^{+}$(mg kg $^{-1}$):1.64±1.68</td><td rowspan="2">Trees: Poplar Populus nigra, var.italica and Paulownia tomentosa and a bush; Cytisus scoparius and a natural growing vegetation</td><td rowspan="2">Field experiment</td><td rowspan="2">3 years</td><td>TPHs mgkg $^{-1}$</td><td>463-2056</td><td>250-1087</td><td>47±16%</td><td rowspan="2">Macci et al. (2013)</td></tr>
<tr><td>PAHs mgkg $^{-1}$</td><td>4.42-60.2</td><td>2.58-15.3</td><td>51%±26</td></tr>
</table>

<table>
<tr><td></td><td></td><td>NO3^{-}(mg kg^{-1}): 38.26±16.23</td><td></td><td></td><td></td><td></td><td></td><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="13">The samples were collected at depths of 0–30 cm and 30–60 cm from 6 plots representing a contamination gradient with a homogenised soil in each plot. The results of contaminant initial and final concentrations represent the range between the lowest and highest concentration in the entire profile (0-60 cm) from all 6 plots. Soil characterization parameters, TPHs and PAHs effectiveness were calculated as mean ±st.dev. of the removal percentage ((initial concentration-final concentration) / initial concentration) where the entire profile and all 6 plots were taken into account. When calculating PAHs effectiveness, plot E was not excluded in calculation because an increase in the PAH value was reported for this plot without any comment or explanation. Data provided in the articles are the means of two composite samples from each plot analysed in triplicate.</td></tr>
<tr><td>TPHs
Aliphatic and Aromatic Hydrocarbons C12–C40</td><td>Ecopiling; rhizoremediation</td><td>Soil: granular in nature, fine to medium silty sandy (sand 84%, silt 11%, clay 5%), OM-mean = 5.72 + 2.17%, pH 7.9–8.7</td><td>Perennial rye grass Lolium perenne and white clover Trifolium repens + chemical fertilizers inoculated with TPH degrading bacterial consortia</td><td>Large scale project</td><td>2 years</td><td colspan="2">Mean 1613 mgkg^{-1}</td><td colspan="2">Below detection limit, except one subsample - 152 mgkg^{-1} in the C16–C35 range</td><td colspan="2">Almost 100 % of low boiling point hydrocarbons (<C20) removed, heavier fractions had been reduced by 67–80%</td><td>Germaine et al. (2015)</td></tr>
<tr><td colspan="13">Ecoplling is combined use of phytoremediation and biopiling,</td></tr>
<tr><td>PHC
Aliphatic and aromatic Hydrocarbons C10 - 40</td><td>Endophyte-enhanced phytodegradation</td><td>Silty clay loam soil 31±3.1 % Sand, 45±4.5 % Silt, 24±2.4 Clay, Denisty (g cm^{-3}) 1.145±0.002, pH 4.02±0.01, OM (%) 6.81±0.03, N_{tot} (%) 0.079±0.001, C_{org}(%) 1.58±0.12, P (mg kg^{-1}) 505.40±29.32, Fe (mg kg^{-1}) 20740.00± 82.56</td><td>Endophyte inoculation in perennial rye grass <i>Lolium perenne;</i> endophytic bacterial strains, <i>Rhodococcus erythropolis 5WK</i> and <i>Rhizobium sp. 10WK</i></td><td>Pot experiment</td><td>75 days</td><td colspan="2">12,853.34 ± 322.62 mg kg^{-1}</td><td colspan="2">Not specified</td><td colspan="2">19% ± 3%</td><td>Pawlik et al. (2020) Pacwa-Płociniczak et al. (2016)</td></tr>
<tr><td colspan="13">Two different methods of endophyte inoculation: (1) direct soil inoculation (SI), and (2) pre-inoculation of the caryopses followed by soil inoculation (PI) were considered in this experiment. The highest removal was achieved after pre-inoculation of ryegrass caryopses with a consortium of both bacterial strains-19.1%± 2.5%. The data are presented here as the mean ± st.dev. of three replicates as it was reported in the article.</td></tr>
<tr><td rowspan="6">TPHs
Aliphatic hydrocarbons (C8–C34) and PAHs</td><td rowspan="6">*Phytoremediation enhancement by PGPR</td><td rowspan="6">Available N 34.0 mg kg^{-1}; available P 28.0 mg kg^{-1} ; pH 8.7; salt content 0.17%</td><td rowspan="6">Tall Fescue Testuca arundinacea L. inoculated with two PGPR strains Klebsiella sp. D5A and Pseudomonas sp. SB and ferlizier (Inorganic nutrients $(NH_4)_2SO_4$ and K_2HPO_4)</td><td rowspan="6">Pot experiment</td><td rowspan="6">4 months</td><td colspan="2" rowspan="6">4407 mg kg^{-1}</td><td rowspan="2">Control</td><td rowspan="2">3316 mg kg^{-1}</td><td>C8-C34</td><td>PAHs</td><td rowspan="6">Hou et al. (2015)</td></tr>
<tr><td>29%</td><td>35%</td></tr>
<tr><td>F</td><td>2533 mg kg^{-1}</td><td>43%</td><td>39%</td></tr>
<tr><td>FP</td><td>2097 mg kg^{-1}</td><td>53%</td><td>50%</td></tr>
<tr><td>FP+D5A</td><td>1674 mg kg^{-1}</td><td>63%</td><td>58%</td></tr>
<tr><td>FP+SB</td><td>1443 mg kg^{-1}</td><td>68%</td><td>63%</td></tr>
<tr><td colspan="13">The pot experiment consisted of five treatments: (1) no-fertilizer (Control); (2) fertilizer (F); (3) fertilizer + tall fescue (FP); (4) fertilizer + tall fescue + Klebsiella sp. D5A (FP + D5A); and (5) fertilizer + tall fescue + Pseudomonas sp. SB (FP + SB). Initial and final contaminant concentrations are shown as the sum of TPS (aliphatic + aromatic). The effectiveness is presented as percentage of contaminant removal.</td></tr>
<tr><td>**Crude oil</td><td>*Phytoremediation</td><td>pH 2.67±0.03 7.01±0.25, EC (mS/cm) 0.034-0.110, TOC (%) - maximum 5.17 in</td><td>Crotalaria pallida</td><td>Pot experiment</td><td>6 months</td><td colspan="2">10,000 ppm (10 g/kg), 20,000 ppm (20 g/kg), 30,000 ppm(30 g/kg), 40,000 ppm (40 g/ kg),</td><td colspan="2">Not specified</td><td>Minimum dissipation in 10, 000 ppm concentration</td><td>51.23%</td><td>Baruah et al. (2016)</td></tr>
</table>

		highest concentration (100,000 ppm), WHC (%) 5.12 - 65.05				50,000 ppm (50 g/kg), 60,000 ppm (60 g/kg), 70,000 ppm (70 g/kg), 80, 000 ppm (80 g/kg), 90,000 ppm(90 g/kg), 100,000 ppm (100 g/kg)		Maximum dissipation in 60, 000 ppm concentration of crude oil 79%	
The pot experiment was composed of a soil from a rice field which was mixed with crude oil in a plastic bucket to make a concentration of crude oil in the soil of about 10,000, 20,000, 30,000, 40,000, 50,000, 60, 000, 70,000, 80,000, 90,000, and 100,000 ppm. The control represents 0 % crude oil in the soil. Soil characterization parameters (means ± SD) are presented in the range minimum-maximum, where minimum is in the highest concentration (100, 000 ppm) and maximum in the control, except for TOC (see above).									
TPHs Aliphatic and aromatic hydrocarbons C10-C40 and 16 PAHs	Aided phytodegradation	Sandy loam: Sand 60.3±1.4%, Silt 35.7±2.6%, Clay 3.8±4%, Moisture 76.1±0.1%, OM 30.83±2.4, N 2283±534.5 mg kg^{-1}, P 1380±218.7 mg kg^{-1}, pH 6.9±0.2, EC 1815±161µs cm^{-1}, DO 3.5±0.5 mg L^{-1}	*Medicago sativa L. either in monoculture or interco-cropped with Helianthus annuus L:* amendment – 10% compost from the food waste	Pilot scale experiment	5 months	C10–C40 mg kg^{-1}: 10,233 ± 465	Not specified	Reduced on average in the MS-10%C: 20%	Marchand et al. (2018)
						PAH -L mg kg^{-1}: 0.82 ± 0.3		18%	
						PAH-M mg kg^{-1}: 1.53 ± 0.1		40%	
						PAH-H mg kg^{-1}: 1.57 ± 0.5		38%	
The experimental set-up consisted of unplanted pile (Unp-10%C), pile planted with M. sativa alone (MS-10%C) and pile co-planted with M. sativa and H. annuus (MSHA-10%C). PAH-L stands for low molecular weight PAHs, PAH-M for medium molecular weight PAHs and PAH-H for high molecular weight PAHs. The data are presented as means ±st. dev. as were reported in the article.									
16 PAHs	Phytoextraction	pH 6.40; OC 24.9 g kg^{-1}; TN 1.2 g kg^{-1}; TP 0.6 g kg^{-1}; total K 15.2 g kg^{-1}	*Alfalfa Medicago sativa* and *Tall Fescue Festuca arundinacea* grass	Field experiment	7 months	747 - 810 µg kg^{-1}	AT µg kg^{-1}: 546±18.2	30%	Sun et al. (2011)
							A µg kg^{-1}: 644±18.9	14%	
							T µg kg^{-1}: 632±14.5	24%	
The field experiment included four treatments: (1) alfalfa monoculture (A), (2) tall fescue monoculture (T), (3) alfalfa intercropped with tall fescue (A/T), and (4) unplanted control soil with neither alfalfa nor tall fescue. Average percentage of total PAHs removal in intercropping (30.5%) was significantly higher than in monoculture (19.9%). Contaminant concentrations are shown as sum of 16 PAHs concentrations. The data are presented as means± st. dev. as were reported in the article.									
PAHs – pyrene C16H10	Rhizoremediation with inoculation	Not specified	*Tagetes erecta L/* inoculum *Klebsiella pneumoniae AWD5*	Pot experiment	60 days	200 mgkg^{-1}	Not specified	44 % by *T. erecta L.* plant alone	Rajkumari et al. (2021)
								inoculation of bacterial strain *AWD5* resulted in 69%	
								Control soil 4%	
The uncontaminated soil was mixed with pyrene at a concentration of 200 mg/kg. The experimental setup included four treatments: (i) plant (control), (ii) plant + AWD5, (iii) plant + pyrene, and (iv) plant + pyrene + AWD5.									
PAHs - pyrene C16H10	*Phytoremediation combined with landfill leachate as a fertilizer	pH 7.2, EC (µs cm^{-1}) 324, Density (gr cm^{-1}) 1.4, Na (%) 6.5, K (%) 0.17, P (mg kg^{-1}) 7.3, N (%) 1.1, OC (%) 0.2, Sand 43.5%, Silt 35.5%, Clay 21%	*Sorghum Bicolor,* grass family plant	Pot experiment	90 days	5 different initial concentrations (150, 300, 500, 750, and 1000 mg kg^{-1})	Not specified	96% of pyrene were removed after 90 days, using 30% of leachate for irrigation of the plant	Salehi et al. (2020)
The experimental setup included following treatments: Planting sorghum in soil without the presence of pyrene (irrigation with tap water); T0: Planting sorghum in pyrene-contaminated soil with five concentrations (150, 300, 500, 750, and 1000 mg kg-1)+ irrigation with tap water; T1: Planting sorghum in pyrene-contaminated soil with five concentrations (150, 300, 500, 750, and 1000 mg kg-1)+irrigation with 30% of landfill leachate; T2: Pyrene-contaminated soil with five concentrations (150, 300, 500, 750, and 1000 mg kg-1) without planting sorghum (irrigation with a=0, b=30, c=50, d=70, and e=100% landfill leachate). T3: Planting sorghum in soil without pyrene, and irrigating with 30% landfill leachate.									
PAHs- pyrene C16H10	*Enhanced Phytoremediation	Loam soil- 45.5% sand, 37% silt, and 17.5% clay, pH 7.5, EC (µs cm-1) 225, K (%) 0.78, P (mg kg-1) 8.2, TN (%) 1.2, OM (%) 2, CEC (cmol.kg^{-1}) 4.83	*Sorghum bicolor* plant and *Pseudomonas aeruginosa* bacteria	Not specified	90 days	150 and 300 mg/kg	Not specified	T0 a 47%	Rostami et al. (2017)
								T0 b 35%	
								T1 a 70%	
								T1 b 53%	
								T2 a 83%	
								T2 b 66%	
The experimental setup was following: T blank, pyrene free soil; P, sorghum plants in pyrene-free soil; T0a, contaminated soil at pyrene concentration of 150 mg.kg^{-1} under unplanted conditions; T0b, contaminated soil at pyrene concentration of 300 mg.kg^{-1} under unplanted conditions; T1a, planting sorghum at pyrene concentration of 150 mg.kg^{-1}; T1b, planting sorghum at pyrene concentration of 300 mg.kg^{-1}; T2a, planting sorghum at pyrene concentration of 150 mg.kg^{-1}, along with P. aeruginosa; and T2b, planting sorghum at pyrene concentration of 300 mg.kg-1,									

along with P. aeruginosa. The effectiveness was presented as a percentage of an initial contaminant concentration reduction in the end of experiment.									
PAHs: Pyrene Chrysene Benzo(b)fluoranthene Benzo(k)fluoranthene	*Enhanced Phytoremediation	pH 7.66, C 45.77, P 0.65, N 0.73, available P 0.002 g· kg^{-1}	Fire Phoenix (a mixture of *Festuca L.*, contains *F. arundinacea*, *F. elata* Keng ex E. Alexeev and *F. gigantea* (L.) Vill.) and Purple coneflower (*Echinacea purpurea* (L.) Moench) with strain N12 *Mycobacterium sp.*	Pot experiment	150 days	The sum of the 4 PAHs in the contaminated soil was 228–398 mg·kg^{-1} The contaminated soil was diluted to the range of 104.79–144.87 mg·kg^{-1} and 169.17–197.44 mg·kg^{-1}	Not specified	PAH concentration between 104.79 to 144.87 mg·kg^{-1} - 87% PAHs concentrations of 169.17–197.44 mg·kg^{-1} - is 68%	Hou et al. (2019)
As Fire Phoenix could not grow in the aged PAHs contaminated soil directly (based on the pre-test), the contaminated soil was mixed with an uncontaminated reference soil, resulting in 2 levels of PAH contaminations 104.79–144.87 mg·kg^{-1} (Low co-contamination) and 169.17–197.44 mg·kg^{-1} (High co-contamination). The experimental setup included: CK (natural degradation, CK+ (Only N12), #1 (only E. purpurea), #2 (only Fire Phoenix), #1+ (E. purpurea + N12), #2 + (Fire Phoenix + N12).The soil parameters refer to the contaminated soil. The highest effectiveness was observed under the strengthening of N12, of Fire Phoenix.									
PAHs: Pyrene Chrysene Benzo(b)fluoranthene Benzo(k)fluoranthene	*Phytoremediation	Low PAH contaminated soil: pH 7.64, TC (%) 7.13, TN (%) 0.37, TP (%) 0.16, available P (mg·kg^{-1}) 27.95 High PAH contaminated soil: pH 7.23, TC (%) 16.83, TN (%) 0.82, TP (%) 0.26, available P (mg·kg^{-1}) 19.80	Fire Phoenix (a mixture of Festuca L., contains F. arundinacea, F. elata Keng ex E. Alexeev and F. gigantea (L.) Vill.)	Pot experiment	150 days	The sum of the 4 PAHs in the contaminated soil was 228–398 mg•kg−1 The contaminated soil was diluted to the range of 104.79–144.87 mg·kg^{-1} and 169.17–197.44 mg·kg^{-1}	Not specified	The degradation effectiveness of the total 4 PAHs reached 65% (lowest contaminant concentration) and 68% (highest contaminant concentration)	Dai et al. (2020)
See above for the explanation of low and high PAHs contamination as initial contaminant concentrations. The experimental setup was following: 1. Experimental group: Fire Phoenix planted; Low co-contamination (labeled as SP1) and high co-contamination (labeled as SP2). SP1 = PAHs (approximately 150 mg·kg^{-1}) + Cd (15 mg·kg–1), Fire Phoenix planted; SP2 = PAHs (approximately 200 mg·kg^{-1}) + Cd (15 mg·kg^{-1}), Fire Phoenix planted. 2. Control Group: No crop planted; low co-contamination (labeled as CK1) and high co-contamination (labeled as CK2). CK1 = PAHs (approximately 150 mg·kg^{-1}) + Cd (15 mg·kg^{-1}), no crop planted; CK2 = PAHs (approximately 200 mg·kg^{-1}) + Cd (15 mg·kg^{-1}), no crop planted.									

Abbreviations: TPHs Total Petroleum Hydrocarbons; PHC Petroleum Hydrocarbons; EC Electrical conductivity; TOC Total Organic Carbon; WSC Water soluble carbon; TN Total Nitrogen, TP total phosphorus, TC Total Carbon, TH Total Hydrogen, OM Organic Matter, N Nitrogen, P Phosphorous, WHC water holding capacity, DO Dissolved Oxygen, WC Water Content, SOM Soil Organic Matter, OC Organic Carbon, CEC Cation exchange capacity

Furthermore, in table 5 it is possible to see the effectiveness of bioremediation which can potentially be combined with the selected phytoremediation strategies for potential organic at the area of interest of the Lindholmen 6:9 property.

Table 5. Effectiveness ofbiostimulation, bioagmentation and biosurfactants which can potentially be used to enhance phytoremediation of potential organic contaminants at the area of interest of the Lindholmen 6:9 property. Two rows describing a short summary of one study are either shadowed or not to distinguish between the presented studies. . All data are presented without manipulation as reported in the articles unless other is specified.

Soil contaminants	Applied strategies	Soil charaterization	Plants/amendments usded	Scale	Time frame	Initial concentration	Final concentration	Effectiveness	Reference
16 PAHs	Biodegradation by means of	pH 7.8, Moisture Content (%)	Biostimulation and bioaugmentation using	Lab experiment	56 days	1483 ± 46.27 mg kg^{-}	Not specified	99 ± 0.2% PAHs were removed in all the	Haleyur et al. (2019)

	bioaugmentation and biostimulation	10.4, Maximum WHC (%) 45.8, Soil: Sandy loam, Sand 62%, Silt 20 %, Clay 18 %, TC 6 % TN 0.28 %, TH 2.36 % TP 0.12 % Soil Porosity 36 %	individual isolates (*Rhodococcus sp.* (NH2), *Achromobacter sp*. (NH13), *Oerskovia paurometabola* (NH11), *Pantoea sp.* (NH15), *Sejongia sp.* (NH20), *Microbacterium maritypicum* (NH30) and *Arthrobacter equ*i (NH21)) and a consortium of these isolates					mesocosms except the control	
The experimental setup included nine treatments: (1) PAH-contaminated soil + Rhodococcus sp. (NH2), (2) PAH-contaminated soil + Achromobacter sp. (NH13), (3) PAH-contaminated soil + Oerskovia paurometabola (NH11), (4) PAHcontaminated soil + Pantoea sp. (NH15), (5) PAH-contaminated soil + Sejongia sp. (NH20), (6) PAH-contaminated soil + Microbacterium maritypicum (NH30), (7) PAH-contaminated soil + Arthrobacterequi (NH21), (8) PAH-contaminated soil + consortium (9) BS (no organism but maintenance of soil aeration, temperature and moisture content).									
PAHs Phenanthrene Fluoranthene Pyrene	Biosurfactant-assisted biodegradation	pH 8.14 ± 0.07, TC (g kg^{-1}) 18.79 ± 1.97, SOM (g kg^{-1}) 32.40 ± 3.40 NO_3^- (mg kg^{-1}) 41.91 ± 0.79, NH_4^+ (mg kg^{-1}), 69.18 ± 19.58 WC (%), 17.32 ± 0.08	Supplementation with the biosurfactant (*rhamnolipids*)	Lab experiment	Up to 35 days	16 PAHs (ΣPAHs) (mg kg-1) 0.42 ± 0.09 Phenanthrene (mg kg-1) 0.05 ± 0.01 Fluoranthene (mg kg-1) 0.04 ± 0.01 Pyrene (mg kg-1) 0.05 ± 0.01 Added concentration of phenanthrene, fluoranthene and pyrene 6.0 µg g−1	Not specified	72% for phenanthrene, 64% for fluoranthene, and 58% for pyrene at day 7	Lu et al. (2019)
In this experiment an urban soil was amended with PAHs (phenanthrene, fluoranthene, pyrene). The experimental setup included four treatments: the PAH, PAH+ rhamnolipid (PAH+ Rh), rhamnolipid-only (Rh), and abiotic PAH-control microcosms. Phenanthrene, fluoranthene, and pyrene were chosen as the three representative PAHs in this study.									

Abbreviations: TPHs Total Petroleum Hydrocarbons; PHC Petroleum Hydrocarbons; EC Electrical conductivity; TOC Total Organic Carbon; WSC Water soluble carbon; TN Total Nitrogen, TP total phosphorus, TC Total Carbon, TH Total Hydrogen, OM Organic Matter, N Nitrogen, P Phosphorous, WHC water holding capacity, DO Dissolved Oxygen, WC Water Content, SOM Soil Organic Matter, OC Organic Carbon, CEC Cation exchange capacity

Finally, in table 6 it is presented the effectiveness of the phytoextraction strategy for potential heavy metals at the area of interest of the Lindholmen 6:9 property.

Table 6. The effectiveness of the phytoextraction strategy for potential heavy metals at the area of interest of the Lindholmen 6:9 property. Two rows describing a short summary of one study are either shadowed or not to distinguish between the presented studies. All data are presented without manipulation as reported in the articles unless other is specified.

Soil contaminants	Soil characterization	Plants/amendments used	Scale	Time frame	Initial contaminant concentration	Final contaminant concentration	Effectiveness of contaminant removal from soils	Reference

Zn	Slightly sandy loam soil, OC 3.6 %, $CaCO_3$ 3.6 %, CEC 32.8 mmol 100 g^{-1} soil, pH mean value of 7.14 (6.43–7.55)	Somaclonal variants of tobacco *Nicotiana tabacum and* sunflower *Helianthus annuus* mutants with enhancements NPK fertilizer, crop rotation	Field experiment	5 years	mgkg^{-1}		Tot	P.A.	Not specified		45–69% decreases in labile Zn in topsoil		Herzig et al. (2014)
					Zn		400–55,000	0,15-55					
In this study the focus was on the phytoextraction of the labile Zn concentration from the top soil, that is, on the removal of only the fractions readily available to plant roots (so-called Bioavailable Contaminant Stripping (BCS)), instead of "total" soil contaminant concentration in the soil. With this approach, the time needed for phytoremediation is reduced. Tot refers to soil pseudo-total concentrations of Zn, whereas P.A. to plant-available Zn concentrations.													
Cd, Pb, Zn	Sand soil, Sand 88%, Silt 8 %, Clay 4%, pH (H_2O)6.1–7.4, pH (KCl) 6.0±0.3, EC (µS cm^{-1}) 137± 38, CEC (Cmol(+)(kg^{-1}) 7.6±0.03, OM (%) 5.0±0.1	Energy maize *Zea mays* with enhancements- low N fertilizer, lime	Field experiment	25 weeks	mgkg^{-1}		Tot	Ext	Most metals accumulated in the shoot in the end of the experiment representing 82% of total accumulated Cd, 94% of total accumulated Pb and 87% of total accumulated Zn.		Overall metal removal per ha soils: between 7-10 g ha^{-1} for Cd, 28–46 g ha^{-1} for Pb and 1447–2826 g ha^{-1} for Zn Annual concentration reductions in the top soil layer 0.002–0.003 for Cd, 0.008–0.01 for Pb and 0.41–0.81 mg kg^{-1}y^{-1} for Zn		Meers et al. (2010)
					Cd	Z1	5.7±2.1	0.55±0.24					
						Z2	5.4±1.5	0.40±0.15					
						Z3	6.2±1.1	0.29±0.03					
						Z4	67±2.3	0.39±0.11					
						Z5	5.0±2.2	0.31±0.09					
						Z6	8.9±2.5	0.39±0.09					
					Pb	Z1	166±34	<0.25					
						Z2	164±25	<0.25					
						Z3	138±31	<0.25					
						Z4	184±38	<0.25					
						Z5	135±46	<0.25					
						Z6	189±37	<0.25					
					Zn	Z1	297±78	21±11					
						Z2	300±75	11±3					
						Z3	289±48	11±4					
						Z4	355±85	16±5					
						Z5	266±96	14±7					
						Z6	398±73	17±6					
The test site was divided in 6 plots: Z1, Z2, Z3, Z4, Z5 and Z6. Tot refers to the total metal concentration in the soil whereas ext to CaCl2-extractable metal concentration.													
Cd, Pb, Zn	Acidic modal Cambisol, CEC 166 mmol kg^{-1} , OC 4.1 %, C/N ratio of 9, humus horizon thickness of 26 cm and soil bulk density of 1.35 t m^{-3}, mean pH_{H2O} is 5.66, and pH_{KCl} is 5.27	Willow *(S1—[Salix schwerinii × Salix viminalis] × S. viminalis, S2—Salix× smithiana clone S-218)* and poplar (*P1–Populus maximowiczii×Populus nigra, P2—P. nigra)*	Field experiment	4 years	mgkg^{-1}		Tot	P.A.	mg plant^{1}		Approximately 60–70% of Cd, Pb and Zn were removed in 3- and 4-year-old shoots, which represented 61–80 % of whole shoot biomass		Zárubova et al. (2015)
					Cd		7.3	4.92	8.82±3.31				
					Pb		1368	705	8.94±3.27				
					Zn		218	37	67.53±26.06				
This study assessed biomass yield and distributions of trace elements in wood and bark. Tot refers to soil pseudo-total concentrations of trace element whereas P.A. to the plant-available concentrations of element in the humus horizon. Final contaminant concentrations are expressed as concentration of trace element accumulated in the plant (wood+bark). The highest amount of removed Cd and Zn was with clone S2, whereas P1 obtained the highest removal of Pb.													
Cr, Ni, Pb	pH 7.32, OC (g kg^{-1}) 19.5, EC (dS m^{-1}) 0.57 CEC [cmol (p+) kg $^{-1}$]	Sunflower *(Helianthus annuus* L.*)*, marigold (*Tagetes patula* L., var. Pusa Arpita), and spinach plant	Greenhouse experiment	S and M plants – 45 and 75 days	mgkg^{-1}		Tot	DTPA-ext	mgkg^{-1}	Plant	Plant	Uptake of metal by shoot	Samal et al. (2023)

<table>
<tr><td rowspan="3"></td><td rowspan="3">23.2, Sand 44.44% Silt 41.56% Clay 14% Texture Loam</td><td rowspan="3">(Spinacia oleracea L., var. Pusa All Green with enchancment dhaincha (Sesbania aculeate L.) and gypsum</td><td rowspan="3"></td><td rowspan="3">Spinach plants – 60 days</td><td>Cr</td><td colspan="2">278</td><td colspan="2">0.09</td><td>3.85</td><td>S</td><td>S,M</td><td>0.07 ±0.01</td><td rowspan="3"></td></tr>
<tr><td>Ni</td><td colspan="2">158</td><td colspan="2">12.2</td><td>8.11</td><td>M</td><td>M</td><td>0.27 ±0.02A</td></tr>
<tr><td>Pb</td><td colspan="2">86.6</td><td colspan="2">3.08</td><td>6.38</td><td>S</td><td>M</td><td>0.18 ±0.02</td></tr>
<tr><td colspan="15">S stands for sunflower, M for marigold. Fertilizer was used for growing marigold, sunflower and spinach. The final concentrations are presented as the mean content of the contaminant in the shoot of accumulator plants taking into account the highest value obtained. The phytoextraction effectiveness of the accumulator plants was quantified by estimating the metal uptake by the accumulator plant from the individual pots by multiplying the concentrations of Ni, Pb, and Cr in the shoot of the accumulator plants by their respective oven-dried shoot weight; Uptake of metal by shoot= (Concentration of the metal/1000) × Shoot biomass yield - presented in the column efficiency.</td></tr>
<tr><td rowspan="7">Pb, Cd, Cu, Zn</td><td rowspan="7">Alkali- hydrolyzed nitrogen 105.0 mg/kg, available phosphorus content 49.81 mg/kg, available potassium 217.5 mg/kg, exchangeable calcium content 3,951 mg/kg, exchangeable magnesium content 142.5 mg/kg, pH 7.860 OM 43.81 g/kg.</td><td rowspan="7">Perennial Pennisetum sinese and Lolium perenne L</td><td rowspan="7">Pot experiment</td><td rowspan="7">5 months</td><td rowspan="2">$mgkg^{-1}$</td><td colspan="2" rowspan="2">Low cont.</td><td colspan="2" rowspan="2">High cont.</td><td colspan="2">Average accumulation µg/plant</td><td rowspan="2">Low cont. %</td><td rowspan="2">High cont. %</td><td rowspan="7">Zou et al. (2023)</td></tr>
<tr><td>leaves</td><td>stems</td></tr>
<tr><td>Pb</td><td colspan="2">402.1</td><td colspan="2">764.3</td><td>29.51</td><td>8.89</td><td>58</td><td>65</td></tr>
<tr><td>Cd</td><td colspan="2">14.92</td><td colspan="2">30.09</td><td>19.60</td><td>17.99</td><td>92</td><td>93</td></tr>
<tr><td>Cu</td><td colspan="2">285.7</td><td colspan="2">575.5</td><td>182.8</td><td>61.68</td><td>81</td><td>79</td></tr>
<tr><td>Zn</td><td colspan="2">293.3</td><td colspan="2">589.6</td><td>178.2</td><td>205.4</td><td>91</td><td>90</td></tr>
<tr></tr>
<tr><td colspan="15">The experimental setup included 2 factors: A - intercropping and monoculture, B - low and high concentration of Pb, Cd, Cu, and Zn. The soil collected did not contain serious heavy metal contamination; hence, it was mixed with compound polluted solution. Low cont. stands for low contaminant concentration, whereas high cont. for high contaminant concentration. The final contaminant concentrations are presented as average accumulation amounts in leaves and stems, where intercropping and the plant P.sinese are considered due to the higher heavy metal accumulation. The effectiveness in the column above is expressed as percentage of contaminant decrease in the soil taking into account intercropping.</td></tr>
<tr><td>Pb</td><td>Sandy loam 8% clay, 30% silt, 62% sand, 6% calcium carbonat</td><td>Brassica juncea with enchanment ethylenediaminetetraacetic acid (EDTA)</td><td>Pot experiment</td><td>3 months</td><td colspan="5">Initial Pb concentration 67.0 mg/kg
Soil spiked with: 200 mg/kg, 500 mg/kg, and 1000 mg/kg</td><td colspan="2">Not specified</td><td colspan="2">Highest extraction effectiveness of 37% with the addition of EDTA and at an initial Pb concentration of 67 mg/kg</td><td>Chen et al. (2023)</td></tr>
<tr><td colspan="15">The soil was spiked by three levels of Pb supplied as Pb ($C_2H_3O_2)_2$; 200, 500 and 1000 mg/kg and the chelating agent EDTA was used to increase the availability of metals for plant uptake.</td></tr>
<tr><td rowspan="3">Cu, Ni, Pb, Zn</td><td rowspan="3">Loamy sand-Sand 83.9%, Silt 6.93%, 9.18 Clay %, average OM around 7%, mean pH 8.5, mean TN 0.07(g kg^{-1}), mean EC 145.85(µS cm^{-1}), Ca 167.5 (g kg^{-1}), Toto P 0.07(% dm), CEC 20.7</td><td rowspan="3">Poplar (Populus deltoides × Populus nigra, cv Orion), Willow (Salix matsudana, cv Levante), Industrial hemp (Cannabis sativa) and alfalfa (Medicago sativa)</td><td rowspan="3">Field experiment</td><td rowspan="3">2 years</td><td>$mgkg^{-1}$</td><td colspan="2">Tot</td><td colspan="2">Ext</td><td>Tot</td><td>Ext</td><td>Tot % of reduction</td><td>Ext % of reduction</td><td rowspan="3">Guidi et al. (2018)</td></tr>
<tr><td>Cu</td><td>64.53i</td><td>29.9</td><td>11.24i</td><td>11.3</td><td>27.3</td><td>10.8</td><td>6</td><td>4</td></tr>
<tr><td>Ni</td><td>26.75i</td><td>31.7</td><td>0.48i</td><td>0.3</td><td>30.9</td><td>0.3</td><td>3</td><td>2</td></tr>
</table>

	(meq 100 g^{-1})				Pb	135i	48.6	28.5i	29.3	48.2	26.7	1	9	
					Zn	286.5i	170	66.7i	57	157.2	53.1	8	7	
The site was divided into 20 plots distributed in 4 blocks. Initial soil characterization parameters are calculated as the mean of the data for each block presented in the article. The same applies to the initial concentrations of contaminants (mgkg^{-1}), which are marked with i and presented first in the column of the initial contaminant concentrations. However, the conducted study compared the initial concentration of contaminants after planting, that is, at the beginning of the trial and the final concentrations at the end of the trial, which are shown as the initial and final concentrations in the upper columns. Both, the initial and final contaminant concentrations consist of the total and extractable concentrations. The column efficiency represents the difference between the aforementioned initial and final contaminant concentrations expressed as percentage of reduction of initial contaminant concentration as follows: ((initial concentration-final concentration) / initial concentration). Alfalfa reduced the extractable Ni (61%) and Zn (46%) in the soil; hemp reduced 32% of the extractable Cd; poplar decreased extractable Cd (37%), Ni (49%), Pb (46%) and Zn (63%); and willow, extractable Zn by 73% compared to the beginning of the trial. Poplar and willow were able to extract and accumulate the highest amount of Zn (3200 and 5200 g ha^{-1} year^{-1} respectively) and Cu (182 and 116 g ha^{-1} year^{-1}), whereas hemp, with 36 g ha^{-1} year^{-1}, showed the best phytoextraction potential for Pb.														
Cd	pH 5.73, CEC (cmol*kg^{-1}) 12.3, OM (gkg^{-1}) 31.4	Red king grass *(Pennisetum sinese R.)* and green king grass *(Pennisetum sinese Roxb)* with enhancement of Polyaspartic acid (PASP)	Field experiment	3 years	mgkg^{-1}	Tot		Ext		Dec. 2019	Dec. 2020	Cd phytoextraction efficiency (%)		Liu et al. (2023)
					Cd	1.17		0.215		Cd in soil 0.76–1.02	Not specified	Dec. 2019	11±0.20 (GHP)	
										RHP-0.76 mg kg^{-1}	Reduced by 0.32 mg kg^{-1}	Dec. 2020	10±0.08 (GHP)	
										GHP-0.77 mg kg^{-1}	Reduced by 0.29 mg kg^{-1}	Sep. 2021	7±0.32 (GHP)	
The experimental setup was following: red king grass (RH), red king grass treated with 1 mmol kg−1 PASP (RHP), green king grass (GH), and green king grass treated with 1 mmol kg−1 PASP (GHP). Three harvest seasons were obtained during the study: first (December 2019), second (December 2020) and third (September 2021). The initial contaminant concentrations presented in the column above are concentrations before planting, where the soil Cd content was approximately 0.94 mgkg^{-1}. The final contaminant concentrations in the soil are not specified in the study. However, changes in the soil total Cd content are presented after first and second harvests which are shown in the column above – final concentrations. The effectiveness of phytoremediation is shown as Cd phytoextraction efficiency in the column effectiveness, where the highest result values are taken into account – GHP treatment. The addition of PASP increased reductions in soil total Cd by 22.58 % and 39.72 % at harvest in December 2019 and 2020.														
Cd, Pb	See Salehi *et al.* (2020) in table 4	*Sorghum Bicolor,* grass family plant	Greenhouse experiment	90 days	mgkg^{-1}		30% leachate			30% leachate and plant		The removal of Pb – 95% and Cd-49%		Salehi et al. (2020)
					Cd		6.15			0.26				
					Pb		2.65			1.3				
The description of the greenhouse experiment is described in table 4, see Salehi et al. (2020.) Heavy metals are added to the soil by leachate. The initial contaminant concentration are shown as concentration in the treatment without planting plants and irrigation with 30% landfill leachate, whereas the final contaminant concentration are presented as the plant planting treatment with 30% landfill leachate.														
Cd, Cr, Ni, Pb, Cu, Zn	See Macci et al. (2013) in table 4	Trees: Poplar *Populus nigra,* var.*italica* and *Paulownia tomentosa* and a bush; *Cytisus scoparius* and a natural growing vegetation	Field experiment	3 years	Cd mgkg^{-1}		3.05-3.55			1.69-2.24		27±14%		Macci et al. (2013)
					Cr mgkg^{-1}		40.5-69.7			34.5-63.8		13±5 %		
					Ni mgkg^{-1}		109-191			101-88.8		30±15%		
					Pb mgkg^{-1}		407-619			380-344		32±24%		
					Cu mgkg^{-1}		135-275			121-210		30±16%		
					Zn mgkg^{-1}		417-641			381-530		15±13%		
The experimental setup and soil characteristics are presented in the table 4, see Macci. et al. (2013). The initial concentrations are shown as the range between the highest and lowest contaminant concentrations in the entire profile (0-60 cm) from all 6 plots. Same applies to the final contaminant concentrations. The effectiveness was calculated as mean±st.dev. of the contaminant removal ((initial concentration-final concentration) / initial concentration) for each plot throughout the entire profile. However, it should be noted that some plots were not taken into account due to the higher final concentration as a consequence of the plot effect. For more details, see Macci et al.(2013).														

Abbreviations: TPHs Total Petroleum Hydrocarbons; PHC Petroleum Hydrocarbons; EC Electrical conductivity; TOC Total Organic Carbon; WSC Water soluble carbon; TN Total Nitrogen, TP total phosphorus, TC Total Carbon, TH Total Hydrogen, OM Organic Matter, N Nitrogen, P Phosphorous, WHC water holding capacity, DO Dissolved Oxygen, WC Water Content, SOM Soil Organic Matter, OC Organic Carbon, CEC Cation exchange capacity

A number of different plants have been identified for phytoremediation strategies potentially applicable to the area of interest in this study (Tables 4, 5, 6). For organic contaminants, grasses are generally used to degrade total Petroleum Hydrocarbons (PHC) and PAHs (Becerra-Castro et al., 2013). The use of perennial ryegrass *Lolium perenne* together with white clover *Trifolium repens*, chemical fertilizers as soil amendments and consortia of TPH-degrading bacteria has been reported to be successful for rhizoremediation of C12-C40 aliphatics in TPHs-impacted industrial soils within a large-scale project in Ireland. About 100% of low boiling point hydrocarbons (<C20) was removed, whereas heavier fractions had been reduced by 67–80% (Germaine et al., 2015). Tall Fescue *Festuca arundinacea*, species of grass, inoculated with two plant growth promoting rhizobacteria (PGPR) strains showed a 68% in total aliphatic and 63% of total PAHs, in a 4-month pot experiment (Hou et al., 2015). Furthermore, *Sorghum Bicolor*, a grass family plant, achieved 96% pyrene removal in 90 days, using 30% of landfill leachate for irrigation of the plant (Salehi et al., 2020). However, the soil was spiked in a pot experiment which could affect such good effectiveness in a short time, compared to aged contaminants. Moreover, *Sorghum bicolor* plant and Pseudomonas aeruginosa bacteria achieved a pyrene removal of 83% (Rostami et al., 2017). Alfalfa *Medicago sativa* L., from the legume family, obtained better results in monoculture within the aided phytodegradation of PHC C10-C40 and PAHs than in intercropping with common sunflower *Helianthus annuus* in a pilot project in southern Sweden (Marchand et al., 2018). On average, the largest reduction in PAHs was 40% for medium molecular weight PAHs, while the reduction in PHC C10–40 was 20% in a 5-month time period (Marchand et al., 2018). In contrast, the intercropping of Alfalfa *Medicago sativa* and Tall Fescue *Festuca arundinacea* achieved better results in phytoextraction of PAHs with 30% removal in a 7 months' field experiment (Sun et al., 2011). In addition to grasses and legumes, trees such as willow and poplar could also be effective in phytoremediation strategies for organic contaminants. In a 3-year field experiment, the effectiveness of phytoremediation of TPHs and PAHs by poplar *Populus nigra, var.italica*, *Paulownia tomentosa*, bush *Cytisus scoparius* and a natural growing vegetation was 47% for TPHs and 51% for PAHs, receptively (Macci et al., 2013). The rhizodegradation of aliphatics and PAHs by willow trees *Salix purpurea* resulted in efficiency of 46% for aliphatics and 83% for PAHs respectively (Yergeau et al., 2014).

In the period from 1995 and 2009, for inorganic contaminants, that is heavy metals, some of the most frequently cited species in phytoremediation studies were indian mustard *Brassica juncea* (L.), common sunflower *Helianthus annuus* L. and maize *Zea mays* L (Szczygłowska et al., 2011). Table 6 present some of the studies involving the aforementioned plants as well as other species for phytoextraction of heavy metals. For instance, somaclonal variants of tobacco *Nicotiana tabacum* and sunflower *Helianthus annuus* mutants were able to reduce 45–69% of labile Zn in topsoil during a 5-year field phytoextraction experiment at Bettwiesen in eastern Switzerland (Herzig et al., 2014). Maize *Zea mays* obtained overall metal removal per ha: between 7-10 g Cd ha^{-1} , 28–46 g Pb ha^{-1} and 1447–2826 g Zn ha^{-1} during a 25-week field experiment in Flanders, Belgium (Meers et al., 2010). Indian mustard *Brassica juncea* achieved the highest Pb extraction effectiveness of 37% with the addition of Ethylenediaminetetraacetic acid (EDTA) as a chelating agent (increasing pollutant availability for plant uptake) during a 3-month pot experiment (Chen et al., 2023). Besides the previously mentioned species, some of the common plants for phytoextraction are trees willow and poplar. Approximately 60–70% of Cd, Pb and

Zn were removed in 3- and 4-year-old shoots, which represented 61–80% of whole shoot biomass of willows and poplar, during a 4-year field phytoextraction experiment near the town of Příbram, 58 km south of Prague (Zárubova et al., 2015). Willow, poplar, industrial hemp (*Cannabis sativa*) and alfalfa were subjected to a 2-year phytoextraction experiment in Taranto, Italy (Guidi et al., 2018). Alfalfa reduced the extractable Ni (61%) and Zn (46%) in the soil; hemp reduced 32% of the extractable Cd; poplar decreased extractable Cd (37%), Ni (49%), Pb (46%) and Zn (63%); and willow, extractable Zn by 73% compared to the beginning of the trial. Poplar and willow were able to extract and accumulate the highest amount of Zn and Cu, whereas hemp showed the best phytoextraction potential for Pb (Guidi et al., 2018). Furthermore, during a 3-year field experiment in the municipality of San Giuliano Terme (Pisa, Italy), poplar *Populus nigra* together with princess tree *Paulownia tomentosa* and leguminous shrub common broom *Cytisus scoparius* were able to remove 27% of Cd, 13% of Cr, 30% of Ni, 32% of Pb, 30% of Cu and 15% of Zn, respectively (Macci et al., 2013). Same as for organics contaminants, grasses could be applied for phytoextraction of heavy metals as well. The intercropping of perennial *Pennisetum sinese* and *Lolium perenne* during 5 months of pot experiment showed promising results for phytoextraction of Pb, Cd, Cu and Zn (Zou et al., 2023). At higher soil contamination (soil was spiked with compound polluted solution), Pb decreased by 65%, Cd by 93%, Cu by 79% and Zn by 90%, respectively (Zou et al., 2023).

5.4 Decision support table

In addition, a decision support table including candidate species, rough estimates of treated soil volumes as well as effectiveness achieved with candidate plant species (according to Tables 4 and 6) is presented below to support decision making once the stakeholder know the type of contaminants, their concentrations and their depth location in the area of interest. The decision table can be used as follows: e.g. if organic contaminants such as aliphatic and aromatic hydrocarbons (C10-C40) and PAHs are found at a depth of 4 m and the whole area of interest have to be treated to this depth, then potentially alfalfa can be used to manage these contaminants in the area since its roots can reach a depth of 4.5 m, which means that 72 000 tonnes of contaminated soil could potenitally be treated total. Furthermore, over a 5-month time frame, the study with alfalfa reported the effectiveness of 20% for C10-C40 removal from soil, and 18% for low molecular weight PAHs, 40% for medium molecular weight PAHs and 38% for heavy molecular weight PAHs.

The area considered for the area of interest was approximately 10 000 m^2 (Eniro's property map), while the density was 1.6 tonnes/m^3 for the calculation of the amount of treated soil. The exact composition of materials underneath asphalt and vegetation cover in the area of interest is not investigated. Based on the previous site investigations (Section 3.1), it can however be assumed that it is a filling material consisting of sand, gravel and stones. Here, the assumption is maid that the density of material is 1.6 tonnes/m^3 corresponding to the density of dry sand. This parameter may be refined based on investigations of the area of interest. The root depths were not reported in the studies, but found elsewhere in the literature as follows: ryegrass - up to 0.6 m (Wedderburn et al., 2010), alfalfa – up to 4.5 m (OVAM, 2019), sorghum – 2.4 m (Lamb et al., 2022), poplar and willow - 3.3 m (Foxx et al., no date).

Table 7. Decision support table with rough estimates of volumes and amounts (assuming the soil density of 1.6 tonne/m^3) of contaminated soils that potentially can be treated with help of candidate plant species in the area of interest at the Lindholmen 6:9 property. A rough estimate of the treated soil volume [m^3] was calculated according to the following formula: depth location of contaminants [m] x area of the area of interest [m^2]. Furthermore, rough estimates of the amount of treated soil were calculated as follows: rough estimates of the volume of treated soil: rough estimates of treated soil volume [m^3] x the density of material [tonnes/m^3].

<table>
<tr><th colspan="2">Candidate plant species (+amendments used)</th><th rowspan="2">Root depth [m]</th><th rowspan="2">Depth location of contaminants [m]</th><th rowspan="2">Rough estimates of treated soil volume [m^3]</th><th rowspan="2">Rough estimates of treated soil amounts [tonne]</th><th rowspan="2" colspan="2">Contaminant</th><th rowspan="2" colspan="2">Reported mean effectiveness [%]</th><th rowspan="2">Reported treatment time</th></tr>
<tr><th>Common name</th><th>Scientific name</th></tr>
<tr><td rowspan="2">Ryegrass + white clover + (chemical fertilizers inoculated with TPH degrading bacterial consortia)</td><td rowspan="2">Lolium perenne + Trifolium repens</td><td rowspan="2">Up to 0.6</td><td rowspan="2">0-0.6</td><td rowspan="2">6000</td><td rowspan="2">9600</td><td rowspan="2" colspan="2">Aliphatic and aromatic hydrocarbons</td><td colspan="2">Almost 100% for low boiling point hydrocarbons (<C20)</td><td rowspan="2">2 years</td></tr>
<tr><td colspan="2">67–80% for heavier fractions</td></tr>
<tr><td rowspan="4">*Ryegrass +fountain grass</td><td rowspan="4">Lolium perenne + Pennisetum sinese</td><td rowspan="4">Up to 0.6</td><td rowspan="4">0-0.6</td><td rowspan="4">6000</td><td rowspan="4">9600</td><td colspan="2">Pb</td><td colspan="2">65</td><td rowspan="4">5 months</td></tr>
<tr><td colspan="2">Cd</td><td colspan="2">93</td></tr>
<tr><td colspan="2">Cu</td><td colspan="2">79</td></tr>
<tr><td colspan="2">Zn</td><td colspan="2">90</td></tr>
<tr><td rowspan="4">Alfalfa + (10% compost from the food waste)</td><td rowspan="4">Medicago sativa</td><td rowspan="4">Up to 4.5</td><td>0-1</td><td>10000</td><td>16000</td><td colspan="2">C10–C40</td><td colspan="2">20</td><td rowspan="4">5 months</td></tr>
<tr><td>0-2</td><td>20000</td><td>32000</td><td colspan="2">PAH -L</td><td colspan="2">18</td></tr>
<tr><td>0-3</td><td>30000</td><td>48000</td><td colspan="2">PAH-M</td><td colspan="2">40</td></tr>
<tr><td>0-4.5</td><td>45000</td><td>72000</td><td colspan="2">PAH-H</td><td colspan="2">38</td></tr>
<tr><td rowspan="2">*Sorghum + (landfill leachate as a fertilizer)</td><td rowspan="2">Sorghum Bicolor</td><td rowspan="2">2.4</td><td>0-1</td><td>10000</td><td>16000</td><td rowspan="2" colspan="2">Pyrene</td><td rowspan="2" colspan="2">96</td><td rowspan="2">90 days</td></tr>
<tr><td>0-2.4</td><td>24000</td><td>38400</td></tr>
<tr><td rowspan="6">Poplar + princess tree + common broom</td><td rowspan="6">Populus nigra, var.italica + Paulownia tomentosa + Cytisus scoparius</td><td rowspan="6">3.3</td><td rowspan="2">0-1</td><td rowspan="2">10000</td><td rowspan="2">16000</td><td>Cd</td><td rowspan="3">TPHs</td><td>27</td><td rowspan="3">47</td><td rowspan="6">3 years</td></tr>
<tr><td>Cr</td><td>13</td></tr>
<tr><td rowspan="2">0-2</td><td rowspan="2">20000</td><td rowspan="2">32000</td><td>Ni</td><td>30</td></tr>
<tr><td>Pb</td><td rowspan="3">PAHs</td><td>32</td><td rowspan="3">51</td></tr>
<tr><td rowspan="2">0-3.3</td><td rowspan="2">33000</td><td rowspan="2">52800</td><td>Cu</td><td>30</td></tr>
<tr><td>Zn</td><td>15</td></tr>
<tr><td rowspan="3">Poplar + willow</td><td rowspan="3">Populus nigra, Populus maximowiczii +Salix schwerinii, Salix viminalis, Salix smithiana clone S-218</td><td rowspan="3">3.3</td><td>0-1</td><td>10000</td><td>16000</td><td colspan="2">Cd</td><td rowspan="3" colspan="2">Approximately 60–70% for Cd, Pb and Zn</td><td rowspan="3">4 years</td></tr>
<tr><td>0-2</td><td>20000</td><td>32000</td><td colspan="2">Pb</td></tr>
<tr><td>0-3.3</td><td>33000</td><td>52800</td><td colspan="2">Zn</td></tr>
<tr><td rowspan="3">Willow</td><td rowspan="3">Salix purpurea</td><td rowspan="3">3.3</td><td rowspan="3">0-3.3</td><td>10000</td><td>16000</td><td colspan="2">C10-C50</td><td colspan="2">46</td><td rowspan="3">6 months</td></tr>
<tr><td>20000</td><td>32000</td><td rowspan="2" colspan="2">PAHs</td><td rowspan="2" colspan="2">83</td></tr>
<tr><td>33000</td><td>52800</td></tr>
</table>

*Plant species were demonstrated effective for removal of the contaminant source in a spiked soil. Contaminants could therefore be more readily available for uptake and thus demonstrating the higher effectiveness compared to aged contaminants in the historically contaminated soil.

6 Discussion

This Chapter, in addition to discussing the objectives of the study and the results obtained, examines the perspective on risk-free versus non-contaminated soils.

6.1 Potential and actual soil contaminants and phytoremediation strategies for the study site

The main identified potential contaminants in the area of interest, according to the Industry List for surveying of Contaminated Sites (SEPA, 2020), are mostly organic contaminants: Aliphatic hydrocarbons and Polycyclic aromatic hydrocarbons (PAHs). However, in addition to the above, lead was also identified as one of the potential heavy metals. The aforementioned contaminants are in accordance with the results of previously conducted site investigations, where aliphatic and aromatic hydrocarbons, PAHs, BTEX and heavy metals (arsenic, barium, cadmium, cobalt, copper, lead, mercury and zinc) were identified as contaminants exceeding soil guideline values (Sweco, 2014; Sweco, 2016; Kodeda Konsulter AB, 2016). In spite of that, the investigations conducted were performed outside the area of interest indicating that there are large uncertainties related to the presence of the identified potential contaminants in the area of interest. As stated, it is necessary to know the type of contaminant for making a decision on applicable phytoremediation (OVAM, 2019). Furthermore, uncertainties about the concentrations of potential contaminants should also be taken into account. Baker et al. (1994) stated that applicability of phytoremediation depends on the identification of plants able to either 1) accumulate high concentrations of heavy metals in the soil in their aboveground parts (phytoextraction), or 2) immobilize them at the soil-roots boundary (phytostabilization). The type and concentration of contaminants, among other things, define the uptake and accumulation of metals in the plant (OVAM, 2019). In addition to the uncertainties in the type of contaminants and their concentrations in soils, the uncertainties of their depth should also be included, because the depth can as well indicate the selection of the appropriate plant which can reach contaminants with roots. For instance, for shallow contamination, plants like ferns and grasses may be suitable. Trees with deeper roots, such as poplars and willows, are in contrast suitable for deeper soil contamination and contaminated groundwater (EPA, 2012). Therefore, soil sampling and analysis is required to confirm the presence of potential contaminants as well as their concentration and depth in the area of interest, see the suggested sampling plan in Appendix B.

Regarding the selection of phytoremediation strategies for the area of interest, removal or destruction of the source of contamination was of the main interest for the stakeholder because the future plans for the area of interest include the construction of residential buildings. For organic contaminants, the focus was therefore on degradation with the help of plants and the associated soil microorganisms, while for inorganic contaminants, i.e. heavy metals, phytoextraction was of greatest interest. Phytoextraction is of interest, since it aims to gradually remove the contaminants from the soil (Koptsik, 2014). In contrast, phytostabilization of soil contaminants is not aimed at their direct removal from the soil (Koptsik, 2014) but rather at their stabilization or immobilization in the soil matrix (Drenning et al., 2022), while reducing their bioavailability (Wong, 2003; Marques et al., 2009). Phytodegradation and/or rhizodegradation, similar to phytoextraction, remove the source of organic contaminants but using biodegrading mechanisms (Drenning et al., 2022).

However, the main drawback for both phytoextraction and phytodegradation is the relatively long remediation time depending on the type of the contaminant and its initial concentreation (Vangronsveld et al., 2009, Prasad et al., 2022). In spite of that, some studies presented in Table 4 and Table 6 result in substantial decrease of contaminants in the relative short remediation time, e.g., using intercropping of perennial *Pennisetum sinese* and *Lolium perenne* for phytoextraction of heavy metals and using *Sorghum Bicolor*, grass family plant for phytoremediation of Pyrene contaminated soil (Zou et al., 2023, Salehi et al., 2020). Still, it should be kept in mind that soils in these studies were spiked, and contaminants could therefore be more readily available for uptake compared to aged contaminants in the soil (Törneman et al., 2009). Besides that, bioavailability and thus effectiveness of uptake and degradation also depends on the specific soil type, considering e.g., texture, pH, organic carbon content, therefore, preliminary studies should be carried out before a full-scale field experiment (Törneman et al., 2009). Also, the conducted studies were pot experiments. However, the conditions in the pots could differ from the actual conditions in the field (Conesa et al., 2007). The phytoextraction of Cr, Cu, Pb and Zn using *Brassica napus* was carried out both in the pot and field experiments, where the obtained results showed a high accumulation of metals in greenhouse conditions, while this was not the case for the field experiment (Brunetti et al., 2011), potentially due to more intensive soil exploration by plants in the pots (Delorme et al., 2000), that is roots explored the soil matrices much more thoroughly (Mench et al., 2010). The ability of the plant to accumulate contaminants more successfully in pots than in the field could be assigned to the different physiological state of the plant and/or some modifications of soil properties and climatic parameters under pot conditions (Conesa et al., 2007).

In addition to the long remediation time, waste management of contaminated biomass can be considered another disadvantage of phytoextraction. In order to avoid leaching of contaminants back into the soil from plant litter (dead plant material), it is necessary to remove contaminated aboveground biomass (Greenberg et al., 2014; Chang et al., 2014; Mench et al., 2010; Kumpiene et al., 2010; Hu et al., 2013; Sinha et al., 2013; Placek, 2016; OVAM, 2019) and phytoextracted contaminants (Gerhardt et al., 2016; OVAM, 2019). Moreover, an appropriate biomass disposal management system is necessary to prevent secondary pollution (Tan et al., 2023). The disposal of the biomass can be managed in different ways, such as disposal to specialized landfill, incineration and subsequent treatment to recover metals, composting, production of biofuels and syn-gas (methane, CO, hydrogen, etc.) through supercritical gasification or liquefaction (Mench et al., 2010). In contrast, phytodegradation does not require biomass disposal management, but still requires a long remediation time and it is applicable only for organic contaminants (OVAM, 2019). If both organic and inorganic contaminants are present at the site, the inorganic contaminants will still be present after treatment with phyto/rhizo-degrading plants. Therefore, intercropping that involves both degrading and extracting plant species should be investigated to address both organics and inorganics in soil.

6.2 Available plants and their effectiveness for potential contaminants at the area of interest

Due to the potential presence of both organic and inorganic contaminants in the area of interest, it would be of interest to investigate intercropping of appropriate plant species to act on both types of contamination. The potential candidates for further investigations could then be grasses *Lolium perenne* ryegrass, *Sorghum Bicolor* and *Pennisetum sinese*, legume alfalfa *Medicago sativa* as well as willow and poplar trees. However, these plant species differ, among other things, in the depth of their roots, which could be the main selection criterion given the depth of contaminants. For instance, perennial ryegrass *Lolium perenne* is characterized by up to 60 cm root depth (Wedderburn et al., 2010), while alfalfa *Medicago sativa* has a root depth up to 4.5 m (OVAM, 2019). Willow's root depth is fairly shallow (OVAM, 2019). However, both willow and poplar have a deeper rooting than grasses/herbs (Zárubova et al., 2015). Further studies are needed to investigate the factors that govern the rooting depth (content of coarse fractions availability of nutrients and water, etc.) for being able to maximise it. Although plant species such as *Sorghum Bicolor* and *Pennisetum sinese* showed very promising results in both phytoextraction and phytodegradation of contaminants (Zou et al., 2023, Salehi et al., 2020) in artificially contaminated soils, their effectiveness should be investigated for the contaminants aged in soils. All of the above plant species should be tested in the laboratory and in pilot field experiments to ensure their effectiveness for Swedish conditions.

If the current car parking function of the area of interest should be kept, further investigations should be focused on candidate grass species for phytoremediation and the grass reinforcement systems (GRS) for parking lots. There are some GRS that do not require bearing layer (Section 2.3) and can potentially be used, however a thorough investigation and testing of such systems is required to assure their suitability for 1) reinforcing the candidate grasses and 2) current parking lots loading. However, grasses cannot reach deep contaminants. Poplar and willow can in contrast reach deep soil contamination, but these trees are incompatible with a car parking function of the area of interest. Still, these trees produce large biomass (Zárubova et al., 2015), which can be used for generating a profit, e.g., in district heating plants combined with power generation (Adler et al., 2008, Burges et al., 2018; Cundy et al., 2016; Gerhardt et al., 2017; GREENLAND, 2014; Robinson et al., 2009), as alternative to profit-generating parking lots. In the case of willow/poplar use for remediation at the area of interest, a landscape architect should be involved for designing an aesthetic environment. In any case, if the present surface impermeable layer, i.e., asphalt, is removed for phytoremediation, leakage of contaminants from soil to groundwater and surface water can increase. Therefore, attention should be given to management of potential contaminant leakage in the course of remedial action.

Moreover, the use of surfactants is receiving increasing attention, as they are capable of enhancing the bioavailability of hydrophobic contaminants, such as PAHs, consequently helping their assimilation by microorganisms (Kavitha et al., 2014; Kim et al., 2001). When compared to chemical surfactants, bio surfactants are characterized by lower toxicity and higher biodegradability (Kiran et al., 2016). The one of the most studied, rhamnolipid, has shown increased biodegradation efficiency of target hydrocarbons (Owsianiak et al., 2009; Tahseen et al., 2016; Whang et al., 2008). In a 35-days laboratory experiment the removal effectiveness resulted in 72% for Phenanthrene, 64% for Fluoranthene, and 58% for Pyrene at day 7 (Lu et al., 2019). Furthermore, the use of bioaugmentation and biostimulation by different bacteria, see in table 5, produced the removal efficiency of 99% for PAHs (Haleyur et al., 2019). The above points to a potential possibility of combining GRO strategies – bioremediation methods in combination with phytodegradation using perennial ryegrass and white clover *Trifolium repens* to degrade organic contaminants and maintain the existing land use as a parking lot, with the help of grass reinforcement protection mesh. However, further investigations are needed.

6.3 Risk-free versus contaminant-free soils

As previously mentioned, both phytoextraction and phyto/rhizodegradation, aim to remove the source of contaminants in the soil (Koptsik, 2014; Drenning et al., 2022). By contrast, phytostabilzation reduces the risk to potential biological receptors, rather than removing the contaminants (Robinson et al., 2009; Mench et al., 2010, Padmavathiamma and Li, 2012; Vamerali et al., 2010; Pelfrêne et al., 2015). Instead of considering the total contaminant concentration in soils which represents a weak estimate of contaminant toxicity (Krishnamurti et al. 1995; Krishnamurti and Naidu 2002; Violante et al. 2010), consideration could be given to the bioavailable fraction of contaminants. The method of sequential extraction is used to assess the bioavailability of the metals in the soil due to its potential to reveal the relationship between metals and various soil solid phases (Ma; Rao, 1997). Metal removal by plants depends on the bioavailability of the metal, as metal uptake is function of the root exposure to bioavailable metal in soil (Robinson et al., 2006).

The approach in which the focus of phytoextraction is the reduction of only the most dangerous fraction for the environment and human health, i.e. targeting the mobile fractions of metals in the soil, is gaining attention (Petruzzelli et al., 2012). So called Bioavailable Contaminant Stripping (BCS) indicates the removal of the soluble metal fractions from contaminated soil, rather than significantly reducing the total metal concentration (Hamon; McLaughlin, 1999). With this approach, the required phytoextraction time can therefore be shorter (Petruzzelli et al., 2012; Herzig et al., 2014; Santa-Cruz et al., 2022). Herzig et al. (2014) conducted a 5-year field experiment where the focus was on phytoextraction of labile Zn concentration from the topsoil, instead of total Zn concentration (Table 6). The authors concluded that "when bio-available metal stripping is the target criterion of remediation, using the labile concentration, instead of the "total" soil contamination, phytoextraction becomes much more efficient". Furthermore, Enhanced BSC (EBSC) was used in mercury-contaminated soil resulting in the removal of the bioavailable Hg fraction (Petruzzelli et al., 2012). The study was conducted in a greenhouse using indian mustard *Brassica juncea* and common sunflower *Helianthus annuus*, while soil was sampled at an industrial site in northern Italy, for more details see Petruzzelli et al. (2012). It should be noted that the BSC approach is not accepted as a soil remediation technology in countries that consider only the total concentration of metals thresholds in soil as legally binding guidelines (Santa-Cruz et al., 2022).

Lead can be very difficult to phytoextract as its bioavailability is usually low in the historically contaminated soils. Although some studies (Chen et al., 2023; Salehi et al., 2020; Zou et al., 2023) specify effective phytoextraction of lead in pot experiments with a spiked soil, their availability, and thus their extraction effectiveness, can significantly differ from historically contaminated soils (OVAM, 2019; Liang et al., 2014; Törneman et al., 2009). A strategy aimed at reducing mobility of lead and thus its availability in soils to biological receptors, using stabilising plants (Bolan et al., 2011) and/or immobilising soil amendments (Kumpiene, 2008; Enell et al., 2020) (chemical stabilisation/immobilisation) could potentially be an effective and relatively quick alternative for management of this contaminant, see also Figure 21. For example, Enell et al. (2020) have demonstrated the effectivnness of a biochar as an effective immobilising soil amendment for both metals and PAHs in soils. However, although this strategy can reduce the risks posed by lead to potential biological receptors, it does not remove this contaminant from the soil, which may however meet the resistance of controlling authorities to accept this strategy for the future residential land use at the site (e.g. see Kumpiene et al., 2019 and GREENLAND, 2014). Furthermore, immobilising soil amendments may provide an immediate risk reduction effect across the whole contaminated soil profile while the effects of stabilising plants are limited by rooting depth and are postponed in time due to root system development.

7 Conclusion

The main conclusions that can be drawn from this study are:

1. The study results suggest phytoextraction and phyto- and rhizodegradation for the removal of identified primary potential contaminants at the area of interest of the study site – lead as a representative of heavy metals and aliphatic hydrocarbons together with polycyclic aromatic hydrocarbons (PAHs) as organic contaminants, respectively.
2. Lead can be very difficult to phytoextract as its bioavailability is usually low in the historically contaminated soils. An alternative strategy aimed at reducing mobility of contaminants in soils with help of stabilising plants (phytostabilisation) and/or immobilising soil amendments (chemical stabilisation/immobilisation) could potentially be considered for managing of this contaminant.
3. The identified candidate species for phytoextraction and phyto- and rhizodegradation in the area of interest are summarized in Table 8.

Table 8. Summary of the candidate plant species for phytoremediation of potential contaminants in the area of interest at the Lindholmen 6:9 property.

Candidate plant species		****Root depth, [m]**	**Contaminant**
Common name	Scientific name		
Ryegrass	*Lolium perenne*	Up to 0.6	Aliphatic and Aromatic Hydrocarbons, TPHs, Pb, Cd, Cu, Zn
*Fountain grass	*Pennisetum sinese*	0.30	Pb, Cd, Cu, Zn
Alfalfa	*Medicago sativa*	Up to 4.5	Ni, Zn, Aliphatics, PAHs
*Sorghum	*Sorghum Bicolor*	2.4	Cd, Pb, PAHs
Poplar	*Populus nigra, Populus deltoides*	3.3	Cd, Cr, Ni, Pb, Cu, Zn, PAHs, TPHs
Willow	*Salix matsudana, Salix schwerinii, Salix viminalis, Salix smithiana, Salix purpurea*	3.3	Cu, Ni, Pb, Zn, Aliphatics, PAHs

*Plant species were demonstrated effective for removal of the contaminant source in a spiked soil.
**Root depth was not reported in the studies. The root depth for plant species was found elsewhere in the literature.

4. Further research is needed to assess the possibility of retaining parking lots during phytoremediation.
5. Soil sampling and analysis is recommended in accordance with a developed sampling plan for the area of interest.
6. Laboratory or (and) pilot field experiments are necessary to confirm the effectiveness of the candidate plant species for site-specific conditions before a full-scale field trial.

References

Adler, A., Karacic, A., Weih, M., 2008. Biomass allocation and nutrient use in fast-growing woody and herbaceous perennials used for phytoremediation. Plant and Soil. 305. 189-206. 10.1007/s11104-008-9551-2.

Avfall Sverige, 2007. Uppdaterade bedömningsgrunder för förorenade massor, Rapport 2007:1.

Baker A.J.M., McGrath S.P., Sidoli C.M.D., Reeves R.D., 1994. The possibility of in situ heavy metal decontamination of polluted soils using crops of metal-accumulating plants. Resources, Conservation and Recycling, Volume 11, Issues 1–4, Pages 41-49, ISSN 0921-3449. https://doi.org/10.1016/0921-3449(94)90077-9.

Bardos, P., Spencer, K.L., Ward, R.D., Maco, B.H., Cundy, A.B., 2020. Integrated and sustainable management of post-industrial coasts. Front. Environ. Sci. 8, 1–14. https://doi. org/10.3389/fenvs.2020.00086.

Baruah, P., Deka, S., Baruah, P. P., 2016. Phytoremediation of crude oil-contaminated soil employing Crotalaria pallida Aiton. Environmental science and pollution research international, 23(11), 10595–10603. https://doi.org/10.1007/s11356-016-6227-y

Becerra-Castro, C., Prieto-Fernández, Á., Kidd, P.S., Weyens, N., Rodríguez-Garrido, B., Touceda-González, M., Acea, M.J., Vangronsveld J., 2013. Improving performance of Cytisus striatus on substrates contaminated with hexachlorocyclohexane (HCH) isomers using bacterial inoculants: developing a phytoremediation strategy, Plant Soil 362,247–260. https://doi.org/10.1007/s11104-012-1276-6

Bolan, N.S., Park, J. H., Robinson, B., Naidu, R., Huh, K.Y., 2011. Chapter four – Phytostabilization: A Green Approach to Contaminant Containment, Editor(s): Sparks, D.L., Advances in Agronomy, Academic Press, Volume 112, Pages 145-204, ISSN 0065-2113, ISBN 978012385538 https://doi.org/10.1016/B978-0-12-385538-1.00004-4.

Brunetti, G., Farrag, K., Soler Rovira, P., Nigro, F., Senesi, N., 2011. Greenhouse and Field studies on Cr, Cu, Pb and Zn phytoextraction by Brassica napus from contaminated soils in the Apulia region, Southern Italy, Geoderma, Volume 160, Issues 3–4, Pages 517-523, ISSN 0016-7061, https://doi.org/10.1016/j.geoderma.2010.10.023.

Burges, A., Alkorta, I., Epelde, L., Garbisu, C., 2018. From phytoremediation of soil contaminants to phytomanagement of ecosystem services in metal contaminated sites. Int. J. Phytoremediation 20, 384–397. https://doi.org/10.1080/15226514.2017.1365340.

Cecotti, M., Coppotelli, B. M., Mora, V. C., Viera, M., Morelli, I. S., 2018.

Efficiency of surfactant-enhanced bioremediation of aged polycyclic aromatic hydrocarbon-contaminated soil: Link with bioavailability and the dynamics of the bacterial community. The Science of the total environment, 634, 224–234. https://doi.org/10.1016/j.scitotenv.2018.03.303

Chang, P., Gerhardt, K. E., Huang, X. D., Yu, X. M., Glick, B. R., Gerwing, P. D., Greenberg, B. M., 2014. Plant growth-promoting bacteria facilitate the growth of barley and oats in salt-impacted soil: implications for phytoremediation of saline soils. International journal of phytoremediation, 16(7-12), 1133–1147. https://doi.org/10.1080/15226514.2013.821447

Chen, D., Soroma, M., Ibrahim, M., Danjaji, H. A., Tian, R., Wang, C., 2023. Chelate-assisted extraction of lead by Brassica juncea in contaminated soil. Int. J. Environ. Sci. Technol. https://doi.org/10.1007/s13762-023-04890-0

Conesa, H. M., Robinson, B. H., Schulin, R., & Nowack, B., 2007. Growth of Lygeum spartum in acid mine tailings: response of plants developed from seedlings, rhizomes and at field conditions. Environmental pollution (Barking, Essex : 1987), 145(3), 700–707. https://doi.org/10.1016/j.envpol.2006.06.002

Cundy, A.B., Bardos, R.P., Church, A., Puschenreiter, M., Friesl-Hanl, W., Müller, I., Neu, S., Mench, M., Witters, N., Vangronsveld, J., 2013. Developing principles of sustainability and stakeholder engagement for "gentle" remediation approaches: the european context. J. Environ. Manag. 129, 283–291. https://doi.org/10.1016/j.jenvman.2013. 07.032.

Cundy, A.B., Bardos, R.P., Puschenreiter, M., Mench, M., Bert, V., Friesl-Hanl, W., Müller, I., Li, X.N., Weyens, N., Witters, N., Vangronsveld, J., 2016. Brownfields to green fields: realising wider benefits from practical contaminant phytomanagement strategies. J. Environ. Manag. 184, 67–77. https://doi.org/10.1016/j.jenvman.2016.03.028

Dai, Y., Liu, R., Zhou, Y., Li, N., Hou, L., Ma, Q., Gao, B., 2020. Fire Phoenix facilitates phytoremediation of PAH-Cd co-contaminated soil through promotion of beneficial rhizosphere bacterial communities. Environment international, 136, 105421. https://doi.org/10.1016/j.envint.2019.105421

Delorme, T.A., Angle, J.S., Coale, F.J., Chaney, R.L., 2000. Phytoremediation of phosphorous-enriched soils. Int. J. Phytoremediation 2, 173–181. 10.1080/15226510008500038.

Denyes, M.J., Rutter, A., Zeeb, B.A., 2013. In situ application of activated carbon and biochar to PCB-contaminated soil and the effects of mixing regime. Environ. Pollut. 182, 201–208. https://doi.org/10.1016/j.envpol.2013.07.016.

Denyes, M.J., Rutter, A., Zeeb, B.A., 2016. Bioavailability assessments following biochar and activated carbon amendment in DDT-contaminated soil. Chemosphere 144, 1428–1434. https://doi.org/10.1016/j.chemosphere.2015.10.029.

Di Lonardo, S., Capuana, M., Arnetoli, M., Gabbrielli, R., Gonnelli, C., 2011. Exploring the metal phytoremediation potential of three Populus alba L. clones using an in vitro screening. Environmental science and pollution research international, 18(1), 82–90. https://doi.org/10.1007/s11356-010-0354-7

Drenning, P., 2021. Gentle Remediation Options (GRO): A Literature Review (Part 1/2). 10.13140/RG.2.2.36086.11849.

Drenning, P., Chowdhury, S., Volchko, Y., Rosén, L., Andersson-Sköld, Y., Norrman, J., 2022. A risk management framework for Gentle Remediation Options (GRO). Science of The Total Environment, Volume 802, 2022, 149880, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.149880.

Enell, A., Azzi, E.S., Berggren Kleja, D., Dahlin, S., Ekblad, A., Flyhammar, P., Fröberg, M., Hallin, S., Hermansson, S., Jones, C., Landen, L., Larsson, M., Leroy, P., Ohlsson, Y., Papageorgiou, A., Rijk, I., Sorelius, A., Sundberg, C., Tiberg, C., 2020. Biochar - from organic waste to resource for treatment of contaminated soil. Final report, Swedish Geotechnical Institute, Linköping

Eniro's property map; Retrived 2023-02-07 from . https://kartor.eniro.se/s%C3%B6k/g%C3%B6teborg

Environmental Protection Emergency (EPA), 2012. A Citizen’s Guide to Phytoremediation. EPA 542-F-12-016, Retrieved 2023-05-18 from https://www.epa.gov/sites/default/files/2015-04/documents/a_citizens_guide_to_phytoremediation.pdf

Evangelou, M. W., Ebel, M., & Schaeffer, A., 2007. Chelate assisted phytoextraction of heavy metals from soil. Effect, mechanism, toxicity, and fate of chelating agents. Chemosphere, 68(6), 989–1003. https://doi.org/10.1016/j.chemosphere.2007.01.062

FAO, ITPS, GSBI, CBD, EC, 2020. State of Knowledge of Soil Biodiversity - Status, Challenges and Potentialities, FAO, Rome https://doi.org/10.4060/cb1928en.

Foucault, Y., Lévêque, T., Xiong, T., Schreck, E., Austruy, A., Shahid, M., Dumat, C., 2013. Green manure plants for remediation of soils polluted by metals and metalloids: ecotoxicity and human bioavailability assessment. Chemosphere 93, 1430–1435. https://doi.org/10.1016/j.chemosphere.2013.07.040.

Foxx, T.S., Tierney G.D., Williams J.M., no date. Rooting depths of plants relative to biological and environmental factors. Los Almos National Laboratory, New Mexico. Retrived 2023-06-22 from https://inis.iaea.org/collection/NCLCollectionStore/_Public/16/061/16061888.pdf

Friesl-Hanl, W., Platzer, K., Riesing, J., Horak, O., Waldner, G., Watzinger, A., Gerzabek, M.H., 2017. Non-destructive soil amendment application techniques on heavy metal-contaminated grassland: success and long-term immobilising efficiency. J. Environ. Manag. 186, 167–174. https://doi.org/10.1016/j.jenvman.2016.08.068.

Garbisu, C., Alkorta, I., Kidd, P., Epelde, L., Mench, M., 2020. Keep and promote biodiversity at polluted sites under phytomanagement. Environ. Sci. Pollut. Res. https://doi.org/ 10.1007/s11356-020-10854-5.

Geological Survey of Sweden, no date. The soil type map viewer, (In Swedish: Sveriges geologiska undersökningen (SGU), Kartvisaren Jordarter 1:25 000-1:100 000). Geological Survey of Sweden, Uppsala, Sweden. Retrived 2023-02-08 from https://www.sgu.se/en/products/maps/map-viewer/

Gerhardt, K.E., Gerwing, P.D., Greenberg, B.M., 2017. Opinion: taking phytoremediation from proven technology to accepted practice. Plant Sci. 256, 170–185. https://doi. Org/10.1016/j.plantsci.2016.11.016.

Germaine, K. J., Byrne, J., Liu, X., Keohane, J., Culhane, J., Lally, R. D., Kiwanuka, S., Ryan, D., & Dowling, D. N., 2015. Ecopiling: a combined phytoremediation and passive biopiling system for remediating hydrocarbon impacted soils at field scale. Frontiers in plant science, 5, 756. https://doi.org/10.3389/fpls.2014.00756

Go kart, Göteborg stad GOkart 3.10.5 goteborg.se

Google maps, Retrived 2023-01-30 from https://www.google.se/maps/

Greenberg, B., Huang, X.-D., Mosley, P., Gerhardt, K., Yu, X.-M., Liddycoat, S., Lu, X., McCallum, B., MacNeill, G., Kroetsch, N., Hamiaberg, M., DiNino, M., Knezevich, N., Gerwing, P., Metzger, M., Ciyer, K., Dunn, A., Minks, R., Chubb, B., Obal, T., 2014. Phytoremediation of PHC and salt impacted soil in terrestrial and riparian environments - Remediation to generic tier 1 guideline values and determination of soil toxicity. Proceedings of the 37th AMOP Technical Seminar on Environmental Contamination and Response. 468-481. 468–481 http://www.researchgate.net/publication/287279541.

GREENLAND, 2014. Best Practice Guidance for Practical Application of Gentle Remediation Options (GRO). GREENLAND Consortium (FP7-KBBE-266124, Greenland)

Green-tech, no date. Grass Reinforcement Protection Mesh. Retrieved 2023-05-14 from https://www.green-tech.co.uk/ground-reinforcement/grass-reinforcement-protection-mesh

Guerra, A. B., Oliveira, J. S., Silva-Portela, R. C. B., Araújo, W., Carlos, A. C., Vasconcelos, A. T. R., Freitas, A. T., Domingos, Y. S., de Farias, M. F., Fernandes, G. J. T., & Agnez-Lima, L. F., 2018. Metagenome enrichment approach used for selection of oil-degrading bacteria consortia for drill cutting residue bioremediation. Environmental pollution (Barking, Essex : 1987), 235, 869–880. https://doi.org/10.1016/j.envpol.2018.01.014

Guidi, W., Palm, E., Mancuso, S., Azzarello, E., 2018. Trace element phytoextraction from contaminated soil: a case study under Mediterranean climate. Environmental science and pollution research international, 25(9), 9114–9131. https://doi.org/10.1007/s11356-018-1197-x

Göteborgs Stad, no date. Lindholmen, Retrived 2023-01-30 from https://goteborg.se/wps/portal/start/goteborg-vaxer/hitta-stadsutvecklingsprojekt/stadsomrade-hisingen/lindholmen

Göteborg Stad, no date. Gothenburg's area division, Statistics and analysis, (In Swedish: Göteborgs områdesindelning, Statistik och analys), Retrived 2023-01-31 from https://goteborg.se/wps/portal/enhetssida/statistik-och-analys/geografi/omradesindelningar

Haleyur, N., Shahsavari, E., Jain, S.S., Koshlaf, E., Ravindran, V.B., Morrison, P.D., Osborn, A.M., Ball, A.S., 2019. Influence of bioaugmentation and biostimulation on PAH degradation in aged contaminated soils: Response and dynamics of the bacterial community. Journal of Environmental Management Volume 238, Pages 49-58, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2019.02.115.

Hamon R.E., McLaughlin M.J., 1999. Use of the hyperaccumulator Thlaspi caerulescens for bioavailable contaminant stripping, Fifth International Conference on the Biogeochemistry of Trace Elements (ICOBTE), Vienna, 908-909.

Herzig, R., Nehnevajova, E., Pfistner, C., Schwitzguebel, J. P., Ricci, A., Keller, C., 2014. Feasibility of labile Zn phytoextraction using enhanced tobacco and sunflower: results of five- and one-year field-scale experiments in Switzerland. International journal of phytoremediation, 16(7-12), 735–754. https://doi.org/10.1080/15226514.2013.856846

Hou, J., Liu, W., Wang, B., Wang, Q., Luo, Y., Franks, A. E., 2015. PGPR enhanced phytoremediation of petroleum contaminated soil and rhizosphere microbial community response. Chemosphere 138, 592–598. doi: 10.1016/j. Chemosphere.2015.07.025

Hou, L., Liu, R., Li, N., Dai, Y., Yan, J., 2019. Study on the efficiency of phytoremediation of soils heavily polluted with PAHs in petroleum-contaminated sites by microorganism. Environmental science and pollution research international, 26(30), 31401–31413. https://doi.org/10.1007/s11356-019-05828-1

Hu, Y., Nan, Z., Su, J., Wang, N., 2013. Heavy metal accumulation by poplar in calcareous soil with various degrees of multi-metal contamination: implications for phytoextraction and phytostabilization. Environmental science and pollution research international, 20(10), 7194–7203. https://doi.org/10.1007/s11356-013-1711-0

IUCN, no date. Nature-based solutions. Retrived 2023-052-24 from https://www.iucn.org/our-work/nature-based-solutions

Kavitha, V., Mandal, A. B., Gnanamani, A., 2014. Microbial biosurfactant mediated removal and/or solubilization of crude oil contamination from soil and aqueous phase: An approach with Bacillus licheniformis MTCC 5514, International Biodeterioration & Biodegradation,Volume 94, Pages 24-30, ISSN 0964-8305, https://doi.org/10.1016/j.ibiod.2014.04.028.

Kennen, K., Kirkwood, N., 2015. Phyto: Principles and Resources for Site Remediation and Landscape Design. First Edit. Routledge https://doi.org/10.4324/9781315746661.

Kim, I. S., Park, J.-S., & Kim, K.-W., 2001. Enhanced biodegradation of polycyclic aromatic hydrocarbons using nonionic surfactants in soil slurry. Applied Geochemistry, Volume 16, Issues 11–12, Pages 1419-1428, ISSN 0883-2927, https://doi.org/10.1016/S0883-2927(01)00043-9.

Kiran, G. S., Ninawe, A. S., Lipton, A. N., Pandian, V., Selvin, J., 2016. Rhamnolipid biosurfactants: evolutionary implications, applications and future prospects from untapped marine resource. Critical reviews in biotechnology, 36(3), 399–415. https://doi.org/10.3109/07388551.2014.979758

Kodeda Konsulter AB, 2016. Urban Cribs Lindholmen 6:9. Environmental engineering ground survey, Project number 16–6245 , (In Swedish: Urban Cribs Lindholmen 6:9. Miljöteknisk markundersökning, Projektnummer 16–6245), Kodeda Konsulter AB. Gothenburg, Sweden

Koptsik, G.N., 2014. Problems and prospects concerning the phytoremediation of heavy metal polluted soils: A review. Eurasian Soil Sc. 47, 923–939 (2014). https://doi.org/10.1134/S1064229314090075

Krishnamurti, G.S.R., Huang, P.M., Van Rees, K.C.J., Kozak, L.M., Rostad, H.P.W., 1995. Speciation of particulate-bound cadmium of soils and its bioavailability. The Analyst 120: 659–665. https://doi.org/ 10.1039/AN9952000659

Krishnamurti, G.S.R., Naidu, R., 2002. Solid-solution speciation and phytoavailability of copper and zinc in soils. Environ Sci Technol 36:2645–2651. https://doi.org/10.1021/es001601t

Kumpiene, J., Lagerkvist, A., & Maurice, C., 2008. Stabilization of As, Cr, Cu, Pb and Zn in soil using amendments--a review. Waste management (New York, N.Y.), 28(1), 215–225. https://doi.org/10.1016/j.wasman.2006.12.012

Kumpiene, J., Fitts, J.P., Mench, M., 2012. Arsenic fractionation in mine spoils 10 years after aided phytostabilization, Environmental Pollution, Volume 166, Pages 82-88, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2012.02.016.

Kumpiene, J., Antelo, J., Brännvall, E., Carabante, I., Ek, K., Komárek, M., Söderberg, C., Wårell, L., 2019. In situ chemical stabilization of trace element-contaminated soil – Field demonstrations and barriers to transition from laboratory to the field – A review. Applied Geochemistry, Volume 100, Pages 335-351, ISSN 0883-2927, https://doi.org/10.1016/j.apgeochem.2018.12.003.

Lacalle, R.G., Aparicio, J.D., Artetxe, U., Urionabarrenetxea, E., Polti, M.A., Soto, M., Garbisu, C., Becerril, J.M., 2020. Gentle remediation options for soil with mixed chromium (VI) and lindane pollution: biostimulation, bioaugmentation, phytoremediation and vermiremediation. Heliyon 6. https://doi.org/10.1016/j.heliyon.2020.e04550

Lamb, A., Weers, B., McKinley, B., Rooney, W., Morgan, C., Marshall-Colon, A., Mullet, J., 2022. Bioenergy sorghum's deep roots: A key to sustainable biomass production on annual cropland. *GCB Bioenergy*, 14, 132–156. https://doi.org/10.1111/gcbb.12907

Liang, S., Guan, D. X., Ren, J. H., Zhang, M., Luo, J., Ma, L. Q., 2014. Effect of aging on arsenic and lead fractionation and availability in soils: coupling sequential extractions with diffusive gradients in thin-films technique. Journal of hazardous materials, 273, 272–279. https://doi.org/10.1016/j.jhazmat.2014.03.024

Liu, Y., Zhou, J., Sun, D., Chen, H., Qin, J., Chen, G., Qiu, R., 2023. Polyaspartic acid assisted-phytoremediation of cadmium-contaminated farmland: Phytoextraction efficiency, soil quality, and rhizosphere microbial community. The Science of the total environment, 862, 160736. https://doi.org/10.1016/j.scitotenv.2022.160736

Lu, L., Zhang, J., Peng, C., 2019. Shift of Soil Polycyclic Aromatic Hydrocarbons (PAHs) Dissipation Pattern and Microbial Community Composition due to Rhamnolipid Supplementation. Water Air Soil Pollut 230, 107. https://doi.org/10.1007/s11270-019-4118-9

Ma L.Q., Rao G.N., 1997. Heavy metals in the environment: chemical fractionation of cadmium, copper, nickel, and zinc in contaminated soils. J Environ Qual 26:259–264. https://doi.org/10.2134/ jeq1997.00472425002600010036x

Macci, C., Doni, S., Peruzzi, E., Bardella, S., Filippis, G., Ceccanti, B., Masciandaro, G., 2013. A real-scale soil phytoremediation. Biodegradation, 24(4), 521–538. https://doi.org/10.1007/s10532-012-9608-z

Marchand, C., Mench, M., Jani, Y., Kaczala, F., Notini, P., Hijri, M., Hogland, W., 2018. Pilot scale aided-phytoremediation of a co-contaminated soil. Science of the Total Environment, 618(Complete), 753–764. https://doi.org/10.1016/j.scitotenv.2017.08.143

Marques, A. P., Rangel, A. O., Castro, P. M., 2009. Remediation of heavy metal contaminated soils: phytoremediation as a potentially promising clean-up technology. Crit. Rev. Env. Sci. Technol. 39, 622–654. doi: 10.1080/10643380701798272

Meers, E., Van Slycken, S., Adriaensen, K., Ruttens, A., Vangronsveld, J., Du Laing, G., Witters, N., Thewys, T., Tack, F. M., 2010. The use of bio-energy crops (Zea mays) for 'phytoattenuation' of heavy metals on moderately contaminated soils: a field experiment. Chemosphere, 78(1), 35–41. https://doi.org/10.1016/j.chemosphere.2009.08.015

Mench, M., Lepp, N., Bert, V., Schwitzguébel, J.P., Gawronski, S.W., Schröder, P., Vangronsveld, J., 2010. Successes and limitations of phytotechnologies at field scale: outcomes, assessment and outlook from COST action 859. J. Soils Sediments 10, 1039–1070. https://doi.org/10.1007/s11368-010-0190-x.

OVAM, 2019. Phytoremediation - Code of Good Practice. (www.ovam.be).

Owsianiak, M., Chrzanowski, Ł., Szulc, A., Staniewski, J., Olszanowski, A., Olejnik-Schmidt, A. K., Heipieper H.J., 2009. Biodegradation of diesel/biodiesel blends by a consortium of hydrocarbon degraders effect of the type of blend and the addition of biosurfactants. Bioresource Technology, Volume 100, Issue 3, Pages 1497-1500, ISSN 0960-8524, https://doi.org/10.1016/j.biortech.2008.08.028.

Pacwa-Płociniczak, M.; Płaza, G.A.; Piotrowska-Seget, Z., 2016. Monitoring the changes in a bacterial community in petroleum-polluted soil bioaugmented with hydrocarbon-degrading strains. Applied Soil Ecology, Volume 105, Pages 76-85, ISSN 0929-1393, https://doi.org/10.1016/j.apsoil.2016.04.005.

Padmavathiamma, P.K., Li, L.Y., 2012. Rhizosphere Influence and Seasonal Impact on Phytostabilisation of Metals—A Field Study. Water Air Soil Pollut **223**, 107–124 https://doi.org/10.1007/s11270-011-0843-4

Pawlik, M., Płociniczak, T., Thijs, S., Pintelon, I., Vangronsveld, J., Piotrowska-Seget, Z., 2020. Comparison of Two Inoculation Methods of Endophytic Bacteria to Enhance Phytodegradation Efficacy of an Aged Petroleum Hydrocarbons Polluted Soil. Agronomy, 10, 1196. https://doi.org/10.3390/agronomy10081196

Pelfrêne, A., Kleckerová, A., Pourrut, B., Nsanganwimana, F., Douay, F., & Waterlot, C., 2015. Effect of Miscanthus cultivation on metal fractionation and human bioaccessibility in metal-contaminated soils: comparison between greenhouse and field experiments. Environmental science and pollution research international, 22(4), 3043–3054. https://doi.org/10.1007/s11356-014-3585-1

Petruzzelli, G., Pedron, F., Barbafieri, M., Tassi, E., Gorini, F., Rosellini, I., 2012. Enhanced Bioavailable Contaminant Stripping: a Case Study of Hg Contaminated Soil. Chemical Engineering Transactions. 28. 211-216. DOI:10.3303/CET1228036

Placek, A., Grobelak, A., Kacprzak, M., 2016. Improving the phytoremediation of heavy metals contaminated soil by use of sewage sludge. International journal of phytoremediation, 18(6), 605–618. https://doi.org/10.1080/15226514.2015.1086308

Prasad, M., Freitas, H., 2003. Metal hyperaccumulation in plants—biodiversity prospecting for phytoremediation technology, Electron. J. Biotechnol. 6 (3), 285–321. doi:10.2225/vol6-issue3-fulltext-6

Prasad, J., Tiwari, S., Kumar Singh, B., Kishore Dubey, N. 2022.,7 - Phytoextraction of heavy metals: Challenges and opportunities, Editor(s): Kumar, V., P. Shah, M.P., Kumar Shahi, S. Phytoremediation Technology for the Removal of Heavy Metals and Other Contaminants from Soil and Water, Elsevier, Pages 173-187, ISBN 9780323857635, https://doi.org/10.1016/B978-0-323-85763-5.00011-8.

Rajkumari, J., Choudhury, Y., Bhattacharjee, K., Pandey, P., 2021. Rhizodegradation of Pyrene by a Non-pathogenic Klebsiella pneumoniae Isolate Applied with Tagetes erecta L. and Changes in the Rhizobacterial Community. Frontiers in microbiology, 12, 593023. https://doi.org/10.3389/fmicb.2021.593023

Robinson, B.H., Schulin, R., Nowack, B., Roulier, S., Menon, M., Clothier, B.E., Green, S.R., Mills T.M., 2006. Phytoremediation for the management of metal flux in contaminated sites For. Snow Landsc. Res., 80, pp. 221-234

Robinson, B.H., Bañuelos, G., Conesa, H.M., Evangelou, M.W.H., Schulin, R., 2009. The phytomanagement of trace elements in soil, Crit. Rev. Plant Sci. 28, 240–266. https://doi.org/10.1080/07352680903035424.

Rosén, L., Back, P.E., Söderqvist, T., Norrman, J., Brinkhoff, P., Norberg, T., Volchko, Y., Norin, M., Bergknut, M., Döberl, G., 2015. SCORE: A novel multi-criteria decision analysis approach to assessing the sustainability of contaminated land remediation. Sci. Total Environ. 511, 621–638. https://doi.org/10.1016/j.scitotenv.2014.12.058

Rostami, S., Azhdarpoor, A., Samaei, M. R., 2017. Removal of pyrene from soil using phytobioremediation (Sorghum Bicolor-Pseudomonas). Health Scope 6:e 62153. doi: 10.5812/jhealthscope.62153

Salehi, N., Azhdarpoor, A., Shirdarreh, M., 2020. The effect of different levels of leachate on phytoremediation of pyrene-contaminated soil and simultaneous extraction of lead and cadmium. Chemosphere, 246, 125845. https://doi.org/10.1016/j.chemosphere.2020.125845

Samal, S. K., Datta, S. P., Dwivedi, B. S., Meena, M. C., Nogiya, M., Choudhary, M., Golui, D., Raza, M. B., 2023. Phytoextraction of nickel, lead, and chromium from contaminated soil using sunflower, marigold, and spinach: comparison of efficiency and fractionation study. Environmental science and pollution research international, 30(17), 50847–50863. https://doi.org/10.1007/s11356-023-25806-y

Santa-Cruz, J., Robinson, B., Krutyakov, Y. A., Shapoval, O. A., Peñaloza, P., Yáñez, C., & Neaman, A., 2023. An Assessment of the Feasibility of Phytoextraction for the Stripping of Bioavailable Metals from Contaminated Soils.

Environmental toxicology and chemistry, 42(3), 558–565. https://doi.org/10.1002/etc.5554

SEPA, 2009. Guideline Values for Contaminated Land – Description of the Model and a Guide: Report 5976 (In Swedish: Riktvärden för förorenad mark - Modellbeskrivning och vägledning). Swedish Environmental Protection Agency, Stockholm, Sweden.

SEPA, 2020. The Industry list for surveying of contaminated sites (In Swedish: Branschlistan). Swedish Environmental Protection Agency, Stockholm, Sweden, Retrived 2023-02-01 from https://www.naturvardsverket.se/4a437e/globalassets/vagledning/fororenade-omraden/inventering/branschlistan-2020-fororenade-omraden.pdf,

SEPA, no date. Guidance, Inventory of contaminated areas, (In Swedish: Vagledning, Inventering av förorenade områden). Swedish Environmental Protection Agency, Stockholm, Sweden Retrived 2023-02-17 from https://www.naturvardsverket.se/vagledning-och-stod/fororenade-omraden/inventering-av-fororenade-omraden,

Sheoran, V., Sheoran, A.S., Poonia, P., 2009. Phytomining: a review. Minerals Engineering, Volume 22, Issue 12, Pages 1007-1019, ISSN 0892-6875, https://doi.org/10.1016/j.mineng.2009.04.001.

Shipyard Historical Association, no date. Lindholmen - the small shipyard with the beautiful boats. Brochure (In Swedish: Varvhistoriska Föreningen i Göteborg. Lindholmen – det lilla storvarvet med de vackra båtarna), Shipyard Historical Association, Gothenburg, Sweden.

Sinha, S., Mishra, R.K., Sinam, G., Mallick, S., Gupta, A.K., 2010. Comparative Evaluation of Metal Phytoremediation Potential of Trees, Grasses, and Flowering Plants from Tannery-Wastewater-Contaminated Soil in Relation with Physicochemical Properties. Soil and Sediment Contamination An International Journal. 22. 10.1080/15320383.2013.770437.

Stadsbyggnadskontoret, 1986. Norra Älvstranden's renewal, Planning document, Report 1A, Report 6 (In Swedish: Norra Älvstrandens förnyelse, Planeringsunderlag, Rapport 1A, Rapport 6), Stadsbyggnadskontoret, Gothenburg, Sweden.

Sun, M., Fu, D., Teng, Y., Shen, Y., Luo, Y., Li, Z., Christie, P., 2011. In situ phytoremediation of PAH-contaminated soil by intercropping alfalfa (Medicago sativa L.) with tall fescue (Festuca arundinacea Schreb.) and associated soil microbial activity. J Soils Sediments 11, 980–989. https://doi.org/10.1007/s11368-011-0382-z

Swartjes, F., 2011. Dealing with contaminated soils. Soil Use and Management. Springer Netherlands https://doi.org/10.1111/j.1475-2743.1991.tb00867.x.

Sweco, 2012. Norra Älvstranden between Älvsborgsbron and Göta Älvbron.

Risk assessment including proposals for measurable action targets regarding contaminated land. Assignment number 1311456.00. (In Swedish: Norra Älvstranden mellan Älvsborgsbron och Göta Älvbron. Riskbedömning inklusive förslag till mätbara åtgärdsmål avseende förorenad mark. Uppdragsnummer 1311456.00.), Sweco, Gothenburg, Sweden.

Sweco, 2014. Registration according to SFS 1998:899, Preschool at Lindholmen 6:9, Assignment number 1311859000 (In Swedish: Anmälan enligt SFS 1998:899 Förskola vid Lindholmen 6:9, Uppdraggsnummer 1311859000), Sweco, Gothenburg, Sweden.

Sweco, 2016. Lindholms gymnasium, Property 6:9. Overview of environmental engineering ground survey, Assignment number 1312131000, (In Swedish: Lindholms gymnasiet, Fastigheten 6:9. Översiktlig miljöteknisk markundersökning, uppdragsnummer 1312131000), Sweco, Gothenburg, Sweden.

Sweco, 2020. Historical inventory and overview assessment of additional costs for handling of contaminated land during development within the properties Lindholmen 6:9, 6:11 and 6:13. South Lindholmen, Assignment number: 13009709, (In Swedish: Historisk inventering samt översiktlig bedömning av merkostnader för hantering av förorenad mark vid exploatering inom fastigheterna Lindholmen 6:9, 6:11 och 6:13 m fl. Södra Lindholmen Uppdrag. Uppdragsnummer: 13009709), Sweco, Gothenburg, Sweden.

Szczygłowska, M., Piekarska, A., Konieczka, P., Namieśnik, J., 2011. Use of brassica plants in the phytoremediation and biofumigation processes. International journal of molecular sciences, 12(11), 7760–7771. https://doi.org/10.3390/ijms12117760

Tahseen, R., Afzal, M., Iqbal, S., Shabir, G., Khan, Q. M., Khalid, Z. M., Banat, I. M., 2016. Rhamnolipids and nutrients boost remediation of crude oil-contaminated soil by enhancing bacterial colonization and metabolic activities. International Biodeterioration & Biodegradation, Volume 115, Pages 192-198, ISSN 0964-8305, https://doi.org/10.1016/j.ibiod.2016.08.010.

Tan, H.W., Pang Y.L., Chong, W.C., 2023. A state-of-the-art of phytoremediation approach for sustainable management of heavy metals recovery, Environmental Technology & Innovation, Volume 30, 103043, ISSN 2352-1864, https://doi.org/10.1016/j.eti.2023.103043.

Törneman, N., Cox, E.E., Durant N. D., Azziz, C., 2009. Bioavailability as occurrence and in risk assessments of contaminated areas. SEPA. Report 5895, (In Swedish: Biotillgänglighet som företeelse och vid riskbedömningar av förorenade områden. Naturvårdsverket. Rapport 5895) Retrived 2023-05-26 from https://naturvardsverket.diva-portal.org/smash/get/diva2:1623744/FULLTEXT01.pdf

Typar, no date. Grass Reinforcement Mesh. Retrived 2023-05-14 from https://typargeosynthetics.com/products/ground-reinforcement-mesh/grassprotecta-grass-reinforcement-mesh.html#:~:text=GrassProtecta%E2%84%A2%20grass%20reinforcement%20mesh%20is%20a%20thick%20plastic,is%20prone%20to%20wear%2C%20rutting%20and%20muddy%20surfaces.

Ultimate one online, no date. Grass Reinforcement Mesh, Retrived 2023-05-14 from https://www.ultimate-one.co.uk/grass-reinforcement-mesh-2mx20m-145mm-thick-2kgsqm-heavy-p-813?osCsid=48b72d28c5pq9jqlfl4n83qm83

Vamerali, T., Bandiera, M., Mosca, G., 2010. Field crops for phytoremediation of metal-contaminated land. A review. Environ Chem Lett 8, 1–17. https://doi.org/10.1007/s10311-009-0268-0

Vangronsveld, J., Herzig, R., Weyens, N., Boulet, J., Adriaensen, K., Ruttens, A., Thewys, T., Vassilev, A., Meers, E., Nehnevajova, E., van der Lelie, D., Mench, M., 2009. Phytoremediation of contaminated soils and groundwater: lessons from the field. Environmental science and pollution research international, 16(7), 765–794. https://doi.org/10.1007/s11356-009-0213-6

Violante, A., Cozzolino, V., Perelomov, L., Caporale, A.G., Pigna, M., 2010. Mobility and bioavailability of heavy metals and metalloids in soil environments. J Soil Sci Plant Nutr 10(3):268–292. https://doi.org/10.4067/S0718-95162010000100005

Wedderburn, M.E., Crush, J.R., Pengelly, W.J., Walcroft, J.L., 2010. Root growth patterns of perennial ryegrasses under well-watered and drought conditions, New Zealand Journal of Agricultural Research, 53:4, 377 388, DOI: 10.1080/00288233.2010.514927

Whang, L. M., Liu, P. W., Ma, C. C., Cheng, S. S., 2008. Application of biosurfactants, rhamnolipid, and surfactin, for enhanced biodegradation of diesel-contaminated water and soil. Journal of hazardous materials, 151(1), 155–163. https://doi.org/10.1016/j.jhazmat.2007.05.063

Wong, M. H., 2003. Ecological restoration of mine degraded soils, with emphasis on metal contaminated soils. Chemosphere 50, 775–780. doi: 10.1016/S0045-6535(02)00232-1

Yergeau, E., Sanschagrin, S., Maynard, C., St-Arnaud, M., Greer, C. W., 2014. Microbial expression profiles in the rhizosphere of willows depend on soil contamination. *The ISME journal*, *8*(2), 344–358. https://doi.org/10.1038/ismej.2013.163

Zárubová, P., Hejcman, M., Vondráčková, S., Mrnka, L., Száková, J., Tlustoš, P., 2015. Distribution of P, K, Ca, Mg, Cd, Cu, Fe, Mn, Pb and Zn in wood and bark age classes of willows and poplars used for phytoextraction on soils contaminated by risk elements. Environmental science and pollution research international, 22(23), 18801–18813. https://doi.org/10.1007/s11356-015-5043-0

Zou, W., Cao, Z., Wang, Y., Jin, M., 2023. Intercropping of Pennisetum sinese with Lolium perenne improved phytoextraction of heavy metal from soil. Restoration Ecology Vol. 31, No. 3, e13702. https://doi: 10.1111/rec.13702

Appendices

Appendix A. Summary of previous site investigations.

Table A1. Contaminants analysed and identified at the Lindholmen property 6:9

Name of the project at the Lindholmen property 6:9	Laboratory analysis of possible contaminants	Number of samples analyzed in laboratory	Comparison of the identified contaminant with soil guidelines								Reference
			Above KM		Above MKM		Above FA		Above site-specific targets		
			Sample	Element	Sample	Element	Sample	Element	Sample	Element	
Förskola vid Lindholmen	Metals, Aliphatic and Aromatic Hydrocarbons, PAH	11 soil 2 asphalt	-	-	-	-	-	-	6	Ba Pb	Sweco (2014). Anmälan enligt SFS 1998:899, Förskola vid Lindholmen 6:9 Uppdraggsnummer 1311859000
Lindholmsgymnasiet	Metals, Aliphatic and Aromatic Hydrocarbons, including PAHs, BTEX	22 soil 2 asphalt	14	PAHs As, Cu, Pb, Zn, Aliphatic and Aromatic, Benzene	2	PAHs, Cu, Pb, Zn	-	-	2	PAHs, Pb, Zn, Aromatic	Sweco (2016). Lindholms gymnasiet, Fastigheten 6:9. Översiktlig miljöteknisk markundersökning, uppdragsnummer 1312131000
Urban Cribs Lindholmen 6:9	Metals, Aliphatic and Aromatic Hydrocarbons, PAH-16	34 soil	28	As, Ba, Cd, Co, Cu, Hg, Pb, Zn, Aliphatic and Aromatic, PAHs	16	-	1	Pb, Zn	8	As, Ba, Cd, Co, Cu, Hg, Pb, Zn, Aliphatic and Aromatic, PAHs	Kodeda Konsulter AB (2016). Urban Cribs Lindholmen 6:9. Miljöteknisk markundersökning, Projektnummer 16–6245

Appendix B. Suggested sampling plan.

Coordinates for 3 randomly selected sampling locations + one reserve location are presented in Table 1.

Table B1. Coordinates for the respective randomly selected sampling locations within the Lindholmen 6:9 property.

		Sweref 99 12 00 (EPSG:3007)		Sweref 99TM (EPSG:3006)		WGS84 (EPSG:4326)	
		North	**East**	**North**	**East**	**Latitude**	**Longitude**
Sample 1	Location 1	6398370	146176	6399937	317429	57.704472	11.935860
Sample 2	Location 2	6398237	146143	6399806	317390	57.703277	11.935308
Sample 3	Location 3	6398261	146182	6399828	317430	57.703493	11.935962
Reserve sample	Reserve location	6398355	146195	6399921	317447	57.704337	11.936179

Figure B1. Map of the sampling area with randomly selected sampling locations (yellow circles).

Table B2. Sample depth division for each sampling location.

<table>
<tr><th colspan="2">Sample depth division, (m)</th></tr>
<tr><td>Asphalt surfaces</td><td>Grass areas</td></tr>
<tr><td>Sample 2, Sample 3, Reserve sample</td><td>Sample 1</td></tr>
<tr><td>The levels apply under asphalt layer + bearing layer</td><td>The levels apply under the turf</td></tr>
<tr><td colspan="2">0-0.3 m</td></tr>
<tr><td colspan="2">0.3-0.6 m</td></tr>
<tr><td colspan="2">0.6-1.6 m</td></tr>
<tr><td colspan="2">1.6-2.6 m</td></tr>
<tr><td colspan="2">Try drilling down to natural clay to see how deep the filling is, possibly taking samples to save.</td></tr>
</table>

NOTE 1: The depth levels apply from below the asphalt and bearing layers of asphalt (or turf for grass areas).
NOTE 2: It may also be of interest to the stakeholder to sample the bearing layer to investigate possible contamination levels in it.
Field observations (weather conditions, soil layer sequence and texture, colour, smell, etc.) during auger drilling should be noted as usual.

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2023
www.chalmers.se

AVANCEZ
1829
CHALMERS
UNIVERSITY OF TECHNOLOGY