Stockholms universitet

Environmental Remediation for Loudden

Course: Environmental Management in Planning, GE7015

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Foreword

This report is the result of a project work within the course *Environmental Management in Planning* at Stockholm University. The course is a mandatory part of the multidisciplinary Master programme *Environmental Management and Physical Planning* at the Department of Physical Geography and includes both Swedish and international students. The course comprises ten weeks of study (15EHTC), of which the project part covers five weeks. The aim is to give the students an opportunity to apply their acquired knowledge on environmental management in planning on a realistic and relevant case.

This time we have chosen to study the Stockholm Royal Seaport (SRS) and its surroundings. The different project groups have focused on remediation and implementation of urban gardening in Loudden (the last area to be developed in SRS), retrofitting of neighboring residential areas as well as The Royal National City Park as a green resource for SRS.

The students alone are responsible for the results and conclusions of this report and it cannot be regarded as the position of Stockholm University. The project supervisor has been Salim Belyazid from the Department of Physical Geography.

We want to thank all those who have been helpful in providing the students with information and materials as well as having taken time for interviews. Without your help this project could not have been realised.

Stockholm, March 2019

Nadja Stadlinger

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Glossary and abbreviations

BTEX → Benzene, Toluene, Ethylbenzene, Xylene. Light aromatics.

CEN → Comité Européen de Normalisation, one out of three organisations within the EU that work with standardizations, often referred to as EU-standards.

EQN → Environmental quality standards

Ex-situ → The remediation work takes place off site, at another location, then where the pollutants were found.

In-situ → The remediation work takes place on site, which means that the polluted soil or water doesn't need to be dug up in order to be treated.

ISO → International Organization for Standardization, a global organisation in charge of standardization within technology.

KM (*Känslig Markanvändning)* → Sensitive land use.

mg/kg TS *(torrsubstans)* → Milligram per kilogram dry substance.

MIFO method → Methodology for inventory of polluted areas.

MKM (*Mindre Känslig Markanvändning)* → Less sensitive land use.

MLC → Mass Logistic Centre.

Royal National City Park → RNCP

SS → Designation of whether a ISO or CEN standard has been implemented in Sweden; the SS are added to the ISO or CEN, such as SS-ISO or SS-CEN.

SRS → Stockholm Royal Seaport

VOC → Volatile Organic Compounds. Gases emitted from certain solids or liquids. Can have adverse health effects.

Summary

Stockholm Royal Seaport is Sweden's largest and most ambitious urban development, with plans to build over 12,000 new dwellings and 35,000 workplaces. As cities globally are continuing to grow at a quicker and quicker pace, Stockholm Royal Seaport aims to become an international model for sustainable urban development.

One of the planned new areas located at the southern end is Loudden. Currently, this area is home to several industries, most notably an oil harbour and container terminal. Industrial operations began almost a century ago and as a result, the area is riddled with many contaminants. In order for Loudden to be developed into a new urban area, with housing, commercial spaces and offices, schools, and both green and open spaces, extensive remediation must be done on the area.

This reports aims to find suitable environmental remediation methods for the development of Loudden, which involves creating a vision of how this development can take place. The vision follows the guidelines for sustainable urban development as outlined by Stockholms stad. In order to bring this vision to fruition, the current contamination situation was examined and an assessment of remediation methods conducted to conclude the most suitable treatment plan in order to reach the vision.

The methods used to do so include: a comprehensive literature review meant to provide insight into the history of Loudden and information regarding specific remediation methods, GIS (geographical information systems) analysis to determine where remediation actions should be targeted, and a matrix used to assess and compare several different kinds of remediation methods to find which would be the most suitable in the context of this development.

It is determined that is feasible that Loudden can be remediated to the extent needed for development of a new, mixed-use residential area as a part of the Stockholm Royal Seaport. The most suitable remediation methods to apply in Loudden are concluded to be ex-situ soil wash together with chemical oxidation. The former will remediate all of the expected pollutants up to a depth of a meter, while chemical oxidation will take care of the contaminants found deeper. Although the excavation and transportation of soil for washing can have a big ecological footprint, the assumption is that the Mass Logistic Centre already built in Frihamnen, adjacent to Loudden, will both sort and treat the contaminated soil. Since Stockholm Royal Seaport strives to be as sustainable of a development as possible, the same mind-set was applied to the area's remediation. Further remediation will be incorporated into the planning of Loudden through the extensive planting of selected tree types and other flora that promote phytosanification.

It is important to note that there were many uncertainties and limitations encountered in this project due to a lack of information. Several informed assumptions were made regarding the contamination situation in Loudden and costs were not considered despite their likely impact on the remediation method chosen. Further investigation and testing is recommended to be done on the area in order to accurately determine the levels and types of contaminants found present and provide a solid scientific basis for the planned remediation.

Contents

1. Introduction

Stockholm Royal Seaport (SRS) is located in north eastern central Stockholm. The new development aims to create residential areas, commercial space and green wedges connected to the Royal National City Park (RNCP). The plan is to build at least 12,000 dwellings and 35,000 new workplaces. SRS is striving to be a sustainable area with regards to climate adaptation and becoming a fossil-fuel free city. The development started in the beginning of 2000 and the ambition is to complete SRS by the year 2030 (Stockholms stad, 2019a).

The main objective with SRS is to contribute to and create a coherent, safe, and attractive city core. The city aims to prioritize a more walkable and bicycle-friendly city with an increased focus on public transportation to reduce car usage. Further on, SRS aims to decrease waste generation in order to promote a more effective use of resources. The dwellings will be constructed to be energy efficient and will use sustainable building materials. The intention is to derive benefits from ecosystem services to create a more resilient and healthy environment (Insyn Sverige, 2017).

1.2 Loudden

Loudden (figure 1.1) is located in the southern end of SRS; there, a new development is planned with residential areas, commercial spaces and offices, and schools that are connected with open streets, squares and parks. Loudden is surrounded by Lilla Värtan, a waterway connected to the Baltic Sea, and the RNCP. The land is largely owned by the city of Stockholm. Today, most of the area is engaged in industrial operations in the form of an oil port and a container terminal. Stockholms stad's intention is to investigate and examine the current conditions in Loudden. Remediation will be needed in order to transform the area into a mixed urban development, while at the same time, maintaining existing and developing further ferry and cruise operations in the port (Stockholms stad, 2017a). However, in the future, ferry activity will only focus on tourism and the rest of the harbour activities are planned to move to a newly built harbour north of Nynäshamn.

Figure 1.1 The picture with dashed lines shows the new development area of Loudden.

Due to hazardous activities in the past and present, the new development will be expected to have a significant environmental impact and thus demands an environmental impact assessment to be conducted (ibid).

2. Aim

The aim of this project is to investigate and plan for the remediation processes at Loudden before developing the area as a part of SRS. A vision of the development was created and the current contamination situation investigated in order to identify and determine the environmental remediation processes necessary to reach the vision. Further on, the aim is to provide decision makers, stakeholders, and the public with solutions to promote sustainable development in Loudden.

2.1 Boundaries

The geographical boundaries in this report are considered not to be dynamic. As such, environmental remediation processes for soil and water within Loudden has been assessed, but not for Lilla Värtan (figure 1.1). However, within this area, dynamic processes such as water flow, soil displacement, and the spread of pollutants have been taken into account.

The time period for remediation considered in this report is based on Stockholms stad's present time plan; from now, 2019, where the current investigation of contaminants is ongoing in Loudden until when the development is supposed to be finished by 2030. The intention is that the first dwellings will be constructed and residents can start to move in by 2025. However, the time span may exceed the year 2030, due to the fact that remediation processes can take longer than expected and monitoring and follow up must also be considered. In terms of the contaminants present, the temporal boundaries considered are from when industrial activity began in Loudden in 1920 until the present time.

Concerning different contaminants, the ones certainly known to occur within the boundaries of Loudden are addressed in this report. However, testing has shown other contaminants present in adjacent areas, and the likelihood of additional contaminants based on previous activities is also high. Groundwater will be assessed as a means of contaminant transport and as a possible secondary source, not as a source of drinking water.

3. Background

3.1 Environmental remediation

3.1.1 Environmental quality standards

Environmental quality standards are legally binding norms according to chapter 5 in the Swedish Environmental Code. Their purpose is to reduce impacts on the environment and to be able to map the diffuse emission sources. Environmental quality standards are based on the extent of disturbance both people and the environment can withstand without any consideration to economic or technical conditions. The standards are set to examine the lowest acceptable environmental quality (HaV, 2018).

Norms for contaminants and different land uses

Naturvårdsverket divides the accepted levels of different contaminants based on land use:

KM (*Känslig Markanvändning)* → Sensitive land use:
The quality of the ground does not affect the choice of land use. All groups of people, children, adults, and the elderly, can permanently stay in the area during their lifetime. Most ecosystems and both groundwater and surface water are protected (Naturvårdsverket, 2009).

MKM (*Mindre Känslig Markanvändning)* → Less sensitive land use:
The quality of the ground limits the choice of land use to facilities like offices, industries or roads. The people visiting the area are expected to be here solely during business hours and children and the elderly are able to visit temporarily. Vegetation can be established and animals can temporarily reside here. Groundwater at a distance up to 200 meters and surface water are protected (ibid).

Table 3.1 lists the contaminants known to occur in Loudden with their respective accepted norms for both KM and MKM. The levels listed in the table specify the level of contamination where the risk of negative effects on people, environment and natural resources is considered acceptable. Exceeding a norm does not imply negative effects will occur at that level, rather that the risk of those negative effects is not acceptable. The contaminants found on Loudden are found in the free phase, bound to soil particles, and dissolved in water (Golder Associates, 2015).

Table 3.1. The norms (both KM and MKM) of the contaminants known to occur in Loudden (Naturvårdsverket, 2009).

Type	Contaminant	KM (mg/kg TS)	MKM (mg/kg TS)	Comment
Petroleum based	PAH-L	3	15	Low molecular weight
	PAH-M	1	20	Medium molecular weight
	PAH-H	1	10	High molecular weight
	Aliphatic >C5-C8	25	150	
	Aliphatic >C8-C10	25	120	
	Aliphatic >C10-C12	100	500	
	Aliphatic >C12-C16	100	500	
	Aliphatic >C5-C16	100	500	Sum of fractions above
	Aliphatic >C16-C35	100	1000	
	Benzene (BTEX)	0,012	0,04	
	Toluene (BTEX)	10	40	
	Ethylbenzene (BTEX)	10	50	
	Xylene (BTEX)	10	50	
	Aromatic >C8-C10	10	50	
	Aromatic >C10-C16	3	15	
	Aromatic >C16-C35	10	30	
Metals	Lead	50	400	

3.1.2 Other possible contaminants

It is likely that there are other contaminants present at Loudden other than the ones listed in table 3.1, which are the ones present for certain. PFAS is one type of contaminant that commonly exists at airfields (Naturvårdsverket, 2019; SGF, 2018e) and since Loudden was previously used as a seaplane port, it is suspected that this pollutant may be present. Other heavy metals like copper, cadmium, chromium and mercury have been measured in sediments in Lilla Värtan (adjacent to Loudden). PCB is believed to be present in building materials around the area (Golder Associates, 2015).

3.1.3 Health and environmental effects of contaminants

PAH-L
Their high solubility in water makes low molecular weight PAHs susceptible to spreading through groundwater; they are highly carcinogenic (SGF, 2018b).

PAH-M, PAH-H
This group has a lower solubility compared to PAH-L and is usually spread in the particle-bound phase through mediums such as flowing water; they are poisonous for all living organisms (ibid).

Aliphatics >C5-C8, >C8-C10, >C10-C12
The lighter aliphatics are volatile and have a high solubility, therefore, they can easily spread from their source and pollute groundwater (SGF, 2018a). If they are present under buildings they can affect air quality within the building. Poor air quality can lead to health effects such as asthma, irritated skin, and allergic symptoms in the nose, eyes and respiratory system (Folkhälsomyndigheten, 2018).

Aliphatics >C12-C16, >C16-C35
The heavier aliphatics are more viscous and are normally found close to their source compared to lighter fractions. They can also penetrate the ground and pollute groundwater. There are health risks associated with handling polluted soil and inhaling dust from it (SGF, 2018a).

BTEX - Benzene, Toluene, Ethylbenzene, Xylene
This group, collectively referred to as BTEX, are light aromatics (C6-C9). They are very prone to dispersion with their high solubility and volatile characteristics. They affect indoor air quality with similar health effects as the lighter aliphatics. Benzene is classified as carcinogenic and according to WHO (2010) there is no safe level of exposure.

Aromatics >C8-C10, >C10-C16
The lighter aromatics are volatile with a high solubility. They affect indoor air quality with similar health effects as the lighter aliphatics. Should be quantified indoors through VOC-measurements. Aromatic hydrocarbons are considerably more toxic than aliphatic ones (SGF, 2018c).

Aromatics >C16-C35
The heavier aromatics are more viscous and are normally found close to their source. There are health risks associated with handling polluted soil and also inhaling dust from it. Aromatic hydrocarbons are considerably more toxic than aliphatic ones (ibid).

Lead

Lead is a naturally occurring metal. It is a cumulative toxicant that can be dangerous to humans and other living organisms. Once it has entered the body it redistributes to the brain, liver, kidney and bones. Lead can cause anaemia with chronic exposure (Newman & Unger, 2002). At high levels, it can even lead to death. Lead is particularly harmful for young children as it can interfere with brain development (WHO, 2018).

3.2 Remediation approaches

Before choosing remediation methods it is necessary to investigate the contaminated soil and water to determine which pollutants are actually present. In Sweden, there are different guidelines and methods from Naturvårdsverket for analysing contaminated soil or water; their purpose is to provide the framework for sampling, preparation and various types of analyses of soil and water. There are no regulations regarding which method to use to examine the contamination situation, except for those involving landfills. Therefore, it is up to the developer or the agency in charge to choose a suitable method (Swedish Standards Institute, 2017). According to the Swedish Environmental Code, the developer is primarily responsible for paying for and carrying out soil remediation and secondly, the property owner (10 kap. § 4 MB).

The most common method to analyse the soil and determine the level of contaminants is to perform soil testing. In Sweden, the MIFO-model is a common method to investigate the level of contaminants and is used to grade the targeted area into one out of four risk classes. The method is performed in two steps: in the first, an orientation study and a risk assessment is made and in the second, samples are collected together with chemical and toxicological analysis, and finally a new risk assessment is made. By this method, a collective assessment is made to place the area into the four-grade scaling system based on their toxicity, impurity level, and potential to spread (Naturvårdsverket, 1999). The most common risk class for oil industries, which is the main industry in Loudden, is the second highest (Naturvårdsverket, 2011).

In order to choose a suitable remediation method based on the soil samples, a range of parameters need to be considered. For example, which contaminants are being handled, the properties of the soil, and the extent of pollutants (Swedish Standards Institute, 2017). In general, there are four different categories of remediation methods: physical, biological, thermal and chemical.

3.2.1 Possible remediation methods for Loudden

Physical

Mechanical remediation techniques use the physical properties of the contaminants to isolate or contain them, mainly by restricting movement. This category is comprised of methods like capping or containment, immobilization through solidification, and soil washing (U.S. EPA, 2011).

Air sparging, in-situ: a treatment used for remediating groundwater that has been contaminated by volatile organic compounds (VOCs) such as propellants, petrol, aviation fuel, light fuel oil spills, and chlorinated solvents. Air is injected below the groundwater level, which causes the VOC to move from liquid into the gas phase. This method is mainly used when dealing with petroleum-contaminated groundwater and preferably where there are sand or gravel soils, since large amounts of air need to be able to infiltrate the soil easily. The method also stimulates aerobic biodegradation in the ground. Estimated treatment time depends on the situation, but it is often between 12 to 36 months (SGF, 2019a; Yodphongsa, 2014).

Soil Wash, in-situ: used for organic pollutants present in the free phase or bound to soil particles. This method can also be used to treat metal-contaminated soil. Water together with solvents are used, often with surfactant; this fluid is injected into the soil and causes the pollutants to dissolve and be extracted from the soil. The contaminated water solution is subsequently gathered and cleaned through, for example, activated carbon. Soil washing can be used in both saturated and unsaturated zones and mainly in permeable soils, but can also be applied in bedrock. Depending on the amount of pollutants, the permeability of the soil, and which solution one uses the estimated treatment time is between a few months up to a few years (SGF, 2019a).

Soil vapor extraction, in-situ: a common treatment for VOCs in soil above groundwater level. Pore gases are pumped into the unsaturated zone and the extracted gas is subsequently cleaned. This method is commonly used in combination with air sparging, biosparging, multiphase extraction, or thermal treatment. This technique is suitable for remediating fuels and organic solvents with high VOC content, and is common for post-treatment of polluted petrol stations. The soil needs to be relatively permeable, such as with sand or gravel soils. Estimated treatment time is between 12 and 36 months, depending on site conditions (SGF, 2019a).

Multiphase extraction, in-situ: a method that treats pollutants found in different phases, i.e. gas, free, or water-soluble, simultaneously. A common way is by vacuum extraction, where wells installed under groundwater level create higher pressure in order to extract substances in all phases. In comparison with soil vapor extraction, the vacuum pressure also catches pollutants in the free and water-soluble phase. The natural vacuum pressure works best in depths up to 9 meters, for deeper levels of contamination, an outer extraction well is needed. The treatment shows good results when dealing with oil-contaminated areas with a mixture of free phase, volatile hydrocarbons, and water-soluble contaminants, but also when handling soil and groundwater contaminants with chlorinated solvent content. This method especially works will in soils with moderate to high permeability, such as sand and silt. The required treatment time varies between 12 months to a few years (SGF, 2019a).

Soil Wash, ex-situ: this method has a wide range of uses and is particularly suitable for metals and other non-organic pollutants. Even heavy organic substances, such as PAHs, PCBs, dioxins, and PFOS can be treated. This technique is most suitable for homogeneous soils where clay and silt content is low. The contaminated soil is excavated and the remediation takes place in several steps, but a process plant is needed, thus, ex-situ. At the plant, the sediments are separated through sieving to sort the silt and clay particles, which often contain most of the pollutants. Water or chemical solutions can later be used to collect finer particles and separate highly contaminated soil from less contaminated soil. The cleaned soil is then returned to the site. A larger excavator is estimated to remove between 150 to 300 cubic meters of soil per day, and the cleaning process can normally handle between 5 to 50 tons per hour, so with 20,000 tons of soil, the entire process would take around 5 to 6 months (SGF, 2019b; Svevia, 2019).

Landfill, ex-situ: with this method, contaminated soil masses, and in some cases even waste or residual products, are excavated and removed from the contaminated area and replaced with clean soil. This method is suitable for all types of soil and sedimentary bedrock as well. By using excavation, it is possible to remove contaminants at a greater depth. Under good conditions, a large excavator can remove 150 to 300 cubic meters of contaminated soil per day. Excavated polluted masses can either be treated on site or transported to an external reception facility for treatment (SGF, 2019b).

Biological

Biological treatments involve contaminants being degraded into non-hazardous, usually organic compounds through microbial action. Biodegradation has its advantages as a low-cost remediation technique, but the process is usually a lot more time consuming. Additional concerns involve the sensitivity of microbes under toxic conditions, unpredictable reliability, and inefficiency in highly-contaminated sites (Kuppudsamy et al., 2016).

Biosparging, in-situ: this method is similar to air sparging, and is used to clean VOCs from groundwater. Air is pumped into the groundwater, but there is a bigger focus on stimulating aerobic biodegradation. Compared to air sparging, this method is used for longer aliphatic molecules. The treatment time is normally between 12 to 36 months, and best results occur in sand and gravel soils (SGF, 2019a; Yodphongsa, 2014).

Biological treatment, in-situ: destruction or conversion of organic pollutants, either by stimulating naturally-occurring microorganisms or by adding suitable ones. This method can accelerate already ongoing biodegradation processes by adding oxygen or nutrients, or initiate new processes. It can be applied on soils contaminated by petroleum hydrocarbons, chlorinated solvents, chlorophenols, and a variety of other organic pollutants. The method works both below and above groundwater level, but the best results are achieved where the soil is rather permeable. The treatment has a long processing time and can take up to several years (SGF, 2019a).

Phytosanification, in-situ: uses plants for the extraction or fixation of contaminants. The technique involves extracting, binding, or breaking down pollutants in soil, groundwater, surface water, or other contaminated media through the root system of plants. The method handles lead, BTEX, and chlorinated solvents, and works best if the concentration of the pollutants is not very high. Via the plant, the contaminants are transported and accumulated. If handling metal or non-organic contaminants, the biomass is taken care of by combustion or composting. The treatment time is long and can take several decades (SGF, 2019a).

Chemical

Chemical remediation techniques utilize the chemical properties of contaminants to conduct reactions and change the chemical structure, and therefore properties, of pollutants to make them safer, less toxic compounds. Compared to other forms of treatment, they tend to be less expensive and can be conducted in a shorter time period (Lodolo, n.d.).

Chemical oxidation, in-situ: organic pollutants such as halogenated solvents, chlorophenols, oil hydrocarbons, and PAHs are broken down by injection of an oxidant, with the end products being carbon dioxide and water. Common oxidants to use include potassium, sodium permanganate, Fenton's reagent (hydrogen peroxide with divalent iron), catalysed percarbonate, ozone, or persulfate. The time required is short, from a few days to a few months, but it is common that a few iterations of treatment are needed in order to reach acceptable levels, therefore the required time can amount to around a year. The best results are obtained in homogeneous soils and this method works both above and below groundwater level (SGF, 2019a; Yodphongsa, 2014).

Thermal

Thermal remediation is classified by the use of heat to decompose, melt, or destroy contaminants. The process is generally quick, but tends to be the most expensive of all remediation methods considering its capital-intensive nature and costs from energy and equipment use. Thermal techniques tend to be useful in highly heterogeneous remediation sites, with the exception of treating any inorganic substances (Kuppudsamy et al., 2016). However, the process faces problems with potential air pollution and public disapproval.

Thermal treatment, in-situ: the soil and groundwater are heated to a temperature where the pollutants enter the gas phase. Steam heating by water vapour, conductive heating, or an electric current are induced in the contaminated soil area. The method works for chlorinated solvents and volatile pollutants such as those from petroleum, but also for mercury and volatile hydrocarbons like PCBs. This method can be used in most common soil types and works both above and below groundwater level. It has a relatively quick treatment time, often under a year, but it depends on how many heat sources are being used. However, it can take several months for the soil to cool down for further use (SGF, 2019a).

Thermal treatment, ex-situ: similar to in-situ treatment, but the soil is excavated and moved to special thermal plants. Most known organic contaminants can be remediated with this method. VOCs, like chlorinated solvents, together with aliphatics and monoaromatics evaporate at low temperatures around 50 to 150°C. Heavier organic compounds, PAHs, PCBs, PFAS, and most organic pesticides, evaporate at higher temperatures from 100 to 800°C. Thermal treatment can also be used to treat mercury, arsenic, and certain organometallic compounds. This method can be applied to all grain size fractions. Depending on the level of silt and clay and the amount of pollutants, organic matter, and water the required time varies, but in general 5 to 50 tons of soil per hour can be treated (SGF, 2019b).

4. Method

4.1 Literature

In order to gain an understanding of the history of Loudden, the state of the area today, and future development plans in the context of Stockholm Royal Seaport (SRS), information has been collected from Stockholms stad's official documents; with this, a vision of a new urban residential area was created in line with SRS objectives and earlier met goals. Due to its industrial history, the area needs extensive remediation in order to make this vision possible. The contaminants in the area and their extent were identified by reviewing reports from an environmental consulting group. When there was a lack of data, information was extrapolated from reports pertaining to remediation from similar industrial sites.

Relevant scientific literature regarding specific remediation methods and background information for the site description was gathered from databases including Google Scholar, Web of Science, and the Stockholm University library, as well as information received from the Länsstyrelsen. This information was then used to create a comparative matrix to evaluate the most suitable methods in the context of the project.

Keywords:

- Environmental remediation, contaminated soil, remediation methods, Stockholm Royal Seaport, Loudden, harbour remediation.

4.2 GIS analysis

ArcMap 10.6 was utilized to create maps that aided in the visualization and analysis of the area. Input data was obtained from Lantmäteriet and SGU, the Geological Survey of Sweden.

The analysis for finding key areas for remediation actions consisted of three steps. First, a map for the developed vision of Loudden was created (figure 6.2) where each area within the boundary was assigned a value of either sensitive land use (KM) or less sensitive land use (MKM), depending on what each specific area would be used for. A second map (figure 6.3) was created of the current contamination situation at Loudden with three categories used to symbolize the different levels of contamination: minor, intermediate, and major pollution. These categories should be considered in relation to each other and not be used as distinctive values. The basis for assigning areas to the different pollution categories was mainly from figure 5.2 from the Golder Associates compilation (2015). Although, since many of the sampling sites were outdated (some as old as 20 years), an assessment of groundwater movement and soil depth and type was done to make an informed guess of where potential contaminants could have spread.

The third step was to do an overlay analysis of figure 6.2 and 6.3. This shows both where KM and MKM will need to be met based on the vision and what the contamination situation is believed to be at those sites (figure 6.4). This was then used to target remediation actions.

4.3 Matrix for method assessment

In order to determine which methods would be most suitable for Loudden, several different remediation methods were compared using a matrix. The matrix covers which contaminants each method treats, and also evaluates important parameters including treatment time, environmental impact, soil suitability, and whether the method works below groundwater level in the saturated zone. Three different colours, green, yellow, and orange, were used to visualize each parameter — their meanings differ based on the parameter, but essentially green is positive or suitable, yellow is neutral, and orange is negative or unsuitable.

After the contamination situation was evaluated in Loudden, the matrix allowed for an easy visual comparison of several different remediation methods all at once and helped provide a framework to determine which remediation methods would be most suitable for this particular area.

5. Site description

Loudden is located in the southern end of SRS with a total area of 0.49 km^2. The eastern area of Loudden has been utilized as an oil depot and harbour since 1920 and the western portion has mixed usage including commercial and industry, but primarily houses a container terminal, see figure 5.1 for visual context. Stockholms stad owns the majority of the land on Loudden and the properties are currently rented by companies, with the exception of a few private-owned properties.

Due to the continued exploitation of the area, there are three national interests to consider in the planning process. They consist of: Stockholm harbour (3 kap. §8 MB), where Loudden is designated as a core harbour according to EU standards, the Royal National City Park (RNCP) that borders Loudden and aims to protect the historical landscape with its timeless natural and cultural values (4 kap §§ 1 and 7 MB), and Stockholm inner city, including Djurgården, an area of high cultural value that is of national interest (3 kap § 6 MB).

Due to Loudden's varied historical and present land use, it has been divided into two different areas for the purposes of this report: the oil harbour and the container terminal.

Figure 5.1. Loudden divided in two sections; Container Terminal and Oil Harbour. The figure also shows cultural protected buildings and the company zones (grayscale), where each zone number corresponds to a company specified in table 5.1. Data used: Background (aerial photo), GSD-Ortofoto, ©Lantmäteriet (2015). Protected buildings, GSD-Fastighetskartan, © Lantmäteriet (2018).

5.1. History

5.1.1 Oil Harbour

In 1926, the town council decided on the construction of the oil harbour. As oil consumption increased after World War II Loudden's harbour expanded, partly by the filling of Lindarängsviken (section 5.1.2), which increased the depot's capacity. Additionally, the construction of caverns for storage of petroleum products was ongoing through the '50s, '60s and '70s (Brantberger, 2017). Since the late '70s the activities and functions of the area have essentially remained the same; it primarily consists of the loading and storage of oil and other petroleum products, but includes other activities such as the production of lube oil, mechanical workshops, the loading of gas, washing of tank trucks, and more (Golder Associates, 2015).

The companies operating in Loudden's oil harbour have changed throughout history. In 2015, this area was divided into 8 zones managed by Statoil Fuel and Retail Sverige (Circle K today), Preem, Univar and Jet (Ingo today), OK-Q8, Petrolia, St1, and Stena Recycling (Golder Associates, 2015).

There are records of incidents and accidents occurring within the area. Many of them being on hard surfaces and have been handled properly, but a few incidents have resulted in substances (such as different oils or kerosene) penetrating the ground surface. Most of the incidents are described as minor (<50 L), but larger spills have occurred. For example, in 2004, 200 litres of kerosene were spilled in zone 3; in zone 6 (figure 5.1), 500 litres of oil were spilled in 2010. The whole area is connected to a sewage system for oil-contaminated water called an OFA-system (*oljeförorenat avloppsvatten*), so that the oil is separated before the drainage water reaches Lilla Värtan. The 2004 kerosene spill did reach Lilla Värtan, but overall the OFA-system is a mitigation measure that has worked for many spills in the area (Golder Associates, 2015; Stockholms stad, 2018a).

5.1.2. Container Terminal

The container terminal is located on the western side of Loudden and was constructed in 1971 on an area previously used as a seaplane port. The seaplane port, named Lindarängen, was built in 1921 and was highly trafficked up until 1936 when Bromma airport was built and the air traffic was redirected. Consequently, the seaplane traffic decreased and the port was later shut down. In 1952, the decision was taken to fill the bay on which the planes had landed with sediments and turn the area into a container terminal as an extension of Frihamnen. Measures to fill the bay began in the early '60s using materials from the blasting of caverns further out on Loudden (Brantberger, 2017; Stockholms Hamnar, 2019a). However, the hangar building, located on the southern border of Loudden, still exists and is now classified with the highest possible cultural value according to Stockholms Stadsmuseum due to its history (Stockholms stad, 2016). The handling of goods in the container terminal is considered to be a successful practice as they are handling big volumes and have a high yearly turnover. Some of the biggest shipping companies in the world work with Frihamnen and the terminal handles both commercial and personal goods, such as food, industrial material, and fossil fuels like oil, petrol, and coal (Stockholms Hamnar, 2019b; Stockholms Hamnar, 2013).

On the western side of the container terminal lies the old Ford factory, which started up in 1931 as a factory where imported car parts assembled. In 1957, when the factory moved to Sollentuna, the building was taken over by Stockholms Hamnar and was given the name Magasin 10. Today, the building is used for offices and is occupied by the stock company Nasdaq OMX. Due to its history and unique design, the old Ford factory has also been classified with the highest possible cultural value (Stockholm stad, 2016). A third building within the study area that is classed with a high cultural value is Magasin 5, an old storage location used by Banankompaniet for ripening fruits. Magasin 5 is located along the water towards Frihamnen and, today, is mainly occupied by Stockholms Auktionsverk (Stockholms Hamnar, 2017).

5.2. Contaminants

5.2.1. Oil Harbour

In both zones 4 and 7 (see table 5.1), petroleum activities have ceased and their associated buildings demolished. Remediation is ongoing at these sites by the consulting company Midroc Miljöteknik AB. As seen in table 5.1, the main products managed by the different companies slightly differ between the zones, but the majority of these products are petroleum-based.

Golder Associates (2015) compiled information from Municipality archives, Länsstyrelsen's database of polluted areas, interviews, and the company's own reports with the purpose of creating a solid groundwork for decision making regarding the area. From this information, it can be concluded that the main pollutants in Loudden's oil harbour are different types of petroleum hydrocarbons.

Table 5.1. List of latest companies within the different zones at Loudden and what products they have managed. Information used in the table is sourced from Golder Associates (2015) and Stockholms stad (2018a).

Zone	Size (m^2)	Latest company	Main products managed	Status
1	13,926	Circle K Sverige AB	Diesel, fuel-oils, petrol	Active
2	12,105	Preem AB	Diesel, fuel-oils	Active
3	18,023	Preem AB	Thick-oil, diesel, fuel-oils, additive	Active
4	7,681	Univar AB & Jet	Diesel, naphtha, glycols	No activity
5	13,665	OK-Q8 AB	Petrol, ethanol, diesel, alkylate	Active
6	20,818	Petrolia AB	Additive, oil base, diesel, fuel-oils, ethanol, kerosene	Active
7	12,760	St1 Sverige AB	Petrol, diesel, fuel-oils, kerosene	No activity
8	9,723	Stena Recycling AB	Diesel, gas oil, waste oil, PCB polluted oil	Active

There have also been findings of free phase oil and high measurements of lead in the ground. Figure 5.2 shows testing sites and their results in relation to KM and MKM. The majority of sample sites within the cistern area, or the central part, have had tests showing pollutants exceeding the values for KM (orange dots) and most of them also exceeding MKM (red dots). This is where the storage of petroleum products mainly has occurred. In the location of the lube oil factory in Zone 6 (Petrolia), just south of the pier, there are many red and orange measurements as well.

However, there are plenty of samples showing results fulfilling KM (green dots) with the majority of them being on the outskirts of the cistern area. Zone 3 (Preem) and Zone 6 (Petrolia) are the areas with the most sample sites and they both contain <KM results. In Zone 3 they can be found in the northern part at lower elevation and in Zone 6 close to the pier, both from a distance from the cisterns. There are also a few <KM samples found relatively central and also close to other samples showing >MKM (red). It should be noted that this is a compilation of several conducted tests that span over many years. Therefore, it is possible that a <KM result surrounded by several >MKM results is an older sample and could be considered outdated, for example, the green dot surrounded by three red dots situated at the border of Zone 3 and 4. Another explanation is obviously that there is in fact a very local difference in the contamination level.

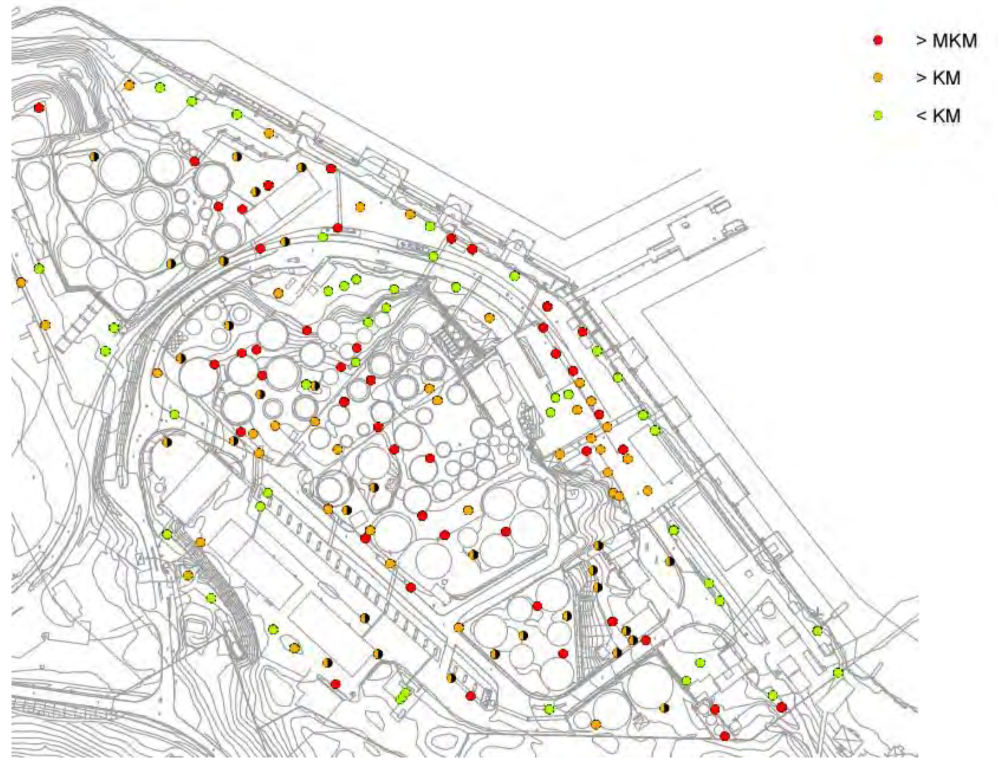

Figure 5.2. Location of previous sampling sites and how their results relate to Naturvårdsverket definitions of KM and MKM. Yellow and black half dots were disregarded. Picture sourced from Golder Associates (2015).

5.2.2. Container Terminal

Earlier investigation (Golder Associates, 2015) regarding the amount of contaminants in the ground underneath the container terminal has concluded it is likely that filled areas, at least to some extent, are polluted. This is because of the higher topography around the container terminal, causing infiltration into the landfilled areas. However, it is also likely that some pollutants have spread in the southwest direction due to groundwater running just underneath the area (ibid). If the container terminal has been infiltrated by pollutants from adjacent areas, it is reasonable to believe they are similar to the ones in the oil harbour. However, the exact degree of pollution in this area is still unknown due to insufficient examination.

At the southern end of the container terminal, the location of the old seaplane port, fuel management with halogenated solvents, toxic paint used on the bottoms on planes, and aviation kerosene were handled at the site in the past (Länsstyrelsen, 2013a; Länsstyrelsen, 2013b). The ground in this area is marshy and the remaining hangar was built on piles. Due to the applied construction, the hangar is stationary but the surrounding soil is slowly sinking into the clay (Länsstyrelsen, 2013a).

5.3. Mass logistic centre

Northwest of Loudden, about 500 metres outside of the boundary, a mass logistic centre (MLC) has been constructed by Stockholms stad. The sorting of polluted soil and other aggregates used for filling will be conducted indoors. It is estimated that the establishment of the MLC will lead to a 50% reduction in transport and a 40-50% reduction in greenhouse gas emissions. Since the centre is constructed as a tent with concrete walls, noise, smell, and dust from the related processes will be also reduced (Stockholms stad, 2019b). According to Stockholms stad (ibid) the masses deemed to be hazardous waste and too polluted for reuse in the development (treatment classes 3 and 4) will be transported from the tent on an encapsulated conveyor belt onto ships for subsequent transport to landfills. This is believed to be around 5-10% of the total amount of masses that will be dealt with in the centre (Stockholms stad, 2018b).

5.4. Geology and hydrogeology

Geology

The oil harbour, situated at the highest topography, also extends towards the sea and lower ground levels. The predominant soil conditions at the oil harbour indicate a soil coverage of low thickness, typically less than 1 to 2 meters (figure 5.3). Several areas of exposed bedrock are identified by Golder Associates (2015) and according to figure 5.3, larger areas in Loudden have low or next to no soil depth. Areas of higher soil depth occur framing the highest areas of the oil harbour; a north-eastern area of soil with a thickness of up to 10 meters, a western area with a thickness of up to 10 meters, and a south-eastern area of a thickness up to 4 meters (figure 5.3). Additionally, SGU, the Geological Survey of Sweden, classifies the majority of Loudden as “filled-in area” concerning both the oil harbour and the container terminal (figure 5.4).

The container terminal, located in western Loudden, has an average elevation of 2.5 meters and is generally flatter. The soil depth varies from 3 to 10 meters with smaller areas of next to no thickness. The thickest areas of soil are located in the west and northeast of Loudden and in an area between the container terminal and the oil harbour (figure 5.3). The filled-in bay is partly, but not fully represented by figure 5.3. Today, Loudden has been fully extended to the boundary used in this report, hence the oil harbour has also been extended by filling of Lilla Värtan (ibid).

The first stage of filling the bay was done with rock obtained from blasting when expanding the oil harbour by levelling and constructing caverns. There are uncertainties about the aggregate or rock used for the complete filling of the bay. It is possible that further blasting products from construction of additional caverns or rock products from further levelling of Loudden was used as filler. It is also possible that other types of aggregate or sediment have been used for the complete filling of Lindarängsviken, covering any existing layers of sediment (Golder Associates, 2015; Stockholms stad, 2015a).

No specific data on soil types within the area was accessible. However, mapped soil types surrounding the area indicates that the predominant soil types are clay and till (figure 5.4). Previous investigations have shown that many of the lower parts are dominated by thicker layers of clay over 5 meters (Golder Associates, 2015); this concludes two possible areas of larger clay mass in relation to the oil harbour.

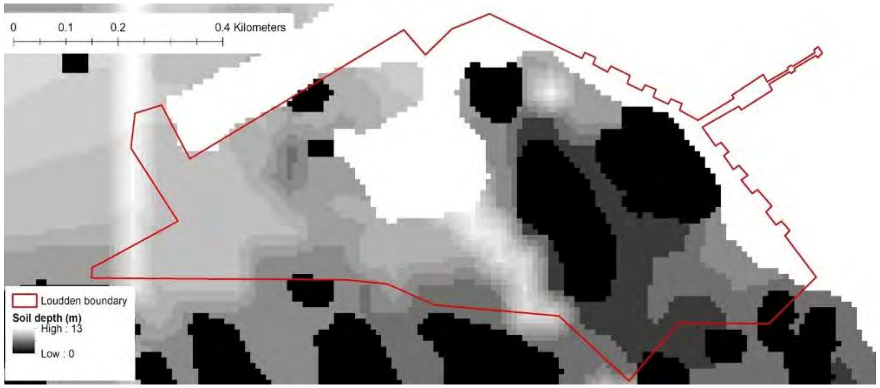

Figure 5.3. Soil depth in the Loudden area. Depths vary from 0 to 13 meters. Water is displayed as white and does not show recently filled in or extended areas of Loudden. Data used: Soil depth, Jorddjup 10x10, © Sveriges geologiska undersökning (2015).

Figure 5.4. Soil types in the Loudden area. Data used: Soil type, Jordarter 1:25,000 - 1:100,000, © Sveriges geologiska undersökning (2014).

Figure 5.5. Elevation of ground at Loudden. Data used: Elevation, GSD-Höjddata, grid 2+, © Lantmäteriet (2015).

Hydrology

The large areas of hard surface in Loudden inhibit infiltration other than in a few areas of permeable ground. The permeable areas are related to non-hardened surfaces around a few oil cisterns in the oil harbour and the limited green areas in Loudden (figure 5.1; Golder Associates, 2015). The oil harbour has been investigated to limited extent and to specific activities. No detailed mapping or investigation at a larger scale has been performed for the oil harbour area (Golder Associates, 2015). The container terminal has no information regarding groundwater.

The few investigations at the oil harbour has shown varying groundwater properties. In the bedrock, the groundwater has higher velocity in fractionated zones of cracks and slower velocity when the bedrock is of higher density. Clay soils have low groundwater velocity, and sandy till soils intermediate groundwater velocity. Groundwater velocity at filling material varies depending on the aggregate size and heterogeneity (Heath, 1987). The groundwater level has been observed to be higher than Lilla Värtan's sea level and up to 1 meter below the surface. A groundwater divider stretches in a northwest-southeast direction through the oil harbour. Combining the divider and the topography of the area the possible flows towards the oil harbour and towards the container terminal is evident.

The existing caverns can also be assumed to disturb the natural groundwater conditions (figure 5.5; Golder Associates, 2015). Thus, since the ground varies between soils, bedrock and filling, it can be assumed that the contamination situation and subsurface dispersal of contaminants is diverse (Heath, 1987). No investigations have observed shallow connected groundwater bodies (Golder Associates, 2015). The container terminal and western areas of Loudden, with varying ground properties due to the fillings, can be assumed to have even larger variance in groundwater properties. Groundwater flow from the higher elevated oil harbour to the container terminal has not been ruled out. Barriers has been used along the shoreline to prevent subsurface interaction and exchange of pollutants within the ground at Loudden and Lilla Värtan (Stockholms stad, 2017a).

5.5 Objectives in Stockholm Royal Seaport

Stockholms stad has strict and ambitious requirements for planning and several demands regarding, for instance, the waste system, building materials, green and open spaces, and energy efficiency. Considering the high variety of developers, one unique aspect of SRS is striving for more environmentally sustainable urban development.

The intention with a large number of developers is to promote architectural diversity, but also to encourage internal competition and inspiration between the companies to push each other to be more environmentally efficient (Stockholms stad, 2017c). Figure 5.6 shows some of the allocated requirements to previous development areas within SRS; these goals have been used as an inspiration to develop the vision described in section 6.1.

- Achieve 22 m^2 green space per apartment and 33m^2 open space per apartment.
- Connect smaller parks and green wedges with The Royal National City Park.
- Reuse 28% of the filling materials from the soil.
- Every apartment has access to a park or natural environment within 200 meters.
- 0,46 parking spaces per apartment.
- Locate 12% of commercial spaces on the ground floor of residential buildings.
- Pre-schools and an F-9 school.

Figure 5.6. Shows some of the met goals in previous SRS developments (Stockholms stad, 2017b). The goals listed have been considered when creating the vision for Loudden (section 6.1).

6. Results and discussion

6.1 Vision for Loudden

A vision for the future development of Loudden was created (figure 6.2) in accordance with the requirements established for SRS by Stockholms stad. The vision was then used to further investigate which areas within the boundary are expected to require remediation actions and to what extent. The vision shows different types of land uses that demands specific norms to be met, as to reduce risk of negative effects on people or the environment. The level of detail is relatively aggregated; the reason for this mainly being that the focus of this report is on remediation rather than specific future physical planning. Although, a higher level of detail in the future plans, in the context of the vision, would also increase the spatial details of needed remediation and therefore be of interest.

The basis for developing the vision for Loudden were mainly met goals from previous developments in SRS stated by Stockholms Stad, but also ideas already formulated as to how Loudden should be developed (Stockholms stad, 2017b). A comprehensive list of all factors considered is found below (figure 6.1). For a few of these factors, a more ambitious level, particularly with the extent of green and open space, has been set than previously stated by Stockholms Stad.

- Dwellings: 5,000.
- Habitants: 14,000.
- Pre-schools: 10 (for a total of 1,000 children).
- F-9 School: 1.
- Offices: 2,000 workplaces. Often located on ground floor of the residential buildings.
- Services: located close to the core of Loudden.
- Green spaces: 40m^2/apartment (instead of 22m^2/apt) and every apartment have access to a park or natural environment within 200 meters.
- Green wedges: connecting Loudden with the RNCP. For both ecological and cultural reasons.
- Open/public space: 50m^2/apartment (instead of 33m^2/apt), located close to the shore line.
- Parking: 2,500 spaces, 0,3/apartment (instead of 0,46/apt).

Figure 6.1. Shows the goals that inspired the created vision for Loudden.

Figure 6.2. The vision for Loudden, created based on the requirements and met goals of previous developments in SRS. Data used: Background (aerial photo), GSD-Ortofoto, ©Lantmäteriet (2015).

In the north western portion of Loudden, close to the existing ferry terminal, commercial office spaces will be built. Since the large ships associated with the adjacent harbour can produce loud noises, these office buildings will act as sound barriers to both school and residential areas just south of them. The office areas are considered to be of less sensitive land use, thus, MKM according to Naturvårdsverket. Parking spaces for these office buildings are located west of Loudden's boundary in Frihamnen.

The old Ford factory in Magasin 10 will be rebuilt to accommodate a F-9 school. This is both because of the obvious future need, but also since the building is considered to be worthy of protecting and keeping for cultural reasons. For similar reasons, the old hangar will be saved, but modified to possibly contain a shopping centre for food and other services. Cistern 1 and 2 are saved for cultural usages in the future, like museum or similar activities. The school is considered to be of sensitive land use: KM, and the other saved cultural heritage buildings are considered to be less sensitive land use: MKM.

The already existing railroad tracks are connected to other public transport lines, and will stop at the shoreline square. Other means of transportation will be needed, where walking or cycling will be prioritized above car transport. However, roads will be constructed even though they are not plotted in the vision map and some of the former caverns will be converted into underground car parking. These transport related areas are considered to be of less sensitive land use: MKM.

Green space will be located along the shoreline and three green wedges coming from the RNCP will intersect Loudden and reach into the residential areas. These green spaces are considered to be of less sensitive land use: MKM. However, the green space adjacent on the east and south side of the school is planned to function as a school yard, and therefore considered to be of sensitive land use: KM.

The areas categorized as green space can also be seen as open and public space. However, some areas will be regarded to be open and public but not green. A small square adjacent to the shopping centre and a bigger one, designed to be the heart of Loudden, at the tram stop reaching out towards the shoreline will be constructed. The open and public spaces are considered to be of less sensitive land use: MKM.

Other areas in Loudden will be used as residential areas where offices, pre-schools and shops can be located at the ground floor if needed. All the areas categorized as residential are considered to be of sensitive land use: KM.

6.2 Contamination situation assessment

Figure 6.3. Assessment of the current contamination situation of Loudden. Divided into three different categories based on previous sampling sites (figure 5.2) and an assessment of hydrological and geological prerequisites of the area. The three different categories are in relation to each other. Data used: Background (aerial photo), GSD-Ortofoto, ©Lantmäteriet (2015).

In the investigated areas (at the oil harbour), pollutants exist in the soil as well as in the groundwater. The main pollutants are different types of petroleum hydrocarbons that have been found in varying but high levels, both bound to soil particles and dissolved in groundwater. Additionally, hotspots of free phase oil have been identified as well as high levels of lead.

The current situation at the oil harbour area is impermeable ground, and current leakage of contaminants into the ground is limited to specific non-impermeable areas. The historic situation has implied a gradual increase in hard surfaces due to the expansion of the oil harbour. Shown in figure 6.3, the eastern part of Loudden is red and classified as majorly polluted. The reasoning of this is the fact that cisterns were previously placed on soft ground where leakage of contaminants would likely penetrate the soil. The cistern area consists, for the most part, of unsaturated soil of a depth between 0 and approximately 3 meters.

Within the oil cistern area, lower contaminant levels have been measured (figure 5.2). However, it is possible that some of these tests are outdated, and without detailed mapping of the soil contamination within this area they have been regarded and classified as major polluted. Exceptions shown in yellow in figure 6.3 are likely to be contaminated to a lesser extent or by no direct leakage to the areas. The yellow patch in the eastern part and in the north western part of the red area have been shown to be free of contaminants exceeding KM norms according to testing. The north-western yellow area is exposed bedrock and the eastern is located relatively far away from a contaminant source. However, they are classified as intermediately polluted areas because of measurement uncertainty and the possibility of contamination migration into the areas.

The soil west of the cistern area is at a lower elevation with a relatively deep soil depth of up to 10 metres, consisting of either till or clay. The subsurface and groundwater flow is believed to follow the natural gradient of the area, which means that a subsurface flow from the higher elevated cistern areas towards (west) the lower elevated areas is likely. This includes flows in both saturated and unsaturated zones, as well as within the bedrock. Possible subsurface transport of contaminants is believed to present a reasonable scenario of pollution transport from the east towards the centre part of Loudden, it is therefore likely that the lower areas have an additional contaminants originating from the cistern areas.

Further, the intermediately polluted area (yellow) at the middle of Loudden is concluded as a possible subject of contaminant migration and subsurface transport from the oil harbour as is described above. But also, from the historical activities of the container terminal (figure 6.3). This increases the risk of a more complex and heterogeneous contaminant situation in the areas categorized as intermediate polluted at the centre of Loudden, with a high level of uncertainty of what contaminants are present.

The intermediate (yellow) polluted areas discussed above and the major (red) polluted areas surrounding the old hangar are both areas where there has been a lack of pollution information. Although, according to Länsstyrelsen (2013a; 2013b) the old seaplane port has been associated with harmful substances such as halogenated solvents and aviation kerosene, but there are uncertainties of whether these contaminants have polluted the ground or not. It is possible that some contaminants north of the hangar have been buried during the filling of the bay.

The pollution situation at the caverns vary, depending on their purpose and historical use. Ongoing plans for remediation of the caverns exist and some remediation measures has already taken place (Golder Associates, 2015). This report will only encourage further and detailed investigations regarding the caverns for using them as underground parking space. But they are not considered in the subsequent part of the report concerning different suitable remediation techniques.

6.3 Remediation methods suitability analysis

The matrix below was constructed with the purpose to analyse and evaluate which of the remediation methods are most suitable at Loudden. The contaminants in the matrix are based on previous soil samples and common contaminants related to past and present industries in Loudden. The parameters used in the matrix are: time, environmental impact, soil suitability and whether the method reaches the saturated zone.

- The time parameter evaluates the average amount of time it takes to perform the remediation technique.
- Environmental impact is the potential for the remediation method to have detrimental effects on the environment; considers off-site activities and factors such as energy use, transportation of materials, and the potential for contaminants to further spread.
- Soil suitability is defined as whether or not the remediation method is effective based on the soil types found in Loudden.
- Saturated zone determines whether or not the remediation method treats contaminants that are found below groundwater level.

Table 6.1. The investigated remediation method's abilities to treat the known contaminants, and an evaluation of each method's time, environmental impact, soil suitability, and application below groundwater level.

Remediation methods	Contaminants							Parameters			
	PAH	Light aliphatics	Heavier aliphatics	BTEX	Light aromatics	Heavier aromatics	Lead	Time	Env. impact	Soil suitability	Saturated zone
Air sparging, in-situ	x	x		x	x						
Soil wash, in-situ		x	x	x	x	x	x				
Soil vapor extraction, in-situ		x		x	x						
Multiphase extraction, in-situ		x	x	x	x	x					
Phytosanification, in-situ:		x	x	x	x	x	x				
Chemical oxidation, in-situ	x	x	x	x	x	x					
Biosparging, in-situ:			x	x		x					
Biological treatment, in-situ		x			x						
Thermal treatment, in-situ:		x	x	x	x	x					
Thermal treatment, ex-situ:	x	x	x	x	x	x					
Landfill, ex-situ	x	x	x	x	x	x	x				
Soil Wash, ex-situ	x	x	x	x	x	x	x				

Time	Years
	> 1
	< 1-3
	< 3

Env. impact	Grade
	Minor
	Intermediate
	Major

Soil suitability	Description
	Suitable for both types of soil
	Is mostly applicable on one of the two soil types (performs good at one type of soil and less effective for the other type)
	Less effective on both sandy till or clay

Saturated zone	Functional
	Yes
	No

6.4 Overlay analysis

The overlay analysis (figure 6.4) is the result from combining the constructed vision map (figure 6.2) and the contamination situation in Loudden (figure 6.3). The overlay analysis shows to what extent each part of the area is contaminated and if it needs to be remediated to fulfil KM or MKM.

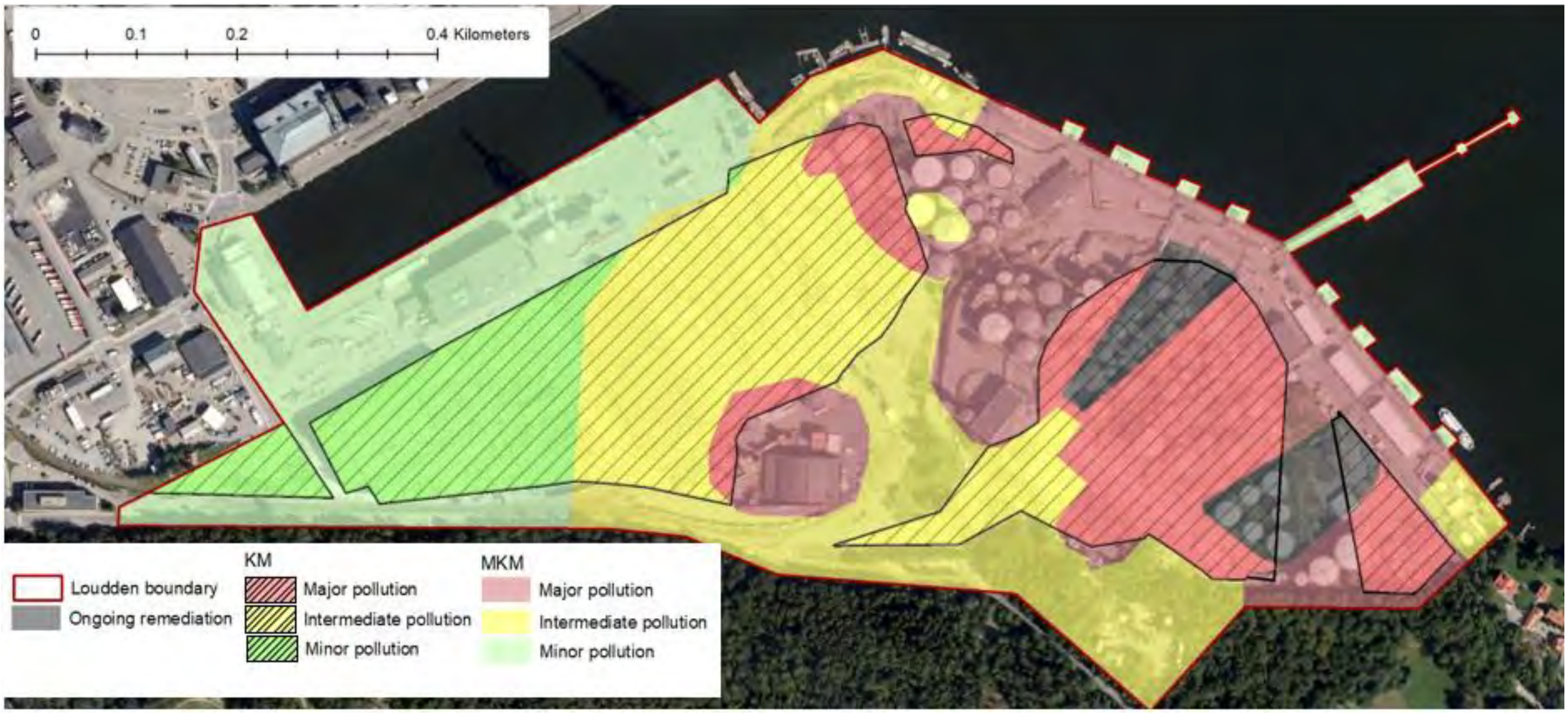

Figure 6.4. *Overlay analysis based on figure 6.2 and 6.3. The figure shows remediation needs to fulfil KM and MKM, where striped areas are KM, and the assessed current contamination situation, where the colours green, yellow, and red represent the level of pollution. Data used: Background (aerial photo), GSD-Ortofoto, © Lantmäteriet (2015).*

If development is adopted according to the vision, there will be multiple areas where the highest ground quality, KM, will be situated at what is categorized as major polluted areas (striped red in figure 6.4). This is where the remediation needs are the highest, for example, at the residential areas located east on Loudden. It is possible that an intermediately polluted area where KM will need to be reached (striped yellow), will need the same extent of remediation as a red MKM area, because of the higher ground quality demands; this all depends on the actual contamination levels found at specific sites. It is evident that a larger extent of the major polluted areas requiring KM quality (red striped), incorporates an area of low soil depth (figure 5.3, 6.4). This eases the remediation efforts to obtain the KM quality norms. The green areas are where the remediation needs are believed to be the lowest, however, this category is also where the uncertainties of the actual situation are the highest.

6.5 Recommended remediation method to reach vision

In order to determine a suitable remediation plan, the overlay analysis (figure 6.4) and the matrix (table 6.1) were analysed. The most suitable remediation solution for Loudden is considered to be soil wash ex-situ and chemical oxidation, alternatively together with soil wash in-situ if needed. The reason why this report suggests soil wash ex-situ together with a combination of chemical oxidation is to prevent landfill, increase the re-use of soil, and to cause as little environmental impact as possible. Using these methods also fits into the time plan Stockholms stad has intended for the development of Loudden, where the first residents will move in by 2025 and the entire development completed in 2030. Excavating and cleaning the soil off-site is a relatively well-tested method in Sweden for oil and PAH contaminated soil (SGF, 2019b). For example, an extensive environmental remediation project in Alvesta resulted in 12,500 tons of refined soil with this method (Alvesta Kommun, 2009).

Soil wash ex-situ involves excavation and transportation, activities that can have a big ecological footprint (table 6.1). However, since there is a mass logistic centre (MLC) at Frihamnen, located approximately half a kilometre from Loudden, where the treatment can take place, the transportation in this case will not be far (section 5.3). Due to the availability of the MLC, the method is considered to only have an intermediate environmental impact. It should be noted that the current plans for the MLC does not include treatment but solely sorting of masses, and that changing the intended use of the MLC would require an authorization procedure. To make the method even greener, it is recommended to use green energy to aspire for a more sustainable development in line with the goal of Stockholm Royal Seaport to be a model sustainable urban area, where climate adaptation and fossil-free energy sources are prioritised.

Regarding chemical oxidation, different oxidants can be used; in this report, the most suitable oxidants have not been investigated and will therefore be a part of future work. Chemical oxidation will work for all of the found pollutants on Loudden except for lead, and has proven to show good results in similar remediation processes (table 6.1). For example, in

Moheda, in southern Sweden, where relatively large areas used to be polluted with petrol fuels. Monitoring work in Moheda showed that significant reductions in contaminants have been obtained in areas where high levels of aliphatics, aromatics and BTEX were initially detected (RGS 90, 2015).

At all areas of major pollution (red in figure. 6.4), the use of soil wash ex-situ is concluded to be suitable for the upper level of the ground and down to approximately one meter. A large part of the majorly polluted areas (red) consist of ground with low soil depth; this reduces the amount of soil that requires treatment and therefore reduces overall treatment time and cost. Soil wash ex-situ will remediate all of the known pollutants found within the area and is one of few methods that also treats lead and PAH. From around one meter and downwards, chemical oxidation will be used to reach contaminants found at a deeper level in the ground. Chemical oxidation works for all of the found pollutants, except for lead, with the benefit of not having to excavate more than necessary since soil wash ex-situ has a worse environmental impact compared to chemical oxidation. Also, soil wash ex-situ can increase the risk of contaminants spreading to adjacent areas due to the movement of soil during the necessary excavation.

The study suggests further testing to see whether lead is found at a deeper level than one meter; if so, the chemical remediation should be complemented with soil wash in-situ in order to remove the lead. It was found in earlier studies that chemical oxidation and soil wash in-situ are two methods that complement each other (SGF, 2018f). The combination of soil wash ex-situ and chemical oxidation, together with soil wash in-situ if necessary, will be used on both areas with KM and MKM norms, due to the fact that they are heavily contaminated.

In the areas with intermediate pollution (yellow in figure 6.4), there are certain areas that will have to fulfil KM (striped yellow). On these sites, soil wash ex-situ and chemical oxidation will be used for remediation in the same way as they will be on majorly polluted areas. The method used for the rest of the yellow area MKM norms, will only consist of chemical oxidation due to the fact that these areas are only considered to be intermediately polluted and no excavation and soil wash will be needed in order to reach acceptable levels. By only using chemical oxidation, the treatment will have lesser environmental impact.

In the green area with minor pollution, there is certain places where it is crucial to reach KM due to building of schools and residential areas (striped green in figure 6.4). Considering the need to reach KM, it is recommended to perform further tests to investigate the level of pollutants. In this report, the overlay analysis has shown that the ground underneath the location of the school and some of the residential housing areas only has minor pollution. If this result is in line with the actual situation, which is something that will have to be proved with further tests, it would be suitable enough to treat the soil through chemical oxidation. However, due to the history of industry in Loudden, there is a risk that the minor polluted area (green in figure 6.4) may be polluted more than predicted, and considering the planned future usage of the site more testing should be conducted. If further investigation will show that the green areas are polluted to a larger extent, it is recommended to perform soil wash ex-situ on the upper level of the soil.

Furthermore, remediation will also be incorporated into the planning of the area through the extensive planting of selected trees and other plants that promote phytosanification. This process can take several decades, but will work as an extension of the remediation work into the future. The purpose of phytosanification is to create an area that not only meets the acceptable norms, but also leads to an even better and healthier environment. Another secondary effect of further remediation beyond the norms is increasing the environmental as well as the economic value of the area.

Monitoring

In order to assure that the level of contaminants is kept within the guideline norms, it is recommended that follow-up work should take place. As a safety measure, samples of the soil should be regularly taken and tested in order to analyse the level of pollutants. When excavating, there is always a risk for pollutants spreading, due to the movement of earth. Another known risk with soil wash ex-situ is that this method can increase the risk of leaching (SGF, 2018g).

Monitoring work is also important to see if the result of the chemical oxidation is reached and kept below KM or MKM. One known disadvantage is that several injections of the oxidants is often needed, due to the fact that the oxidation solution are broken down as a part of the process. Therefore, large amounts of the oxidant are commonly needed, which in itself can result in a surplus left in the soil, inhibiting biological processes in the ground or form toxic substances during the degradation of pollutants (Nilsen, 2013; RGS-90, n.d.).

Regarding the phytosanification, a maintenance plan regarding how the biomass shall be handled is necessary to make sure that the pollutants in the biomass are taken care of. It is recommended that the accumulated contaminants are managed by either composting or combustion.

Sustainability “of the development and plan”

One major objective of SRS is to be a world-class sustainable area, thus, it is important to consider the environmental impact of the chosen remediation methods. This includes energy use, transportation of materials, carbon emissions, and the risk for further spreading of pollutants.

In the developed vision, stricter objectives have been implemented than in the previously developed areas like Hjorthagen. For example, a higher proportion of green area and open space per dwelling and fewer parking spaces.

Uncertainties and limitations

There are several uncertainties and limitations encountered in this report, the main reason being a lack of information. When planning environmental remediation, a large component of the process is collecting extensive knowledge of the contaminants in the area by sampling. Although many conclusions in this report were drawn from Golder Associates’ (2015) compilation of data addressing the contamination of the oil harbour, there is a lack of information regarding the container terminal, and some of the information is outdated, so there is a chance the situation has changed. As a result, many assumptions about the pollutants and the potential for dispersion were extrapolated from knowledge of the area, the industries present, and their typical contaminants.

The removal and changing of hard surfaces in the cistern area will lead to areas of increased water infiltration. It is not yet known if this will affect any deeper accumulated contaminants. At depths and minor water flow contaminants can be stable. However, increased infiltration may cause spreading because of an increased subsurface flow. Any implications of this should be determined before remediation measures are taken. Secondary sources like this or possible contaminant hotspots can cause future remediation implications, if not taken into account.

Migration of contaminants in the soil has not been thoroughly investigated in this report. Creating a buffer zone when treating KM areas, as a small overlap into the MKM classified areas, could prevent any contaminant migration from less remediated areas into areas of more sensitive land use.

Another limitation of the study was cost consideration. The cost of remediation methods is extremely site-dependent with respect to contaminant levels and depth, soil type, soil permeability, and hydrologic conditions, so it is very difficult to estimate. As a result, costs have not been considered in this report, even though it is likely to have a big impact on the choice of treatment methods. However, since SRS strives to be a leader in sustainable development, costs should not be the deciding factor when it comes to environmental remediation.

In general, the contamination situation (section 6.2) consists of uncertainties and should ideally be regarded as a basis for further investigation, rather than a basis for remediation methods and plans suggestions, as it has been in this report. Since the levels and types of contaminants is clearly key information when investigating remediation actions, it is suggested that further testing is done within the whole area, with the focus of the testing pointed towards future KM areas and their surroundings.

6.6 Possible future outcomes

Further investigations can result in a change in the suggested remediation plan due to new findings; for example, higher levels or a wider extent of known pollutants than what was found in previous samples. Findings of new contaminants may require other remediation methods that have not been discussed in this report. A revision of the developed vision for Loudden could be necessary if the contamination situation assessment changes from new sampling. For instance, it can be difficult to reach the strict requirements of KM in certain highly polluted areas, and therefore changing the use of a specific area to MKM instead of KM can be seen as an effective and adaptive approach.

7. Conclusion

Development according with the vision is feasible, based on the contamination situation and the suggested remediation approach. It also fits into the timeframe for development as set by Stockholms stad, where Loudden is intended to be a completed development by the year 2030. The chosen remediation methods have been proven to work in similar projects and are therefore applicable in Loudden. The overlay analysis (figure 6.4) can be helpful to minimise and specify the need for effective remediation due to different requirements for different land uses. In certain areas, it is not necessary to fulfil the highest standards which therefore can reduce the cost and be more time efficient for the developer.

In conclusion, the suggested short-term remediation methods consist of chemical oxidation and soil wash ex-situ. The short-term methods are necessary to achieve EQNs and make it possible to start the development. However, if during the treatment process, lead is found at a deeper level than a metre, soil wash in-situ will be used locally to minimise the environmental impact. The methods will be used to different extents depending on the level of pollutants in a specific area and what the future land use will be at that site. Phytosanification will work as a long-term treatment for Loudden to assure that the pollution levels are kept under the recommended EQNs and to improve the quality of the soil beyond the norms.

However, sampling at areas that have not been tested for contaminants is needed to provide a solid basis for the remediation plan, as the existing samples only address a minor part of Loudden and with varying reliability. Therefore, new testing is important to strengthen and verify the contamination assessment in this report. New results could, however, potentially lead to conflicts between the planned land use and the current contamination situation and would require an adaptation of the vision of Loudden.

Therefore, due to the uncertainties and limitations encountered in this project, this report should be regarded as a basis for further investigation rather than a basis for the remediation plan.

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