Sveriges lantbruksuniversitet
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Remediation of contaminated sites within development projects in Uppsala
– A study of current working procedure and practices

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Master's Thesis in Soil Science
Soil and Water Management – Master's Programme

Examensarbeten, Institutionen för mark och miljö, SLU
2017:05

Uppsala 2017

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Credits: 30 ECTS
Level: Second cycle, A2E
Course title: Independent project/degree project in Soil Science - Master´s thesis
Course code: EX0430
Programme/Education: Soil and Water Management – Master's Programme 120 credits

Place of publication: Uppsala
Year of publication: 2017
Title of series: Examensarbeten, Institutionen för mark och miljö, SLU
Number of part of series: 2017:05
Online publication: http://stud.epsilon.slu.se

Keywords: cleanup, brownfield, risk assessment, environmental superintendence, contaminated soil

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Abstract

Contaminated sites are commonly remediated as a response to development plans of former industrial areas. General guidance, valid for all types of contaminated sites, is provided by the Swedish Environmental Protection Agency (SEPA). This thesis has investigated the working procedure and practice of cleanups within development projects, with the purpose of discussing the applicability of the SEPA guidance for such cleanups, as well as, identifying potential consequences from deviating from the guidance. The study includes twelve cleanups in Uppsala. Material in form of investigative reports and official documents about the cleanups were collected at the Environmental Office at the Municipality of Uppsala. The material was analyzed with the SEPA guidance as reference. The determining factor of how cleanups were performed, was found to be excess of soil within the development projects, due to underground constructions. As a result of this, dig and dump was the prevailing remediation technique in all of the studied cleanups. It is clear that a practice for cleanups within development projects in Uppsala has evolved between the Environmental Operational Authority (EOA) and the Environmental Consultancy Companies (ECC) in Uppsala. The practice is in many ways effective in regards of transparency and consequent superintendence of cleanups. However, it is concluded that there is room for improvements concerning statistical analysis of data and increased use of site specific guideline values for soil that is left or reused on site. Furthermore, the perception differs of how the SEPA guidance should be applied on cleanups within development projects, between the EOA and ECC, but also between ECCs. In addition, it seems as individual preferences, as well as, the time available for investigations, decide the level of investigations, rather than the actual conditions. In conclusion, there is a clear need for a guidance from SEPA that focuses on cleanups within development projects.

Keywords: Cleanup, brownfield, risk assessment, environmental superintendence, contaminated soil

Sammanfattning

Förorenade områden saneras mer och mer i anslutning till exploatering av före detta industriområden. Naturvårdsverket (NV) tillhandahåller vägledning om efterbehandling av förorenade områden. Vägledningarna är generella och ämnade att kunna användas för alla typer av förorenade områden. Denna studie har undersökt arbetssätt och praxis vid efterbehandling inom exploateringsprojekt, i syfte att diskutera tillämpbarheten av NV:s vägledningar, samt eventuella konsekvenser av att avvika från dem. Studieområdet för uppsatsen var Uppsala och inkluderade tolv efterbehandlingsprojekt. Material i form av rapporter och officiella dokument om efterbehandlingsprojekten inhämtades från Miljöförvaltningen i Uppsala. Materialet analyserades med NV:s vägledningar som referensnivå. Den dominerande faktorn för hur efterbehandling inom exploateringsområden utfördes var massöverskott inom exploateringsprojekten, på grund av konstruktioner under mark. Följaktligen var schaktsanering den rådande saneringstekniken i samtliga efterbehandlingsprojekt. Det är tydligt att en praxis för genomförande av efterbehandlingsprojekt i exploateringsprojekt har utvecklats i Uppsala mellan tillsynsmyndighet och miljökonsultföretag. Denna praxis är i många aspekter användbar då den erbjuder transparens och ett konsekvent utövande av tillsyn. Däremot har denna uppsats visat på förbättringsmöjligheter gällande tillämpning av statistik samt ökad nyttjande av platsspecifika riktvärden för jord som lämnas kvar eller återanvänds inom samma område. Vidare konstaterades att uppfattningen skiljer sig åt om hur NV:s vägledningar bör tillämpas för efterbehandling inom exploateringsprojekt, både mellan tillsynsmyndighet och konsultbolagen, men också emellan konsultbolag. Dessutom noteras att individuella preferenser hos de inblandade parterna, samt hur mycket tid som finns tillgänglig, påverkar omfattningen av utredningar, istället för de faktiska förhållandena. Slutsatsen är att det finns ett tydligt behov av en vägledning från NV som fokuserar på efterbehandling inom exploateringsprojekt.

Nyckelord: Efterbehandling, ruderatmark, riskbedömning, miljötillsyn, förorenad mark

Populärvetenskaplig sammanfattning

Industrier har bidragit till att det förekommer ett stort antal förorenade områden i Sverige. I en inventering som länsstyrelserna ledde mellan åren 1999 till 2015, bedömdes totalt 24 000 förorenade områden utgöra en risk för människor eller miljön. Det är Naturvårdsverket (NV) som koordinerar det nationella arbetet med förorenade områden i Sverige, men en rad andra myndigheter är involverade såsom Sveriges geologiska undersökning, Statens geotekniska institut och Kemikalieinspektionen. Kommuner och länsstyrelser har tillsynsansvar över miljöfarliga verksamheter, vilket innebär att de leder det operativa arbetet och ser till att ansvariga ställs till svars och bekostar undersökningar och eventuella saneringar av förorenade områden (efterbehandling).

NV har publicerat vägledningsdokument för hur undersökningar, riskbedömningar och sanering av förorenade områden ska utföras. Dessa vägledningar är generella och ska vara tillämpbara på alla sorters förorenade områden. Den här studien visar dock att det finns ett tydligt behov av en vägledning som bara gäller efterbehandling inom exploateringsprojekt. Detta eftersom efterbehandling av förorenade områden inom exploateringsprojekt skiljer sig från andra typer av efterbehandlingsprojekt på t.ex. landsbygden, då exploateringsprojekten ofta är tidsbegränsade. Utvärdering av olika saneringsmetoder och undersökningar är därför inte alltid tillämpliga.

Denna skillnad gör att det är otydligt vilka delar av de gällande vägledningarna som ska användas. Enligt denna studie som baseras på genomförda efterbehandlingar i Uppsala, har detta resulterat i att olika personer och aktörer har olika uppfattning om vad som gäller. Ibland genomförs t.ex. riskbedömningar, i andra fall inte alls. Studien visade även att provtagningsdata sällan analyseras med statistiska metoder, trots att föroreningar inom exploateringsområden ofta är ojämnt fördelade med avseende på föroreningskoncentrationer. Dessutom utgår man inte från platsspecifika förutsättningar speciellt ofta när beslut tas och skydd av markmiljö utreds sällan.

Studien utfördes genom att systematiskt gå igenom hur efterbehandling av förorenade områden har utförts inom exploateringsprojekt i Uppsala. Arbetssätt och praxis identifierades, för att undersöka om NV:s vägledningar efterföljdes och vilka konsekvenser som kan uppstå av att inte följa dem. Dessutom utvärderades tillämpbarheten av NV:s vägledningar på exploateringsprojekt. Enligt studien, är det tydligt att det har uppstått en praxis i Uppsala för hur efterbehandling inom exploateringsprojekt ska genomföras. Arbetssättet präglas av transparens samt konsekvent handledning från tillsynsmyndighetens sida. Frågan kvarstår dock om detta sker i enlighet med vad NV rekommenderar. Innan en tydlig och enhetlig vägledning ges ut som enbart riktar sig mot efterbehandling inom exploateringsprojekt, kommer branschen fortsätta att själva bedöma vad som gäller, vilket leder till att olika tillämpning tillåts i olika delar av landet.

Glossary and abbreviations

English	Swedish	Abbreviation
Remedial action plan	Handlingsplan	
Environmental Operational Authority	Miljötillsynsmyndighet	EOA
Backhoe pit	Provgrop	
Brownfield	Ruderatmark	
Cleanup	Efterbehandling av förorenade områden	
Continuous flight auger	Skruvborrning (med borrbandvagn)	
Dig and dump	Schaktsanering	
Environmental Consultancy Companies	Miljökonsultbolag	ECC
Feasibility study	Åtgärdsutredning	
Generic guideline values	Generella riktvärden	GGV
Guideline Value	Riktvärde	GV
Guideline Value Model	Riktvärdesmodellen	GVM
Less sensitive land use	Mindre känslig markanvändning	MKM
Method for inventory of contaminated sites	Metod för inventering av förorenade områden	MIFO
Order	Föreläggande	
Protection target	Skyddsobjekt	
Quantifiable remedial objectives	Mätbara åtgärdsmål	
Remediation goals	Övergripande åtgärdsmål	
Remediation technique	Åtgärdsmetod /saneringsmetod	
Representative value	Representativ halt	
Risk assessment	Riskbedömning	
Risk evaluation	Riskvärdering	
Sensitive land use	Känslig markanvändning	KM
Site specific guideline values	Platsspecifika riktvärden	SSGV
Soil investigation plan	Provtagningsplan	
Superintendence	Tillsyn	
Swedish Environmental Protection Agency	Naturvårdsverket	SEPA

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APPENDICES

1 Introduction

Throughout time, anthropogenic actions have caused introduction and accumulation of pollutants into the environment. A famous example is the Roman Empire where people experienced severe health related issues coupled to the extensive use of led (Selenius, 2010). Today we face even bigger environmental and health related issues from the chemically produced substances that have been introduced to the environment, some of which are very toxic and persistent. Industries have contributed largely to the accumulation of pollutants in the environment, especially during the middle 1900's due to lack of both knowledge of the harmful effects and environmental regulations. This is something we now have to manage and try to mitigate.

Remediation of contaminated sites (cleanup) is important for several of the 16 environmental quality objectives set by the Swedish Parliament (SEPA, 2016). Whereas the most relevant goal is "A Non-Toxic Environment", the goals "A Good-Quality Groundwater" and "A Good Build Environment" are also benefited by remediation of contaminated sites (Lindén *et al.*, 2014).

The Swedish Environmental Protection Agency (SEPA) have funded an extensive and systematic inventory of potentially contaminated sites in Sweden. In this inventory about 24 000 sites have been identified which potentially pose a risk to human health or the environment due to contaminants. About 8 000 of the sites are prioritized to be investigated further due to the potentially high risk they pose to human health and the environment (Carlbom *et al.*, 2016). The work with contaminated sites is regulated in the Environmental Code (Sw. Miljöbalken SFS 1998:808, "MB") and in guidance by SEPA. The guidance present a general procedure of how to work with cleanup (SEPA, 2009c; SEPA, 2009b; SEPA, 2009a). However, the procedure may differ depending on factors such as geology, geographic location and time. A cleanup within a development project has different starting conditions than a cleanup at the countryside, with respect to time and possible investigations and remedial solutions (Sweco, 2009).

Development projects in cities are increasingly located at brownfields (previously developed land that is abandoned or underutilized, often associated with existing infrastructure and contaminants) (Lesage *et al.*, 2007). There is a vast demand for land in the cities on which new residences and offices can be constructed. Thus, former industrial land, which for a long time has been considered to be brownfields, are now seen as assets (Morais & Delerue-Matos, 2010). For this reason, it has since 2016 been possible to apply for funding from SEPA for a cleanup that results in increased construction of residence houses. A prerequisite to get the funding is that no one can be found legally responsible to pay for the cleanup (SEPA, 2016).

With the increased development of brownfields, where extensive cleanup actions may be needed before development, it is important that the working procedure with such cleanups is effective and clear. However, the guidance from SEPA is general, and does therefore not include guidance about cleanups within development projects specifically. A few studies have investigated the work with cleanups funded by the state (Skår, 2014; Edebalk, 2013) as well as for privately funded cleanups, on a national level (Skår, 2014). However, no study is known to have investigated the working procedure and the field practice that has evolved around cleanups within development projects in Sweden on a local level, where all cleanup projects had the same environmental operational authority (EOA). Such a study would allow for comparison and analysis of the working procedure with contaminated sites within development areas, without interference from the differences that may exist in operational practice at different authorities.

1.1 Purpose

This thesis investigates how cleanups in development projects on brownfields are performed in Uppsala in general, with the purpose of

i) identifying general characteristics of the working procedure in these cleanups,

ii) identify, if any, the general practices that have developed both from the perspective of the environmental consultancy companies and the operational authorities, and the potential advantages or disadvantages with these practices,

iii) investigate if, and to what extent, the cleanup guidance's from SEPA are followed (e.g. regarding initial planning, investigations, guideline values, risk assessment and feasibility study) and the potential benefits/drawbacks of deviating from the official guidance material.

1.2 Delimitations

The study will focus on cleanups within development areas in the city of Uppsala. This is due to 1) the same operational authority allows for a unified comparison between the cleanups and 2) practical reasons such as access to information.

Additionally, the cleanups should:

- Be completed,
- be located at a brownfield,
- be part of a development project,
- not exist of a small, single, hot spot.
- Additionally, the remediation should be performed after 2009, since the updated risk assessment guidance and the model to calculate guideline values was released in 2009 by SEPA (SEPA, 2009c; SEPA, 2009b; SEPA, 2009a).

2 Theory

2.1 Cleanup of contaminated sites in Sweden

The development of a uniform method for cleanups in Sweden was initiated in 1990, when SEPA was commissioned to present a plan for the remediation of contaminated sites in Sweden (SEPA, 1999). The definition of a contaminated site according to SEPA (2009c) is when the contaminant levels exceed background levels. However, this may still not mean that there are risks for human health or the environment. Risk assessments of contaminated sites are performed to estimate if a potentially contaminated site pose a risk to human health or the environment.

It is the probability of exposure to a contaminant in hazardous concentrations that is determining the risk. Even if there are extremely high levels of a contaminant at a site, but the probability for exposure is not existing, or extremely low, there is no prevalent risk (SEPA, 2009c). An example of this are low-energy bulbs, which contain the toxic metal mercury. We have those light bulbs around us in our everyday life, but they are not posing any significant risk if they are not broken. Thus, it is important that the risk is considered from a neutral perspective, unbiased from the negative perception the word “contaminated” brings with it.

The general investigation steps for a contaminated site are: identification, classification, risk assessment (basic and/or detailed), feasibility study and finally remediation. The following sections will describe the principles and regulations regarding how contaminated sites are managed in Sweden today.

2.1.1 Identification

Contaminated sites are in general identified by either the authorities in their superintendence or in the context of development projects. Additionally, the County Administrative Boards (Sw. “Länsstyrelserna”) have managed a national inventory to identify potentially contaminated sites, which was carried out between the years 1999 to 2015. The inventory was based on an identification of industries and other actors that may have caused contamination (Carlbom *et al.*, 2016).

2.1.2 Risk classification

The inventory of contaminated sites that the County Administrative Boards managed between 1999 to 2015, identified approximately 81 500 sites as potentially contaminated (Carlbom *et al.*, 2016). In order to prioritize among these, a guidance for risk assessment was published by SEPA in 1999, in which the MIFO method (Method for inventory of contaminated sites) is described. MIFO is divided in two phases: MIFO 1 and MIFO 2. In both phases, the site is given a risk class between 1 and 4, where class 1 signifies “very large risks for human health and the environment" and class 4 signifies "small risks for human health and the environment". MIFO 1 presents an overview of the potential risk situation based on accessible information about the site, such as historical information, maps, geologic information, oral information etc. However, no field samples are taken or analyzed. If the site is placed in risk class 1 or 2, it is generally considered that further investigations are required (MIFO 2 phase), where a basic risk assessment is performed, to investigate the potential risk further, including a basic sampling strategy (SEPA, 1999).

The MIFO phase 1 classifications of the 81 500 potentially contaminated sites was finished in 2015. The result was that approximately 24 000 sites were given a risk class between 1 and 4. The remaining sites were assessed to not pose any significant risk to human health or the environment. Among the risk classed sites, 1 000 were placed in risk class 1 and 7 000 in risk class 2 and will be prioritized for further investigations (Carlbom *et al.*, 2016).

By the end of 2016, about 3 100 of the sites that were given a risk class, had been remediated or partly remediated. Some financed by the state, others by a legally responsible operator or land owner (SEPA, 2017a). One of the national goals for the environmental objective "A-Non-Toxic Environment", is that all sites given a risk class 1 and 2 shall be remediated by 2050 (Carlbom *et al.,* 2016).

2.1.3 General risk assessment procedure

Since the purpose of the MIFO method was to prioritize objects and only included a basic risk assessment, further development of a general risk assessment procedure in Sweden was sought for. Therefore, updated guidance about cleanup of contaminated sites was published by SEPA in 2009, including updated generic guideline values (GGV) (SEPA, 2009c; SEPA, 2009b; SEPA, 2009a). Additionally, these GGV was published together with, what is known as, the Guideline Value Model (GVM). The GVM has since then been free to use for everyone, which has contributed to more comparable and transparent risk assessments (SEPA, 2009b).

The Swedish risk assessment methodology follows a tiered risk assessment approach, which means that it is divided in different levels, depending on the need for investigations. In the guidance, they are described as basic and detailed, but both the basic and the detailed assessment include several levels respectively, which are performed when needed. In that way, unnecessary investigations may be avoided if it can be concluded at an early stage that a site does not pose a risk to human health or the environment (SEPA, 2009c).

The risk assessment is based on four different parts; problem description including a conceptual model, exposure analysis, effect analysis and risk characterization. Finally, a conclusive risk assessment is presented. Each part contains a number of different questions and analysis, depending on relevance for the site (Figure 1) (SEPA, 2009c).

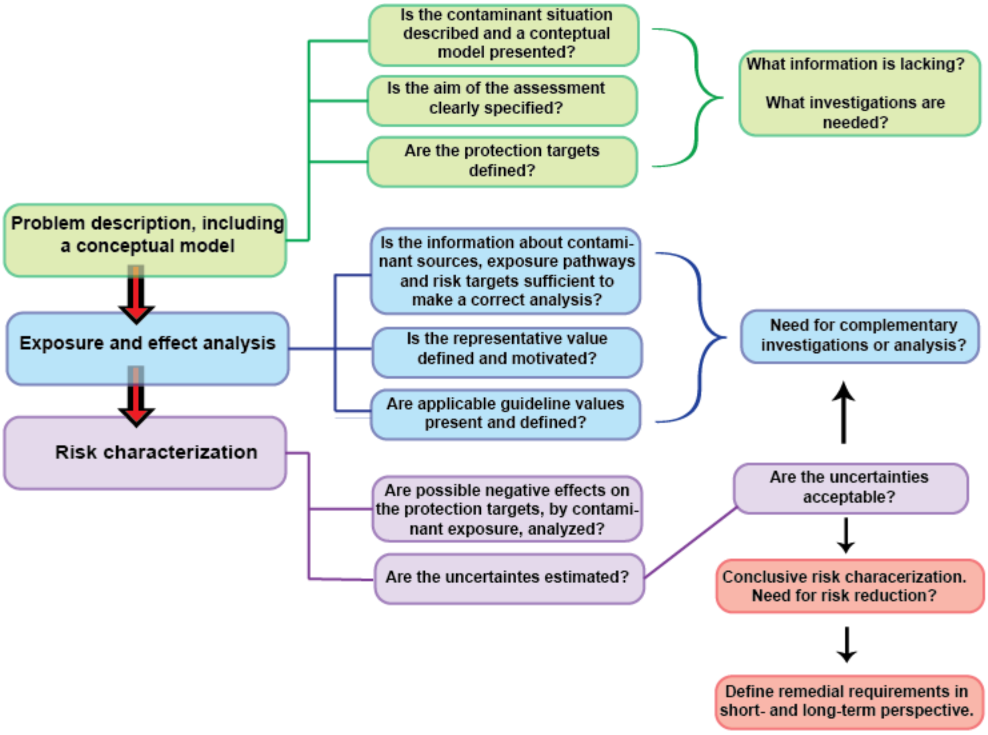

Figure 1. Flow scheme of the general risk assessment procedure. Based on SEPA (2009c)

The *problem description* present an overview of the site, independent of the level of the risk assessment. By gathering information about the contaminant, potential contaminant plumes, exposure pathways, protection targets and future land use scenarios, a first estimation of the risk can be performed. The conceptual model visualizes the potential risk, since it shows the protection targets in relation to the occurring exposure pathways. The protection targets are human health, the soil ecosystem, groundwater and surface water (Figure 2). The problem description also identifies possible data gaps or need for further investigations (SEPA, 2009c).

When the problem description is completed, an *exposure* and *effect analysis* is performed. An effect analysis investigates the level of contaminant that a protection target can tolerate before any harmful effects occur. Effect analysis of human health is determined by dose-response data. The dose-response relations are used to calculate a tolerable daily intake (TDI). Effect analysis of the soil ecosystem are based on dose-effect data from ecotoxicological studies (SEPA, 2009b).

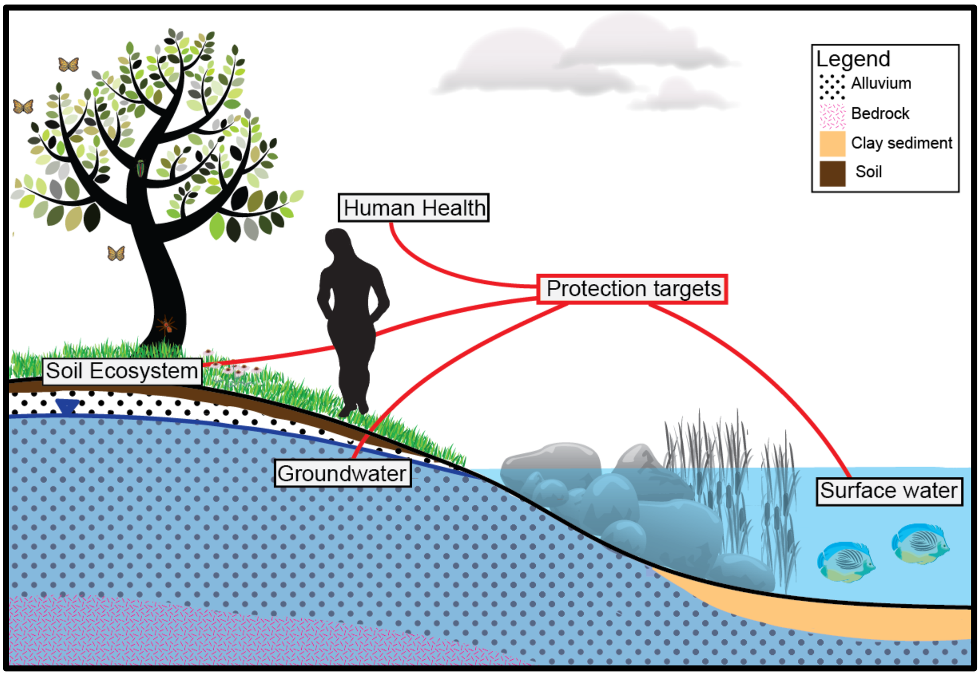

Figure 2. A conceptual model of the four protection targets included in the Swedish risk assessment methodology

Furthermore, to determine what concentrations of contaminants that a protection target is actually exposed of, an exposure analysis is conducted. First, the exposure pathways, from the contaminant source to the existing protection targets must be defined. This is important because if there are no exposure pathways present between the source of contamination and the protection target, there is no present risk of exposure. However, the exposure pathways must be defined according to the intended future land use, both in a short and a long-term perspective (SEPA, 2009c).

The GVM includes the following possible exposure pathways for the protection target human health: inhalation of vapor, inhalation of dust, ingestion of soil, dermal intake, intake of drinking water, ingestion of fish and ingestion of plants (Figure 3).

The physical and chemical properties that govern the contaminant transport to a protection target (Figure 2) vary for the different protection targets as well as exposure pathways. Therefore, a variety of different equations for the exposure analysis of different protection targets, exist. Detailed information of how the exposure and effect analysis are calculated in the GVM can be found in the guidance about the GVM (SEPA, 2009b).

The GGV include an implicit effect and exposure analysis, based on a generic scenario. Therefore, the sample data can be compared directly with the GGV in basic risk assessments. However, if the risk situation is complex and a detailed risk

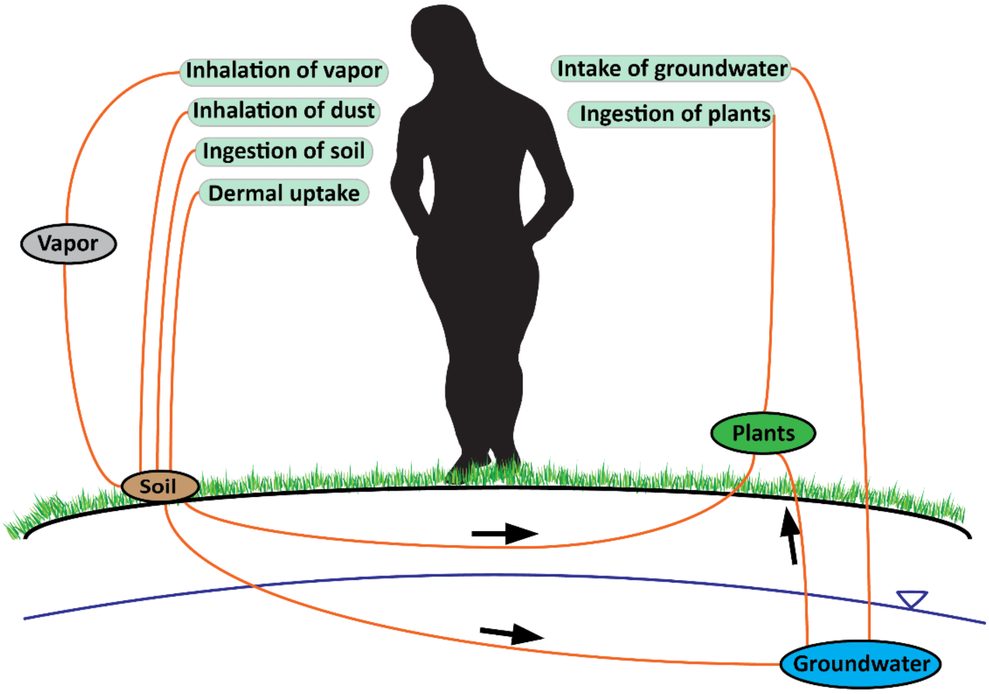

Figure 3. Exposure pathways for the protection target human health. Based on SEPA (2009c)

assessment is performed, ecotoxicological tests and other biogeochemical analysis can be necessary in order to present a correct exposure and effect analysis, representing the site specific conditions (SEPA, 2009c).

When the guideline values (GV) are calculated in the GVM, a GV for each protection target in a given scenario is given as result. However, the most restrictive GV for each contaminant, within a certain scenario, will be the governing GV for that contaminant within that specific scenario. Furthermore, when calculating GV for protection of human health, exposure from the surroundings is considered as well. Because of that, the GVM adjust the GV for human health so that one particular site only allows for 50 % of the tolerable daily intake (TDI). For some substances which are known to have much higher exposure rate in society, such as lead, this value is even lower (SEPA, 2009b).

Finally, the representative value, i.e. the value that best represents the risk situation of a predefined area or volume, without underestimating the risk, must be decided in order to calculate what levels of a contaminant that a protection target is exposed to. The method to analyze the representative value is of high importance, since it affects the outcome of the risk assessment (see section 2.3.3 for further information) (SEPA, 2009c).

As a final step, a conclusion about the risk assessment is presented. It should present the potential need for risk reduction, both in a short- and long-term perspective, including defined requirements for potential remediation measures (SEPA, 2009c).

2.1.4 Basic and detailed risk assessment

According to SEPA (2009c) the level of risk assessment is case dependent. In some cases, a detailed risk assessment might not be needed (see Figure 1). One reason to do a detailed risk assessment is when the contaminant situation is complex in a way that demand further information to evaluate the risk.

In a basic risk assessment, contaminant concentrations are compared either to GGV or to site specific guideline values (SSGV) (SEPA, 2009b). However, if there are no GV available, or if the GVM is not valid due to for example a complex contaminant situation, it can be necessary to do a detailed risk assessment. The risk of not doing a detailed risk assessment when appropriate, but relying only on a basic risk assessment, is that the outcome of the risk assessment becomes of low relevance, with respect to the significance of the estimated risk (SEPA, 2009c).

An example of when a detailed risk assessment may be required is when a pollutant is dispersing in a complex way from a contaminant plume in groundwater. Since the GVM cannot describe complex site specific groundwater flow, measurements and modelling may be needed before the contaminant situation can be understood. In other cases, chemical properties of the soil have to be measured in order to depict the risk situation, such as pH, organic carbon, redox properties and the distribution coefficient (Kd). Examples of analysis included in an advanced exposure analysis is bioavailability, bioaccumulation, biomagnification, degradation and mineralization processes of the contaminant (SEPA, 2009c).

Furthermore, synergetic effects of toxicity when several contaminants are involved is an example of an analysis that can be performed in a detailed risk assessment. Another important part of the detailed risk assessment is to test a hypothesis in different ways, arriving at a so-called chain of events or chain of proof. If several tests show the same results, the significance of the result becomes greater than if only based on one test (SEPA, 2009c).

2.1.5 Generic and site specific guideline values

Representative values that describe the contamination level of the site must be compared with GV which are valid for the site. What GV that are valid for the site must be decided from the fate and transport of the contaminants, in relation to the exposure targets. To facilitate the risk assessment procedure as well as implementing a national standard for GV, SEPA has provided GGV for two general land use scenarios of contaminated soil.

The two generic scenarios are Sensitive Land use (Sw. “KM”) and Less Sensitive Land use (Sw. “MKM”) (Table 1). An area with residences or kindergarten is a typical KM scenario and an industrial area is a typical MKM area. For groundwater and surface water there are also GV, from among others the Swedish geological survey (SGU), the Swedish Agency for Marine and Water Management (SwAM) and the Water Authorities (SEPA, 2009c).

Table 1. Level of protection for the given scenarios sensitive land use (KM) and less sensitive land use (MKM). Based on SEPA (2009b)

	KM	MKM
Exposure:	Full time	Part time
Soil ecosystem:	75 % of species protected	50 % of species protected
Groundwater:	Protected at and nearby the site	Protected 200 m downstream the site
Surface water and aquatic organisms:	Protected	Protected

The generic scenarios include a set of given conditions, such as distance to groundwater and surface water, dispersion of contaminants in groundwater, biochemical properties and exposure pathways. In general, the assumptions for the generic scenarios are such that they are assumed to represent a reasonable worst-case scenario in terms of exposure and transport. If the situation on a site differ significantly from the generic scenario parameters, a site-specific risk assessment should be done in order to arrive at accurate GV. If not, the estimated risk might not be significant (SEPA, 2009b). According to the risk assessment guidance (SEPA, 2009c) the GGV should not automatically be used as quantifiable remedial objectives.

2.1.6 Feasibility study

If a risk assessment concludes that remediation is needed, a feasibility study of possible remediation techniques, including a risk evaluation, should be performed. This is followed by a selection process of remediation technique/s, which leads to new quantifiable remedial objectives and finally a decision about remediation (SEPA, 2009a).

The process for feasibility study consists of:

1. Identification of possible remediation techniques
2. Initial feasibility analysis
3. Detailed feasibility analysis
4. Presentation of Acceptable Remediation Techniques

The initial feasibility analysis considers the remediation goals, the prevailing conditions of the stakeholders, technical possibilities and goal achievement. The detailed feasibility analysis consider costs, risks during and after the remedial operation and disturbance. Disturbance in this context are factors such as dust, noise, emissions, etc. (SEPA, 2009a).

The feasibility study should present a number of possible remediation techniques, based on the remediation goals and information from the risk assessment. It should include a null alternative, a maximum alternative, the best available technology (BAT) and other alternatives between the null and maximum alternative. The null alternative is when no remedial action is taken, i.e. the contaminant situation is left as it is, so called natural attenuation. The maximum alternative can be a remedial action that results in complete risk reduction, or levels under background levels, considering a physically realistic measure. Another criteria for the maximum alternative can be that there will be no limitations for future land use (SEPA, 2009a).

The size of the project and the contaminant situation determines how many alternatives that should be presented. For projects with a well-defined contaminant situation, it can be enough to evaluate a few alternatives (SEPA, 2009a).

To be able to evaluate if a certain remediation technique is possible to use, sufficient information must be available. Clearly, a good and detailed material from previously performed investigations and risk assessments, will facilitate and benefit the feasibility study (SEPA, 2009a).

2.1.7 Remediation techniques

A large number of remediation techniques exist, of which some are more established. The by far most common remediation technique in Sweden today is dig and dump, i.e. to excavate the contaminated media and transport it to a landfill (SGI, 2016). Other examples of remediation techniques are immobilization/stabilization, soil washing and enhanced biodegradation (Helldén *et al.*, 2006). According to SEPA (2009a), an evaluation of remediation techniques should always be conducted by looking at present available techniques and the latest publications concerning those, since the research is continuous.

SEPA (2009a) make it very clear that dig and dump remediation should be the last alternative when different alternatives are evaluated. SEPA state that the following order is desired when choosing remediation method (in decreasing order):

1. Destruction of the contaminant, however only applicable for organic pollutants;
2. to separate and concentrate the pollutants which are then disposed in a controlled way;
3. to change the chemical properties of a pollutant into a less toxic one;
4. to immobilize contaminants and
5. disposal to landfill, or encapsulation methods (SEPA, 2009a).

However, due to case specific circumstances, remediation techniques from all levels may be the most suitable alternative, which is why there is a need for a feasibility study (SEPA, 2009a).

2.2 Legislation and responsibility for contaminated sites

According to SEPA, risk assessments should be based on both a short- and a long-time perspective, where the short-time perspective is about 100 years and the long-time perspective is 100 to 1000 years (SEPA, 2009c). This is in accordance with the Swedish Environmental Code (Sw. Miljöbalken SFS 1998:808, "MB"), which in its first paragraph say that:

> "The purpose of this Code is to promote sustainable development which will assure a healthy and sound environment for present and future generations. Such development will be based on recognition of the fact that nature is worthy of protection and that our right to modify and exploit nature carries with it a responsibility for wise management of natural resources" (Ds 2000:61).

This paragraph can have great impact, if used correctly together with other legislation. The environmental objectives together with the Environmental Code are regulating and setting the boundaries for how contaminated sites should be dealt with. Several government agencies are involved in the work of identifying, assessing and remediating contaminated sites. The Swedish Chemicals Agency (KEMI) are responsible for the Environmental Quality Objective "A Non-Toxic Environment". However, SEPA are coordinating the work with cleanup on a national level, including administrating the funding of cleanups when no one can be found legally responsible (KEMI, 2015). The Swedish Geological Survey (SGU) is the responsible authority for the environmental objective A Good-Quality Groundwater, as well as responsible for assessments and cleanup where the operator was a central government agency that does not exist today (SGU, 2016b). On a local level it is either the local municipality or the County Administrative Board, depending on the size of the company, who are the operative authorities that inspect assessments and remedial operations (Lindén *et al.*, 2014).

The operator of a company that caused a contamination should always be hold primary responsible for the cleanup, in accordance with the Polluters Pay Principle (2^{nd} chapter 8 § MB and 10^{th} chapter 2 § MB). If there is no such operator, the land owner can in some cases be hold secondary responsible, depending on if the person knew about the contamination at the time of the purchase of the property. The purchase also had to be completed after the 1 of January 1999, when MB came into effect. The legally responsible company or person have to pay for the required remedial actions. This is coordinated by the operational authorities through superintendence (SEPA, 2014).

2.3 Statistical analysis of data

It is impossible to measure and delineate the contaminant situation in every single point at a site, unless an absurdly extensive sampling is performed. With statistical methods, however, it is possible to arrive at an assumption which is close to the real situation, within a confidence interval. Geostatistical techniques have proved to be the best available methods in order to delineate the occurrence of contaminants at a potentially contaminated site (Cui *et al.*, 2016). Despite that, geostatistical methods, or statistics, are not commonly used for this purpose in Sweden (Sweco, 2016a). The following section will describe how basic statistics can be used within the field of contaminated sites.

2.3.1 Representative data

SEPA and the Swedish Geotechnical Institute (SGI) have attempted to increase knowledge about the use of statistics in the field of contaminated sites, by a number of reports published by SEPA within the report series “Sustainable Remediation”. In one such report, Norrman *et al.* (2009b) write that statistical analysis of data is needed to arrive at an objective and transparent assessments of data. In another such report, Starzec *et al.* (2008) conclude that uncertainties of the contaminant situation, must be described by statistics, otherwise the operational authority cannot judge the uncertainty interval of the investigation. Hence, there is a gap between what is done in practice, and what the environmental authorities suggest.

A requirement to perform statistical calculations on a dataset is that it is representative for the media that it support (Engelke *et al.*, 2009). Statistical representativeness of data can be defined as when the data describes the actual situation, within a given confidence interval, i.e. the uncertainty is known. The confidence interval is not set but must be decided in relation to the risk, however often set to 5 % (Mattuck *et al.*, 2005). If the data can describe the target population, for example a contaminated site, it is representative (Engelke *et al.*, 2009).

2.3.2 Sampling strategies

Sampling strategy affect representativeness. Sampling strategies can be divided in two groups: probability-based sampling designs and judgmental sampling designs. The basis of a probability-based sampling design, is that each point at the investigated site should have equal possibility to be sampled. The opposite is true for judgmental sampling, where the sample plan is based on expert knowledge. Statistics can only be performed on probability-based sampling (USEPA, 2002).

Examples of two common probability-based sample designs are systematic sampling and simple random sampling. Grid-sampling is an example of systematic sampling, where a grid with equally large squares, rectangles, triangles, etc., is defined with coordinates on the investigation map. One or several sample points are then defined within all grid cells. The point of sampling can be fixed at the same spot in each grid cell, or it can be randomly distributed within the grid, thus being a random systematic sampling. Simple random sampling is when the sample points' coordinates are randomly generated by a computer, over the investigated area or volume (USEPA, 2002).

Furthermore, sampling error or handling of samples affect the representativeness of the results. The Swedish Geotechnical Society (SGF) provide national standards for sampling of contaminated sites in order to avoid such sample errors (SGF, 2013).

Grid-sampling design raises an important question: if one sample is taken within every grid, how big should the size of each grid be, to arrive at representative data? That is, how many samples are required for a certain volume, and how big should the sample be in order to support that volume? If the size of heterogeneity is known, the number of samples required can be calculated by statistical software. Heterogeneity in contaminant concentrations and distribution over an area may result in high variability of data, which require a large number of samples to arrive at representative data (Mattuck *et al.*, 2005).

Contaminants are commonly heterogeneously distributed at a contaminated site. To be able to perform statistical analysis on data from a site with heterogeneously distributed contaminants, without an extremely extensive sampling strategy, the site can be divided in several subunits. Each subunit represents a target population, given that the subunit is somewhat homogenous (Norrman *et al.*, 2009a). Such a division into subunits should not be mixed with grid-sampling, which is a sampling design. The purpose to divide a site into subunits is for analytical reasons and the subunits may therefore be divided in different sizes including different number of grids. However, the size of the grids affect the representativeness of one particular sample.

Since the heterogeneity of contaminant concentrations and distribution is difficult to know before actual sampling of the site, the division of subunits can at first be based on the conceptual model, hence requiring a good conceptual model (Norrman et al., 2009a). Division of population targets into subunits may also be done on basis of depth, when different geological units are present (Singh & Maichle, 2013).

2.3.3 Representative value

For a subunit that is shown to be representative, a representative value can be defined. The representative value is the value that will be compared to the GV, either they are generic or site specific, and display the risk for exposure from that particular subunit (Norrman *et al.*, 2009b).

The representative value is defined by SEPA as the value that best represents the risk situation of a predefined area or volume, without underestimating the risk (SEPA, 2009c). This is the same as the United States Environmental Protection Agency's (USEPA) term Exposure point concentration (EPC) (Singh & Maichle, 2013). However, SEPA has decided to translate this to representative value in their guidance documents, which is why this term is used in this thesis.

There are several statistical methods which according to Norrman *et al.* (2009b) can be used to define the representative value, such as max value of sample data, arithmetic mean, 95 % upper confidence limit of the mean (UCLM95) or different percentiles of sample data. Which of these that are correct to use depends from case-to-case and must be decided by the project group.

2.3.4 Descriptive statistics

To find out if a dataset is representative for a target population, and if so, which statistical method that is valid to use for further statistical analysis, descriptive statistics about the data set can be performed. Examples of descriptive statistics are arithmetic mean, median, variance, standard deviation and skewness. It is also useful to plot data graphically, using for example box plots, histogram, quantile-quantile (Q-Q) plots, time-trend plot and geospatial correlation plots. By using such tools, outliers are easier to detect (Norrman *et al.*, 2009b).

Another way to evaluate the distribution of data, is to perform a goodness of fit test (GOF-test). This will calculate if the dataset show a parametric distribution such as normal, lognormal or gamma distributions. It is also possible to use nonparametric data. There are several methods that can fit a model to nonparametric datasets as well, for example different types of Bootstrap or Chebyshev. However, for highly skewed data it is recommended to not perform any statistical analysis but rather re-evaluate the defined target population (Singh & Maichle, 2013).

2.4 Cleanup in development projects

As cleanups within development projects are a common phenomenon in the cities of Sweden, it is important that the practice concerning such cleanups is clear. In 2014, the Swedish Geotechnical Institute performed a survey on the topic of contaminated sites in spatial planning (Ländell *et al.*, 2015). The conclusion from the survey was that increased knowledge and research was needed concerning risk assessment, feasibility study and remediation techniques, as well as spatial planning and construction on contaminated sites. One question in the study was if the guidance from SEPA was thought to be applicable on cleanups within development projects. The results showed that 20 % thought they were applicable, 3 % did not think so, 27 % answered that they were partly applicable and 40 % answered that they did not know. Interestingly, if the answers were divided depending on the working field of the responders, the answers from the group that worked with contaminated sites differed slightly: 25 % answered yes, 4 % answered no, 47 % answered partly and 24 % answered that they did not know (Ländell *et al.*, 2015).

Another question was if good guidance was present concerning how contaminated sites should be handled in spatial planning, such as construction on contaminated sites. The results showed that 16 % thought there was good guidance, 46 % however did not think so, and 38 % did not know (Ländell *et al.*, 2015).

Furthermore, a common view among the people that participated in the survey was that cleanups within development projects were handled differently in different municipalities in Sweden. The survey concluded that the type of development project and individual competence at authorities seemed to have a high impact on how cleanups were performed (Ländell *et al.*, 2015).

Based on interviews with different environmental consultants at Sweco in different parts of Sweden, the statement saying that contaminated sites within development sites are handled different by different authorities is confirmed (Sweco, 2016a). For example, using SSGV instead of GGV as quantifiable remedial objectives, does not seem to depend on the contaminant situation, but rather on the preference of the actors involved in the project. As an example, for volatile contaminants in a highly permeable soil, the GGV_{KM} can be too high. In such a situation SSGV should be calculated instead of using GGV_{KM}. Use of statistics to define the representative value for a certain volume of soil, also seems to differ between which people are involved in a project (Sweco, 2016a).

According to consultants at Sweco (Sweco, 2016a), it differs between small and large projects, how extensive the investigations such as risk assessments are in development projects. For small development projects the development company might consider it easier to treat all the soil as contaminated, instead of using resources to investigate the risk that the potentially contaminated site pose. The consultants (Sweco, 2016a) also point out that the size of the investigations performed at a development site also depends on at which point of time the consultants are introduced into the project. If at an early stage, before the construction plan is set, there is more potential for enough investigations to be planned for and performed. If, however, they are introduced when construction is about to start, there is usually not any time to perform a complete risk assessment and they have to rush into the remediation phase directly. Though, this is a generalization and can of course differ among individual projects.

Another issue, which is repeatedly mentioned in the interviews with consultants at Sweco from different parts of Sweden, is that even if a lot of people do have knowledge about for example how the risk can be evaluated in a more precise way in a risk assessment, a time consuming process of motivating choices and assessments to the operative authority arise, that sometimes the development company decides that there will be no time for a detailed assessment (Sweco, 2016a).

2.5 Common contaminants at brownfields

SEPA (2009a) defines a contaminant as a substance that exceeds natural background levels and is present in soil, bedrock, sediments, water and building material, due to anthropogenic actions. Anthropogenic actions include both actions that introduce hazardous substances into the environment and actions that cause release of naturally occurring toxic compounds that would not have occurred otherwise, such as acid mine drainage.

Furthermore, a contaminant is not by definition toxic to be exposed for. The toxicity is dependent on several physiochemical factors, including but not limited to: exposure concentration, exposure time and the bioavailability. Additionally, since the most restrictive GV from all different protection targets are determining the final guideline value, concentrations above the GV do not automatically mean that the present contaminant is toxic for the other protection targets. The governing protection target for common contaminants are presented in Table 2 (SEPA, 2009c). An important aspect that must be remembered when discussing a contaminant situation, is that it is only the substances that have been analyzed for, that can appear in the sample analysis results. Thus, it is important to define what substances that are expected to be present at a contaminated site (Engelke *et al.*, 2009). If a site is contaminated due to industrial activities that are well documented, it is easier to decide what substances that should be sampled and analyzed for.

Table 2. The governing protection targets for the generic guideline value KM (GGV_{KM}), is presented for a number of common contaminants (SEPA, 2017b)

Contaminant	Governing protection target for GGV_{KM}
As	Background value
Ba	Protection of soil ecosystem
Pb	Ingestion of soil
Cd	Ingestion of plants
Co	Ingestion of plants
Cu	Protection of soil ecosystem
Cr-tot	Protection of soil ecosystem
Hg	Inhalation of vapor
Ni	Protection of groundwater
Zn	Protection of soil ecosystem
PAH-L	Protection of soil ecosystem
PAH-M	Inhalation of vapor
PAH-H	Ingestion of plants

At brownfields, a history of different industrial activities are common. It is also common to find filling material at brownfields (Sweco, 2009). Presence of filling material makes the contaminant situation more difficult to estimate beforehand, since filling material can contain a mixture of waste, deposited at different time periods. As a result many different contaminants can be present at brownfields (Helldén *et al.*, 2006). However, some contaminants are more commonly found than others. The following sections will describe the chemical properties of the common contaminants found at brownfields.

2.5.1 Metals

Common metals encountered at brownfields are arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), mercury (Hg), lead (Pb), nickel (Ni) and zink (Zn) (Sweco, 2009). All of those, except from Ba are heavy metals. The original source of those metals are the primary minerals that form bedrock. Enrichment of metals, so called ores, can be natural due to geologic processes. However, enrichment of metals by anthropogenic actions alter the biogeochemical balance of an ecosystem, leading to potentially increased rate of metal exposure on the protection targets (Nagajyoti *et al.*, 2010). The solubility and dissolution of metals in soil are defined by the speciation of the metals, which depends on the metal and soil properties. The soil properties that predominantly govern the metal speciation are the redox potential and pH. Metals can occur either dissolved in soil solution, or sorbed to soil organic matter, oxyhydroxides or clay mineral surfaces. The dissolved metals can occur as hydrated cations or anions, as well as complexed to inorganic or organic compounds. Dissolved metals are more mobile. However, sorbed metals can be transported through particulate transportation (Essington, 2015).

Arsenic is a heavy metal that has been used for many different purposes throughout history. A few examples is as a component in medicines, color pigment and wood impregnation. Mining is also a source of arsenic contamination, since altering the chemical properties of bedrock that naturally contain arsenic, can cause metal leaching (Selenius, 2010). An industry that has contributed to arsenic contamination during the 1900's is the pulp and paper industries that involved a sulfite pulp mill. In the sulfite mill process, a waste byproduct is received (in Swedish "kisaska") that contains high concentrations of arsenic, cadmium, copper and lead. Until the 1960's the byproduct was often used as filling material, thus encountered at for example brownfields (Nordbäck *et al.*, 2004).

The possible oxidation states of arsenic is -3, 0, +3 and +5 (Selenius, 2010). In soil, arsenic is commonly appearing in two inorganic oxidation states: As^{III} (arsenite) and As^{V} (arsenate). Arsenite is mobile and is therefore the more toxic form of arsenic (Essington, 2015). In reducing conditions arsenite is the thermodynamically stable oxidation state and in oxic conditions arsenate is the thermodynamically stable oxidation state (Yang *et al.*, 2002). Arsenate is less bioavailable and thus less toxic, since it is adsorbed strongly to hydrous metal oxide surfaces (Essington, 2015). Although, at high pH above 8,5, the sorption capacity decreases rapidly, causing high levels of arsenic in solution (Selenius, 2010).

Barium is a component in for example tiles, automobile clutch and brake linings, rubber, brick, paint and glass, which has altered the accumulation of the element in environments where human activity is present. Barium has a similar ionic radius to K^+ and is therefore showing similar geochemical behavior. Barium is retained in soil due to strong complexation on oxyhydroxides and clay mineral surfaces (Stjernman-Forsberg & Eriksson, 2002).

Cadmium is a rare heavy metal in natural soils (Essington, 2015). However, mining and metal industries have contributed to cadmium pollution. Cadmium is also added to the environment through air-pollution from waste incineration and combustion of fossil fuels. The use of inorganic phosphorous fertilizer which contain cadmium, is another source of cadmium pollution of the environment (Karolinska Institutet, 2015b).

Cadmium occur in the oxidation state +2. Precipitation of cadmium in soil solution is uncommon since it is rarely occurring in significant concentrations. At pH > 6, Cd^{2+} is forming stable complexes on Fe, Al and Mn oxyhydroxides and on the edges of clay mineral, by inner-sphere surface complexation. During acidic conditions, Cd^{2+} is occurring as an exchangeable cation and form weak complexes on clay mineral surfaces, by outer-sphere surface complexation (Essington, 2015).

Chromium has been used in metallurgy and in the chemical industry, due to its high resistance to corrosion and hardness (Vodyanitskii, 2009). Chromium has also been used extensively in wood impregnation (Selenius, 2010). It is also found in the byproduct "kisaska" as mentioned in the section about arsenic (Nordbäck *et al.*, 2004).

Cr is found in two oxidation states in the soil environment, Cr^{III} and Cr^{VI} (chromate). In mineral phase it occurs at Cr^{III}. Cr^{III} is amphoteric, i.e. it can behave as both acid and base. Depending on the soil pH, Cr^{III} can either exist as a free ion (Cr^{3+}), or as a hydrolysis product. Cr^{III} is forming strong chelating complexes with solid as well as dissolved soil organic matter. Cr^{III} is considered to be relatively immobile and biologically inaccessible.

Chromate is a ligand which in acidic soil conditions exist as $HCrO_4^-$, and in alkaline conditions as CrO_4^{2-}. Cr^{VI} is reduced to Cr^{III} in oxic conditions by solid and aqueous phase soil organic matter, or by Fe^{II} and sulfides in suboxic and anoxic environments. The oxidation of Cr^{III} to Cr^{VI} is only known to be possible by Mn-oxide minerals. The chromate species are considered to be relatively mobile and bioavailable, especially in alkaline environments. This is because the chromate species do not form stable mineral precipitates and the inner-and outer-sphere complexation that chromate form on Fe and Al oxyhydroxides, only occur during acidic soil solution conditions, when the Cr^{III} is the predominating oxidation state (Essington, 2015).

Cobalt is a heavy metal that by industrial activities such as mining and smelting has been spread in the environment due to anthropogenic actions (Collins & Kinsela, 2010). Cobalt commonly exist in the oxidation state +2 in soil solution, both in acid and alkaline conditions. Stable soluble complexes are formed between the Co^{2+} species and ligands such as CO_3^{2-}, SO_4^{2-}, HPO_4^{2-}, organic acids and amines and dissolved soil organic matter. In soil, the Co^{2+} species are retained by inner-sphere and outer-sphere complexation at Fe and Mn oxyhydroxide surfaces, clay minerals and organic matter. However, presence of dissolved organic matter reduces the Co^{2+} adsorption, due to aqueous complexation. Additionally, the Co^{2+} species and the base cations compete for sites at the clay mineral surfaces which affects Co^{2+} adsorption

(Essington, 2015). Finally, the Co bioaccessibility can be reduced significantly by coprecipitation into a Mn oxide structure, a process which involves oxidation of Co^{II} to Co^{III}, with hydrous Mn^{IV} oxides as the catalyzing agent (Essington, 2015).

Copper commonly exist in the +2 oxidation state in soil. Cu can be either inorganic, when forming part of a soil mineral, or organic, when complexed to soil organic matter. The complexation of Cu to soil organic matter is very strong, resulting in that if organic matter are present, Cu is likely to be predominantly found in the organic form (Essington, 2015).

Lead is another common heavy metal that is not only encountered at brownfields (Sweco, 2009), but in the environment in general due to its extensive use throughout history. For example, it has been used as a component in coins, color pigments, boiling vessels, tins, water pipe infrastructure, flavoring and gasoline. Current use of lead is in batteries, color pigment, ammunition and solder material (Karolinska Institutet, 2015a).

Lead occur in soil with oxidation state +2. In soil solutions with pH less than 7,7 the free Pb^{2+} species dominates whereas if higher pH the hydrolysis products $PbOH^{+}$ or $Pb(OH)_2^0$ dominate. Lead has a high affinity for clay mineral surfaces as well as complexation formation with oxyhydroxides (Essington, 2015). Lead also binds strongly to organic matter. Lead has a similar ion-radius to the potassium ion (K^{+}), thus it can substitute for the (K^{+}) in clay minerals (Essington, 2015).

Mercury can occur in the oxidation states 0, +1 and +2, of which Hg^0 and Hg^{II} are the most common inorganic forms present in the environment. In oxic conditions Hg^{II} is the dominating oxidation state. The free Hg^{2+} ion forms highly stable aqueous complexes with for example halides (such as Cl^- and OH^-) and HS^-, on dissolved soil organic matter. Therefore the free Hg^{2+} ion is not present in significant concentrations at normal soil pH. The most toxic form of mercury is the methylated, organic form of mercury species; methyl- and dimethylmercury, which are synthesized by fungi and bacteria (Essington, 2015).

Nickel is a heavy metal that has been concentrated in the environment due to anthropogenic activities such as mining, emission of smelters, burning of coal and oil and use of sewage phosphate fertilizers and pesticides (Nagajyoti *et al.*, 2010). Nickel only occur with the oxidation state +2 in soil. In soil solutions, Ni^{2+} species occur, which have a high affinity to form stable soluble complexes with ligands such as CO_3^{2-}, SO_4^{2-}, HPO_4^{2-}, organic acids and amines and dissolved soil organic matter. In soil, Ni^{2+} form stable inner-sphere surface complexes on Fe, Mn and Al oxyhydroxides and clay minerals, during neutral to alkaline soil conditions. At acidic conditions, Ni^{2+} is predominantly occurring as an exchangeable cation and form outer-sphere surface complexes on clay mineral surfaces (Essington, 2015).

Zink is a heavy metal that has become enriched in certain environments by anthropogenic actions, such as use of fertilizers, sewage sediments and industrial air dust (Vodyanitskii, 2006).

Zink only occur in the oxidation state +2 in soil, as Zn^{2+} species and the hydrolysis products $ZnOH^+$ and $Zn(OH)_2^0$. Zink is retained in soil both during acidic conditions, by outer-sphere complexation on organic matter and clay mineral surfaces and during neutral to alkaline conditions, by stable inner-sphere surface complexation on Fe, Mn and Al oxyhydroxides and edges of clay minerals (Essington, 2015)

2.5.2 Aliphatic and aromatic hydrocarbons

Aliphatic and aromatic hydrocarbons are also commonly encountered at brownfields (Sweco, 2009). Hydrocarbons are a group of organic compounds containing mainly hydrogen and carbon. Gas and petroleum products consist of hydrocarbons. Dependent on their different chemical structure they are divided in different groups, aliphatic or aromatic. Aliphatic hydrocarbons can be either straight, chained, branched, unsaturated, saturated or cyclic (Verbruggen *et al.*, 2000). Aromatic hydrocarbons exist of one or several benzene rings. Hydrocarbons are subject to biodegradation since they are organic compounds. However, the more complex the molecule structure is, the more recalcitrant it will be to degradation (Atlas & Bragg, 2009).

Polynuclear aromatic hydrocarbons (PAH) are aromatic hydrocarbons that exist of two or more benzene rings. PAH are a product of incineration of organic material, thus, it can be produced naturally as well as through anthropogenic activities. PAH contamination is commonly found at industrial sites, where oil spill is commonly present. It is also a component of creosote, used for wood-preservation. Gas works is another industry from which PAH contamination is likely to have occurred (Wilson & Jones, 1993).

The arrangement of the rings affect the stability of the different PAH, the more angular the more stable, and the more linear the more unstable. PAH occur dominantly in particulate form, sorbed to for example organic matter. Generally, PAH are relatively insoluble in water and the solubility of PAH generally decrease as the number of rings increase (Wilson & Jones, 1993).

3 Material and Methods

3.1 Selection of data

Information of how cleanups were performed in Uppsala within development projects on brownfields, was collected at the Environmental Operational Authority (EOA) at the Municipality of Uppsala. From the material that was collected, twelve cleanup cases (from here on referred to as "cleanups") were chosen to be included in the study. This selection was based on the delimitations.

The County Administrative Board of Uppsala did not have any completed cleanups within Uppsala from the defined time period. Thus, all the cleanups that were reviewed in this thesis had the same EOA.

The following material was gathered for each cleanup, when present:

- Official decisions and orders from the operational authorities (both the EOA at the municipality of Uppsala, and the County Administrative Board of Uppsala),
- soil sampling investigations, and other investigative reports,
- risk assessment report,
- feasibility study,
- remediation report,
- official communication between the development company, the Environmental Consultancy Companies (ECC) and the EOA.

Each case registered at the EOA, was treated as one cleanup since investigations and remediation reports have generally been undertaken for each such registration separately. Within a development area, the different phases of remedial actions are often performed by different ECCs and development companies. Accordingly, one development area can include several cleanup cases.

3.2 Site description of cleanups

The twelve studied cleanups are located in three development areas in Uppsala: the east side of the station "Östra Station", "Industristaden" and "Librobäck" (Figure 4). All of those areas are located within the zone of the outer water protection area for Uppsala and Vattholmaåsarna, which is connected to certain legal restrictions by regulation "03FS 1990:1 Kommunala grundvattentäkterna i Uppsala-Vattholmaåsarna" (Uppsala-läns-författningssamling, 1990).

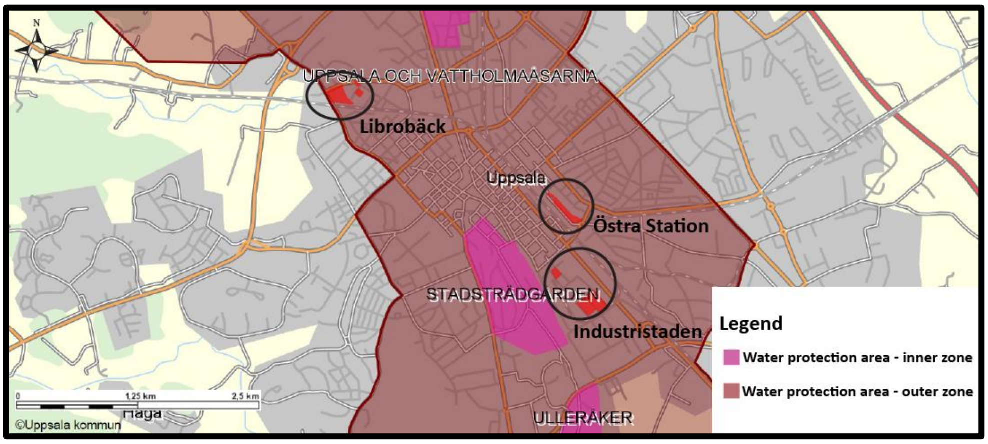

Figure 4. Overview of the location of the studied cleanups. Background map from Uppsalakartan, Uppsala kommun. Printed with permission

The soil stratification in Uppsala is generally dominated by a surface cover of filling masses ranging from a few centimeters to several meters. The filling masses are overlying a postglacial clay, from a few meters to over 50 meters thick, depending on the location. Below the postglacial clay, glaciofluvial sediments are found, forming the Uppsala esker (SGU, 2016a). General soil profiles for the different sites are presented in Figure 5-7.

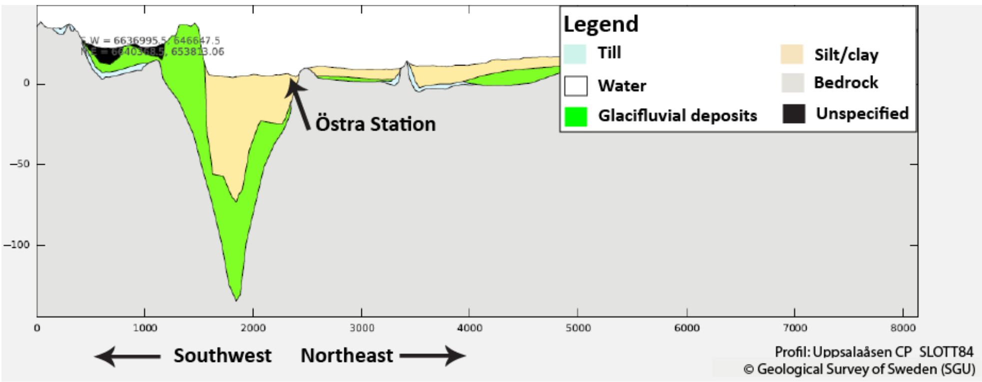

Figure 5. Profile for approximate location of the cleanups at Östra Station. Modified from SGU (2016a). Printed with permission

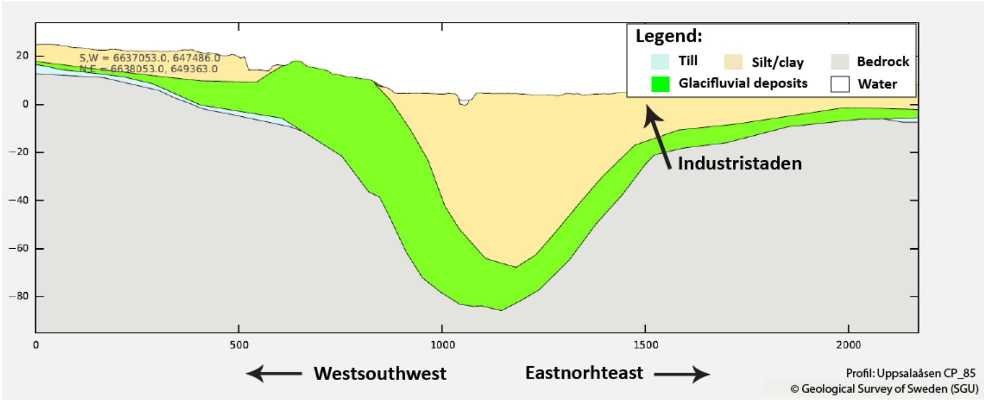

Figure 6. Profile for approximate location of the cleanups at Industristaden. Modified from SGU (2016a). Printed with permission

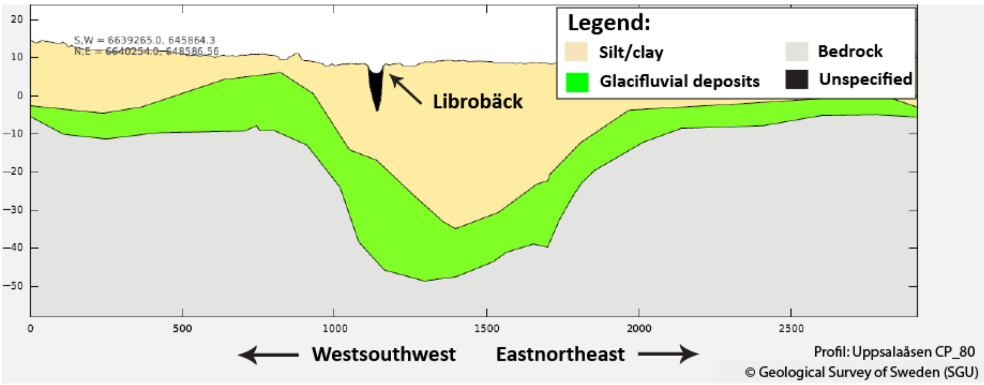

Figure 7. Profile for approximate location of the cleanups at Librobäck. Modified from SGU (2016a). Printed with permission

The twelve cleanups are summarized in Table 3. For a more comprehensive description, see Appendix A.

Table 3. Summary of the reviewed cleanups

	Previous land use	Size of area	Dominating contaminants
Östra station			
Fålhagen 69:1	- The area surrounding Uppsala station has been industrialized since the mid 1860's, when the railway was constructed. - The Östra Station area was mainly used as a railway yard. - A mobile impregnation facility for railroad ties was also located in the area. - Diesel and oil has been stored in tanks on the site and pesticides were used over the entire area.	1 000 m^2	- As, Cd, Pb - PAH-H
Fålhagen 70:1		3 000 m^2	- As, Pb - PAH-H
Uppsala Entré		8 000 m^2	- As, Pb - PAH-H, PAH-M - Aliphatic hydrocarbons
Frodeparken		5 000 m^2	- As, Cu, Pb - PAH
Industristaden			
Mjölnaren	- Sawmill - Gas plant on the neighboring property in the north	4 200 m^2	- Cd, Cu, Hg, Pb, Zn - PAH
Spolen	- A grain industry. Processes around this, such as storage of pesticides and oil, as well as a facility to mordant the seeds, have contributed to chemical use on the property. In the northern part of the site, as well as on the property north of Spolen, metallic fiber was manufactured between the years 1924 to 2000.	13 000 m^2	- As, Cd, Pb, Zn - PAH
Varpen 1	- Offices and a transport terminal	10 000 m^2	-As, Pb - PAH - Aliphatic hydrocarbons
Varpen 2	- Printing and ink manufacturing - Several petroleum stations	10 000 m^2	- As, Pb - PAH - Aliphatic hydrocarbons
Libroбäck			
Gimo 1	- The site was industrialized in 1964. - Several business has been active on the site, including but not limited to: garage, carwash, car mechanics, car merchandize, storage buildings and glass manufacturing. - Parts of the site is within the zone of a former clay pit.	10 000 m^2	- Chlorinated hydrocarbons
Gimo 2	- Industry on the site was established in 1965. - Different types of engineering mechanics and engineering merchandize. - Parts of the site is within the zone of a former clay pit.	15 000 m^2	- As, Hg - PAH - Aliphatic and aromatic hydrocarbons
Klockaren 1	- Car mechanics - Garage for trucks	2 300 m^2	- Cd, Pb, Zn - PAH-H - Aliphatic and aromatic hydrocarbons
Klockaren 2	- Industrial storage - Car-wash facility	3 400 m^2	- Zn, Ni - PAH

3.3 Data processing

The cleanups were reviewed with respect to several aspects (Table 4) originating in the aim of the thesis. In order to obtain a systematic review of the cleanups, a number of questions were formulated from the defined aspects and set up in a Microsoft Excel matrix. When possible, one ECC and the EOA were interviewed as an additional source. When all the information had been reviewed, the material was both quantitatively and qualitatively analyzed. The analysis was performed with the SEPA guidance (SEPA, 2009c; SEPA, 2009b; SEPA, 2009a) and environmental regulations as reference.

Table 4. Summary of the different aspects and questions that was systematically investigated

Planning and investigation	Conceptual model Aim of assessment	➢ Has a conceptual model been developed? ➢ Is the aim of the investigations clearly specified? ➢ Are the protection targets defined?
	Sample strategies	➢ Which sample strategies were used (random, systematic, judgmental)? ➢ Was grid-sampling used? If so, what was the size of the grids? ➢ Did the operational authority influence or request additional information regarding the investigations/sample plan?
Risk assessment	Guideline values	➢ Were site specific guideline values used? ➢ Are protection targets discussed? ➢ Are exposure pathways discussed?
	Analysis of sample data	➢ How was representative values calculated?
	Conclusive risk characterization	➢ Has a risk assessment been performed, in accordance with the guidance from SEPA?
Remedial process	Remedial alternative evaluation and risk evaluation	➢ Was a feasibility study performed? ➢ Which were the quantifiable remedial objectives?
	Remedial action	➢ Which remediation technology was used?
	Pre-classification of soil masses prior to an excavation operation	➢ Was a pre-classification of soil done prior to the excavation operation?
	Impact from construction plans on cleanup	➢ Was excavation needed for the majority of the site anyway, due to construction requirements?

4 Results

The excess of soil due to underground constructions was, within all cleanups, found to be the single most important factor of how the cleanups studied in this thesis were performed. The sites where green areas were planned between the houses, also show this trend since the underground constructions often continued between the houses. Most of the surface area had to be excavated one meter or more due to constructional requirements within all cleanups, except for Spolen and Klockaren 2, which included green areas without constructions underneath. Despite that, more than half the surface area of Spolen and Klockaren needed to be excavated, due to constructional requirements on the rest of the sites. This shows that all cleanups considered in this thesis were driven by constructional requirements, and not mainly by risk reduction purposes.

Excess of soil due to construction largely affect the procedure and practice regarding cleanups of brownfields within development projects in Uppsala, as will be presented in the following sections.

4.1 Working procedure

This section will present the working procedures that have been identified among the studied cleanups. See Appendix B and C for the complete presentation of the results.

In contrast to cleanups that are located outside development sites it appears that many of the cleanups within development projects in Uppsala have been performed in a reverse order compared to the SEPA guidance. In cases where construction plans were set from the project start and thereby concluding that excavation to a specified depth was needed within a certain area of a site, the remediation technique was automatically set to dig and dump. This means that the step where remediation techniques are evaluated was skipped. Even though differences in remedial actions occurred, such as on-site separation of different soil fractions, or on-site treatment of groundwater (Uppsala Entré and Frodeparken), the main remediation technique was dig and dump.

With the remediation technique already selected, the next step automatically became management of the soil that was excavated, and here the aspect of possible contaminants and how they should be managed, became relevant. Instead of focusing on underlying risk and exposure to human health and the environment, key questions concerned to which landfill the soil should be sent to, and what quantifiable remedial objectives that was appropriate due to planned land use.

However, for some of the cleanups, soil investigations, risk assessments and feasibility studies were conducted prior to the establishment of the construction plan (Appendix B and C). Therefore, three general types of working procedures were identified in this thesis:

1. Detailed risk assessment performed prior to decisions about remediation. Remediation by excavation over most of the surface was required due to constructional requirements.
2. Basic risk assessment performed separately or as part of a soil investigation report, with the main purpose to classify the soil prior to, or during, excavation of soil masses over the entire area, due to constructional requirements.
3. No complete risk assessment performed, but one section in a soil investigation report discusses risk in some way. Soil masses at the site primarily investigated with the purpose to classify the soil prior to or during excavation of soil masses over the entire area, due to constructional requirements.

The working procedure for five of the cleanups that represent the three groups (Table 5) will be presented in detail in the following sections. Those are: Uppsala Entré, Mjölnaren, Varpen 1, Gimo 2 and Klockaren 1. See Appendix B and C for comprehensive information regarding the remaining cleanups.

Table 5. Categorization of cleanups due to which general working procedure that was used

1	2	3
Fålhagen 69:1	Varpen 1	Mjölnaren
Fålhagen 70:1	Varpen 2	Spolen
Uppsala Entré	Gimo 1	Gimo 2
Frodeparken	Klockaren 2	
Klockaren 1		

4.1.1 Uppsala Entré

Several investigations of the contaminant situation at the area Östra Station, where Uppsala Entré is located, has been performed. The first investigation was performed for the whole area. A detailed risk assessment and feasibility study for the entire development area was presented in 2004 and 2005, respectively (Golder Associates, 2005b). As the development plans proceeded, the different properties in the area were remediated separately, by different ECC (Sweco, 2014c).

Although the risk assessment and feasibility study reports were published earlier than 2009, and thus outside the scope of this thesis, they were found to be essential for describing the working procedure for the cleanups at the area Östra Station and included nonetheless. These reports have therefore been compared to the guidance concerning risk assessment and feasibility study that was present at that time (SEPA, 1997b; SEPA, 1997a).

The SSGV that was presented in the risk assessment was not approved by the EOA. The EOA, as well as the Geological Survey and the County Administrative Board of Uppsala, were critical to the calculation of the SSGV. Their comments mostly addressed that the soil ecosystem and the groundwater were not protected enough. As a result, the EOA requested a feasibility study (Miljökontoret Uppsala kommun, 2005a).

In the feasibility study, a few different remediation techniques were presented, but the only alternative that was found realistic to evaluate further was dig and dump, due to constructional requirements. Additionally, the ECC (Golder Associates, 2005b) wrote that the cleanup should not aim for the same level of risk reduction as in cleanups financed by the government, since the planned cleanup was a response to development plans. Instead, they wrote that the remedial action should rather be a preventive act.

The major part of the feasibility study discussed the economic outcome depending on which scenario of GV that were chosen as quantifiable remedial objectives. The two scenarios of quantifiable remedial objectives were 1) GGV_{KM} for the entire area or 2) SSGV. The feasibility study also presented a method for delineation of contaminated soil during the excavation (5 samples for 20x20 m grid), as well as for pre-classification of soil (in remedial volumes of 100 m^3) (Golder Associates, 2005b). After communication with the EOA, a third option of GV were presented. The third option was based on the GGV, but not with GGV_{KM} as quantifiable remedial objectives for the entire area. Instead two of the subareas had the GGV_{MKM} as quantifiable remedial objectives (Golder Associates, 2005a).

The feasibility study was not approved at first by the operational authorities. SGU commented on the section in the feasibility study about the level of risk reduction. SGU clarified that the reasoning was wrong and that the SEPA guidance of cleanups was relevant also for cleanups within development projects (SGU, 2005). Further, the EOA requested additional information concerning the protection of groundwater.

The final decision for the case from the EOA was that the quantifiable remedial objectives should be set to the third option, except for PAH, for which modified SSGV was accepted (Miljökontoret Uppsala kommun, 2005b). However, this was valid for the remedial actions performed during construction work with cables as well as the road Stationsgatan. For the cleanups from Östra Station that are included in this study, new official decisions concerning quantifiable remedial objectives were taken.

Uppsala Entré was the last property where remediation was fully completed at the area Östra Station. Another remedial action is still proceeding in the southern part of the area. As described above, a risk assessment as well as a feasibility study was conducted that included the Uppsala Entré site. The quantifiable remedial objective was set to GGV_{KM}, as residences were to be constructed at the site. The most relevant components of the working procedure during the cleanup at Uppsala Entré, which followed the risk assessment and feasibility study reports, are presented in Figure 8.

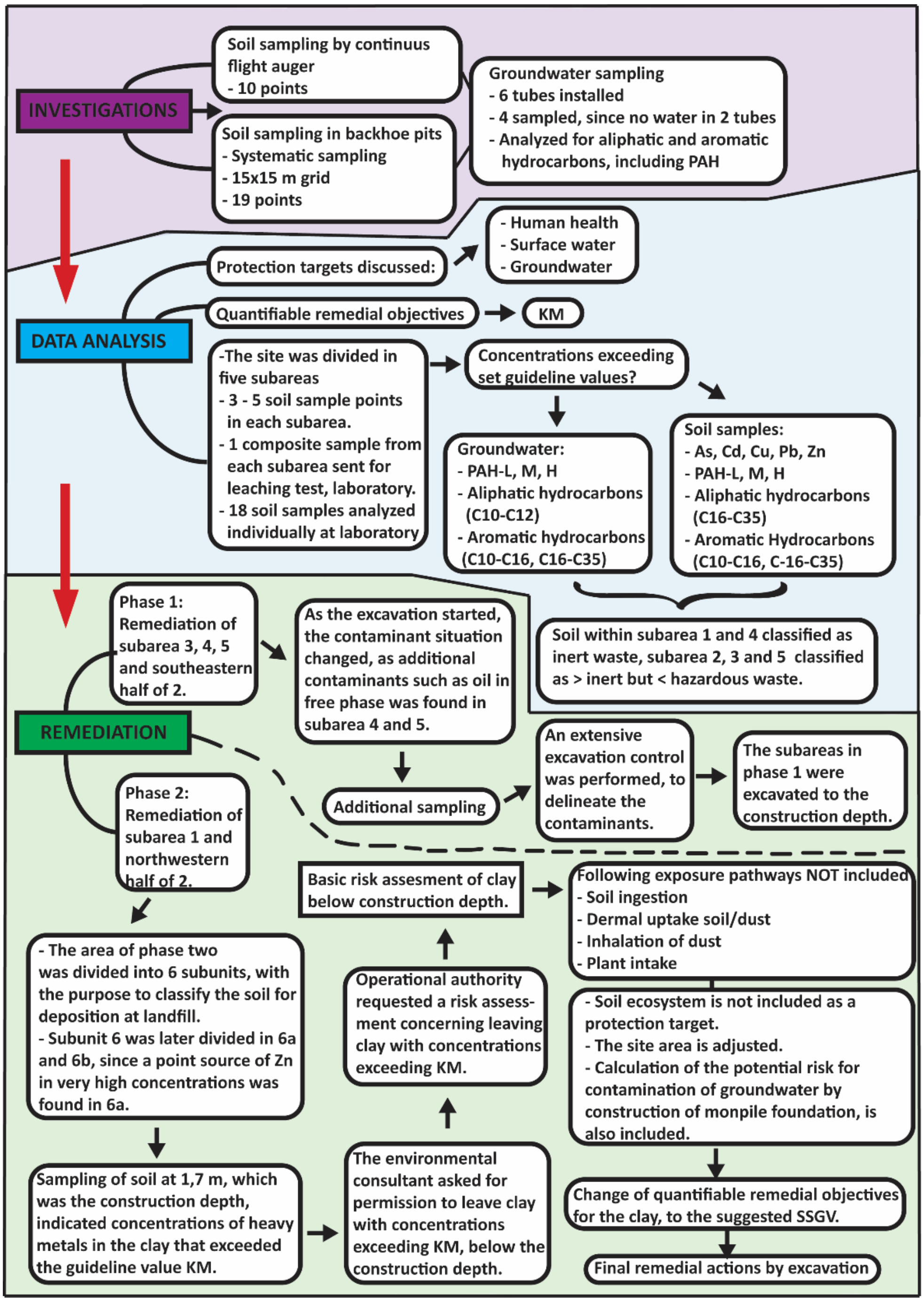

Figure 8. Flow chart of the most relevant components of the cleanup of Uppsala Entré (Sweco, 2015b; Sweco, 2014a; Sweco, 2014b)

4.1.2 Mjölnaren and Varpen 1

Relevant information about the working procedure for two of the cleanups at the area Industristaden can be found in Figure 9 (Mjölnaren) and Figure 10 (Varpen 1).

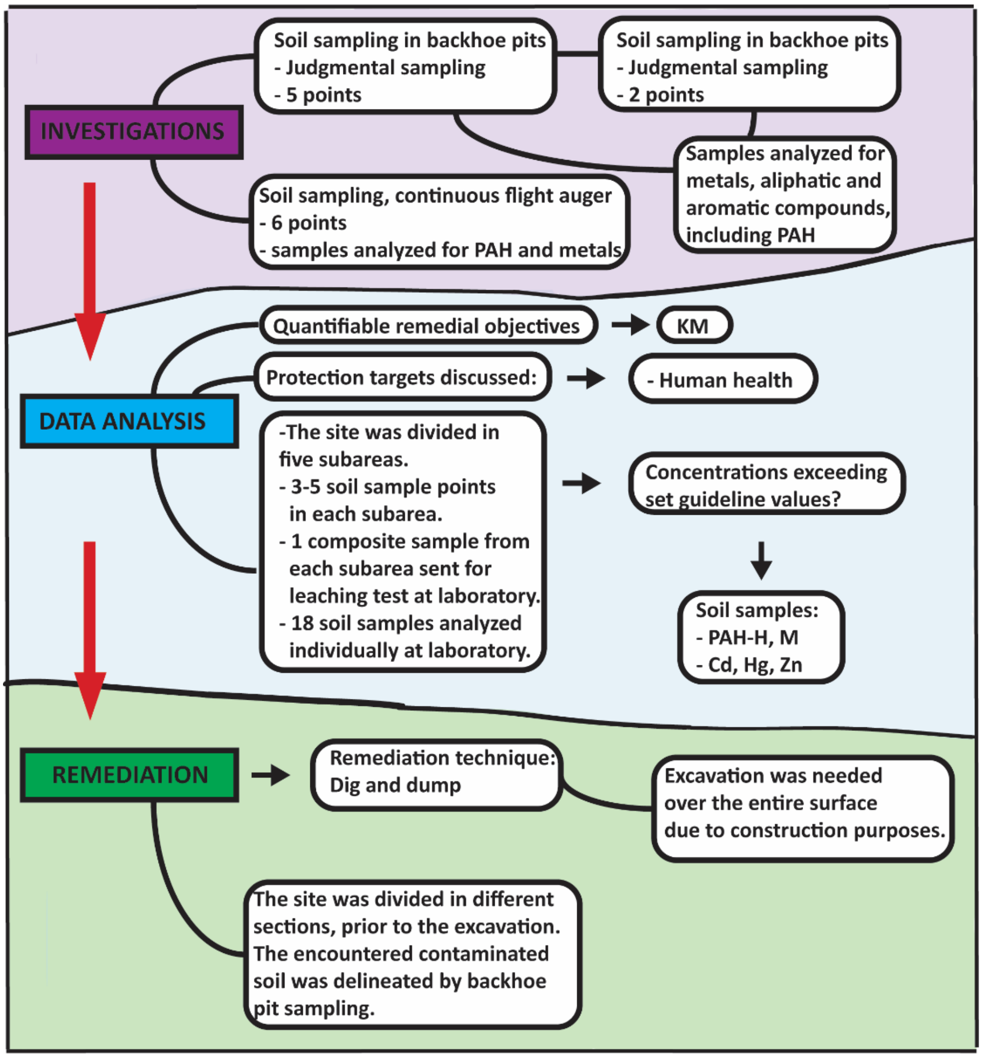

Figure 9. Flow chart of the most relevant components in the cleanup of case Mjölnaren (NCC, 2010; Miljökontoret Uppsala kommun, 2009a)

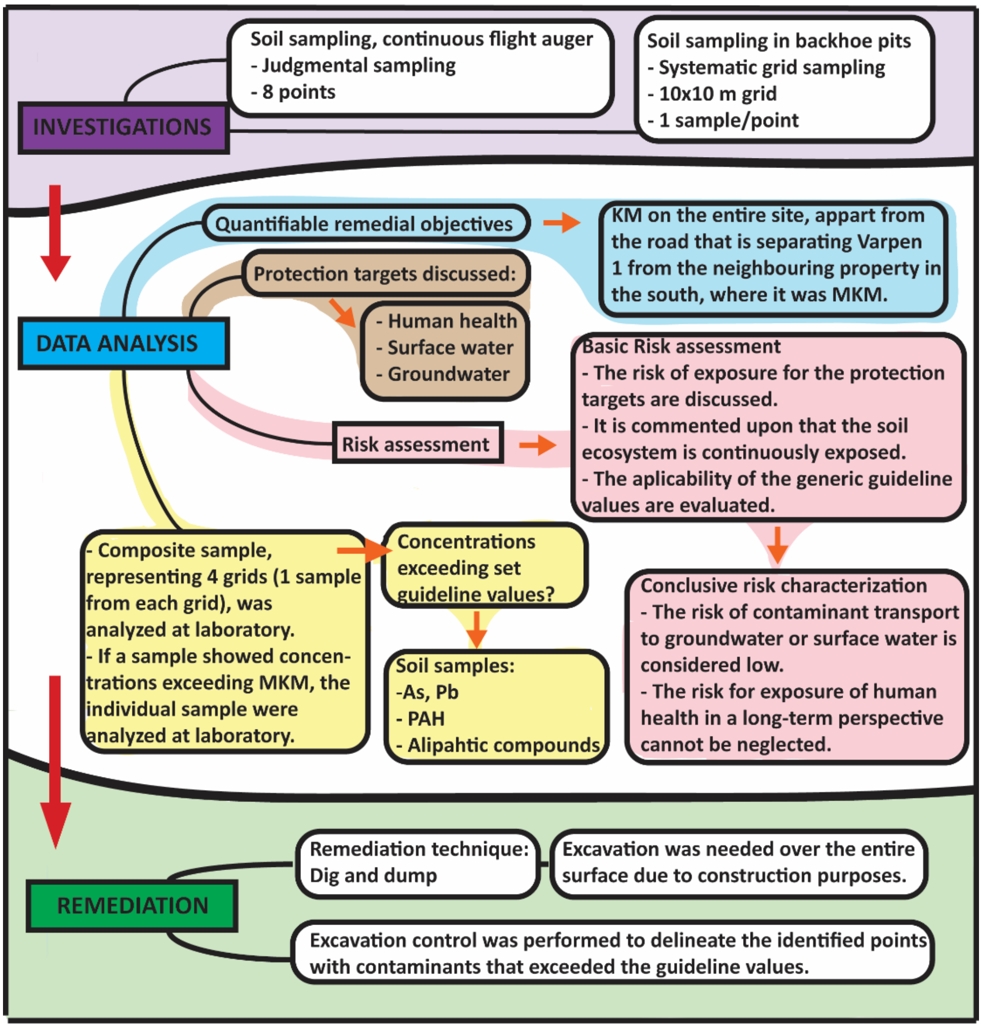

Figure 10. Flow chart of the most relevant components in the cleanup of case Varpen 1 (Geosigma, 2014; JM, 2013; WSP, 2009)

4.1.3 Gimo 2 and Klockaren 1

Relevant information about the cleanups at Librobäck are presented in Figure 11 (Gimo 2) and Figure 12 (Klockaren 1).

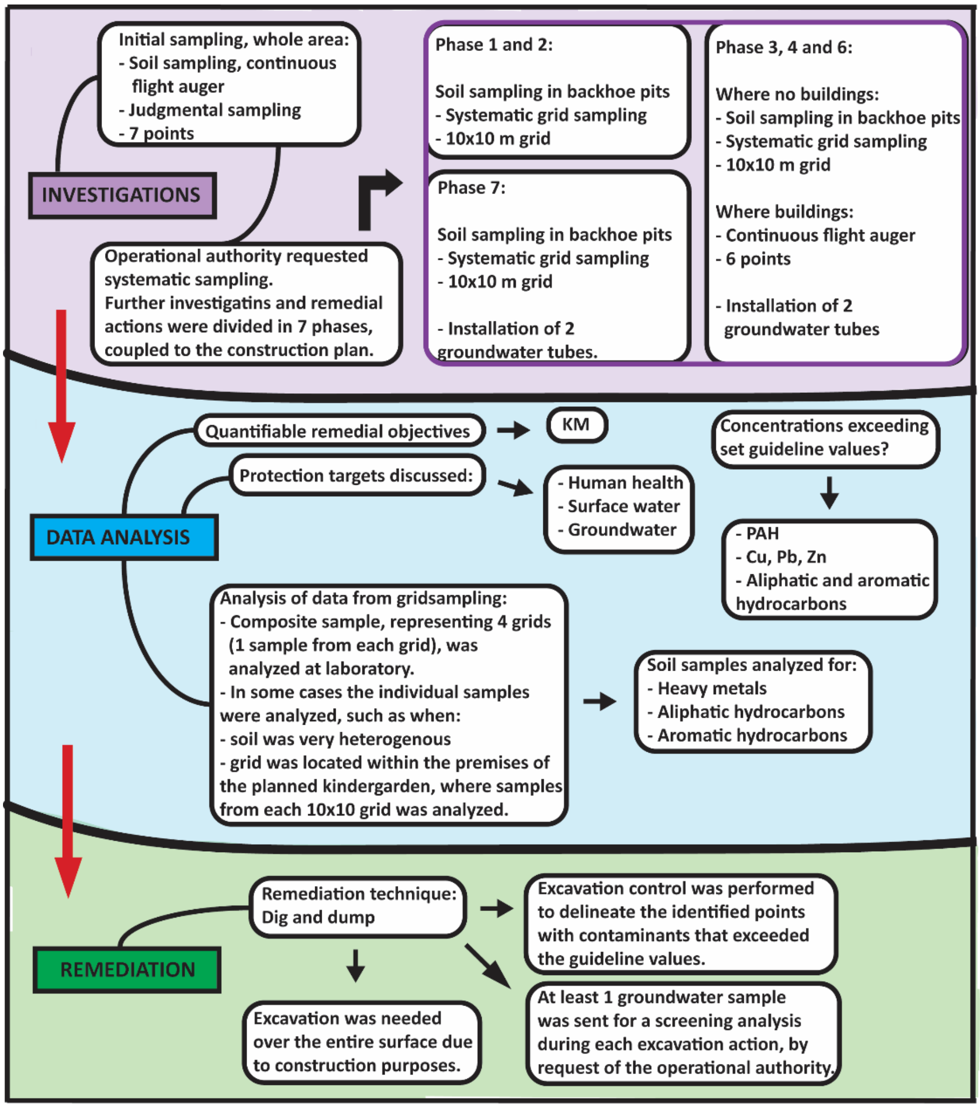

Figure 11. Flow chart of the most relevant components in the cleanup of case Gimo 1 (Sweco, 2016b; Bjerking, 2015; Sweco, 2015a; Bjerking, 2014; Bjerking, 2012)

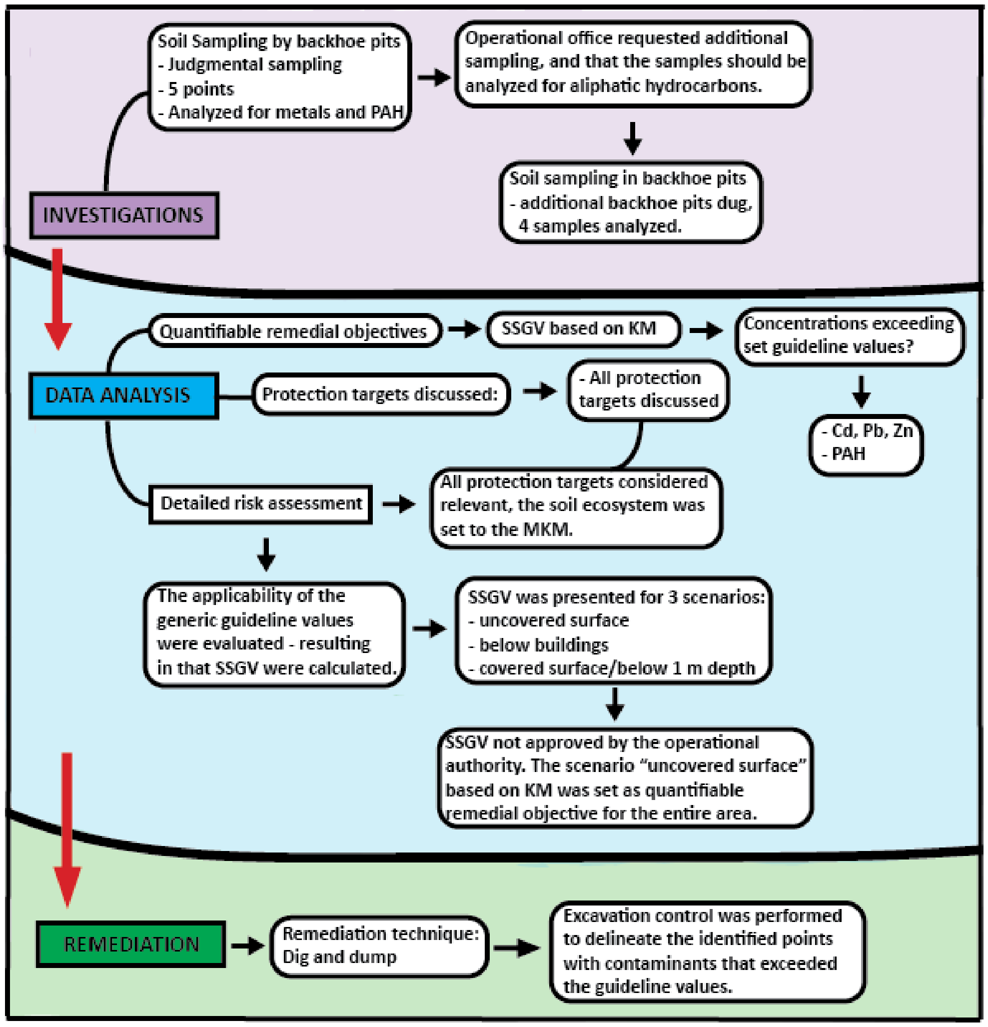

Figure 12. Flow chart of the most relevant components in the cleanup of case Klockaren 1 (Miljökontoret Uppsala kommun, 2009b; Ramböll, 2009; Peab, 2007)

4.2 General practices

This section will summarize the general practices that have been identified among the studied cleanups, both in the perspective of the ECC and the EOA. See Appendix B and C for the complete presentation of the results.

4.2.1 Practices – Environmental Consultancy Companies

The following general practices have been identified:

- Dig and dump was selected as remediation technique for all cleanups, since excavation was needed for constructional requirements, independently of the contaminant situation.
- Conceptual models that show the protection targets in relation to the source of risk and exposure pathways, were not presented clearly in any cleanup.
- Time was a limiting factor in all cleanups. There are examples from each case, where the ECC, on behalf of the development company, asked for fast decisions regarding the cleanup case, since they wanted to start construction work the following day or week, or that they were much delayed.
- The choice of sampling methodology as well as data analysis, such as determining representative values, does not seem to correlate clearly with the contaminant situation, but rather on the predilection of the ECC.
- The aim of the cleanups was a complex aspect to investigate, due to extensive available data for each cleanup. Therefore, no conclusive evaluation of this aspect could be performed in this thesis.
- The protection target groundwater is extensively discussed in risk assessments, whereas the soil ecosystem is seldom discussed.
- For the cleanups where a complete risk assessment was performed (group 1), exposure pathways were discussed thoroughly. For the remaining cleanups (group 2 and 3), the degree of such an analysis was less extensive and in some cases deemed insufficient, according to this thesis. However, for the cleanups in group 2 and 3 the purpose might not have been to discuss the exposure pathways, resulting in that this may be irrelevant to evaluate.
- When the ECC did get the opportunity to do a complete risk assessment due to available time and resources (as for group 1 cleanups), it was done thoroughly. However, regardless of risk assessment or not, the final decisions concerning remediation does not differ significantly between the cleanups in group 1, 2 and 3.
- A common sampling strategy for initial sampling was judgmental sampling, which was used in most of the cleanups.
- Systematic sampling in a grid with one sample per grid cell, were used in six of the twelve cleanups. In five of them, 10 x 10 m grids were used and

in one, 15x15 m grids were used. Systematic random sampling was performed in one cleanup.

- In five of the cleanups, a composite sample was created from four individual samples, representing four 10 x 10 m grid cells, where each such composite sample represented 20 x 20 m. If a composite sample showed high concentrations, exceeding for example GGV_{KM} or GGV_{MKM}, the individual samples from each 10 x 10 m grid cell were then analyzed as to delineate the contaminant occurrence further.

4.2.2 Practices – Environmental Operational Authority

When it comes to practices from the perspective of the EOA, standardized practices concerning contaminated sites within development projects in Uppsala have evolved between the ECC, the development companies and the EOA. Some practices are set by the environmental regulations; however, others are local occurrences. In accordance with the 10th chapter 11 § in MB, the EOA must be notified when contaminants are encountered. This results in that all investigative reports concerning contaminants are registered at the EOA and become official deeds which anyone in Sweden can access by request. Furthermore, all remedial actions have to be registered at the EOA, in accordance with §28 (Förordningen om miljöfarlig verksamhet och hälsoskydd: SFS 1998:899). The practice that was observed, was that a "remedial action plan" was delivered to the EOA together with the registration form. If needed the EOA requested supplementary information, before the remedial action plans were finally approved.

When the remedial action plan was approved, the EOA issued a legally binding order that requested a remedial action, when needed. In the order, the EOA stated what needed to be fulfilled before the remedial action plan could be approved. Commonly, in the order they repeated the different commitments that was suggested by the ECC in the remedial action plan. While fulfilling the quantifiable remedial objectives is the most important part of such a order, presenting a remediation report is also part of the commitments that must be fulfilled before the remedial action can be finalized and the case closed. According to the EOA (Miljöförvaltningen Uppsala kommun, 2017), it occurs that the remediation report, regardless of an ordered deadline, is received more than a year later. In such a case, they say, it is difficult to properly inspect the remediation report and, if required, request further actions since buildings are perhaps already constructed on the site and the responsible ECC possibly working elsewhere.

Examples of practices that was identified from the perspective of the EOA are as follows:

- Orders concerning remedial actions contained similar, or even identical, formulations and paragraphs.
- During a few years, the EOA demanded that at least every 10th field sample, should be analyzed at laboratory. This is no longer the case (2017).
- Complementary investigations were requested when the EOA considered that insufficient amounts of data were presented. However, it is not clear where the limit of sufficient data is set. Statistical representativeness is not asked for in any of the cases studied in this thesis, which makes it difficult to overview the decisions regarding sufficient data.
- Sufficient investigations and analyzes concerning protection of groundwater was always requested, if not presented by the ECC.
- SSGV were not requested by the EOA if the development company suggested the use of GGV.
- The reasoning behind sample methodology and data analysis was requested a few times when not present, but not as a standard.

5 Discussion

5.1 Working procedure and general practices

The results from the review, show that a straightforward general working procedure exist for cleanups within development projects in Uppsala. All parts involved (EOA, ECC and the development companies) seems to be aware of this general practice in Uppsala that has evolved for these cleanups since 2009 when the SEPA guidance was published. The EOA is considered to have well-established routines for cleanups in development projects, and the ECC in Uppsala is, in general, considered aware of what is expected from them from the EOA. This enables compliance with the legal system. Generally, the occurrence of the general practice can be considered positive, since it enables a general level of protection that stems from the cautionary principle. This general practice also highlight important protection targets, especially protection of groundwater and human health. The downside might be that other protection targets are insufficiently addressed.

However, a few points of improvements have been identified with the existing practice:

- **There are general routines involved in cleanups within development projects from both the ECC and the EOA in Uppsala, which may fail to capture the natural heterogeneity in contaminant distribution that exist between sites.**

Example: As mentioned in section 4.2.2, the EOA demanded for a period that at least one of every ten samples taken had to be analyzed at a laboratory as a standard, independently of the size of the area to be investigated. Such a standard may ignore the heterogeneity between different locations. Consequently, that standard was later abandoned, but it is an important example which show that routines must be adaptable to site specific heterogeneities. If not, there is a risk that the actual contaminant situation is not correctly depicted which can result in either unexpectedly high concentrations of contaminants encountered during the excavation control, or excessive remediation. The consequence of the former may be high additional costs, whereas the consequence of the later may result in decreased sustainability of the project.

The ECC, in this thesis, are considered to follow standardized routines to a great extent for cleanups within development projects, for both soil investigation plans and remedial actions i.e. Routines are helpful, and sometimes necessary, as long as the heterogeneity of environment is acknowledged, otherwise misguided decisions might be taken. For example, the objective of an investigation, based on the site-specific conditions, should decide the design of a soil investigation plan, not a predefined routine. Perhaps an evaluation, based on site-specific conditions, is performed automatically when the sample plan is set, but if the motivation to this is not presented to the EOA, they cannot evaluate it.

Furthermore, when the employment of ECC is conducted by the development companies, it is possible that the economic factors impact the choice of ECC, since it is likely cheaper to hire an ECC that uses a standardized soil investigation plan than an innovative and unique one, since this naturally takes more time to produce; hence a higher cost for the development company. Thus, the practice to use a standard routine in investigations may neglect possibilities to perform investigations of differing magnitude when it is needed, since it will result in a higher cost. According to one ECC (Sweco, 2016a) this is a common situation which affect their possibilities to perform investigations. It can therefore be concluded that economy is often given a greater importance when performing soil investigations, than the environment. Even though individual examples probably exist of where the opposite is true, changing this situation on a national level probably requires stronger enforcement of the environmental regulations.

Another factor which is important in order for environmental issues to gain more attention in the development process, is to increase the understanding of the environmental implications which may follow of not performing the necessary investigations. Perhaps, the development companies do not fully understand the potential environmental problems to their full extent and that lack of knowledge drives the development of standardized routines to keep costs down.

- **A statistical analysis of data is seldom presented in the ECC reports, nor asked for by the EOA**

When sample data were presented to the EOA, represented by the sample data's maximum concentration for example, it was inspected and questioned in detailed by the EOA. Considering this, if the ECC presented statistical analysis of sample data as well as statistical motivation for different choices of practice, the EOA would perhaps be able to question the investigations and remedial actions in more detail. This would also create a more transparent view of the superintendence. Indeed, it is possible that the lack of statistical analysis of data makes the EOA less capable of questioning the quality of investigations and remedial actions, with respect to data representativeness.

An example of when statistical analysis of data is of importance, is when representative values are presented. However, statistics is not widely used in practice, neither by the EOA or the ECC. From a statistical point of view, the accuracy of representative values is always important for soil investigations, since these values are what is later compared to the GV. As described in section 2.3.3, a representative value can for example be either the maximum concentration of one sample that represent the target population, or several samples (composite samples or statistically calculated average concentrations) that together represent the target population. The degree of "representativeness" is crucial, since if the uncertainty of a data set is not statistically evaluated, one cannot statistically define if the data set is representative or not. If the representativeness is not evaluated, it cannot be named a representative value. Instead, the sample data will only describe the contaminant situation in certain sample points, resulting in that the spatial dimension is lost. More practically, if the uncertainties of a data set are not presented to the EOA, they cannot truly evaluate questions such as if additional investigations are needed, since the data presented may not be representative. Relevant decisions can, of course, be made based on field knowledge but may result in arbitrary decisions, compared to if decisions were to be based on statistically supported data. Since statistics can also be handled wrong, a combination of statistical analysis and field knowledge is the best option, as is also suggested by Norrman *et al.* (2009b).

The more heterogeneous the contaminant situation is, the more important it becomes to evaluate how close the investigation results are to the real contaminant situation. With extended and clearer guidance on this topic, geostatistical methods could be used to a much greater extent in the field of contaminated sites.

- **SSGV for soil that is left on site after remediation or development could be requested to a greater extent by the EOA**

It is, in this thesis, concluded that it is irrelevant to calculate SSGV for soil that is to be disposed at landfill, since such soil must be classified depending on the landfill's criteria, which often are standardized. However, SSGV may still be desired for the soil which will not be excavated, as well as for potential reuse of soil within the site. One example of when this was successfully performed, is the Uppsala Entré cleanup.

It was not possible to quantitatively evaluate if excessive remediation occurred within the studied cleanups, it can only be concluded that in theory SSGV should provide the most correct GV seen to risk reduction purposes. The use of GGV may result in either too high or too low protection of the protection targets, which increases the risk of an unsustainable remediation, either by leaving contaminants that pose a risk, or by remediating excessive amounts of soil. Therefore, it is important to evaluate the applicability of the GGV.

Despite that, it seems as the general viewpoint from the EOA is that the GGV_{KM} always gives a full protection of all the protection targets, even if the guidance from

SEPA show that this is not always the case for scenarios that differ from the generic scenarios. If this observation is accurate, there is a clear need of additional guidance on the topic.

Furthermore, the result shows that the soil ecosystem is hardly discussed in the risk assessments. This is interesting, especially since the soil ecosystem governs the GGV_{KM} for several common contaminants and ought to be given a greater focus and require a high level of understanding by both ECC and EOA. Presumably the reason for this is that it is a complex question that require specific investigations, which is commonly not performed in smaller projects.

5.2 Degree of compliance to the SEPA cleanup guidance

Since the SEPA's guidance about risk assessment follows a tiered approach (see section 2.1.3) it is adaptable to all types of contaminated sites in the sense that only the investigations that are needed to reduce the potential risk, shall be undertaken. The level of investigations needed must be decided for each cleanup case and depends on the contaminant situation and need of risk reduction. This is positive in the aspect that it is adaptable to the heterogeneity that exist within and between sites, but it is also subject to arbitrary decisions.

The results of this thesis show that it is quite unclear which parts of the SEPA guidance that should be applied on cleanups in development projects. First, the fact that all the studied cleanups were primarily driven by constructional requirements, and not by risk reduction purposes, results in that risk reduction, the primary goal of the SEPA guidance, is given a secondary position. This affects the practice of cleanups within development projects. As described in the results, the approach of cleanups can be described as somewhat reverse, compared to cleanups that are not located at development sites.

When a site contains concentrations of contaminants that exceed the background levels, it is defined as a contaminated site that has to be treated according to 10th chapter MB and its supplementary regulations. Subsequently, a key question is which parts of the SEPA guidance that are still applicable for cleanups within development projects and to what extent. According to the results of this thesis, this is not obvious. This conclusion is in agreement with the survey concerning contaminated sites in spatial planning performed by SGI (see section 2.4) (Ländell *et al.*, 2015). The following sections will discuss the applicability of the SEPA guidance concerning feasibility study, risk assessment, soil investigations and initial planning, for cleanups within development projects.

5.2.1 Feasibility study

As presented in the results (section 4.1; Appedix C), only one feasibility study was performed among the studied cleanups. However, as it was done for the entire area of Östra Station, it comprised four of the cleanups presented in the study (Fålhagen 69:1, Fålhagen 70:1, Uppsala Entré and Frodeparken).

It can be concluded that the feasibility study was partly performed in accordance with the SEPA guidance, but not entirely. One aspect that the ECC did not analyze in enough depth was the protection of soil ecosystem. This was only mentioned briefly and the protection of it was limited.

A quite interesting part of the feasibility study from Östra Station was that the ECC claimed that the level of risk reduction should not be the same for development projects, compared to cleanups financed by the government. The authorities responded that this reasoning was wrong, but it is interesting that it was mentioned. Apparently, in this case the ECC did not believe that the SEPA guidance concerning cleanups were entirely applicable on cleanups within development projects, which affected their approach to the investigation. In this case the authorities made it clear that they considered it applicable, however it is a good example of when it has been unclear what ambition level of investigations that are correct to request for cleanups in development projects. Certainly, the ECC and the EOA did not perceive the applicability of the SEPA guidance the same way. However, since the current risk assessment guidance, published in 2009, was not present at that time, this only relates to the former guidance.

Another interesting observation concerning the feasibility study of Östra Station, is that it was not mentioned explicitly in any of the material that have been included in the current study. For example, the suggestions for classification of soil, as well as, delineation of soil during the excavation control that were presented in the feasibility study, were not referred to in the cleanups from Östra Station that were included in this study. Perhaps, this is due to that parts of the feasibility study were criticized by the operational authorities. Nevertheless, the significance with the feasibility study can be questioned, since it did not really affect the outcome of the subsequent cleanups.

5.2.2 Risk assessment

The question if risk assessments should be performed for cleanups within development projects, is somewhat complex. It depends on what is perceived, or defined, to be a risk assessment. Since risk assessments should follow a tiered approach, a basic risk assessment might not include much information, if that is the level estimated to be sufficient. With respect to this, the investigations performed in the cleanups in group 2 and 3, where risk assessment or a short risk discussion, was integrated in a soil investigative report, might have been sufficient and therefore in accordance with the SEPA guidance. Interestingly, the final remedial actions for the cleanups where a detailed risk assessment were performed did not differ much compared to the cleanups where no risk assessment were performed, except from the cleanup of Uppsala Entré where SSGV was approved at a late stage in the remedial phase of the cleanup. This may lead to the simple conclusion that risk assessments might not be mandatory to conduct for cleanups within development projects.

However, again, this depends on what is perceived to be a risk assessment. It can be argued that by comparing maximum sample concentration data with GGV, a basic risk assessment has by definition been performed, because behind the GGV there is information that defines when a risk occurs for the generic scenario. This is another example of the complexity of defining when a risk assessment has been performed or not, as well as what type of risk assessments that could be requested for cleanups in development projects. Clearly, as long as SEPA do not clarify this, the ECC and EOA will continue to create its own practice, which may differ between different parts of Sweden, as well as between EOAs.

5.2.3 Soil investigation and initial planning

Independently of a potential excavation due to constructional requirements, a contaminated site has to be investigated and the contaminants delineated. Thus, the soil investigative parts of a cleanup are always important. As the results show (Appendix C), it was common to encounter additional contaminants during the excavation control, which in some cases, such as in the cleanup of Frodeparken, caused a lot of delay and additional costs within the project. This suggest that enough investigations were not performed during the initial investigations. Hence, it cannot be assumed that the contaminants are only associated with the soil that will be excavated. Therefore, a sample plan with a carefully prepared aim, originating in the potential risk situation, is important also for cleanups within development projects. Furthermore, as mentioned previously the aspect of representative samples are also still as important, even if the purpose is to classify soil for landfill disposal.

Conclusively, from the results shown and based on the reasoning above, it seems as the SEPA guidance are followed in many aspects, for example that investigations are performed in a tiered way. However, certain aspects can be improved, such as presenting a soil investigative plan that originates in the actual situation, as well as evaluating the uncertainty of sample data. Furthermore, it seems unclear which ambition level that should be aimed for concerning investigations of cleanups within development projects. It is possible that that in some situations, more material could be requested from a scientific perspective. However, it must be pointed out that the reason for this is not caused by lack of competence, neither at the EOA or the ECC. It is coupled to the limitations of time and utmost the economic constraints that are present in most development projects. As long as it is unclear how the SEPA guidance should be applied on cleanups within development projects, interests such as time and economy will continue to set the limits. If a consistent management of cleanups within development projects is desired, it is suggested that SEPA provide a guidance that only focuses on such cleanups.

6 Limitations of the study

The results of the study and the discussion are based on the material that was available at the Environmental Office at the Municipality of Uppsala, but it is possible that additional information is available elsewhere. However, since all information concerning the cleanups was retrieved from each cleanup’s file at the EOA, the information used for official decisions has been reviewed. If not present there, it was neither present when decisions regarding the cleanup was taken.

Some of the aspects that were investigated were found difficult to evaluate, since it is not clear when they are supposed to be present. Such aspects were if protection targets were discussed and if exposure pathways were discussed. In the guidance from SEPA these two aspects are connected to the risk assessment methodology, resulting in that if a complete risk assessment was not the aim of an investigation it cannot be demanded that those aspects should be present in the report.

Another aspect that was found difficult to evaluate is if the aim of reports were clear or not. It was found difficult to calibrate an exact limit between clear and not clear aim, which is why no results are shown for this aspect (Appendix C).

7 Conclusions

- A general practice has developed between the Environmental Consultancy Companies and the Environmental Operational Authority in Uppsala.
- The general practice is considered to be transparent and the superintendence is found consistent, which enables a secure compliance of the legal system.
- The cleanups followed the SEPA guidance concerning cleanups to a large extent, however, there are a few improvements that can be made concerning statistical analysis of data and increased use of SSGV.
- If a more consistent management of cleanups within development projects is desired, SEPA must provide clearer guidance for such cleanups. Based on the results of this thesis, it is suggested that SEPA provide a guidance that focuses on cleanups in development projects. Such a guidance should include a clear recommendation of a national field practice, as well as clear guidance and suggestions of how the superintendence can utilize the existing environmental regulations to a greater extent.

8 Acknowledgement

I want to thank my three supervisors for all the support you have given me throughout the process of this thesis:

Emelie Larsson and Fredrik Stenemo at Sweco, you took the chance to introduce me to the consultancy world and I have learned a lot from this experience. Not only have you guided me in detail when I have needed it, you have also advised me about the working life in general which I will carry with me from now on. I could not have hoped for more encouraging and caring supervisors.

Dan Berggren Kleja at the Swedish University of Agricultural Sciences, I wish to thank you for all the interesting discussions within the broad topic of this thesis that resulted in a well-delimited purpose.

I also wish to thank all the employees at the Environmental Office at the Municipality of Uppsala, who have helped me at several occasions with the information retrieval, as well as for sharing your views and experiences. Especially, I want to thank Marie Nilsson, Karin Boman, Mats Dahlén, Babis Zisimopoulos and Monica Pettersson. I also wish to thank Ebba Tiberg at the Environmental Office, who was unfortunately not able to participate during my thesis work, but who previously have guided me in the field of contaminated sites and inspired me a lot.

Furthermore, I wish to thank all the people at Sweco that I have interviewed as well as everyone who has guided me in the work. A special thanks to Anders Lindelöf, Anders Sivertsson, Anna Paulsson, Claes Thureson, John Wrafter, Maria Brolin, My Ekelund, Pehr Rylander and Sofie Lücke. I also want to point a big thank you to everyone at Sweco in Uppsala, especially group 1170!

Finally, Per Eriksson, you deserve a huge thank you for all the effort that you put into taking care of both of us during these intensive months, without you I would not have made it even halfway.

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Appendix A - General description of all 12 cleanups

Östra Station

Östra Station is situated east of the current railways at Uppsala station and comprises an area of about 6 hectares in total (Figure 1) (Golder Associates, 2004). The area surrounding Uppsala station has been industrialized since the mid 1860’s, when the railway was constructed. The Östra Station area was mainly used as railway yard. A mobile impregnation facility for railroad ties was also kept and used in the area. Additionally, diesel and oil has been stored in tanks on the site and pesticides was used over the entire area (Zetterblad, 2004).

The first investigations of the contaminant situation started in 2002, as a response to development plans for the area (Golder Associates, 2004). Today, the whole area except a property in the southeast corner (Figure 1) has been remediated and developed to an area comprising residences, offices, mall and a hotel.

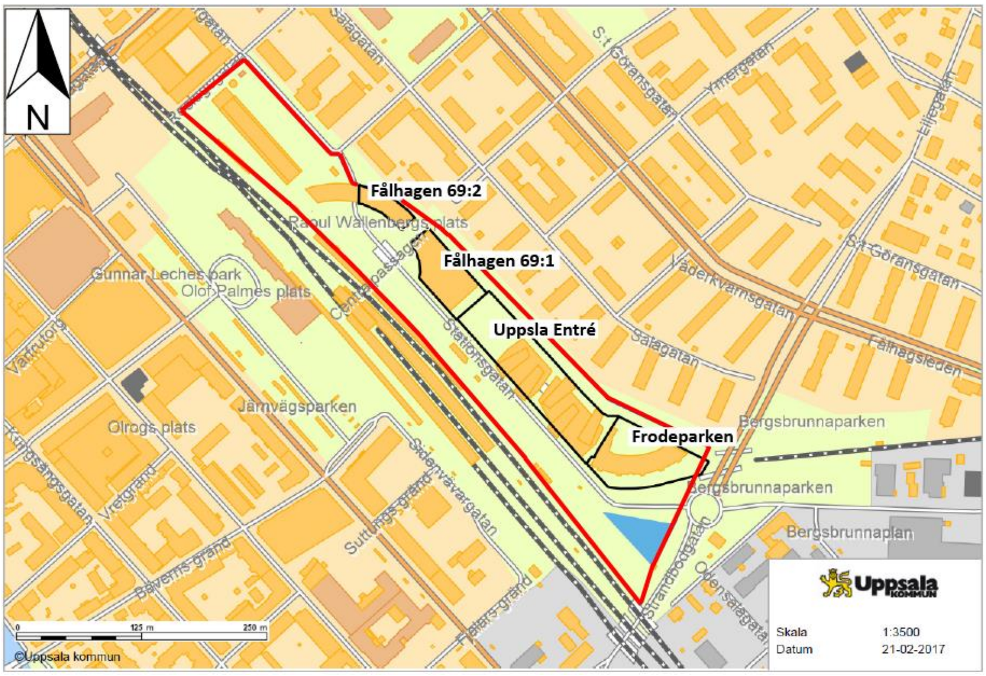

Figure 1. The approximate area that was included in the investigations before development of Östra Station, is outlined in blue. The remediated properties are outlined in black. The shaded blue area in the southeast is the last property that is still to be developed. Background map from Uppsalakartan, Uppsala kommun. Printed with permission

The general contaminant situation at the premises of Östra Station was dominated by heavy metals and PAH in the filling material, that exceeded the guideline values (Sweco, 2014).

In total, four cleanup projects within the Östra Station development area have been included in the review: Fålhagen 69:1, Fålhagen 70:1, Dragarbrunn 33:2 (Frodeparken) and Fålhagen 70:2 (Uppsala Entré) (Figure 1).

In 2010 the part of the property Fålhagen 69:1 that had not yet been remediated, was remediated (Bjerking, 2010) followed by remediation of the adjacent property Fålhagen 70:1 in 201 (Bjerking, 2011). Fålhagen 70:1 is now encompassing a building with offices and a mall. The property in the east, Frodeparken, was remediated in 2012 and the remediation of Uppsala Entré was finished in 2014 (Sweco, 2015). On the two last mentioned properties residence houses are located. West of the above mentioned properties, the road Stationsgatan is located, which was remediated in 2006 when the road was constructed.

At Fålhagen 69:1 As, Cd, Pb and PAH-H that exceeded the guideline values was detected (Bjerking, 2010). At Fålhagen 70:1 As, Pb and PAH-H that exceeded the guideline values was found in the filling material. Tetrachloroethene, tetrachloromehtane and trichloromethane was also detected, however in low concentrations (Bjerking, 2011).

At Uppsala Entré, PAH-H and PAH-M in the filling material were the dominating contaminants that exceeded the guideline values. Also aliphatic compounds, As and Pb that exceeded the guideline values was found in the filling material. However, the contaminated soil could not be delineated when the soil that had to be excavated for construction requirements (down to 1,7 m below soil surface) was removed. Several samples of the clay below the filling material showed concentrations of As, Ba, Co, Cr and Ni (Sweco, 2015).

At Frodeparken, a known hotspot of creosote left from an earlier point source remediation was known to be present in the west corner, towards the road Stationsgatan. The sample data showed to be in agreement with this, as concentrations of As, Cu, Pb and PAH that exceeded the guideline values was encountered in the filling material, predominantly in the west and southwest part of the property. However, in the west corner where the hot spot was located, containing oil and creosote, the contaminated soil could not be delineated vertically below the filling material. The oil and creosote contaminated soil expanded through the soil, into the till and was present also below the groundwater surface (Vectura, 2013).

Industristaden

Industristaden is the name of an area that is currently being developed in Uppsala. It is located east of the river Fyrisån, south of the station. Four cleanups was included in the review: Mjölnaren, Spolen, Varpen 1 and Varpen 2. Together, they comprise an area of about 4 hectares (Figure 2).

The area of Mjölnaren is located in the northern part of the former industrial area at Kungsängen (Figure 2). A sawmill was active on the site. On the neighboring property Munin, a gas plant was located. The property is filled out with masses that can origin from the gas plant. The dominating contaminates are Cd, Cu, Hg, Pb, Zn and PAH (Miljökontoret Uppsala kommun, 2009).

At Spolen, a grain industry started in the early 1900's. Processes around this, such as storage of pesticides and oil, as well as a facility to mordant the seeds, have contributed to chemical use on the property. In the northern part of the site, as well as on the property north of Spolen, metallic fiber was manufactured between the years 1924 to 2000. The contaminant concentrations measured in the area were generally quite low. Although, in a few points PAH:es, aliphatic compounds and heavy metals that exceeded the guideline values, was detected (Geosigma, 2012).

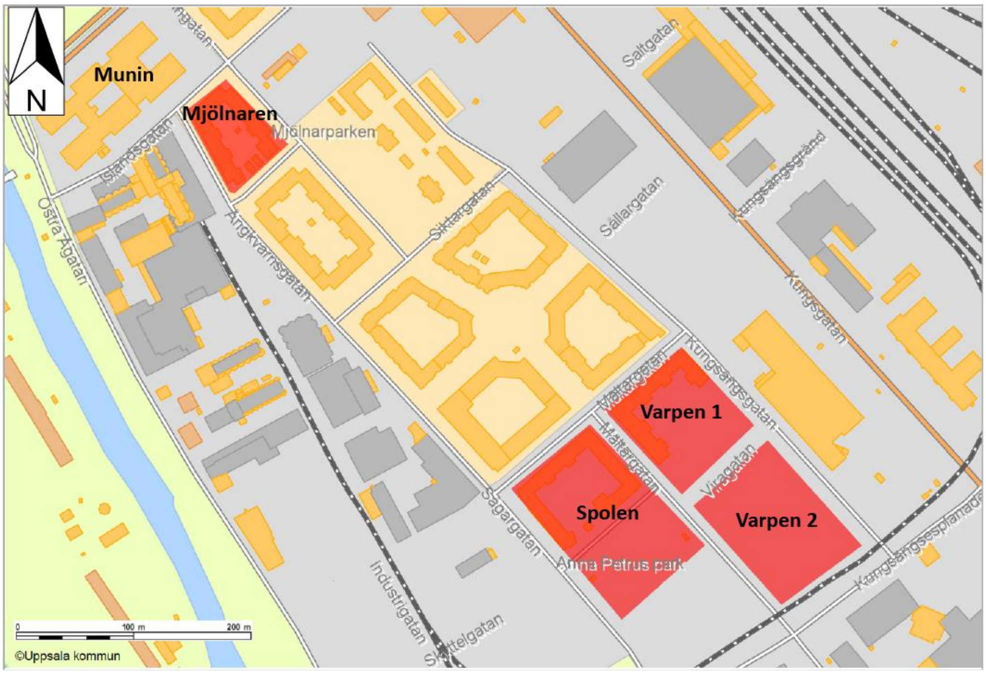

Figure 2. The cleanups at Industristaden that was included in the analysis, are highlighted in red. Background map from Uppsalakartan, Uppsala kommun. Printed with permission

The area on which Varpen 1 and 2 is located was not developed until the early 1960's. Business' on the Varpen 1 site has since then been offices and a transport terminal. On the Varpen 2 site, a printing business and several petroleum stations have been active, as well as other smaller businesses (WSP, 2009). The dominating contaminates at Varpen 1 and 2 were As, Pb, PAH:es and aliphatic compounds (WSP, 2009).

Librobäck

Librobäck is an area in the northwest of Uppsala, which is currently being developed. It has been an industrial area since the 1940's, with a big expansion of industrial activities in the 1960's. The development of the city district to an area encompassing business, offices and residences has proceeded since the 1990's (Uppsala kommun, 2005).

In total, four different cleanups in Librobäck was included in the review. To distinguish between them they were given names based on the neighborhood designations: Gimo 1, Gimo 2, Klockaren 1 and Klockaren 2 (Figure 3).

Gimo 1, is roughly 15 000 m2. Industry on the site was established in 1965. Different types of engineering mechanics and engineering merchandize has been present on the site. Gimo 2 is also comprising parts of a former clay pit. The site is contaminated with dominantly As, Hg, PAH, aliphatic and aromatic hydrocarbons (Sweco, 2016).

Gimo 2, is roughly 10 000 m2. The site was industrialized in 1964. Several business has been active on the site, including but not limited to: garage, carwash, car mechanics, car merchandize, storage buildings and glass manufacturing. Additionally, parts of the site is also within the zone of a former clay pit, which are often filled with a mixture of soil and waste. Chlorinated hydrocarbons are known to have been used at the site. The dominating contaminants at Gimo 1 are chlorinated hydrocarbons, PAH and metals (As, Pb, Cd, Co, Cu, Hg, Ni, Zn) (Bjerking, 2015).

Klockaren 1, is roughly 2 300 m2. Previous industries at the site was a car mechanics and garage for trucks. Contaminants that exceeded the guideline values were Cd, Pb, Zn, PAH-H and aliphatic and aromatic compounds (Ramböll, 2009).

Klockaren 2, is roughly 3 400 m2. The site was used for industrial storage and contained a car-wash facility (Sweco Viak, 2003). The dominating contaminants were Zn, Ni and PAH (Bjerking, 2009).

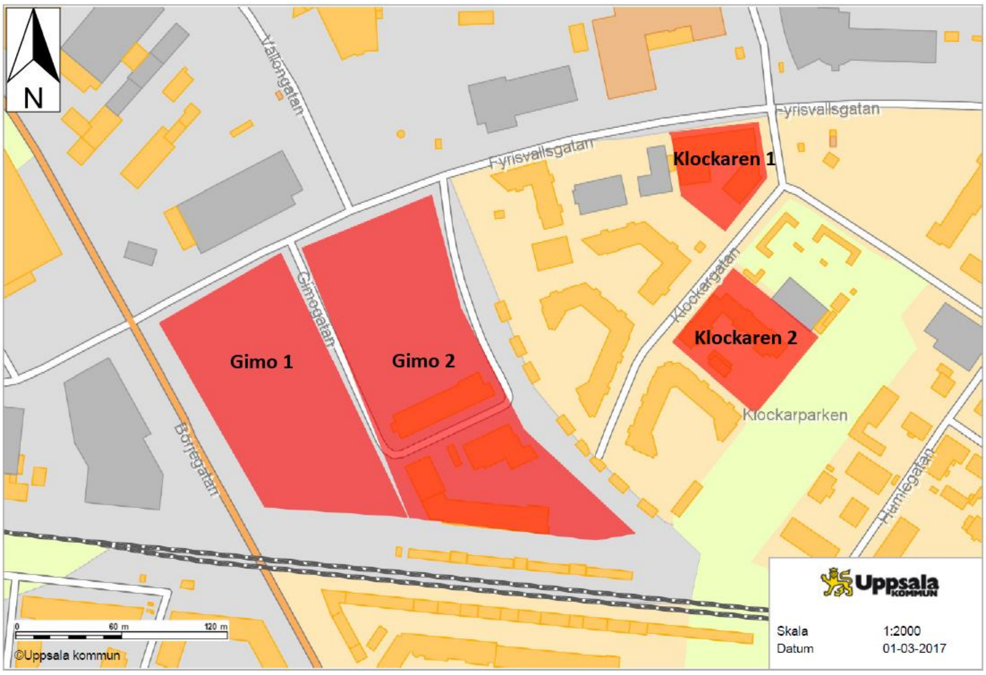

Figure 3. The cleanups at Librobäck that was included in the analysis, are highlighted in red. Background map from Uppsalakartan, Uppsala kommun. Printed with permission

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Appendix B – Presentation of contaminant situation, planned land use and soil, groundwater and pore-air sampling

Cleanup	Contaminants	Planned land use	Soil sampling	Groundwater (gr.w.) and pore-air sampling
Fålhagen 69:1	**> MKM:** As **KM-MKM:** Cd, Pb, Hg, PAH-H, Pb.	Hotel	1) Judgmental sampling by continuous flight auger, 2 points. 1 sample analyzed at laboratory for heavy metals. - Judgmental sampling in backhoe pits, 4 points. 6 sample analyzed at laboratory for heavy metals and PAH:es.	
Fålhagen 70:1	**> MKM:** As, Pb, PAH - Chlorinated hydrocarbons detected, but below the set guidelines	Mall/offices	1) Judgmental sampling in backhoe pits, 10 points. 6 samples analyzed for heavy metals and PAH:es, at laboratory. 2) Judgmental sampling in backhoe pits, 5 points. 1 sample analyzed for heavy metals and PAH:es, at laboratory.	2) 1 groundwater sample analyzed for chlorinated hydrocarbons. 2) 1 pore-air sample, analyzed for chlorinated hydrocarbons.

Uppsala Entré	**> MKM:** AS, Pb, Zn, PAH, apliphatic and aromatic hydrocarbons **> MKM-KM:** Co, Ni, Ba, Cr(tot)	Residences	1) Systematic sampling with continuous flight auger, and in backhoe pits. 15x15 m grid. 5 composite samples analyzed by leaching test (metals, chloride, fluoride, sulphate, dissolved organic carbon (DOC). 18 individual soil samples analyzed at laboratory, for metals, aliphatic and aromatic hydrocarbons, including PAH:es.	1) 6 groundwater wells installed, possible to sample 4. In total 4 gr.w. samples analyzed at laboratory, for hydrocarbons, including PAH:es. During the excavation phase, gr.w. in the excavation hole was pumped to a mobile water treatment facility at the site, to be cleaned before let to the gray water.
Frodeparken	**> MKM:** As, Cu, PAH, aliphatic and aromatic hydrocarbons **MKM-KM:** Ba, Cd, Co, Hg, Ni, Pb, Zn	Residences, offices	1) Systematic random sampling, by continuous flight auger and backhoe pits. 16 samples analyzed at laboratory, for metals, aliphatic and aromatic hydrocarbons, including PAH:es. 2) Systematic sampling, in backhoe pits, 10 points. 5 samples analyzed at laboratory for aliphatic hydrocarbons and PAH, and by leaching test metals, chloride, fluoride, sulphate, dissolved organic carbon (DOC).	1) Groundwater not encountered. Pore-air was sampled in 4 points. 2) Groundwater sampling: During the excavation phase, the groundwater was sampled 1 time/month in various gr.w.-tubes/wells, in order to investigate potential gr.w. contamination and its distribution. Water in the excavated hole was also sampled. The gr.w. was analyzed for metals and hydrocarbons. The water was pumped to a mobile water

				treatment facility at the site, to be cleaned. The outgoing water was analyzed, before let to the gray water.
Mjölnaren	**> Km:** Cd, Cu, Hg, Pb, Zn, PAH	Residences	1) Judgmental sampling, backhoe pits, 5 points. 1 sample was analyzed at laboratory for metals, 2 samples were analyzed for PAH-16, 2 samples were analyzed for aliphatic and aromatic compounds. Additionally, 2 samples of the clay underlying the filling material, was analyzed with respect to its neutralizing capacity. 2) Judgmental sampling, backhoe pits, 2 points. 2 samples was analyzed at laboratory for metals, PAH and aliphatic and aromatic hydrocarbons. 3) Judgmental sampling, continuous flight auger, 6 points. Samples analyzed for PAH and metals.	
Spolen	**> MKM:** Ba, Cu**,** Pb, Zn, PAH **MKM-KM:** As, Cd	Residences, playground	1) Judgmental sampling, by continuous flight auger, 6 points. 6 samples analyzed at laboratory, for metals, aliphatic and aromatic hydrocarbons and pesticides. 2) Systematic sampling, backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a sample showed concentrations exceeding KM, the individual sample was analyzed at laboratory. 34 samples analyzed for metals, and aliphatic and aromatic hydrocarbons	2) Pore-air analyzed for chlorinated hydrocarbons in 8 points, randomly distributed over the site.

			including PAH and BTEX. 3 samples analyzed for pesticides (judgmentally chosen).	
Varpen 1	**> MKM:** As, aromatic hydrocarbons, PAH **MKM-KM:** Pb, Cd, Cu, Zn, aliphatic hydrocarbons	Residences	1) Judgmental sampling, continuous flight auger, 8 points. 3 samples analyzed in laboratory for metals, aliphatic and aromatic hydrocarbons. TOC and pH analyzed for 1 sample. 2) Systematic sampling, backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a sample showed concentrations exceeding MKM, the individual sample was analyzed at laboratory.	During the excavation, water was found in the excavated hole, and analyzed for metals and aromatic and aliphatic hydrocarbons.
Varpen 2	**> MKM:** aromatic hydrocarbons, PAH **MKM-KM:** Hg, aliphatic hydrocarbons	Residences	1) Judgmental sampling, continuous flight auger, 10 points. 6 samples analyzed in laboratory for metals, aliphatic and aromatic hydrocarbons. TOC and pH analyzed for 2 samples. 2) Systematic sampling, backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a sample showed concentrations exceeding MKM, the individual sample was analyzed at laboratory. 3) Systematic sampling, backhoe pits. 10x10 m grid. 34 points. 9 composite samples, representing 4 grids each (1 sample from each	1) 1 pore-air sample analyzed at laboratory.

			grid), was analyzed at laboratory, 6 samples was analyzed individually. All samples were analyzed for metals, aliphatic and aromatic hydrocarbons.	
Gimo 1	• Contaminants in soil: PAH, PCB-7, As, Ba, Zn, Pb, Cd, Co, Cu, Hg, Ni, Zn. • Chlorinated hydrocarbons in water and soil, such as: 1,1,2-Trichloroethene, Cis-1,2-Dichloroethene, Trichloroethane, dichloroethane.	Residences	1) Systematic sampling, backhoe pits, 10x10 m grid. 40 samples analyzed at laboratory for aliphatic and aromatic hydrocarbons including BTEX and PAH. 26 samples analyzed for aliphatic and aromatic hydrocarbons including PAH. 65 samples analyzed for metals. 4 screening analyzes were performed (including chlorinated pesticides, chlorophenols, aliphatic and aromatic compounds, PCB, chlorinated compounds and metals). Total organic carbon (TOC) analyzed for 21 samples.	Sampling of soil water in 4 soilwater tubes. Sampling of pore-air below buildings in 3 points. Sampling of pore-air on the remaining part of the site (outside) in 8 points. 1) 7 gr.w. samples analyzed for volatile organic carbon (VOC),
Gimo 2	**> MKM:** PAH **MKM-KM:** Cu, Pb, Zn, aliphatic and aromatic hydrocarbons. • Aliphatic hydrocarbons in soil water	Residences	1) Judgmental sampling, continuous flight auger, 7 points. 6 samples analyzed at laboratory: screening was done on two samples (includes chlorinated pesticides, chlorophenols, aliphatic and aromatic compounds, PCB, chlorinated compounds and metals), hydrocarbons including PAH and metals were analyzed for 3 samples, and metals was analyzed for 1 sample. 2) Systematic sampling in backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at	1) 4 gr.w. samples analyzed at laboratory. 1 screening analysis and 2 VOC-analysis. 2) 1 Gr.w. sample analyzed by screening test. 3) 2 gr..w. samples analyzed by screening test. 4) 2 gr.w. samples analyzed for metals, aliphatic compounds, aromatic

			laboratory. If a sample showed high concentrations, the individual samples was analyzed at laboratory. Samples analyzed for metals, aliphatic and aromatic compounds, including PAH and BTEX. Some samples were analyzed for pesticides. Sulphide content in clay measured for 2 samples. 3) Systematic sampling in backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a sample showed high concentrations, the individual samples was analyzed at laboratory. Additionally, continuous flight auger sampling was performed where buildings was located, 6 sample points. All samples analyzed for metals, aliphatic and aromatic compounds, including PAH and BTEX. 4) Systematic sampling in backhoe pits. 10x10 m grid. Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. Samples analyzed for metals, aliphatic and aromatic compounds, including PAH and BTEX. TOC analyzed for 7 samples.	compounds, PAH, VOC, MTBE, PCB and pesticides.
Klockaren 1	**> KM:** Cd, Pb, Zn, PAH,-H and aliphatic and aromatic compounds.	Residences and park	1) Judgmental sampling, backhoe pits, 5 points. 5 samples analyzed at laboratory, for metals and PAH.	Gr.w. could not be detected.

			2) Judgmental sampling, backhoe pits, 5 points. 4 samples analyzed at laboratory, for metals and aliphatic hydrocarbons.	
Klockaren 2	**> KM:** Zn, Pb, PAH	Residences	1) Judgmental sampling by continuous flight auger, 19 points. 1 sample was analyzed for metals, 1 sample was analyzed for aliphatic hydrocarbons, 1 sample was analyzed for PAH. 2) Continuous flight auger, 10 points. 10 samples analyzed at laboratory, for metals, aliphatic hydrocarbons, PAH and dry weight.	

Appendix C. A compilation of the excel matrix questions, based on what type of risk assessment that was performed.

A: Detailed risk assessment					
	Fålhagen 69:1	**Fålhagen 70:1**	**Uppsala Entré**	**Frodeparken**	**Klockaren 1**
Is the purpose of the different investigations clearly specified?	-	-	-	-	-
Has a conceptual model of the contaminant situation, protection targets and potential exposure pathways, been developed?	No	No	No	No	No
Was site specific guideline values (SSGV) used?	No	No	Yes	No	Yes
Comment, SSGV	SSGV presented, but not approved.	SSGV presented, but not approved.	SSGV approved for clay below the construction depth, between remediation phase 1 and 2.	SSGV presented, but not approved.	Different SSGV for different locations at the site was presented, but not approved by the operational authority. Instead, the SSGV scenario based on GGV_{KM} was chosen for the entire site.

Are exposure pathways discussed?	Yes	Yes	Yes	Yes	Yes
Are protection targets specified?	Yes	Yes	Yes	Yes	Yes
Which risk targets are discussed?	All risk targets relevant	All risk targets relevant	All risk targets relevant	All risk targets relevant	All risk targets relevant
Was grid-sampling performed?	No	No	Yes	No	No
Size of grids?	-	-	15x15 m	-	-
How were representative values calculated?	Maximum concentration of sample was compared to the guideline values.	Maximum concentration of sample was compared to the guideline values.	The site was divided in 5 subareas. 3-5 samples from each subarea was made to a composite sample that should represent each subarea. However, the classification of subareas could not be followed as more contaminants were encountered as the excavation work started.	The site was divided in 5 subareas. 2 samples from each subarea was made to a composite sample that should represent the subarea. However, the classification of subareas could not be followed as more contaminants were encountered as the excavation work started.	Maximum concentration of sample was compared to the guideline values.
Did the operational authority influence or request additional information regarding the	Yes, additional sampling.	Yes, additional sampling, both soil and gr.w.	-	Yes, pore-air sampling was requested. They also requested a suggestion for guideline values for water which could	Yes, they requested additional investigations, more samples and that the samples were to be

investigations/sample plan?				potentially be encountered in the excavated hole.	analyzed for aliphatic compounds, since that was not included in the first investigations.
Was a feasibility study performed?	Yes	Yes	Yes	Yes	No
Which were the quantifiable remedial objectives?	MKM	MKM	KM	KM	SSGV (based on KM)
Which remediation technology was used?	Dig and dump	Dig and dump	Dig and dump, on-site water treatment of groundwater	Dig and dump, on-site water treatment of groundwater	Dig and dump
Are the size of remedial volumes motivated?	No	No	No	No	No
Was a pre-classification of soil masses done prior to the excavation operation?	No	No	Yes	Yes	Yes
Other practical reasons that influenced the remedial process?	Time	Time	Time. Change of environmental compliance inspector in charge of the case at the operational authority.	Time - the remedial work did not start from the most contaminated part of the site, which resulted in that when this part was finally arrived at, the project got much delayed.	The first investigations that showed contaminants at the site was not presented to the operational authority until 2 years later, during which further investigations or remedial actions could have been

					requested by the operational authority.
Was excavation needed for the majority of the site anyways, due to construction requirements?	Yes, the entire area was excavated	Yes, the entire area was excavated	Yes, the entire area was excavated	Yes, the entire area was excavated	Partly, most soil had to be excavated, but not to 100 %

B: Basic risk assessment				
	Varpen 1	**Varpen 2**	**Gimo 1**	**Klockaren 2**
Is the purpose of the different investigations clearly specified?	-	-	-	-
Has a conceptual model of the contaminant situation, protection targets and potential exposure pathways, been developed?	No	No	No	No
Was site specific guideline values (SSGV) used?	No	No	No	No
Comment, SSGV	-	-	SSGV was calculated for water, but not approved by the operational authority.	SSGV was presented but not approved.
Are exposure pathways discussed?	Yes	Yes	Yes	Yes

Are protection targets specified?	Yes	Yes	Yes	Yes
Which risk targets are discussed?	Human Health & Surface Water/Groundwater	Human Health & Surface Water/Groundwater	Human Health & Surface Water/Groundwater	All risk targets relevant
Was grid-sampling performed?	Yes	Yes	Yes	No
Size of grids?	10x10 m	10x10 m	10x10 m	-
How were representative values calculated?	Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a composite sample showed concentrations exceeding MKM, the individual samples were analyzed at laboratory.	Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a composite sample showed concentrations exceeding MKM, the individual samples were analyzed at laboratory.	Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a composite sample showed concentrations exceeding MKM, the individual samples were analyzed at laboratory.	Maximum concentration of sample was compared to the guideline values.
Did the operational authority influence or request additional information regarding the	Yes, concerning preparedness off potential occurrence of gr.w. in the excavation hole.	Yes, an investigation concerning chlorinated hydrocarbons was requested.	Yes, additional sampling to delineate the contaminants (chlorinated hydrocarbons). A systematic sample strategy was asked for.	Yes, they requested a change regarding the quantifiable remedial objectives, which were suggested to be different for different depths. They

investigations/sample plan?				changed it so that KM was used for the entire site.
Was a feasibility study performed?	No	No	No	No
Which were the quantifiable remedial objectives?	KM on site, MKM on the street Viragatan south of the site.	KM	KM for soil	KM
Which remediation technology was used?	Dig and dump	Dig and dump	Dig and dump, partly on-site water treatment of gr.w.	Dig and dump
Are the size of remedial volumes motivated?	No	No	No	No
Was a pre-classification of soil masses done prior to the excavation operation?	Yes	Yes	Yes	No
Other practical reasons that influenced the remedial process?	Time	Time	Time	Time

Was excavation needed for the majority of the site anyways, due to construction requirements?	Yes, the entire area was excavated	Yes, the entire area was excavated	Yes, the entire area was excavated	Partly, most soil had to be excavated, but not to 100 %

C: Short discussion concerning risks are included in another report			
	Mjölnaren	**Spolen**	**Gimo 2**
Is the purpose of the different investigations clearly specified?	-	-	-
Has a conceptual model of the contaminant situation, protection targets and potential exposure pathways, been developed?	No	No	No
Was site specific guideline values (SSGV) used?	No	No	No
Comment, SSGV	-	-	-
Are exposure pathways discussed?	Yes	Yes	Yes
Are protection targets specified?	No (Groundwater not mentioned)	Yes	Yes
Which risk targets are discussed?	Human Health	Human Health & Surface Water/Groundwater	Human Health & Surface Water/Groundwater
Was grid-sampling performed?	No	Yes	Yes
Size of grids?	-	10x10 m	10x10 m
How were representative values calculated?	Maximum concentration of sample was compared to the guideline values.	Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a composite sample showed	Composite samples, representing 4 grids each (1 sample from each grid), was analyzed at laboratory. If a composite sample showed concentrations exceeding MKM, the

		concentrations exceeding MKM, the individual samples were analyzed at laboratory.	individual samples were analyzed at laboratory.
Did the operational authority influence or request additional information regarding the investigations/sample plan?	-	Yes, the number of sample points, sampling of soil/gr.w. and reuse of soil masses within the site, was discussed between the EOA before the remedial action plan was approved.	Yes, they asked for a systematic sample strategy.
Was a feasibility study performed?	No	No	No
Which were the quantifiable remedial objectives?	KM	KM	KM
Which remediation technology was used?	Dig and dump	Dig and dump	Dig and dump
Are the size of remedial volumes motivated?	No	No	No
Was a pre-classification of soil masses done prior to the excavation operation?	Yes	Yes	Yes
Other practical reasons that influenced the remedial process?	Time	Time	Time
Was excavation needed for the majority of the site anyways, due to construction requirements?	Yes, the entire area was excavated	Partly, most soil had to be excavated, but not to 100 %	Yes, the entire area was excavated