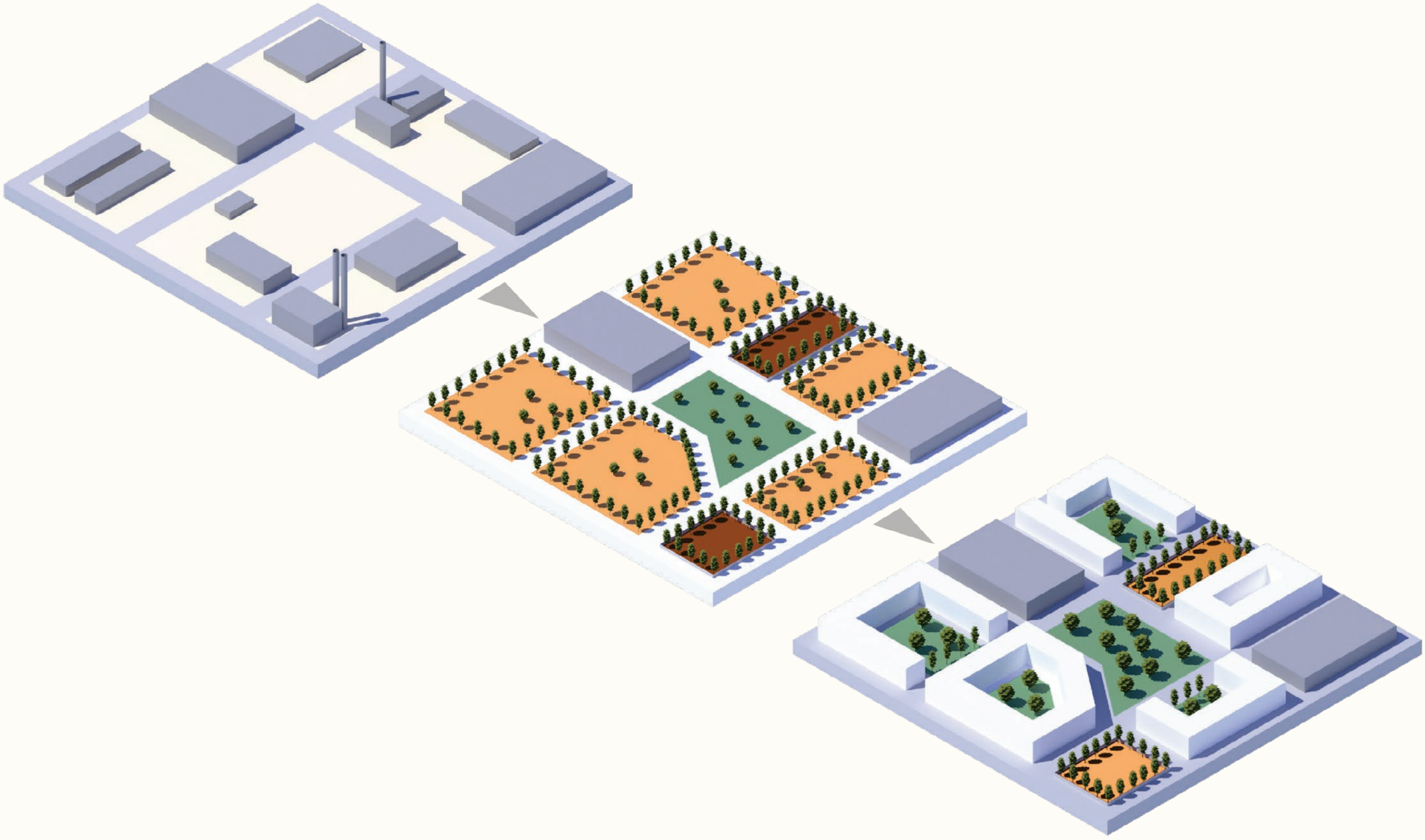
CLEAN BY GREEN

Sustainable Brownfield Development with Phytoremediation



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Master's Thesis at Chalmers School of Architecture
Master's Programme Design for Sustainable Development
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CHALMERS

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Foreword

This thesis will finalize my master studies at Design for Sustainable Development at Chalmers University. It has been an amazing time with many new friends and a lot of new knowledge to put in my backpack that I can use in my future career as a spatial planner.

My interest in sustainable urban development has grown a lot during this time and I think my choice of topic reflects this. Using phytoremediation may be considered as an area primarily for landscape architects. But I think it is important also for other architect professions to know what can be achieved from the nature, and to integrate the aspects of sustainability as much as possible in their projects.

I would like to thank my tutor Nils Björling who has given me a lot of inspiration, support and guidance, and my examiner Lena Falkheden for giving me a lot of inspiring and helpful material and comments, throughout the whole process.

I would also like to thank Dimitris Vassiliadis and his colleagues at the city planning office in Uddevalla municipality for their hospitality, and for being very helpful by giving me very valuable material for my work.

A last thank is given to Ulf Stenberg, CEO at Uddevalla harbour, for taking his time talking to me and giving me a guided tour of Uddevalla harbour.

Johan Delvert

Gothenburg, 10:th of May 2017

Abstract

Many cities are facing the problem of old industrial areas whose soil has been contaminated with toxic substances created by different historical activities within the area. Common remediation methods, like excavation, can be very expensive and harmful for the environment because of the mechanical extraction and the disposal of the contaminated soil.

The aim of this master's thesis is to explore the method of remediating contaminated areas on site by using the natural remediating ability of certain plants, also known as phytoremediation, and how this method could be integrated in a brownfield development. The exploration contains different aspects. Especially the aspect of time, because the process of phytoremediation can take many years, but also, the social, economic, and ecological aspects will be explored.

Further, the aim to test the method through an urban design proposal of the industrial harbour area of Bäve/Badö in Uddevalla, using phytoremediation to clean the soil. The design deals with several parameters, primarily the contamination of the soil, but also the existing activities on site, the historical values, and the flood risk.

Literature studies about phytoremediation and spatial planning, along with field studies on the chosen site is playing a leading role to create frame to work within. Also, meetings with different key stakeholders, such as the harbour and the municipality of Uddevalla is an important source of information.

The result shows the complexity, but also the great potential to be able remediate and transform an industrial site into new uses in an ecologically, socially, and economically sustainable way with phyto-remediation.

Sammanfattning

Många städer runt om i världen har gammal industrimark med markföroreningar som har uppkommit från tidigare användningar inom området. Att sanera dessa områden med traditionella metoder, såsom schaktning, kan vara dyrt och skadligt för miljön på grund av grävningen och bortforslandet av den kontaminerade jorden till deponi.

Syftet med det här mastersarbetet är att undersöka metoden där marken renas på plats med hjälp av växters naturliga reningsförmåga, även kallat fytoremediering. Den syftar även till att undersöka hur denna reningsmetod kan integreras vid utveckling av gammal industrimark med förorenad mark. Undersökningen behandlar olika aspekter, framförallt tidsaspekten, då fytoremedieringsprocessen kan ta lång tid. Även den sociala, ekonomiska, och ekologiska aspekten behandlas.

Vidare syftar arbetet till att testa denna reningsmetod teoretiskt genom ett planförslag för området Bäve/Badö i Uddevalla. Planförslagets primära fokus är att visa hur marken kan renas genom fytoremediering och hur det kan integreras i utvecklingen. Även andra parametrar tas ställning till i designen, såsom platsens nuvarande användning, historiska värden, samt översvämningsrisken.

Litteraturstudier om fytoremediering och stadsplanering, tillsammans med fältstudier på platsen har spelat en stor roll i att skapa ett kunskapsunderlag och ett ramverk att arbeta inom. Även möten med olika aktörer, såsom Uddevalla hamnterminal och Uddevalla kommun har varit en viktig informationskälla.

Resultatet av arbetet visar på komplexiteten, men också den stora potentialen att kunna sanera och utveckla gamla industriområden på ett ekologisk, socialt, och ekonomiskt hållbart sätt med hjälp av fytoremediering.

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1. Introduction

Background

Since the beginning of the industrial revolution, the impact from humans on the environment have steadily been increasing. Many cities around the world have the problem of old industrial areas whose soil has been contaminated with toxic waste created by the different activities in the area. Only in the European Union, about three million areas are potentially contaminated, and around 250 000 of them are confirmed contaminated and needs to be sanitized (Ansari, et al., 2016). Cleaning this contaminated soil can be very expensive. The high cost to sanitize the soil can either make the new development of housing or other functions very expensive or the area can be left untreated and undeveloped depending on the economic situation of the municipality. Today, the most common way of remediating contaminated areas is by excavation (Raskin & Ensley, 2000). The method is quick but expensive, and all the masses of soil that is excavated must be put somewhere, usually on landfill. The sustainability aspects of this method can be questioned. For example, during the remediation of Hammarby Sjöstad in Stockholm, about 20 000 tons of contaminated soil where excavated and transported by train and put on landfill in Storfors, Värmland, about 300 km away (Classon, 2015).

In recent decades, the question of how to address the problem with contaminated areas has been growing, and new sustainable ways of remediation have been developed. One of these methods is phytoremediation, which uses certain plants to remove, stabilize or transport contaminants in the soil. Though, the research in this field is still quite young and unpractised, especially on how to integrate the method in spatial planning.

The harbour Bäve/Badö in Uddevalla, which has a long industrial history, is one of those contaminated areas. The municipality has a future vision to develop the site into a housing area, but first the soil must be remediated. This site will serve as an arena where this method will be theoretically tested through a design proposal for the site.

Figure 1: Location of the site Bäve/Badö.

Figure 2: Photo from the site Bäve/Badö.

Aim and questions

The aim of this master's thesis is to explore how phytoremediation can be integrated in a brownfield development. This approach is tested through an urban design proposal for the industrial harbour of Bäve/Badö in Uddevalla.
Following this aim, the study tries to answer the following questions:

- *When, and in what scale should phytoremediation be integrated in the planning process?*
- *How is phytoremediation balanced with other aspects such as historical values, existing activities, and climate change?*
- *How can different phytoremediation techniques be used to develop specific spatial qualities?*

Method

The main approach of this thesis is research for design. Literature studies about phytoremediation is playing a leading role in this thesis but also interviews with key stakeholders such as the municipality and the landowners of the site. Field studies are done to gain knowledge about the area of Bäve/Badö, for example; what kind of industries and other activities that exist on the site today, to get a social and economic picture, but also to get a picture of what toxic substances that might be in the ground.

As the process of phytoremediation is very slow, its unfortunately not possible to do experiments on this in practise. Instead, different reference projects are studied to see how the problem has been solved on other sites.

Disposition

Chapter 2 – Theoretical framework

This chapter begins with a brief background of brownfield development and the question of how to treat the contaminated soil, the most common sanitation method today, the policies in Sweden and the responsible actors.

The chapter will also explain the basics of phytoremediation, it's benefits and disadvantages, a comparison to other methods, and reference projects will also be presented. The purpose of the chapter is to create an adequate understanding of the method and its possibilities within spatial planning.

Chapter 3 – Phytoremediation and spatial planning

In chapter three, the potential to use and integrate phytoremediation within spatial planning will be explored. It begins with a section about phytoremediation in the Swedish planning context, followed by a proposed concept model on how to use and integrate phytoremediation in brownfield development.

Chapter 4 - Implementation

This chapter is about testing phytoremediation as a sanitation method theoretically in a Swedish industrial area. The result will work as an example on how phytoremediation could be integrated in the development process and which qualities that it would create.

The chapter begins with an analysis of the site to create an understanding of its strengths, weaknesses, history, values, and context. A development program is then presented, based on the site analysis and the theoretical framework. The program is followed by a design proposal that stretches over a period of 30 years, divided into two development phases.

Chapter 5 - Conclusion

The thesis ends with a conclusion that tries to answer the questions asked in the beginning. The chapter also includes discussions about other questions in relation to the subject.

Delimitation

This thesis will not describe how the method of phytoremediation works into detail, it will only present the basics of the method to be able to understand it and its potential to be used in urban planning.

The implementation will be presented as a large scale, long-term development of an industrial harbour into a housing and commercial area. An urban planning project like this has a vast amount of aspects and parameters that needs to be taken into consideration. The purpose of the implementation is to show how phytoremediation can be used as an economically, socially, and ecologically sustainable way of sanitizing the area, and therefore the focus will especially be on that aspect. But, the most urgent aspects, like the rising water levels, connections to surrounding areas, movements, historical values, etc. will be considered in the proposal.

Explanation of terms and acronyms

BTEX = Benzene, Toluene, Ethylbenzene, Xylenes
EPA = Environmental Protection Agency
Hyperaccumulators = Plants that are capable of absorbing and concentrate a very high level of metals in their tissue.
KM = Sensitive land use (Känslig Markanvändning)
MKM = Less sensitive land use (Mindre Känslig Markanvändning)
PAH = Polycyclic Aromatic Hydrocarbons (a group of substances found in coal and petroleum, can also be created from incomplete burning of organic matter)
PCP = Pentachlorophenol (pesticides & disinfectants)
Rhizosphere = The narrow layer of soil that is directly influenced by the biological processes of the root
TPH = Total Petroleum Hydrocarbons (can be found in crude oil)

2. Theoretical framework

Problem background

During the last two centuries, there has been an urbanization and industrialization of Western Europe with a massive increase of production and consumption of goods. The positive is that the economy and our living standards have increased, though it has severely affected the environment, with a major change in the urban landscape and contamination of the soil (Theuws & Wilschut, 2009).

Contaminated areas are created by emissions from various activities or events, either intentionally or unintentionally, for example due to an accident. The majority of the contaminated areas have been created between the end of second world war until the 1980's. Some examples of areas that has been contributing to the contaminations are old gasworks, landfills, industrial buildings, and gas stations. Contaminated areas can consist of many different types of substances, and some of the more toxic ones that can be found are heavy metals like mercury, cadmium, lead and arsenic, and organic compounds such as PCB, dioxins, pesticides, and PAH. Several of these substances are forbidden to use today (Naturvårdsverket & Boverket, 2006).

Figure 3: The harbour Bäve/Badö in Uddevalla

In Sweden, there are an estimated 80 000 potentially contaminated areas which can be old industrial areas, railways, harbours, or other uses that has polluted the soil. Many of these areas are quite centrally located within or at the outskirt of the cities and are attractive for other uses like housing and commercial activities etc. However, in order to be able to transform these areas into new uses, it has to be remediated. The level of remediation depends on the future use, for example housing, which requires a more extensive remediation than, for example, offices (Naturvårdsverket & Boverket, 2006).

Reusing a site like this, that already has been built, is called *brownfield* development, and is the opposite of *greenfield* development where you build on undeveloped land. Reusing areas is considered to be a sustainable way of developing land, and it has a lot of benefits, like taking advantage of existing infrastructure and reducing urban sprawl. The possibility of making use of infrastructure that is already in place is one of the most attractive features of brownfield development. Further, many brownfields have a close access to labour, materials, and transportation facilities like water, railways, and highways. What can frighten developers from building on these sites are the extent of the contamination of the ground, which can be very expensive to remediate. This may result in the site being left abandoned and unexploited (Geltman, 2010).

How is the problem addressed?

In most of the industrialized countries, the problem with contaminated soil has got an increased focus during the last decades. Some Western European countries are far ahead in the work towards this problem, like Germany and the Netherlands. Sweden was quite slow in the beginning but is working to put more effort into this question (Naturvårdsverket, 2003).

In Sweden, there are two types of guideline values to determine the quality of the soil; *Sensitive land-use* (KM) (e.g. housing), and *less sensitive land-use* (MKM) (e.g. offices and shopping centres). These were developed in 1996 by the Swedish Environmental Protection Agency (Naturvårdsverket) and are used as a reference to decide if the soil quality is good enough for building on or if it needs to be treated first. The purpose of the guidelines is to protect humans, animals, and the environment from exposure to dangerous contaminations (Cornelis et al., 2006).

The Swedish parliament has adopted 16 environmental quality objectives. One of the objectives related to contaminated areas is "*A non-toxic environment*". This objective means that the concentrations of toxic substances in our environment should be close to zero and have a small impact on humans and the ecosystem services. A lot of efforts have been made to reach this objective the last decade. Unfortunately, the objective has not been reached and cannot be reached with our current instruments and measures. Another objective that also is related, is "*A good built environment*". This objective means that cities and other built environments should provide a good, healthy living environment and contribute to a good regional and global environment. Natural and cultural assets must be protected, cities should have a good sound environment and should have a sustainable management of land, water, and other resources. However, this objective is unfortunately not reached either (Naturvårdsverket, 2017).

Today, the most common remediation method is excavation of the soil. The contaminated soil is then transported and disposed off-site, or *ex-situ,* at an enclosed landfill for toxic waste. After the site has been excavated and the soil has been disposed, new, clean soil is added (Naturvårdsverket, 2009).

One of the main reason for choosing this method is because the remediation of the contaminated site is often done in connection to the development of the site. A tight project schedule often makes the remediation process a kind of "emergency action" with a lot of time pressure, which in many cases leads to a worse cleaning result and higher cost (Naturvårdsverket & Boverket, 2006).

Figure 4: Excavation of soil.

The remediation of a contaminated site is regulated in chapter 10 of the Swedish environmental code (Miljöbalken). This chapter also regulates the responsibility of the remediation. The main rule is that if the contamination occurred after 1 july 1969, those who caused the contamination, have the responsibility to perform or pay for the investigation and the remediation of the site. If the contamination occurred before 1969, or if the responsible actor is unknown, the current owner of the land will be responsible for the remediation (Naturvårdsverket & Boverket, 2006).

Phytoremediation

What is phytoremediation?

Phytoremediation (from the ancient Greek *Phyto* meaning "plant" and the Latin *Remedium* meaning "restoring balance") is a quite new term that was coined in 1991 and refers to a collection of different techniques were certain plants is used to clean contaminated soil (EPA, 2000). These plants, termed *hyperaccumulators*, have been shown to be resistant to many types of contaminants and are able to transport, decompose, and store, for example; oil, metals, and chemicals, to high concentrations in their tissue (Gupta, et al., 2000; Gratão, et al., 2005; EPA, 2012). Phytoremediation is considered to be a cheap and environmentally friendly way of sanitizing contaminated areas, in some cases the cost can be decreased by 90 % compared to conventional methods, like excavation (Gratão et al., 2005).

The term *phytoremediation* is quite new but the knowledge of *hyperaccumulation* has been known for a longer time. In 1885, a German botanist called A. Baumann, discovered that certain plant species that was growing on soils with a high natural level of zinc had a high level of zinc concentrated in their leaves compared to plants growing on soils with no zinc (Salt. et al, 1998).

There is a limit of how much contamination certain plants can handle and how deep they can reach before it loses efficiency. Therefore, phytoremediation as a sanitation method suits best in areas where the level of contamination is relatively low and are located shallow in the ground (Gratão et al., 2005).

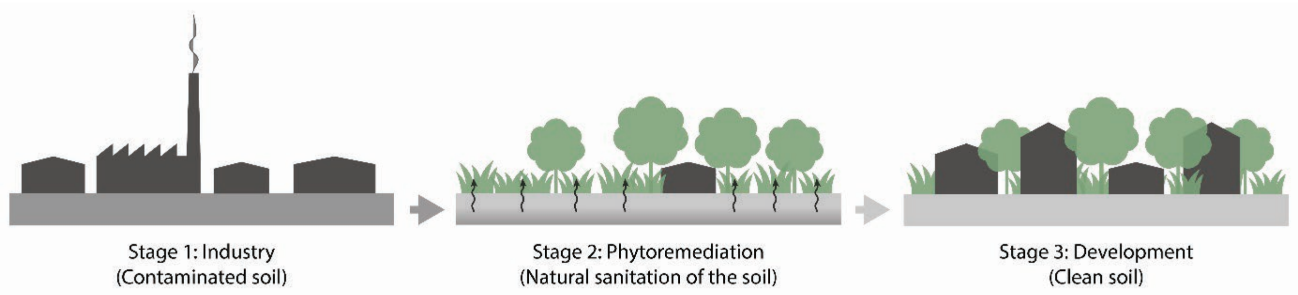


Figure 5: The basic concept of using phytoremediation to clean and develop a contaminated industrial site

The contaminant must be in contact with the root system for the plant to be able to remediate the ground. The effective root depth varies by the species and it also depends on the soil and climate condition in the area. Some species of hyperaccumulators and their approximate maximum root depth are:

- Indian mustard: ~ 0,3 m
- Grasses: ~ 0,6 m
- Alfalfa: ~ 1,2 – 2 m
- Poplar trees: ~ 5 m

(EPA, 2000)

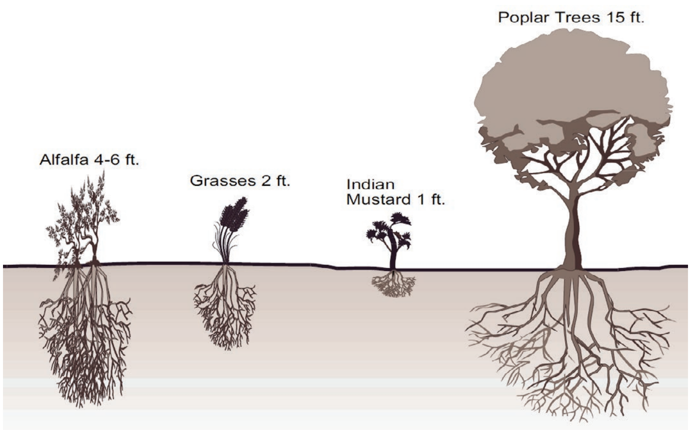


Figure 6: Example of some root depths (EPA, 2000)

One of the main characteristics of phytoremediation is that it can take a long time before the contaminated area is treated. It can take everything from some months up to years, and in some cases even up to several decades. The required time depends on some factors, for example:

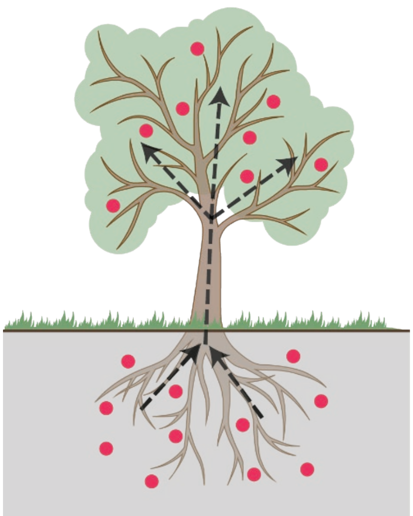
- The concentration of contaminants in the soil
- The size and depth of the contaminated area
- The growth time of the plant (the longer growing time, the slower remediation)
- The climate and the growing season in the area
- Damages to the plant that interrupts the process, for example; extreme weather, pests, or animals

(EPA, 2012)

Phytoremediation techniques

Phytoremediation consists of different remediation techniques treating the contaminants in different ways. Some of the techniques are using accumulation. Accumulation means that the plant has the ability to take up and concentrate the contaminants within the plant, but it cannot degrade it. Some techniques are using degradation, that, compared to accumulation, are able to decrease the contaminants in the soil until it is restored, close to its original soil quality. There are some techniques that aren't using either accumulation or degradation, but can control the contaminants in other ways, preventing the contaminants from spreading. The choice of techniques for remediation of a specific site depends on different factors, such as soil type, level of contamination, current land use, soil pH, and the purpose of the remediation (Gupta et al., 2000). Some plants have the ability to use several techniques simultaneously, like the poplar tree, while other only use one of them. To create an effective cleaning process, it's important to know which plants are using which techniques to be able to plant them on the spots where they can do the greatest impact. To make this possible you also need to know what kind of pollution there is in the ground and where it is located. The following part will present eight different phytoremediation techniques which can be considered the most common ones based on an overall assessment of the literature.

Phytoextraction (Accumulation)



Function

Phytoextraction is the use of certain plants that are able to take up contaminants from the soil by the roots, and then transport and concentrate them into the parts of the plant that are located above ground, like the stem and the leaves. If the concentration of contaminants in the plants gets too high, it must be harvested and disposed as hazardous waste (EPA, 2000; Raskin, Ensley, 2000). Though, some types of plants can be turned into a resource by processing its biomass to create energy. During the incineration of the biomass, the contaminants in the exhaust are caught in a filter and disposed as toxic waste. This way of making use of the plants makes the cleaning process more cost effective (Chaney et al., 2000).

Figure 7: Phytoextraction

Suitable for
According to studies, *Phytoextraction* are best suited for treating soil contaminated with various types of metals, metalloids, and radionuclides (EPA, 2000).

Plants
Hybrid poplar, willow, Indian mustard, pennycress, alyssum, sunflowers (EPA, 2000; Classon, 2015).

Figure 8: Alyssum

Phytodegradation (Degradation)

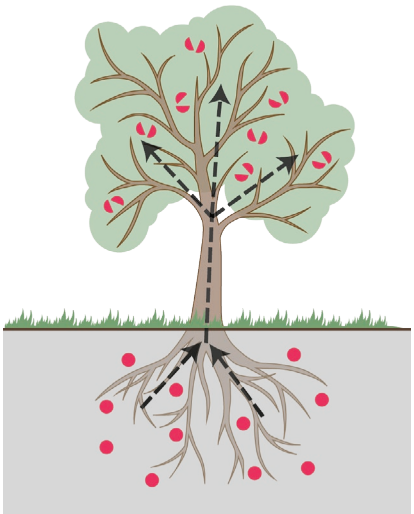


Figure 9: Phytodegradation

Function
In *phytodegradation* the plant takes up contaminants from the soil by the roots and transport it to its aboveground parts, just like in *phytoextraction*. But except from just containing the contaminants in the stems and leaves, the plant also has the ability to break them down with metabolic processes within the plant, alternatively they can be broken down externally by enzymes produced by the plant (EPA, 2000).

Suitable for
Soil contaminated with organic compounds (PAHs, pesticides chlorinated solvents, PCBs) (EPA, 2000).

Plants
Hybrid poplar, black willow, silver birch, wild roses, stonewort, algae (EPA, 2000; Classon, 2015).

Figure 10: Silver birch

Phytovolatilization

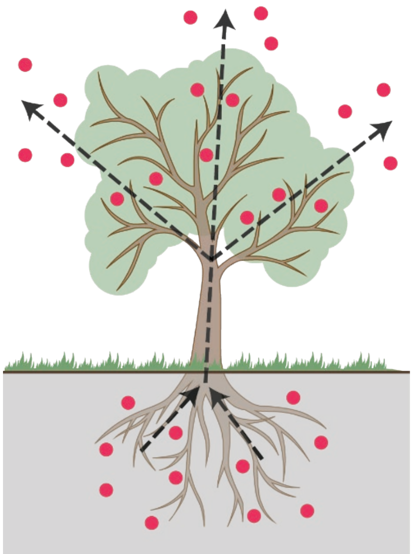


Figure 11: Phytovolatilization

Function
Phytovolatilization is when the plant takes up certain contaminants from the soil and transpires them, or a modified form of them, into the atmosphere as gas. This technique is related to *phytodegradation*, and these can occur simultaneously (EPA, 2000).

Suitable for
Soil contaminated with chlorinated solvents and some inorganic substances (Hg, As, Se) (EPA, 2000).

Plants
Poplars, alfalfa, black locust, Indian mustard (EPA, 2000).

Figure 12: Alfalfa

Phytostabilization (Accumulation)

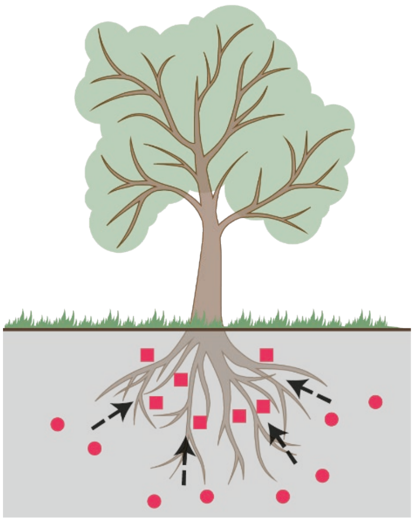


Figure 13: Phytostabilization

Function

Phytostabilization is a technique were the plant can immobilize and control the contaminants by absorbing and accumulating them in the roots, fixing them onto the roots, or containing them within the root zone of the plant by precipitation. This prevents them from spreading to other areas. Another purpose is to make the soil more stable by using the plant to prevent wind and water erosion, and scattering of soil, that may lead to spreading of the contaminants (EPA, 2000).

Suitable for

Phytostabilization can be used to stabilize metals such as arsenic, cadmium, chromium, copper, mercury, lead and zinc in soils, sediments, and sludge (EPA, 2000).

Plants

Hybrid poplar, Indian mustard. grasses (EPA, 2000).

Figure 14: Indian mustard

Rhizodegradation/Phytostimulation (Degradation)

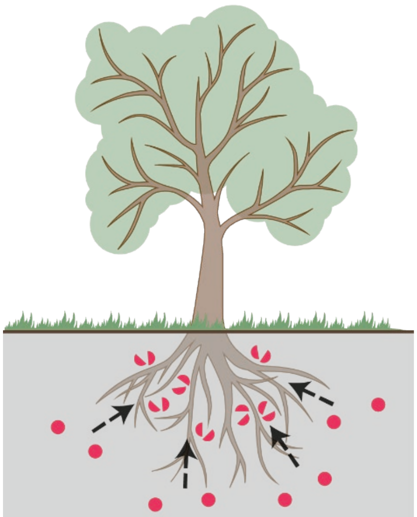


Figure 15: Rhizodegradation/Phytostimulation

Function

Rhizodegradation, or *Phytostimulation*, are similar to the earlier described *phytostabilization*, but with the difference that *rhizodegradation* has the ability to break down organic contaminants in the soil by microbes which are enhanced by the plant's root zone. This technique is also called plant-assisted degradation, plant-assisted bioremediation, or plant-aided in situ biodegradation. One of the advantages with *Rhizodegradation* is that the contaminants are less likely to be spread to the aboveground plant or the atmosphere because they are being treated underground (EPA, 2000).

Suitable for

Based on various field tests, this technique is best suited for the treatment of soil contaminated with different types of petroleum, chemicals, and pesticides, like; TPH, PAH, BTEX, chlorinated solvents and PCP etc. (EPA, 2000).

Plants

Hybrid poplar, red mulberry, cattail, grasses, rice (EPA, 2000).

Figure 16: Cattail

Rhizofiltration (Accumulation)

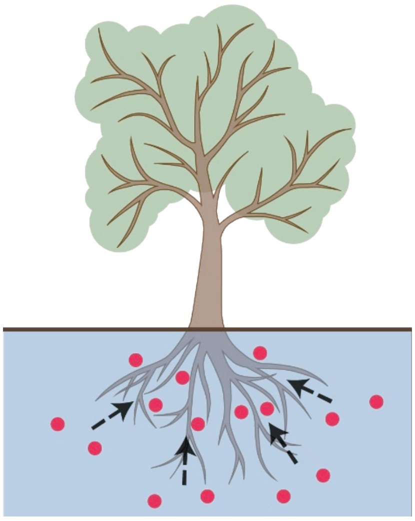


Figure 17: Rhizofiltration

Function

In *Rhizofiltration*, certain plant's root system can absorb, concentrate and/or precipitate metals from water surrounding the roots, the rhizosphere. The contaminants are then removed when the plant is removed physically. After removal, the plant can be processed into biomass and used as bioenergy. This ability to absorb pollutants in water is common among all plants but varies between different species. The contaminant needs to be in water in order to be absorbed by the root system, for that reason this technique does not work well with soil, sediments, or sludges (Raskin, Ensley, 2000; EPA, 2000). Sunflowers is an example of a plant that has good properties in treating water containing heavy metals like, lead, uranium, strontium, caesium, cobalt, and zinc to levels below the accepted water standards (Raskin, Ensley, 2000). Except that sunflowers have good cleaning properties, they also have aesthetical properties that gives recreational values to the treated area (EPA, 2000).

Figure 18: Sunflowers.

Suitable for

Rhizofiltration is a good technique for water contaminated with metals like lead, cadmium, copper, nickel, zinc and chromium, and radionuclides like uranium, caesium and strontium (EPA, 2000).

Plants

Sunflowers, Indian mustard, water hyacinth, duckweed (EPA, 2000; Classon, 2015).

Hydraulic control

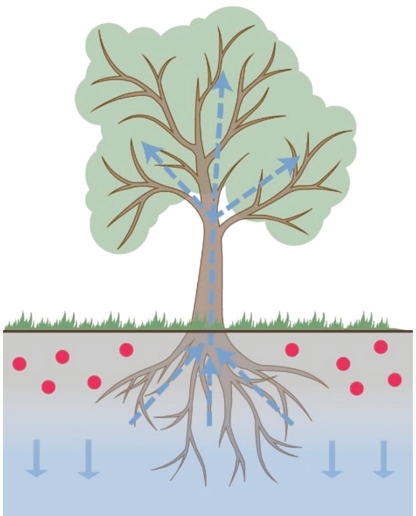


Figure 19: Hydraulic control

Function

Hydraulic control means that plants are used to prevent pollution from migrating to waterways, lakes or similar by its uptake and consumption of groundwater, which the contaminants otherwise would use as a medium for transportation (EPA, 2000).

Sutable for

Groundwater and surface water contaminated with water-soluble organics and inorganics (EPA, 2000).

Plants

Hybrid poplar trees, cottonwood, willow (EPA, 2000).

Figure 20: Poplar trees

Vegetative cover systems

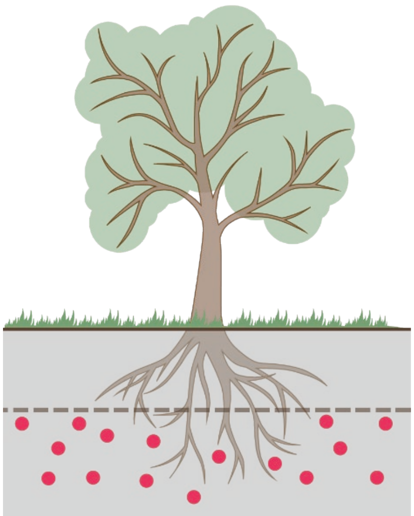


Figure 21: Vegetative cover systems

Function

This technique is about using plants to cover materials in the soil which can be considered an environmental risk. Using this technique can lower this risk and it generally requires little maintenance. There are two different kind of covers; evapotranspiration cover, and phyto-remediation cover. The main task for both of them is to isolate the underlying contaminants, but the phytoremediation cover also has some remediating effects (EPA, 2000).

Suitable for

Soil contaminated with organic and inorganic compounds (EPA, 2000).

Plants

Poplars, grasses (EPA, 2000).

Benefits with phytoremediation

- Low cost to initiate and maintain
- Economic benefits when using harvested biomass to create bioenergy
- Remediation on site, does not require excavation or transportation
- Can be applied to various types of contaminations
- The plants can give aesthetical values to the site

(EPA, 2010; Theuws & Wilschut, 2009)

Disadvantages with phytoremediation

- Slow remediating process and dependent by the seasons
- Cannot remove all the contaminations completely
- Only capable to clean the soil within the root zone of the plant
- High concentrations of metals may be harmful for the plant

(EPA, 2010; Theuws & Wilschut, 2009)

Comparison with conventional method

As mentioned earlier, the most common remediating method today is excavation and off-site disposal on landfills. Below follows a brief comparison between excavation, and on-site phytoremediation, in terms of economic, ecological, and social aspects of sustainability.

Economic aspect

For any site, the cost is a necessary consideration when choosing the remediation method. Scott Cunningham and William Berti (2000) have done assumptions of the cost to remediate a one-hectare large area contaminated with lead down to 30 centimetres which is 3000 cubic metres, during a period of ten years. The cost assumptions, which include a 3 % inflation rate, clearing of the ground, maintenance of the plants, are:

- Excavation and off-site disposal at landfill: $1 600 000 (14 400 000 SEK) /ha
- Phytoextraction and disposal of biomass (20 years): $416 000 (3 750 000 SEK) /ha
- Phytoextraction and disposal of biomass (10 years): $279 000 (2 500 000 SEK) /ha
- Phytostabilization: $60 000 (540 000 SEK) /ha

(Cunningham & Berti, 2000)

According to the assumptions made, phytoextraction can, depending of the remediation time, save between 82-74 % of the cost compared to excavation, without the potential income from the biomass included. Phytostabilization, which require less maintenance is ever cheaper. However, phytostabilization does not remediate the soil, it just stabilizes it and prevents the contaminants from spreading.

Additionally, if the site is planted with poplars or willows, which can be used for bioenergy when harvested, the total cost for using phytoremediation can be further decreased, or even lead to a profit.

Ecologic aspect

When using phytoremediation, you bring green structures to the site which can increase the biodiversity and provide ecosystem services in the area (Grant, 2012). Some of these ecosystem services are; decreased levels of air pollution, reduced heat-island effects, and storm water treatment (Classon, 2015).

Excavation on the other hand, is a mechanical remediation method which, compared to phytoremediation, has negative effects on the ecological sustainability with excavators digging in the ground and a lot of trucks transporting the soil to landfills, which requires fuel and creates exhausts gases.

Social aspect

The green structures created when using phytoremediation can give recreational values for the people moving, living, or working in the neighbourhood. It can also be used for pedagogical purposes, for example by showing school classes on how to cultivate and maintain plants, and to spread the knowledge of how the plants are remediating the site (Classon, 2015). If local residents are planting the phytoremediation plants together, it can create a stronger sense of belong and connection to the site.

Except from recreational and pedagogical values, the green structures also provide benefits for the human's psychological health through reduced stress and fatigue (Kaplan, 1995).

Reference projects

To study what has been done before and to learn from previous experiences is important when working with architecture and urban planning. The research about phytoremediation is relatively new, and the cleaning process may take a long time. This means that are quite few finished projects with results that show whether the method works or not.

In the following section, four different projects where phytoremediation is used are presented and reflected upon. The projects are on different scales and have different purposes.

Sommarhyttan/Orrefors Park, Sweden

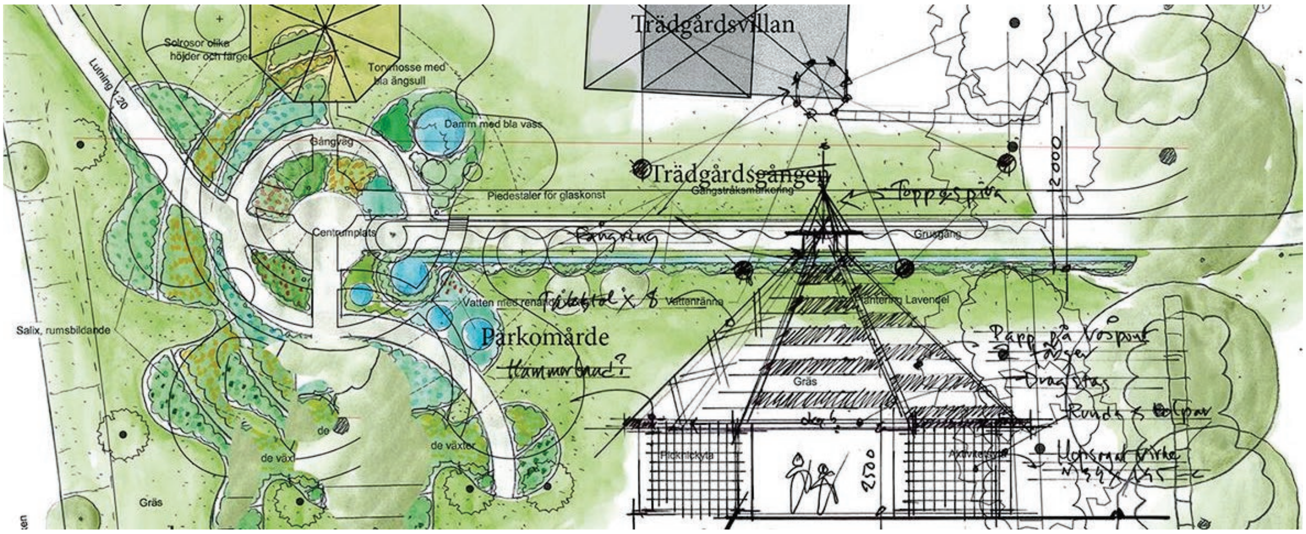


Figure 22: Illustration of Orrefors park and the temporary glassworks studio "Sommarhyttan" (Image: Orrefors park, 2017).

The kingdom of Crystal (Glasriket), is an area located in the province of Småland in south-eastern Sweden, known for its many glassworks. However, during the last decade, some of these glassworks has been closed. One of them is the famous Orrefors, located in the middle of the small town Orrefors. It was closed in 2012 and afterwards it was discussed how to save the trademark and regain the attractiveness of the village.

There were thoughts about building a small glassworks studio called “Glashyttan”, and in 2016, the local entrepreneur Ingemar Andersson decided to finance the project. Unfortunately, the site where Glashyttan was supposed to be built was contaminated from the old glass industry. Due to the usage rights, nothing permanent could be built if the soil was contaminated. To solve this problem, a phytoremediation park was created, “Orrefors park”, along with a temporary glass works studio, “Sommarhyttan”, during the summer of 2017. The remediating plants will clean the soil until the site is clean enough to be able build a permanent glassworks studio. This is the first project in Sweden integrating phytoremediation in an urban park. The 1000 square metre large park and the temporary studio was planted and built for 45 days during May and June by around 60 volunteer entrepreneurs and local residents. At the 1:st of july the park was finished and had its grand opening with over 1000 visitors. The park consists of various types of remediating plants, such as; Salix, sunflowers, and lupines that together can create an aesthetically pleasing park. The park and the temporary glassworks studio was built in a short period of time, but about nine months was devoted to lobbying and establishing partnerships with actors, such as the municipality, companies, and local entrepreneurs. To reach people and get them involved can be difficult and may require hard work and commitment (Jeanette Lennartsdotter, CEO & Project leader Orrefors park, personal communication, August 9, 2017).

The main purpose of the glassworks studio and the phytoremediation park is to maintain the trademark and give new life to the village. It aims to spread the art of glassblowing and the knowledge about phytoremediation, but also to integrate people with different backgrounds. Since the opening of Sommarhyttan, there has been an event two times a week. At this event, local residents and asylum seekers can meet and buy local food at a farmer's market, exchange experiences, and learn Swedish. It is hoped that Sommarhyttan can continue its activities also during the summer of 2018, and that the phytoremediation park will expand on an area that are more contaminated than the first one (Jeanette Lennartsdotter, CEO & Project leader Orrefors park, personal communication, August 9, 2017).

Figure 23: Volunteer local entrepreneurs and residents building Orrefors park summer 2017 (Image: Orrefors park, 2017)

Reflections

At the time of writing, the phytoremediation park has just been planted in Orrefors, so there is yet no evidence that the method is working. However, the project can be considered successful in other aspects, such as the social aspect, cultural aspect, and the pedagogical aspect. The combination of different aspects and their benefits is the strength of this project. The project managed to attract many volunteers and maybe one of the reasons is that Orrefors is a rather small town with around 800 inhabitants where "everyone knows everyone". A strong sense of belong can be even stronger with a project like this, while also integrating newly arrived residents.

A successful project like Orrefors park could be a start of a snow ball effect with more projects using phytoremediation in city planning throughout Sweden. It may be difficult to get resources such as municipal funding for a method that is relatively untested in Sweden. But, with an increased number of successful reference projects, both in the aspect of remediating the soil and other aspects, the interest may grow among decision-makers and developers.

Landscape Park Duisburg-Nord, Ruhr District, Germany

Figure 24: Illustration map of the Landscape Park Duisburg-Nord (Image: Latz und Partner).

The landscape park Duisburg-Nord is about 230 hectares in size and is built on a former industrial site in the Ruhr district in Germany. The site, that primarily consisted of a metallurgical plant, has, since its closure in 1985 been left untouched, taken over and revitalized by the nature. Many people thought the area was ugly and wanted it to be teared down. In 1989 the architectural firm Latz und Partner won a competition assigned by the municipality on how to develop the site and give it a public use. By mixing the existing built structures with the nature, they have developed an outstanding project in the history of the regeneration of old industrial sites (Latz und Partner, 2017; Podner, 2017).

In their proposal, they preserve and reutilize as much as possible of the existing structures and integrates it with the vegetation. By preserving the existing structures, which is central to the design, they wanted to celebrate the industrial history of the site. The site consists of several buildings and structures such as a gasometer, a power plant, blast furnaces, cooling tanks, and railroad tracks. These structures are preserved and converted into multifunctional performance venues as well as playgrounds and aesthetical parts integrated in a landscape park. For example; the railroads are used as walking and biking paths, and the gasometer has been transformed into a diving centre.

The vegetation on the site is balanced between informal, as it was grown spontaneously, and formal, as it was more planned in the park design. The vegetation consists of different plants that are able to clean the contaminated soil through phytoremediation. Some of these plants are trees like poplar and black locust. Also, the sewage canal that floats through the area cleans the site through filtering of contaminants in the water (Latz und Partner, 2017; Podner, 2017).

Figure 25: Abandoned industrial structures and the old sewage system integrated in the park (Image: Latz und Partner).

Figure 26: An old blast furnace plant in the background of a square (Image: Latz und Partner).

The site is divided into different areas depending on existing roads, railways, buildings, and the type of plants that has started to grow there. Each area has its own character and are connected through a network of walkways and waterways based on the old network of railways and the sewage system. The size of the park can be considered quite large, but it is only a small part of Germany's effort to reuse old industrial sites in the Ruhr area. The aim is to create a green belt in the Emschler region where industrial sites are transformed into parks based on the natural regeneration of the soil (Podner, 2017).

Reflections

Duisburg-Nord is a great example on how a large piece of land squeezed into an urban area can be transformed, from a disliked industrial site to a beloved park and event area. Since many buildings are preserved and reused, not only is the industrial history of the site preserved, but it is also likely to be less expensive to develop or reuse in the future. However, in some cases, reuse of old structures may be more expensive depending on its condition and degree of contamination. Integrating old industrial structures in a park with remediating plants may give the visitors more awareness of the possibilities to clean industrial sites using phytoremediation. This is something I think Duisburg-Nord succeeds with, and hopefully this area can inspire others to do something similar when taking care of old industrial areas.

Based on my findings, there are no plans to develop the area of Duisburg-Nord with other uses, such as housing or offices, when the area is remediated. From my point of view, the area should be preserved as long as possible and work as a museum and showcase park, showing both the industrial history, but also how to naturally remediate the site.

De Ceuvel phytoremediation park, Amsterdam, Netherlands

De Ceuvel is a project located on a one-hectare large site next to the canal Johan van Hasseltkanaal-West in the partly abandoned harbour area Buikslotherham, in northern Amsterdam. The site is contaminated with both organic compounds and heavy metals, especially zinc. The project was born in 2012 as the winning contribution in an architecture competition assigned by the municipality on how to create a temporary and accessible use for a specific site that is going to be developed in ten years. The creators behind the project is the two firms *Space and Matter architects* and *Marjolein Smeele*, together with the landscape architect Pieter Theuws. Their winning concept was to create an ecologically and socially sustainable environment that is self-sufficient (De Ceuvel, 2017; Lundén, 2014).

Figure 27: Illustration of the project De Ceuvel (Image: De Ceuvel).

Mobility is one of the key features in the project, and on the site, there are reused houseboats from the local area, which contains restaurants, offices, ateliers, and bed & breakfast. The houseboats can easily be removed when ten years has passed and the development of the site will be initiated. To clean the contaminated soil, several different types of phytoremediation plants are used, creating a flourishing park between the houseboats. To avoid pedestrians from getting in direct contact with the plants, there are elevated wooden pathways winding though the site (De Ceuvel, 2017; Lundén, 2014).

De Ceuvel is not only a park whose purpose is to clean the contaminated soil, but it is also a kind of a playground for sustainable technologies. On the site, experiments are done to be as self-sufficient as

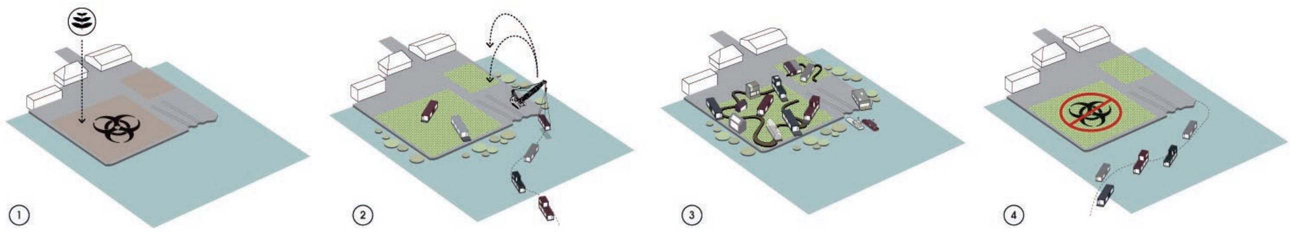


Figure 28: Illustration showing the development process of De Ceuvel. (1) Contaminated soil. (2) Adding phytoremediation plants and temporary structures. (3) Using, while cleaning the site. (4) Site is clean, removal of plants and the temporary structures (Image: Delva landscape architects)

possible in terms of energy-usage, for example through processing waste in new, innovative ways (De Ceuvel, 2017).

When the project won the competition in 2012, a 10-year lease of the site was secured. At the time of writing, half of the time has passed, but the project is never really finished. All the time, volunteers are invited to the site, to make it even more inviting and sustainable. The vision for the site is to be a symbol of the social transition from a linear, to a circular, more sustainable lifestyle (De Ceuvel, 2017).

Figure 29: Photo from De Ceuvel showing the houseboats and the elevated pathways (Image: Delva landscape architects)

Reflections

De Ceuvel is a good example on how to temporarily utilize a brownfield site until future development, while at the same time remediating the contaminated site. One of the strongest characteristics of the project is that it combines phytoremediation with urban features, making it vibrant and used by many different people. I think that the close connection between the visitors and the sustainability aspects, like recycling and phytoremediation, is one of the key concepts of a successful dissemination of knowledge. However, in order to create a vibrant and popular place to visit, it is essential to have activities well fit into the local context. Also, the location of the site is an important factor to attract visitors. De Ceuvel is located relatively central in Amsterdam, which provides a catchment area with many residents within walking distance from the site.

The project is implemented on a relatively small plot, which shows that a phytoremediation project not necessarily has to be done on a large scale, all at once. Projects like this can be initiated whenever an abandoned and contaminated plot is planned to be developed in a rather distant future.

Wheat fields at Brunnby and Torslunda, Sweden

Between 2005 and 2010, two parallel field tests were done at two different farms, one on Brunnby farm outside Västerås with clay soil, and one in Torslunda on Öland with sand soil. The reason for the tests was to see how much time is needed for a certain type of Salix to extract enough cadmium from the soil of a wheat field to achieve a reduced level of cadmium in the wheat kernel. Cadmium is a known health hazard, and about 43 % of the Cadmium intake in Sweden is from wheat. Salix was planted and harvested during the four first years, and in the fifth year, wheat was planted and harvested. The result showed that after four years, the level of cadmium in the soil was reduced by about 25 % in Brunnby, and about 33 % in Torslunda (Greger & Landberg, 2010).

Reflections

In comparison to the previous projects, this project was done for industrial/agricultural purposes only. However, it shows that Salix is a suitable plant to be used in Sweden. This is one of few tests on phytoremediation in Sweden that presents a result, and a very successful result. Projects and positive results like this are desirable to be able to inspire others to do similar projects and research, to spread knowledge about the method in Sweden.

3. Phytoremediation and spatial planning

Phytoremediation in the Swedish planning process

In Sweden, the municipalities have the main responsibility for planning the physical environment within the municipality. The planning is regulated by the Planning and Building Act (PBL). PBL was first issued in 1987, and a new, updated version was issued in 2010 (Riksdagen, 2017). The third chapter of the PBL states that all municipalities in Sweden must have a comprehensive plan that shows the long-term vision for the development of the municipality. The comprehensive plan is not legally binding, but works as a guideline in the decision-making. The plan shows the basic features of the intended land and water use, and how the built environment will be used, developed, and maintained, for example, where there are most favourable to build new residential areas, or industrial areas. The purpose of the comprehensive plan is to promote a sustainable and "good" development of the municipality, and to predict the long-term consequences (Boverket, 2017).

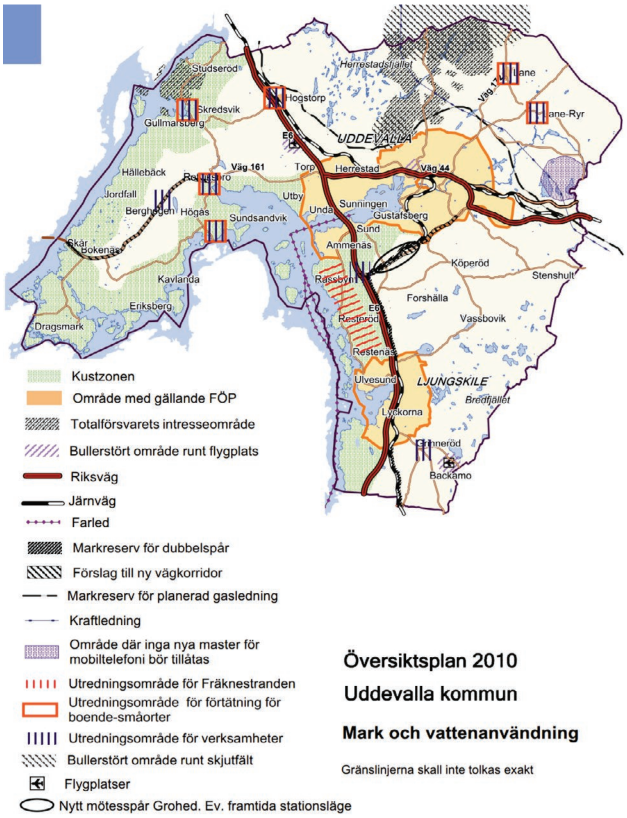


Figure 30: Comprehensive plan for Uddevalla municipality.

The fourth chapter of PBL states that a detailed development plan is needed when building an assembled group of buildings or other major changes in land-use that requires building permit. The detailed development plan is legally binding and tests the suitability of the planned development of a certain area. The plan shall present the use and the boundaries of public space, private space, and water areas, and has an implementation period between 5 to 15 years from adaptation (Riksdagen, 2017).

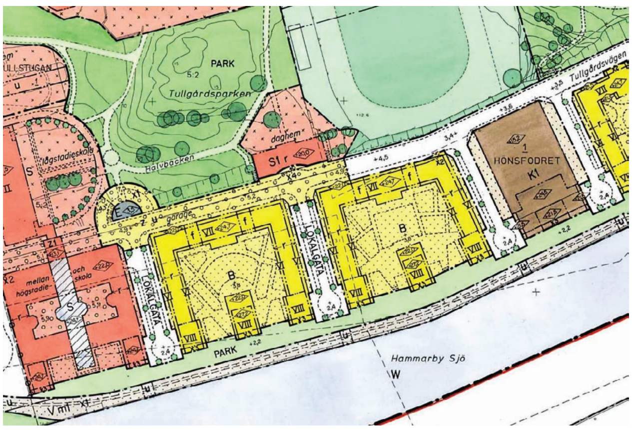


Figure 31: Example of a detailed development plan (Stockholms stadsbyggnadskontor/Creative Commons CC BY-SA 3.0).

In some cases, the comprehensive plan points out brownfields as areas to be development in the future. These areas are usually abandoned or active industrial areas, which can be heavily contaminated from the earlier activities. The municipality often knows that these brownfield sites are potentially contaminated, and can mention it in the comprehensive plan. But in most cases, the investigation and sanitation happens in connection to the detailed development plan, just before the area is being built, as a last-minute act (Naturvårdsverket & Boverket, 2006). A municipality that adopts a detailed development plan without having full control over the contamination on the site poses great risks as a detailed development plan ensures that the site is suitable for its purpose (Naturvårdsverket & Boverket, 2006).

To map and investigate contaminated areas within a municipality is a very costly and laborious work to do. However, conducting soil investigations on the contaminated areas that has a potential to be developed provides a good overview of the contamination situation. This in turn gives you a wide margin in time determining what kind of remediation method that are the most suitable for a certain area. The greater the margins you work within, the greater the potential of using phytoremediation to clean the area, because of its long remediation time.

If an area can be cleaned through phytoremediation it could ultimately make the soil investigation a worthwhile investment for the municipality. Both economically, because phytoremediation is cheaper than conventional methods like excavation. But also, ecologically, as the plants helps restore nature and increases the biodiversity in the area, even if the area is not being built.

The municipal comprehensive plan is an appropriate tool for addressing the problem with contaminated areas and how they should be treated. Like mentioned above, the issue of contamination can be mentioned if the specific area is affected, but with no actual plan on how it will be remediated. An example of this is description of the area of Bäve/Badö in the in-depth comprehensive plan for Uddevalla.

The in-depth comprehensive plan says that the area is contaminated, but it does not mention how this problem will be solved (Uddevalla Kommun, 2016b). A reason for not mentioning how the contaminated areas will be treated could possibly be a lack of knowledge about remediation methods, or that it is taken for granted that the area is remediated through excavation. An increased level of knowledge about alternative remediation methods, like phytoremediation, among planners and politicians, could influence the decision-making.

To achieve a sustainable development, the municipal comprehensive plan should include concrete strategies on how to initiate the remediation process of contaminated areas at an early stage. The comprehensive plan may also specify that phytoremediation should be considered when choosing remediation method, both to reduce the remediation cost but also to reduce the environmental impact.

Figure 32: The contaminated industrial site Bäve/Badö in Uddevalla.

Concept for using phytoremediation in a brownfield development

The following section will present a concept for using phytoremediation when transforming a brownfield site into other uses such as housing, based on the knowledge gained from the theoretical framework and the reference projects. The drawing below shows the basics of the concept, and the relation between different aspects in the development. Each aspect will be further explained on the following pages.

The idea with the concept is that the site analysis, phytoremediation techniques, the aspect of time, climate change, municipal planning, and the future vision for the area, determines how the development will look like and how the phytoremediation process will be planned and integrated. All these aspects are playing a role in the design of a phytoremediation park. The purpose of the park is to clean the soil while giving social and/or economic benefits at the same time.

Throughout the whole development process there is a constant connection between these aspects, and the process is not linear and solid with a fixed objective. It may change due to changing conditions in the various aspects, such as a longer remediation time than expected, or changes in the economic or political conditions in the municipality.

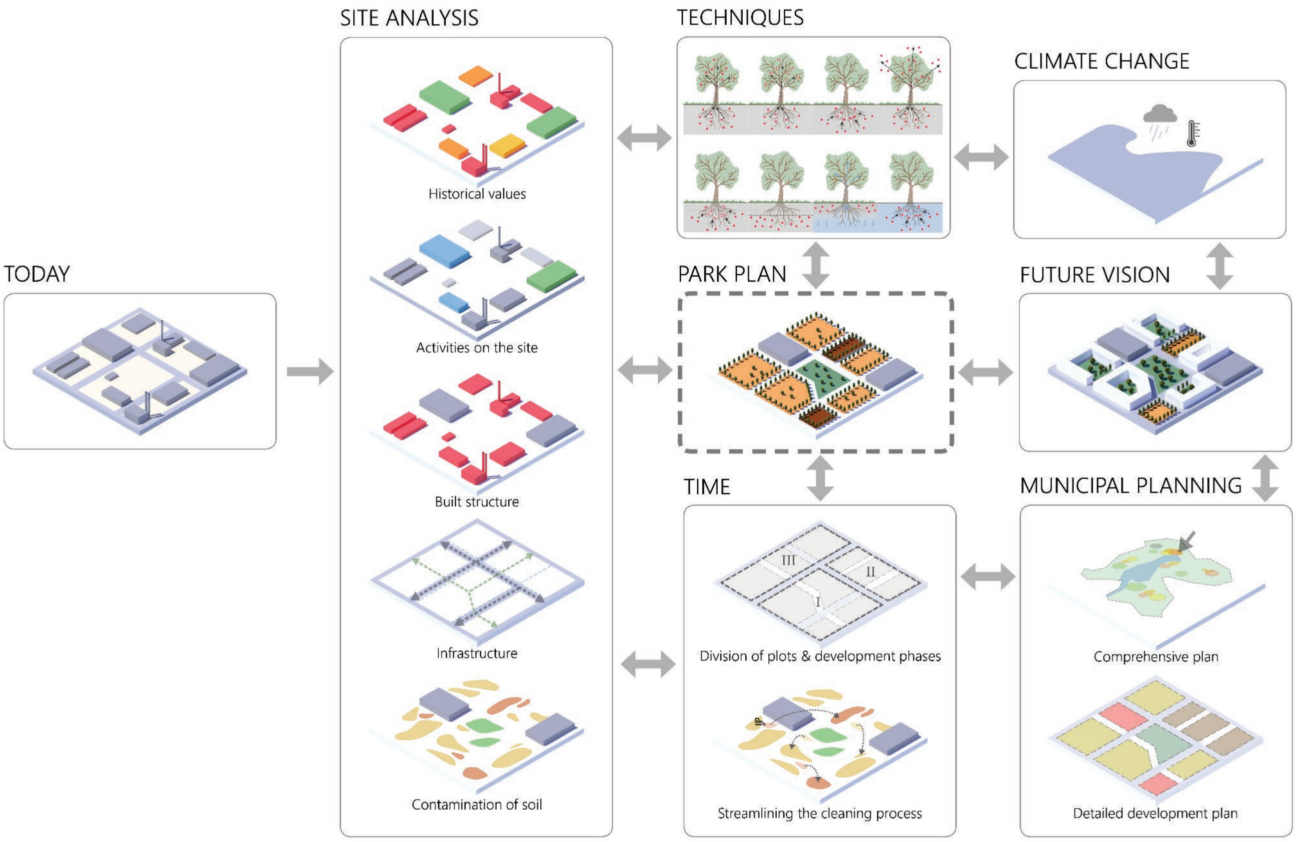


Figure 33: Concept model for using phytoremediation in a brownfield development

Site analysis

A proper site analysis is always an important first step when planning for a new development on a site. When reusing an already developed site, a brownfield, the analysis becomes even more important due to the previous uses of the site. Brownfields have a lot of different aspects to take into consideration compared to undeveloped sites, also known as greenfields. Some of these aspects is the historical values, existing activities on the site, built structure, infrastructure, and the possible contamination of the soil.

Historical values

A site that has been used for a very long time can have historical and cultural values that has to be considered. Preserving these values can give a strong identity to the place closely connected to its history. For example, an industrial site where some of the buildings and other industrial features are preserved when transforming it to other uses like housing, takes advantage of the old identity instead of creating a new one.

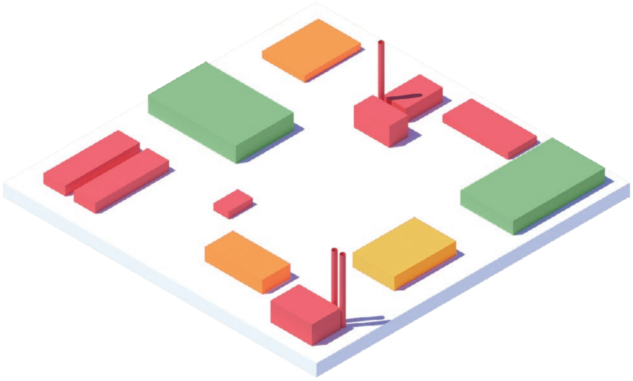


Figure 34: Site analysis - Historical values

Existing activities on the site

In some cases, the site, or parts of the site are still in use with industrial or commercial activities, and in these cases conflicts of interest may arise that needs to be solved.

Some activities that can be considered as unharmful, like offices, commercial activities, and some industrial activities, may possibly be integrated in the future development without compromising the health and well-being of the residents or the visitors of the site. If this solution cannot be achieved the activity needs to be relocated, or it can remain on site, but then the new development has to be adapted to the activity and its safety distance.

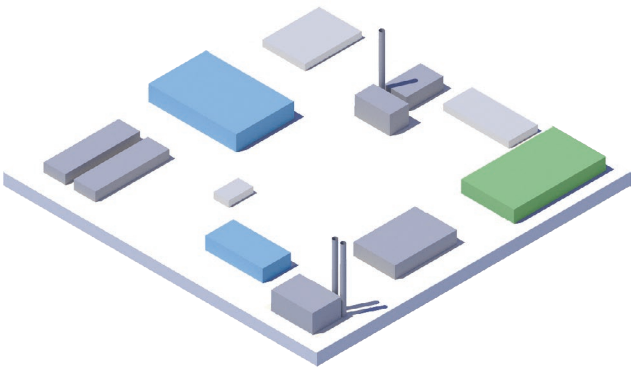


Figure 35: Site analysis – Existing activities on the site

Built structure

Brownfields usually consist of some form of built structure, it can be large industrial buildings, offices, or warehouses etc. This is often the first thing you notice when investigating a site. When planning for a transformation of the site, these buildings has to be considered. There are two simple options; either they will be preserved and reused and integrated in the future development if they are in decent condition, or, they will be demolished and replaced by new ones, depending on the contemporary demand.

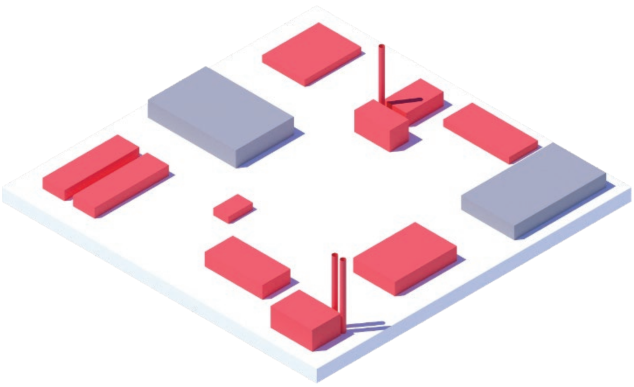


Figure 36: Site analysis - Built structure. In this example buildings marked in red will be demolished and the grey ones

Infrastructure

Another important aspect to investigate on site is the infrastructure. Is the quality of the roads and the public utilities like the water and sewage system good enough to be preserved and reused in the future development? If this is the case, it can save a lot of work and money, and also, when preserving the road system of the site, you are preserving some of its morphological history.

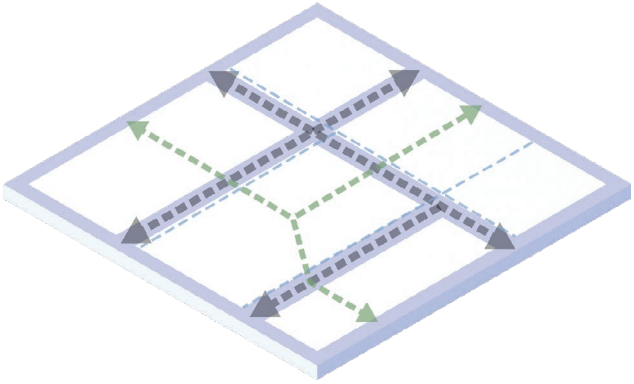


Figure 37: Site analysis - Infrastructure

Contamination of soil

When the existing buildings that are not worth preserving are demolished, the next part of the site analysis is to investigate the quality of the soil and what kind of contaminations the former activities have left behind on those parts that are planned to be developed. The soil investigation is crucial when using phytoremediation to remediate the site. The contamination of the soil affects the configuration of the phytoremediation park, due to the variating levels of contamination and the techniques that are used for each part, which in turn affects the future development of the site.

Figure 38: Site analysis - Contamination levels

The mapping of the contamination can be divided into three different categories depending on the level of contamination in the soil; "low level" (green colour in the example), "medium level", (yellow colour), and "high level", (red colour). These levels are defined based on the national guidelines for soil quality. The green zone with a low level of contamination has a level around the limit for KM (sensitive land-use) or below, which means that there is a low health risk for people who spend their full time on the site, for example by living there. The yellow zone with a medium level of contamination has a level higher than the limit for KM (sensitive land use), and around, or lower than the limit for MKM (less sensitive land-use), which means that the area is suitable for activities where people do not spend as much time, like offices or commercial activities. The red zones, which have a high level of contamination, in some cases several times higher than the limit for MKM (less sensitive land-use). This means that the red zones are not suitable for any kind of activity where people spend time, and in the worst case, the zone may need to be enclosed to eliminate the health risks to humans and animals.

Except from mapping the level of contamination, it is also important to map the type of contaminants, mainly divided into two different types; metals and organic compounds, which in turn can be further divided into what type of metal or organic compound it is, for example; zinc, lead, PAH, or PCB etc. (EPA, 2000). This division is important in order to be able to decide what kind of phytoremediation technique and which plant that should be used on certain parts of the site to make the sanitation process as effective as possible. Another important reason to know which type of substances that are on the site is because some substances are more toxic to humans than others, and should therefore be treated more carefully.

Phytoremediation techniques

Once a comprehensive analysis of the contamination of the site is done, along with all others necessary aspects, it can be decided which techniques and specific plants that are the most suitable for each of the various parts of the area. Also, if the basic requirements for using phytoremediation are fulfilled, because, as presented earlier, hyperaccumulator plants have the ability to concentrate and/or degrade contaminants in their tissue, but there is a limit on how high levels these plants can handle. If the contamination level in the soil exceeds the maximum level that any hyperaccumulator plant can handle, then that specific part may be remediated with conventional methods instead, like excavating.

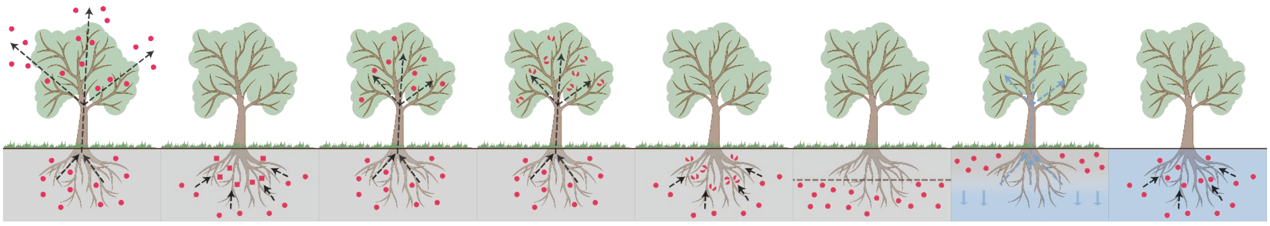


Figure 39: Phytoremediation techniques

Time

Using phytoremediation to sanitize the soil can require, as mentioned before, a lot of time before the soil can be considered clean enough to build upon. Therefore, it is favourable to have a plan for the future development that can work as guidance when designing the phytoremediation park. A clear site plan, along with an implementation plan, makes it possible to take advantage of the long time it takes to remediate the soil.

Especially the green structure is a component that can be used in the long-term development. Normally, green structure like trees are planted during or after the construction of the buildings. But if the trees are planted in advance before the construction begins, it is possible to get relatively large trees, already in place, depending on the time it grows. However, it is important to ensure that the trees will not be in the way when constructing the buildings.

Streamlining the cleaning process

Different types of contaminants spread out on the site require different phytoremediation techniques and different plants, which in turn creates an interesting area with the variation of plants, but you have less control over the process. To further increase the efficiency and to gain control of the remediation process, the most severely contaminated areas may be gathered into fewer, more controlled areas. The excavation and moving of the contaminated soil can be used in the design of the landscape by creating interesting landscapes with hills, valleys, or ponds.

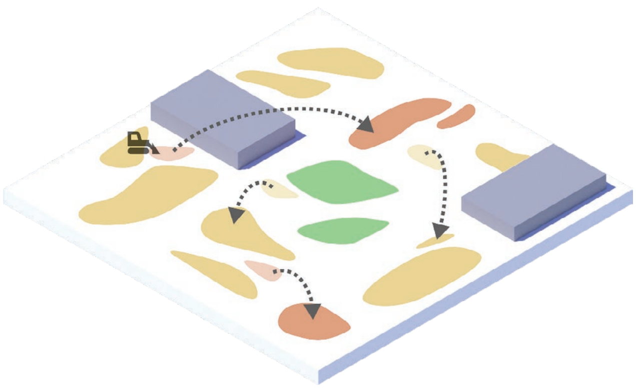


Figure 40: Gathering of same type of contaminants for more effective and controllable treatment

Division of plots and development phases

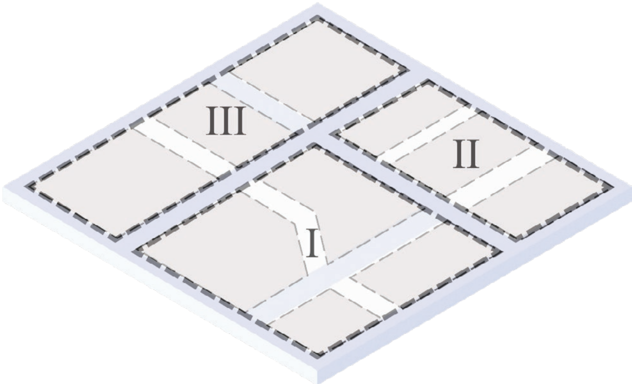


Figure 41: Division of plots and development phases

Since some parts usually are more contaminated than others and take longer time to be cleaned, it is beneficial to adjust the plots in the area based on the contamination zones. These zones should also have an appropriate size for the future blocks and street pattern. The division of the plots depending on the level of contamination makes it possible to build on each plot as soon as they are clean enough. Obviously, the cleaner plots can be built earlier than the more contaminated plots. At the same time as the plots are planned, a possible development of the infrastructure, like new streets and blocks, is also being planned, based on the future vision for the area.

Until the plot is being built, it can be used either as a recreational park or as an energy forest, which can give economic benefits to the owner of the plot. Moreover, just because a plot is clean, it must not be built, it can serve as green structure until a demand to build the plot occurs.

If the area is relatively large compared to the demand for exploitation, has a varied level of contamination, or some other reason, the development can be divided into different development phases. This division of phases were the parts are developed during different periods of time enables the creation of an area that has a mix between built environment and phytoremediation parks. This mix can give both ecological and recreational values to the area.

Climate change


Figure 42: Climate change

Due to logistical reasons, many industrial sites are located in direct contact with the sea, like the Bäve/Badö harbour in Uddevalla. Another example is the industrial areas along Göta Älv in Gothenburg.

If the sea level rises in the future as an effect by the climate change, these industrial sites are potentially at the risk of being flooded. Therefore, rising water levels is an important aspect to consider when transforming a brownfield site located near water.

In a British report made by Building Futures and ICE (Institution of Civil Engineers), three approaches on how to address this problem are presented. The first one, *retreat*, is that buildings and infrastructure are moved to, and built upon, safe ground, allowing the low-lying areas to be flooded. The second one is *defend*, which means that the area is protected from the floods with some kind of built defence, like walls. The third one is *attack*, meaning that buildings and infrastructure are built out onto the water, floating, or built upon poles (Building Features & ICE, 2010).

For example, if the *retreat* approach is used, the site could be used as a park with hyperaccumulator plants remediating the soil, including wetlands with plants using rhizofiltration. Using plants also reduces the impact on climate change. Mainly through reduction of the level of carbon dioxide, but also through absorption of solar energy that reduces the heat island effect in cities (Classon, 2015).

Municipal planning

Comprehensive plan

As considered earlier in this chapter, the municipal comprehensive plan is an important component in the development process when using phyto-remediation. The comprehensive plan is the first step in the process, deciding the future vision of the site. It should briefly show the level of contamination and the possibility of using phytoremediation at the specific site.

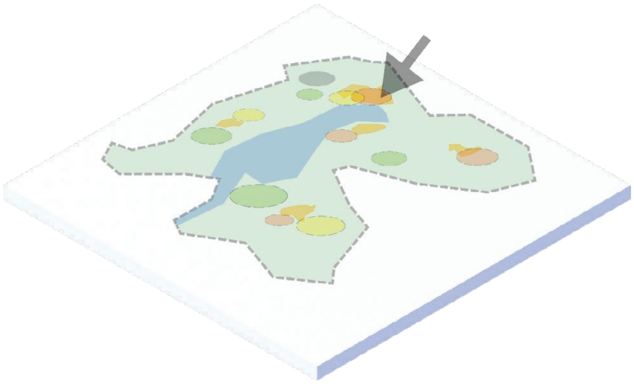


Figure 43: Comprehensive plan

Detailed development plan

Further in the development process, a legally binding detailed development plan is done which shows the development in more detail. This plan has an implementation time between 5-15 years depending on the extension of the plan (Riksdagen, 2017). The detailed development plan should be flexible enough to be able to change over time depending of the outcome of the phytoremediation process.

The detailed development contains a certain number of regulations, and one of them could be that phytoremediation should be used, and that the plots can be built as soon as the soil is remediated by the plants.

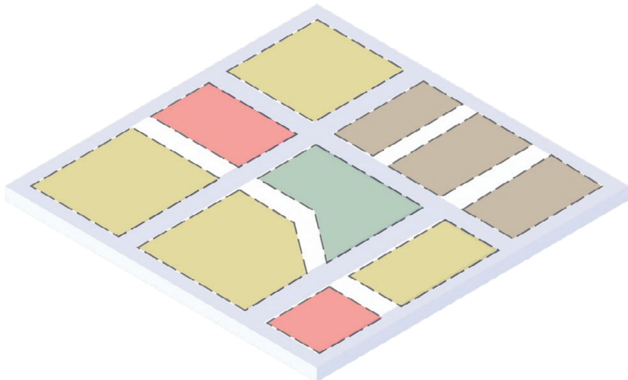


Figure 44: Detailed development plan

Phytoremediation process

The planning and design of the phytoremediation park is a compilation of all the parameters just described, together with the future vision for the site. The entire park will not necessarily be developed at once, but can be incrementally developed depending on the conditions of the site. Each plot consists of a phytoremediation park using the techniques and plants most suitable for the contamination of the soil.

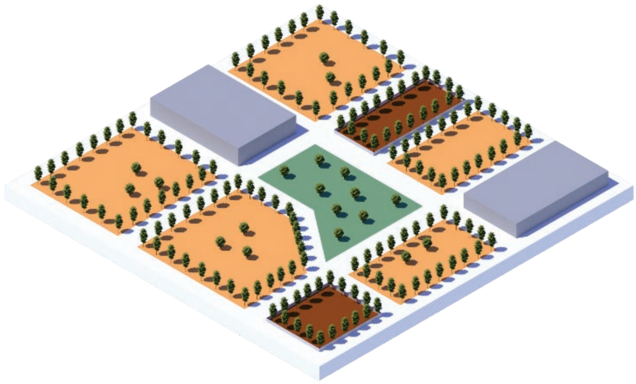


Figure 45: Phytoremediation park

There are three main types of parks depending of the three levels of contamination, low, medium, and high. The parks marked in green with a low level of contamination have the potential to have an open park, fully accessible without risking the health of people and animals. The parks marked in yellow with a medium level of contamination has an increased risk of affecting people and animals. Therefore, these parks should only be partly accessible, with for example elevated walkways passing through the area just above the ground, to avoid contact with the contaminated plants and soil. The parks marked in brown are cleaning the most heavily contaminated areas, and may need to be inaccessible for people due to the high health risk. However, after some time when the soil has become cleaner, it can be more accessible for people.

Future vision and development

The future vision for the site works as a guideline when planning the phytoremediation park. However, an important distinction that has be considered is the *vision* for the future development, and the *actual* development of the site. Many things can change throughout the process, especially when working with phytoremediation. The remediation may take longer than expected, the plants are relatively sensitive and can be damaged by for example extreme weather, deceases, or insects (EPA, 2000). Other things that may change the outcome of the development is for example the housing situation, the economic situation, and the political situation in the municipality.

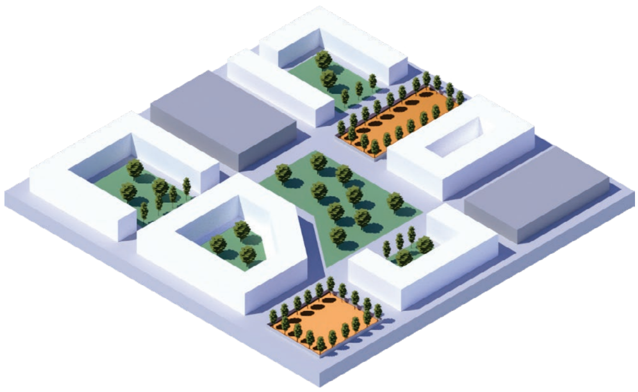


Figure 46: Future development

4. Implementation

The site that is chosen to test the method of phytoremediation is the industrial area of Bäve/Badö, just next to the outlet of the river Bäveån in Uddevalla, Sweden. The site, that primarily incorporates an active industrial harbour, is approximately 35 hectares in size and is about a five-minute walk from central Uddevalla. The reason for choosing this site is because of several motives. The main reason is because of a collaboration with the municipality of Uddevalla who provided with important materials such as; base map, soil investigations, and information through personal meetings. Probably there are many other places that suits better for this kind of remediation method, but in this case, it was the availability of the material needed that led to the decision.

Another reason is that the municipality has a vision to develop the area with housing in a long-term time perspective, but the soil on the site is contaminated from the industrial activities. Also, the municipality is relatively small which can argue for having a cheaper sanitation method. The area's proximity to the city centre is also a reason, because when using the area for recreational purposes during the phase of phytoremediation, it will be a lot of potential users in the nearby area.

Figure 47: Uddevalla's location in Sweden.

Figure 48: The site in the context of Uddevalla.

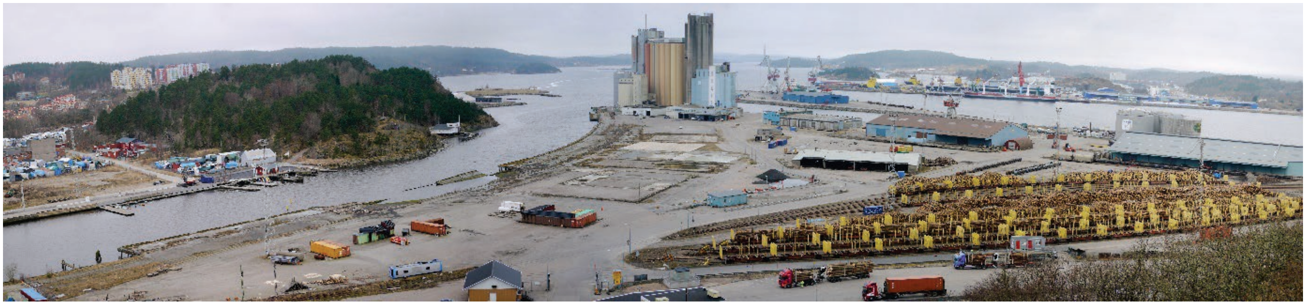


Figure 49: The area of Bäve/Badö shown from the top of Skansberget, north-east of the area. The most visible landmark on the site is the large silo buildings in the southwest which are still active today as storage for grain.

Site analysis

When planning for a development of a site, it is necessary to have a good understanding of the site and its context. Therefore, a site analysis needs to be done where the different relevant factors and characteristics are mapped out and analysed. The site analysis will create a framework for the site and it will determine the site's suitability for a certain land-use or a combination of land-uses. To conduct the analysis at an early stage and detect the site's opportunities and constrains increases the chance of creating a sustainable site planning (LaGro, 2013).

This site analysis will consist of the following eight layers:

- Topography and green structure
- Sea levels
- History
- Built structure and activities
- Infrastructure
- Contamination
- Soil composition
- Municipal development

Figure 50: Railways at the site.

Topography and green structure

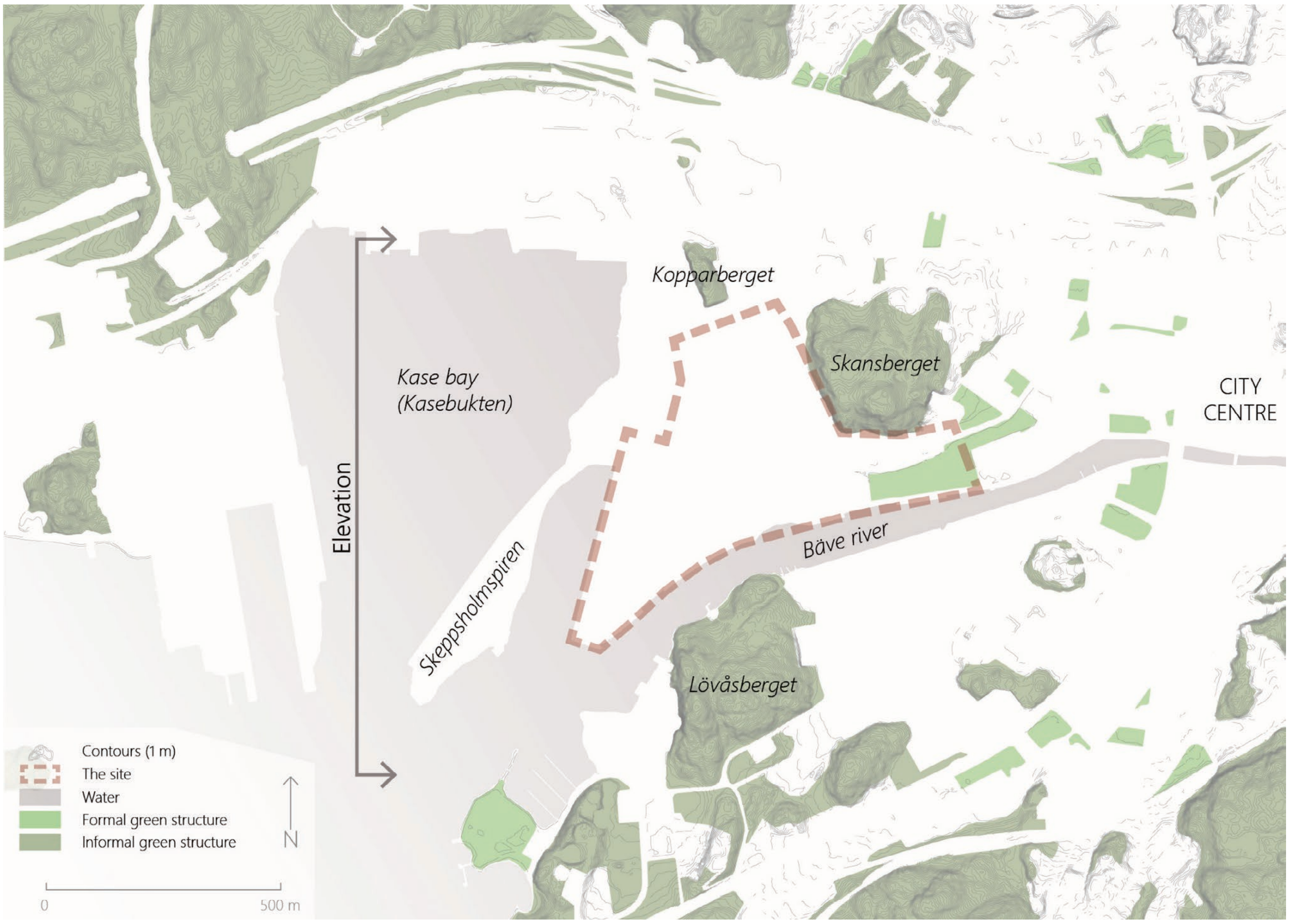


Figure 51: Map of topography and green structure.

The topography of the site and its surroundings are quite remarkable, either its extremely hilly, or extremely flat. The site itself belongs to the latter description. The reason is that almost the entire site is located on a landfill that was made to make room for the harbour during the last centuries. The majority of the site is adjacent to the water, which, together with the flat and low terrain gives a lot of opportunities to develop the site, but it also creates great challenges because of the risk of flooding. The wind coming from the sea is also an aspect that needs to be considered when developing the site.

The site is surrounded by steep mountains that frames the site and creates a visual contact to nature. The most significant mountains are; Lövåsberget south of the area, on the other side of Bäveån, with a height of 56 meters above sea level. Skansberget, on the eastern border of the area, with a height of 50 meters above sea level, is an important mountain in the history of Uddevalla, with old defensive structures preserved, like walls and bunkers from various historical periods. North of the area there is a small mountain called Kopparberget that is about 24 meters above sea level.

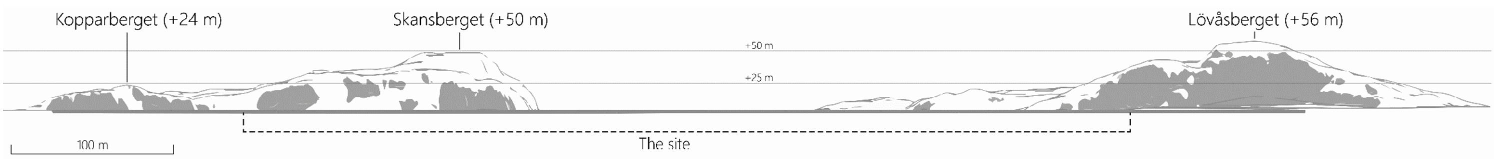


Figure 52: Elevation seen from west, showing the flat terrain of the site and the steep surrounding mountains

The mountains work as green lungs in the city, and the steep terrain has both benefits and limitations. The benefits are that they will most probably never be built upon, but the limitation is that they are partly inaccessible for the inhabitants, especially those with impaired mobility. Skansberget is marked as informal green structure on the map, but pathways, stairs and benches makes it partly formal. Formal green structures marked on the map are otherwise mainly parks with lawns and trees, while the informal green structures consist mainly of forest and less maintained green areas that do not have the main purpose of being a public park.

The river Bäveån, which flows through the city of Uddevalla has its outlet next to the site. The river is acting both as barrier to the other side of the river, but also as a connection to the city centre and to the sea if you travel by boat. The river can also give potential recreational values to the site and it can be connected to the city centre through a seafront promenade along the river.

Figure 53: Bäveån outlet (The silo to the left and Lövåsberget to the right).

In the eastern part of the area, between the road Bastiongatan and the river, there is a grass field called the *Riverside field (Riversideängen)*. This is a popular place for arranging different events such as the music festival *Uddevalla Solid Sound*. Though, since a collapse of a part of the quay in 2008, the field is closed due to the risk of erosion. Due to the closure, no events can be arranged there, including *Uddevalla Solid Sound*, that is arranged at car parking in Kampenhof (located between the Rivderside field and the city centre) instead (Uddevalla kommun, 2016a).

Except the Riverside field, the site has basically no green structure at all. Almost the entire site is covered by hard, impermeable material like asphalt and concrete. However, you can find some parts that consist of permeable material like gravel, and very few, small areas with grass and other kinds of vegetation.

Figure 54: The site shown from north west.

Sea levels

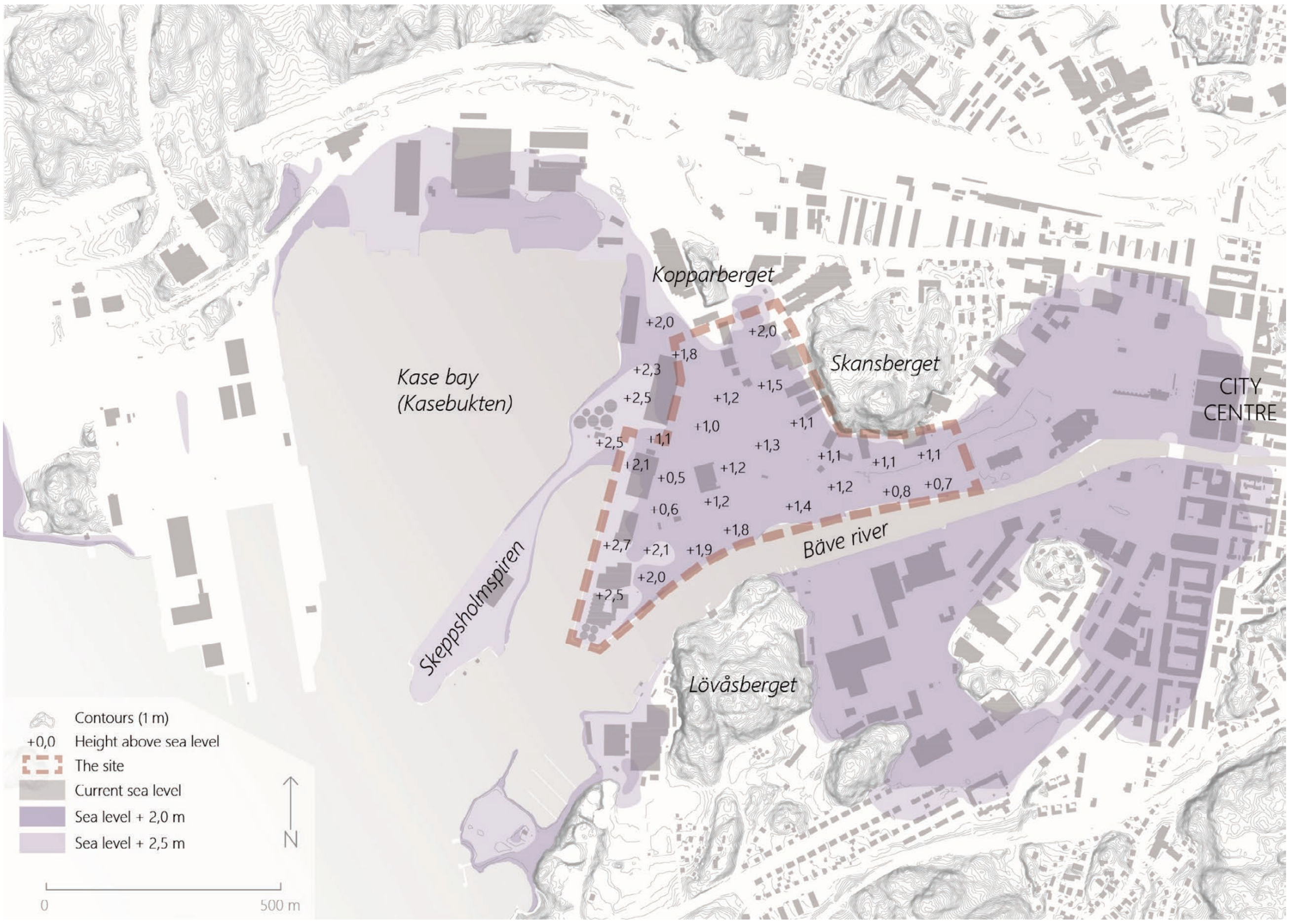


Figure 55: Map showing scenarios with rising sea levels.

As mentioned in the previous section, the site is extremely flat and at a low level above sea. As the map above shows, a rise of the water level with only two meters is enough to flood almost the entire site. Even a rise of one metre will flood some of the lowest points, which are the east and the central parts.

Almost the entire site is a landfill and over the time the ground level have sunk and this can clearly be seen around the buildings in the central part where the ground level is sometimes 1-1,5 meters below the level of the building's foundation, as they are piled which keeps them from sinking.

Figure 56: Flood warning sign at the site.

Figure 57: This photo shows the lowest point in the western part of the site. It is just about half a meter above sea level and are regularly flooded. A height difference between the foundation of the building and the ground level can be seen. Underneath this building the landfill has been washed away, shown in the photo to the right. In the background to the left, the silo building is visible.

Figure 58: Photo showing the space filled with sea water under the building shown on the photo to the left.

History

Investigating the history of a site is essential when doing a site analysis. In this case, the history is important due to two different aspects. Firstly, it is necessary to know what kind of industries that has been active in the area to be able to know approximately what kind of toxic substances that might be found, so the cleaning process can be as effective as possible. Secondly, it is important to know the historical values of the site to be able to make use of the history, instead of removing the history. Preserving historical values might give a stronger character to the future development of the site.

1500-1600s – Uddevalla as an important trading post

The city of Uddevalla was founded around 1500, and the city was an important trading venue between the sea and the lake of Vänern. In the early 1620's you could see Uddevalla in the trading statistics for the first time. The ships sailing from Uddevalla were most often loaded with timber, planks, firewood, meat, animal hides, butter, and later also iron. The destinations were Denmark and other harbours around the Baltic sea and the Northern sea. The ships that arrived to Uddevalla mostly carried vegetables, salt, and other groceries. In the year of 1640 a total of 231 ships sailed from Uddevalla (Aue, 1998).

1700s – Herring and the first industries

In the middle of the 1700s another trading good became important; herring. For some years, over 30 000 barrels of herring were produced every year in Uddevalla. In the end of the 1700s, you could find about 115 salting houses in the city. During this time, the first real industries were established; there were four shipyards, cooperages (barrel-makers), and a rope-walk that produced all the ropes for the ships and the loading in the harbour (Aue, 1998).

1800s – Export of oat with train and steamboat

In the 1860s Uddevalla and its harbour was connected with a railroad to Vänersborg and Herrljunga in Västergötland. This created a major increase in the export of oat which grew in the fields of Västergötland. Between 1878 and 1879, more than 4000 train wagons of oat arrived to Uddevalla harbour and was loaded onto ships, a lot of them with England as destination. Uddevalla was at this time the home port for 363 sailing ships and nine steamers.

From the middle of 1800s and onwards many new large factories where built in the area, for example, a cotton mill, a match-stick factory, a barrel factory, and a foundry/ mechanical workshop (Aue, 1998).

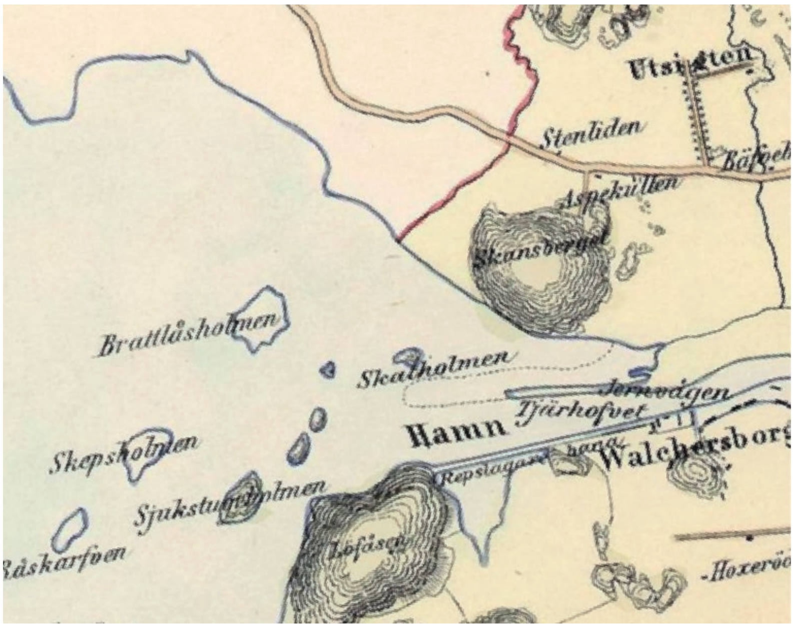


Figure 59: Map from 1855 showing the area before it was filled out.

1900s – The great industrial era

The end of the second world war was the beginning of a great and significant time in Uddevalla's history. In 1946 Uddevalla shipyard was founded just outside the site in north-west. The shipyard built very large cargo ships exported to all over the world. The shipyard grew and a huge number of workers moved to Uddevalla which lead to a rapid growth of the city with many new residential areas and industries. In the 1970s and 1980s the shipyard suffered many crises and in 1986 it had to close due to financial reasons, leaving 2000 people unemployed (Aue, 1998). The map below shows how the area of Bäve/Badö starts to be filled out and that there is a mechanical workshop, slaughterhouse, and a carpenter factory, along with a lot of railways crossing the area. In the mid-1900s, the large concrete silos were built to store grain.

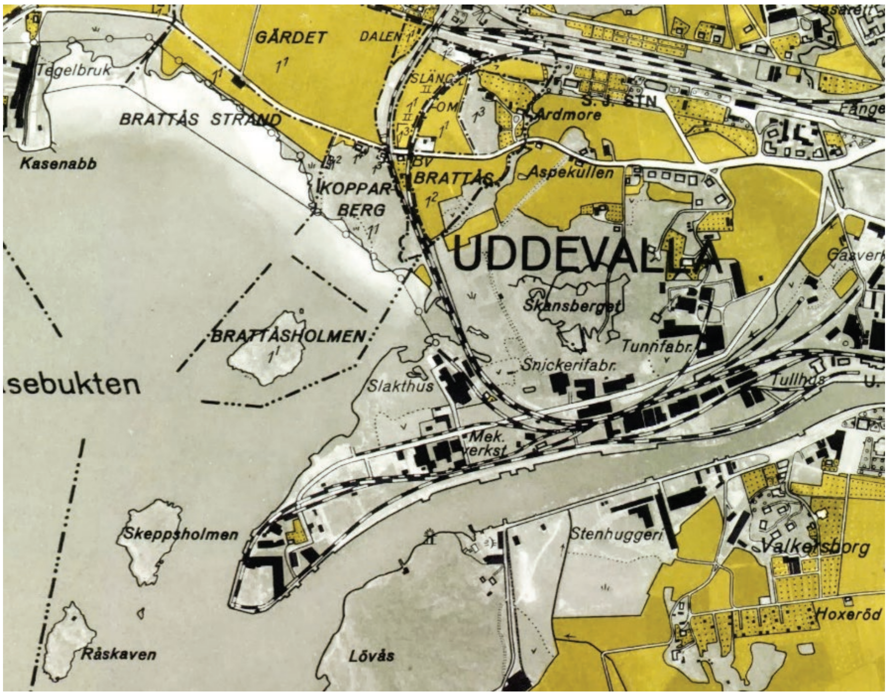


Figure 60: Map from 1937.

Figure 61: Map from 1984, the shipyard in the north has just been closed and the entire site is now filled.

2000s – Large scale harbour

No significant changes in the built structure in the area has occurred during the last decades. The site has been used as an industrial harbour with transportation of various types of goods, for example acid, petrol, wood, coal, and coke (fuel made from coal).

In 2008, a 100-meter long part of Bäve quay collapsed due to a heavy weight of anthracite, a certain type of coke, which is not harmful for the environment. Since the accident, a large area of the quay, from the collapsed part all the way to the city centre, is closed due to the risk of erosion.

Figure 62: Photo of cisterns in the north part of the area, formerly used for petroleum, but is now used to store acid and lye.

The harbour's activity has grown during the last years. During 2016, about one ship and two cargo trains arrived at the site every day, which is a doubling over the previous five years. The silo building is still very much active today, storing grain, with many trucks arriving every day (Ulf Stenberg, CEO of the harbour, personal communication, March 27, 2017).

Figure 63: The collapsed part of Bäve quay.

Figure 64: The silo and moored ships at Skeppsholmspiren.

Built structure and activities

Neighbourhood context

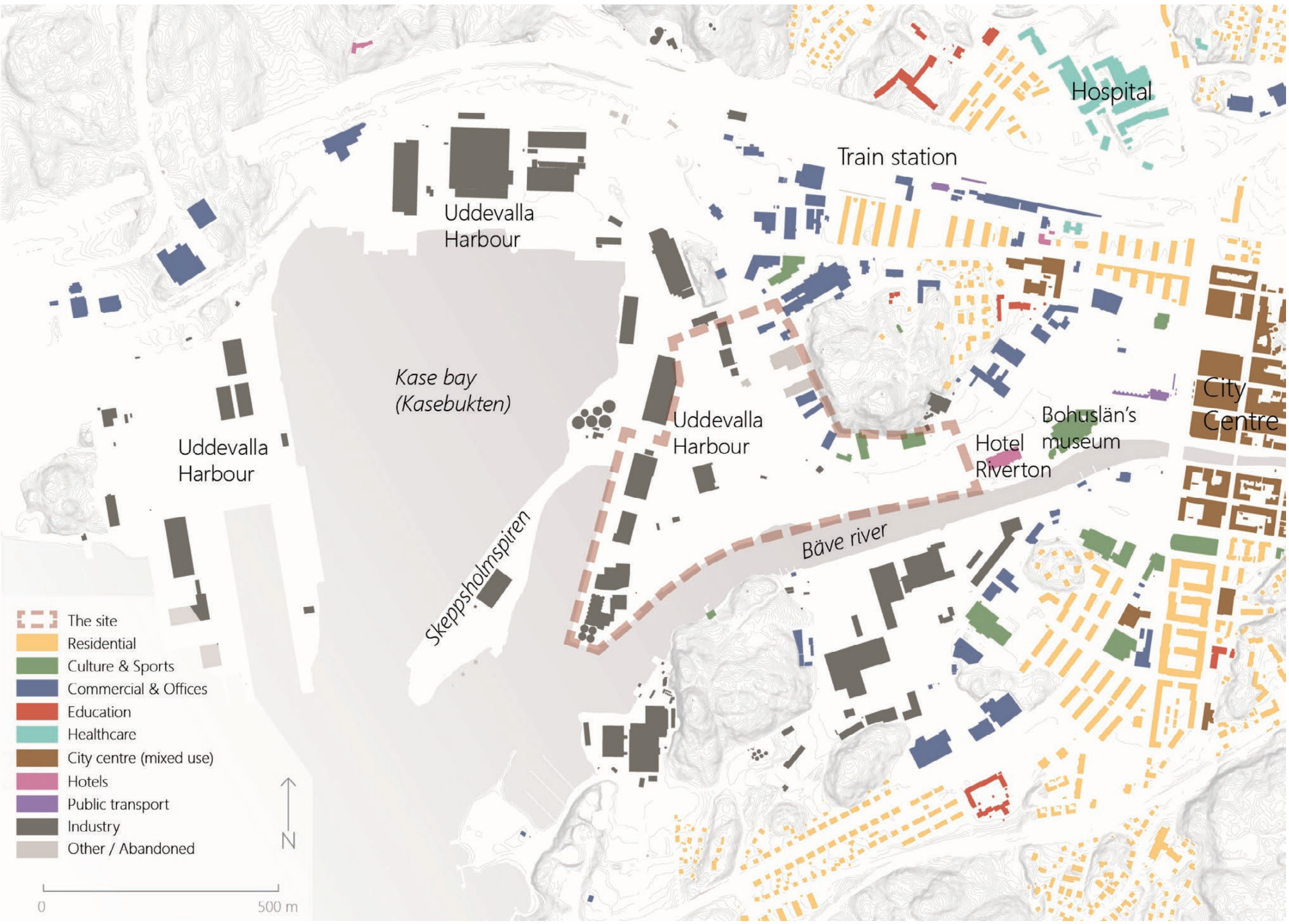


Figure 65: Map showing the built structures and activities within the site and its surroundings.

The built structure in the surrounding area is quite mixed and consists of four main characters. The buildings closest to the sea in the western part of the site have very much an industrial character. They are mostly very large in size and the building material is mainly steel frameworks covered with metal facades, but some buildings are made of concrete, like the silo in the south-western part. Not far from the site, in the east, the city centre is located, and the character of this area is completely different. This area is dominated by closed quarters and a distinct rectangular street pattern. Between the site and the city centre next to the Bäve river, you can find the hotel *Riverside* and *Bohuslän's museum*.

The residential areas nearby have two different main characters, it's the large apartment buildings, most of them closer to the city centre, and the detached villas, a bit further from the city centre.

Site context

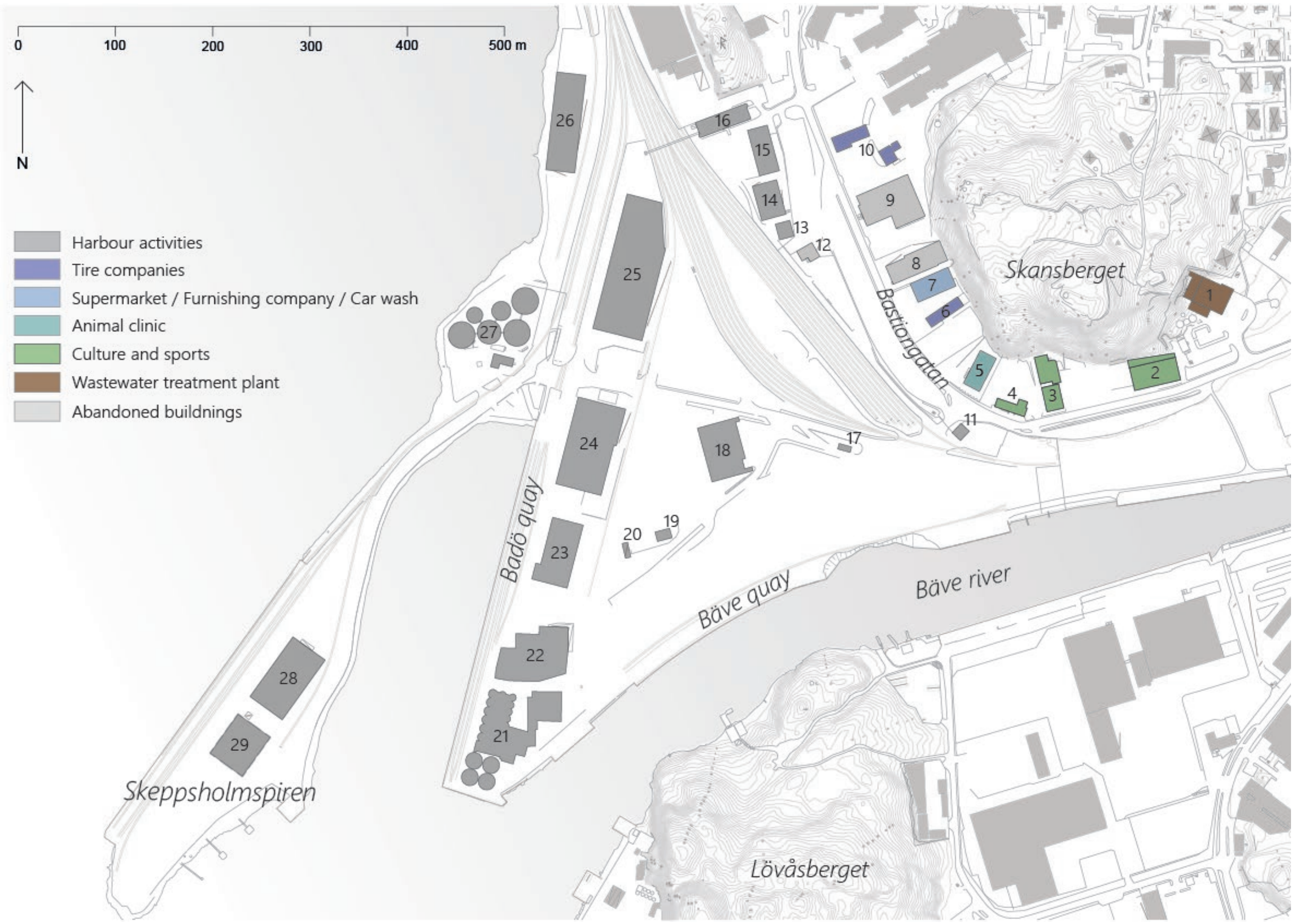


Figure 66: Map showing activities within the site.

1. Wastewater treatment plant
2. Gym (STC Training Club)
3. Culture house (Kulturhuset Bastionen)
4. Art workshop/exhibition (Anette's ateljé)
5. Clinic for small animals (Bohusläns smådjursklinik)
6. Tire company (Bastionens däckpool i Uddevalla AB)
7. Supermarket (Zam Zam Supermarket) / Car wash (Mr Car Wash) / Furnishing company (Inredningshuset)
8. Abandoned building *(Intended to be demolished by the Municipality)*
9. Abandoned office building
10. Tire company (Däckcenter väst AB)
11. Goods reception (Uddevalla harbour)
12. Abandoned gas station
13. Warehouse/garage (Uddevalla harbour)
14. Warehouse/garage (Uddevalla harbour)
15. Warehouse/garage (Uddevalla harbour)
16. Head office (Uddevalla harbour)
17. Weighbridge (Truck scale) (Uddevalla harbour)
18. Warehouse/garage ("Gamla tobaken"("The old tobacco")) (Uddevalla harbour)
19. Decayed barracks building (private person renting it by Uddevalla harbour)
20. Transformer station (Uddevalla harbour)
21. Grain silo (Uddevalla harbour, rented by Lantmännen)
22. Grain silo (Svenskt foder)
23. Old head office / Warehouse (Uddevalla harbour) *(Indented to be demolished by the harbour)*
24. Warehouse (Uddevalla harbour) *(Indented to be demolished by the harbour)*
25. Warehouse (Uddevalla harbour)
26. Warehouse (Uddevalla harbour)
27. Cisterns with acids and l (Wibax AB)
28. Warehouse (Uddevalla harbour)
29. Warehouse (Thomas cement) *(Under construction)*

Figure 67: Photo from the north part of the site, facing south along Bastiongatan. Skansberget can be seen to the left behind some abandoned buildings, and to the right is an abandoned gas station.

The majority of the buildings and the activities on the site are related to the harbour. The road Bastiongatan works as a border between the harbour and all other activities, with the harbour to the west and all the others to the east along the foot of the mountain Skansberget.

Except from the harbour, there is an interesting mixture of various types of activities and businesses in the area. Though in some cases, there can be quite difficult to determine which one of them is active or not, because some of the buildings are in rather bad condition and looks like it is abandoned.

One interesting activity is the Culture house Bastionen in the eastern part of the site (nr. 3 in figure 66). It was established in a reused industrial building in 2009 and arranges concerts, mainly rock and jazz, and various kinds of courses for newcomers and others that want to learn something new (Kulturhuset Bastionen, 2017).

Figure 68: Culture house Bastionen (nr. 3 in figure 66).

Figure 69: Supermarket, car wash, and furnishing company (nr. 7 in figure 66).

Infrastructure

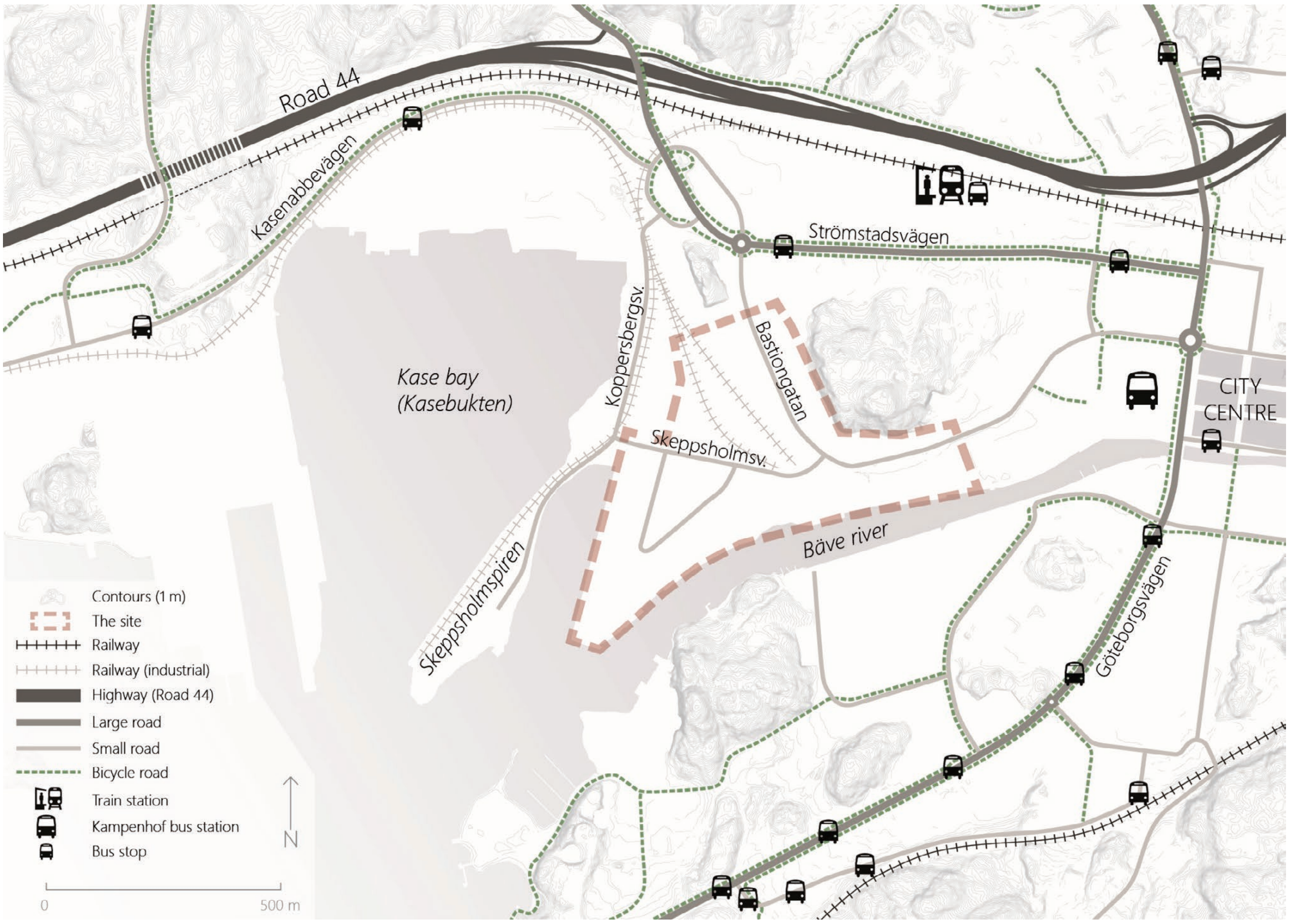


Figure 70: Map showing the infrastructure

The site is generally very well connected, both to the local road system via Bastiongatan in the east, and the regional road system via road 44 in the north. Bäve/Badö has a road system at the site that is in relatively good condition and can possibly be reused in a future development.

The site has been connected to the railway system for a very long time and is still today, with approximately two industrial train sets arriving and arriving each day, usually transporting timber.

Within 500 meters from the site, both Uddevalla train station and the regional bus station Kampenhof, can be reached. From the train station, one train per hour departures to Gothenburg, a trip that takes about 1 hour and 15 minutes. The closest local bus stop is about 100 meters north of the area and is served by seven different bus lines departing every 3-5 minutes.

Figure 71: Bus in Uddevalla.

Contamination of the site

As the area has been used for industrial purposes for many centuries, a lot of different contaminations has been left in the ground. To map out all these contaminations and to assess the environmental risk, a soil investigation of the area of Badö was done in 2010 by the company Tyréns commisioned by the municipality of Uddevalla. Around eighty holes where drilled across the area to investigate the composition and the qualiy of the soil.

The result showed that many parts of the area was contaminated with various kinds of metals and organic substances. According to Tyréns, the area should be sanitized through excavation and that a "protection screen" should be dug down in the ground to prevent contaminants from spreading. The estimated cost for the sanitation is about 6 000 000 SEK, and half of which will be spent on the protection screen only (Tyréns, 2010b). This cost is based on a treatment of the absolutely most crucial areas, to prevent the contaminants from spreading to the surroundings. The extension of the remediation according the report is relatively small compared to how much that actually needs to be remediated to make the area clean enough for development of dwellings and other, more sensitive uses.

The map below is created mainly based on the data gathered from the soil investigation report (Tyréns, 2010a). To make the map easier to understand, it has been divided into zones depending on the level of contamiantion. The definition of the zones are the same as described earlier, green is relatively clean, yellow has a medium level of contamination, and red has a high level.

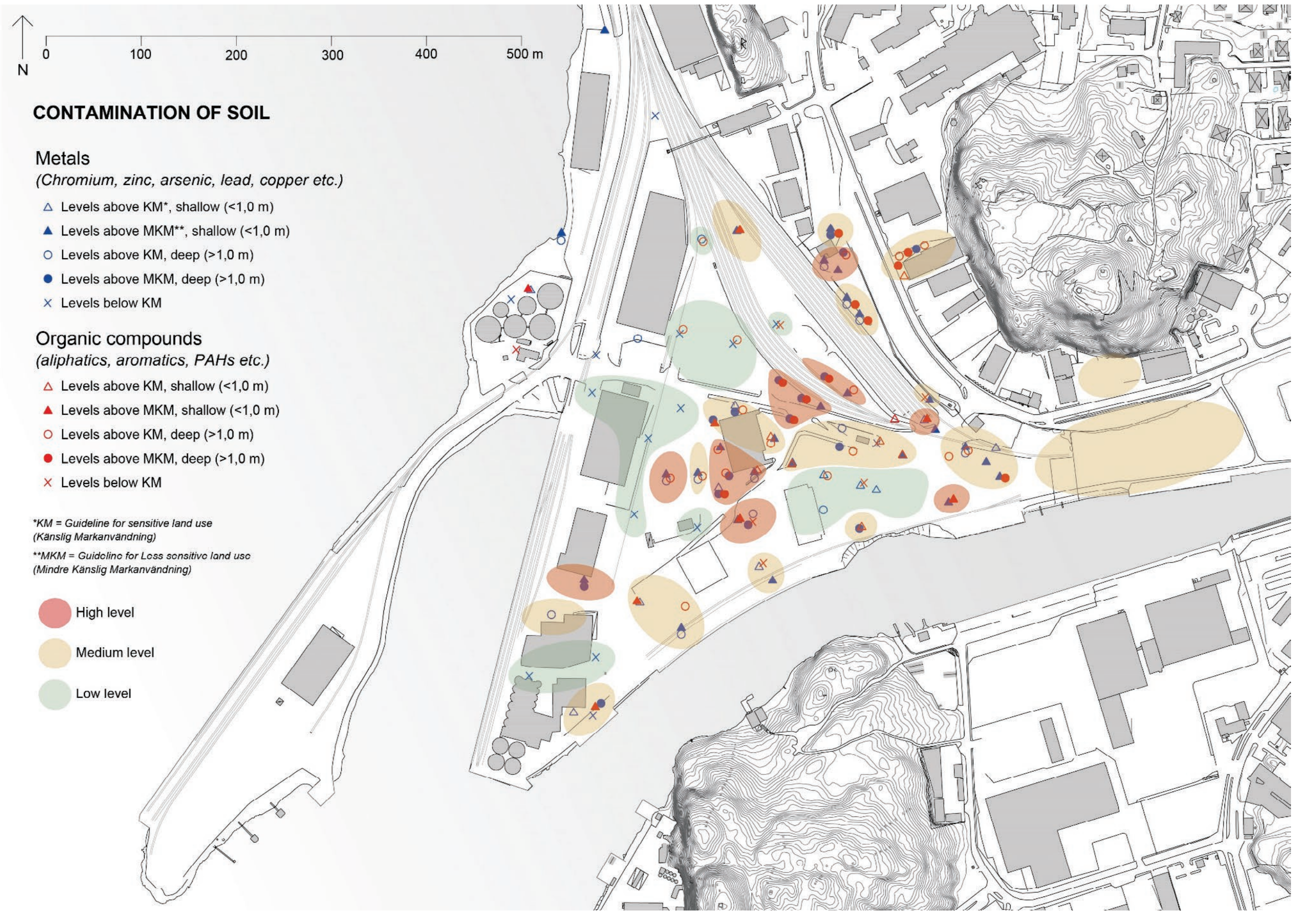


Figure 72: Map showing the contamination of the site based on the data gathered in the soil investigation from 2010.

Soil composition

Almost the entire site consist of filling that stretches from the old mainland at the foot of Skansberget in north-east, to the small underlying islands of bedrock in south-west, marked with red lines on the map. The filling consist of basically everything that could be used to create land, some examples are; dredged material, construction waste, household waste, sewage sludge, slaughterhouse waste, an residues from industriy. The north and the eastern area that connects the site to city consists mainly of clay and silt (Aue, 1998).

Figure 73: Photo taken next to the silo showing a glimpse of the landfill underneath the asphalt

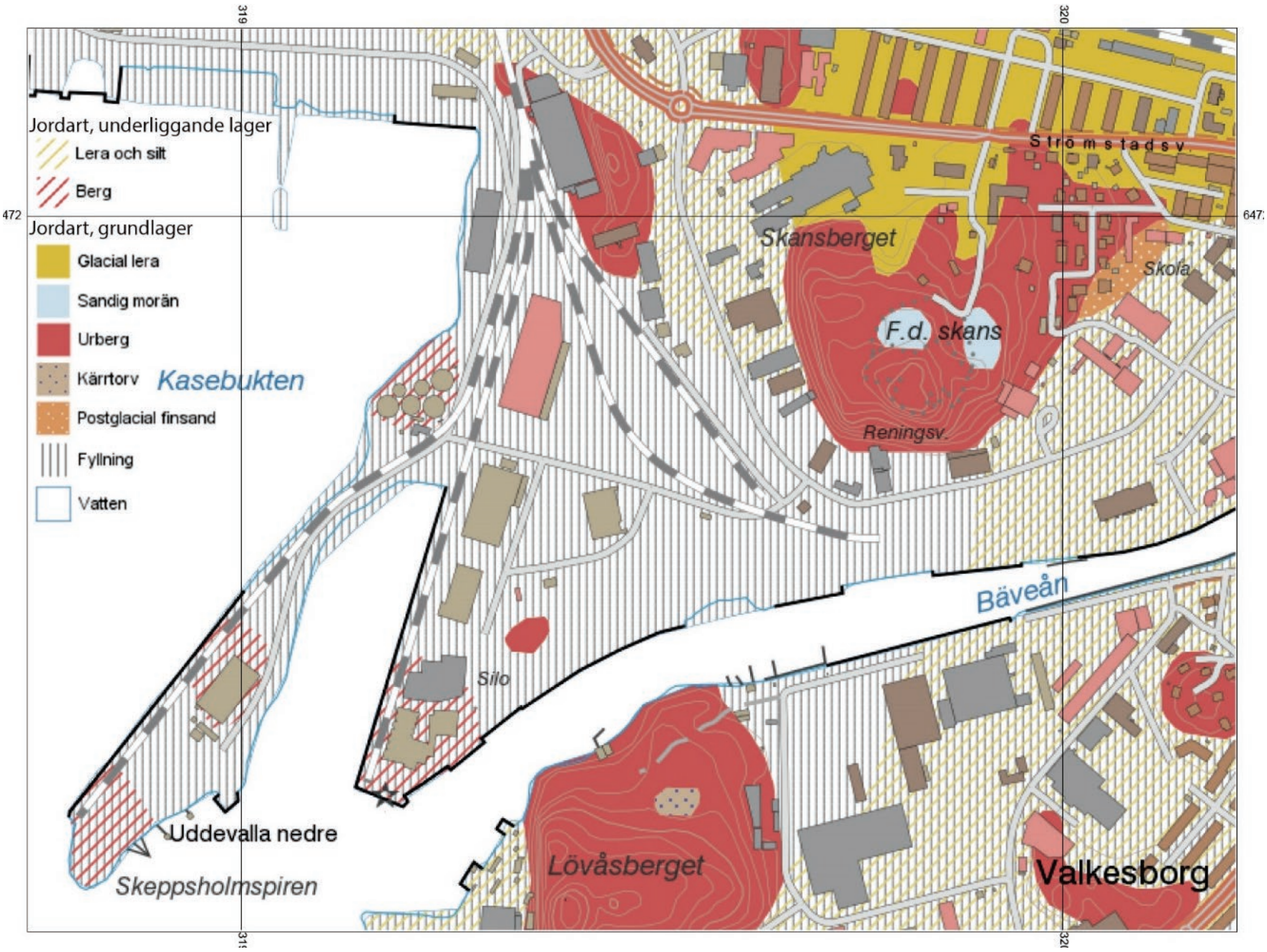


Figure 74: Map showing the soil composition of the site (Image: SGU).

Municipal development

Population growth

Uddevalla have grown with an average of 300 inhabitants each year since 2000. Between the years 1970-2000 there was stagnation as large employers like the shipyard, and later Volvo, left the city, but now the population is growing again. At the year of 2016, the population in Uddevalla is back the 1970's level (Aue, 1998; SCB, 2017).

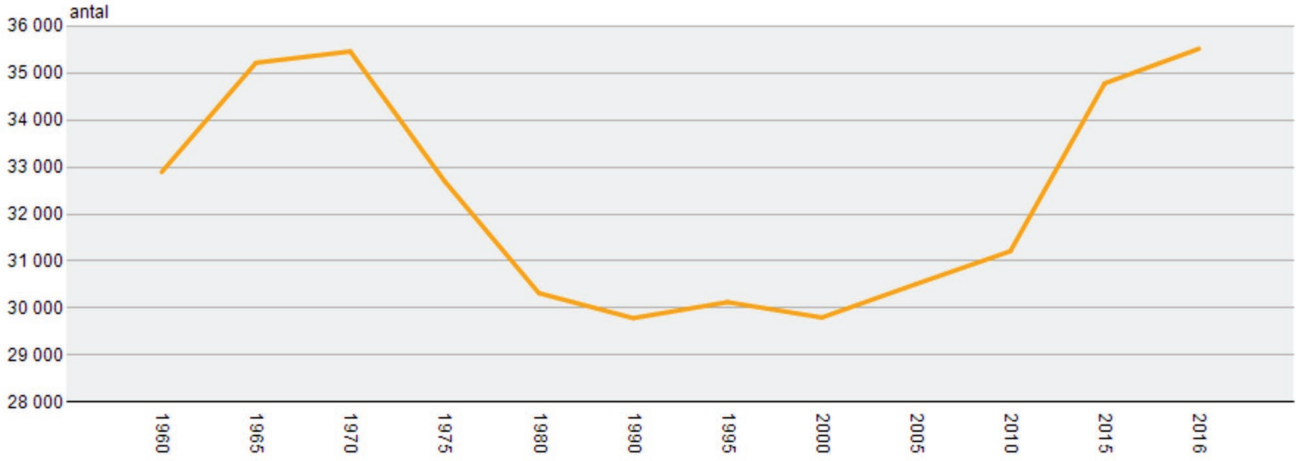


Figure 75: Diagram of the population growth in Uddevalla between 1960 and 2016. (Image: SCB)

Comprehensive plan

The municipality have a comprehensive plan issued in 2010 that works as a vision of how the municipality are going to be developed in a long-term perspective.

According to the comprehensive plan, the municipality has certain environmental objectives that say that all inhabitants and local businesses should contribute to reduce the overall environmental impact. One of the objectives is that the spatial planning should be implemented to ensure maximum environmental benefits and minimize the environmental impacts. Another objective is to reduce the number of unnecessary transports as much as possible, and the ones that are done should be carried out with a small environmental impact. The decreased amount of toxic substances and the remediation of contaminated soil is also one of the environmental objectives (Uddevalla, 2010).

The maritime activities and the marinas are an important part of the business community in Uddevalla, and according the comprehensive plan, Uddevalla will develop this part further to become a maritime centre (Uddevalla, 2010).

In-depth comprehensive plan

Except from the comprehensive plan, the municipality also has an in-depth comprehensive plan for the city of Uddevalla. At this time, in spring 2017, this plan is still under examination and has not yet been adopted by the municipality. According to this document, central Uddevalla is facing major challenges, and that the city centre needs to raise its attractiveness and highlight its unique features, such as its cultural heritage, relation to the sea, mountains, and proximity to the nature. It points out that housing is a prerequisite for a vibrant city centre and provides the basis for activities and businesses such as cafes, restaurants, shops, and cultural events. Also, in order to have a sustainable development, it is important that new development and densifications are using the existing infrastructure, such as municipal sewer systems, roads, walking and bicycle paths, and public transport, as far as possible. The municipality are stating that they are prepared to make plans that allows densification in the central parts of Uddevalla, and within a few years, large areas next to the water will be available through a change in land use (Uddevalla Kommun, 2016b).

The Housing program for the city of Uddevalla shows that there is an anticipated demand of around 120 new dwellings until the year of 2020, and that there should be a plan prepared for this (Uddevalla Kommun, 2016b).

The first version of the in-depth comprehensive plan for Uddevalla from 2016 marks the area of Bäve/Badö as a development area where 1000 dwellings can be built. Though, this development can only happen if the area is protected against floods (Uddevalla Kommun, 2016b).

In the public exhibition version of the in-depth comprehensive plan for Uddevalla from 2017 the number of dwellings that can be built in the area of Bäve/Badö has increased to 1500 dwellings (figure 77). The plan does not say in what period of time this development will happen, it only says that it will happen after the year of 2018 (Uddevalla Kommun, 2017).

Figure 76: Map from the first in depth comprehensive plan for Uddevalla where the site is marked as a development area (orange)

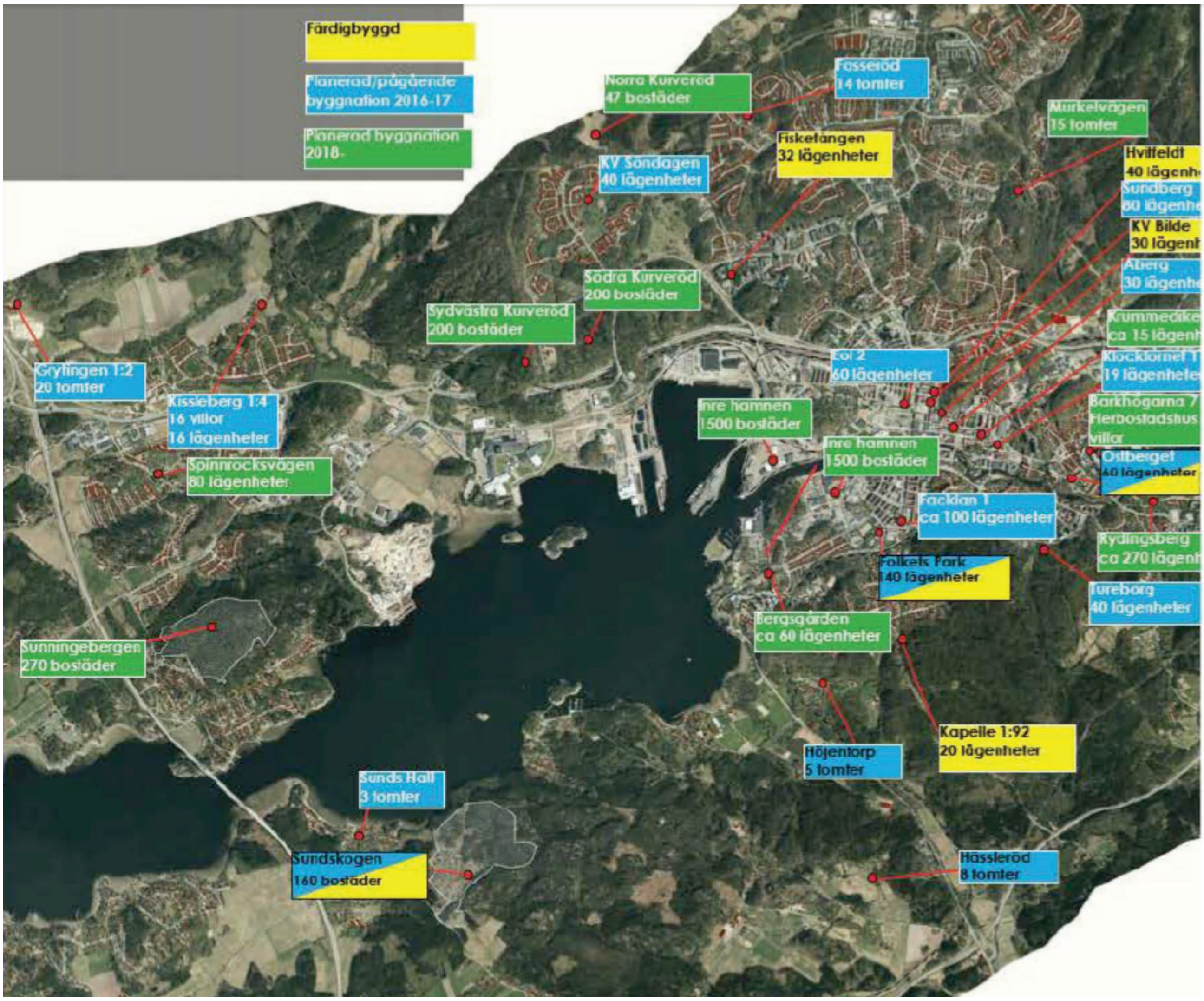


Figure 77: Map from the latest in-depth comprehensive plan from 2017 showing the housing development in Uddevalla. Yellow = Finished. Blue = Planned/on-going in 2016-2017. Green = Planned 2018 and onwards.

Relocation of the harbour

According to the in-depth comprehensive for the city of Uddevalla, the harbour is of national interest due to its importance for the Swedish and international trade. Due to the great interest from the city to develop the area it can create conflicts with other interests. The in-depth comprehensive plan also says that, if it is necessary, it's possible to relocate the harbour to, for instance, Sörvik and Fröland in the west. Though, this would require major investments in infrastructure to be able to meet the transportation demand (Uddevalla kommun, 2016).

According to the CEO of the harbour, Ulf Stenberg (personal communication, March 27, 2017), the harbour has considered the relocation of the harbour in their future plans, in about 25 years or so, and therefore the harbour adapts their investments according to that time perspective. The harbour defends their amount of land, meaning that for every square meter of land they let go to other uses, they want new land on another location to relocate to. According to Stenberg, the most important part of the harbour is the western part, the pier, because of the great crane capacity, and that part will be kept going for as long as possible.

Development program

The proposed development of the site will be based on various parameters, or strategies. The main strategy is how to use phytoremediation to solve the problem of the contamination of the site which is logical due to the purpose of the thesis. However, there are also other strategies that is considering local conditions, like how to handle the active harbour, the rising water levels, the historical values, and the connections to the surrounding areas. This section will explain the different strategies used in the development on a more schematic and conceptual way, and will then be followed by a design proposal.

Incremental transformation from harbour, to park, to housing

As mentioned earlier, the site is today an active industrial harbour that does not plan to shut down their business on site unless they get new land equal in size to relocate to. Though, the harbour knows that the municipality has the intention to transform the site into new uses in about 25 years, and a new harbour area is being built in Sörvik, about two kilometres west of the site. When talking about 25 years its mainly the western pier, *Skeppsholmspiren*. The other part of the harbour, with the silo buildings and the railways, could be released earlier, but only if the railways and other infrastructure are stretched to the new harbour area in Sörvik, which requires large investments.

The site is relatively large compared to the size of the city of Uddevalla. Even if Uddevalla's population is growing rather quickly, it is too large to develop all at once. It needs to be developed step by step meeting the contemporary demand for housing. As the land is "waiting to be developed" into housing or other activities, it can be used as a park with hyperaccumulator plants cleaning the soil until the land is built.

As long as the harbour and the industrial activities still are active, it has a safety distance surrounding it that needs to be taken into consideration, especially when building housing. The early phases of the development will mainly be park which does not require as large safety distances, and can be developed as the harbour still is active.

The development is proposed to be divided into two different phases with 15 years each. These two phases will be described in more detail in the design proposal.

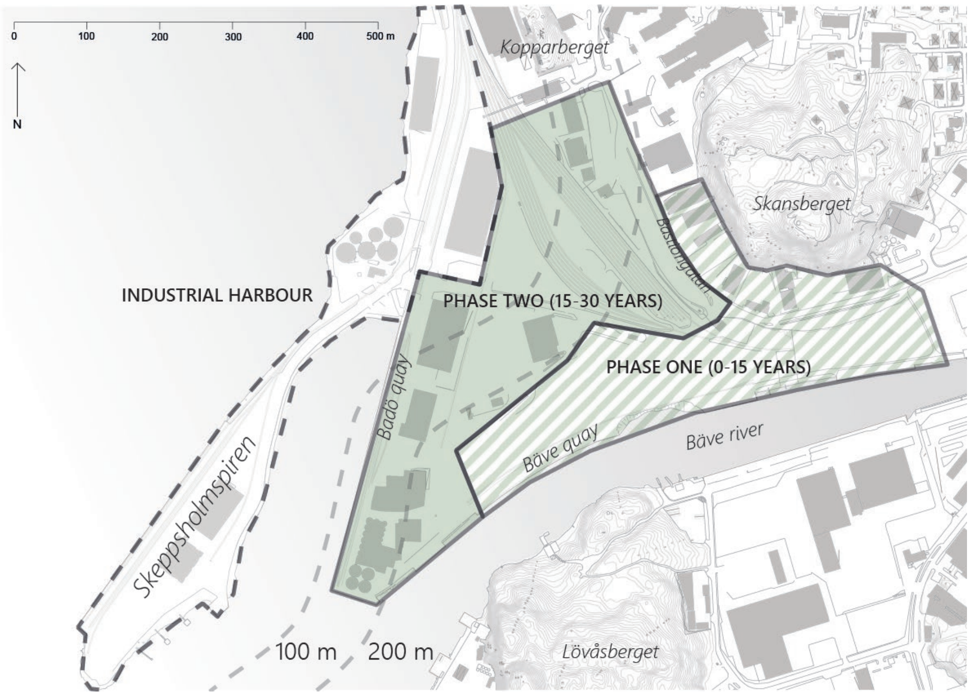


Figure 78: Map showing the incremental development and the distance from the industrial harbour Skeppsholmspiren.

Preservation of history

As presented in the site analysis, the site has very long industrial history. However, the site has changed a lot in recent decades due to the industrial activities that continuously develop their business. Though, some parts of the site that are considered valuable are proposed to be preserved in the future development, to give the site an identity connected to its past. The preserved historical features can be seen on the map below, and are followed by a brief description of each feature.

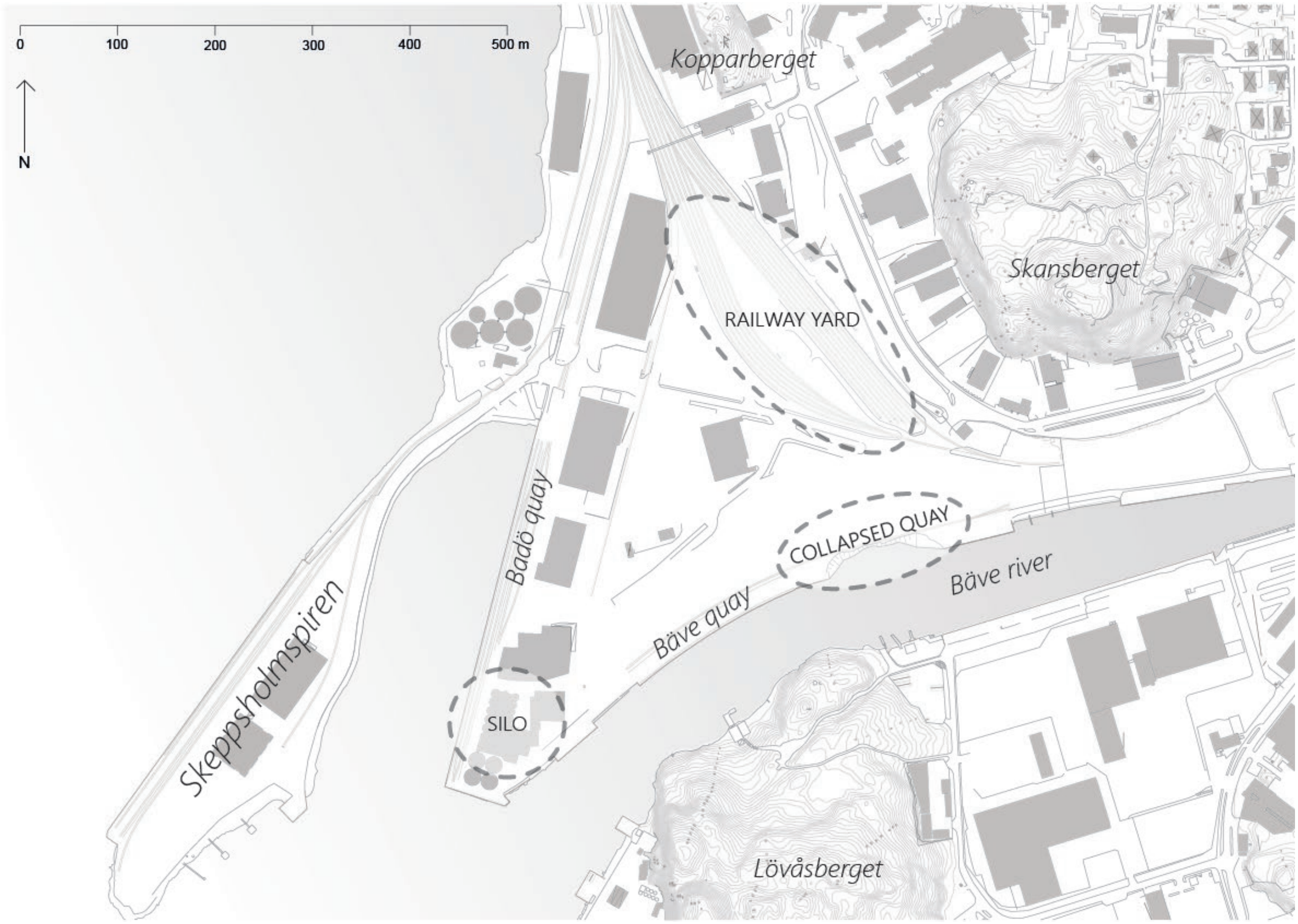


Figure 79: Map showing historical buildings and features to be preserved (marked with dashed lines).

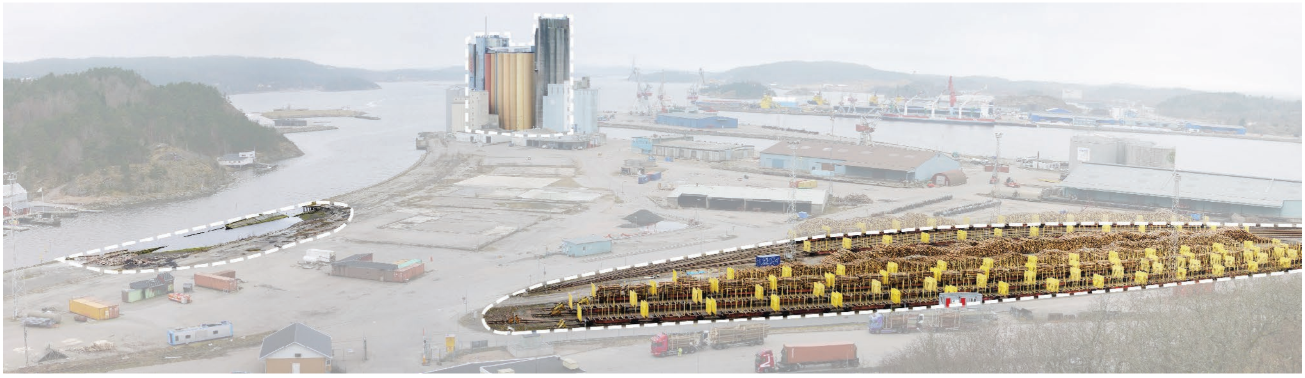


Figure 80: View over the site and the historical buildings and features to be preserved; the collapsed quay o the left, the railway yard to the right, and the silo in the back.

The railway yard

The railway yard covers a large area in the north-eastern part of the site. At most there are thirteen tracks in width, divided into two parts with six respectively seven tracks in each part with a loading area in between. This railway yard is proposed to be reused as a park with poplar trees planted along the tracks using hydraulic control to prevent the contaminants in the soil from leaking to the groundwater. The poplars create long alleys and some of the tracks will be used as pathways, by filling gravel between the tracks. A reference project to this idea is the Natur-park Schöneberger Südgelände in Berlin, where a railway yard is converted into a species-rich nature reserve with the industrial character still preserved.

Figure 81: Südgelände, Berlin.

Figure 82: The railway yard seen from south-east.

The silo

The silo which has a height of 82 metres and was built in the mid-1900s, is a big landmark at the site, especially when approaching Uddevalla from the sea. Reusing this building could be a very interesting feature in the area which gives it a clear industrial character and preservation of its history. Some years ago, the real estate company Uddevallahem made a proposal of how the silo could be used as a residential building.

Figure 83: The silo in 2017.

Figure 84: Uddevallahem's proposal for the silo (Image: Uddevallahem).

The collapsed quay

As mentioned earlier, a part of the quay collapsed in 2008 due to a heavy load of anthracite. This is an interesting historical feature that easily can be forgotten in a design by simply rebuilding the quay as it was. Instead, the new quay can be built around this area, thus breaking off the otherwise straight quay while preserving some of the history of the site.

Figure 85: The collapsed part of Bäve quay

Existing activities within the site

Except from the industrial harbour, there are no activities within the site that need to be relocated when developing the site. The activities that are preserved are located along Bastiongatan and in the proposed development this part will continue to be used for commercial purposes, due to the relatively high traffic flow on Bastiongatan. The existing buildings are in various conditions. Some of them can be considered in quite good condition and can therefore be further used in the near future. Though, some renovations may be needed. The different type of activities is rather mixed and consist of, for example; culture house, supermarket, animal clinic, art gallery, and gym. These activities can be considered appropriate and have a potential to be integrated in the future development of the site. In between these activities there are some empty plots which are potentially contaminated and may need to be remediated. In this proposal, the plots will be remediated with phytoremediation and can be developed as soon as they become clean.

Cleaning the soil

As presented on the map in figure 72, the site is contaminated with various kinds of metals and organic compounds. These contaminants are spread out almost on the entire site, and the concentrations can be different in various parts of the site. This creates a great complexity when using phytoremediation to sanitize the soil because the various parts requires different plants and techniques to achieve an effective treatment. Though this can also create a very interesting and aesthetical park because of the mix of different plants and trees.

Some parts can be too contaminated for the plants to be able to survive or it will simply take too long time for the plant to treat the soil. In these cases, other more traditional methods, like excavation, can be required to be able to clean the soil.

To know what kind of techniques and plants are the most favourable on each part, the site is mapped out, showing if it is metals or organic compounds in the soil, and the level of contamination. The level of contamination is divided into three levels; low, medium, and high. When the contamination level is low the soil is relatively clean and the treatment process is likely to take less time. The area can also be more open for the people to move freely within the area without exposure to contaminants. These parks are proposed to be designed to be similar to the wild nature with a lot of trees and vegetation. Parks in contemporary cities mainly consist of large lawns, some trees and paths made of asphalt or concrete, such landscapes can be seen as artificial and species-poor. Parks that are more similar to real nature brings the wildlife back and leads to a greater biodiversity (Grant, 2012).

The parts of the site that has a medium level of contamination are in most cases able to be treated by phytoremediation, though the process can take quite a long time depending on the concentration in the soil. The ground in these areas can in some cases not be directly accessible because the risk of exposure to contaminants, especially for children and animals who are more vulnerable to toxic substances. A solution to this can be elevated pathways crossing the areas.

An area that has a high level of contamination needs in some cases to be inaccessible for pedestrians and animals because the risk of exposure, for example by fencing. Also, if the contamination level in the soil is too high it may require another sanitation method than phytoremediation, because plants have a certain limit how much contaminants they are able to live in, degrade, or accumulate in their tissue. Since the areas with a high level of contamination are less accessible due to health risk, they can be used solely as energy forest for biomass production. An energy forest does not have as high recreational values due to the homogeneity compared to the parks with a mixed use of plants.

The time it takes to clean each zone can vary a lot. According to an estimation based on the contamination levels that can be found in each zone, it can take between 0-5 years for the green zones, 5-20 years for the yellow zones, and the red zones can take up to 20-30 years depending on the contamination level. To make a correct estimation of the time it takes to clean the soil, further investigations are necessary. This investigation should take into consideration all the aspects needed, like the concentration, depth and the type of substance, the local climate, and the growing time for the specific plant.

Figure 86: Bäve quay.

Movements and connections

To promote walking and bicycling, the site is going to be well connected to the city centre to the east, the train station to the north, and over a bridge to Anegrund to the south which the municipality has a vision to develop. All these connections are creating an intersection on the site next to the bridge, this intersection will be a node where potentially large flows of people will pass.

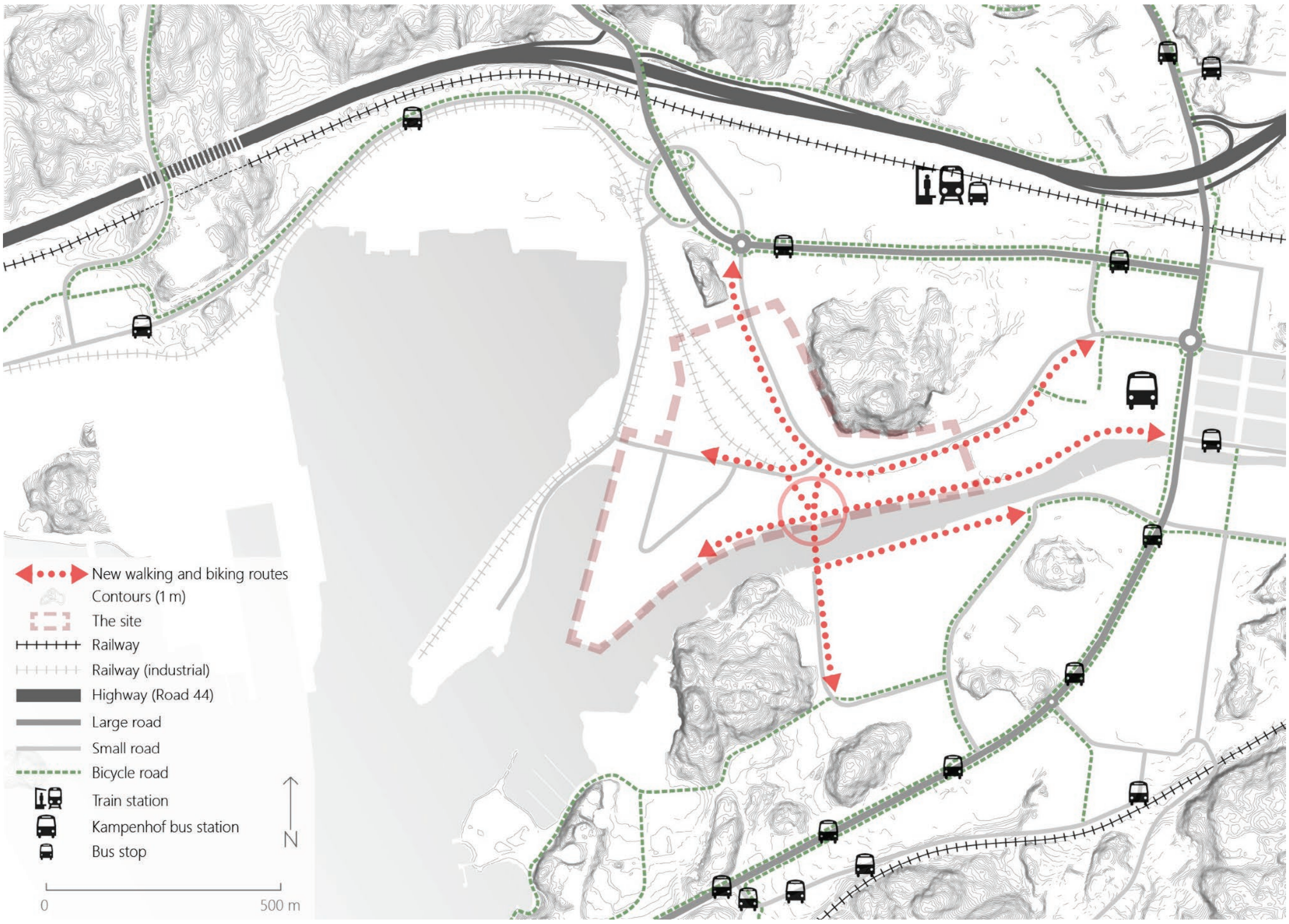


Figure 87: Map showing new walking and biking routes that will connect the site to the rest of the city. The red circle will become a node where many paths will meet.

Flood protection

As we could see in the analysis, the entire site is extremely flat and has a risk of flooding. Therefore, certain measures are necessary to be made to protect the site. Both against the regular high tides, that is on average 1,2 meters above normal sea level, but also against the risk of future, extreme floods, up to 2,5 meters above the normal sea level. A proper flood protection is a prerequisite to be able to develop the area in a long-term time perspective (WSP, 2016). Two different solutions are proposed. The first is to build a barrier covering the entire seafront, and the second is to relocate soil from one part to another to raise the ground level of the lowlands closest to the sea.

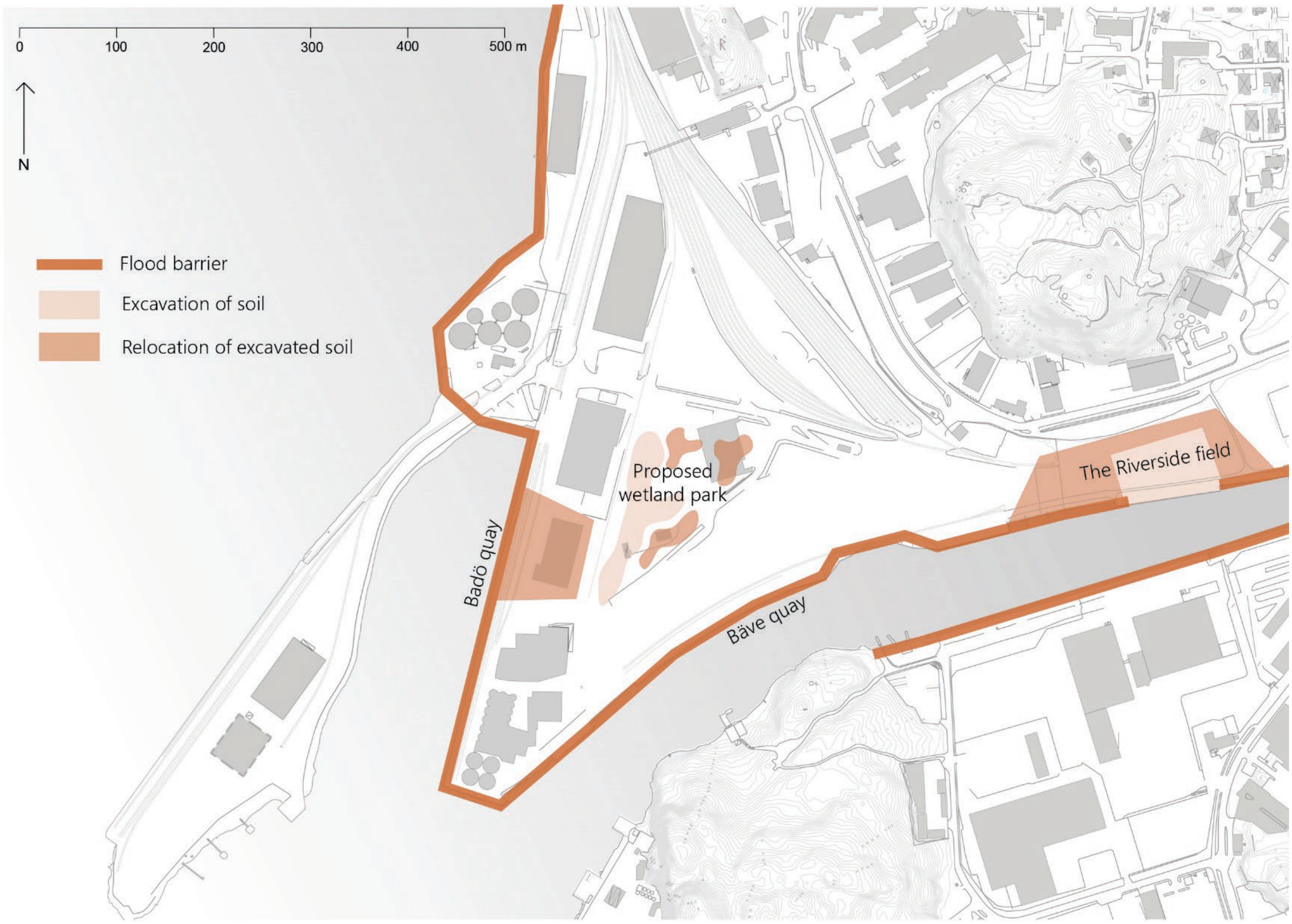


Figure 88: Map showing the proposed solution to protect the site against flooding.

Flood barrier

In this proposal, a flood barrier is built, stretching all the way from the Riverside field, along the Bäve and Badö quay, and across the harbour area. The ground on this stretch varies in terms of height, from about 1,4 meters above normal sea level up to about 2,5 meters which is the protection level required. This means that the height of the flood barrier varies depending on the ground level.

The section on next page shows the current situation of Bäve quay, and how the flood barrier could be designed along this stretch. The barrier consists of a half-meter high flood-wall which is built along the quay and can be used to sit on. To prevent the quay from being excluded from the rest of the area, there can be openings in the wall that can be closed during floods. During normal sea level, the quay will work as a walkway with a wooden promenade with possibilities to sit along the quay.

Bäve quay

Current situation

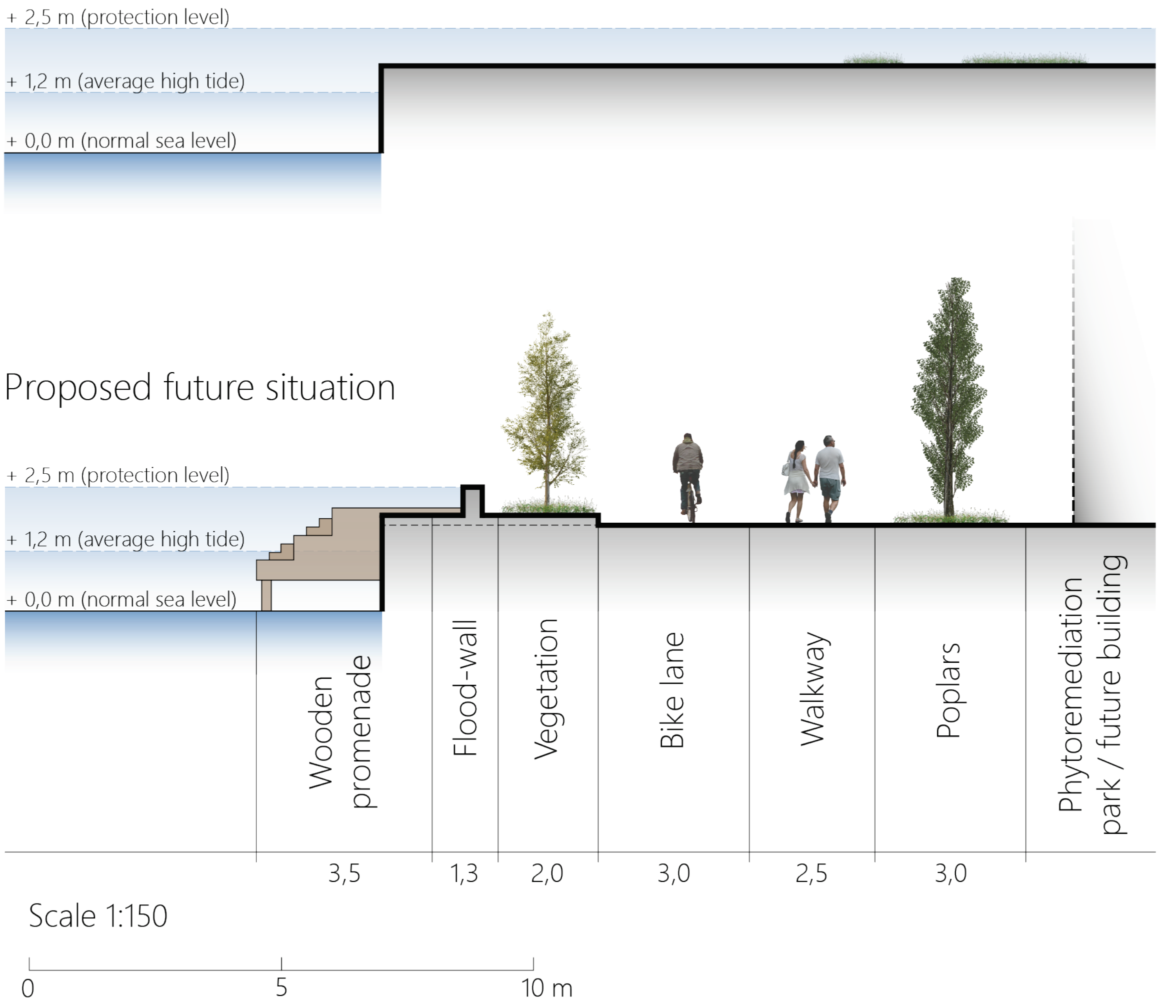


Figure 89: Section of Bäve quay showing the proposed flood barrier.

The Riverside field

Some parts of the site are very low-lying. Especially the Riverside field is a critical point which is located only about 0,7-0,8 meter above sea level. Instead of moving tons of soil from another location outside of the site to here, a solution could be to instead relocate soil within the site. Among the visionary plans done by the municipality, there is a plan to build a marina at this place, initiated by the company Promarina that already have an existing marina, but on the other side of Bäve river (Bohuslänningen, 2010).

When building a marina like this, vast amounts of soil has to be excavated. This soil could be reused on site to raise the ground level of the rest of the Riverside field along with other low-lying parts. Because the soil is contaminated with both heavy metals, organic compounds, and PAH, it has to be remediated. After the soil has been relocated, those parts will then turn into a phytoremediation park that remediates the soil until its clean and can be developed.

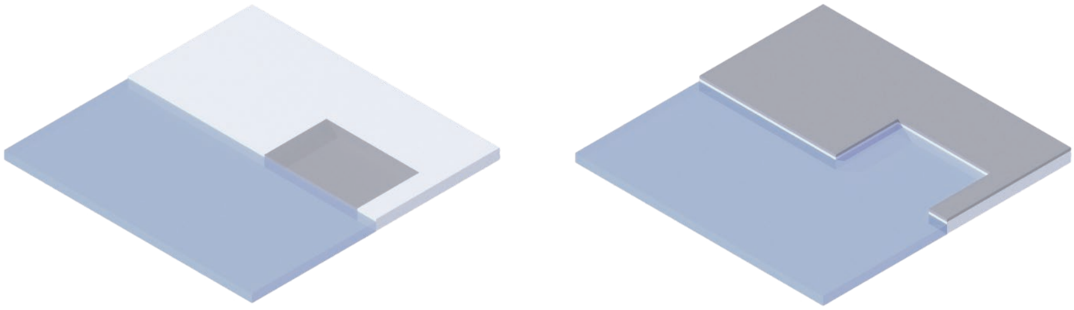


Figure 90: Relocation of soil to build a marina and raise the surrounding ground level at the Riverside field.

Wetland park

Another part that is extremely low-lying is the western/central part, marked as the wetland park on the map. At this location, the lowest point is about 0,5 meters above sea level, and it is regularly flooded. As presented in the analysis part, the ground next to the Badö quay is washed away and the building in the red zone on the map is resting only on its pillar foundation.

On this site, the proposal is to work basically with the same principle as the Riverside field, to relocate the soil from one point to another. The lowest parts will be excavated and the soil will be used primarily to reinforce the area closest to the Badö quay, creating a pond in the wetland. Around the wetland there will be a barrier that protects the surrounding area from being flooded. The wetland is not connected to the sea but can still be flooded since the groundwater level can rise as much as the sea level during flooding (Länsstyrelserna i Skåne och Blekinge län, 2008).

Where the proposed wetland park is located, the ground consists of many different contaminants, for example; chromium, lead, zinc, copper, PAH, PCB and organic compounds, some of which in high concentrations. These contaminants can be excavated and collected to create as an effective remediation process as possible, it can also create an interesting landscape with hills and valleys.

Figure 91: Section of the map in figure 88, showing the proposed wetland park.

Design proposal

The purpose of the design proposal is to test how phytoremediation could be integrated in an urban design project, in this case, the harbour Bäve/Badö in Uddevalla. The focus is mainly on the design of the different phytoremediation parks. The design of the different parks and the shape of the plots depends on the level of contamination and the preconditions of the plot. The built structure is supposed to be presented very abstract in this proposal. Both to have a clear focus on the method of phytoremediation, but also to have a flexible plan which allows the developer to determine the design of the buildings.

The proposal consists of two different phases, with a time-period of 15 years each. The reason for choosing this amount time is because of the estimated time it takes to clean the contaminated soil. Also, detailed development plans in Sweden has a maximum implementation time of 15 years. So, when the first phase of 15 years has passed, a new detailed development plan must be adapted to enable further development of the site.

Phase one – 0-15 years

The first development phase covers a relatively small and narrow area, from the Riverside field in the east, along the Bäve quay, to the silo buildings in south-west, together with some plots along Bastiongatan in the north. This part is already released from the harbour and is not used today, which allows for an immediate establishment, with the rest of the harbour still active.

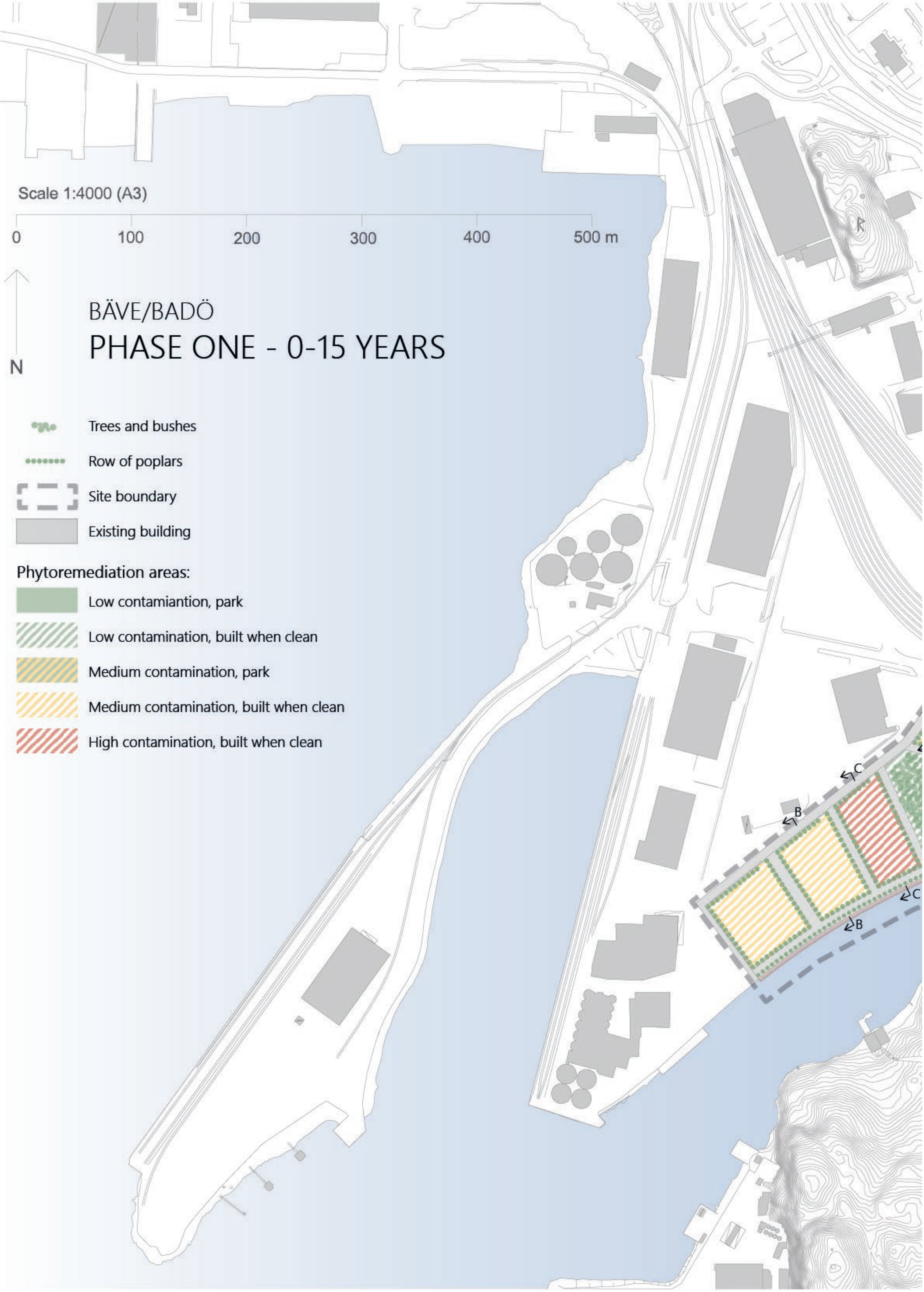
As mentioned in the development strategies, a marina will be built on the Riverside field, of which the soil that is excavated will be used to raise the ground level of the surrounding low-lying areas. The surrounding area will be cleaned with phytoremediation until built. Except from the marina, this development phase consists entirely of various types of remediating parks. The parks are divided into plots, and each of the plots can be built as soon as the phytoremediation process is finished.

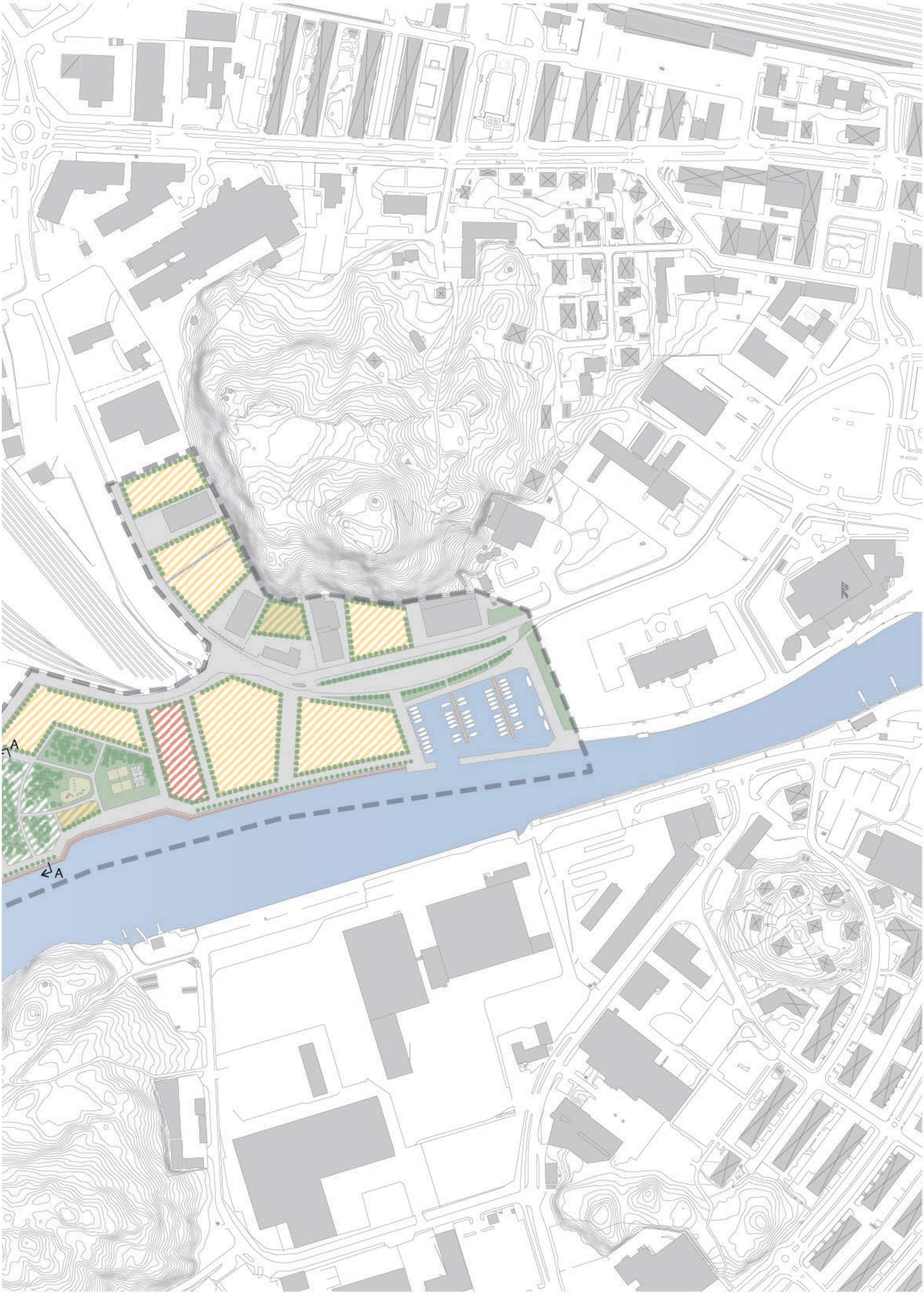
There are three different kind of parks based on the contamination level of the soil. These three types of parks are presented in the sections which also shows the different plants and techniques used in each park.

The park that has a low level of contamination will be a remediating forest park consisting of trees, bushes and other plants using degrading and stabilizing methods that do not require as much maintenance. The areas will be planted but then left for the nature to take over, creating a wild and natural green structure. These areas will also include some activities such as a playground and sport facilities, in front of the old collapsed part of the quay. This former collapsed part which is like a notch in the quayside, will be an amphitheatre with wooden steps where people can sit and enjoy the sun and the water in the south direction.

Parks with a medium level of contamination will be phytoremediation parks that is containing a mix of different plants that can be considered both effective in remediating, but also aesthetically pleasing to create an interesting and beautiful park. Since there is some risk that the levels of toxins in the soil could be a health hazard, precautionary measures will be used, such as elevated walkways that prevent people from getting into contact with potential contaminated soil and plants.

Areas with a high level of contamination which mostly consist of heavy metals, will mainly be used as energy forests with Salix using phytoextraction to take up the metals. The biomass will then be used for bioenergy which can give some economic benefits.


Scale 1:4000 (A3)
0
100
200
300
400
500 m
N
BÄVE/BADÖ
PHASE ONE - 0-15 YEARS
Trees and bushes
Row of poplars
Site boundary
Existing building
Phytoremediation areas:
Low contamiantion, park
Low contamination, built when clean
Medium contamination, park
Medium contamination, built when clean
High contamination, built when clean
C
B
C
B

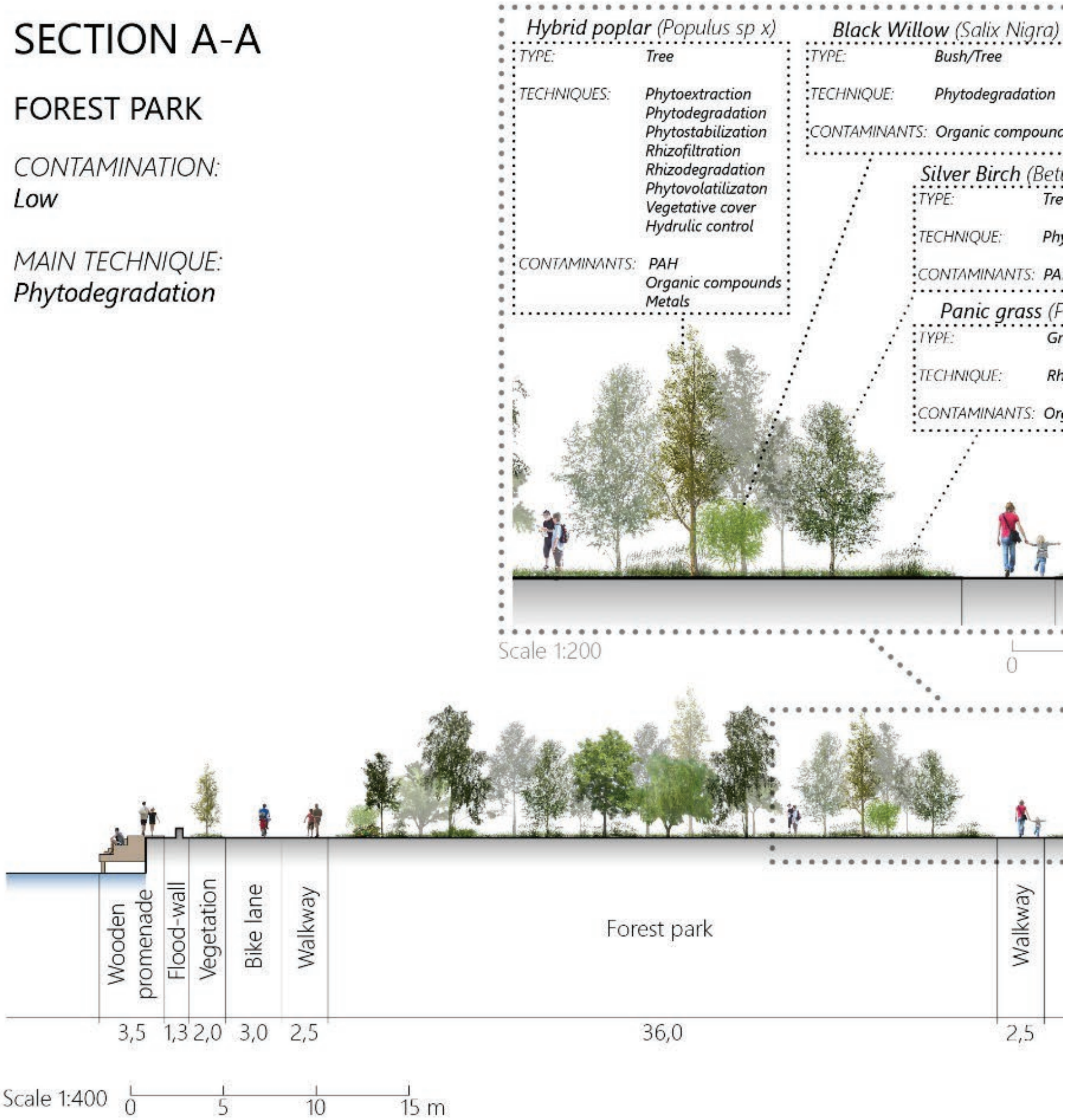

A
A

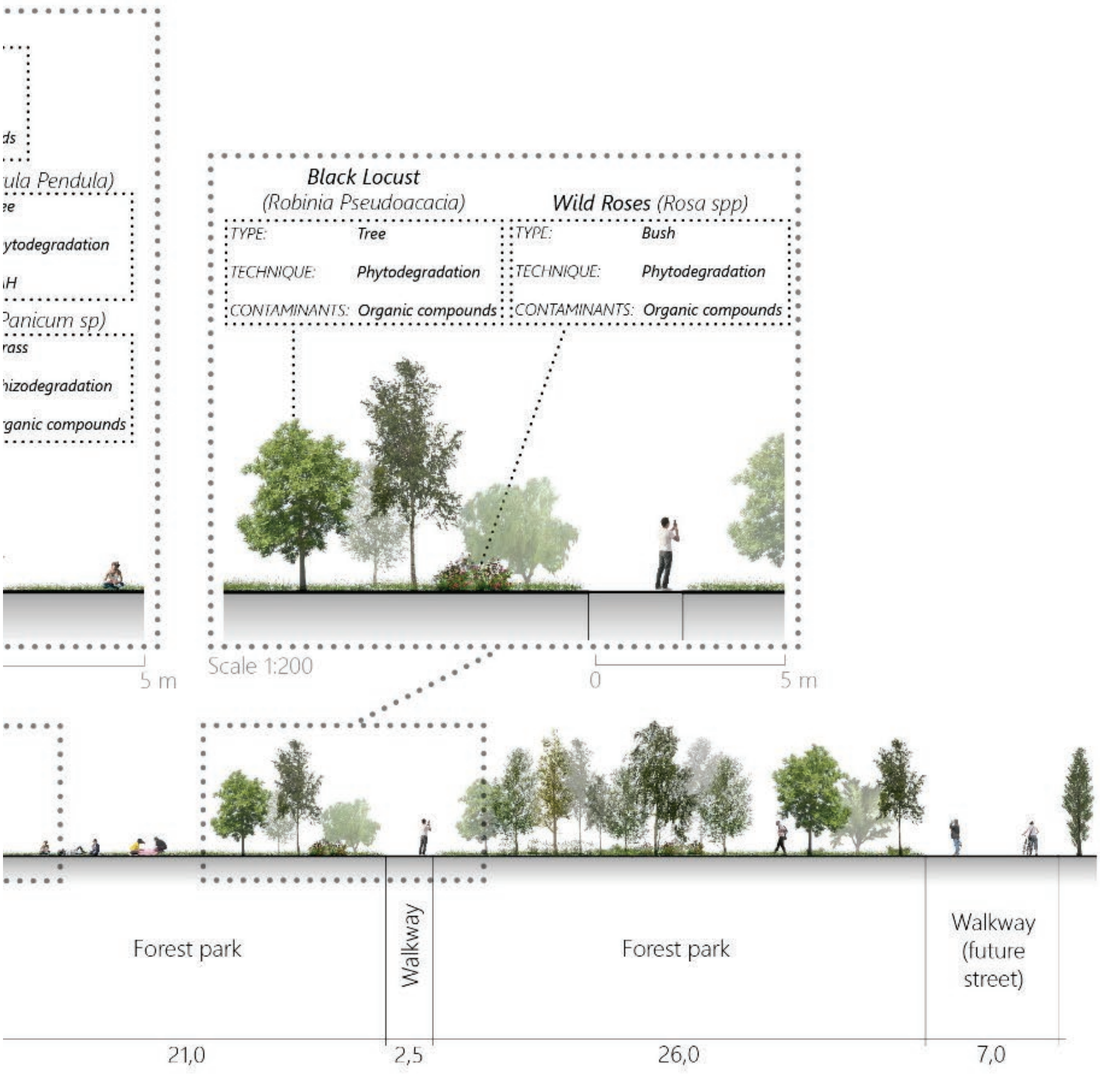
SECTION A-A

FOREST PARK

CONTAMINATION:
Low

MAIN TECHNIQUE:
Phytodegradation





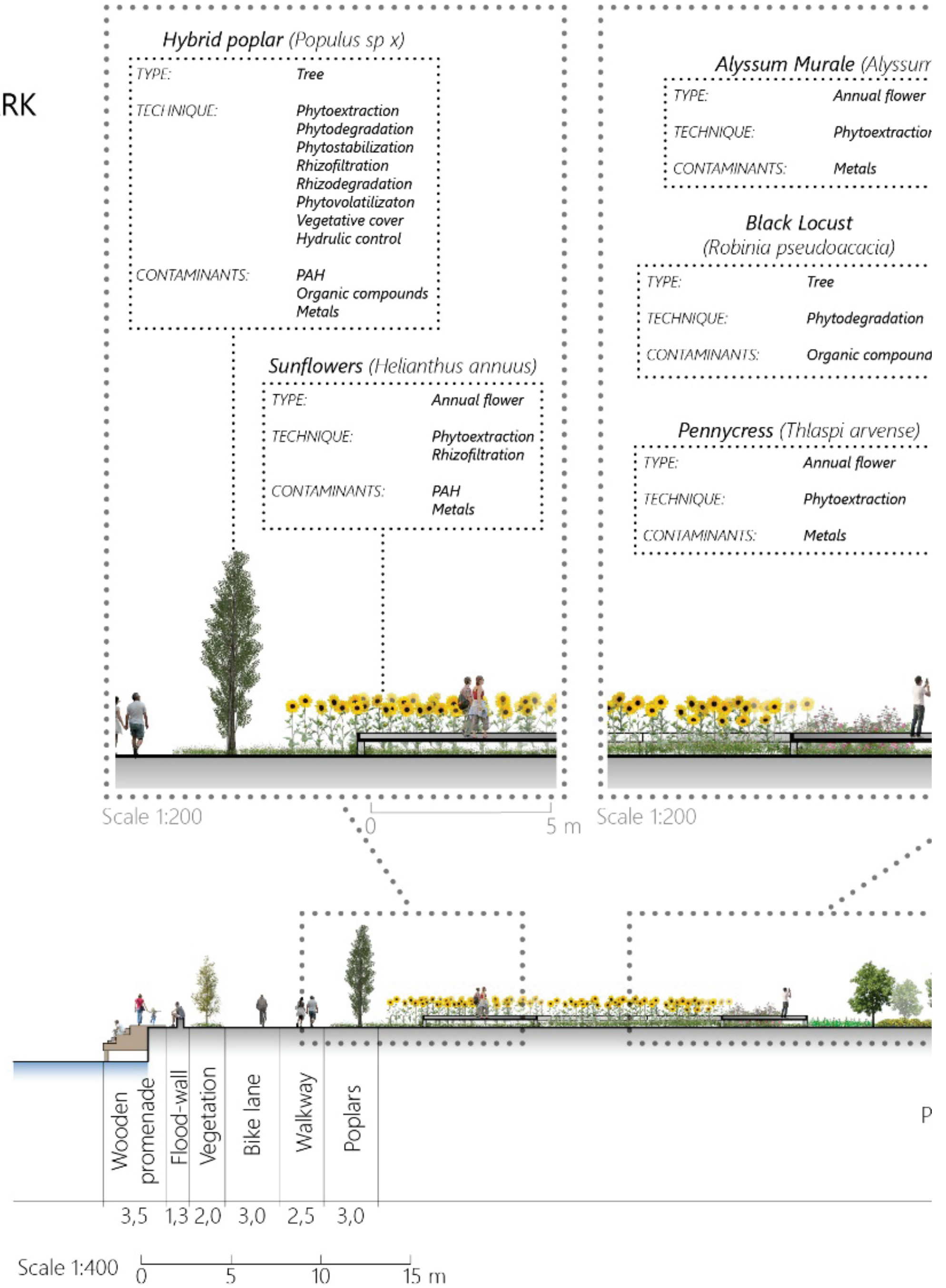
ds
ula Pendula)
ee
ytodegradation
H
Panicum sp)
rass
hizodegradation
ganic compounds
5 m
Black Locust
(Robinia Pseudoacacia)
TYPE: Tree
TECHNIQUE: Phytodegradation
CONTAMINANTS: Organic compounds
Wild Roses (Rosa spp)
TYPE: Bush
TECHNIQUE: Phytodegradation
CONTAMINANTS: Organic compounds
Scale 1:200
0
5 m
Forest park
Walkway
Forest park
Walkway (future street)
21,0
2,5
26,0
7,0

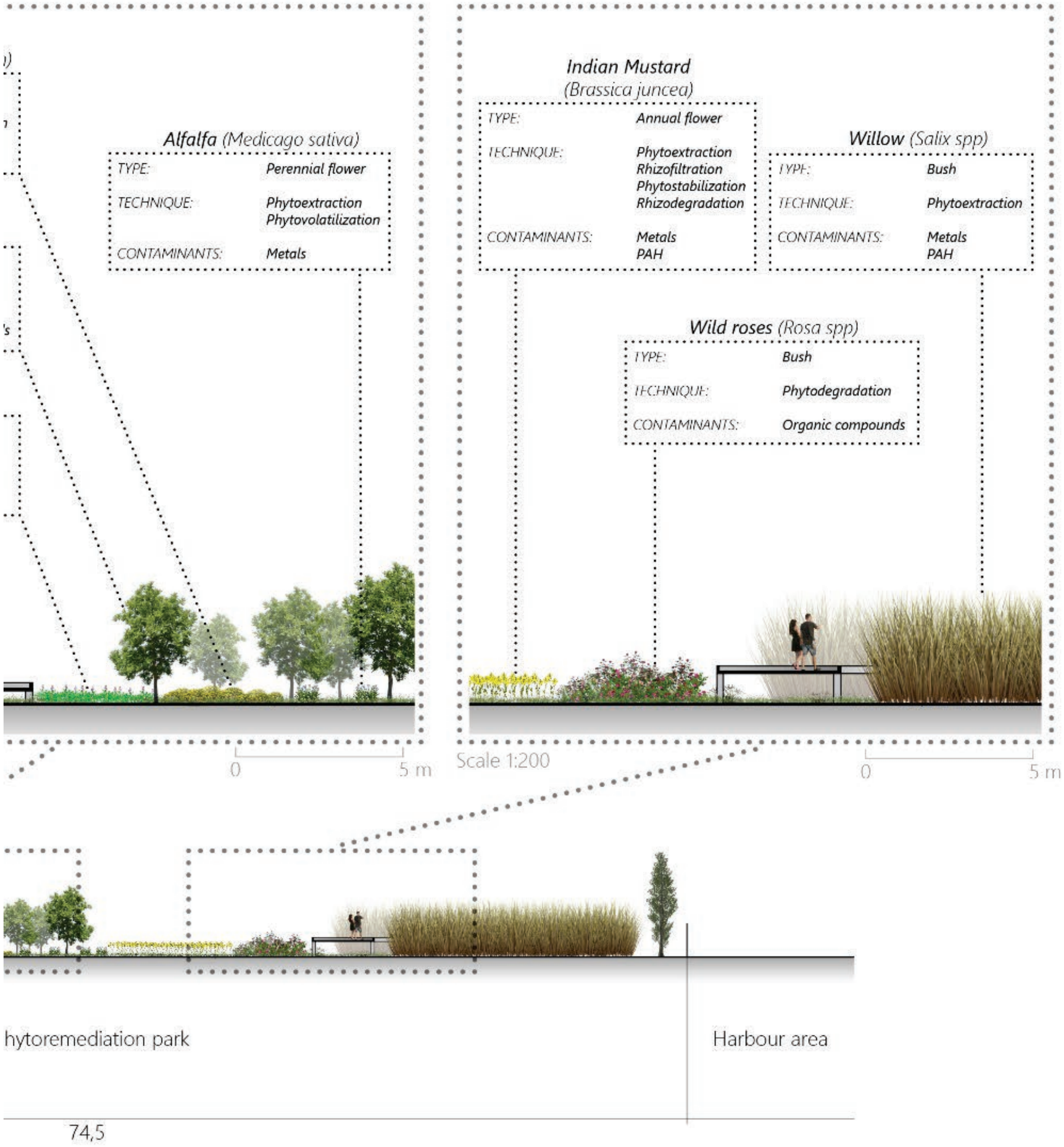
SECTION B-B

PHYTOREMEDIATION PARK

CONTAMINATION:
Medium

MAIN TECHNIQUE:
Phytoextraction



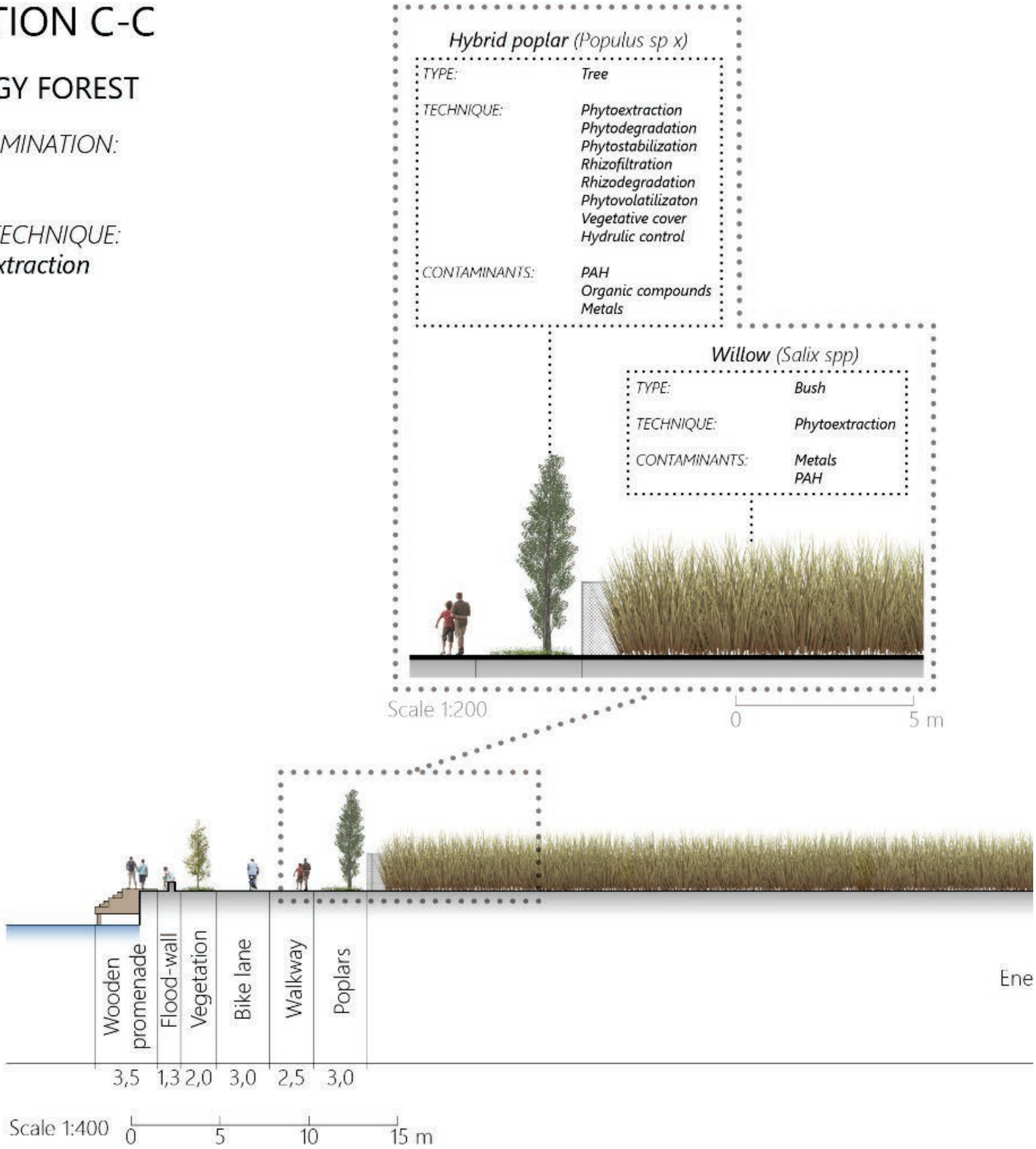

Alfalfa (Medicago sativa)
TYPE: Perennial flower
TECHNIQUE: Phytoextraction Phytovolatilization
CONTAMINANTS: Metals
Indian Mustard (Brassica juncea)
TYPE: Annual flower
TECHNIQUE: Phytoextraction Rhizofiltration Phytostabilization Rhizodegradation
CONTAMINANTS: Metals PAH
Willow (Salix spp)
TYPE: Bush
TECHNIQUE: Phytoextraction
CONTAMINANTS: Metals PAH
Wild roses (Rosa spp)
TYPE: Bush
TECHNIQUE: Phytodegradation
CONTAMINANTS: Organic compounds
0
5 m
Scale 1:200
0
5 m
hytoremediation park
Harbour area
74,5

SECTION C-C

ENERGY FOREST

CONTAMINATION:
High

MAIN TECHNIQUE:
Phytoextraction




rgy forest (inaccessible)
Poplars
Harbour area
82,2
3,0

Phase two – 15-30 years

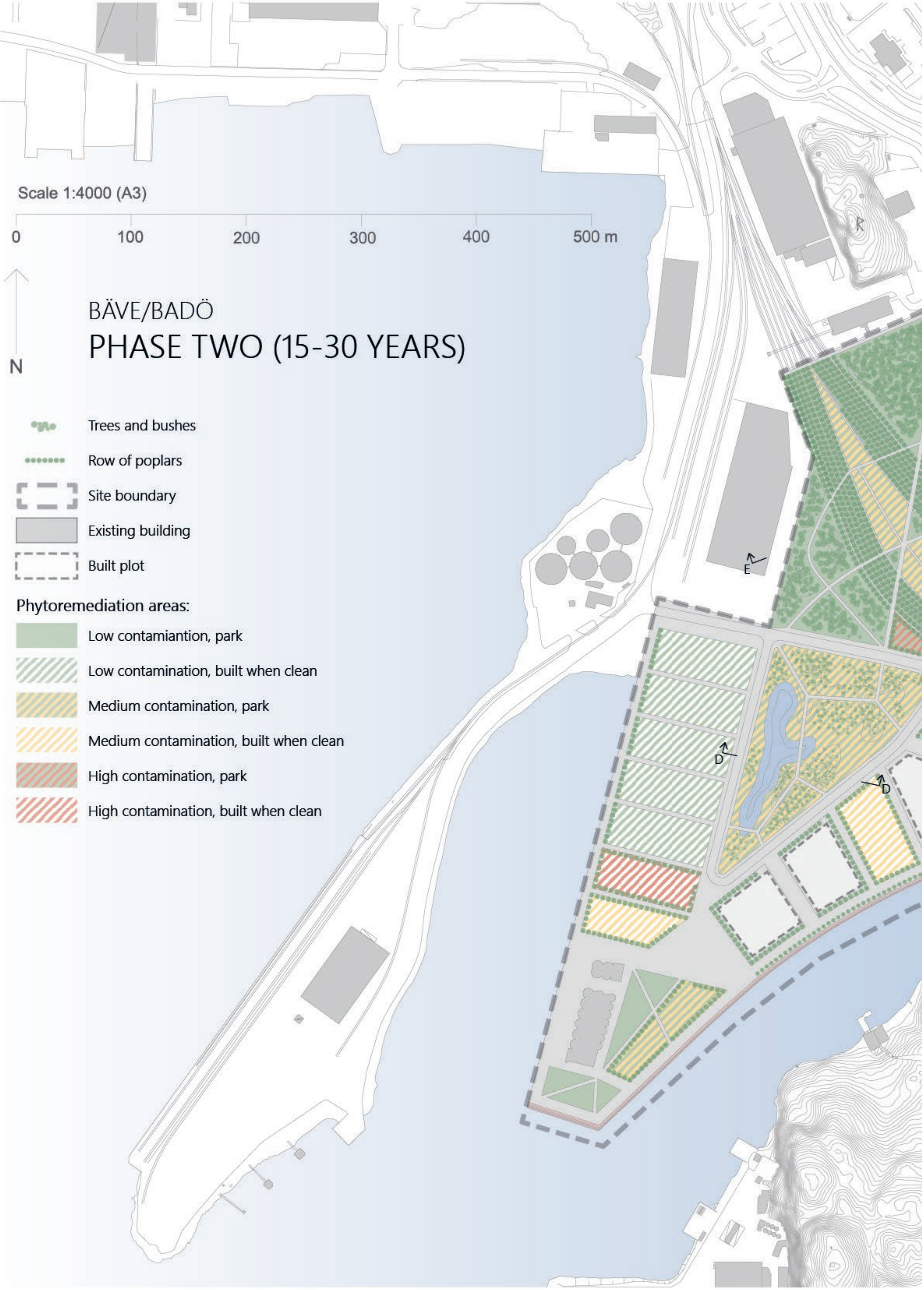
In the second development phase, it is assumed that the industrial harbour has been relocated, except from the part on the pier Skeppsholmspiren which still will be in use. Until now the plots with a low and a medium level of contamination should be clean and can be developed with housing, offices and services, if needed. Two different large parks will be developed during this phase, the wetland park, and the park covering the railway yard.

The place for the wetland park is today already very low-lying, and it will be further excavated and therefore have a slightly lower height than the rest of the area. Elevated walkways will allow pedestrians to get close and see the different phytoremediation plants found in the wetland, like sunflowers, water hyacinths, and duckweed. When the wetland is flooded during high water levels, the elevated walkways make the park still accessible.

The other park is located at the old railway yard. As mentioned in the program, poplars are planted along all the tracks to create a hydraulic barrier, while creating majestic alleys, reminds the visitors of the history of the site. In the pocket between the two railway yards, a space will be created, framed by the poplars, where there will be a phytoremediation park. The phytoremediation park will have a mix of different plants, both for aesthetical purposes, but also for pedagogical purposes, teaching the visitors about the techniques, and the recreational possibilities of phytoremediation. The railway yard will be surrounded by untamed forests with hyperaccumulator trees, and paths crossing them, creating interesting walks in close connection to the nature.

The municipality has a long-term vision to develop the area Anegrund, on the other side of Bäve river, with housing and offices. To connect to this area, a walking and cycling bridge is suggested to be built. This bridge should be able to be opened to allow boats to pass from the marina and the city centre, to the sea.

Some areas in the second development phase are relatively clean, for example the western part, along the Badö quay. The intention is to build on those plots as soon as the harbour has been relocated completely, and a demand to build occurs. Until then this part can be used as an energy forest to get economic benefits, while ensuring that the ground is clean when the construction starts.



Scale 1:4000 (A3)
0
100
200
300
400
500 m
N
BÄVE/BADÖ
PHASE TWO (15-30 YEARS)
Trees and bushes
Row of poplars
Site boundary
Existing building
Built plot
Phytoremediation areas:
Low contamiantion, park
Low contamination, built when clean
Medium contamination, park
Medium contamination, built when clean
High contamination, park
High contamination, built when clean
E
D
D

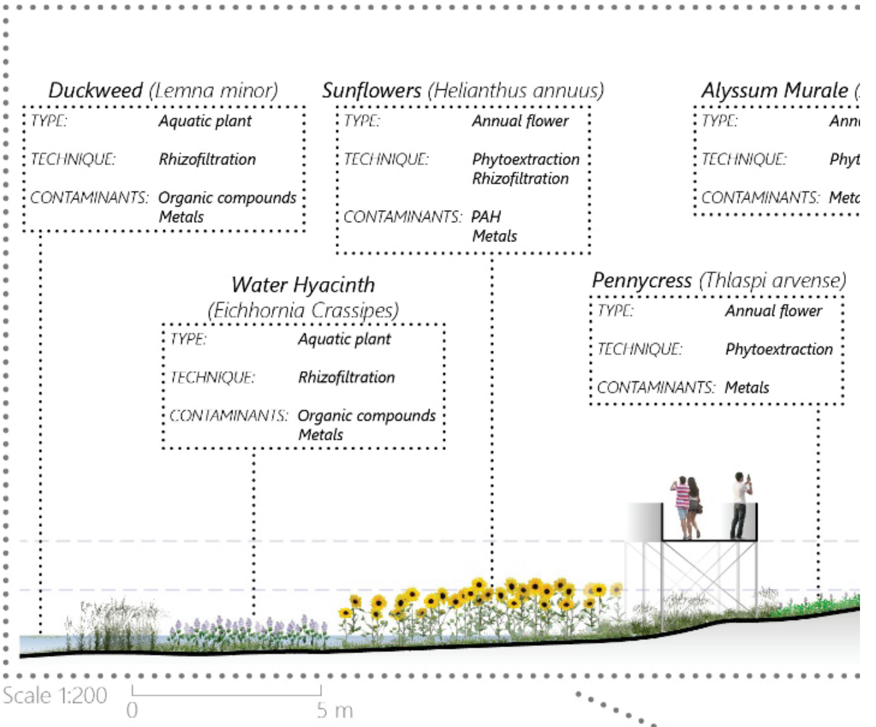

E
VISIONARY DEVELOPMENT
BY THE MUNICIPALITY

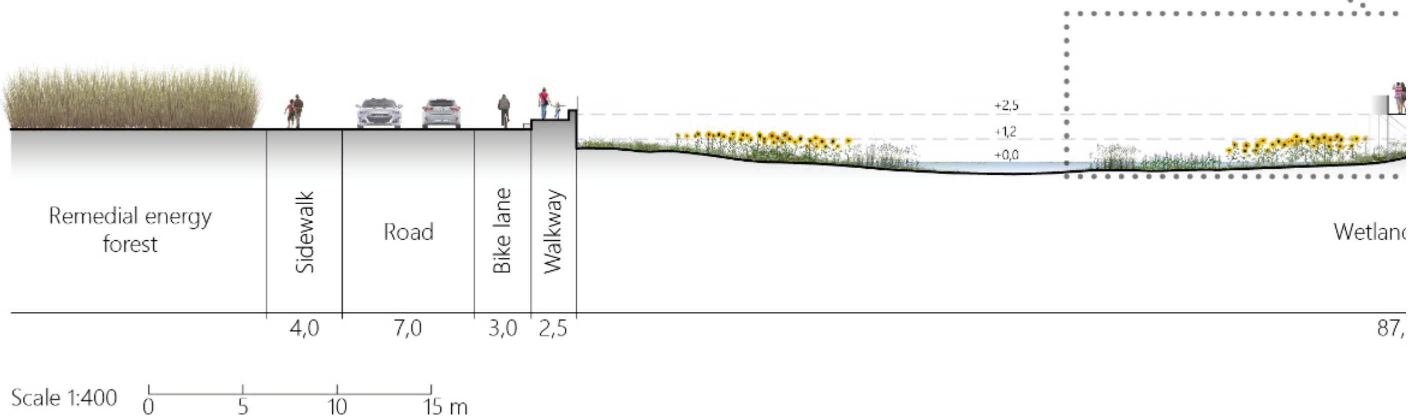
SECTION D-D

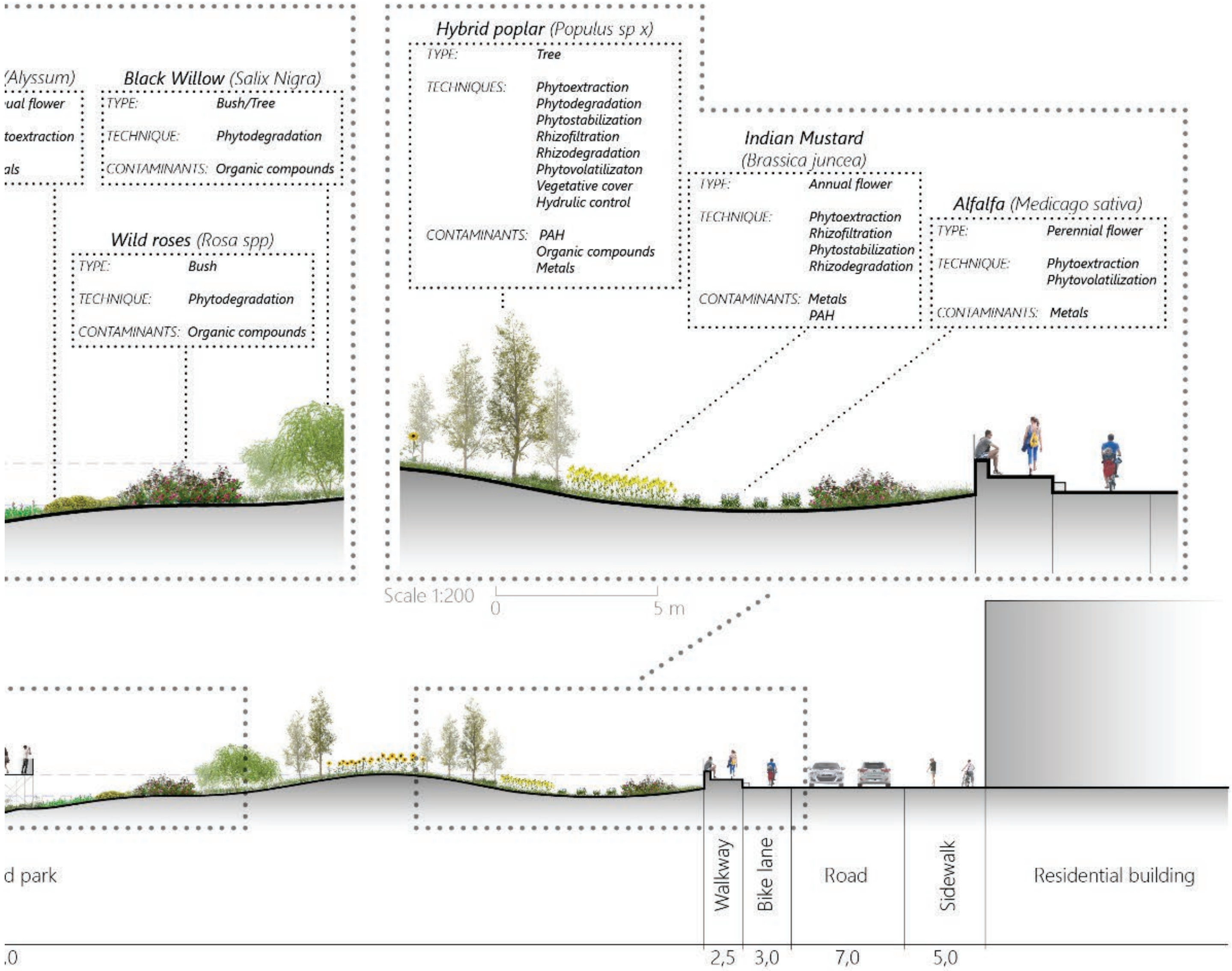
WETLAND PARK

CONTAMINATION:
Medium/High

MAIN TECHNIQUES:
Phytoextraction
Rhizofiltration

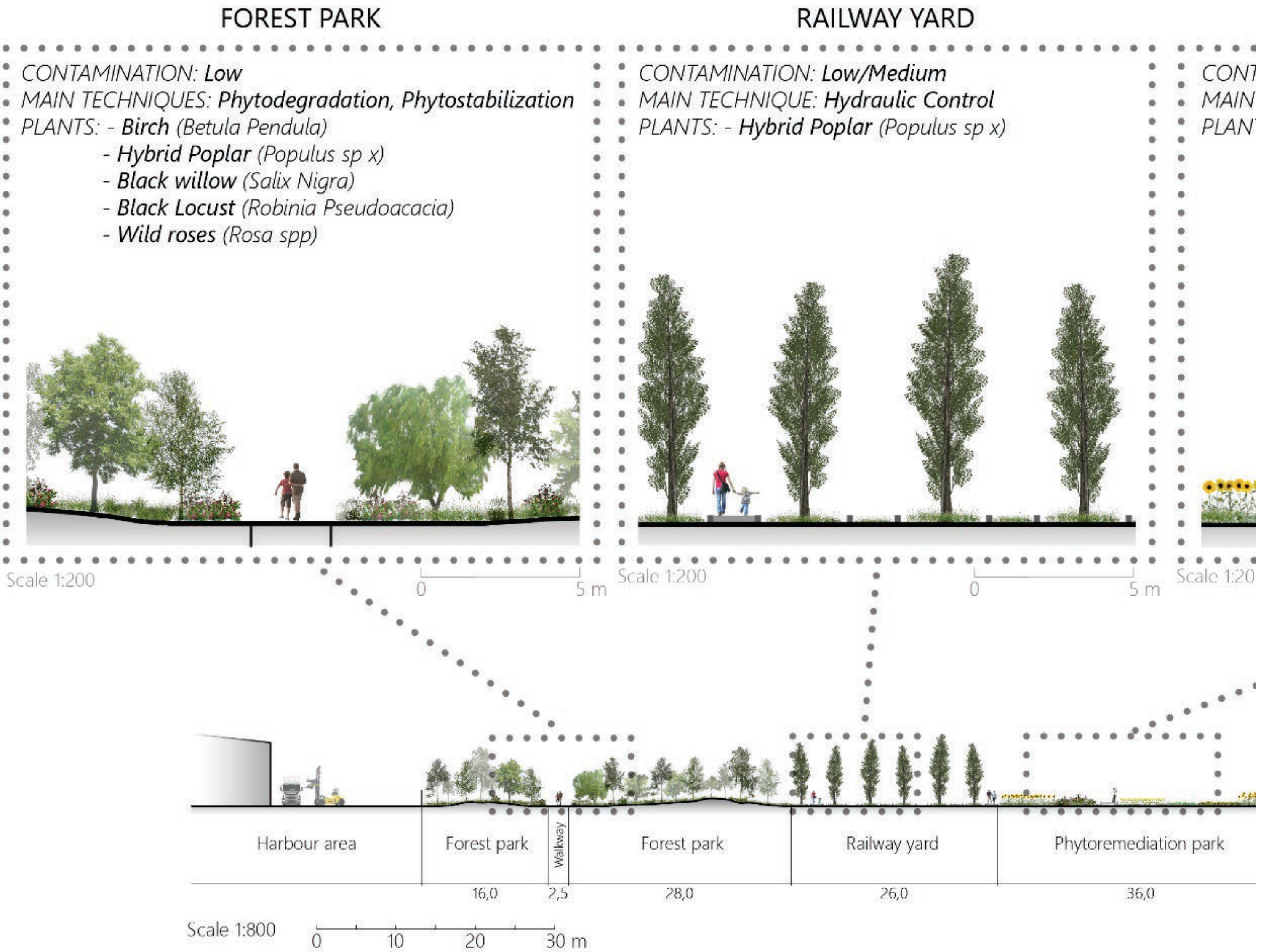






(Alyssum)
ual flower
toextraction
als
Black Willow (Salix Nigra)
TYPE: Bush/Tree
TECHNIQUE: Phytodegradation
CONTAMINANTS: Organic compounds
Wild roses (Rosa spp)
TYPE: Bush
TECHNIQUE: Phytodegradation
CONTAMINANTS: Organic compounds
Hybrid poplar (Populus sp x)
TYPE: Tree
TECHNIQUES: Phytoextraction Phytodegradation Phytostabilization Rhizofiltration Rhizodegradation Phytovolatilizaton Vegetative cover Hydrulic control
CONTAMINANTS: PAH Organic compounds Metals
Indian Mustard (Brassica juncea)
TYPE: Annual flower
TECHNIQUE: Phytoextraction Rhizofiltration Phytostabilization Rhizodegradation
CONTAMINANTS: Metals PAH
Alfalfa (Medicago sativa)
TYPE: Perennial flower
TECHNIQUE: Phytoextraction Phytovolatilization
CONTAMINANTS: Metals
Scale 1:200
0
5 m
d park
Walkway
Bike lane
Road
Sidewalk
Residential building
,0
2,5
3,0
7,0
5,0

SECTION E-E


FOREST PARK
CONTAMINATION: Low
MAIN TECHNIQUES: Phytodegradation, Phytostabilization
PLANTS: - Birch (Betula Pendula)
- Hybrid Poplar (Populus sp x)
- Black willow (Salix Nigra)
- Black Locust (Robinia Pseudoacacia)
- Wild roses (Rosa spp)
Scale 1:200
0
5 m
RAILWAY YARD
CONTAMINATION: Low/Medium
MAIN TECHNIQUE: Hydraulic Control
PLANTS: - Hybrid Poplar (Populus sp x)
Scale 1:200
0
5 m
Harbour area
Forest park
Walkway
Forest park
Railway yard
Phytoremediation park
16,0
2,5
28,0
26,0
36,0
Scale 1:800
0
10
20
30 m

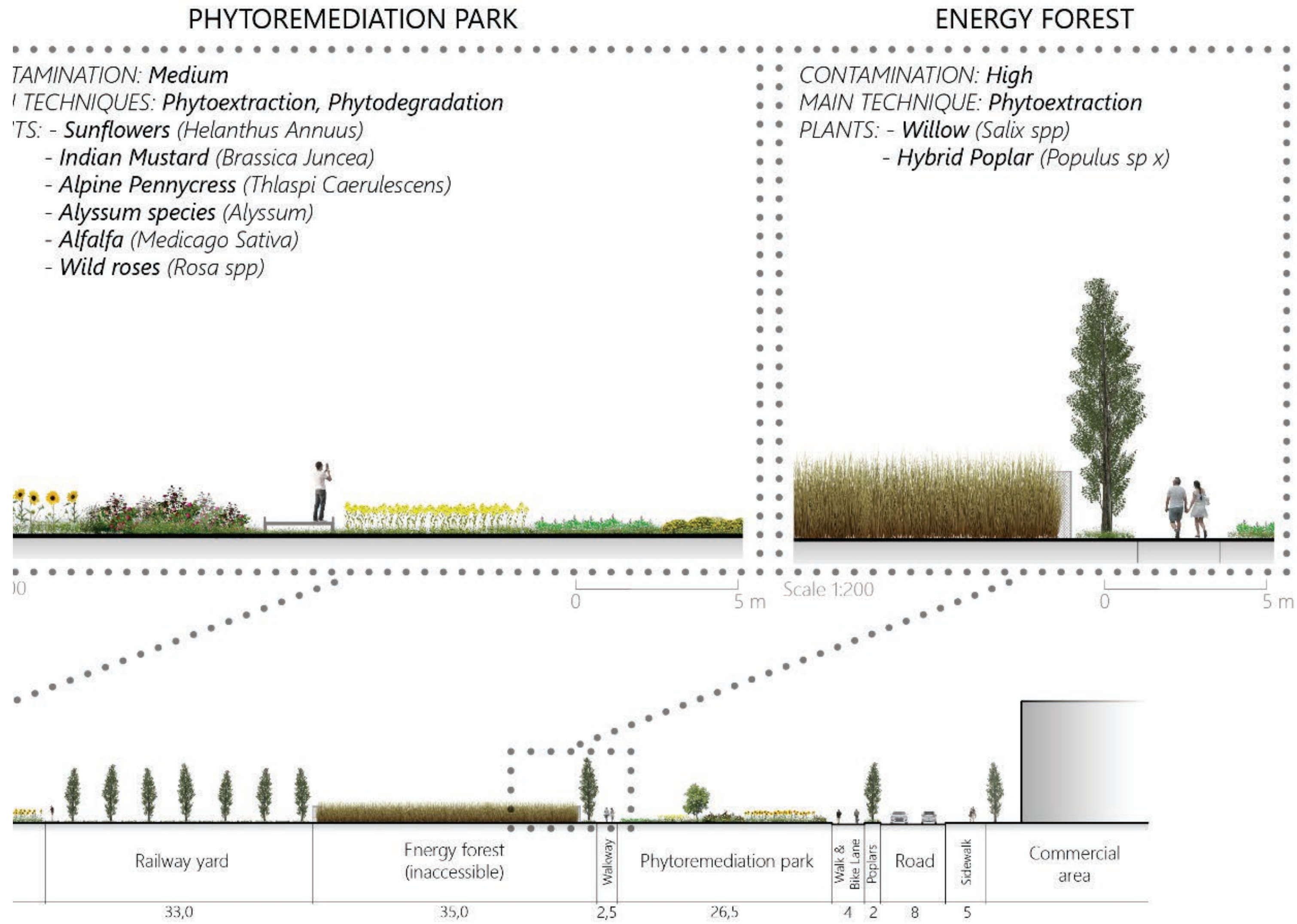

PHYTOREMEDIATION PARK
TAMINATION: Medium
TECHNIQUES: Phytoextraction, Phytodegradation
TS: - Sunflowers (Helanthus Annuus)
- Indian Mustard (Brassica Juncea)
- Alpine Pennycress (Thlaspi Caerulescens)
- Alyssum species (Alyssum)
- Alfalfa (Medicago Sativa)
- Wild roses (Rosa spp)
0
5 m
ENERGY FOREST
CONTAMINATION: High
MAIN TECHNIQUE: Phytoextraction
PLANTS: - Willow (Salix spp)
- Hybrid Poplar (Populus sp x)
Scale 1:200
0
5 m
Railway yard
33,0
Energy forest (inaccessible)
35,0
Walkway
2,5
Phytoremediation park
26,5
Walk & Bike Lane
4
Poplars
2
Road
8
Sidewalk
5
Commercial area

Figure 92: Illustration of a phytoremediation park

Figure 93: Illustration of Bäve quay by the former collapsed part.

Figure 94: Illustration of the wetland park

Figure 95: Illustration of the railway yard

Economic comparison with excavation

To make an economic comparison between using phytoremediation and excavation to remediate the site, the same assumptions as presented in the theoretical framework will be used. However, there are many uncertainties when trying to make a calculation of the cost. This will only be a rough estimation to get an indication of the cost difference between the two methods.

The calculation of the cost for excavation is based on the scenario that the plots with a medium level, and a high level of contamination will be remediated ($1 600 000/ha). The calculation of the cost for using phytoremediation is based on the scenario that the plots with a low level of contamination, phyto-stabilization will be used ($60 000/ha), on the parts with medium level, phytoextraction will be used for 10 years ($279 000/ha), and the parts with a high level, phytoextraction will be used for 20 years ($416 000/ha).

Excavation and off-site disposal on landfills

- Parts with medium level (7 hectares): $11 200 000 (89 600 000 SEK)
- Parts with high level (1,5 hectares): $2 400 000 (19 200 000 SEK)
- Total cost: $13 600 000 (108 800 000 SEK)

Phytoremediation

- Parts with low level (7,3 hectares): $440 000 (3 500 000 SEK)
- Parts with medium level (7 hectares): $1 950 000 (15 600 000 SEK)
- Parts with high level (1,5 hectares): $620 000 (5 000 000 SEK)
- Excavation of wetland park (1 ha, -1 m) $150 000 (1 200 000 SEK)
- Total cost: $3 160 000 (25 300 000 SEK)

According to these calculations based on the assumptions made by Cunningham and Berti (2000), using on-site phytoremediation could save over ten million dollars (83 million SEK), or about 77 % compared to using excavation and off-site disposal on landfills.

This calculation is based on either using one method or the other. But of course, excavation and phytoremediation can be combined as remediation methods, depending on the prevailing situation. Different methods can also be used during different development phases. For example, phytoremediation can be used first, to reduce the spread and the degree of the contamination, before an excavation.

5. Conclusion and reflections

The aim of this thesis has been to explore how phytoremediation can be integrated in a brownfield development. This approach was then tested through an urban design proposal for the industrial harbour of Bäve/Badö in Uddevalla.

Following this aim, the study tries to answer the following questions:

- *When, and in what scale should phytoremediation be integrated in the planning process?*
- *How is phytoremediation balanced with other aspects such as historical values, existing activities, and climate change?*
- *How can different phytoremediation techniques be used to develop specific spatial qualities?*

Answers to the questions

When, and in what scale should phytoremediation be integrated in the planning process?

Due to the potentially very long remediation time for plants, phytoremediation should be integrated as early as possible in the planning process. The greater the margins you work within, the greater the potential of using phytoremediation to clean the area.

The municipal comprehensive plan is an appropriate tool to present contaminated areas and how they should be addressed in the long term. To achieve a sustainable development, the municipal comprehensive plan should include concrete strategies on how to initiate the remediation process of contaminated areas at an early stage. The comprehensive plan may also specify that phytoremediation should be considered when choosing remediation method, both to reduce the remediation cost but also to reduce the environmental impact.

How is phytoremediation balanced with other aspects such as historical values, existing activities, and climate change?

Contaminated areas are in many cases old industrial areas. These areas can still have some structures left within the area, such as buildings. These structures could be combined with phytoremediation to create a park with an industrial character. Preserving these structures can give the site a stronger historical identity while being remediated by the plants.

However, not all contaminated sites are abandoned. Some sites which is intended to be developed may still be fully, or partially, active, like the harbour in Bäve/Badö. In these situations, phytoremediation can still be used on some parts while the site is still active. Though, it is important with a close communication between the actors to be able to find common objectives.

Industrial areas are often located by the sea due to logistical reasons. The proximity to the sea makes the site vulnerable to future floods. A park is not as sensitive to floods as buildings, so during the phytoremediation process, the park can be temporarily flooded until the area becomes clean and built-up, then other flood solutions must be made. Phytoremediation can also reduce the environmental impact through the provision of ecosystem services and a reduced number of transports due to the on-site treatment.

How can different phytoremediation techniques be used to develop specific spatial qualities?

The design proposal gives examples of different spatial qualities that phytoremediation can provide. Plants that have the ability to clean soil varies between trees, bushes, flowers, and grasses. This variation can potentially create beautiful and interesting environments which gives recreational values to the site. A long remediation process can be used as a strength, especially when planning the green structure in an area. For example; growing trees takes a lot of time, and when planting them in an early stage you have the possibility to have large trees already in place when the construction of the buildings starts.

The method can both create recreational qualities, but also economic benefits. Not only because it is cheaper than excavation, but also that some of the plants, like willow and poplars, can be used as bioenergy when harvested.

Reflections

Contaminated soil is a big problem for many cities which has been characterized by the urbanisation and industrialisation during the last centuries. The remediation of contaminated areas is mostly done through excavation and off-site disposal on landfills, which can be very expensive and harmful for the environment with a lot of transportation.

The research of using phytoremediation as an alternative, more sustainable way of remediating contaminated areas has been growing during the last decades. Though the research is still quite undeveloped in Sweden, especially on how to integrate the method within the field of spatial planning, and how to take advantage of the natural values created during the remediation process. For example, by using the area for recreational purposes, like a park, until the area is remediated and can be developed.

To be able to use the fully potential of phytoremediation and to make the remediation process as effective as possible, a lot of knowledge about the method and the different techniques is required along with a deep knowledge about the conditions of the site. In many cases, contaminated sites have a mix of many different toxic substances which can make the remediation complicated, and the harbour area Bäve/Badö is an example of such an area.

Restoration of nature

Many contaminated sites are left abandoned and undeveloped because of the estimated high cost to remediate the soil, which can make the development unprofitable. Instead of just leaving the site to decay, hyperaccumulator plants which are cheaper and that does not require as much maintenance could be placed here that will remediate the soil in a long-term time perspective.

Even if the site is not developed in the future, it will be restored to its natural state which is a great success in the work towards a non-toxic environment. In other words, nothing is lost by doing it this way.

How to create incentives for landowners to use phytoremediation?

Generally, a more extensive research, successful reference projects, and better information could get more landowners to choose phytoremediation over excavation. A contaminated site has a lower land value and is less attractive than a clean site. By using phytoremediation, the site can achieve a higher land value over time, and an increased attractiveness in a relatively inexpensive manner. This is especially suitable for owners of abandoned sites that they potentially want to build or sell in the future. The cleaner the place is, the more freedom of choice there is for its land use. Landowners can also get economic benefits if the site is used as energy forests that produce bioenergy during the remediation process. This method can even give a profit greater than the cost of cleaning the site.

Since phytoremediation is a sustainable way of remediating contaminated soil, it is good for the environment in double sense. This should be a strong argument for providing major financial support for those who choose this method.

The design proposal in the context of Uddevalla

Since the design proposal is only a test on how to design a site and its development using phytoremediation to clean the soil, some contextual aspects have been excluded.

The site where the design proposal has been made is quite large in the context of Uddevalla. Designing a park with this size in such a relatively small city can be questionable. However, large parts of the park consist of untamed nature that do not require that much maintenance, which, in my opinion, cannot be too large for its context.

Almost the entire site is a landfill which is slowly sinking. Building on such a location can be complicated and may require resource-intensive measures such as increased landfilling and piling. There is also an uncertainty if the landfilled soil is fertile enough to be planted with the specific hyperaccumulator plants.

Uncertainties with phytoremediation

One of the major uncertainties when using phytoremediation is the time it takes to remediate the soil. This can create conflicts with development projects which sometimes can have a tight schedule and a lot of interests and money involved. Plants are relatively sensitive and the remediation process may turn out to take longer time than expected. To avoid creating these conflicts, it is important to do an extensive investigation of the conditions of the site to be able to choose the most suitable techniques and plants to make the process as effective as possible. Also, it is beneficial to have a relatively abstract and flexible plan which takes these uncertainties and potential future changes into consideration.

Phytoremediation may not always be suitable because of various reasons, like a very high level of contamination, or the local climate. In these situations, conventional remediating methods, like excavation may be needed. No remediation method works for all the situations, you always need to compromise and find a solution that is suitable for each given situation.

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