ROYAL INSTITUTE OF TECHNOLOGY

Which volumes have to be excavated?

A survey of the relation between target values and mean concentrations after excavation in four remediation projects funded by the Swedish Environmental Protection Agency.

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Abstract

The Swedish Environmental Protection Agency (SEPA) have been monitoring and financing a large amount of remediation projects in Sweden during the last couple of decades. In addition to this SEPA have been providing general guidelines, methods and reference values for remediation of contaminated land. The aim of this study has been to analyse the results from four remediation projects funded by SEPA, determine whether an over remediation is occurring and discuss the possible sources and effects of the situation. To come to such a conclusion results from the foundation-pit base were analysed statistically. One of the projects was studied more extensively, with additional calculations of the resulting concentrations in the surface after fill up and economic consequences of the over remediation. The results show that an over remediation is occurring, the mean level in the foundation pit base is approximately one fourth to one half of the target value, while the mean level on the surface after fill-up is less than a tenth of the target value. Conclusions are that the current methods and standards used by consultants in the remediation projects result in removal of too much soil. Remediation projects are therefore unnecessarily expensive and cause unreasonable strains to the environment.

Sammanfattning

Svenska Naturvårdsverket (SNV) har under de senaste decennierna övervakat och finansierat en rad efterbehandlingsprojekt av förorenade områden i hela Sverige. Utöver detta producerar SNV en rad rapporter och riktlinjer för det övergripande arbetet med sanering av förorenade områden och bildar därmed referenspunkt för hela branschen. Mycket talar dock för att saneringarna drivs för hårt och att för mycket jord tas bort i relation till åtgärdsmålen, det vill säga att man genomför en översanering. Syftet med denna studie är att undersöka resultatet i fyra projekt finansierade av SNV och jämföra den kvarvarande halten med de uppsatta åtgärdsmålen för respektive projekt. För att fastställa om översanering sker kommer data från schaktbotten att analyseras för samtliga projekt. Ett av projekten undersöks mer utförligt, med analys av de ekonomiska konsekvenserna och fastställande av halten i ytan efter ifyllning med rena massor. Resultaten visar tydligt på en översanering; medelhalten i schaktbotten ligger i storleksordningen en fjärdedel till halva åtgärdsmålet. Medelhalten i ytan efter ifyllnad är knappt en tiondel av åtgärdsmålet, och en tredjedel av bakgrundshalten i området. De ekonomiska konsekvenserna av översaneringen är svåra att utvärdera eftersom en bättre måluppfyllelse kommer att kräva ett metodikskifte, vilket försvårar en analys av kostnadsskillnaden med enbart en av metodikerna som material. Undersökningens slutsats är att de processer och metoder som används inom efterbehandlingsarbetet idag resulterar i en översanering, vilket i sin tur innebär att saneringarna blir onödigt dyra och, med ett mer holistiskt synsätt på miljön, att de inte heller är enbart av godo för miljön. Upphovet till översaneringen är bland annat den otydlighet inom beskrivningen av riktvärdena, det vill säga om riktvärden gäller för en enskild saneringsvolym eller som ett medelvärde för hela området som saneras. SNV har ett ansvar både när det gäller tydligheten i deras riktlinjer och att driva utvecklingen mot mer ekonomiskt och miljömässigt hållbara saneringsmetoder. För att få till stånd en förändring krävs det förmodligen att flertalet aktörer; kunder, konsulter och entreprenörer, är delaktiga och lyhörda för problematiken som belyses i denna studie.

Table of contents

1 Background and introduction

The Swedish government, via the Swedish Environmental Protection Agency (SEPA), annually spends approximately 500 million kronors on remediation of contaminated land all across Sweden (www.naturvardsverket.se.) SEPA fund remediation of sites where it is not possible to hold someone responsible for the contamination, for example sites where the activities were terminated a long time ago. Remediation projects are large efforts, including several stakeholders, multiple studies and demanding procedures for testing, classification and removal of contaminated soil. As a guidance and reference point to the remediation industry SEPA has developed generic guideline values for common contaminants and excessive material on the processes and methods applied during remediation projects (for more (www.naturvardsverket.se).

1.1 Purpose of this study

The typical method used in SEPA funded remediation projects is a removal of soils with levels exceeding the target value and fill-up with clean soil. This procedure ought to result in a final mean contaminant concentration that is significantly lower than the target value. This means that remediation projects are unnecessarily expensive and harmful to the environment, since the extra measures leading to the over remediation are bound to have economic and environmental consequences. The possibility and consequences of an over remediation of contaminated land is at the core of this survey, as stated below in the aims and objectives paragraphs.

1.1.1 Aims

The aim of this study is to determine whether over remediation is a typical situation in remediation projects funded by SEPA. If this is the case a second aim will be to discuss the sources and consequences of the observed over remediation, and finally to propose some alternative methods and perspectives, aimed at avoiding the situation.

1.1.2 Objectives

The study has several objectives, as listed below:

- Select a number of remediation projects funded by SEPA, but with different character in order to establish a good breadth of projects, thus giving the study a more general character.
- Analyse material and data from the selected projects, calculate the mean concentrations after remediation and compare these concentrations with the target values. If a general trend of over remediation is established the study moves to phase two, with the following objectives.
- Interpret material and data from selected projects to understand in which aspects the current methods result in the observed over remediation.
- Discuss the economical effects of the observed over remediation.
- Discuss alternative methods, aimed at avoiding or reducing over remediation.

1.2 Overarching purposes and goals for remediation of contaminated soil

Remediation of contaminated land has the double purpose of reducing the risk to humans and the environment, and allowing re-use of the site. Risk assessments for contaminated sites require an investigation of current and potential threats due to exposure of humans and the environment to soil and groundwater contaminants (Carlon *et al* 2007.) Thus, a risk assessment of a contaminated site aims at answering the two following questions:

1. Which and how big are the risks with the current and future situations if no measures are taken?
2. How low does the level of contaminant need to be in the area for there not to be any risks to humans and the environment? (Naturvårdsverket 1997a)

1.3 General procedures and methods for remediation of contaminated soil

The process of remediation of contaminated land involves several steps, such as field studies, risk assessments, planning, implementation and follow-up. Sites that are thought to be potentially contaminated are screened as the initial step, where after decisions are made concerning further measures. As the process evolves the discussion becomes more and more specific, including specifications of target values for each contaminant at the site. Surrounding and practical factors, such as economics and available technology, are taken into account at later steps in the process. After a more or less comprehensive survey of the site and different means of action the process evolves to the implementation step; the excavation, with environmental control made continuously to ascertain that the target values are reached. This study is focused at the implementation and follow-up steps of the process. However, the specification of target values, sampling process and remediation volume are also important to consider in this study, since they influence the nature of the implementation. The most central parts of the steps preceding the implementation are summarised in the sections below, starting with a schematic illustration of the entire remediation process.

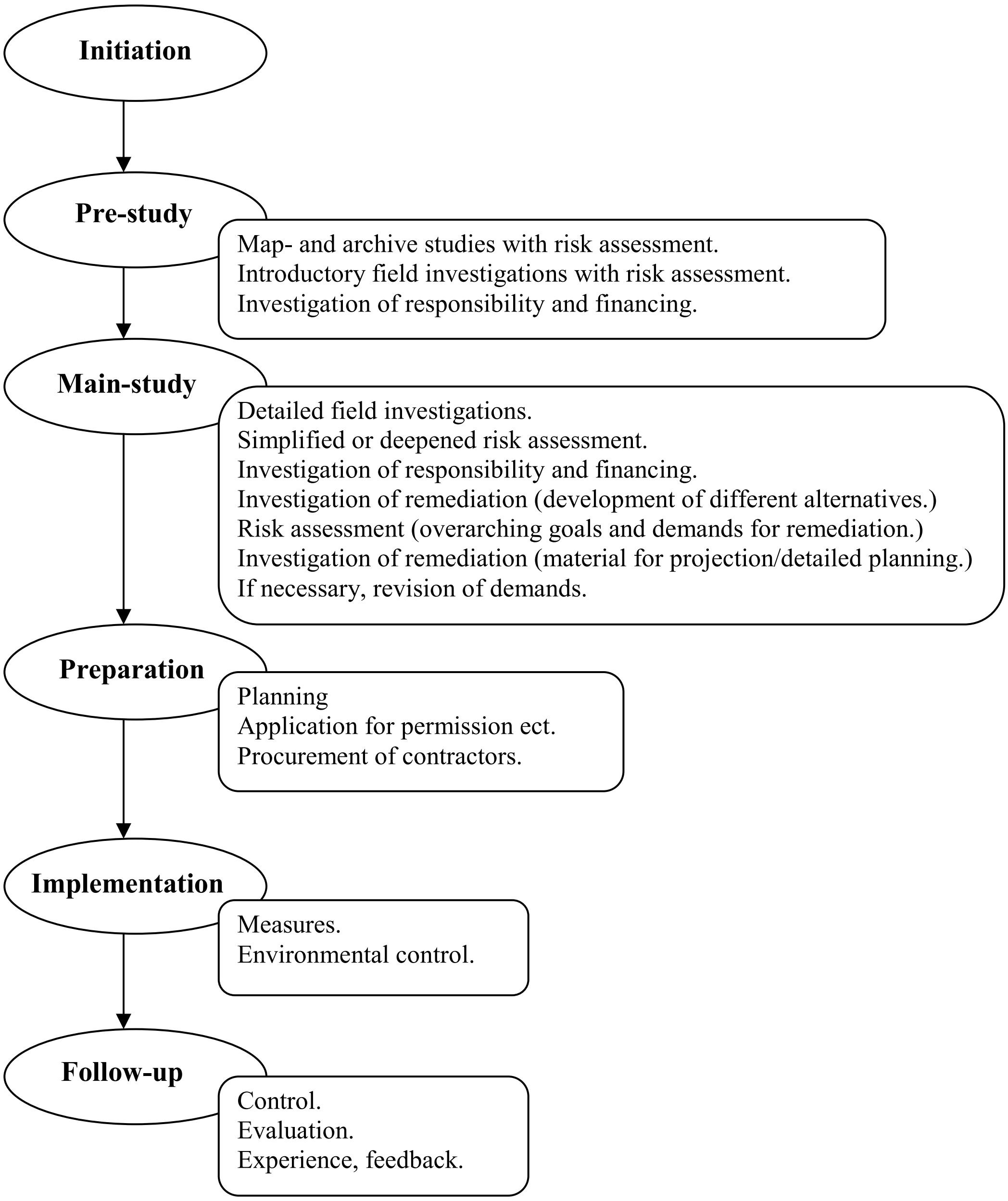

Figure 1.1 The general work process during remediation projects of contaminated sites. Source: Naturvårdsverket 1997.

1.3.1 Generic guideline values from SEPA

SEPA has determined generic guideline values for several typical contaminants found in Swedish soils. The generic guideline values are based on an assessment of the risks involved for both humans and the environment. Models for estimation of generic guideline values address the following topics:

1. distribution and transport of the contaminant in the environment
2. pathways for exposure of humans to the contaminant
3. estimation of toxicological risks from exposure
4. estimation of ecotoxicological effects (Naturvårdsverket, 1997b)

Exposure pathways
The second consideration, exposure pathways for the contaminant, is based upon a future potential use of the site. Future potential uses of the site are divided into three types:

- Land with sensitive use (KM), for example in residential areas, children playgrounds, agriculture and ground water uptake.
- Land with less sensitive use (MKM GV), but with groundwater extraction, such as industries, offices and roads.
- Land with less sensitive use as above but without groundwater extraction (MKM.) (Naturvårdsverket, 1997b)

Toxicological risks
The third consideration, human toxicological risk of the contaminant, is based partly on toxicological information on contaminant, and partly on the potential future land uses described in the section above.

Table 1.1 Exposure pathways considered for the different potential future land uses of the site. Source: Naturvårdsverket 1997b.

Exposure pathway	**KM**	**MKM GV**	**MKM**
Direct intake of soil	X	X	X
Dermal contact	X	X	X
Inhalation of dust	X	X	X
Inhalation of vapours	X	X	X
Intake of groundwater	X	X	
Intake of vegetables	X		
Intake of fish	X		

For each exposure pathway a reference soil concentration is calculated, resulting in an exposure that corresponds to a certain toxicological reference value. Toxicological reference values for a contaminant are based upon the dose-effect relationship for humans. The dose-effect relationship is used to identify a threshold level for a specific adverse effect. The threshold level is typically expressed as a tolerable daily intake (TDI, mg/kg body weight/day.) For carcinogenic contaminants it is not possible to calculate a threshold value since even small levels can be dangerous. For this reason the risk is mathematically extrapolated to give a value that represents an acceptable risk level. For the generic guideline values a lifetime excess cancer risk of 1 to 100 000 was used (Naturvårdsverket, 1997b)

Ecotoxicological risks
Environmental risks are calculated for on- and off-site effects of sensitive (KM) and less sensitive (MKM) future land uses. The on-site value represents the level at which the soils capacity to carry out a range of ecological functions is not seriously disturbed. Soil function is assumed to be disturbed if the species composition is severely changed. The level of protection in a less sensitive land area is allowed to be somewhat lower, although of course elimination of biological activity in the soil ecosystem is not considered acceptable. Off-site values are calculated upon the effects on nearby surface waters (Naturvårdsverket, 1997b)

The human and environmental risks are combined to produce a generic guideline value for each contaminant, depending on the potential future land uses. Generic guideline values indicate levels of contaminant under which there are no unacceptable risks to humans or the environment (Naturvårdsverket, 1997b) The values are often used as a reference and starting point in the site-specific discussions on target levels. The detailed risk assessment must contain guideline values for all contaminants that are to be removed in the remediation project. The purpose of the generic guideline values from SEPA is to ease the, often complex and costly, process of determining guideline values, since it is possible to apply the generic guideline values as guideline values for the remediation project if the conditions on site are simple and general. However, if the conditions on site are complex and unique it is not possible to apply the generic guideline values. In this case it is necessary to calculate site-specific guideline values, which is done according to the same method as for the generic guideline values but with special regards taken to the conditions at the site (Naturvårdsverket 1997a)

1.3.2 From guideline values to measurable target values

Guideline values, both the generic and site-specific, represent levels under which the contaminant poses no risk to either the environment or humans. They are, however, not calculated with respect to surrounding, practical factors in a project, such as economy, psychology and technology. Measurable target values are calculated with these factors taken into account and therefore represent a "realistic" target value for the contaminant for a specific remediation project. Measurable target values are expressed as a mean level for one SRV (Selective Remediation Volume, see section 1.2.4) of contaminated soil (Naturvårdsverket 1997d)

1.3.3 Sampling

Sampling of contaminated soil is carried out throughout the entire remediation process, from the initial screening and discovery, to the very final tests after excavation. Sampling of the actual soil is of course the only way of getting an idea of the level of contaminant, why it is of outmost importance that the sampling and analysis is carried out in a correct and accurate way (Naturvårdsverket 1996) There are three different ways of dividing the area to be sampled; directed, random and systematic sampling. Directed sampling is based upon an estimation of the contamination on the site using historical facts or visual sights (discolouring and such.) Random sampling means that the sampling points are distributed at random without consideration to the place of the other sampling points. Systematic sampling means that the site is divided into a squares or triangles (Naturvårdsverket 1996) The method used for dividing the remediation site has an obvious effect on the accuracy of the sampling, with different problems for each method. Other things that affect the accuracy of the data are for example uncertainty as to where the contamination sites are located, mobility of the contaminants, sampling method, chemical analysis, handling of the sample, chemical and physical properties of the contaminants and so on (Naturvårdsverket 1996)

1.3.4 Excavation

The excavation phase is initiated when the measurable target values, area of remediation and other important factors have been set. During the excavation the contaminated soil is classified according to target values and, based on this classification, either left at the site or removed. The area to be excavated is divided into volume units, called selective remediation volumes (SRV), which represent the smallest volume of soil that will be separated and classified during the excavation. The size of the SRV has to be determined from case to case, depending on the heterogeneity of the contaminant, practical considerations and so on. In normal cases a SRV between 50 and 100 m^3 is considered a good size. Soil samples for classification of the SRV can be taken either in situ (in the foundation pit base) or from piles of excavated material, a choice that is made based on practical and economical considerations. Regardless of the method used the idea is to take a number of samples in different locations of the SRV and combine them to form a general sample, which is to be analysed chemically (Naturvårdsverket 1997c)

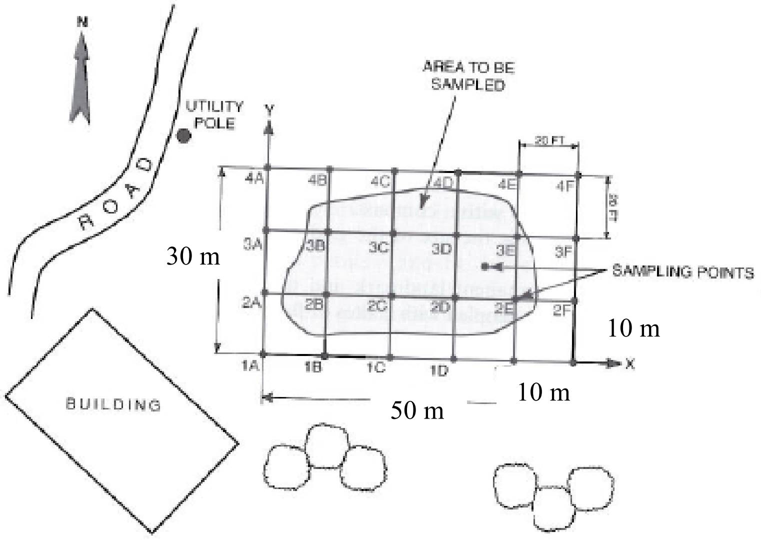

Figure 1.2 Example of a square sampling grid. Source: Popek 2003.

1.3.5 Sampling and excavation in relation to target values

There are two general problems to address during classification and handling of a single SRV. The first problem is one of reliability and fault, and mainly concerns the sampling process. The calculated mean of a number of soil samples is only an estimation of the real, albeit unknown, mean. However, it is not necessary to know the real mean concentration of an SRV, a secure estimation of the real mean is enough. The reliability of a mean concentration depends upon the number of analysed soil samples and the spread of the results. The second problem is one of classification, and concerns the determination of which soil should be left at the site and which should be removed, a question that is very important to this study. The two problems of reliability and classification can be handled with two different approaches; one statistic and one deterministic.

The statistic approach

The statistic approach, which requires a lot of sampling and analysis, is necessitated for a large and heterogeneous spread of contaminants. The sampling process is quite complex and demanding and aimed at providing a result that, within practical limits, is as representative for the SRV as possible. Each SRV is sampled and classified, with in situ sampling in the foundation pit base as the preferred method. A good surface spread of the samples is important in order to achieve the best possible representativity. Five single samples should be taken systematically per fourth of the SRV, and combined to one single combined sample, a procedure repeated for every fourth of the SRV leading to the collection of four combined samples per SRV. Finally, the combined samples are put together to from a general sample, which is analysed and seen as representative for the entire SRV. However, the initial step of the statistic approach is to determine whether the SRV is too big or too small, why the procedure is a bit different for the first six SRVs to be sampled. For these SRVs both the general sample and the combined samples are analysed chemically. Variations are studied both between the combined samples and between the combined and general sample. If the variations are too large, according to a reference value set on forehand, the SRV must be made smaller and vice versa (Naturvårdsverket 1997c.) Once an appropriate size of the SRV has been decided upon the excavation can proceed to classification and handling of the SRVs. In the statistic approach the SRVs are handled according to one of the following principles:

- Specifications that only a smaller part (for example 10% or 25%) of the analysed samples are allowed to have concentrations exceeding the target value.
- Compare the mean at a certain confidentiality limit (for example 95% or 90%) with the target value.
- Make sure that there aren't hot spots of a given volume with contamination levels exceeding the target value.
- Use other statistical methods (such as kriging-simulations.) (Naturvårdsverket 1997c)

In sum, the statistic method provides a strong tool for determination of the fault inherent in the estimation of the mean and also a method of evaluating the mean in relation to the target values.

The deterministic approach

The deterministic approach is simpler than the statistical approach and is only applicable to small and/or well defined sites. Some requirements for the deterministic approach are that the soil to be excavated doesn't exceed 500 m^3, that the contaminant is well defined and that the contaminated soil is surrounded by compact layers of earth (such as clay) or is separable visually. The excavation is an interactive process in which direction of the excavation and control samples succeed each other. The soil can be sampled either by combined samples, made up of four to five single samples, every 100 m^2, or by analysing single randomly distributed samples (Naturvårdsverket 1997c)

There are several methods for classification and handling of the samples with respect to the acceptable residual concentrations, as described below:

- Comparison of the concentrations in the sample with the target value (without statistical modelling.)
- Using geological conditions as starting point (for example natural barriers such as rocks or clay.)
- Using the localisation of the contaminants as starting point (Naturvårdsverket 1997c)

2 Methods and materials

2.1 Case studies

As mentioned earlier, SEPA have been monitoring and financing a substantial number of remediation projects in Sweden, especially in sites where it has not been possible to hold someone responsible for the cause of the contamination. Projects funded by SEPA are interesting to study for several reasons, including that SEPA has a special position in the business due to its role as a government agency and that the projects often have a similar organization and methodology, thus making them especially suitable for comparisons.

2.1.1 Collecting projects

The study was initiated by contacting almost every (17 out of 21) county administrative boards in Sweden, and asking for information concerning recent and completed remediation projects of contaminated land. County administrative boards have the overarching control and coordination, while municipalities govern the projects in detail, why municipalities were contacted on basis of the information given from the county administrative board. From municipalities reports were collected, and data was typically collected from the consultant responsible for environmental studies, planning and implementation of the project.

2.1.2 Selecting projects

Several projects were collected using the method described above, of different character and quality. Four of the collected projects were included in the study, see descriptions below. The four projects were selected partly due to their similar project type and organization and partly due to the high accessibility and quality of reports and data. One of the projects, Sjösa såg, was studied in more detail, while the other projects were included more as to give generalness to the study.

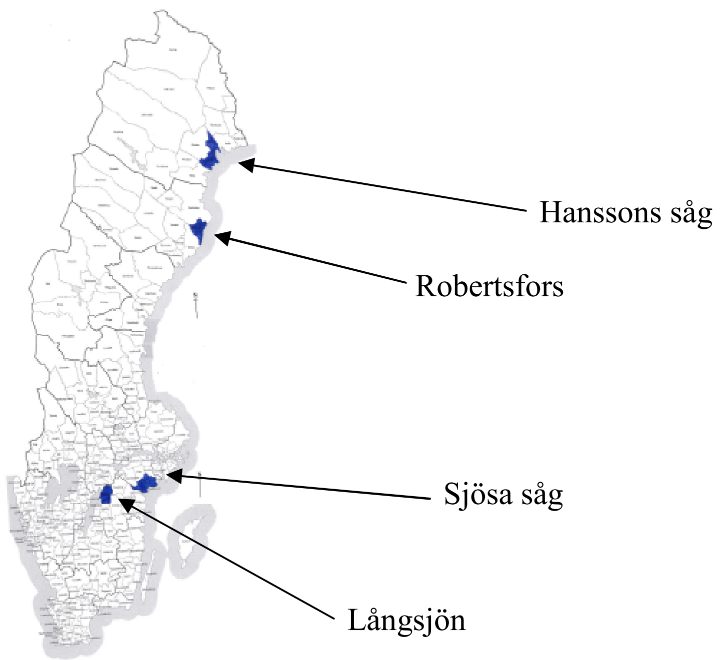

Figure 2.1 Map of Sweden with locations of the four case studies marked.

Hanssons såg

Hanssons såg is a sawmill located at the southern side of the Luleälv in Luleå municipality in Norrbotten. At the sawmill impregnation of timber was carried out during 1961 to 1975. The impregnation was done using cuprionol and pentachloridephenol, which has given rise to a dioxin contamination in the area. The dioxin contamination was spread out on a 600 m^2 field, reaching 0,5 m below surface. Copper was also found in high levels in a 400 m^2 area next to Luleälv. The copper contamination reached the groundwater at approximately 2 meters below the surface and followed the water out into Luleälv, thus spreading the contamination to the surrounding environment.

Figure 2.2 Airscape of Hanssons såg from 1981. Source: Luleå Kommun 2006.

The goal of the remediation was to clean the soil from copper and dioxin and clean the groundwater from copper. The remediation was carried out as an excavation where the contaminated soil was excavated and transported to special landfills, after sampling and classification. WSP Samhällsbyggnad planned and did environmental control of the project, which was carried out during 2001 to 2005, resulting in approximately 3680 tons of soil being removed.

Robertsfors bruk

Robertsfors bruk is situated in Robertsfors municipality in Västerbotten, right next to the southern rim of Rickelån. Between the years 1942 and 1968 poles were impregnated with a fluid containing copper, chrome and arsenic. After impregnation the poles were put to dry with the fluid dripping straight down to the ground, giving rise to a very severe contamination situation threatening humans, animals and the surrounding environments. The contamination covered an area of approximately 60 000 m^2, with arsenic being the main contaminant in need of remediation. The remediation was carried out as an excavation where the soil was classified and either left on site or transported to landfills. Approximately 80 000 tons of contaminated soil was removed from the site. SWECO VIAK were responsible for planning and environmental control of the project.

Långsjön
The contamination site is located in Motala municipality in Linköping at the north shore of a small lake called Långsjön. Impregnation with chalcanthite took place at the site until 1918, resulting in a severe copper contamination of both soil and water. The contamination was estimated to cover an area of 7200 m^2. The aim of the remediation project was to restore the ground to make the soil available for plants and trees and avoid further spreading of the contaminants into the environment, especially the nearby lake. Envipro Miljöteknik AB were contracted for pursuing planning and environmental control of the project. Approximately 4500 tons of contaminated soil was excavated and transported to landfills.

Sjösa såg
Sjösa såg is located in Nyköping municipality in Östergötaland. During roughly 50 years several activities involved in handling wood and timber have taken place in the area. Timber has been treated both by being dipped into a liquid bath, resulting in contaminations of chlorphenols and dioxin, and impregnation, giving contaminations of copper, chrome and arsenic. Arsenic, chlorphenol and dioxin were the main contaminants and became controlling for the whole remediation process. The aim of the remediation was to avoid further spreading of the contaminants into surrounding ground and water environments. Approximately 23 780 tons of contaminated soil was removed, with SWECO VIAK as consultants for planning and environmental control of the project.

Figure 2.4 Airscape of Sjösa såg from 1985. Source: SWECO VIAK 2006a.

2.1.3 Target values, sampling and excavation in the Sjösa såg project

Site-specific guideline values had to be calculated for Sjösa såg. Measurable target values were calculated based on the site-specific guideline values (see SWECO VIAK 2005a.) The soil on the site was divided into SRVs with a volume of 50 m^3 , with surface measures of 10 times 10 meters and a depth of 0,5 meters (SWECO VIAK 2006) In every SRV, having an area of 100 m^2, five single samples from the foundation pit base were taken to form a combined sample, which was analysed at a laboratory (SWECO VIAK 2006) The result from the laboratory analysis was taken as the mean concentration for the whole SRV and thus compared to the target value. If the mean concentration of the SRV exceed the target value the excavation continued one level further, thus removing the entire SRV, and if the concentration was below the target value the SRV was classified as clean and the excavation stopped for that particular square (SWECO VIAK 2006)

2.2 Statistical operations

The initial aim of this study is to determine the precision with which remediation projects tend to reach their target values, thus concluding whether over remediation is occurring. To determine this it is necessary to perform statistical operations on a specific set of data, thought to be interesting and representative for the site. In all four projects data from the foundation pit base have been analysed.

2.2.1 Calculation of results

The choice to use data from the foundation pit base means that every square is represented with one value, equal to the mean value in the bottom of the square before fill up with clean soil. Data from the foundation pit base was statistically analysed by a computer program designed especially for use in remediation projects of contaminated soil. Several statistical measures were calculated; including the arithmetic mean, the Chebyshev 95% upper confidentially limit (Chebyshev 95% UCL) and the median. The mathematical theories underpinning these statistical methods can not be covered here. For general information on statistical methods and measures see Körner & Wahlgren (1983). For specific information on how the 95% UCL and Chebyshev 95% UCL are calculated see United States Environmental Protection Agency (1992) and Singh & Singh (2007).

2.2.2 Additional analyses and calculations for Sjösa såg

Additional analyses, aimed at providing a picture of the extent and cause of the over remediation and its' economical effects, were performed for Sjösa såg, For Sjösa såg data from all levels of excavation for all squares was available, providing a complete picture of the excavation process and an opportunity to evaluate the results of alternative decisions.

Calculation of economic effects

For each square all levels above the foundation pit base were analysed, and if the level of contaminant was just above the target value (40 mg/kg TS) this value was used as the foundation pit base value instead, upon which the same statistical operation were performed. By doing this it was possible to get a picture of how many SRVs that were removed "unnecessarily", thus providing information to the last step of the study; determining the economical effects of the over remediation. The number of "unnecessarily" removed SRVs was multiplied by the cost for removing one SRV with all the infrastructure and required organisation already in place. This number was then finally compared with the final cost of the entire project.

Calculation of concentrations in the surface

The Sjösa såg project had measured the contaminant concentration in the fill up soil, thus providing an opportunity to establish the mean concentration in the surface after fill up. The same principle as described in section 2.2.1 was used for these calculations, with one square being represented by one value. The level of contaminant in the fill-up soil was used for squares in which excavation had taken place, and the original level was used for squares in which no excavation had taken place. These results are interesting since it is the surface area that humans most frequently come in contact with.

3 Results

In this section results are presented for each of the analysed case studies.

3.1 General results

Table 3.1 Results for the soil in foundation pit bases situated 0-1 m below the surface at Robertsfors bruk. *Values taken from SWECO VIAK 2006b.

Robertsfors bruk < 1m (mg/kg TS)			
Number of samples	198	**Arithmetic mean**	**7,1**
Smallest value	1,3	Standard deviation	7,6
Largest value	52,0	**Chebyshev 95% UCL**	**9,5**
25-percentile	2,5	**Target value**	**15,00**
Median	4,1	**Background level**	**5***
75-percentile	9,1	Level in fill-up soil	<2,0*

The arithmetic mean of 7,1 is more than half of the target value and close to the background value. The Chebyshev 95% UCL of 9,5 is somewhat higher but still well below the target value.

Table 3.2 Results for the soil in foundation pit bases below 1 m from the surface at Robertsfors bruk. *Values taken from SWECO VIAK 2006b.

Robertsfors bruk > 1m (mg/kg TS)			
Number of samples	198	**Arithmetic mean**	**12,2**
Smallest value	1,90	Standard deviation	19,1
Largest value	140,00	**Chebyshev 95% UCL**	**18,1**
25-percentile	2,50	**Target value**	**60,0**
Median	4,4	**Background level**	**5***
75-percentile	12,00	Level in fill-up soil	<2,0*

The arithmetic mean is a fifth of the target value, and the Chebyshev 95% UCL is about a third. Thus, the difference between the resulting concentrations and the target value is larger at this deeper level than at the surface level.

Table 3.3 Results from the soil in the foundation pit base at Hansson såg.

Hanssons såg (mg/kg TS)			
Number of samples	132	**Arithmetic mean**	**47,1**
Smallest value	9,0	Standard deviation	32,1
Largest value	108,0	**Chebyshev 95% UCL**	**59,2**
25-percentile	21,8	**Target value**	**110,00**
Median	35,0	Background level	-
75-percentile	74,0	Level in fill-up soil	-

The Chebyshev 95% UCL and the arithmetic mean are approximately half of the target value.

Table 3.4 Results for soil in the foundation pit base at Långsjön.

Långsjön (ng/kg TS)			
Number of samples	306	**Arithmetic mean**	**150,0**
Smallest value	75,0	Standard deviation	203,0
Largest value	1920	**Chebyshev 95% UCL**	**200,5**
25-percentile	75,0	**Target value**	**200**
Median	75,0	Background level	-
75-percentile	127,3	Level in fill-up soil	-

This is the project in which the arithmetic mean and the Chebyshev 95% UCL are closets to the target value. However, these results are very uncertain since the detection limit of the XRF used in the analysis was unmentioned of. These results are based upon an assumption of the detection limit to 75 ng/kg TS.

3.2 Results for Sjösa såg

Table 3.5 Results for the soil in the foundation pit base at Sjösa såg. *Values taken from SWECO VIAK 2006a.

Sjösa såg (mg/kg TS)			
Number of samples	307	**Arithmetic mean**	**12,0**
Smallest value	1,9	Standard deviation	10,3
Largest value	56,0	**Chebyshev 95% UCL**	**14,5**
25-percentile	3,9	**Target value**	**40,0**
Median	7,9	**Background level**	**9,0***
75-percentile	17,0	Level in fill-up soil	<1,8*

The arithmetic mean and the Chebyshev 95% UCL are quite close to each other and approximately a third of the target value. The arithmetic mean is also quite close to the background level.

Table 3.6 Results for the surface soil after fill up at Sjösa såg. *Values taken from SWECO VIAK 2006a.

Sjösa såg (mg/kg TS)			
Number of samples	255	**Arithmetic mean**	**5,8**
Smallest value	1,8	Standard deviation	7,7
Largest value	42,0	**Chebyshev 95% UCL**	**7,9**
25-percentile	1,8	**Target value**	**40,0**
Median	1,8	**Background level**	**9,0***
75-percentile	5,8	Level in fill-up soil	<1,8*

Note that the arithmetic mean and Chebyshev 95% UCL are approximately on sixth of the target and smaller than the background level, meaning that the surface soil on the site is cleaner than the surrounding soil.

Table 3.7 Statistical measures for soil in the foundation pit base at Sjösa såg. *The numbers for total cost and volume have been taken from SWECO VIAK 2006a. **A value of 970 kr/m^3 has been used, calculated with data from SWECO VIAK 2005b.

Limit of excavation (mg/kg TS)	**40**	**50**	**60**	**70**	**80**	**90**	**100**
Median	7,9	8,1	9,1	9,2	9,5	9,9	10,0
Arithmetic mean	**12,0**	**12,7**	**13,9**	**14,5**	**15,1**	**16,0**	**17,5**
Chebyshev 95% UCL	**14,5**	**15,4**	**17,1**	**17,9**	**18,8**	**20,2**	**22,5**
Number of SRVs	-	7,4	16,6	22,2	28,2	33,2	41,2
Volume (m^3)	-	370	830	1110	1410	1660	2060
Percent of total volume*	**-**	**2,8%**	**6,3%**	**8,4%**	**10,7%**	**12,6%**	**15,6%**
Approximate cost**	-	359’	805’	1067’	1368’	1610’	1965’
Percent of total cost*	**-**	**1,2%**	**2,7%**	**3,6%**	**4,6%**	**5,4%**	**6,6%**

The limit of excavation row shows the different levels of contaminant that have been employed for calculation of how much soil is excavated unnecessarily. Based on the new values for the foundation pit base new statistical measured has been calculated. For arsenic the acute toxic dose is approximately 100 mg/kg TS, why this is set as the upper limit. The number of SRVs is a cumulative measure since all soil that was removed with the excavation limit of 50 will also will be removed with an excavation limit of 60. The arithmetic mean and Chebyshev 95% UCL increases with the limit of excavation. The concentration is still approximately one half of the target value when the acute toxic level is set as the excavation limit. 2 million kronors were used for excavating soil with 40-100 mg/kg TS of arsenic, only lowering the concentration of arsenic from 20 to 13 mg/kg TS.

4 Conclusion and discussion

The results of this study are very clear; the methods used by SWECO and other consultants in the industry are resulting in an over remediation, simply that too much soil is being removed and replaced by clean soil. Table 3.5 shows that the mean level of contaminant in the foundation pit base at the Sjösa såg project is approximately one third of the target value and close to the measured background level of the surroundings. Table 3.6 shows that after fill up of clean soil the level of contaminant in the surface is one sixth of the target value and smaller than the background level. This means that the soil in the surrounding woods is more "contaminated" than the surface soil at the previously contaminated site, a fact that, putting it mildly, seems to be quite unnecessary. The remediation of Sjösa såg was based on a potential future use of the site as an industrial area (MKM), but the results from this study show that the soil is clean enough for the site to be used for more sensitive uses (KM), such as residential areas.

The economical consequences were somewhat difficult to determine, table 3.7 shows that the additional costs for removing all the soil with levels between 100 and 40 mg/kg TS is just below 7%, or approximately 2 million, of the total cost. This is very rough estimation of the actual cost and the number will probably be quite different for different projects, depending on the contamination situation. Additionally, a project aimed at avoiding over remediation will have a completely different approach than the current one used in Sjösa såg, thus making it difficult to make a precise appreciation of the costs. Nevertheless, a lot of money is spent for removing soil that, with a different approach, could have been kept at the site without posing additional risks to humans or environment.

4.1 Sources of the over remediation

The overarching cause of the over remediation is a confusion on how the generic guideline values provided by SEPA should be used. As of today they are being interpreted as a mean concentration for a single SRV, leading to the current situation in which large masses of soil are unnecessarily removed. SEPA does not explicitly state if the guideline values should be understood as a mean for one SRV or as a mean for the entire site (Naturvårdsverket 1997b.) This distinction has profound consequences for the remediation project. A project in which the target value is used as a mean for a single SRV would have the same approach as the projects studied in this report, whereas projects in which the target value is set as a mean for the entire site must have a different approach, much like the statistic one described earlier. Based on a risk assessment approach it would seem natural to set the target value as a mean for the entire site, since the risks (unless for concentrations above acute toxicity) are calculated based on a larger area to which humans are exposed during a longer period of time (*idid.*)

As mentioned in the introduction, remediation projects are large efforts involving several stakeholders and complex relationships. Consultants often find themselves trapped between different, and sometimes conflicting, demands from the client, the general public and the contractor. Contractors want clear directives for the excavation and don't want long periods of standstill due to complex methods for soil classification. In addition to this they are naturally not too interested in a shift to remediation strategies that result in smaller excavation volumes. The projects of this study all had SEPA as final client, who seem to have a view that it is better to be on the safe side and remove too much instead of too little contaminated soil. As a governmental agency they are more sensible to the concerns of the general public, where a lot of the psychology makes its entrance. Contaminated sites are often described as a lethal, acute threat to humans, animals and the environment, and the generic guideline levels are often discussed as a level above which the contaminant poses a significant risk. This makes it difficult for a remediation project to adopt a strategy aimed at reaching an acceptable mean level, something that either requires very small remediation volumes, at an unacceptable cost, or leaving soil with contamination levels exceeding the target value. It is alarming that SEPA is not capable of a more holistic approach to remediation projects and overall environmental control. Even though the environmental effects of the over remediation have not been determined in this study there is no doubt that remediation implies a strain to the environment. Large volumes of soil are removed and transported to landfills, fill-up soil is transported to the site and the soil ecosystem is disturbed. The obvious aim would be to minimize these types of disturbances, while at the same time removing enough contaminants so that the site is no longer a risk to humans and the environment. In sum, there seems to be an inherent problem in remediation projects funded by the Swedish EPA, where factors such as caution, tradition, drive for profit and lack of a holistic perspective all enable over remediation to occur in project after project, year after year.

4.2 Ideas for alternative methods

This section discusses alternative methods for remediation of contaminated soils, methods that will hopefully result in a final mean concentration that lies closer to the target value than what is achieved with the current methods. They all have an approach in which the target values are used as a mean for the entire site, and not for a single SRV as has been done previously. The ideas are merely introduced as a discussion of how different approaches could look like and are not to be seen neither as comprehensive, nor finished.

4.2.1 Division into subgroups and focus on hotspots

To reach the target value with better precision projects could be more specific and aim solely on the most contaminated areas of the site; the hot spots. According to the Swedish EPA it is preferable to divide the soil at the contaminated site into three subgroups; contaminated soils/ hot spots (with contamination levels well above the target value), transition soils (with contamination levels that are either close to the target value, unknown or with great variations) and clean soils (with contamination values well below the target value.) The hot spots pose the biggest risk to humans and the environment and have to be excavated. Since the business that caused the contamination is often well known to the remediation project it is quite easy to establish where the hotspots are located, due to dripping, spills and alike, or by sampling the site before the excavation. Further, areas classified as clean do not need to be included in the remediation. The really interesting areas are ones in which the soil is classified as transition soil (Naturvårdsverket 1997c) It is in these areas that both economic and environmental improvements can be made. Today SWECO and other consultants excavate almost all transition soils, resulting in a severe over remediation. A focus on hotspots would mean that the most transition soils are left at the site, resulting in soil with levels above the target value left at the site, but also that the final mean level of contaminant will have a better correspondence to the target value. The level of the target value is of biggest importance in relation to the transition soils, since hot spots often have very high concentrations and clean soils have very low concentrations. Discussions on target values thus should take consideration to the effects on transition soils as one parameter, of course along with the toxicological and environmental effects as well. Additionally it is possible to, after division into subgroups, use the target value as a mean level for a single SRV for the hotspots, but as a mean level for the entire site for transition soils.

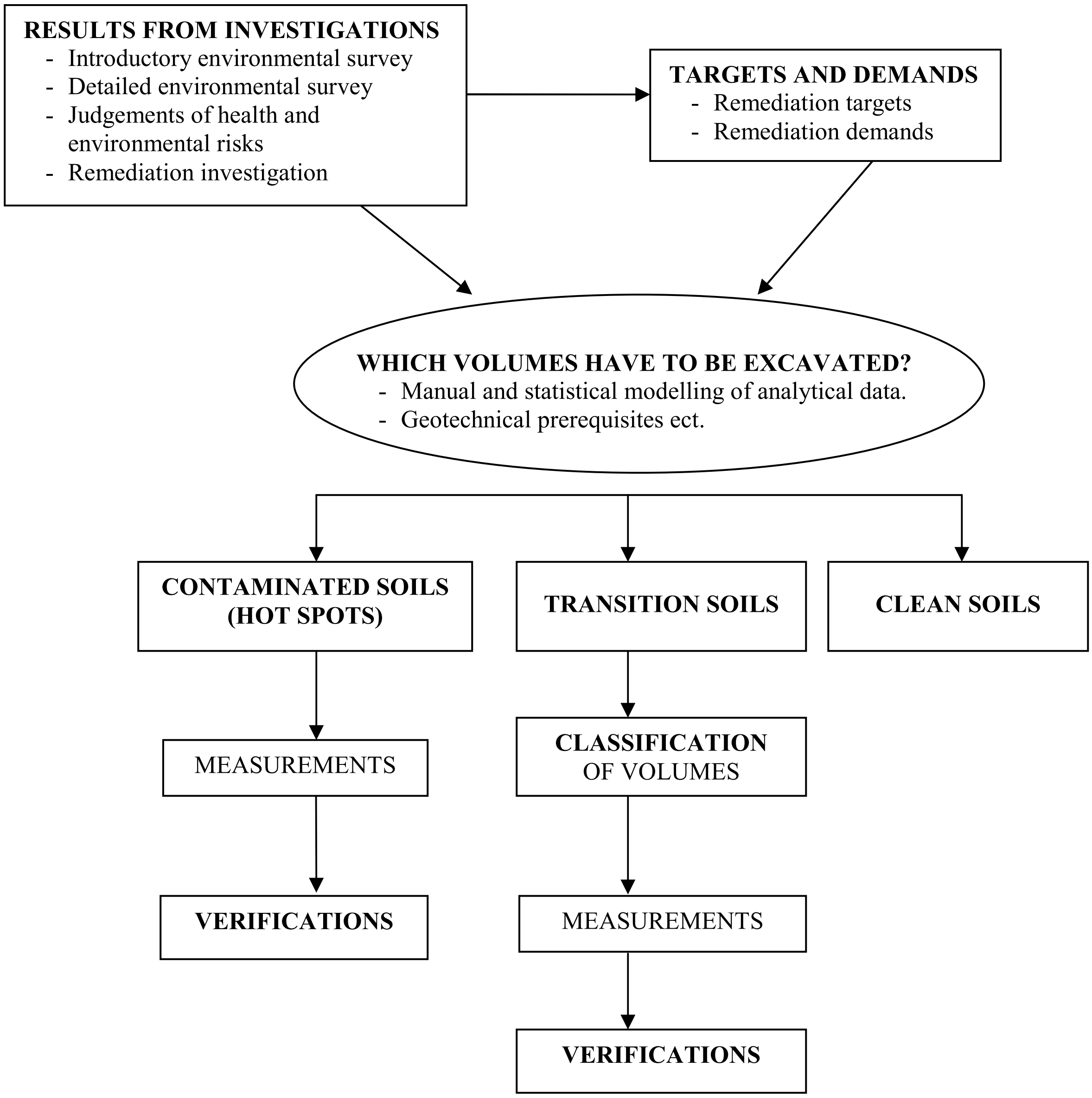

Figure 4.1 Schematic illustration of the procedure for classification of the soil at a contaminated soil. Source: Naturvårdsverket 1997c.

4.2.2 Statistic approaches

These methods are described in the introduction of this study, see section 1.2.5. The general idea is to map the contaminated site and excavation process with statistical methods. A thorough sampling process is required and the fact that the excavation is evaluated continuously during the project means that the procedure for sampling, classification and determination of further actions is quite complex and probably also costly. This is the reason why the deterministic approach is often used in projects for which a statistical method would have given a better result in relation to the target value. However, this does not mean that statistical methods should be abandoned completely; perhaps we just need to find methods that combine the strengths of the statistic and deterministic methods. Statistical methods can be very useful in the initial, surveying steps of a remediation project, as is described below.

4.2.3 Detailed surveys before excavation

The statistic approach has clear advantages when it comes to reaching the target value with a good precision and certainty, but has weaknesses due to the thorough sampling and analysis required during the excavation. The deterministic method is more straightforward and due to this easier to implement during the excavation. A way to combine the strengths of statistic and deterministic methods would be to make a thorough and statistic analysis of the soil and contaminant concentration in different areas before starting the excavation. The collected data gives an idea of the degree of uncertainties thus makes it possible to adjust the project accordingly. Additionally it is possible to calculate a new value to be used as the level above which the soil is removed in order for the target value to be reached as a mean for the entire site. The excavation is done using the traditional, deterministic method, with the new value as the target value. This approach is, as mentioned, a combination of the analytical/theoretical strength of the statistical method and the practical strength of the deterministic method. Extra resources will have to be invested at the initial steps of the remediation since a more thorough sampling is required. The idea is however that the extra resources invested during the surveying will pay back during the excavation due to the higher value used for classification and the resulting smaller volumes of excavation.

4.2.4 Different target values and/or methods for surface and depths

A fourth idea would be to use different methods for the surface and depths. The surface soil is the soil that humans typically come in direct contact with, why it is crucial that this soil does not contain high contaminant concentrations. Depending on factors such as mobility of the contaminant and groundwater uptake at the site humans and the environment can be more or less affected by concentrations in deeper lying soil. This means that different approaches can be employed for surface and depths. For the surface soil it is preferable to use a deterministic approach, such as the one used today, in which all soils with concentrations higher than the target value are removed. For deeper layers the approach can be somewhat different and, depending on the nature of the project, it's possible to either adopt higher target values (a method used in the Robertsfors bruk project of this study) or switch to a statistic method (perhaps like the one described above.)

4.3 Limitations of this study

This study is not to be seen as a comprehensive survey of remediation projects funded by SEPA, nor is it to be seen as a full scale statistical survey of the studied projects. The projects studied and methods used could surely have been chosen and used with more precision and detail. The projects were chosen partly due to the fact that there was enough information and data available, something that of course makes the study vulnerable to discussions on principles of selection and representativity. The projects were quite large, especially Sjösa and Robertsfors, meaning that a lot of data had to be analysed. Before the statistical operations could take place the data to be used had to be collected, selected and organised. Sometimes it was unclear what the data represented, especially for factors such as depth of measurement and limit of detection for the analysis. Small decisions of which data to include in the calculations had to be made all the time, a fact that of course affects the reliability of the results.

However, the aim of this survey has been to determine whether there is a general trend of over remediation, and to engage in a discussion of the causes and effects of this over remediation, something that can be done despite the complications and uncertainties inherent in the data analysis. The results are so clear that they can withstand the problems at hand, especially if the results are viewed as an indication of a trend rather than hard-facts.

4.4 Suggestions for further research

If Sweco see this as a path worth developing further it would perhaps be necessary do a more comprehensive study of the extent and sources of the over remediation than the one presented here. It would also be interesting to analyse other types of projects, such as exploitation projects, and to compare the results of the methods used in those types of projects with the ones described here. This initial screening and comparison could serve as a starting point for development of other techniques with better precision. Drawing on earlier discussions it seems difficult for Sweco to run the process alone. It is necessary for SEPA to be involved in a discussion about how the generic guideline values are to be implemented. SEPA have, as the final client and financier, the power to decide the direction of projects and without their understanding and involvement it will probably be very difficult to change the present practices. Without commitment, or at least understanding, from all stakeholders the current situation will persist, with unnecessary costs for society and unmotivated strains upon the environment as the only results.

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6 References

Carlon *et al* (2007) *A spatial risk assessment methodology to support the remediation of contaminated land.* Environment International 34 (2008). 397-411.

Envipro Miljöteknik (2007) *Efterbehandling av den före detta impregneringsplatsen vid Långsjön. Erfarenhetsåterföring.* Linköping: Envipro Miljöteknik.

Körner, Svante & Wahlgren, Lars (1983) *Statistisk dataanalys.* Lund: Studentlitteratur.

Luleå Kommun (2006) *Slutrapport. Gäddvik, sanering av f.d. Hansson såg 2003-2004*. Luleå: Tekniska förvaltningen.

Naturvårdsverket (1997a) *Generella riktvärden för förorenad mark – beräkningsprinciper och vägledning för tillämpning*. Stockholm: Naturvårdsverket. Report 4638.

Naturvårdsverket (1997b) *Development of generic guideline values – model and data used for generic guideline values for contaminated soils in Sweden*. Stockholm: Naturvårdsverket. Report 4639.

Naturvårdsverket (1997c) *Åtgärdskrav vid efterbehandling – vägledning för säkerställande av att acceptabla resthalter och restmängder uppnås – metoder och säkerhet.* Stockholm: Naturvårdsverket. Report 4807.

Naturvårdsverket (1996) *Rätt datakvalitet – vägledning i kvalitetssäkring vid miljötekniska undersökningar.* Stockholm: Naturvårdsverket. Report 4667.

Naturvårdsverket (1997d) *Efterbehandling av förorenade områden – vägledning för planering och genomförande av efterbehandlingsprojekt.* Stockholm: Naturvårdsverket. Report 4803.

Popek, Emma P. (2003) *Sampling and Analysis of Environmental Chemical Pollutants*. San Diego: Academic Press.

Singh, Anita & Singh, Ashon K. (2007) "Chebyshev inequality based UCL" in *ProUCL Version 4.0 Technical Guide*. Report: EPA/600/R-07/041. Washington DC: US EPA

SWECO VIAK AB (2005a) *Sjösa sågverksområde – Platsspecifika riktvärden och förslag till åtgärdsmål.* Stockholm: SWECO VIAK AB.

SWECO VIAK AB (2005b) *Förfrågningsunderlag. Sjösa sågverksområde, marksaneringsarbeten. Mängdbeskrivning.* Stockholm: SWECO VIAK AB.

SWECO VIAK AB (2006a) *Sjösa såg, Nyköping. Marksanering. Slutrapport och erfarenhetsåterföring.* Stockholm: SWECO VIAK AB.

SWECO VIAK AB (2006b) *Robertsfors bruk. Marksanering. Slutrapport och erfarenhetsåterföring.* Umeå: SWECO VIAK AB.

United States Environmental Protection Agency (1992) *Supplemental Guidance to RAGS: Calculating the Concentration Term.* Washington D.C: US EPA. Publication: 9285.7-08I.