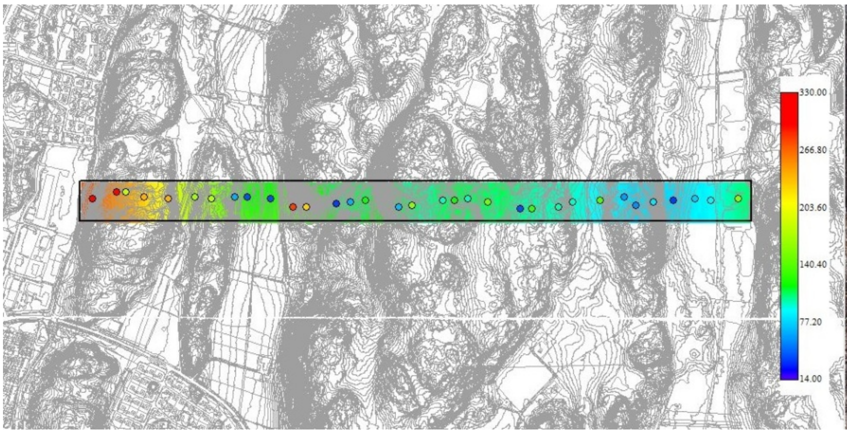

Mapping and Interpretation of Background Levels of Lead Concentrations in Natural Soils

A case study of Ale municipality

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

PETRA ALMQVIST, ROBERT ANDERSON

Department of Civil and Environmental Engineering
Division of GeoEngineering
CHALMERS UNIVERSITY OF TECHNOLOGY
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Interpolation map for the Nödinge profile and characteristic forest of Ale. Photo: Petra Almqvist

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ABSTRACT

Based on unexpectedly high background lead levels measured in peat soil in Ale municipality in 2011, a further, more comprehensive investigation of lead concentrations in Ale forests was required. Ale municipality, bordering the Göta River and the E6 and E45 highways to the east, has a long industrial history, but is currently undergoing residential growth and development. Much of Ale is characterized by large north-south ridges with outcropping metamorphic rocks of the fennoscandian shield and very little soil cover. Most of the natural soil studied could be classified as peat or mor forest soil, which is highly organic, and known to retain metals. Three west-east profiles of 2km in length were studied in the municipality, along with a small reference area in the furthest, most remote corner of Ale. A total of 104 soil samples, taken at a depth of 10cm, were sent to laboratory for metal analysis. The mean concentrations of total lead in each profile, including the reference area, were found to far exceed the Swedish EPA's generic guideline value (KM), with very few samples below this 50 mg/kg TS level. Cadmium and arsenic levels were also found to exceed guideline values in all three profiles. A correlation analysis was conducted to investigate the effect of elevation, distance to the E45 highway, northing, dry content, and soil type on the concentration of lead, arsenic and cadmium. Generally weak correlations were observed, except for dry content, which showed some stronger correlation for arsenic and cadmium. The spatial correlation of the data was modeled using ordinary kriging, and interpolation of the data was achieved using the SADA software. The resulting semi-variogram and profile mapping shows fairly good spatial correlation and some localized pattern of the lead deposition. As a result of the investigation, it can be said that the lead deposition pathways for the area studied are quite unclear, and it is likely that much of it could be attributed to long range sources, given the lack of correlation with distance to the highway and industry. An assessment of the risk of the lead concentrations to human health is difficult, since it depends on several unanswered questions, such as the potential exposure and bioavailability of lead from the organic soil.

Key words: Contaminated land/soil, Lead, Natural soil, Kriging, Mapping, Peat, Background levels

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Appendix I: Map of lead levels, Ale.

Appendix II: Laboratory analysis results

Preface

A total of 104 samples were taken in this study to evaluate and map lead concentrations in natural soil. Sampling was conducted in May of 2013. The Master's thesis work was carried out at the Department of Civil and Environmental Engineering at Chalmers University of Technology. The project was financed by Ale Kommun and Sweco Environment AB.

We would like to thank our supervisors, Professor Lars Rosén at Chalmers, and MSc Ingela Forssman at Sweco Environment AB, who provided so much of their time for this project. Their patience in guiding us throughout is greatly appreciated. Additional thanks to Lena Hedlund from Ale Kommun for her assistance.

Gothenburg, September 2013

Petra Almqvist and Robert Anderson

1 Introduction

About 20km north of Gothenburg, alongside the Göta River, in the municipality of Ale, an investigation revealed unexpectedly high background levels of metals, especially lead, in the natural forest soil (Sweco, 2011). The results from the investigation showed that many of the samples were above the generic sensitive land use guideline (KM) set up by the Swedish Environmental Protection Agency (SEPA). This raised questions regarding the source of the elevated lead levels and their possible hazard to humans should the area be developed and inhabited.

Ale municipality is growing rapidly, and housing developments are being planned in previously non-exploited areas. It is of course important for all municipalities to provide safe housing for its inhabitants, and one aspect of this is to ensure a non-toxic environment. If the soil in the natural areas in Ale has elevated levels of heavy metals, it may pose a threat to human health and the environment; remediation might be required in order to ensure safe and healthy housing.

A non-toxic environment is not only a concern to the local municipalities but also for the Swedish government. It is one of the environmental objectives set up by the SEPA with the goal by 2020 to have naturally occurring substances close to background levels and non-naturally occurring close to zero (SEPA, 2012a). Guideline values for harmful substances have been set up by the SEPA in order to help property owners, regulators and stakeholders. Different levels of contamination are accepted for different land uses, where the lowest value is accepted for residential areas, classed as sensitive land use.

According to the SEPA there are about 80,000 contaminated sites in Sweden and the goal is to remediate these to such an extent that they no longer pose a threat to human health and environment (SEPA, 2012b). This extensive remediation work has already started around Gothenburg, with Surte glassworks being one of these contaminated sites that has now been remediated (SEPA, 2012c). These 80,000 sites alone pose a great challenge, but if natural forested areas affected only by diffuse off-site sources also carry large concentrations of pollutants, then the task of achieving a non-toxic environment would be a much greater one.

1.1 Problem description

The Swedish Geological Survey (SGU) conducts investigations and mapping on a national level, regarding, amongst other things, bedrock and soil classifications, and soil chemistry. These larger surveys and mapping of contaminants in natural, non-contaminated soils are largely conducted in mineral soil and provide a general description of the background levels of many substances.

The soil samples in the Sweco investigation were peat, a highly organic soil type which behaves differently than the mineral soil which the guideline values are based on. Even though the guideline values are flexible and adjustable for site specific conditions, they are firstly made for mineral soil. The characteristics and predispositions differ between different soils types, thus it becomes necessary to investigate how lead behaves in organic soils like peat. The forest and soil types studied in the Sweco investigation (Sweco, 2011) is found throughout Ale municipality. A more widespread study is therefore needed in order to achieve a more comprehensive understanding of the present situation and the possible implications for housing constructions in Ale and areas with potentially similar conditions elsewhere.

Humans affect their surroundings in many ways; industrial activities, transportation, utilization and exploitation of our environment have a large impact on the natural environment on both a local and global scale. How chemical and organic pollutants move in our surroundings is not yet fully understood. The origin of the lead found in the forest soil in Ale is unclear, a comprehensive understanding of how hazardous this lead is and how widespread this issue might be, is also missing.

1.2 Aim

The aim of this thesis is to construct a more comprehensive mapping of the lead concentrations in the natural soils in the municipality of Ale. This will be achieved by collecting a larger number of samples from profiles throughout Ale. An investigation of possible lead sources, historical and recent, will be made, as well as research on background levels of lead in natural soils in other areas with the intention of shedding light on the origin and cause of these lead levels. A human health risk assessment will be performed in order to assess whether development of the studied areas for residential purposes is feasible.

Expected results of the study are maps where the lead levels are presented, combined with a report covering possible lead sources and risk implications, providing a bigger picture of the current status of the natural soils in Ale.

1.3 Disposition

The disposition of the Thesis is shown in Figure 1.1, starting with this introduction, followed by a theoretical background, method, results, discussion and conclusion. Appendices containing lab results and maps follow afterwards.

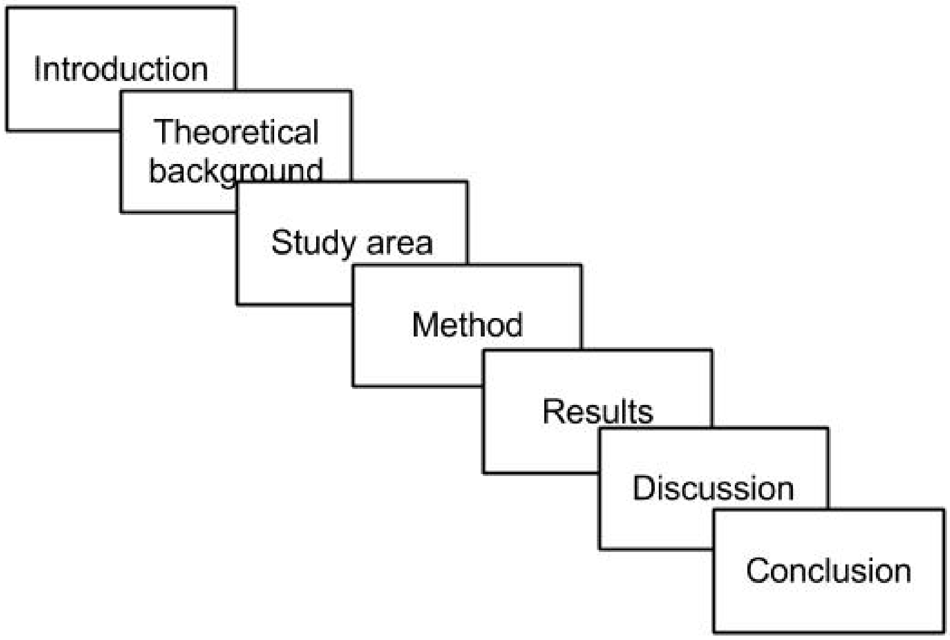

Figure 1.1: Disposition of the thesis

2 Theoretical background

This chapter will provide a description of the preconditions to this thesis and the analyses made in it. The chapter contains a background on previous surveys of lead in natural environments, behavior and characteristics of lead and forest soils, as well as a background on the statistics used in the analysis.

2.1 Natural soils

Soil covers the earth's bedrock. Physical, chemical and biological processes over time turn parent material of mountains and rock into soils of finer particles; composed of minerals and organic material. Swedish geological survey (SGU) makes inventories of the soils and bedrocks of Sweden, and according to SGU most of the soils have formed during and after the last ice age (SGU, n.d.).

Figure 2.1 illustrates the layering of bedrock, soil cover, and top soil. The soil cover is the loose mass on the surface of the Earth, while the top soil in some ways has been affected by climate and organisms (Andréasson, 2006). In Sweden, the most common top soils are podzol and brown earth, while glacial till is the most common soil cover and covers 75% of the ground surface (Fredén, 2009).

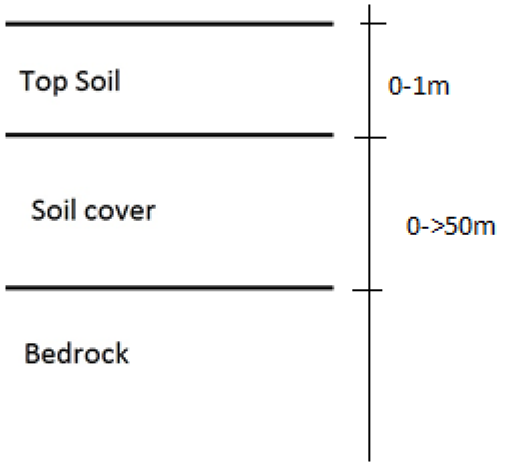

Figure 2.1: Schematic figure of soil layer order

The glacial till composition varies somewhat but generally it consists of angular material with an unsorted mixture of grain sizes and is mostly dominated by sand and silt (Andréasson, 2006). Moraines are deposited by glaciers or ice sheets and often lie directly on the bedrock.

The uppermost layer, above the soil cover, is the top soil. Figure 2.2 shows a map of the dominating top soil layers for Sweden. The depth of the top soil layer in Sweden is normally about 0.5-1 m, which is relatively shallow since it was formed after the last ice age (ibid). In tropical and sub-tropical areas where the top soil has had a longer time to develop they can amount to several tens of meters.

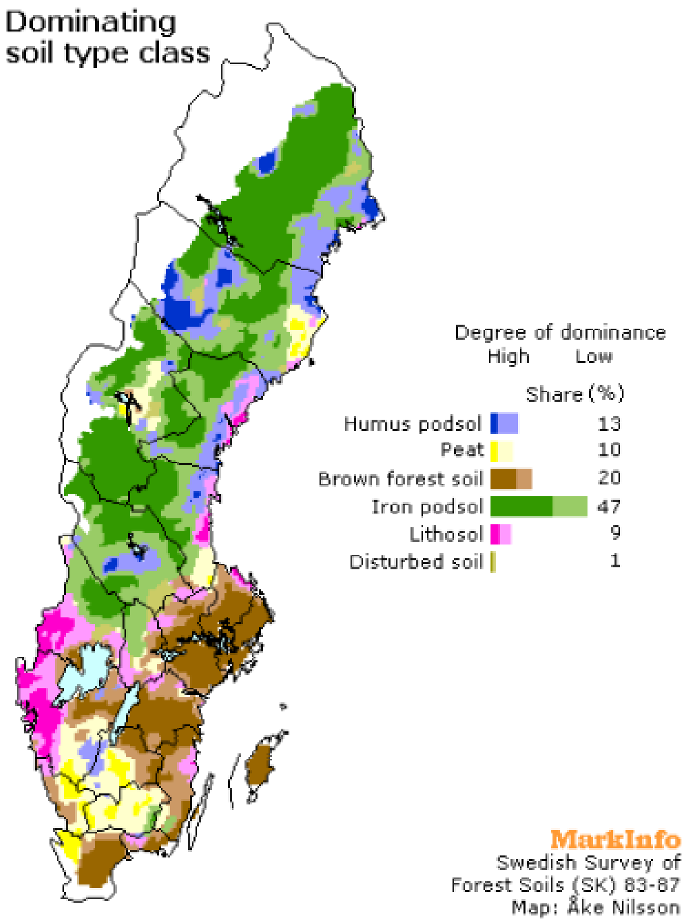

Figure 2.2: Dominating top soil layers of Sweden (SLU, 2006)

Podsol soil can be found in coniferous forest and covers 70% of Sweden's land surface, while brown earth is more likely to be found in deciduous forests and is less common. The pH in podsols is generally lower than brown earth, making it less suitable for agriculture (Andréasson, 2006).

In Ale, the focus area of this study, the most common top soils are peat and lithosol. Clay soil cover, with brown forest and disturbed top soils, is also found in the lower valleys in and around the Göta River. The lithosol and peat soils are especially dominating in the forest areas in which the sampling for this study was carried out.

2.1.1 Peat

Peat is an organic sediment which forms in wetland conditions, and depending on the vegetation and water supply, the composition and characteristics of the peat that is formed varies. The features of peat also depend on the degree of decomposition of the organic material. In Sweden, peat is traditionally classified by botanical composition, degree of decomposition i.e. humification, content of plant fibers, wood residue and water content. The soil needs to contain at least 80% organic material in order to be classified as peat (SGU, n.d a).

The accumulation of peat is a balance between the annual organic production at the surface and the mineralization throughout an entire peat column (Wieder et al., 1990). According to Shotyk (1988) and the Swedish Geological Survey (SGU) a peat land is a peat-forming ecosystem which has accumulated at least 30 cm of peat. There are mainly two types of peat-forming ecosystems; rainwater fed (bogs) and groundwater fed (fens and swamps). Rainwater fed peat-forming ecosystems are ombrotrophic, nutrient-poor environments while groundwater fed ones are minerotrophic, more nutrient rich environments where minerals and nutrients are transported from the surrounding ground.

On an area basis Sweden has a considerable amount of peat lands, about 5-17% of the country (Shotyk, 1988). Peat is more prevalent in the southern parts of the country and some of these peat assets are mined and used, primarily as fuel and for cultivation, as potting and soil improver.

Metals and other substances bind relatively easy to peat, how well depends on the conditions in the soil.

- With decreasing pH the mobility of heavy metals increases (VTI, 2005).
- Dissolved organic content (DOC) form complexes with metals, a large percentage of DOC therefore decreases the mobility of the heavy metals in the soil.
- The redox potential, also called reduction potential is a measure of how easily a solution can gain or lose electrons. With a presence of competing ions, for example in the soil water, precipitation can occur; this increases the mobility (SEPA, 2006a).

Peat, as with most humus rich soils, has a very high ability to absorb trace elements, especially cations, i.e. positively charged metal ions. This ability is partly due to the large specific surface area of peat and the specific chemical properties of humic substances. The highest concentrations of metals are often found in the outermost portions of marshes and in deep trenches. Metals that are normally easily leached and transported with the groundwater can accumulate to a high extent here (Statens energiverk, 1984).

The affinity to bind onto humic substances differs between metals. At pH4-5 the stability constant decreases in the following order: U> Hg> Sn> Pb> Cu> Ni> Co> Zn> Cd> Mn> Sr (ibid). This illustrates the ability and tendency of these substances to migrate after being absorbed in the soil. As shown, uranium is the most tightly bound and strontium is loosely bound and has greater tendency to move in the soil.

The enrichment of trace elements like metals in peat is complex and can vary greatly between peat bogs as well as within, with high variations in levels of trace elements in both horizontal and vertical direction (ibid). Due to a high organic content in peat soil the affinity for metals and lead to bind is stronger than in mineral soil.

2.1.2 Lithosol

Lithosols are immature, thin soils that often appear in areas with outcrops (Andréasson, 2006), they are most frequent on the northern part of the west coast of Sweden but are also somewhat common alongside the east coast.

Lithosols of coniferous forests are similar to the surface layer of podzols, the mor, with organic material that have negatively charged groups which effectively sorbs most metals (Andersson et al., 1991). The mor layer acts in some ways as a filter for the podzols, and similarly for lithosols, the decomposition of the organic material is incomplete due to a naturally low pH and a dominating fungal micro flora.

The residence time for metals and minerals in the mor layer can be long, for carbon up to 250-300 years. (Johansson et al., 2001). The metals residing in these surface layers originate from centuries of accumulated atmospheric deposition.

2.2 Lead

Lead has been used by man since long before the industrial revolution. Human lead production dates back as far as to about six millennia ago (Hong et al., 1994). Ancient Greek and Roman civilizations also mined and processed a substantial amount of lead.

Lead is ever-present in the environment around us, in the air, soil and water. It has a tendency to accumulate in the body, and is toxic to humans causing lead poisoning if the exposure is high enough. According to the Swedish Food Administration (SFA), exposure to lead can damage the nervous system and the intellectual development, especially in small children and fetuses which are more susceptible than adults (SFA, 2012).

Symptoms of lead poisoning can often be diffuse or vague, like poor appetite and fatigue. In order to ensure human health and a non-toxic environment, limiting and monitoring the levels of lead in our environment is important. Lead can exist in organic or inorganic forms but since the body more easily absorbs organic lead it is more toxic than inorganic lead (ATSDR, 2007).

There are several distribution and exposure pathways for harmful substances. Lead can spread through soil, water and air before being taken up by plants and animals.

Humans can be exposed to lead by:

- Breathing in fumes or particles
- Eating and drinking soil, water and plants carrying contamination
- Dermal uptake when contaminants are in contact with skin

The amount of lead exposure depends not only on distribution and exposure but also on the source, how much lead there is in the soil in the first place. Some useful terms when describing soil contamination content are:

Natural content: the condition that would prevail in an area if it had not been subjected to any anthropogenic influence (SEPA, 1997).

Background content: the sum of natural levels and diffuse inputs, an area with background levels has not been affected by point sources (ibid).

Contaminated area: the environment is altered by human-made chemicals or activities. The source of contamination is typically an industrial activity, agricultural chemicals, or improper disposal of waste (ibid).

2.2.1 Natural and background contents of lead

There is a natural content of lead in soils and bedrocks, but placed at nr 36 among the most common elements in the earth's crust, lead is rare in comparison to other metals (NE, 2013). The average concentration of lead in rocks in the accessible part of the crust is in the range of 13-15ppm, but varies between different types of bedrocks (SLU, 2006). In Table 2.1 below, normal values for natural contents of lead for different bedrocks and soil is shown. For bedrock it can be said that acidic and sedimentary types carry higher contents of lead.

Table 2.1: Normal values of trace elements in rocks and soil (Statens energiverk, 1984)

	Average content in bedrocks (ppm)				Average content in soil (ppm)
	Ultrabasic	Basic	Acidic	Sedimentary	
Pb	1	4	18	5-25	17

Genuine, i.e. pure forms of lead are uncommon in nature; there are only a few Swedish locations where this can be found. More common are lead minerals like galena and lead sulfide (NE, 2013).

When measuring levels of substances and compounds in soil the result will vary depending on several factors, for example which method of analysis that has been used, which soil type that was tested and the location of the sample. Knowledge of background levels makes it possible to assess whether a site is contaminated or not, to what degree and what remediation actions that might be needed.

SGU started a geochemical mapping of Swedish soils in 1983, where samples are taken in a grid of 2,5km between sampling points and the plan is to cover the whole area of Sweden (SEPA, 1997). The sample material consists exclusively of till, taken in undisturbed mineral soil 1m below the ground surface.

Other, smaller geochemical mappings have been made, by amongst others SLU and SEPA. Generally investigations regarding background levels of contaminants like heavy metals or organic compounds in Sweden have been conducted in mineral soils with low organic content, like glacial till. In 1997, SEPA made a summary analysis of the data gathered from urban soil samples taken in 1993 and 1995 by SGU, see table 2.2.

Table 2.2: Summary of results from 108 samples taken in urban areas. ICP-analysis results divided into percentiles and values presented in mg/kg TS, (SEPA, 1997).

	Samples	Min value	10:th perc	50:th perc	90: perc	Max value
Superficial glacial till soil	108	>LOD	12	36	88	409
Deep glacial till soil	108	>LOD	3	11	24	59
Superficial sediment soil	93	>LOD	7	23	60	143
Deep sediment soil	93	>LOD	1	10	25	34

Background levels of heavy metals found in glacial till and mineral soil is generally lower than levels found in the mor (compacted humus) layer and organic soils due to the ability of organic soils to bind heavy metals (SEPA, 1998). SEPA (1997) also concludes that higher concentrations of metals are exhibited in till soils than in clays and silts, that urban soils have higher metal concentrations than rural soils and that many metals showed a higher concentration in near surface soils than in samples from deeper levels.

Figure shows measured levels of lead in both the superficial mor layer of Swedish forest soils and in deeper mineral soil. Levels in the organic soil, the mor, are generally higher and also seem to be tilted, with higher levels in the south, gradually lowered towards the north.

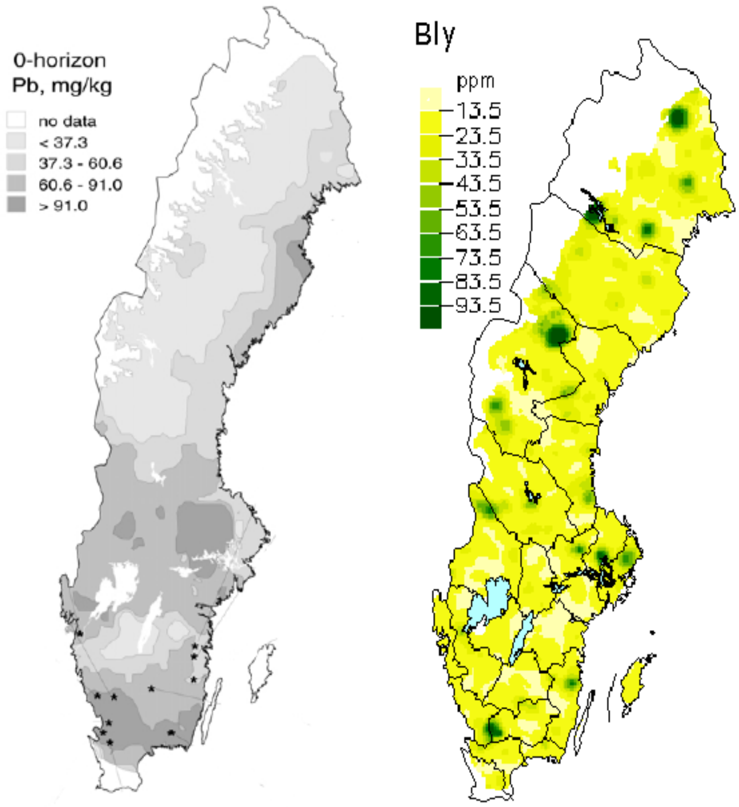

Figure 2.3: Levels of lead in the mor layer to the left, and in glacial till to the right (Johansson et al., 2001) (SGU, n.d a).

In the mor layer, lead levels vary regionally from 30 mg kg^{-1} in the north of Sweden to about 100 mg kg^{-1} in the southern part of the country (Johansson et al., 2001). In addition to regional and global variations in lead levels the concentration also varies locally, with great differences between different peat lands (Sohlenius, 2013).

Johansson et.al (2001) concludes that distribution patterns of Cd, Hg and Pb are mainly due to long-range atmospheric transport since there is no correlation between the concentration in the mor and the parent till material.

SGU reports a mean level of lead in Swedish peat to be 64ppm, although also states this figure most likely is too low since the values reported in application forms for peat extraction sites are often much higher than 64ppm (Sohlenius, 2013). Since the background levels of lead in peat varies locally, regionally and globally a mean concentration might not be of very much use.

It can be said that the natural and background levels of lead present in Swedish soils differ greatly, dependent on factors like soil type and characteristics, site location, latitude, and groundwater conditions.

An overview of results from soil investigation looking at lead presence have been made in Table 2.3. The investigations are made for different organic soil types, in different areas and with differing scope.

Table 2.3: Summary of results from previous lead investigations

Study	Area	Lead [ppm]	Comment
Berrow et al. (1982)	World	29.2	Average concentration of lead in the soils around the world.
Krumis et al. (2001)	Elki Mire, Latvia	0.51	Peat from minerotrophic mire in western Latvia.
	Viki Mire, Latvia	1.63	Peat from minerotrophic mire in western Latvia.
Klavins et al. (2009)	Latvia	4,77	Concentration in peat, from 44 Latvian bogs.
Orru (2006)	Estonia	9,62	Peat.
De Vleeschouwer (2007)	Belgium	61,6	Peat.
Bindler et al. (1999)	Bottnaryd, Sweden	70	Mean of 11 samples in the mor layer.
	Norra Kvill	42	Mean of 4 samples in the mor layer.
	Höstahult	83	Mean of 25 samples in the mor layer.
SGU	Sweden	64	Peat. Likely to be above this figure.
Statens energiverk, (1984)	Björkemossen, Sweden	129	Southern Swedish bog, above the highest shoreline.
	Ralbomossen	106	Marsh and bog. Chemical influence of salt water.
	Storflyten	41	Marshes in fractured, weakly radioactive granite.
	Skette-myren	46	Influenced by Cambrian Alum shale with elevated concentrations of trace elements.
Johansson et al. (2001)	Sweden	30-100	Measured in mor layer. Lead levels higher in southern parts of the country.
Deska et al. (2011)	Poland	99	0m from road
	Poland	24	50m from road
	Poland	21	100m from road

2.2.2 Lead sources

The sources of elevated levels of lead in soil can differ; either it originates from local point or line sources or diffuse long range sources. Anthropogenic lead, from local point sources or global diffuse sources is deposited in the urban, rural and forest soils. Once deposited in the soil, lead is very immobile, unlikely to migrate or to be taken up by plants (Bindler et al., 1999).

In the case of local lead sources, transportation is usually limited; contamination is therefore often strongly geographically constrained. Examples of this type of sources are landfills, industries and factories, gas stations, and roads.

Today there are an estimated 80 000 contaminated sites throughout Sweden. About 1300 of these are high risk and many are sites with previous or ongoing industrial activity (SEPA, 2013).

Long range deposition of chemicals on the other hand, affects a much larger area. There are currently no soils not exposed to atmospheric pollution (Bindler et al, 1999). The present levels of lead contamination in soils are a consequence of historic contaminations as well as present continued deposition of atmospheric lead pollution.

Due to an increase of anthropogenic emissions to the atmosphere, concentrations of lead in the soil increased considerably during the 20th century. Traffic has traditionally been the major source of anthropogenic lead and despite a significant reduction in these emissions due to removal of lead from petrol and gasoline, traffic is still the largest polluter of lead (Johansson et al, 2001). Results from Deska et al. (2001), in

2.3 shows how levels of lead are increased closer to a road, decreasing with distance.

Within the European Union, sales of leaded petrol has been banned since 2000 (European Council, 1998) and within Sweden since 1994, resulting in a considerable decrease in the atmospheric deposition of lead during the last decade (Board of Transportation, 2011). The developments on air emissions of lead in Sweden can be seen in Figure , with a reduction of lead emissions from 1990 to 2000 to 10%.

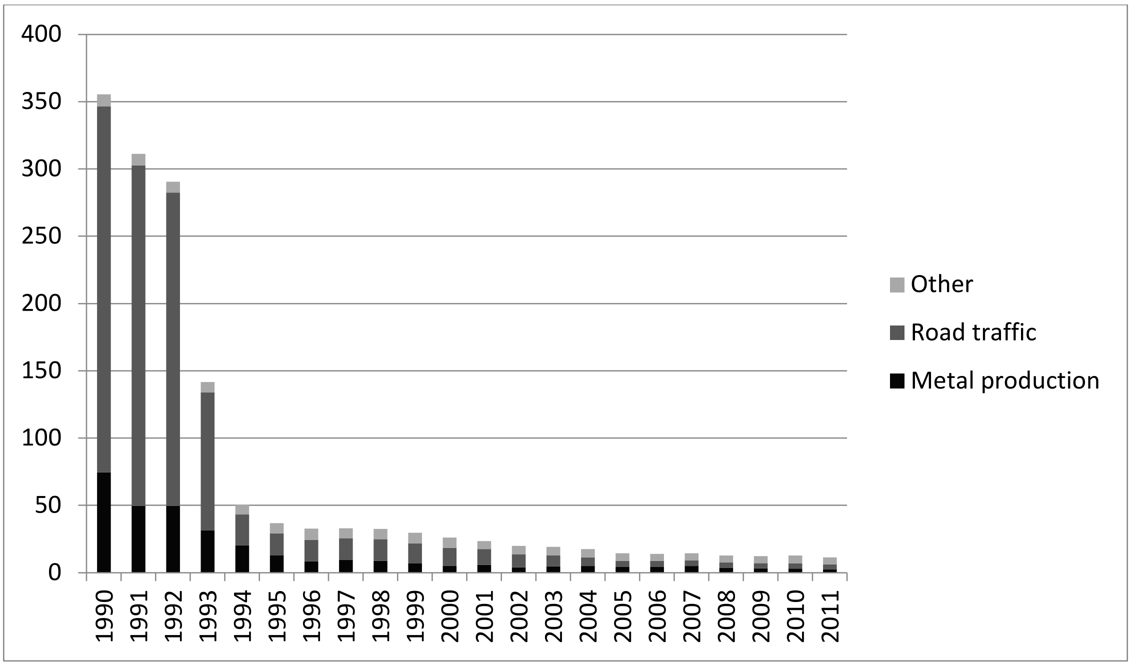

Figure 2.4: Lead emissions to air in Sweden between 1990-2011 (SEPA, 2013)

According to the Swedish Environmental Research Institute (IVL) the major part of the heavy metal deposition in Sweden is due to long-range transport from Europe (IVL, 2001).

In the beginning of the 20th century the Swedish emissions constituted for less than 1% of the European emissions, and at the same time more than half of the lead deposited in Sweden originated from sources outside the country (Johansson et al, 2001). According to Bindler (2011) "the cumulative anthropogenic burden of atmospherically deposited lead is *2–5g Pb m^{-2} and *1g Pb m^{-2} in the ‘‘pristine’’ north", half of which was deposited before the industrialization (Bindler, 2011).

The decline in atmospheric deposition is not enough to prevent a further net accumulation of lead in the forest soil. Lead concentrations in the top 50cm are still increasing by around 0.2% every year; if further reduction of the deposits are to be achieved, international efforts are necessary.

2.3 Guideline values

The SEPA has developed models to generate both generic and site-specific guidelines values for acceptable or non-harmful levels of contaminants. The respective guideline values depend on the expected land use of the site or area. For sensitive areas the stricter KM value is derived, whereas for less sensitive land use the MKM value (SEPA, 2009). Residential areas are considered sensitive (KM), where protection of human health is of primary concern. In addition to the KM and MKM guidelines, the FA guideline value dictates when a soil must be treated as hazardous waste. The guideline values are also based on exposure assessments and harmfulness of the substances.

2.3.1 Generic

The generic guideline values laid out by the Swedish EPA are intended for normal conditions at contaminated areas in Sweden. They are meant to cover an average contaminated site with the goal of protecting those living or visiting the site, as well as the soil and receiving environment (SEPA, 2009). The generic guideline for lead in a KM area soil is 50mg/kg TS, which means that soils that exceed this limit value are not suitable for sensitive land use without remediation.

2.3.2 Site-Specific

Site-specific guideline values are used in cases where the generic guideline values are not applicable or when a more situation-specific value is required. The SEPAs generic guideline value is set for a soil with 2% organic content, and a dry matter (Total Solids) of 82%. Peat soil in Ale, however, consists mainly of organic matter with a dry matter of 25% on average. In cases like this, site-specific guideline values can be calculated based on the site conditions and the expected exposure pathways.

2.4 Statistics

Statistics is the study of how to collect, organize, analyze, and interpret numerical information from data. It is not possible to sample every location and therefore estimations must be made for unknown values; reliable estimations are made possible with statistics.

"*The quality of results of environmental investigations is dependent on a reliable evaluation of the available information and collected data. Due to technical and* *financial limitations, the underlying data is usually limited, this requires a knowledge of how to by a few observations to form a picture of a population in a representative way to reflect the degree of contamination throughout the study area. A properly conducted statistical data analysis reduces the subjective element in the evaluation process and provides a framework for quantifying uncertainties*" (SEPA, 2009).

2.4.1 Statistical parameters

Some of the basic but informative statistical parameters are listed and described below. Depending on the characteristics of the data analyzed and what information is sought after, some are more useful than others.

- **Mode** is the most likely value. It can be used to give an accurate description of a central tendency on the nominal level range (SLU, 2013).
- **Range** describes how far the smallest value is from the largest one.
- **Median** is the middle value.
- **Mean** is the average value, calculated by dividing the sum of values by number of values. With normally distributed data mean values and standard deviation are of interest. When working with data that are not normally distributed median, scope and quantiles are more informative (ibid).
- **Standard deviation** and **Variance** describes the spreading of values around a mean value and how far away values are from the expected value (mean).

These summary statistics are relatively simple, they are easy to use but can reveal a lot of about the data being examined. They form the basis of any statistical analysis.

2.4.2 Random sampling

Random sampling is a probability-based approach and can be used when the objective is to produce representative statistics of an area or compartment. It can also be used when quantifying amounts of pollutants in contaminated soil (SEPA, 2009). Such statistics can then be compared with guideline values and used in risk assessments.

2.4.3 Correlation

Looking at correlations is useful when investigating connections between values (SLU, 2013). The Pearson Correlation calculation can be used when looking for relationships between two variables. Pearson's correlation coefficient, 'r', can be calculated with the covariance and standard deviations of the two variables (A,B) as follows.

$$r_{AB} = \frac{\text{Covariance}_{AB}}{\sigma_A \cdot \sigma_B} \qquad (1)$$

The result is a value between -1 and +1, with the following interpretation:

- **+1:** Perfectly positive linear relationship
- **0:** No relationship
- **-1:** Perfectly negative linear relationship

2.4.4 ANOVA

ANOVA, Analysis of Variance, or more specifically, one-way ANOVA, can be used when analyzing differences in means between different groups (SLU, 2013). It is a hypothesis test that works when looking at more than two groups at a time. Even though the name, Analysis of Variance, suggests that the variance is in focus, it is in fact the mean values which are analyzed. The null hypothesis (H_0) is typically that the population means are equal, and the alternative hypothesis (H_A) that at least one mean is different. Assumptions in a one-way ANOVA are that the groups are normally distributed, independent, and with homogeneous variances.

A one-way ANOVA is conducted by calculating the variation within groups, and the variation between groups (ibid). An *F* statistic can then be calculated as the variance between groups divided by the variance within groups. The probability of exceeding the value of F is then expressed as the p-value and compared to the significance level (α). The null hypothesis is rejected if the p-value is less than or equal to the significance level.

2.4.5 Kriging

Kriging is a geostatistical method of spatial interpolation, the prediction of values between sampled locations. Unlike other spatial analysis methods, like Inverse Distance or Nearest Neighbour, kriging accounts for the spatial statistical correlation between samples at varying distances. With a basic spatial analysis approach such as inverse distance, a single estimate for an unsampled point is achieved. With kriging, however, a distribution of possible values is obtained for the unsampled point, and both an estimate and model of uncertainty can be achieved (SADA, 2013). In the inverse distance method, the sampled points are weighted by their distance to the unsampled point, whereas in kriging, the weighting is based on the spatial correlation (Isaaks & Srivastava, 1989).

If data is said to be spatially correlated, then points which lie close together are more alike than points lying further apart. This can be measured using the semi-variogram method (SADA, 2013). A measure of semivariance (γ), for any given separation distance or lag distance (*h*) between sampled points *x* and *y*, can be calculated as follows:

$$\gamma(h) = 0.5\,\frac{\sum_{i=1}^{N(h)}(x_i - y_i)^2}{N(h)} \qquad (2)$$

which can be defined as half the average square difference between all sampled points separated by a specific lag distance (*h*), where *N(h)* is the number of these paired points. It's unlikely to have sampled points separated by exact lag distances, and therefore a lag tolerance is assigned so as to limit the number of separate semivariance calculations. For example, lag distances could be set as 10±5m, 20±5m, 30±5m and so on, allowing for more paired points captured for a given lag distance. An empirical semi-variogram is produced by plotting the semivariance on the y-axis with lag distance on the x-axis, as seen below in Figure .

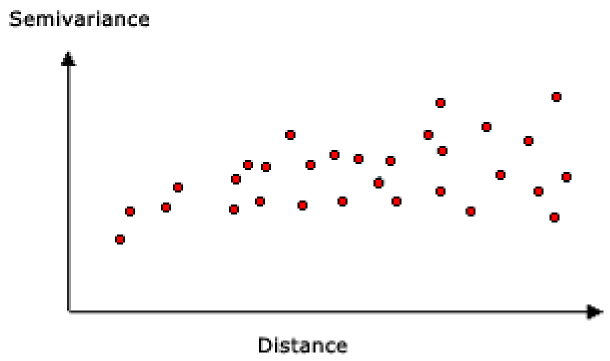

Figure 2.5: Empirical semi-variogram (ArcGIS, 2012)

Once an empirical semi-variogram is created, a model must be fit to the points in it, which is the basis for the prediction of unsampled points. A number of functions can be used to model the empirical semi-variogram, including: Spherical, Exponential, and Gaussian (ArcGIS, 2012). A semi-variogram fit by a spherical model is seen below in Figure .

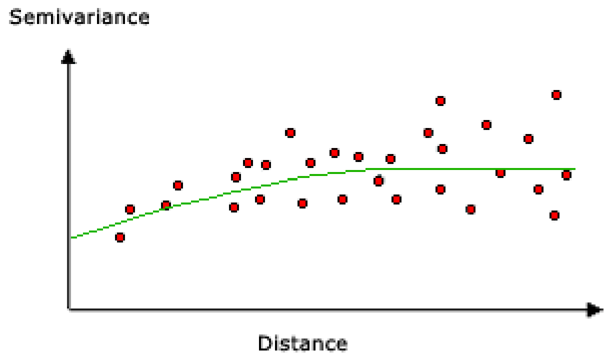

Figure 2.6: Spherical modeled semi-variogram (ArcGIS, 2012)

A semi-variogram model can be described using the terms Nugget, Sill, and Range, as shown in Figure . The nugget of a semi-variogram describes how much error is in the model, giving the modeled variance for two points at zero distance separation, which theoretically should be equal to 0. This can be attributed to sampling error or small-scale variability (Isaaks & Srivastava, 1989). The Range is the distance at which the semivariance levels-out to the sill value.

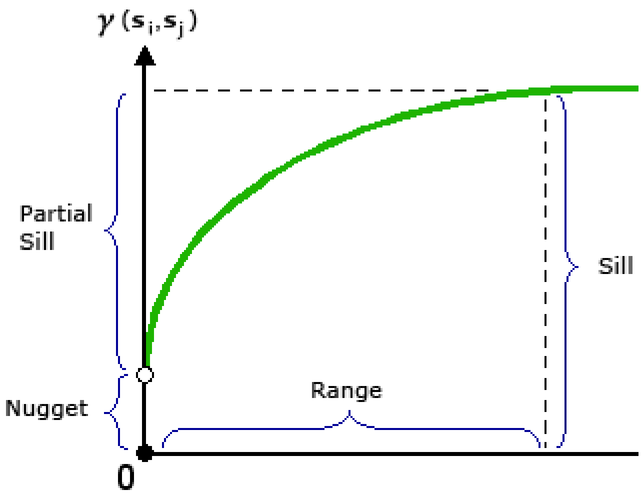

Figure 2.7: Fitted semi-variogram (ArcGIS, 2012)

3 Study Area

This section provides a description of the area of focus, Ale municipality, as well as a presentation on the findings of the previous study made in the municipality. It also presents local potential sources of lead that might have impacted the accumulation of lead in the soil that was found in the previous investigations.

The main area of interest in this study is the municipality of Ale, located 20 km north of Gothenburg and bordering the Göta River. The Göta River valley is home to a lot of industrial activity and is also a main transportation corridor, as the river carries a lot of sea freight and both the road E45 and a railway cuts thorough the municipality. The E6 runs along the opposite side of the river, in a different municipality. Figure 3.1 shows a map of Ale and the main towns, with the E45 and Göta River marking the western boundary.

Today, approximately 26 500 people reside in Ale and most of them live in one of the communities alongside the river (Ale Kommun, 2013). The municipality was founded in 1974 when the three smaller municipalities of Nödinge, Starrkärr and Skepplanda merged. Ale is rich in wildlife and 12 nature reserves are located within it (Naturskyddsföreningen, 2011).

Figure 3.1: Map of Ale municipality. The Göta River and E45 mark the western boundary (Ale Kommun, 2013)

Alongside the river, a flat valley bottom extends to the east. Most of the industries and residential buildings in Ale are located here, as well as the majority of roads and farmlands. This concentration of polluting activities has led to the areas alongside the Göta River to contain a lot of contamination.

There has been major cleanup work performed along the Göta River in Ale. Three major areas have been remediated in order to remove contaminated soil and create more stable shorelines, avoiding landslides and further dissemination of pollutants (Ale kommun, 2012).

Further to the east, long fennoscandian shield ridges oriented in the north-south direction cut through the landscape. The valleys in between are typically filled with glacial clay deposits. The soil depth on the ridges is generally 0-1m but at some locations along the river and riverbanks the clay deposits can exceed a depth of 50 m (SGU, 2013)

The Göta River, which marks the western border towards Kungälv is one of the largest rivers in Sweden; on its course to the outlet in Gothenburg it drains about 50,000 square km (SMHI, 2004) and serves as a drinking water reserve for 700,000 people (Göta älvs vattenvårdsförbund, 2011). In order to ensure safe drinking water for these consumers, parts of the river are protected. A 28 km^2 water protection area for the Göta River is located south of Surte port (Ale Kommun, 2011) and here there are special regulations for potential pollution sources, such as industrial activities, agriculture, roads and transport.

According to the SGU map service, the soil chemical investigation of the background concentrations of metals shows low levels of lead in the municipality with measurements up to 11 ppm in Ale for mineral soil, see Appendix I: Map of lead levels, Ale. (SGU 2013)

3.1 Previous study of Skårdal Skans

A previous study of the soil in Skårdal Skans, a forested area in the southern part of Ale has been made by Sweco in 2011. Skårdal Skans lies adjacent to the town of Bohus to the North West, at a height up to 100 m above the river. Ale municipality plans to develop the 30ha area to accommodate 200 homes (Sweco, 2011). An environmental investigation of the planned housing area was initiated by a shooting range found just to the south of the area.

Skårdal Skans can be considered to be one large hilltop, which is currently completely forested. The forest type is primarily coniferous but with some deciduous species such as birch. A large fraction of the area consists of outcropping bedrock. In the lower lying water logged areas, patches of peat soil can be found between stretches of bare rock (ibid). The western and northern boundaries of the area are very steep hillsides which go down to existing residential areas. Two north-south valleys cut through the area.

Part of the current planning area is located on the outskirts of the Vättlefjäll nature reserve and is marked as a national interest area for outdoor recreation. The area is also home to some ancient monuments, such as stone walls and fortifications (ibid).

Most of the Skårdal Skans area consists of exposed porphyritic granite or granodiorite bedrock (SGU, n.d). Postglacial sand is the predominant soil type in the two north-south valleys through the area.

The peat soil sampled in the first study of the area made by Sweco was mainly found in local depressions in the hilly terrain. The soil depth was minimal and the sampling was only made to a few centimeters of depth (Sweco, 2011). The pH of the soil was found to be between 3.9 and 4.6 with a high moisture content of around 75%.

Based on the topography, main runoff could be expected to flow in all directions. The area falls however in a larger catchment area with discharge to the Göta River. Runoff flows to the south can end up in a small lake (Viksjön) or in a bog north of the shooting range (Kringelmossen). At a smaller scale, runoff from the exposed bedrock is expected to pool and accumulate in the small peat depressions with little possible drainage (ibid).

It was suspected that the area in and around the shooting range was contaminated and this was the motivation behind the soil investigation. A total of 95 samples from 58 locations were analyzed in the previous study (Sweco, 2012b). Of the samples analyzed, 77 were from within the area considered to be affected by the shooting range activity. The remaining 18 samples were taken in the assumed undisturbed natural areas that make up the larger part of the planning area.

Results of the Sweco investigation showed very high metal contamination, mainly lead and arsenic, close to the shooting range (Sweco, 2011). Lead and arsenic levels were also high in the rest of the area as well, above the general guidelines for sensitive land use (KM) and industry (MKM) set by SEPA. Reference sampling was performed 1 km south of the study area for comparison purposes, and to study how much of the contamination could be explained by the shooting range or from other sources, such as the precipitation of airborne lead from traffic and industry (Sweco, 2012a). The results of the reference study were unexpected, showing that 11 of 12 samples were above the sensitive land use guideline (KM).

Table 3.1 contains a summary of the results for lead from the investigation (ibid). The mean value of the samples taken in the assumed undisturbed natural areas is more than double the guideline value for sensitive land use. Samples in the shooting range area were on average higher than the FA guideline.

Table 3.1: Lead levels (mg/kg TS) from previous study of Skårdal Skans (Sweco, 2012b)

	Samples Analyzed	Min	Median	Mean	Max	Guideline Values		
						KM	MKM	FA
Total of Planned Area	95	3	210	3665	150000	50	400	2500
Area close to Shooting Range	77	3	270	4490	150000	50	400	2500
Outer Area	18	42	101	134	310	50	400	2500

Since nearly all of the analyzed soil sample at Skårdal Skans can be classified as peat, with high organic and water content, the generic guideline for lead is not applicable and site-specific values are required. It should be noted that, when this site specific value was calculated by Sweco, due to the ability of peat to absorb and bind metals, site-specific guidelines were not calculated specifically for the protection of the environment. This is because an overestimate of the leaching of lead to receiving waters would likely have resulted from the SEPA model (Sweco, 2012b).

Site-specific guideline values for human health were calculated based on the expected exposure pathways of lead from the peat soil as well as the site conditions. The peat soil in Skårdal Skans is found in small depressions between rocky outcroppings. The pH of the soil was found to be between 3.9 and 4.6, which falls within the optimal range for binding of metals. The drainage in these low lying areas is considered to be very low, and with high moisture and vegetative cover, the spreading of dust is not considered to be a big factor. With development, however, the drainage of these areas could increase, and drying out of the peat areas would lead to increased dust. In addition, changes in the pH of the soil from rainfall could affect the binding of the metals in the peat. The uptake of lead from plants must be considered, where contamination can be spread to humans from the eating of berries or mushrooms from the area. All things considered, the spread of lead contamination from the area is considered to be limited, but development could increase dispersion and exposure (Sweco, 2012b).

The calculation of the site specific value for human health made by Sweco in 2013 was based on lead as a design pollutant and the assumption of 365 days/year of stay (Sweco, 2012b). The ingestion of lead from drinking water was not considered, since the area would be connected to municipal water. The ingestion of contaminated soil was the main deviation from the generic assumptions, where the high moisture content of the Skårdal Skans soil would lead to lower daily intake of lead. Two site-specific health guidelines were calculated, for residential soil, as well as for natural soil. The health based guideline value for residential soil came out to 100 mg/kg TS. The health based guideline value for natural soil came out to 910 mg/kg TS. A summary of the above guideline values, both generic and site-specific, is seen in Table 3.2 below.

Table 3.2:Generic and site-specific guideline values for Skårdal Skans

	Generic [mg/kg TS]			Site-Specific [mg/kg TS]	
	KM	MKM	FA	Residential	Natural
Guideline Value, Pb	50	400	2500	100	910

The calculated site-specific value of 100 mg/kg TS is double that of the generic guideline value of 50 mg/kg TS. It can here be noted that even with a higher site-specific value many of the sample results still exceeds the accepted value.

3.2 Local sources of lead

There are several potential sources of contamination for lead in Ale municipality and also local point sources close to Skårdal Skans. Lead is a heavy metal and usually does not travel too far. It is therefore assumed that these local sources have a relatively local spread, that the lead from these have not traveled very far before settling in the ground.

Shooting range – The activities at the shooting range in Skårdal have been going on for almost 70 years (Sweco, 2011). Remains from ammunition contain metals and semi-metals, primarily lead. Lead from shotgun hail can spread over large areas and convert into different compounds that are soluble in water with low pH (SEPA, 2006b). Contamination from the shooting range is mostly rather local but smaller amounts of lead can be transported by animals or groundwater if the lead is leached.

Manufacturing industries – The Göta River valley has a long history of industrial production and a large parts of the soil here is known to be contaminated. One example is the Tudor battery factory upstream the river. The municipality and SADA have together funded a cleanup program for the river valley, to be finished 1012/1013 (Ale kommun, 2012). Although large parts of the river valley have been remediated now, contamination might still be left in other areas.

Landfills and dumps – Ale has two, one at Sörmossen and one at Älvängen (Ale Kommun, 2012b). Contaminants could possibly leach from here and pollute the surrounding environment.

Roads, mainly E45 and E6 – Roads are widely known as a source of emissions and pollutions. Soil close to roads have elevated levels of heavy metal concentrations as well as animals living in roadside habitats and runoff water carries pollutants to receiving watercourses (VTI, 2005). Lead is one of the heavy metals that are emitted from traffic in such an extent that it might influence the surrounding environment (IVL, 2001). Larger and heavier particles settle in the immediate vicinity of the road while smaller and lighter particles can travel larger distances before settling.

The roads E45 and E6 are possible local sources of lead; there would have been especially high emissions before the abandonment of lead in petrol/gasoline in the mid 90's. This lead could have been transported and deposited into the surrounding forests/environment. The predominant wind direction is from the West, South-West; therefore it can be expected that emissions settle on the East side of the road to a higher degree.

Out of these four potential sources of contamination roads have the widest spread and would impact a much larger area.

4 Method

In this chapter, a description of the execution of creating the sampling plan, sampling and analyses will be presented. Within the section, the sampled profiles are described, sampling procedure accounted for, and methods of analyses, risk assessment and mapping presented.

4.1 Sampling Plan

A total of around 100 samples were allotted for the project, to investigate the levels of lead in the natural soils in Ale. This posed a limitation to the extent of sampling that could be achieved in combination with the sample resolution. Approximately 10 profiles from south to north along the E45 were originally of interest, as seen in Figure 4.1. The profiles were overlaid onto 1:50,000 SGU soil maps (SGU, 2013) as well as Google aerial photographs (Google, 2013). In order to get good sampling resolution and range, to make the most of the number of samples given, the number of investigated profiles had to be reduced to 3. These are marked in green in Figure 4.1.

Figure 4.1: Profiles of initial interest. (Google, 2013) (SGU, 2013)

The three profiles chosen have a south-north range of 7km, from Surte in the South, to Bohus, and Nödinge in the north. Each of the three profiles is 1,980m in length, lying at 90deg, in the west-east direction. 33 samples were set for each profile at an average spacing of 60m. An overview map of the three profiles can be seen below in Figure 4.2.

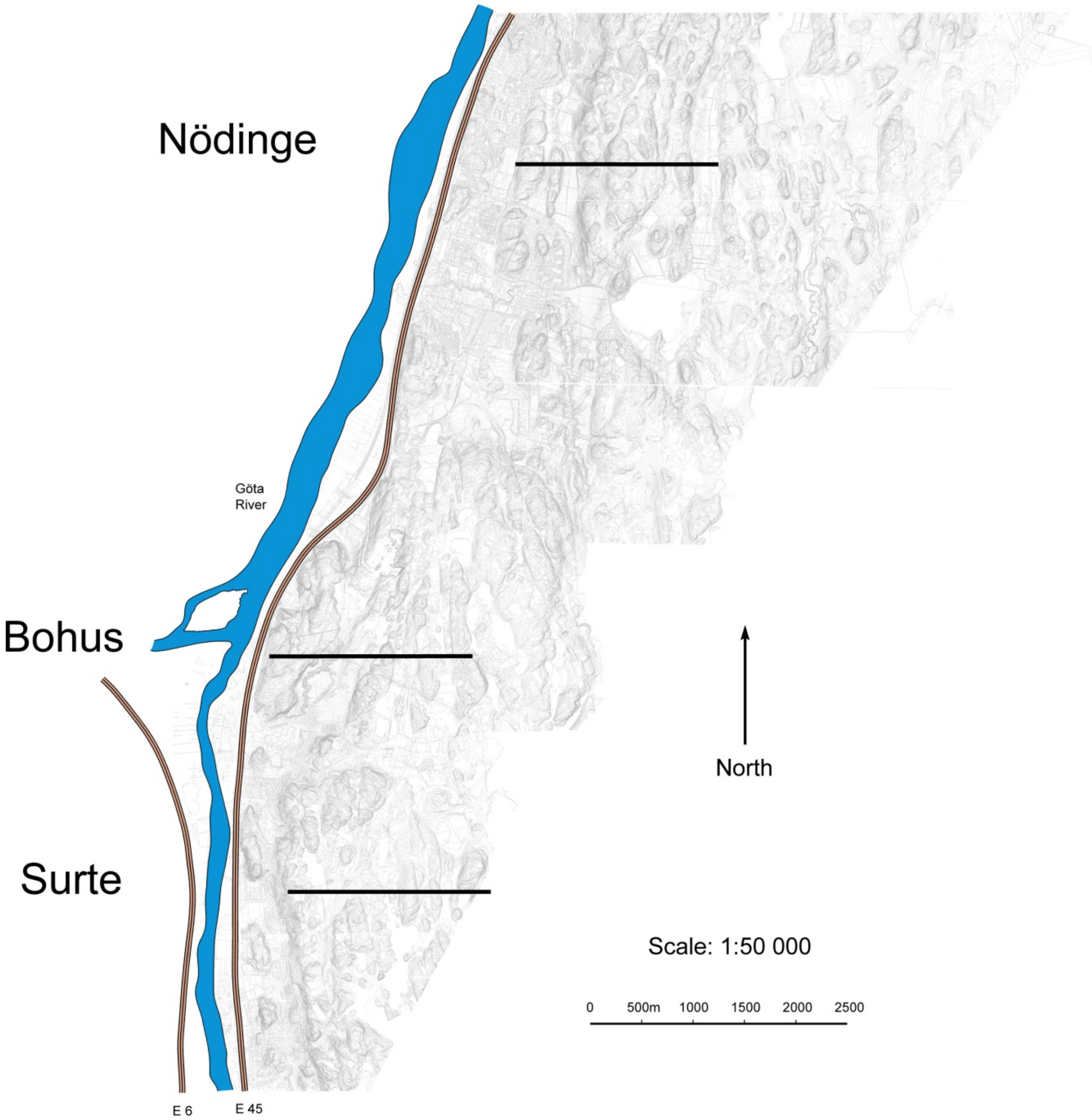

Figure 4.2: Overview map of the three profiles

The three profiles have a general pattern of terrain and soil types in common. The profiles extend from the Göta River and the E45 across two or three ridges, mostly covered with mixed forest and shallow ground cover, with valleys in between dominated by peat soils and clay. The specific locations of the profiles were selected so as to have the complete extent in natural soil, uninterrupted by roads and buildings. This was done to allow for the complete interpolation of levels throughout the profiles.

Stratified random sampling was performed in selecting the sampling locations along the profiles. The locations were randomly generated within 60m increments along the 1980m long profiles. The north-south position of the samples was kept the same, however, meaning all sampling locations were along the same line. The generated stratified random sampling positions over the 60m grid can be seen for each profile below in Figure 4.3.

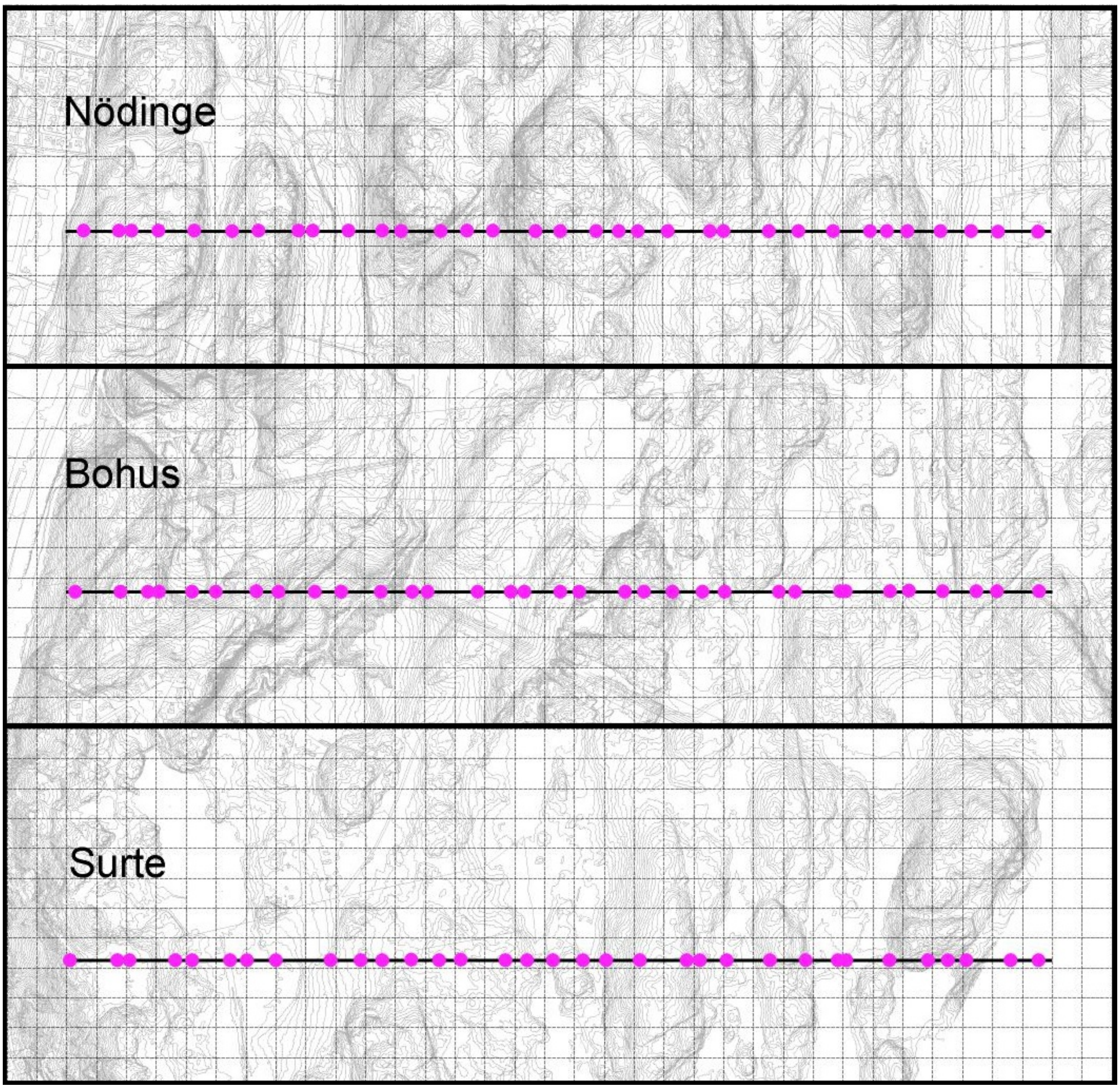

Figure 4.3: Stratified random sampling plan over 60m grid.

After the initial round of sampling it was decided that an additional 5 samples should be taken for reference purposes a large distance away from the E45 and the Göta River. These were taken 10km north and east of the Nödinge profile at the northeast extent of Ale municipality. These samples can be said to have been taken from a more undisturbed remote forest area. Rather than taking the 5 samples in a west-east profile, the sampling locations were randomly generated within a 100m x 100m box. The distribution of these reference samples can be seen below in Figure .

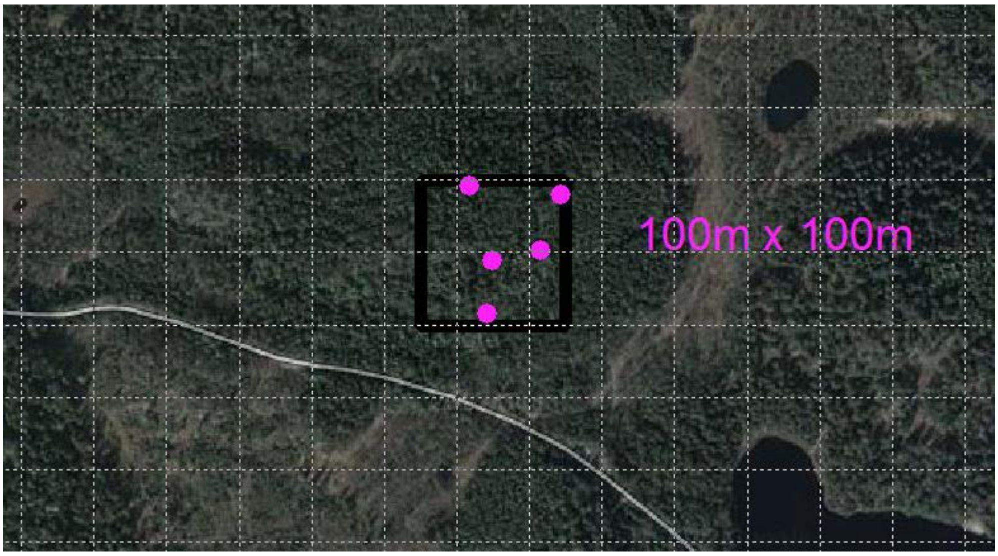

Figure 4.4: Reference sampling plan east of Skepplanda (Google, 2013)

4.2 Sampling

All the sampling was conducted in early May, after the ground had completely thawed. For both the Surte and Nödinge profiles, all 33 samples were taken in one day each. For the Bohus profile, samples were taken over two days. The reference sampling was conducted two weeks after the sampling of the three profiles. The sampling procedure undertaken was as follows.

4.2.1 Procedure

1. Once sampling spot was found, GPS waypoint was taken.
2. The top layer of forest litter was scraped off.
3. A large handful of sample was extracted with a small shovel up to a depth of 10cm. (See Figure). Large roots and stones were removed.
4. Sample was placed in plastic sampling bag, sealed and labeled. The samples for the Surte profile were labelled S1-S33, for Bohus B1-B33, and Nödinge N1-N33.
5. Relevant observable information was recorded, for example the characteristics of the sample and surroundings; soil type, heterogeneity, vegetation and water conditions.

4.2.2 Soil Type

Due to the nature of the terrain, a large variation in soil type from one sampling location could be seen. The lower lying peat marshes can be quite small and lie interspersed between small ridges of forest and outcropping bedrock. This meant that the sampled soil often changed from one location on the profile to the next, but almost exclusively from peat to mor soil and vice versa. In total, 66 samples were taken in mor soil, and 35 in peat soil. In addition, 3 samples were taken in glaciofluvial soil, from the few clay valleys lying between the larger hills in Ale.

Figure 4.5: Sample extraction and bagging from peat soil (left) and mor soil (right). Photo: Petra Almqvist

4.2.3 GPS Correction

The sampling locations were overlaid onto a CAD base map with 1m laser contours prior to sampling. This allowed for easy and precise navigation between sampling locations. The accuracy of the actual sampled locations compared to the intended coordinates was verified by a GPS unit, by taking a waypoint when the sample was being taken. The average error in sampling was approximately 15m. A map of the actual sampled sites compared to the intended sites, over a 60m grid, can be seen below in Figure 4.6. The GPS tracking overlays can be seen in Figure 4.7.

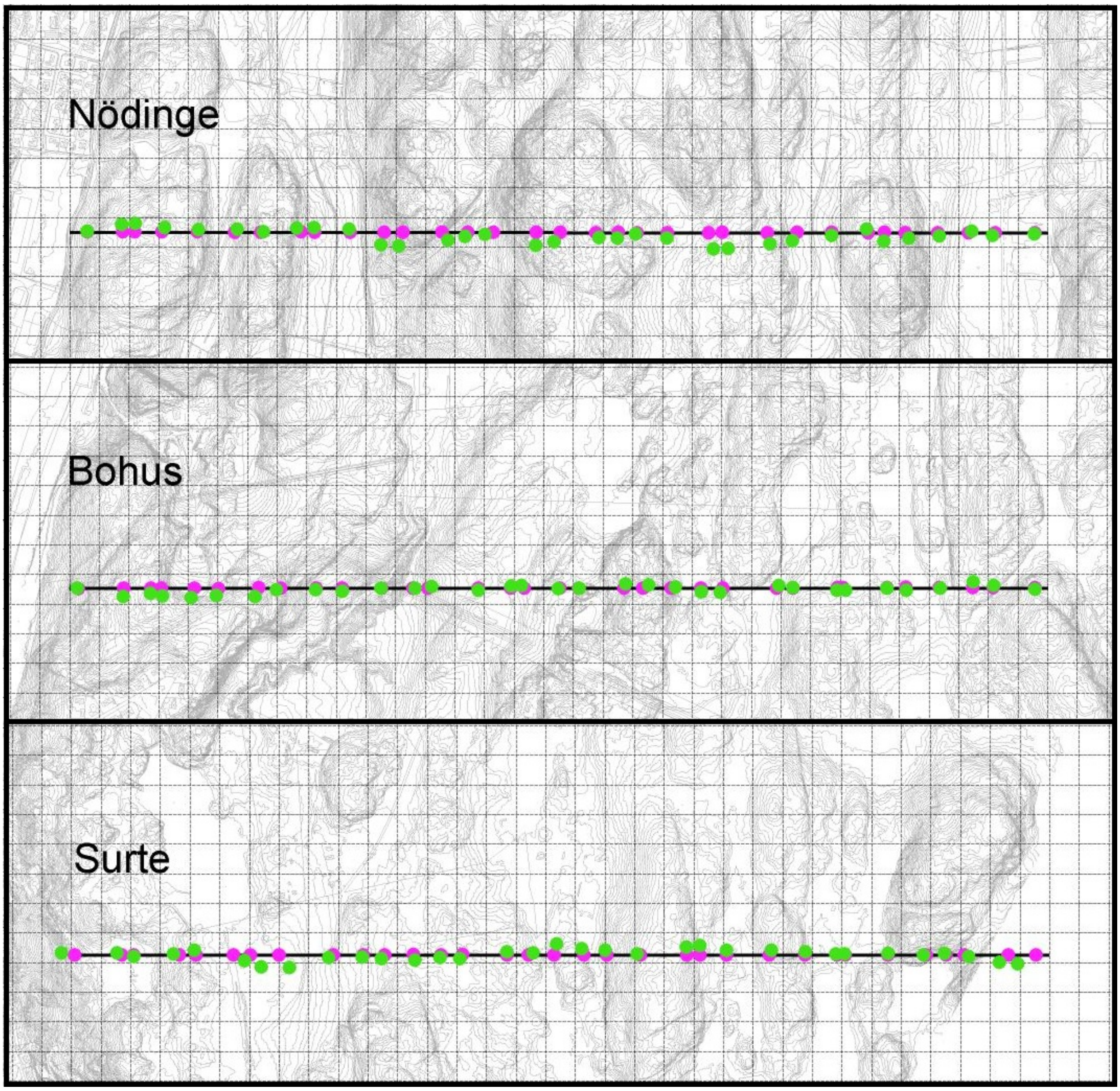

Figure 4.6: Actual sampled locations (green) vs. intended sampling points (pink).

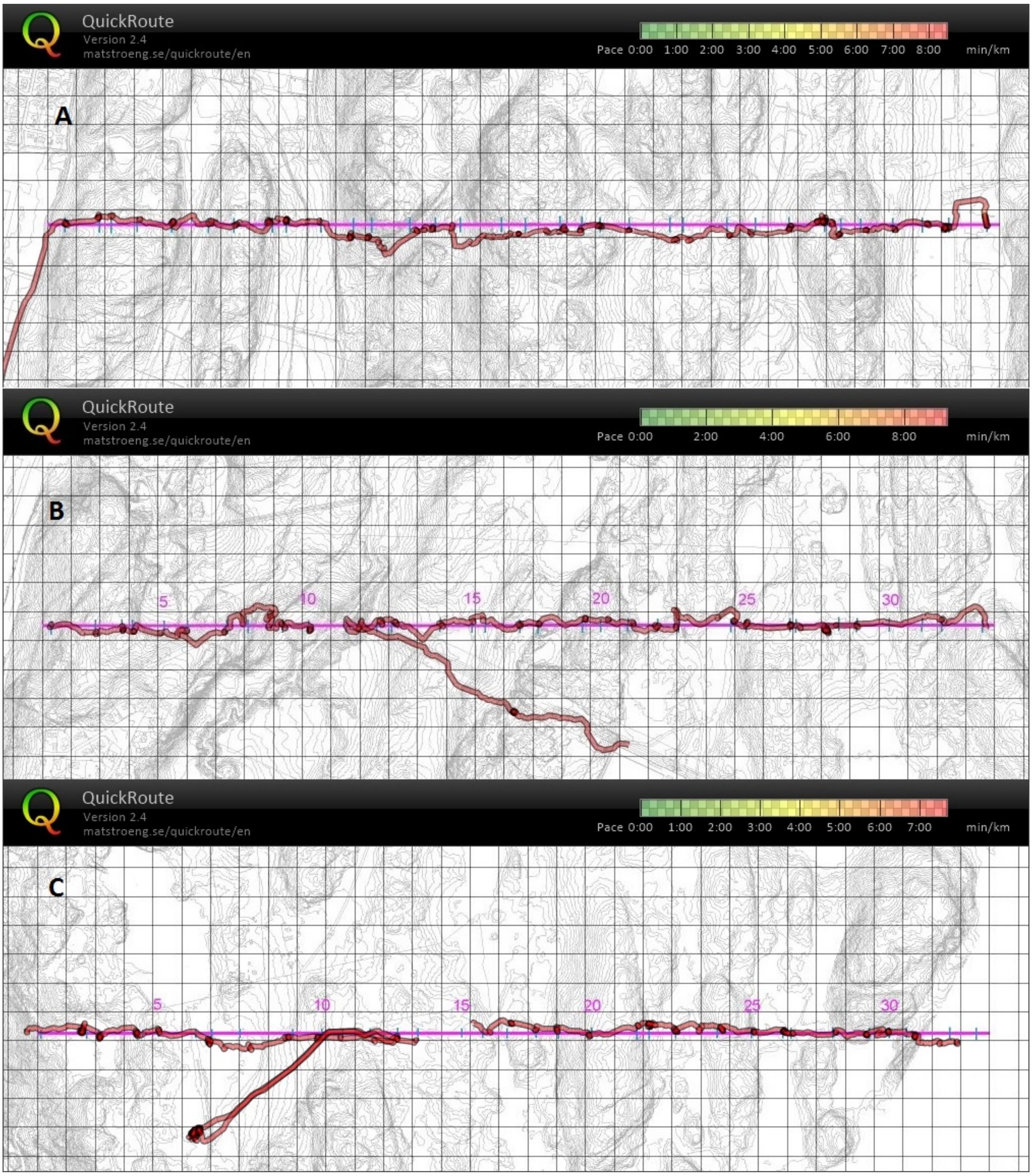

Figure 4.7: GPS Route overlays. A-Nödinge, B-Bohus, C-Surte

4.2.4 Elevation

Each of the three profiles has large changes in elevation, ranging from 10masl to 130m. Altitude measurements were taken from the GPS device, as this was determined to be the most feasible solution. The elevation displayed with the GPS overlay for the Nödinge profile can be seen below in Figure 4.8.

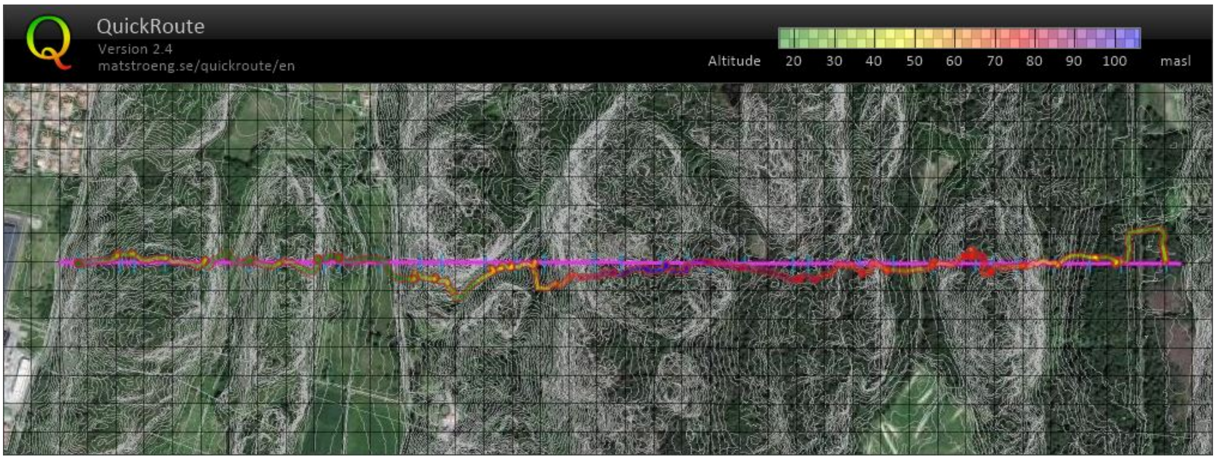

Figure 4.8: GPS Overlay with Elevation

4.3 Analysis

4.3.1 Laboratory Analysis

The sealed and labelled samples were sent to Eurofins Environment AB in Lidköping Sweden. In addition to the water content of the soil samples, the following metals were analyzed: Arsenic (As), Barium (Ba), Cadmium (Cd), Cobalt (Co), Copper (Cu), Chromium (Cr), Lead (Pb), Nickel (Ni), Vanadium (V), and Zinc (Zn). It should be noted that the total concentrations for each metal was considered and analyzed, as opposed to the individual speciation.

The analysis reports for each sample can be found in Appendix II: Lab Analysis Reports.

4.3.2 Software

The different software used in the analysis process are listed below, along with a short description of how they were used.

SADA

SADA - Spatial Analysis and Decision Assistance is a tool that facilitates looking at data from a spatial context (SADA, 2013). With SADA, it was possible to visualize the acquired data in an organized way, and to perform geospatial interpolation. Version 4.1 was used for the analysis. More on how the software was used for mapping and interpolation can be found in section 4.5.

Excel

Microsoft Excel was used to perform basic statistical analyses, like ANOVA and Pearson Correlation.

A one-way ANOVA test was used to analyze the variance between the three profiles for Lead, Arsenic, and Cadmium.

The correlation between the lab results and different parameters of interest were analyzed using the Pearson Correlation function in excel. The correlation between the contaminant levels and distance to the E45, water content, northing, soil type, and to the elevation were calculated.

The resulting correlation coefficients were evaluated according to Table 4.1.

Table 4.1: Interpretation of Pearson correlation coefficients (SLU, 2013)

Correlation coefficient, *r*	**Strength**
0-0,19	Very weak
0,20-0,39	Weak
0,40-0,69	Moderate
0,70-0,89	Strong
0,9-1	Very strong

ProUCL

The statistical software ProUCL, version 4.1.00, provided by the United States Environmental Protection Agency (USEPA) was used to generate histograms and to illustrate distribution of the lab results.

Quickroute

Quickroute version 2.4 was used to overlay the GPS tracks for each profile onto the CAD base-map. It was also used to extract elevation data from the GPS files.

4.4 Human health risk assessment

A simple human health risk assessment was made by comparing lab results from the three profiles and the reference sampling with guideline values from the SEPA, both generic and site specific values. For the site specific guideline value, the value calculated in previous investigations made by Sweco (2012b) has been used, which pertains to residential land use.

4.5 Mapping and Interpolation

Mapping and spatial interpolation of the data was performed in SADA 4.1. The coordinates and results for each sampled point were imported to SADA through a CSV File. A GIS overlay (.dxf) was also imported, and polygons were set for each of the three profiles, allowing for individual interpolations within one large SADA file. Easy visualization of the data could then be seen, with the sampled locations overlayed over the contour base map with color coded concentrations.

The method of interpolation was geostatistics (kriging). Ordinary kriging was used with the assumption that the data is normally distributed for each profile. The spatial correlation of all the data together was calculated for the kriging process. A major axis of 90° (west-east) was considered. A lag number of 20 with a lag distance and lag tolerance of 200m was used, as seen in Figure below. Since only two-dimensional variography is investigated, no Z angle is considered. A grid spacing of 10m was used, with a search neighborhood with major and minor radii of 300m and 200m respectively.

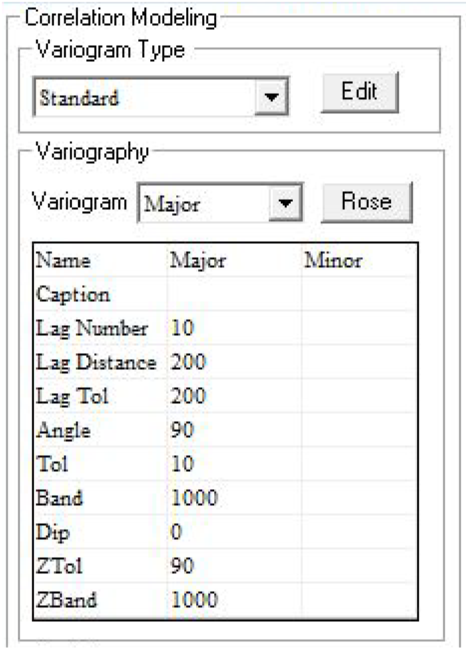

Figure 4.9: Correlation modelling inputs (SADA, 2013)

5 Results

This chapter presents the lab results from the sampling made in the three profiles Surte, Bohus and Nödinge and the reference sampling. Results from the interpolation and correlations are also presented in this chapter. First a short summary of the findings of lead is given, followed by a more detailed account for each profile and the reference area.

5.1 Lab results

The lab results from the 104 analyzed samples contain measured values on Arsenic, Barium, Cadmium, Cobalt, Cupper, Chromium, Lead, Nickel, Vanadium and Zinc. The lab results for each sampling point can be seen in Appendix II.

The dry substance of the samples was also measured at the lab and varies from 8-72%, with a median of 25% dry substance.

Table 5.1 below contains a summary of the statistics of the lab results for lead, with min, median, mean and max values as well as standard deviation and range of values. In Figures 5.1-5.4 histograms of the lab result values together with the distribution are shown. Table 5.2 shows the goodness of fit for each profile to normal, lognormal and gamma distributions at 0.05 significance level.

Table 5.1: Summary of lab results for lead levels in the profiles and reference area.

Area/Pb (mg/kg TS)	Min	Median	Mean	Max	Standard deviation	Range
Surte	36	89	92	190	40,2	154
Bohus	14	94	114	260	65,77	246
Nödinge	36	100	130	330	130,2	294
Reference	68	110	129	220	58,53	152

Table 5.2: Summary of the goodness of fit for the profiles and reference area to normal, lognormal and gamma distribution, at the 0.05 significance level.

	Normal	Lognormal	Gamma
Surte	Yes	Yes	Yes
Bohus	Yes	No	Yes
Nödinge	No	Yes	Yes
Reference area	Yes	Yes	Yes

The distribution of lead levels along the Surte profile in Figure 5.1 below are illustrated by the histogram. As seen in Table 5.2 the lab results for Surte are interpreted by ProUCL as normally, lognormally and gamma distributed. Surte has the smallest standard deviation out of the 4 areas sampled.

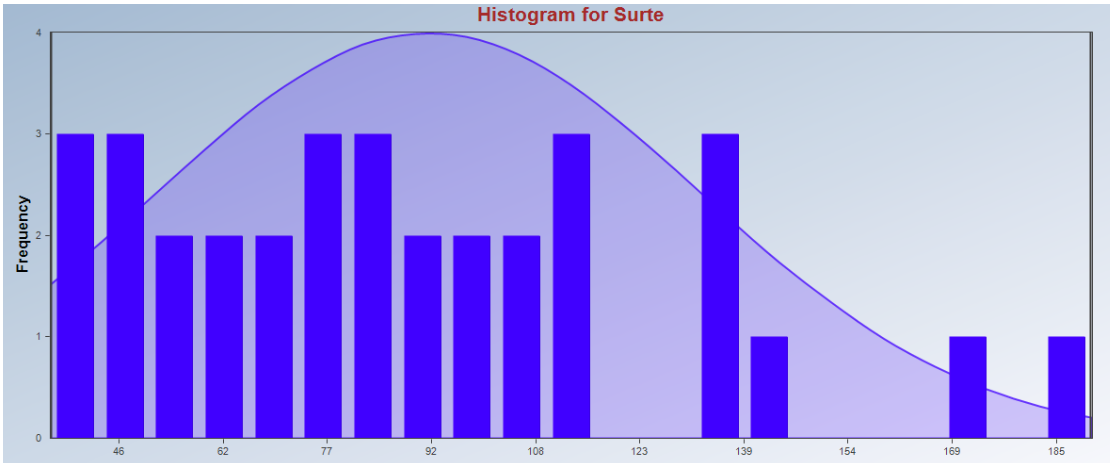

Figure 5.1: Distribution of lab results for lead, Surte profile.

The distribution of results from the sampled locations in Bohus are normally, lognormally and gamma distributed. This distribution can be seen in Figure 5.2 below.

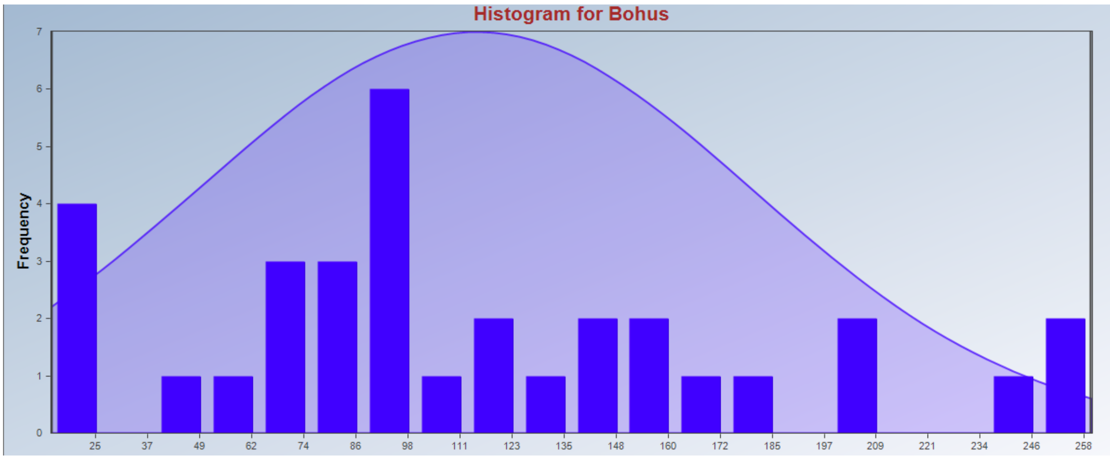

Figure 5.2: Distribution of lab results for lead, profile Bohus

The Nödinge profile is the one with the largest range and the largest standard deviation. In Figure 5.3 below the distribution of the values can be seen. It is the only area out of the 4 sampled that do not have normally distributed results for lead.

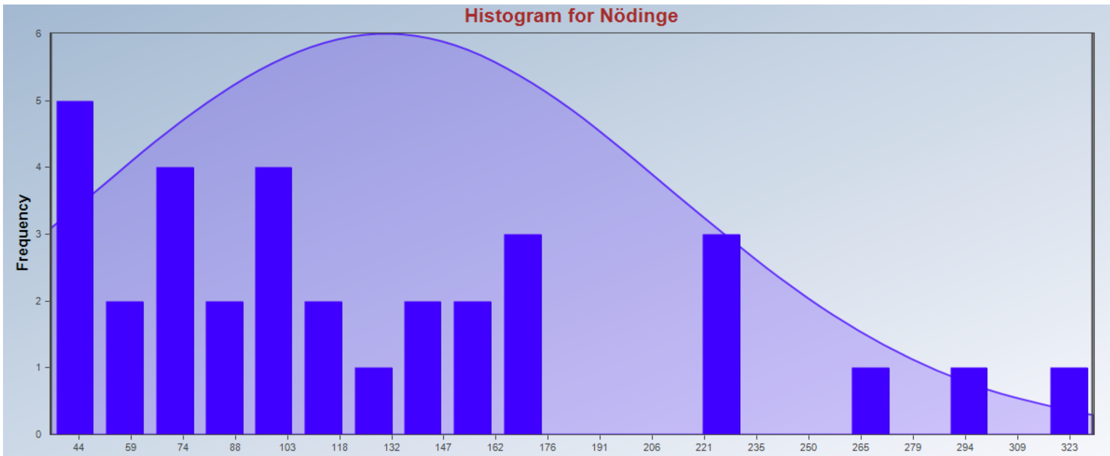

Figure 5.3: Distribution of lab results for lead, profile Nödinge

The reference area contains only 5 samples, and out of the 4 areas sampled the reference area has the smallest ranges of lead levels. In Figure 5.4 the distribution of lab results from these samples can be seen.

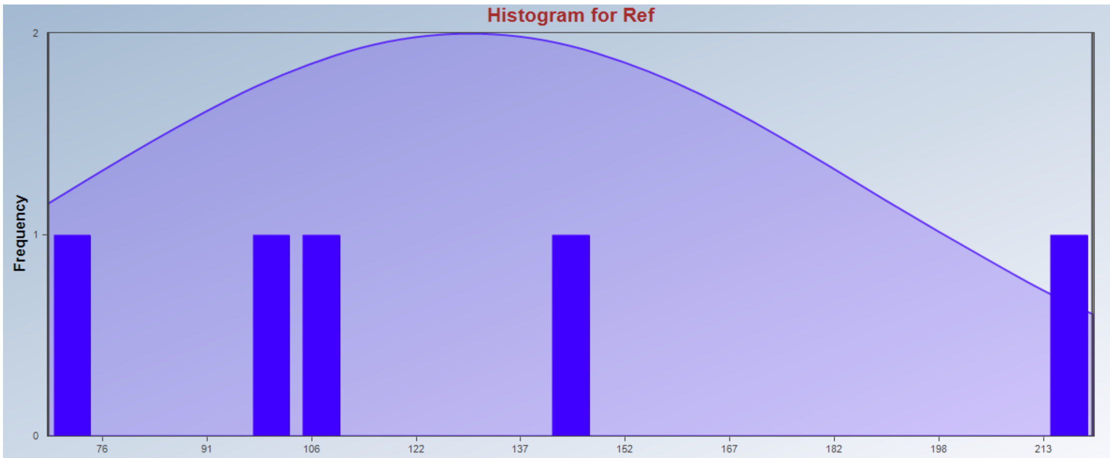

Figure 5.4: Distribution of lab results for lead, reference area

A summary of the results for each profile as well as the reference area is presented in Figure 5.5 below.

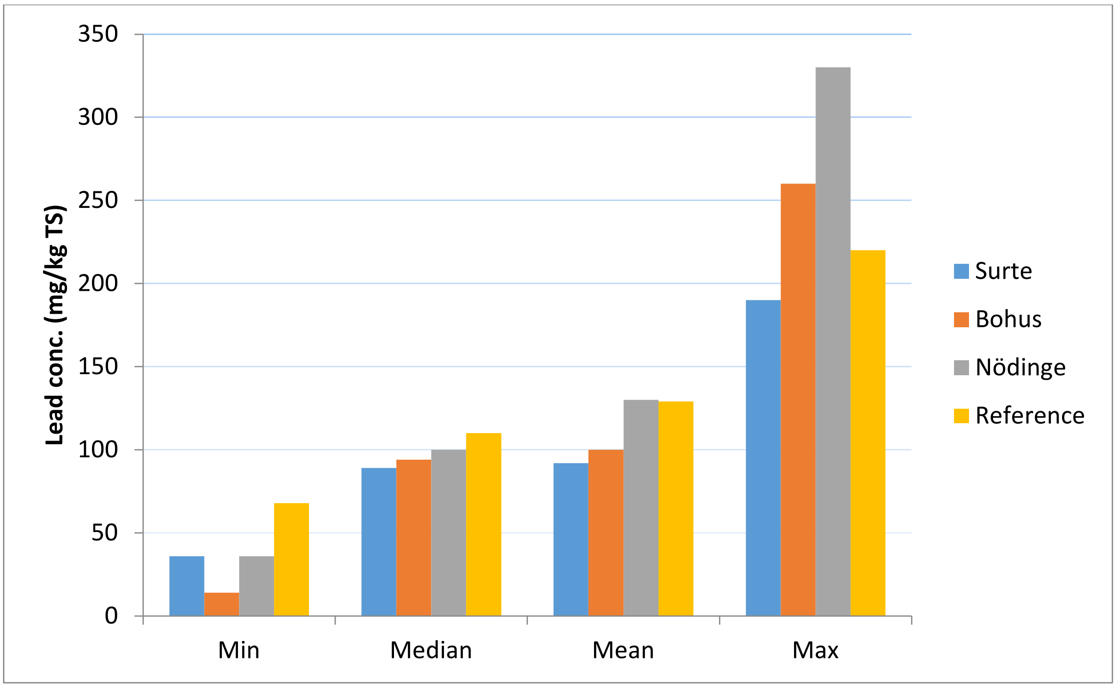

Figure 5.5: Results summary chart for the three profiles and reference area, mg/kg TS

5.1.1 Surte

In Tables 5.3-5.6, a summary of the results from the lab for each profile are shown. For some of the results Arsenic, Lead and Cadmium exceed the guideline value for sensitive land use, KM, set up by the SEPA. These are marked in bold letters.

Table 5.3: Summary of lab results for Surte mg/kg TS

	Min	Mean	Median	Max	KM
Arsenic	4,2	9,63	8,8	**22**	10
Barium	16	39,7	31	110	200
Cadmium	0,2	0,36	**0,63**	**1,2**	0,5
Cobalt	0,98	2,15	2	5,4	15
Cupper	6,6	13,86	13	32	80
Chromium	2	4,64	3,7	17	80
Lead	36	**91,94**	**87**	**190**	50
Nickel	1,7	5,52	5,4	9,6	40
Vanadium	1	17,68	15	43	100
Zinc	7,8	57,75	43	170	250

High levels of Cadmium can be harmful to people if exposed over long periods of time. Cadmium accumulates in the kidneys which can eventually be damaged (EFSA, 2009). Exposure to Arsenic can cause adverse effects like skin lesions, cancer, neurotoxicity, and cardiovascular diseases (EFSA, 2010). Harmful effects of exposure to Lead is covered in chapter 2.2.

Except for Arsenic, Cadmium and Lead the lab results for Surte are all well below the KM guideline values.

5.1.2 Bohus

For Bohus the min, mean, median and max values found in the profile are found in Table 5.3. Arsenic, Lean, Cadmium, Copper and Zinc are found to exceed the KM guideline values.

Table 5.4: Summary of lab results for Bohus, mg/kg TS

	Min	**Mean**	**Median**	**Max**	**KM**
Arsenic	3	9,38	9,4	**18**	10
Barium	17	43,39	39	100	200
Cadmium	0,2	**0,64**	0,5	**2,6**	0,5
Cobalt	0,71	3,28	2,3	11	15
Cupper	4,3	25,2	19	**110**	80
Chromium	1,8	7,99	6,7	22	80
Lead	14	**114,24**	**94**	**260**	50
Nickel	1,7	7,19	7	14	40
Vanadium	7	23,90	19	66	100
Zinc	17	52,94	43	**330**	250

In addition to the health risks associated with elevated levels of Lead, Arsenic and Cadmium, the soil in the Bohus profile also contained high levels of Cupper and Zink. Exposure to these metals can cause nausea and vomiting (SLV, 2013).

5.1.3 Nödinge

Results for the Nödinge profile are found in Table. Arsenic, Lead, Cadmium and Cobalt levels are found to exceed the KM guideline values.

Table 5.5: Summary of lab results for Nödinge, mg/kg TS

	Min	Mean	Median	Max	KM
Arsenic	3,9	8,43	8,7	**13**	10
Barium	18	45,52	42	87	200
Cadmium	0,2	0,41	0,37	**0,98**	0,5
Cobalt	0,2	6,28	2,9	**67**	15
Cupper	4,1	14,52	13	30	80
Chromium	3,5	10,85	8,2	37	80
Lead	36	**130,15**	**100**	**330**	50
Nickel	2,3	6,76	6,1	24	40
Vanadium	6	30,42	24	**110**	100
Zinc	15	48,79	45	100	250

In the Nödinge profile the highest lead value of all the samples is found, 330 mg/kg TS. In addition the elevated levels of Lead, Arsenic, and Cadmium there are also levels of Cobalt and Vanadium exceeding the KM Guideline value.

5.1.4 Reference area

Lab results from the reference area are presented in Table 5.6. Arsenic, Lead, and Cadmium levels are found to exceed the KM guideline values.

Table 5.6: Summary of lab results for reference area, mg/kg TS

	Min	Mean	Median	Max	KM
Arsenic	4	7,34	7	**13**	10
Barium	30	103	94	180	200
Cadmium	0,23	**0,616**	0,4	**1,2**	0,5
Cobalt	0,95	1,81	1,8	3,1	15
Cupper	3,7	8,9	9,8	13	80

Chromium	3,6	4,22	4,3	5	80
Lead	**68**	**129,4**	**110**	**220**	50
Nickel	2,2	5,24	5,5	8,2	40
Vanadium	11	19	14	29	100
Zinc	23	70,2	78	97	250

Even the lowest result for lead among the sampled values is above the KM guideline value in the reference area.

5.2 Correlation

The correlations between the levels of Arsenic, Cadmium and Lead and several variables suspected to have an impact on the presence of these contaminants have been investigated using the Pearson Correlation in Excel. Arsenic and Cadmium have been included because the lab results show elevated levels that exceed the KM guideline value.

The reference area is not included in the correlation analysis, except for the northing and 5 of dry substance.

The results have also been plotted in order to illustrate possible correlations and spread of values.

Table 5.7: Summary of calculated Pearson correlations

Pearson correlation (r)	Lead	Arsenic	Cadmium
Distance to road	-0,295	0,018	0,126
Dry substance %	-0,343	-0,63	-0,557
Northing	0,228	-0,149	-0,279
Altitude	-0,223	0,222	0,393
Mor vs. Peat	-0,076	0,383	0,31

5.2.1 Distance to E45

Table 5.8: Pearson correlation: to E45

Lead	Arsenic	Cadmium
-0,295	0,0180	0,126
weak	no	no

The lead levels measured in the three profiles have a weak correlation to the distance to the road E45 while arsenic and cadmium have none. In Figure 5.6 lead levels for the three profiles plotted against distance to the road E45. A trend line is also inserted, demonstrating the negative correlation.

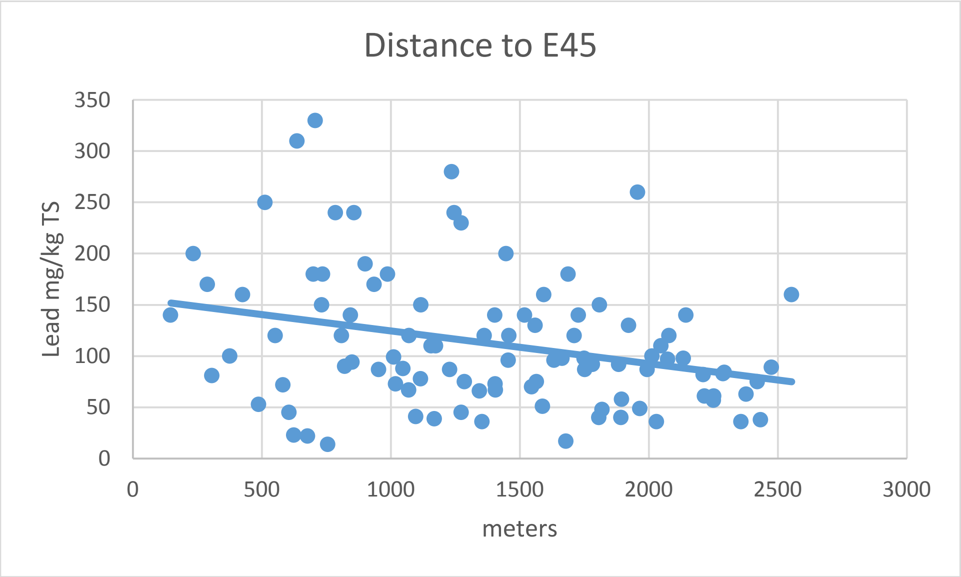

Figure 5.6: Lead levels found in the three profiles plotted against their distance to the road E45.

5.2.2 To % dry substance

Arsenic shows a strong negative correlation to % of dry substance in the sample. Cadmium and lead also show correlations but to a slightly weaker degree.

Table 5.9: Pearson correlation: to % dry substance for the three profiles and the reference area.

Lead	Arsenic	Cadmium
-0,352	-0,633	-0,567
Weak	Strong	Moderate

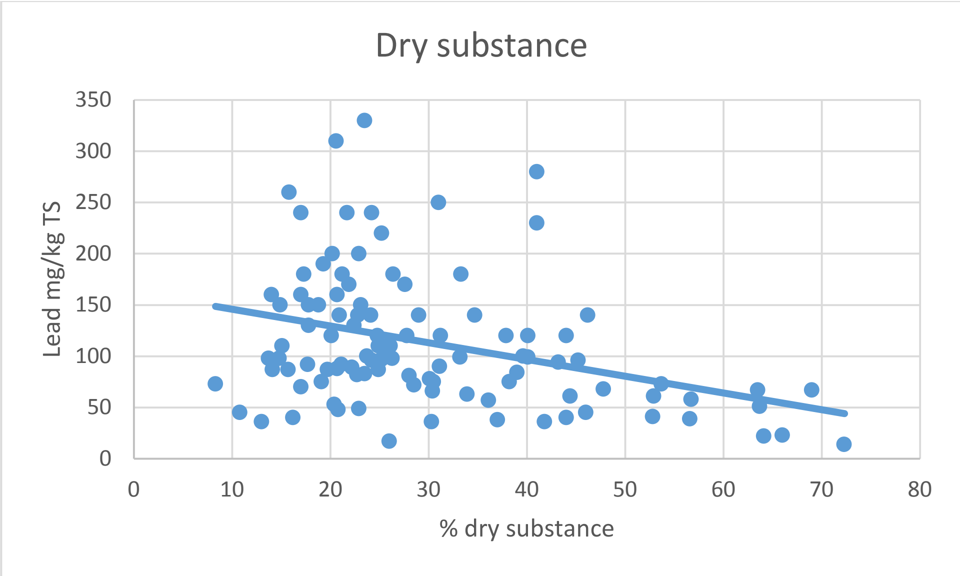

Figure 5.7: Lead level correlation to % dry substance, for the three profiles and the reference area.

5.2.3 To northing

Lead and cadmium show a weak correlation to the road, positive for lead and weal for cadmium.

Table 5.10: Pearson correlation: to northing for the three profiles and the reference area.

Lead	Arsenic	Cadmium
0,196033508	-0,181448727	-0,163453301
weak	no	no

In Figure 5.8 the four sample areas are easliy distingishable, the correlation between lead levels and northing is clarified with the inserted trendline.

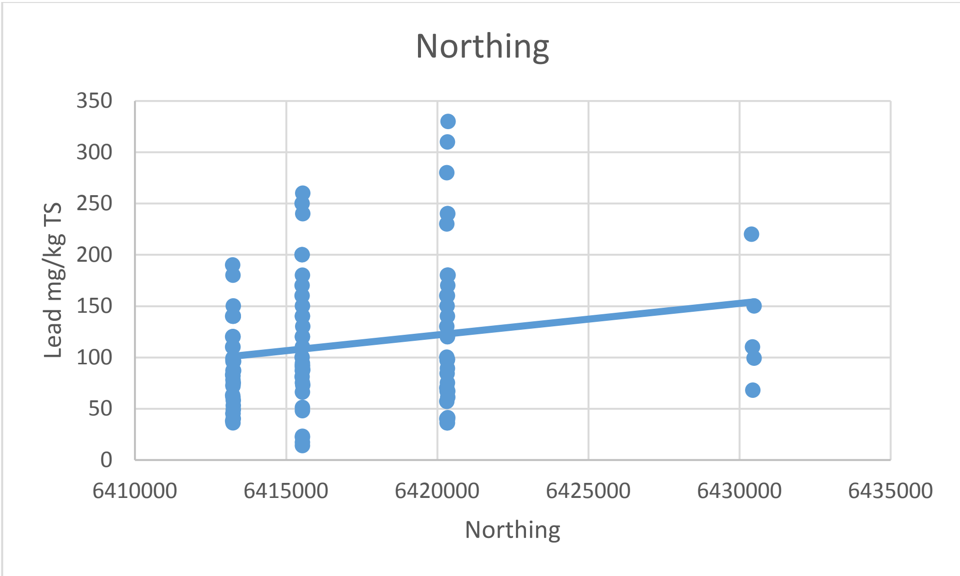

Figure 5.8: Lead levels correlation to Northing coordinates, the three profiles and the reference area.

5.2.4 To elevation

All three metals, lead, arsenic and cadmium show a weak correlation to elevation. For arsenic and cadmium the correlation is positive but for lead it is negative, meaning the greater the altitude the lower the lead level.

Table 5.11: Pearson correlation: to elevation

Lead	Arsenic	Cadmium
-0,222875827	0,221555371	0,393117261
weak	Weak	weak

Figure 5.9 shows the negative correlation of lead to altitude.

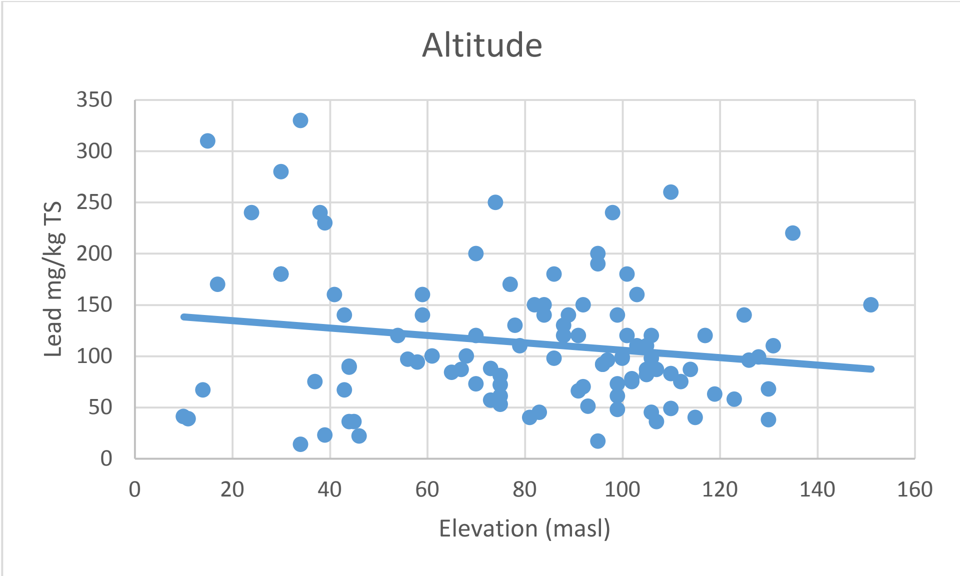

Figure 5.9: Lead levels vs. Elevation

5.2.5 To soil type

Both arsenic and cadmium show a weak correlation to the soil type while lead shows no correlation. In Figure 5.10 the distribution of lead levels for mor and peat is shown, demonstrating how little they differ.

Table 5.12: Pearson correlation: to soil type

Lead	Arsenic	Cadmium
-0,0756	0,383	0,310
no	weak	weak

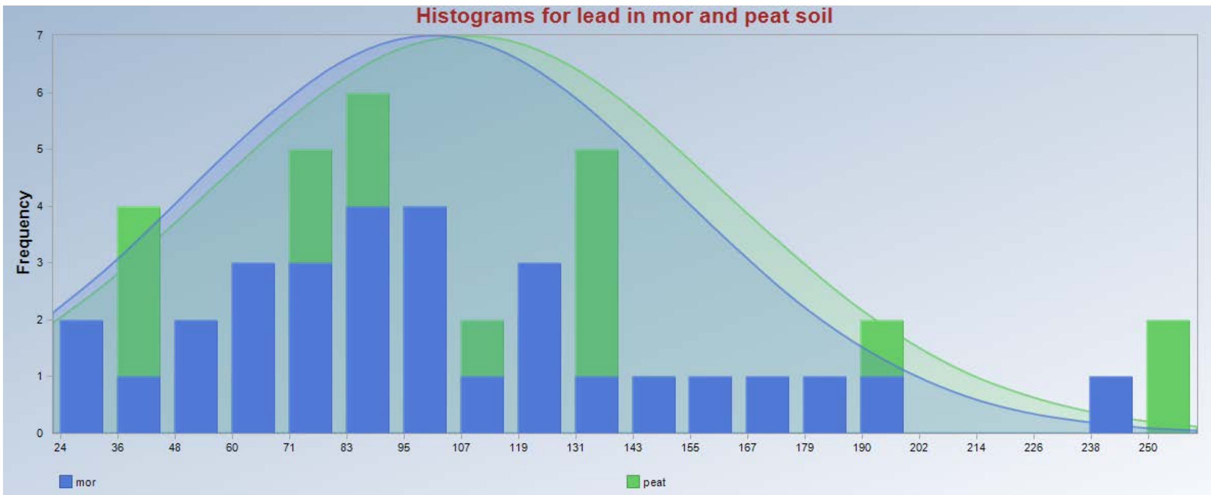

Figure 5.10: Comparison of lead level distribution between the two predominant soil types.

5.3 ANOVA

The ANOVAs for lead, arsenic and cadmium were performed with the null hypothesis that there is no significant difference in the means between the three profiles. A significance level of $\alpha = 0.05$ was used. The data for each profile is assumed to be normally distributed with equal variance.

5.3.1 Lead

The result of the ANOVA between the three profiles for lead can be seen below in Figure 5.11. With a p-value of 0.059 we fail to reject the null hypothesis. However, the low p-value indicates that it may be relevant to assume that there is some difference in lead content between the profiles.

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Surte	33	3034	91.93939394	1616.246212
Bohus	33	3770	114.2424242	4325.814394
Nödinge	33	4295	130.1515152	6645.632576

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	24317.59596	2	12158.79798	2.897782255	0.059984	3.091191
Within Groups	402806.1818	96	4195.897727			
Total	427123.7778	98				

Figure 5.11 ANOVA result for lead levels between profiles

5.3.2 Arsenic

The result of the ANOVA between the three profiles for arsenic can be seen in Figure 5.12. With a p-value of 0.33 we fail to reject the null hypothesis.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Surte	33	317.7	9.627272727	14.24204545
Bohus	33	309.7	9.384848485	15.23070076
Nödinge	33	278.1	8.427272727	6.382045455

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	26.57292929	2	13.28646465	1.111689459	0.3332	3.091191
Within Groups	1147.353333	96	11.95159722			
Total	1173.926263	98				

Figure 5.12: ANOVA result for arsenic levels between profiles

5.3.2.1 Cadmium

The result of the ANOVA between the three profiles for cadmium can be seen below in Figure 5.13. With a p-value of 0.019 we reject the null hypothesis. It can be safely assumed that Nödinge has significantly lower cadmium levels than the other two profiles.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Surte	33	20.82	0.630909091	0.061164773
Bohus	33	20.98	0.635757576	0.257537689
Nödinge	33	13.46	0.407878788	0.043110985

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.118642424	2	0.559321212	4.637648629	0.011949	3.091191
Within Groups	11.5780303	96	0.120604482			
Total	12.69667273	98				

Figure 5.13: ANOVA for cadmium levels between profiles

5.4 Mapping and Interpolation

The results of the interpolation of lead levels from ordinary kriging are presented below. The mapping was only conducted for lead, as it is the contaminant of primary concern of this thesis.

5.4.1 Correlation Modeling

A summary of the correlation modeling from SADA can be seen below in Figure 5.14: Correlation modelling input 5.14. A spherical model was assumed, with a range of 2000m, and a contribution and nugget of 4500 and 2253 mg/kg TS respectively. Only a major axis was considered, in the west-east direction.

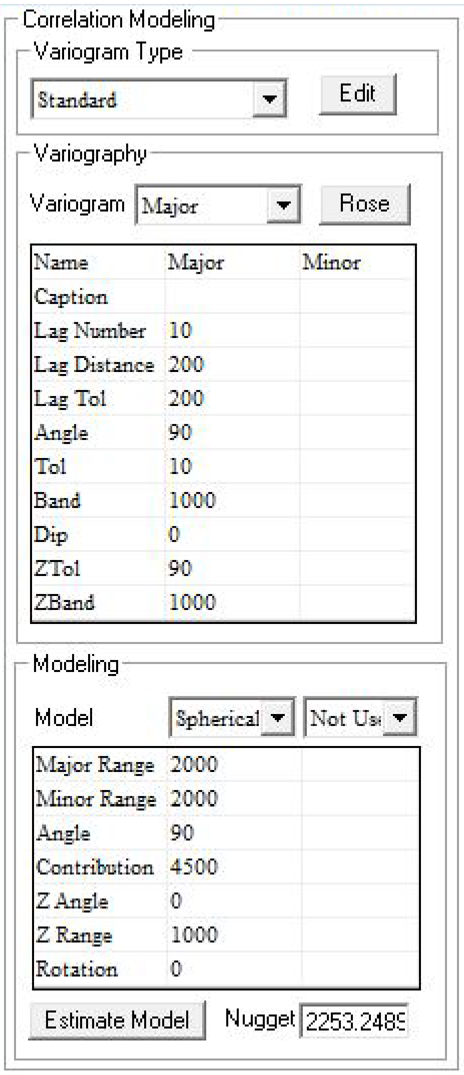

Figure 5.14: Correlation modelling inputs (SADA, 2013)

The resulting semi-variogram for all the data points is seen in Figure 5.15.

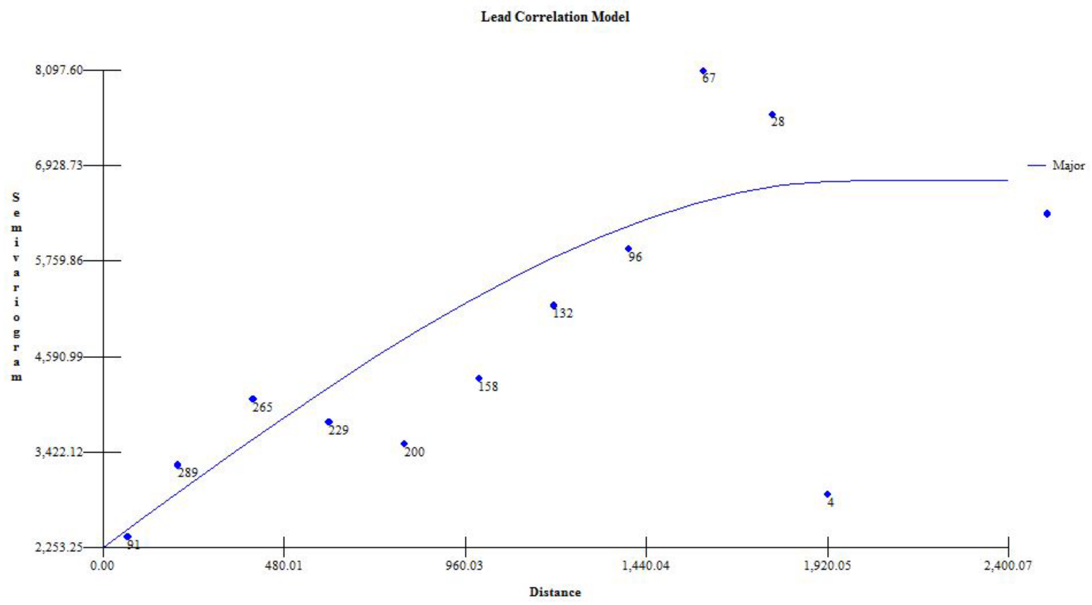

Figure 5.15: Modelled Semi-Variogram (Spherical) (SADA, 2013)

5.4.2 Surte

Figure 5.16 shows the resulting output from SADA for the interpolation of the Surte profile. The KM limit of 50mg/kg TS is labeled as dark blue. SADA has interpolated a large portion of the western end of the profile in green (80-150 mg/kg TS), which is mostly found on a plateau between two steep west facing slopes. Much of the eastern end has been interpreted as being quite close to 50mg/kg TS.

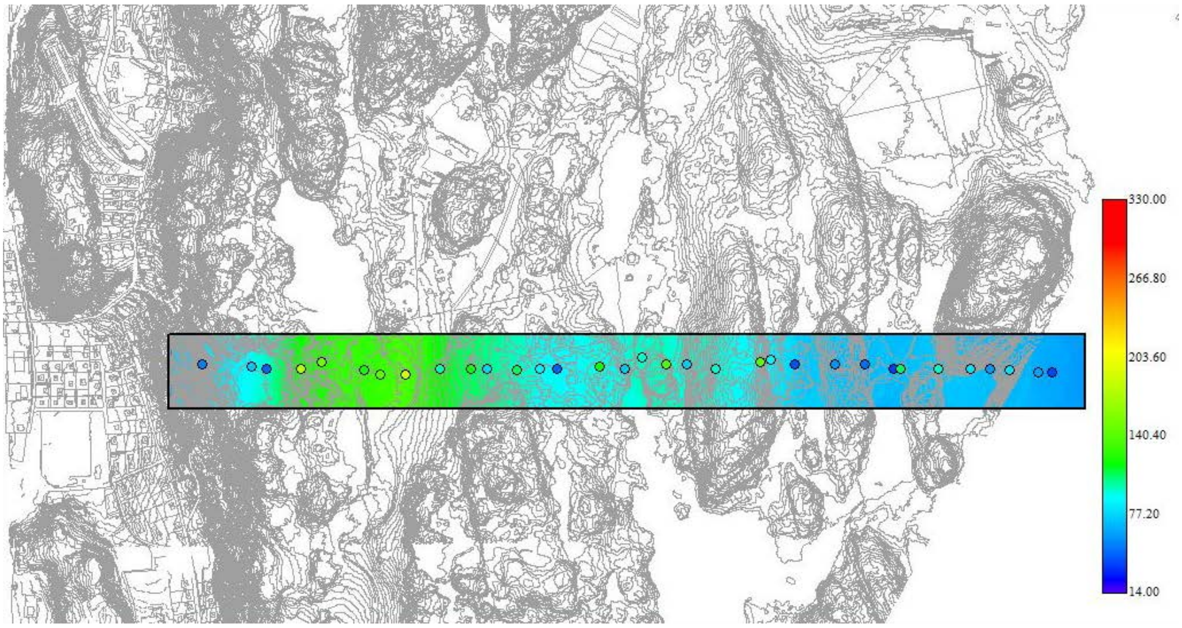

Figure 5.16: Lead interpolation map for Surte (SADA, 2013)

5.4.3 Bohus

Figure 5.17 shows the resulting output from SADA for the interpolation of the Bohus profile. The KM limit of 50mg/kg TS is labeled as dark blue. Most of the profile has been interpolated as green (80-150mg/kg TS). In the western part of the profile, from around 500 to 1000m, SADA has interpolated quite low values of less than 70mg/kg TS. This section cuts through a large valley where the sampled soil was mainly silt or clay.

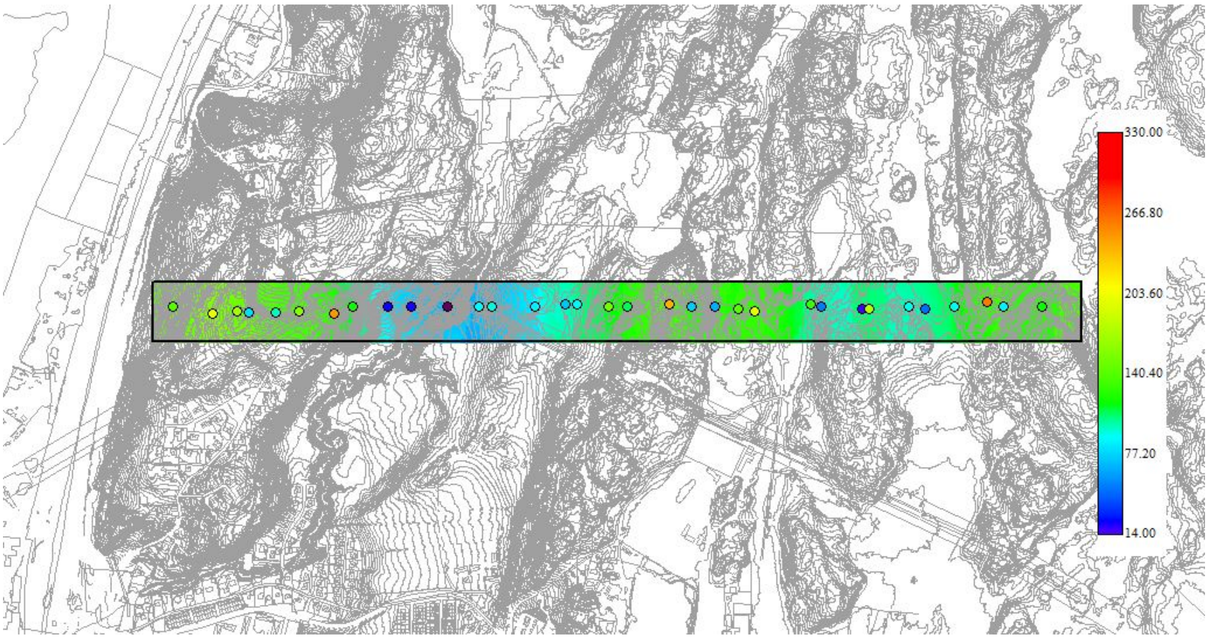

Figure 5.17: Lead interpolation map for Bohus (SADA, 2013)

5.4.4 Nödinge

Figure 5.18 shows the resulting output from SADA for the interpolation of the Nödinge profile. The KM limit of 50mg/kg TS is labeled as dark blue. Nödinge had the highest lead levels of the three profiles with very high levels sampled in the western end of the profile. The westernmost ridge, closest to the town and the E45, is interpolated as yellow and orange (250-270 mg/kg TS). Much of the rest of the profile is interpolated as green (around 140mg/kg TS).

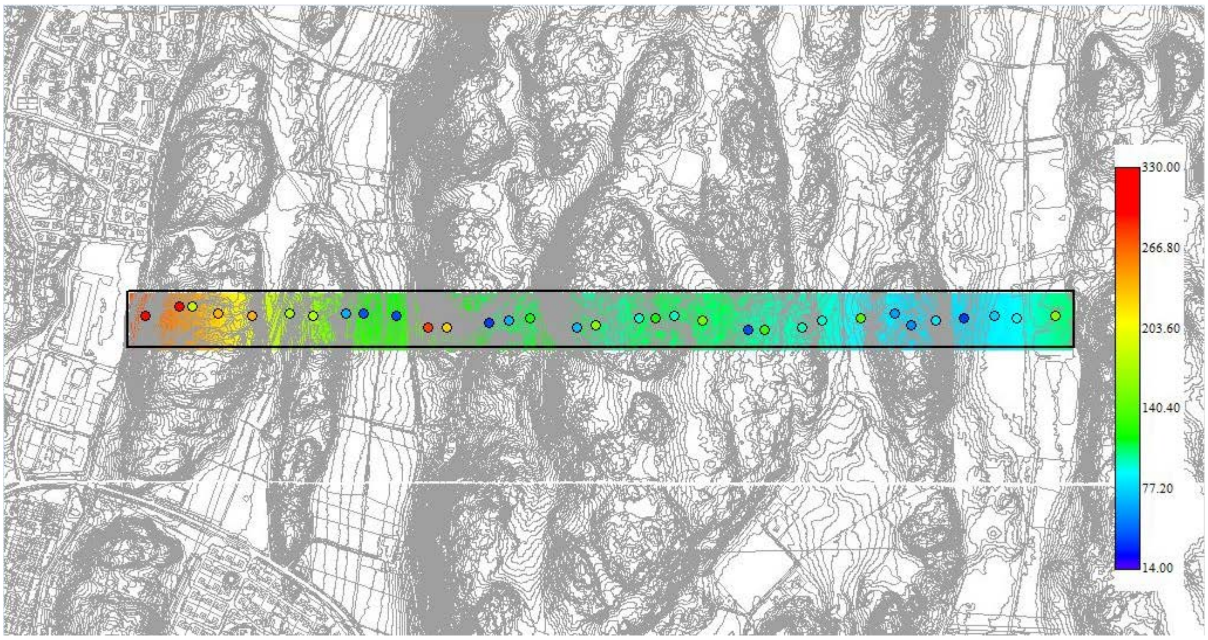

Figure 5.18: Lead interpolation map for Nödinge (SADA, 2013)

5.5 Human health risk assessment

Comparing with the guideline values, using either generic or site-specific values, is one way to make a human health risk assessment. The mean for all three profiles as well as the reference sample far exceed the generic KM guideline value for lead (50mg/kg TS). Bohus, Nödinge and the reference area also exceed the site specific guideline value (100mg/kg TS), while Surte is quite close to this limit with a mean of 92mg/kg TS. The resulting assessment is that these areas are not fit for sensitive land use, like housing, without remediation.

5.6 Comparison with Previous Study in Skårdal Skans

A comparison of the results to those of the previous study in Skårdal Skans can be seen in Figure 5.19. It can be seen that the background results from Skårdal Skans, outside the shooting range, are in line with the current results.

	Samples Analyzed	Min	Median	Mean	Max
Skårdal Skans					
Total of Planned Area	95	3	210	3665	150000
A. Area close to Shooting Range	77	3	270	4490	150000
B. Outer Area	18	42	101	134	310
Ale					
Surte	33	36	89	92	190
Bohus	33	14	94	114	260
Nödinge	33	36	100	130	330
Reference	5	68	110	129	220

Figure 5.19: Comparison of the results to previous study of Skårdal Skans (mg/kg TS)

6 Discussion

A discussion of the methodology, results, and interpolations are presented here. In addition, risks to human health, possible sources of error, and the lead sources/transport are discussed.

6.1 Methodology

A larger number of profiles would have given more insight into the contamination throughout more of Ale municipality. By limiting the investigation to the three profiles chosen, however, a better sampling resolution was achieved, as well as better study of any west-east patterns. The three profiles have a good south-north range, and lie in, what could be said as, the most industrial part of the municipality. Further research could involve looking at similar profiles north of Nödinge, and, if possible, to the west of the E45.

One of the challenges in selecting the location of the chosen profiles was to find accessible west-east profiles uninterrupted by roads and buildings. This was to allow for interpolation of the results throughout the profile. Finding additional profiles without interruption at reasonable north-south intervals might prove to be difficult.

The initial intended sampling locations were plotted in a straight line at 90°. While this enabled good analysis for the effect on distance away from the E45 and industry, it was quite difficult in practice to achieve perfect sampling in a straight line. The accuracy to the intended locations was quite good, as observed from GPS data, however there is some error there. In places, the variation in soil type within the area of the sampling location was quite high, and some bias or systematic error could have resulted from choosing which soil to extract the sample from.

The soil samples were taken to a depth of 10cm, as was done in the study in Skårdal Skans. Taking the samples at a greater depth would likely have yielded significantly different results. It should be noted however that in many locations the soil cover was very thin, and sampling at a depth more than 10-15cm would not have been possible. In addition, investigating the concentrations at a low depth gives more insight into the risk to human health should development in the areas go forward.

The classification of the sampled soil was done in a very general, observational manner. Distinction between the forest mor soil and the peat areas was at times difficult, likely due to large differences in the soil water content between areas. A more objective method of looking at soil type could have been performed, such as measuring the organic content of each sample.

6.2 Results

In all three of the profiles, as well as in the reference samples, the lab results showed concentrations above the generic KM guideline value (50mg/kg TS). In addition, average levels were higher than the site-specific guideline of 100mg/kg TS decided upon by Sweco in the study of Skårdal Skans. The areas in which these samples have been taken are regarded as non-contaminated, i.e. areas with background levels of heavy metals and other contaminants. While the results are quite alarming at first glance, the lead levels are not significantly higher to what was found to be the range in mor soil in Sweden (30-100mg/kg TS) (Johansson, et al., 2001), and should perhaps not be so surprising given the organic nature of the soil.

6.2.1 Elevation, Northing and Distance to E45

The calculated Pearson correlation to the road E45 was lower than expected, a weak negative correlation for Lead and no correlation for Arsenic or Cadmium. Even though the correlation is weak it's there, meaning the road has had some effect on the presence of lead in the soil. The further away from the road, the lower the lead levels in the soil.

A weak correlation exists between lead levels and northing, with higher levels of lead further north. It could have been expected that southern levels would be higher, with closer proximity to Gothenburg. This could suggest some effect from local industry along the E45 together with the prevailing winds from the south-west. The Nödinge and Bohus profiles could be more affected by the local industry than the southern Surte profile.

For all three metals there is a weak correlation to the elevation of the samples. Lower elevation gives lower levels of arsenic and cadmium but higher values of lead. With differing correlations amongst the different metals, it's difficult to draw any clear conclusions. It would have been expected that higher concentrations would be found at lower elevations, based on the flow with water. The result could suggest however that not much transport of the metals occurs once deposited, since the metals are so strongly adsorbed to the organic soil. The correlation could also be influenced by the fact that the mineral soil, with low concentrations, was sampled in the lower valleys.

The high concentrations found throughout are likely a result of long range deposition. The low correlation to the distance to the road speaks for this and there doesn't seem to be any other point source responsible. In fact, very high median and mean values of lead were found in the reference area, much further away from the road than the three profiles. Since long range deposition would affect a larger area it can be assumed that similar levels can be found in the natural soils in other municipalities in the region.

While the results speak for long range deposition, it's likely that several different transport pathways are at play, which are quite complex. Although local pollution from industry and highways are likely a factor, they are perhaps masked by the contribution of long-range transport. Another possibility is that the 2km west-east profiles were too short to see any change in deposition. The reference samples were taken much further to the east, but only 5 samples were taken, which is too few to draw any conclusion to the effect on moving further to the east. More samples taken further east of Ale could be suggested.

The results are consistent with the background results from Skårdal Skans, further emphasizing the argument that the source is more likely long-range transport, and that similar levels could be found throughout Ale. If this is the case, it could also be argued that much of western Sweden is in a similar situation.

The previous studies made of the Skårdal Skans area as well as this thesis investigate levels in the top soil level. If the source of lead is long range deposition that is bound in the top soil level with high organic content it is probable that the levels decrease with depth, however in large parts of these areas the soil cover is very thin, sometimes non-existent in the large areas of exposed bedrock.

6.2.2 Soil Type and % Dry Substance

There was no correlation between soil type and lead levels. The two main soils sampled were peat and mor. Both peat and mor have a large percentage of organic content, making it easy for lead to bind to the soil, and it seems that the differences between soil types are negligible in this case. Although there is some uncertainty in the soil type between samples, the levels are consistently high throughout, and seem to be unrestricted by the soil type.

The strongest correlation was found between the percentage of dry substance and the concentrations of Arsenic. There is also a weak correlation between lead levels and the percentage of dry substance in the sample, with dryer soils showing lower levels of lead. The transportation and accumulation process for lead likely follows that of water, leading to higher concentrations in the small organic soil marshes between outcrops. A similar correlation could perhaps be seen to organic content, with metal concentrations increasing with organic content, however organic content was not measured in the lab analysis.

6.2.3 ANOVA

The result of the ANOVA tells us that there is no significant difference in the mean lead levels between profiles. This fits with the weak correlations seen with respect to northing and distance to E45. The probability of a type II error is high, however, with a p-value of 0.059.

For cadmium, we could reject the null hypothesis, and can assume that at least one profile mean is different. The mean concentration for Surte and Bohus are quite close (approx. 0.63mg/kg TS), higher than that of Nödinge (0.4 mg/kg TS). Since the Bohus and Surte profiles are closer to one another than to Nödinge, it could be suggested that, at least for cadmium, the Bohus and Surte profiles are affected by a local point source.

6.2.4 Spatial Correlation and Interpolation

The resulting empirical semi-variogram (Figure 5.15) shows fairly good spatial correlation. The nugget effect is quite high, but a clear increase in semi-variance with distance can be seen. The plot does however lack a clear range or sill. This is likely due to the very small amount of paired points at a separation distance of close to 2km, which perhaps only coincidently have quite low semi-variance between them.

Another observation from the empirical semi-variogram is that there seems to be a "cycle" in the spatial correlation. The semi-variance increases up to around a distance of 500m but then decreases down towards 800m of separation. Interestingly, this can be seen in the interpolations in Figures 5.16 to 5.18. In the Surte profile in Figure 5.16 for example, the levels in the first three samples are closer to those located more than 500m to the east, separated with a region shown in green. This cycling could be explained by the nature of the terrain in Ale, with parallel north-south ridges and the valleys between them. The mentioned green area, with higher lead levels, is a flatter plateau with different soil and forest characteristics than the slopes to the east and west. Similar patterns can be seen in the Bohus and Nödinge profiles.

Despite very little correlation seen from statistics, patterns are clearly seen from the kriging and interpolation mapping in SADA. No correlation with elevation, or soil type was observed, however the interpolations clearly show that some of the valleys and some of the ridges have significantly higher or lower levels. The interpolation for Bohus clearly models a dip in levels from 500-1000m within a large valley where mineral soil was found. The interpolation for Nödinge showed very high levels in the first ridge, which could give indication of a very local source. The interpolation maps show much more than the simple statistics, however they only give very local insight, and don't show patterns over Ale as a whole.

Some error is observed in the interpolations map outputs from SADA. One example is in the Nödinge profile, where a clay valley about 500-600m into the profile was modelled as having quite high lead levels (approx. 100mg/kg TS), whereas it could be reasonably assumed, based on the topography, and the two sampled concentrations, that much lower levels are found throughout the valley. This could be explained by the weighting that the kriging placed on the next nearest samples, which had very high concentrations. It could also be influenced by the high nugget effect of the modeled semi-variogram. The nugget effect is approximately one third of the sill, leading to higher, more averaged estimations. The high nugget effect could be due to sampling error or high small-scale variability in the data.

Ordinary kriging was performed, assuming that the data as a whole was normally distributed, however the Nödinge data alone was not normally distributed at 0.05 significance level. This was assumed so that kriging could be performed for the whole dataset, and allow for an analysis of the overall picture, knowing that each profile is interpolated in the same way. Due to this, it was not possible to perform a lognormal transformation in SADA for the nödinge profile. A spherical model was fit to the semi-variogram. Using a gaussian or exponential model would have yielded different variogram shapes, and thus different weightings on the sampled points, but likely wouldn't have changed the overall patterns observed.

6.2.5 Human health

A very simple human health risk assessment was made based on mean lead concentrations in each profile. The mean concentrations in each profile were above the generic KM guideline value and even above the site-specific value in three of the areas. It is therefore not advisable to build residential housing at or in the surroundings of any of the investigated areas without any remediation or containment of the soil first.

The expected sensitive, residential land use of the areas means that people would be exposed to the soil frequently, and over a lifetime. Multiple exposure pathways to the soil need to be considered with residential land use, which includes ingestion, inhalation, and dermal contact. Exposure to children is also very important to consider here, since they likely are most exposed and most at risk to contamination from heavy metals.

The performed risk assessment was done very roughly and quickly, and a more thorough investigation of risks should be performed with expert opinion. There are many questions unanswered with respect to the exposure to the lead and heavy metals from the sampled organic soil. The majority of the soil sampled was highly organic, with high water content, and better retention of the contamination could be expected. The spreading of soil dust is unlikely with such high water content, in addition to the fact that the soil is often covered by a layer of forest litter of leaves and pine needles. If the metals accumulate and bind so well to the organic soil then it can be assumed that not much is leached out with water, reducing potential exposure and intake.

No study of lead speciation in the organic soil was studied and therefore it is unclear about the bioavailability of the lead and metals in the sampled soil. Further study of this is required to fully assess the risk from the contamination in the investigated areas. Expert judgement should be sought in a more involved risk assessment as well as for decision making processes concerning remediation of the areas.

Remediation could depend on the chosen building methods in the areas. While high concentrations were found, the thickness of the soil cover was very low, resulting in not so high total amounts of lead. The removal of the top soil is probably not so difficult, which would make remediation much easier. Typical building methods would likely involve the removal of top soil, and therefore, aside from proper disposal of the contaminated soil, not much extra effort or costs would be required. Housing built on stilts on the low soil cover however would require the extra cost of remediation.

6.2.6 Comparison to Previous Study

As mentioned previously, the results of this study are in agreement to what was found from the Sweco investigation in 2011. The distribution of lead concentrations in the outer area of Skårdal Skans is close to the distribution for the Nödinge profile, with very similar min, mean and max concentrations. It can be said that the results from each area do not differ greatly, and that the results of this study confirm the high background levels from the previous study. The results of this study are also in agreement with the results given by Johansson et al. (2001) for lead levels in mor soil (30-100mg/kg TS).

It could be expected that such soil contamination is found in much of western Sweden, with similar organic soil conditions and topography. This begs for a re-examination of the SEPA guideline values or calls for new guidelines specifically for organic soil types.

7 Conclusions and Recommendations

Sampling of three profiles with good sample resolution and west-east range was achieved in the study. This enabled analysis of the effect of several factors including the distance of the samples to the E45 highway. By choosing profiles uninterrupted by roads or buildings, and solely from natural forest soils, interpolation using ordinary kriging could be performed. It would be recommended in further study to investigate additional profiles to the north and to the east to get a better picture of the extent of contamination.

The laboratory results showed mean lead concentrations above the KM guideline values in all three profiles as well as in the sampled reference area. Additionally, lead levels in three of the four areas had mean concentrations above the site-specific guidelines for sensitive land use set by Sweco in the study of Skårdal Skans. Arsenic and Cadmium concentrations were also found to exceed KM guideline values.

While the results are alarming, they are in line with what was found in the previous study and from literature for organic soil. It could therefore be assumed that similar contamination can be found outside of Ale kommun, elsewhere in southwestern Sweden. The results serve as a reminder that natural forested areas should not be assumed to be free from contamination. A review of the SEPA guidelines as well as creation of new guidelines specifically for organic soil would be recommended

The correlation analysis did not yield any clear results of patterns of the lead contamination. Weak or no correlation is seen for the effect of distance to the E45 highway, elevation, northing and soil type. The strongest correlation seen was to dry content, where a negative correlation exists. This is in line with the conceptualization of how the metals accumulate in the wet low lying areas in the terrain. A correlation analysis to organic content would be recommended for future study.

The results of the correlation analysis suggest that the main source of lead contamination in Ale is from long range deposition, since the soil concentrations are quite evenly spread throughout. This further emphasizes the need for an even wider investigation of background levels outside of Ale, since it is likely not simply a local issue.

No significant difference between profile means for lead or arsenic is observed. A significant difference is seen for Cadmium however, with lower concentrations in the Nödinge profile than in Bohus or Surte. The presence of a point source for cadmium affecting Bohus and Surte could be argued, although further investigation would be required.

Fairly good spatial correlation was seen in the data which allowed for ordinary kriging using a spherical model. The resulting interpolation maps show some patterns that could not be observed from the simple statistical analyses. Cycling in the empirical variogram can be seen in the maps, and can be explained by the topography in Ale, with the profiles cutting perpendicularly across several north-south ridges. The mapping of concentrations clearly outlines the least and most contaminated areas which could aid in further study or remediation.

It can be concluded from the simple human health risk assessment that remediation of the sampled areas is required prior to residential development. It is unclear however how the exposure, lead speciation, and bioavailability differ for the sampled organic soil, which can be recommended for further study. A more in-depth risk assessment should be performed with expert opinion on the potential risks with residential development.

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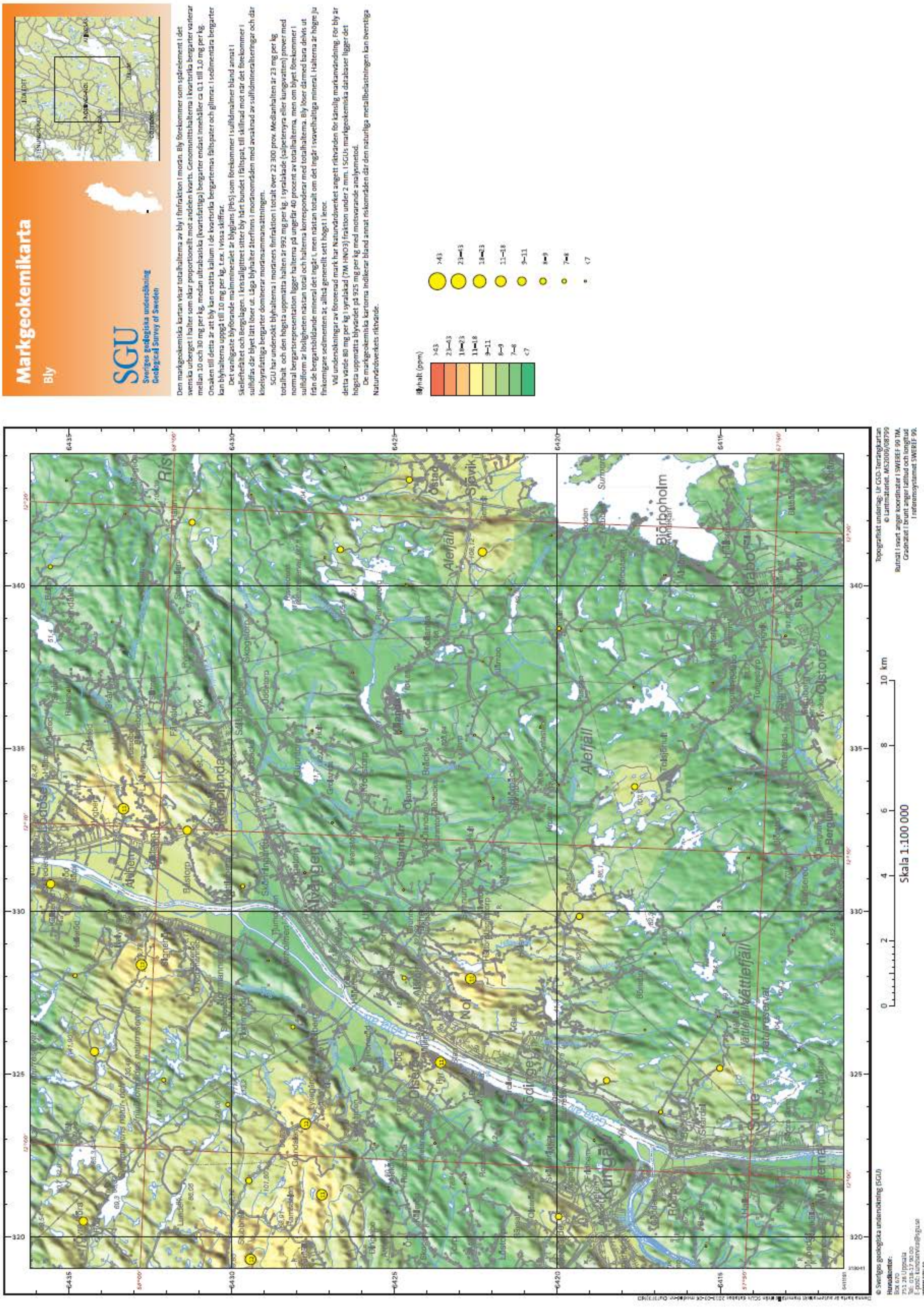
Appendix I - Map of Lead Levels, Ale

Map of lead levels in mineral soil. Note: Not to scale. (SGU, 2013)



Appendix II - Laboratory Analysis Reports

Please find the full set of laboratory results on the attached CD.

Sample Naming:

Surte: S1 - S33 (west-east)

Bohus: B1 - B33 (west-east)

Nödinge: N1 - N33 (west-east)

Reference Area: R1 - R5