Assessment of Remediation by Vacuum Excavation to Preserve Amenity Trees

Application and Evaluation of a Cost-Benefit Analysis Method

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

ROGER LINDQVIST

Department of Civil and Environmental Engineering
Division of GeoEngineering
Engineering Geology Research Group
CHALMERS UNIVERSITY OF TECHNOLOGY

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Department of Civil and Environmental Engineering
Division of GeoEngineering
Engineering Geology Research Group
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Remediation by vacuum excavation at the green space, Beckholmen, Stockholm. Photo: Sweco (2011c).

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ABSTRACT

An environmental goal set by the Swedish parliament is that all contaminated sites in Sweden, considered as acute health risks, should be remediated by 2050. The process to prioritise between sustainable remediation methods has long been considered a difficult task. Within the *Sustainable Remediation Programme*, initiated by the Swedish Environmental Protection Agency, a cost-benefit analysis method able to prioritise between remediation alternatives was developed. This method was applied to assess the performance of remediation by vacuum excavation for a project at Beckholmen, Stockholm. Vacuum excavation is a relatively unpractised remediation method that aims at preserving valuable amenity trees. The largest independent monetised benefit applying vacuum excavation was the value of the saved trees. However, the results from the cost-benefit analysis show a negative net present value. A sensitivity analysis using Monte Carlo simulation shows that the uncertainty of the results is relatively insignificant. On the other hand, it can be concluded that additional underlying uncertainties, not included in the uncertainty analysis, most likely contribute to a larger degree of uncertainty than what the statistical distributions of the net present value exhibit. The additional uncertainties mainly originate from the benefit valuations. Three benefits have not been monetised. The size of these benefits is uncertain. However it is concluded that the net present value of the vacuum excavation is probable to be positive, which in turn indicate that the remediation methodology has been beneficial in comparison with not taking any measures at all.

Key words: Cost-benefit analysis, Beckholmen, remediation, tree appraisal, health risks, contaminated soil, vacuum excavation, Monte Carlo simulation

Bedömning av sanering med vakuumsugning för att bevara värdefulla träd
Tillämpning och utvärdering av en kostnads-nyttoanalysmetod
Examensarbete inom Infrastructure and Environmental Engineering
ROGER LINDQVIST
Institutionen för bygg- och miljöteknik
Avdelningen för geologi och geoteknik
Teknisk geologi och geoteknik
Chalmers tekniska högskola

SAMMANFATTNING

Den svenska regeringen har definierat ett miljömål inom vilket alla förorenade platser som utgör en akut hälsorisk ska vara sanerade innan 2050. Att prioritera mellan olika saneringsmetoder har länge ansetts vara en svår uppgift. Inom Naturvårdsverkets kunskapsprogram *Hållbar sanering* har Rosén et al. (2008) utvecklat en metod för kostnads-nyttoanalys som syftar till att prioritera mellan olika saneringsmetoder. Denna metod har används för att bedöma utförandet av en sanering som utförts med vakuumsugning på Beckholmen i Stockholm. Vakuumsugning är en relativt obeprövad saneringsmetod som syftar till att rädda värdefulla träd. Den enskilt största nyttan av att använda vakuumsugning var värdet av de räddade träden medan det totala resultatet av kostnads-nyttoanalysen visar ett negativt nettonuvärde. Samtidigt visar en känslighetsanalys genomförd med Monte Carlo-simulering att resultatets osäkerheter är obetydliga. Å andra sidan har slutsatsen dragits att ytterligare underliggande osäkerheter föreligger, vilka sannolikt bidrar till en större osäkerhet än vad den statistiska fördelningen av nettonuvärdet visar. De ytterligare osäkerheterna har huvudsakligen sitt ursprung i nyttovärderingarna. Tre nyttor kunde inte moneteriseras och dess storlek är osäker. Hur som helst har slutsatsen dragits att nettonuvärdet av vakuumsugningen sannolikt är positiv, vilket i sin tur indikerar att saneringsmetoden har varit till nytta i jämförelse med att ingen saneringsåtgärd hade vidtagits.

Nyckelord: Kostnads-nyttoanalys, Beckholmen, sanering, trädvärdering, hälsorisker, förorenad mark, vakuumsugning, Monte Carlo-simulering

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Preface by the author

This Master's thesis was the final part of my civil engineering studies at Chalmers University of Technology. The study assesses a remediation project in Stockholm, Sweden, where vacuum excavation has been applied to preserve amenity trees. For this purpose a cost-benefit analysis method has been used. The work was carried out from June to October 2012 in cooperation with Sweco Environment AB (Sweco).

First and foremost, my deepest gratitude goes to my supervisors Professor Lars Rosén, and Assistant Professor Jenny Norrman, at Chalmers University of Technology, for valuable guidance and advice.

I extend my thanks to PhD student Johan Östberg at the Swedish Agricultural University, and consultant Örjan Stål at the firm VIÖS AB, for sharing their knowledge within the field of tree appraisal.

I am also indebted to the personnel at the Department of Contaminated Land at Sweco in Stockholm. I specially thank Christer Egelstig, my supervisor at Sweco, for always answering my e-mails, often within less than one hour, and providing all materials wanted. I would also like to acknowledge Charlotte Gyllenhammar, Johanna Åberg, and Niklas Ekberg for many valuable discussions that helped me understand my area of research better.

Finally, I wish to express my great appreciation to Hanna Björklund, and my opponent Erik Andersson, for their valuable and constructive suggestions during the final completion of this thesis.

Stockholm October 2012

Roger Lindqvist

Preface by the supervisors

Performing a cost-benefit analysis (CBA) for the purpose of evaluating the societal profitability of different remediation alternatives typically entails several difficulties since some of the costs, and in particular many of the benefits, are non-market goods and services. Although there are methods for valuing such goods and services, it is in general difficult to quantify some of those values. However, an increasing demand on these types of analyses makes it important to apply CBA in real cases to be able to evaluate the advantages as well as the limitations associated with cost-benefit analyses.

In his master's thesis work, Roger Lindqvist has carried out a CBA for evaluating different remediation alternatives at Beckholmen. He has applied two different valuation methods for estimating the economic value of trees and evaluated the practical use of CBA as a decision support tool for selecting remediation alternatives.

Roger has worked in a highly independent way, identifying what to analyse, seeking information and pushing the work forward. It has been a true pleasure to supervise you in this work. We wish you all the best in the future!

Jenny Norrman
Main supervisor

Lars Rosén
Assistant supervisor and examiner

List of Abbreviations

CBA	Cost-Benefit Analysis
CTLA	Council of Tree & Landscape Appraisers
D&D	Dig-and-Dump
EPA	Environmental Protection Agency
MCS	Monte Carlo Simulation
MSEK	Million Swedish Kronor
MVUT	the model for Monetary Valuation of Urban Trees
NPV	Net Present Value
SADA	Spatial Analysis and Decision Assistance
SEK	Swedish Krona
SITA	SITA Sweden AB
Sweco	Sweco Environment AB
TFM	Trunk Formula Method
VE	Vacuum Excavation

1 Introduction

The Swedish government has adopted an environmental policy with the overall goal to provide future generations with a society free from environmental problems. To be able to reach this, 16 national environmental goals have been set by the Swedish parliament. One of these is a Non-toxic Environment. A milestone of this goal is that all contaminated sites, considered as acute health risks due to direct exposure, should be remediated by 2050. This also includes sites that threaten important water or natural resources. The Swedish county administrations have estimated that there are more than 77,700 potentially contaminated sites in Sweden (NV, 2012). In total, the remediation costs for the 1,500 most contaminated sites are estimated to 60 billion Swedish krona (SEK). A large number of these sites are possibly dangerous to both human health and the environment (Rosén et al., 2008).

In total, about 1,350 remediation projects have been performed and reported in Sweden. Approximately 50% of these projects have been conducted by excavation and disposal of soil, which is normally referred to as "dig-and-dump" (D&D). It is the most commonly applied remediation method in Sweden. The second most common method is vacuum extraction. It is a technique where air is being injected into the soil by pressure. The air thereafter encapsulates and separates the contaminants from the soil material. Other methods include air sparging, soil washing, thermal desorption, and various filter techniques. However, these methods are much rarer, and more specifically applied (Helldén et al., 2006).

Any firm responsible for the remediation of a contaminated site must, on behalf of its client, ensure that the chosen approach is as cost-effective as possible, while meeting all environmental obligations (Day et al., 1996). The process of selecting an appropriate remediation method is always a site-specific decision, and there is often more than one suitable method to choose from (Bardos, 1994). Prioritising between sustainable remediation methods has long been considered a difficult task due to the lack of an easy and user friendly decision making tool. Within the *Sustainable Remediation Programme,* initiated by the Swedish Environmental Protection Agency[1] (EPA), Rosén et al. (2008) developed a cost-benefit analysis (CBA) method able to prioritise between remediation alternatives.

Stål[2] claims that if a contaminated site includes valuable amenity trees[3], that are required to be preserved, no conventional remediation method has so far been available. In 2002, a pilot project was carried out at Påskbergsgatan in Gothenburg, Sweden, where five oak-trees standing in contaminated soil were saved using vacuum excavation[4] (VE). It is a method that removes contaminated soil around the root system of a tree, similar to the function of a vacuum cleaner (Blom, 2002). In 2011 the problem of saving valuable amenity trees at a contaminated site was brought to the fore again, although, to a much larger extent than in Gothenburg.

[1] Naturvårdsverket in Swedish.
[2] Örjan Stål (CEO, VIÖS AB) discussing with the author on the 14th of June 2012.
[3] An amenity tree is a tree that is not grown or managed for its value as timber or other crop and that provide other benefits or values (Cullen, 2007).
[4] In Swedish this method is often referred to as "vakuumsugning" or "dammsugningsteknik".

1.1 Problem statement

Beckholmen is an islet located in the city centre of Stockholm, Sweden. It was long one of the most contaminated places in the country. The contamination was considered a health risk to people who live, work, or by other means occupy themselves at the islet. It also had a negative effect on Saltsjön, the lake surrounding the islet. Due to this, the Swedish EPA took the decision to grant funds to the Royal Djurgården Administration[5] for a remediation of Beckholmen. A Swedish engineering consulting firm, Sweco, was commissioned as project manager in 2011.

The outer parts of Beckholmen did not contain any valuable amenity trees. Consequently, it could be remediated by the well-known remediation method D&D. However, at the centre of Beckholmen, which is an elevated green space, an amenity tree population of 46 trees was present. It was considered valuable from an historical point of view. Thus, a remediation method able to save as many trees as possible was demanded. It was decided to apply the relatively unpractised method VE. It was, however, impossible to save all trees due to very high levels of contaminants at certain locations that exceeded guideline values. Furthermore, some trees were in a relatively bad condition, and were therefore taken down due to their low probability of surviving the stress from the remediation process. Altogether 23 trees were saved applying VE.

The total financial cost of the VE was considerably higher than traditional D&D. Hence, if all trees would have been taken down applying D&D, the remediation costs would have been significantly lower. Consequently, saving 23 trees came at an additional financial cost. Today, when the project is completed, those involved in the Beckholmen project ask themselves if this additional cost was worthwhile, and if the VE method should be applied again in future projects.

1.2 Purpose

The purpose of this thesis is twofold: (1) to test and evaluate the CBA method developed by Rosén et al. (2008); and (2) to contribute to existing literature on the performance of alternative remediation methods by determining whether or not VE was beneficial at Beckholmen.

1.3 Research questions

This thesis will target the following research questions:

- Is the CBA method by Rosén et al. (2008) an easy and user friendly decision tool for prioritising between remediation alternatives? Is it comprehensive enough? How certain are the results?
- Was it beneficial to remediate the contaminated soil at the green space by VE, in comparison to not taking any measures at all, and, would it have been more beneficial to apply D&D?

[5] Kungliga Djurgårdsförvaltningen in Swedish.

1.4 Limitations

This thesis will only consider one type of decision making tool to evaluate the performance of VE. CBA assesses the economic aspects of the different remediation alternatives to society. The economic aspect is however, only one of the three dimensions of what is commonly defined as sustainability. In order to identify a sustainable solution the ecological and socio-cultural dimensions should be included as well. This can be achieved with a more extensive decision support tool, for example multi-criteria analysis (Rosén et al., 2009).

Furthermore, only one case study has been conducted assessing the CBA method developed by Rosén et al. (2008). To get a representative basis for conclusions about the performance of a relatively extensive and complex decision tool, such as the current CBA method, numerous case studies are preferable.

1.5 Disposition

Chapter 2 is initiated by providing a presentation of the narrow field of previous literature available on VE. Thereafter, focus is put on CBA in general terms, and more specifically on the theoretical foundations of the method developed by Rosén et al. (2008). Next, Monte Carlo simulation, which is an important part of the methodology of this thesis, is presented. Finally, the chapter ends with a brief theoretical presentation of the extensive field of tree appraisal, focusing on the chosen methods.

Chapter 3 provides an informative background concerning the case study at Beckholmen. General information about the site and its contaminants is described. Last, the reference and remediation alternatives considered in the CBA are presented.

Chapter 4 describes the methodology used throughout the thesis. First the overall procedure of the CBA is given. Next, valuation methods considering both costs and benefits are described in detail. Last, the methodology of the sensitivity and distributional analyses is presented.

Chapter 5 shows the results of the case study.

Chapter 6 discusses and analyses both the applied methodology and the outcome of the results.

Chapter 7 concludes the thesis by answering the research questions.

Last, references are given in Chapter 8, after which appendices follow for details concerning figures and calculations.

2 Theory and Literature Review

2.1 Vacuum excavation

VE is a method commonly used for amenity tree treatment in Sweden. This is done by loosening and removing the upper soil layer around a tree. The gap is then filled with new and nutritious soil material. The aim of this approach is to extend the life length of amenity trees (Stål, 2004). Three examples of projects where this method has been applied in Sweden are Erikslustgatan in Malmö (Stål, 1998), Vaksala square in Uppsala (Stål, 2004), and Kungsbroplan square in Stockholm (Embrén et al., 2009). VE as a remediation method for trees standing in contaminated soil is claimed by Stål[6] to have only been used twice in Sweden: Påskbergsgatan, Gothenburg, in 2002; and at Beckholmen, Stockholm, during 2011/2012. When the method was applied in Gothenburg the aim was to save five oak-trees, which were standing in soil contaminated with lead, arsenic, copper, and cadmium. During four intense days approximately 60 m^3 of contaminated soil was removed by VE. Immediately after the excavation the gap was filled up with new and nutritious soil material. The VE method was concluded to be both suitable and satisfactory as a remediation method at Påskbergsgatan. The method was gentle towards the oak-trees, which did not suffer any harmful effects due to the remediation (Blom, 2002). According to Stål[7] the project in Gothenburg was not very extensive in terms of time and excavation volume in comparison with Beckholmen.

2.2 Cost-benefit analysis

The environment in which decisions must be made is more complex than ever before, and it is often desirable to achieve multiple objectives at once. Decision analysis is a way to handle decision complexity in a structured way (Keeney, 1982). One way to prioritise between different environmental projects is to measure the effect of each project on public welfare. A standard tool commonly used for public welfare calculations is CBA (Pearce et al., 2006).

CBA in civil and environmental contexts was first introduced in the 19th century. In 1808 Albert Gallatin, U.S. Secretary of the Treasury, recommended comparisons between costs and benefits in water-related projects. This resulted in water resource development receiving formal attention regarding returns on public spending. The Flood Control Act was released in 1936. It required evaluation of costs and benefits of all water resource projects in the U.S., which resulted in different guides and documents being produced. Besides providing practical guidance these publications encouraged academic interest (Hanley et al., 1993). In accordance with Eckstein (1958), the CBA techniques employed were related to the foundation of welfare economics. He critically investigated the techniques for benefit estimation within the field of water resource development using market information. Thus, at first water quantity was the primary concern, but as the U.S. dam construction business slowed down in the 1960s, focus began to turn to other issues (Eckstein, 1958). Clawson et al. (1966) emphasised the importance of both the valuation methods and the data required for measuring the environmental benefit in relation to outdoor recreation possibilities. As a result, interest expanded from water related recreation into a

[6] Örjan Stål (CEO, VIÖS AB) discussing with the author on the 14th of June 2012.

[7] Ibid.

broader perspective on public goods such as wildlife, air quality, human health, and aesthetics. At this time, CBA in relation to the environment was faced by many challenges regarding the treatment of long-term effects, risk and uncertainty. A strong research community was built up in the U.S. mainly including universities in the Rocky Mountain region. Meanwhile in Europe, development considering both research and practice was slow. In the U.K. for instance, CBA was mainly used within projects such as the M1 motorway in the 1960s and the Channel tunnel in the 1970s (Hanley et al., 1993). The importance of public funds being efficiently used in major governmental investments is emphasised more every year. This has resulted in the fusion of the academic field of welfare economics, which has mainly been CBA, and practical decision making. Today CBA is recognised as the major appraisal technique for both public policy and investments (Pearce et al., 2006). In Sweden CBA is widely used in various types of governmental projects as well. However, concerning environmental investments, such as remediation of contaminated soil, CBA is not commonly applied (Rosén et al., 2008).

Within the field of economic theory there are always disagreements concerning the correct approach. Thus, the structure of the CBA process has been designed in many ways. However, the aim of a CBA is always the same (Hanley et al., 1993). It is to calculate changes in public welfare, as the costs and the benefits for all people and firms affected by the project (Rosén et al., 2008). Consequently, the essential theoretical foundation of a CBA defines benefits as increases in human well-being, and costs as reduction in human well-being (Pearce et al., 2006). According to Hanley et al. (1993) the essential steps of a CBA are often the same, including (1) defining the project; (2) identifying impacts economically relevant; (3) quantifying and monetising impacts including summarizing calculations; and (4) sensitivity and distributional analyses.

When identifying impacts being economically relevant Pearce et al. (2006) stress the importance of identifying whose costs and benefits are to consider. In order for physical measures of impacts to be co-measurable, they must be valuable in common units. The common unit in CBA is money (Hanley et al., 1993). Various rules are used when comparing costs and benefits. However, the correct criterion is, in accordance with Pearce et al. (2006), to use the net present value (NPV) rule. Pearce et al. (2006) further underline the broad conclusion among researchers to be the same. Discounting is a term applied in all welfare economics calculations. It means that costs and benefits taking place in the future are discounted, using a specific interest rate, to present time. In turn, all costs and benefits are possible to compare with one another (Rosén et al., 2008). The CBA simply determines whether or not the sum of the discounted benefits exceeds the sum of the discounted costs. If it does, the project can be said to represent an efficient shift in resource allocation (Hanley et al., 1993). Kelman (1981) draws the conclusion that when conducting an environmental CBA a certain decision might be right even though its benefits do not outweigh its costs. Hanley et al. (1993) further emphasise that effort should be put on determining the time horizon, over which costs and benefits should be discounted, when impacts are being monetised. The reason for this being important is that different individuals have different preferences concerning when they suffer costs and when they receive benefits.

Monetising is generally easier when costs and benefits concern products and services that are present at the market. It gets more complicated if products and services are not subject to business at a market, which is often the case considering environmental and health related products and services (Rosén et al., 2008). Driesen (2006) argues that estimating the magnitude of health effects usually requires a lot of guesswork to extrapolate the estimation. Consequently, Hanley et al. (1993) refer to these products and services as externalities. They further state that these unpriced impacts are the most important feature of an environmental CBA. Externalities could be either positive or negative. An example of a positive externality could be a beautiful tree, which no one is paying the owner to watch, and, on the contrary, a negative externality could be acid rain. No one owns clean air, thus the power station pays nothing for polluting it (Hanley et al., 1993). According to Kelman (1981) there are good reasons to oppose efforts to put monetary values on unpriced costs and benefits.

There are numerous critiques of CBA (Pearce et al., 2006). According to Driesen (2006) CBA favours industry and disfavours health, safety, and environmental protection. CBA is a tool that is of help for prioritisation between different alternatives, and it is a procedure for obtaining increased knowledge in a structured way. On the other hand, a drawback is that the results may seem to be more informative than they really are. A consequence of this is overconfidence in the results (Pearce et al., 2006). Hanley et al. (1993) conclude that CBA is a useful contribution to the decision-making process but that it is not sufficient as a single criterion.

The CBA method developed by Rosén et al. (2008), focusing only on remediation projects, is more or less constructed in accordance with the essential steps of a typical CBA. It includes concrete examples of the costs and benefits commonly associated with remediation projects, which aims at supporting the process of identifying impacts economically relevant. Both costs and benefits have been divided into three main categories, respectively. See Table 2.1. Thereafter, each main category is divided into different sub-categories.

Table 2.1 Rosén et al. (2008) divided both costs and benefits into three main categories, respectively. Each category has systematically been assigned with either C (Costs) or B (Benefits) and an additional figure.

	Costs
C1	Performance costs of measures
C2	Negative effects on health due to measure
C3	Negative effects on eco-system services/goods due to measure
	Benefits
B1	Increased land value
B2	Net impact on market-priced services/goods
B3	Net impact on non-market-priced services/goods

Cullen (2007) argues that the immediate and obvious reason for most valuations is to form the basis for rational decision. An important part of the CBA procedure is to choose valuation methods to be able to quantify and monetise certain costs and benefits (Rosén et al., 2008). Many valuation methods are included in the CBA method by Rosén et al. (2008). Examples of fields considered by the valuation methods included are as follows: the benefits considering reduced acute and non-acute health risks; benefits from increased land value; and costs regarding reduced eco-systems off-site. A benefit Rosén et al. (2008) consider specifically problematic to express in monetary terms is increased land value. When it comes to more specific fields of valuation, such as increased access to eco-system goods, valuation methods are not included. For this thesis, valuing the saved trees has been an important part of the CBA. Thus, finding appropriate appraisal techniques has been included in the work.

When discounting the monetised effects of costs and benefits considering remediation projects both SIKA[8] and the Swedish EPA recommend a discount rate of 4%. The CBA method developed by Rosén et al. (2008) follows this recommendation. On the contrary, Stern (2006) recommends 1.4% as discount rate. Accordingly, Rosén et al. (2008) recommend including this proposal by Stern (2006) in the sensitivity analysis. Rosén et al. (2008) further advocates examining 0% as well.

Both Hanley et al. (19993) and Pearce et al. (2006) highlight the importance of assessing the distributional effects of costs and benefits in society. Correspondingly, Rosén et al. (2008) argue that it is crucial to include a distributional analysis in order to show if certain groups or people are affected more by the outcome than others.

2.3 Monte Carlo simulation

Costs and benefits are rarely known with certainty. In turn, this means that risk and uncertainty have to be taken into account when conducting a CBA (Hanley et al., 1993). This is further stated by Pearce et al. (2006) who conclude that many calculations in a CBA must be considered highly uncertain. Uncertainty is preferably dealt with in terms of a sensitivity analysis (Pearce et al., 2006). A sensitivity analysis means studying changes in results when different variables and parameters take other values than the most probable. Consequently, it is a tool that helps measuring the robustness of the results (Rosén et al., 2008).

According to Guastaldi et al. (2012), Monte Carlo Simulation (MCS) is a preferable approach to estimate uncertainties associated with environmental problems. It is further stated by Burgman (2005) that MCS is an often applied approach to assess uncertainty. The idea of MCS arose when people attempted to estimate probabilities by following all chains of possibilities, which was a very time consuming and difficult task for all but the simplest cases. This problem formed what became known as MCS (Burgman, 2005). Many definitions of MCS have been given (Elishakoff, 2003). James (1980) defined it as “any technique making use of random numbers to solve a problem”, whereas Niederreiter (1992) defined it as “a numerical method based on random sampling”. Some researchers argue that MCS is a poor technique in comparison to analytical methods. However, at present, the only universal methodology appropriate to solve for both simple and practical problems is MCS. As a result, MCS is performed whether or not an analytical method is available, thus, it is clear that more effort ought to be taken to develop the methodology of MCS for a wider range of problems (Elishakoff, 2003). According to Burgman (2005) a MCS provides an additional possibility to justify a decision.

An important step conducting a MCS is to choose appropriate statistical distributions of the likelihood of different uncertain scenarios to happen (Burgman, 2005). The

[8] The Swedish Institute of Communication Analysis. Statens institut för kommunikationsanalys in Swedish.

number of distributions applied within the field of statistics is many. Three of the most commonly applied basic distributions are triangular, lognormal, and discrete uniform (Oracle, 2012). These distributions are all visualised in Figure 2.1.

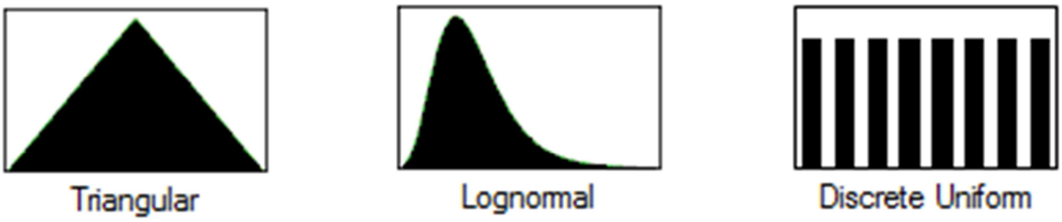

Figure 2.1 Three of the most basic statistical distributions (Oracle, 2012).

The triangular distribution is commonly applied when the minimum, maximum, and likeliest values are all known. It is a continuous distribution of probabilities. Three different conditions are underlying the triangular distribution: the minimum value is fixed; the maximum value is fixed; and the likeliest value decreases at a point between the minimum and the maximum values, forming a triangular shaped distribution. The values near the minimum and maximum values are less likely to occur than the values close to the likeliest value. The lognormal distribution is frequently applied when most of the values occur near the minimum value; thus, when values are positively skewed. It is a continuous probability distribution. The parameters are mean and standard deviation. Lognormal distribution is founded on three different conditions: the uncertain variable can increase without an upper boundary, but is confined to a finite lower value; the uncertain variable shows a positively skewed distribution; and the natural logarithm of the uncertain variables gives a normal curve. The discrete uniform distribution is a discrete probability distribution. The parameters are minimum and maximum value. The foundation of the discrete uniform distribution includes three different conditions: the minimum value is fixed; the maximum value is fixed; and all values between the minimum and the maximum are equally likely to occur (Burgman, 2005).

When distributions have been chosen for all uncertain variables they are all combined making up a forecast (Burgman, 2005). This has been visualised by Suter (1993), as shown in Figure 2.2.

Rosén et al. (2008) discuss that many calculations in a CBA are characterised by large uncertainty. In accordance with this, Rosén et al. (2008) advocate to always perform a sensitivity analysis. A sensitivity analysis can be conducted with different levels of both complexity and ambition. A simple way to identify the most uncertain variables is by changing their values and observe how the results are affected. A more advanced method is to make a statistical simulation where uncertain variables are described by statistical distributions (Rosén et al., 2008). Rosén et al. (2008) mention MCS as a commonly used simulation method. Remediation projects may typically be associated with substantial uncertainties concerning, for example, the investment costs, the benefits of reduced health risks, and the effects on property values (Rosén et al., 2008).

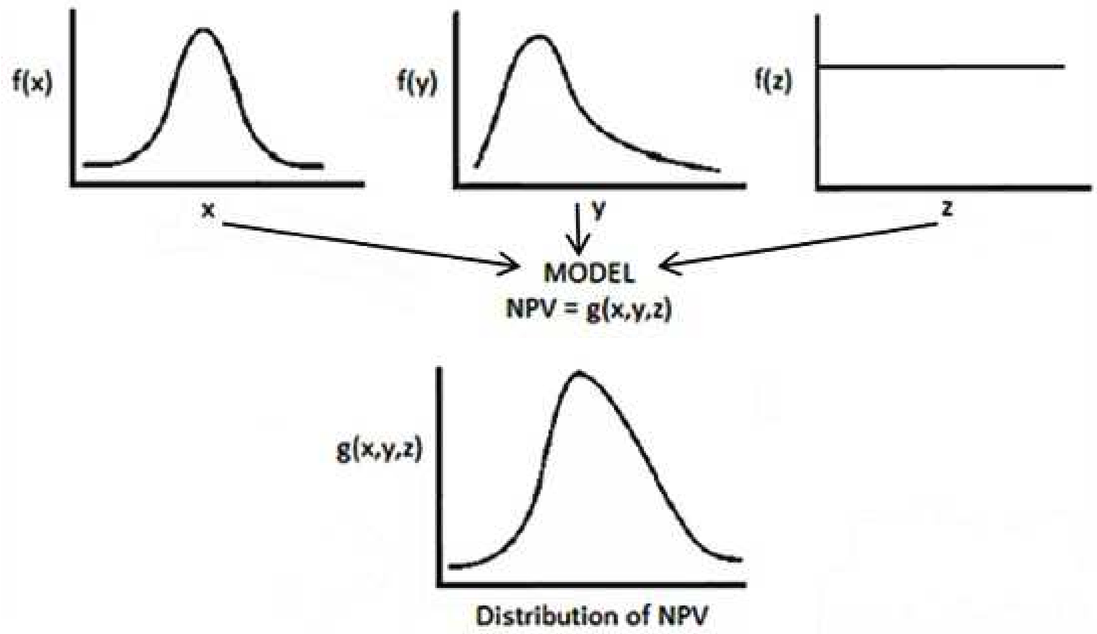

Figure 2.2 Schematic representation of the combination of uncertain variables using Monte Carlo simulation (Suter, 1993). The three combined distributions are normal, lognormal, and uniform.

2.4 Tree appraisal

Beyond social and aesthetic contributions, trees have economic values. Both public and private trees can be assigned a monetary value (Cullen, 2007). Cullen (1997) defines value as the current worth of future benefits. He further states that trees contribute to property values with 6 to 15%. The value of large trees is not easily established. At some point, a tree becomes too large to be practically replaced with another. The most common and widely used method of establishing the values of large trees worldwide is through the use of formula methods (Watson, 2002). In Sweden it has also been a tradition to use formula methods to appraise the value of trees (Stjernberg, 2012). Two basic types of formulas are used. The first type is initiated by establishing a value based on the size of the tree. Thus, it is assumed to be a direct relationship between the cost of regional nursery stocks and the values of larger trees. This value is adjusted for factors such as location and condition. The second type of formula methods applies a rating system for these factors, introducing a monetary value at the end. With the second approach, size is usually one of several factors, which are equally weighted, and therefore, size has less influence on the final appraised value (Watson, 2002).

Each method has certain advantages and limitations. Consequently, the reliability and appropriateness of each method can only be judged in light of the specific situation (Cullen, 1997). According to Stjernberg (2012), one of the greatest problems with formula methods is for people that are not familiar with the methodology to make an interpretation of the results and use them. Stjernberg (2012) further advocates the presence of overconfidence in the results as another drawback with formula methods.

In accordance with Watson (2002) not much has been published considering the relative performance of different formula methods. Watson (2002) performed a comparative research study on five different formula methods: the Trunk Formula

Method (TFM); Helliwell; the Standard Tree Evaluation Method; Norma; and Burnley. One of his findings was that TFM and Helliwell always appraised the lowest values. For many formula methods it is necessary to estimate the age of trees, which generally is not an easy task. However, estimating age is not necessary for some methods. An example of such a method is TFM (Stjernberg, 2011). In accordance with Cullen (1997) the TFM is a familiar and useful appraisal tool.

The TFM may be the most widely employed formula method for appraising amenity trees (Cullen, 1997). According to Watson (2002) this method has been used since 1951. However, since 1975, the Council of Tree & Landscape Appraisers (CTLA), has continuously revised the TFM and has published several editions of an appraisal guide. The 9th edition of the *Guide for Plant Appraisal* provides information on how to properly determine size, species, condition, and location factors that influence the value of trees. The method is based on the area of a cross-section of the tree trunk. This value is then multiplied by a monetary value per area unit. Moreover, this value is reduced by factors for species quality, condition, and location in the landscape (Watson, 2002). The TFM has been criticised for excessive differences between appraisers (Abbot et al., 1991). The variation often reaches values of 100 to 200% or higher (Watson, 2001). Some of this variation is probably due to subjective evaluation by the appraiser of tree attributes (Watson, 2002). This is especially significant for the factors considering condition and location, which several authors have argued to be too subjective. Thus, the expertise and experience of the appraiser is important. Species rating and price per square centimetre of trunk area are more objective (Watson, 2001). Chadwick (1975) argues that values for very large trees often are unrealistically high. He advocates the cross-sectional area of the trunk, used as size measurement, to be inappropriate as a foundation for large tree appraisal. It is an exponential calculation that increases rapidly for larger trees (Chadwick, 1975).

In addition to the accepted and commonly used formula methods, a new method is under development by Östberg et al. (2012) at the Swedish Agricultural University. Due to the fact that many different valuation methods are being applied today, Sweden is suffering from a lack of legal precedent from each method. It was therefore decided to develop a new national penalty method for amenity trees in Sweden to be used in court cases and prevention work, for instance when conducting construction work in conjunction with trees (Östberg et al., 2012). The working paper by Östberg et al. (2012) is in Swedish and therefore there is yet no official name for the method in English. However, if translated word by word, the working title is *the model for Monetary Valuation of Urban Trees*[9] (MVUT). Two important aspects that have been highly prioritised developing the MVUT have been to develop the method not to overestimate the value of the tree, and moreover, to make the method provide an appraised value reflecting the market value of the tree (Östberg et al., 2012).

[9] The working title of the method in Swedish is *"Modellen för ekonomisk värdering av urbana träd".*

3 Case Study at Beckholmen

3.1 General information

Beckholmen is situated just south of the island of Djurgården in the eastern parts of Stockholm’s city centre. The topography varies; the elevation of the outer parts of Beckholmen is close to the sea level, whereas the green space in the middle of the islet is significantly more elevated. Two properties are located at the green space, one in the northern end, and the other in the middle. At present one family lives in each property, respectively (Sweco, 2011c). The National Property Board Sweden[10] is the owner of both the land and the properties at the green space (SFV, 2012). In Figure 3.1 an overview of Beckholmen is presented.

Beckholmen is regarded as a historical monument of national interest. By its location, it forms part of the National City Park, an area of the harbour of Stockholm, containing maritime environments of historical interest. After the remediation the green space is supposed to serve as a shorter walking trail for the public, both for purposes of recreation and for cultural heritage. As mentioned in Chapter 1, the main aim of the remediation of Beckholmen was to reduce the substantial leaching of contaminants to Saltsjön, and moreover, it was also motivated for reducing health risks (Sweco, 2011a).

Figure 3.1 Aerial photo of Beckholmen, which is the islet in the lower part of the photo. In the upper part of the photo one can see the island of Djurgården. The black line marks the border of the green space (Sweco, 2011a).

[10] Statens fastighetsverk in Swedish.

3.2 Contamination

The contaminants at Beckholmen mainly originate from usage of wood tar, which started during the 17th century, and from three shipbuilding yards dating back to the early 18th century (Sweco, 2011a). During the main study of the green space, which was made by Sweco (2011c), three different origins of contaminants were identified: landfill materials; airborne materials; and fire debris. The landfill material mainly consisted of lead, mercury, copper, arsenic, zinc and PAH. On the contrary, the airborne materials were represented by different shallow contaminants, mainly consisting of lead. The fire debris can probably be derived from two fires, which ravaged the islet in the past, although another probable source of origin could be the process of tar incineration. The main contamination from the fires, or the tar incineration, is PAH (Sweco, 2011c). According to Sweco (2011a) lead and PAH were regarded as the most crucial contaminants considering the present land use at the green space. In Figure 3.2 an overview of the contaminants at the green space before the remediation are presented (Sweco, 2011c).

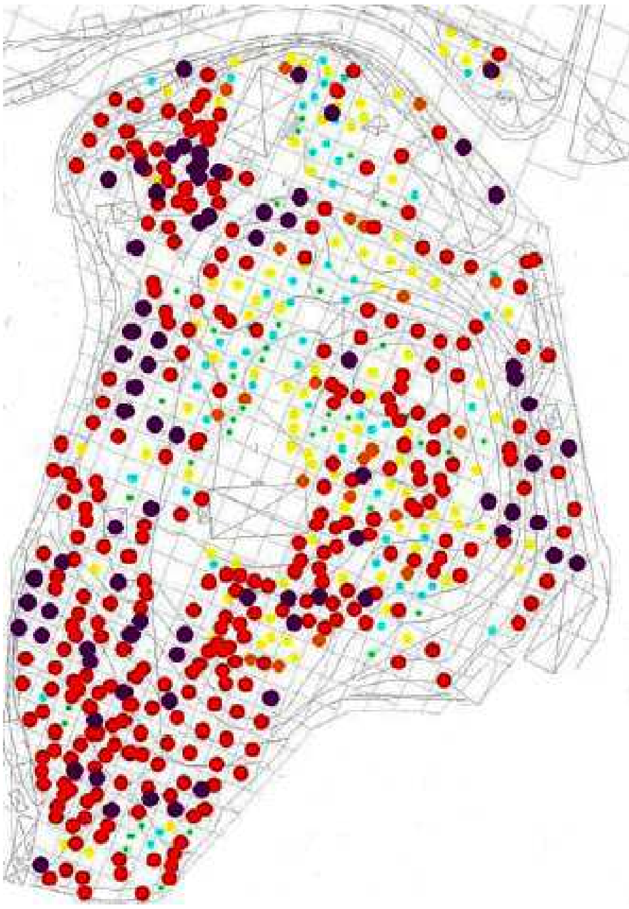

Figure 3.2 The classification has been made in accordance with the generic guidelines for contaminated sites developed by the Swedish EPA (NV, 2009). The coloured dots show the maximum value of the contamination with the highest value for each location a sample has been made. KM means sensitive land use, MKM means less sensitive land use, and FA stands for hazardous waste. The different colours are defined as follows: green is under KM; blue is between KM and MKM; yellow is between MKM and 2 MKM; orange is between 2 MKM and 5 MKM; red is between 5 MKM and FA; and purple is above FA.

3.3 Reference and remediation alternatives

The first step of the CBA method by Rosén et al. (2008) is to define reference and remediation alternatives. One reference alternative and two remediation alternatives have been defined. The main remediation alternative of this thesis is VE. The secondary alternative is D&D and has mainly been included for comparison.

3.3.1 Reference alternative

In accordance with Rosén et al. (2008) a reference alternative must be defined when conducting a CBA. Here, a null-alternative has been chosen as reference alternative implicating that no remediation action would have been taken at the green space. As mentioned in Section 1.1, 46 trees were present at the green space before the remediation. Some of these trees were taken down because they were standing in contaminated soil or were in very bad condition. From this, these trees were considered worthless in the reference alternative. Furthermore, the 23 trees that were saved were also considered of no value before the remediation. This simplification rests upon the idea that these trees were growing in contaminated soil. A tree growing in contaminated soil is not possible to purchase at a nursery garden. Thus, trees affected by contamination are not present at the market, and therefore, the trees were assumed to have no market values.

3.3.2 Vacuum excavation

As mentioned in Chapter 1, the remediation strategy applied at the green space was VE, which was chosen with the aim to save as many trees as possible. The VE alternative has been evaluated for two different cases, with the only difference between the cases being the benefit associated with the saved trees. The TFM and the MVUT method, which were presented in Chapter 2, have both been used for valuing the benefit of saved trees, separately. Thus, the two cases of the VE alternative will be referred to as VE TFM and VE MVUT.

To be able to save a tree VE is necessary within a radius of 2-5 metres around a tree, depending on the expansion of its roots (VIÖS AB, 2011). Due to the high density of trees VE was applied for the entire green space. The natural environment has adapted well to the local contaminant conditions at Beckholmen. Therefore, the generic environmental guideline values, set by the Swedish EPA, were not considered appropriate at the green space. Instead, mainly health-based guideline values, also set by the Swedish EPA, have been used for the remediation. At some locations the level of contamination was well above the health-based guideline values. Therefore, some trees, that were not considered valuable enough, were taken down. On the contrary, certain trees considered more valuable, also standing in soil contaminated above health-based guideline values, were saved. For these trees site specific environmental guideline values were accepted by the Swedish EPA. The reason why site-specific guideline values had to be used was because the risk of excavation measures damaging the trees would have been too high if all soil would have been excavated (Sweco, 2011c).

The soil was first loosened by air pressure using a pipe installed on a light weight excavator. To get a significant pressure a compressor run by diesel with an air capacity of 8,600 cubic metres per hour was used. When loosened, the soil was removed using a vacuum excavating nozzle, which was installed onto another excavator. Soil consisting of stiff and dry clay materials had to be moist before loosened by air pressure. When excavated, the soil material went through a hose until it reached the cyclone, where the majority of the soil materials ended up. On the contrary, some fine material went with the air flow all the way to the compressor. Finally, the excavated soil material was transported to a deposit in Löt, located in the outskirts of Stockholm (VIÖS AB, 2011). Figure 3.3 shows a sketch of the VE process applied at the green space.

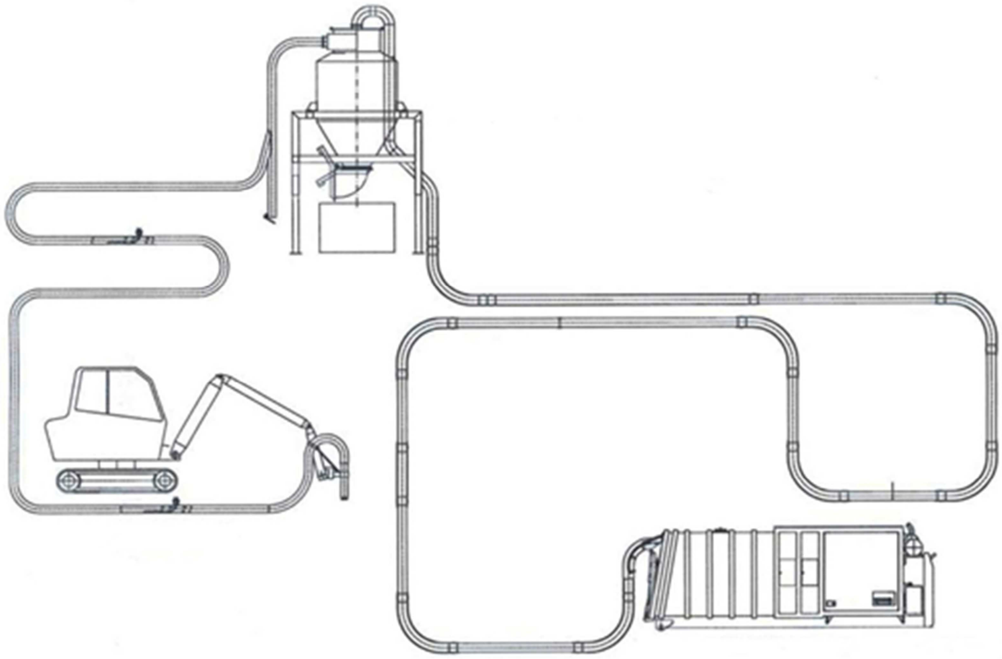

Figure 3.3 *A sketch showing the methodology of the vacuum excavation used at the green space. On the left hand side in the figure one can see the excavator. A vacuum excavation nozzle is installed on the excavator. When excavated, 99% of the soil ends up in the cyclone in the upper part of the figure. To the right one can see the compressor (*Sweco, 2011c).

3.3.3 Dig-and-dump

For the D&D alternative it is assumed that all costs and benefits identified are the same as for VE, although with one important exception - the costs and benefits associated with the trees. In turn, this aims at emphasising the most important differences between the two remediation methods; that is, the ability of saving the trees. If D&D had been applied, all trees would have been taken down due to the working procedure of this methodology. Thus, the benefit of saving the trees would have been non-existing for D&D. On the other hand, the financial costs would have been lower due to the fact that D&D is a relatively cheap remediation method in comparison with VE. This remediation alternative was chosen because the method was used at the outer parts of Beckholmen, and most likely would have been applied if the VE method would not have been used. Also, as mentioned in Chapter 1, D&D is the most commonly applied remediation method in Sweden. This is another reason why it is interesting to compare its performance relative to the performance of a remediation method such as VE.

4 Method

The CBA method developed by Rosén et al. (2008) is a five step procedure including (1) definition of reference and remediation alternatives; (2) identification of costs and benefits; (3) quantification of costs and benefits; (4) calculations; and (5) sensitivity and distributional analyses. A flowchart of the procedure is presented in Figure 4.1.

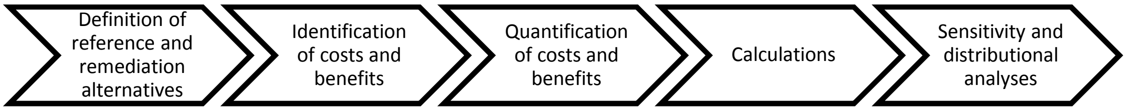

Figure 4.1 Flowchart of the procedure of the CBA method.

When the CBA was initiated the essential first step – definition of reference and remediation alternatives – was to select an appropriate reference alternative, and moreover, to define different remediation alternatives for comparison with the reference alternative as seen in Section *3.3.*

The aim of the second step - identification of costs and benefits – is to qualitatively identify all positive and negative consequences associated with the remediation project. The identification process was supported by considering the common costs and benefits, associated with remediation projects, identified by Rosén et al. (2008). Both costs and benefits are divided into three main categories, respectively. Each main category is then divided into different sub-categories. Each sub-category has been assigned with a certain level of importance: great importance; important; and no importance.

The third step – quantification of costs and benefits – considers finding appropriate valuation methods for as many costs and benefits as possible, and then, monetise each cost and benefit separately. Most valuation methods have been chosen according to Rosén et al. (2008). Considering the benefit of saving trees, a literature study was conducted in order to find appropriate methods, and consequently two different valuating methods were chosen. The reason why two methods were chosen was to emphasise the large range of results that different valuating methods generate, while appraising the same set of trees. Not all consequences were possible to quantify. Nevertheless, it is important to include these as well, however without a monetary figure. The size and relative importance of the consequences are discussed in Chapter 6. It is also discussed why these were difficult to monetise. The methodology of all the applied valuation methods is explained in Sections 4.1- 4.2.

In the fourth step – calculations – the sum of all monetised costs and benefits were calculated for the remediation alternatives. This gave NPVs where the sum of all discounted benefits where subtracted by the sum of all discounted costs.

In the last step – sensitivity and distributional analyses - a robustness check of the CBA results was conducted in terms of a sensitivity analysis. The methodology of this analysis is presented in Section 4.3. Furthermore, a distributional analysis of all costs and benefits was performed. The approach of this analysis is explained in Section 4.4.

4.1 Valuation of costs

4.1.1 Performing the measure

All bills related to the remediation measures taken at the green space were provided by Sweco. Two different contractors were procured: Binsell AB and NCC AB. For consulting services regarding the trees a firm called VIÖS AB was signed. SITA Sweden AB (SITA) was responsible for transports and disposal of soil materials. The costs for performing the remediation measures include several operations: VE; the purchase of new refill material; removing and chipping trees; transports of land masses to deposit, and fees for depositing. Costs for project management performed by Sweco are included as well. Apparently there is no documentation available for the latter costs; however, the main project manager at Sweco, Egelstig[11], was able to contribute with an assumption about these costs to be 0.4 MSEK. The same principle applies for the SITA costs. The bills considering transports and deposit have been invoiced for all of Beckholmen. Thus the precise share of costs that should be assigned to the green space is missing. Egelstig[12] was able to make an assumption about this proportion to be 7.5%. Consequently, all costs could be added and compiled.

The costs of the remediation alternative D&D were calculated with a simplifying assumption. It was assumed that the same volume of soil materials, which was removed by VE, instead would have been remediated by D&D. Thus, the number of tons excavated by VE at the green space was multiplied by the mean costs per ton from the D&D conducted at the outer parts of Beckholmen. The total number of tons transported to and from Beckholmen has been summarised in a document by SITA. Thus, the precise share of tons belonging to the green space was not known. However, Egelstig[13] estimated that 10% of the weight ought to be assigned to the green space. This estimation made it possible to calculate the mean costs per ton using D&D. Total costs for all of Beckholmen at a certain date was subtracted by the total financial costs at the green space at the same date, and then this figure was divided by the number of tons remediated by D&D.

The costs for performing the measure have not been discounted due to its appearance in time. All data regarding costs performing the measure are presented in Appendix A.

4.1.2 Conducting and performing a control program

The control program has been conducted by Sweco. Thus, invoiced bills for these measures were obtained from Sweco. Consequently, all costs were added and compiled. All data regarding costs for conducting and performing a control program are presented in Appendix A.

4.1.3 Reduced access to eco-system services and goods off-site

These calculations concern emissions related to transports of soil materials to and from the green space, and have been performed in accordance with Rosén et al.

[11] Christer Egelstig (Project manager, Sweco) discussing with the author on the 25th of September 2012.
[12] Ibid.
[13] Ibid.

(2008). Different data was needed for the calculations. As mentioned in Section 4.1.1, the share of tons belonging to the green space was proposed by Egelstig. This figure was also necessary for the calculations associated with the transport emissions. The distance between Beckholmen and the deposit in Löt was given by Eniro (2012). According to SIKA (2005) the costs of CO_2 emissions is 1.5 SEK/kilo, whereas the costs of local effects of NO_X is 49 SEK/kilo. Egelstig[14] argues that the trucks, which have been used for the transports to and from the deposit, were of type city trailers. Moreover, Egelstig[15] made the assumption that the mean value of load per truck was 10 tons. In accordance with Rosén et al. (2008) a truck with this load incinerates 0.4 liters of diesel per kilometre. The amount of CO_2 released per liter incinerated diesel is 2.5 kilos, whereas the amount of NO_X is 5 grams (Rosén et al., 2008). The number of round-trips back and forth to the deposit has been calculated by dividing the total amount of tons transported by the capacity of the truck. In turn, this made it possible to calculate the total number of kilometres, and the total amount of liters of diesel incinerated. The total costs were then calculated by multiplying kilos of emissions with costs per kilo.

The costs for emissions have not been discounted due to its present appearance in time. Other emissions have been assumed to be insignificant in comparison with CO_2 and NO_X, and therefore neglected in the calculations. All calculations regarding reduced access to eco-system services and goods off-site are presented in Appendix A.

4.2 Valuation of benefits

4.2.1 Reduced acute health risks

Arsenic is a contamination considered as an acute health risk to humans (Liljelind et al., 2008). Field and laboratory tests of shallow soil samples, conducted by Sweco (2011b), show a very high level of arsenic at the green space. Most samples are collected less than 1 metre below the ground surface, whereas some samples are collected at greater depths.

The benefit from the reduced acute health risks was calculated according to Rosén et al. (2008). It was a three step procedure including (1) calculation of the concentration of arsenic (C_{AE}) for which acute-toxic effects are probable to occur; (2) calculation of the probability of the amount of arsenic in a random sample to exceed C_{AE} both before and after the remediation; and (3) put a monetary value on the benefit in terms of a NPV.

First, the concentration of arsenic [mg/kilo], for which acute-toxic effects are probable to occur, was calculated in accordance with equation (4.1):

$$C_{AE} = \frac{ARV * m_{child}}{m_{intake}} \tag{4.1}$$

[14] Christer Egelstig (Project manager, Sweco) discussing with the author on the 25th of September 2012.
[15] Ibid.

where *ARV* is the fatal reference dose for acute-toxic effects [mg/kilo body mass]; m_{child} is the weight of a child [kilo] exposed to the contaminant; and m_{intake} is the amount of soil intake [kilo] at one occasion (Rosén et al., 2008). *ARV* was set to 1 mg/kilo (White, 1999). In accordance with Norrman et al. (2009) m_{child} was set to 15 kilos, and m_{intake} was assigned with a value of 5 grams.

Second, the probability for the amount of arsenic to exceed the calculated value of C_{AE} was calculated. In total 693 soil samples have been evaluated regarding its arsenic content (Sweco, 2011b). In accordance with Norrman et al. (2009) the samples were assumed to be lognormally distributed. Next, the C_{AE} value, the mean value of the sample, and the standard deviation of the sample were calculated on the log scale. Consequently, the probability for the level of arsenic at a random point to be above the C_{AE} value was calculated with the normal distribution command in Excel (Norrman et al., 2009). This was initially conducted for the sample values before the remediation. Afterwards, the sample values were reduced by 73% and the procedure could be repeated. The reduction factor was motivated by the fact that the amount of arsenic was reduced by 73% as a mean value for the entire green space because of the remediation (Kungliga Djurgårdsförvaltningen, 2011). Thus, the probability for a random sample of soil to exceed C_{AE} both before and after the remediation was determined.

Last, a NPV was computed for the reduced acute health risks. As a first step, the number of children between 0-2 years old living at the green space was identified as zero, and the number of children between 5-7 years visiting the green space (*C*) per day was estimated to 2. Calabrese et al. (1997) have estimated that the probability that a child between 5-7 years will eat soil is 0.027%. By this, the number of children likely to eat soil from the green space could be calculated. Hence, the probability of a child to eat soil containing arsenic could be calculated both before and after the remediation. By multiplying the risk reduction with the value of a statistical life, a monetary benefit per year (MB_A) was achieved. The value of a statistical life in a traffic accident is 21 million SEK (MSEK) (SIKA, 2009). However, SIKA (2009) recommends a doubling of this value for environmental related accidents; thus, the value of a statistical life (*VSL*) is considered to be 42 MSEK. Next, recommended by Rosén et al. (2008), was to discount the MB_A for a time horizon (*t*) of 10 years with a discount rate (*r*) of 4%. This was made according to equation (4.2):

$$NPV = \sum \frac{1}{(1+r)^t} * MB_A \qquad (4.2)$$

All figures associated with the valuation of the reduced acute health risks are presented in Appendix B.

4.2.2 Reduced non-acute health risks

As mentioned in Chapter 3, lead and PAH were regarded as the most crucial contaminants before the remediation considering the present land use at the green space. Consequently, both lead and PAH are carcinogenic (TIEM, 2005). Thus, the non-acute health risks were assumed to be governed only by these contaminants.

The calculation of the benefit from the reduced non-acute health risks was a three step procedure including (1) calculations of risk levels before and after the remediation; (2) computation of annual monetary benefits due to reduced risk levels; and (3) calculation of a NPV by discounting the annual benefits.

First, the magnitudes of the risk levels were calculated. Rosén et al. (2008) use two different methods calculating these values; one by the Swedish EPA, and one by the U.S. EPA. In accordance with Norrman[16] the latter methodology was chosen for this thesis. This methodology is implemented in Spatial Analysis and Decision Assistance (SADA), a software including a module for human health risk assessment (TIEM, 2005). As a first step, sample data collected by Sweco (2011b) was imported in SADA. For lead, 811 samples were available and imported, whereas 705 samples were available and imported for PAH-H. The majority of these samples were collected between ground surface and two metres depth. However, all depths were set to zero in SADA for practical reasons. The same principal goes for the coordinates. All samples are collected at certain coordinates; however, new squared areas were set up where the distance between all samples was the same. It is not clarified what specific sub-categories the lead and PAH-H samples consider. Therefore, the choice of which contaminants to register as lead and PAH-H, from the toxilogical database implemented in SADA, was based on which type is the most commonly occurring. Lead is represented by Pb-205, whereas PAH-H is represented by Benzo[a]pyrene. Site-specific data was used in the SADA model. Exposure ways were set to ingestion, inhalation, and external effects for lead, whereas external effects were replaced by dermal contact for PAH-H. According to Rosén et al. (2008) it is reasonable to use the weighted arithmetic mean value as a foundation for the non-acute health risk; hence, this recommendation was followed. TIEM (2005) can be consulted for further information on the general methodology using SADA. When the risk levels had been calculated before the remediation (R_B) the same procedure was repeated for the risk levels after the remediation (R_A). This was performed multiplying the sample values before the remediation by the size of the reduction of contaminants. Lead was reduced by 73%, whereas PAH-H was reduced with 78% (Kungliga Djurgårdsförvaltningen, 2011).

Second, the annual monetary benefits from reduced non-acute risk levels (B_r) were calculated according to equation (4.3):

$$Br = \left(\frac{R_B * n}{t} - \frac{R_A * n}{t}\right) * VSL * P_M \tag{4.3}$$

where n is the number of people living at the green space; t is the duration of exposure for those living at the green space; VSL stands for value of statistical life; and P_M is the probability of death from cancer. An assumption was made about the size of n to be six adults. It was assumed that people do not live at the same place their entire life, which resulted in the assumption of t to be 30 years. Also mentioned in Section 4.2.1, VSL is equal to 42 MSEK. The probability of dying from cancer is of course lower than the risk of developing cancer (Rosén et al., 2008). According to Cancerfonden

[16] Jenny Norrman (Assistant Professor, Chalmers University of Technology) discussing with the author on the 4th of October 2012.

(2009) the overall probability of dying from cancer is approximately 40%. As a simplification, P_M was assigned with the same value. However, it should be noticed that the most common types of cancer associated with lead are stomach and lung cancer, whereas the most common kinds of cancer associated with PAH are lung, bladder and skin cancer (Liljelind et al., 2008).

Last, the annual monetary benefits were discounted over a certain period of time. It was assumed reasonable that the benefit of the reduced health risks should be discounted over a period of approximately two generations, or 70 years, with a discount rate of 4%. This was conducted in accordance with equation (4.2).

All figures associated with the valuation of the reduced non-acute health risks are presented in Appendix B.

4.2.3 Increased access to eco-system goods using the TFM

The TFM is a two-part calculation including (1) determination of basic value; and (2) calculation of appraised value.

First, the basic values were computed in accordance with equation (4.4):

$$Basic\ value = RC + [BP + (TA_a - TA_r)] \tag{4.4}$$

where *RC* is the replacement cost of an average tree in the region, including installation costs; *BP* is the basic price, which is the cost per square centimetre of the trunk area of the replacement tree; TA_a is the trunk area of the appraised tree; and TA_r is the area of the trunk of the replacement tree (van der Hoeven, 2000). To be able to calculate *RC* and *BP*, secondary data considering market prices was provided by Johan Östberg at the Swedish Agricultural University, which had been collected from six nursery-gardens: Lorenz von Ehren; Bruns; Flyinge; Splendor Plant; Tönnersjö nursery garden; and Hallbergs nursery garden. The replacement tree available at the nursery gardens with the trunk area closest to the area of the appraised tree has been used for each appraised tree, respectively. Mean values for all nursery gardens for both *RC* and *BP* have been calculated. For TA_a primary data in terms of perimeter were collected for all trees at the site. This was carried out by measuring each tree trunk at a height of one metre above ground surface. These figures were then used to calculate the trunk area of each tree (CTLA, 2000).

Second, the appraised values were calculated using equation (4.5):

$$Appraised\ value = Basic\ value * CR * LR * SR \tag{4.5}$$

where *CR* is a Condition Rating; *LR* is a Location Rating; and *SR* is a Species Rating. To assign a tree with these ratings an expert in tree appraisal is required (van der Hoeven, 2000). For this thesis *CR*, *LR*, and *SR* were all collected in cooperation with a tree consultant called Örjan Stål from the firm VIÖS AB. Örjan Stål also assisted in determining the species of each tree.

For the *CR* a scoring system was used to rate five different factors (*F*). The factors Roots, Trunk, and Scaffold Branches were rated with consideration to both structure

(*S*) and health (*H*), whereas the factors Small Branches and Twigs, and Foliage and/or Buds were only rated with consideration to health. Each of these factors was rated with consideration to the different properties shown in Table 4.1. The range of the scoring system stretches from $1<S/H<4$, where each figure equals a certain degree of problems: 1 equals extreme problems, 2 equals major problems, 3 equals minor problems, and 4 equals no apparent problems. The total sum of all factors (*TF*) then took a value within the range $8<TF<32$. This value was divided by the figure 32. Thus, a value within the range $0\%<CR<100\%$ could be assigned to each tree, respectively. All *CRs* have been performed following CTLA (2000).

Table 4.1 For the Condition Rating a scoring system was used to rate five different factors. Each of these factors was rated with consideration to different properties.

Factors	Properties
Roots	Root anchorage, Collar soundness, Mechanical injury, Girdling roots, Waterlogged roots, Toxic gases, Presence of insects or disease, Fungus
Trunk	Sound bark and wood, Cavities, Mechanical or fire injury, Cracks, Swollen or sunken areas, Presence of insects or disease, Conks
Scaffold Branches	Strong attachments, Smaller diameter than trunk where attached, Vertical branch distribution, Free of included bark, Free of decay and cavities, Well pruned, Proper taper, Wound closure, Deadwood of fire injury, Insects or disease
Small Branches and Twigs	Vigor of current shoots, Well distributed through canopy, Appearance of buds, Presence of insects or disease, Presence of weak or dead twigs
Foliage and/or Buds	Size of foliage/buds, Coloration of foliage, Nutrient status, Herbicide/Chemcial/Pollution injury, Wilted or dead leaves, Dry buds, Presence of insects or disease

The *LR* adjustments consider whether, and how, physical characteristics of the appraised tree are likely to be enjoyed or experienced (Cullen, 1997). The *LR* calculation is the average of three sub-factors: site, contribution; and placement (CTLA, 2000). These sub-factors (*SF*) were all assigned within the range $0\%<SF<100\%$. The values were then added together and divided by the figure three giving a final *LR* for each tree between $0\%<LR<100\%$. The value of a specific site rating is expressed by its relative market value within the area in which the site is located. The contribution rating includes factors such as functional and aesthetic contributions of the tree. These benefits are affected by plant size, shape, branch structure, foliage density, and distribution. The placement rating is considering how effective the tree is in providing its functional and aesthetic attributes. The sub-factor ratings were made in accordance with the following percentage system: very low 10-59; low 60-69; average 70-79; high 80-89; and very high 90-100. All *LR* adjustments have been performed following CTLA (2000).

The *SR* adjustments consider species related attributes such as growth characteristics, maintenance requirements, and aesthetics (Cullen, 2000). In the same way as the above ratings, *SR* was also rated in percentage according to 0%<*SR*<100%. An indigenous, native tree tolerant of a site's environment can be assigned with a *SR* of 100% (CTLA, 2000).

In Appendix C a map showing the locations of the trees is exhibited. Further detailed templates on all figures are also presented.

4.2.4 Increased access to eco-system goods using MVUT

The MVUT is a two-part calculation including (1) determination of basic value; and (2) calculation of appraised value. These calculations have been performed in accordance with Östberg et al. (2012).

First, the basic values were computed according to equation (4.6):

$$Basic\ value = TA_a * BP_{13} \tag{4.6}$$

where TA_a is the trunk area of the appraised tree; and BP_{13} is price/area for a nursery garden tree with the area 13 square centimetres. To calculate BP_{13} a mean value for each species was calculated using data from the six nursery gardens mentioned in Section 4.2.3.

Second, the appraised values were calculated using the two equations (4.7) and (4.8):

$$RE_{dv} = \frac{\sum D + V}{16} \tag{4.7}$$

$$Appraised\ value = Basic\ value * RE_{dv} \tag{4.8}$$

where RE_{dv} is a reduction factor computed adding the sum of all damages ($\sum D$) with vitality (*V*) and then dividing the sum by 16, which provides a figure in percentage. In cooperation with Örjan Stål at VIÖS AB primary data considering damage at crown, trunk, and roots was collected at the site for each tree, respectively. This was performed in accordance with Östberg et al. (2012). Crown, trunk, and roots were all rated within the range 1-4, where each figure corresponds to the following system: 1 equals very difficult damage; 2 equals difficult damage; 3 equals minor damage; and 4 equals no damage. *V* was given multiplying *CR* with the figure four. Last, an appraised value for each tree could be computed multiplying the basic value with the reduction factor.

A map showing the locations of the trees is exhibited in Appendix C. Further detailed templates on all figures are also presented.

4.3 Sensitivity analysis

It is recommended by Rosén et al. (2008) to perform a sensitivity analysis, but it is not specified what methodology to use. As described in Chapter 2, MCS is emphasised as one possible approach conducting a sensitivity analysis. Hence, this methodology was chosen for this thesis. The spreadsheet-based application Oracle Crystal Ball was used for the MCS.

The MCS conducted was a four-step procedure including (1) identification of uncertain variables; (2) determination of appropriate statistical distributions for the uncertain variables; (3) computation of statistical distributions of the calculated results using Oracle Crystal Ball; and (4) examination of the sensitivity of different discount rates on the statistical distributions.

First, the uncertain variables were identified. This was done by revising all monetised values, and by doing so, determine which variables that ought preferably to be included in the MCS. Second, appropriate distributions were chosen for each uncertain variable, respectively. This was conducted in accordance with the theoretical presentation of statistical distributions in Chapter 2. The range of uncertainty has been based on the estimated magnitude of uncertainty of each assumption, separately. Third, assumptions and forecasts were defined in Oracle Crystal Ball. Consequently, the simulation was run 10,000 times. Finally, when the MCS had been completed, the sensitivity of each remediation alternative was examined with respect to different discount rates. As mentioned in Chapter 2, Rosén et al. (2008) recommend a discount rate of 4%. However, Rosén et al. (2008) also recommend examining both 1.4% and 0% in the sensitivity analysis. Thus, these two additional percentages were examined for both the remediation alternatives.

4.4 Distributional analysis

As mentioned in Chapter 2, Rosén et al. (2008) recommend to always include an analysis of the distributional effects of costs and benefits in society. However, no methodology for this analysis is neither recommended nor mentioned in the CBA method. On the other hand, Rosén et al. (2008) refer to Boardman et al. (2001) and Mattsson (1988) for a review of different methods available to highlight distributional effects. Consequently, Rosén[17] claims that it is both difficult and time-consuming to conduct a detailed distribution analysis, but it is preferable to at the least make a brief estimation about the effects. Looking deeper into the available methods has been considered to be beyond the scope of this thesis. Instead the achieved results from the remaining CBA study, in conjunction with project associated material provided by Sweco, are discussed at the end of Chapter 6 as a brief alternative to a detailed distributional analysis.

[17] Lars Rosén (Professor, Chalmers University of Technology) discussing with the author on the 25th of September 2012.

5 Results of the Cost-Benefit Analysis

5.1 Identification of costs and benefits

Costs for investigation and framing of measures (C1a) and costs for purchasing of concession (C1b) are both included in the costs for performing the measure (C1d). Therefore, both C1a and C1b are assigned with no importance. On the other hand, C1d must be considered of great importance due to its likelihood of constituting most of the financial costs associated with the remediation project. According to Söderqvist[18], costs associated with default returns due to locked-up capital (C1c) should be regarded of no importance for this case. Costs for conducting and performing a control program (C1e) are considered important because of the normally extensive content of such a program. Projects risks (C1f) are regarded as included in C1d because the CBA was carried out after the remediation, and therefore, C1f is considered of no importance. According to Kronberg[19] there have been no accidents associated with the remediation or traffic related or at the green space. Therefore, increased health risks due to measure on site (C2a), and increased health risks due to transports associated with measures (C2b), have both been considered not important. All identified costs are presented in Table 5.1.

Table 5.1 The costs associated with the remediation of the green space have been identified within three main categories: performance costs of measure (C1); negative effects on health due to measure (C2); and negative effects on eco-system services and goods due to measure (C3). Each sub-category of costs has been assigned with a certain level of importance, where "X" equals great importance, "(X)" equals important, and "0" equals no importance.

	Costs	Importance "X" ; "(X)" ; "0"
C1	Performance costs of measure	
C1a	Costs for investigation and framing of measures	0
C1b	Costs for purchasing of concessions	0
C1c	Costs associated with default returns due to locked-up capital	0
C1d	Costs for performing the measure	X
C1e	Cost for conducting and performing a control program	(X)
C1f	Project risks	0
C2	Negative effects on health due to measure	
C2a	Increased health risks due to measure on the site	0
C2b	Increased health risks due to transports associated with measures	0
C2c	Increased health risks at depositing site	0
C3	Negative effects on eco-system services/goods due to measure	
C3a	Reduced access to eco-system services/goods on site	0
C3b	Reduced access to eco-system services/goods off-site	(X)
C3c	Reduced access to eco-system services/goods at the depositing site	0

[18] Tore Söderqvist (Consultant, Enveco) discussing with the author on the 14th of December 2012.
[19] Hans Kronberg (Project manager, Sweco) discussing with the author on the 1th of October 2012.

Consequently, increased health risks at depositing site (C2c) have been considered of no importance due to the assumption that a deposit is a controlled and restricted area managed by experienced employees. Reduced access to eco-system services and goods on site (C3a) is regarded as non-existent and therefore assigned with no importance. On the contrary, reduced access to eco-system services and goods off-site (C3b) have been considered important because of the negative effects of transport emissions. A deposit is made for contaminated soil, and its personnel are assumed to possess the knowledge for treating it well. Thus, reduced access to eco-system services and goods at the depositing site (C3c) has been assigned with no importance.

The increased land value (B1a) is often a large benefit due to a remediation, especially when the land is aimed for the development of new housing, although, this is not the case at the green space. Thus, the B1a was considered to be important. It is recommended by Rosén et al. (2008) not to include increased land value at surrounding real estates (B1b) when including net impact on non-market-priced services and goods (B3). Therefore, the B1b has been considered of no importance. All identified benefits are presented in Table 5.2.

Table 5.2 The benefits associated with the remediation of the green space have been identified within three main categories: increased land value (B1); net impact on market-priced services and goods (B2); and net impact on non-market-priced services and goods (B3). Each sub-category of costs has been assigned with a level of importance, where "X" equals great importance, "(X)" equals important, and "0" equals no importance.

	Benefits	Importance "X" ; "(X)" ; "0"
B1	Increased land value	
B1a	Increased land value	(X)
B1b	Increased land value at surrounding real estates	0
B2	Net impact on market-priced services/goods	
B2a	Increased possibility for more profitable production of services/goods	
B2aa	Production with lower costs, better quality and higher returns	0
B2ab	Less business restrictions	0
B2ac	Increased business trust	0
B2ad	Less legal responsibility	0
B2ae	Better working environment	0
B3	Net impact on non-market-priced services/goods	
B3a	Reduced health risks	
B3aa	Reduced acute health risks	X
B3ab	Reduced non-acute health risks	X
B3b	Increased access to eco-system services/goods	
B3ba	Increased possibilities for recreation within the site	X
B3bb	Increased possibilities for recreation in the surrounding area	0
B3bc	Increased access to other eco-system services/goods	X

In accordance with Rosén et al. (2008) net impact on market-priced services and goods (B2) are all considered to be included in B1a, and therefore, all items in B2 have been assigned with no importance. To reduce health risks have been a main target of the project. From this, both reduced acute health risks (B3aa), and reduced non-acute health risks (B3ab) have been considered to be of great importance. Another main purpose of the remediation project has been to make the green space more attractive and more available in terms of recreation. Thus, increased possibilities for recreation within the site (B3ba) must be considered to be of great importance. On the other hand, increased possibilities for recreation in the surrounding area (B3bb) are considered to be of no importance. The surrounding area cannot be directly considered as a better environment for recreation due to the remediation of the green space. The driving force behind using VE was to save trees. Therefore, increased access to other eco-system services and goods (B3bc) has been considered to be of great importance as well. Another reason which contributes to the great importance of B3bc is the reduced leaking of contaminants to Saltsjön.

5.2 Quantification of costs and benefits

Costs for performing the measure (C1d) have been monetised for both the remediation alternatives, respectively. Consequently, costs for both conducting and performing a control program (C1e) and reduced access to eco-system services and goods off-site (C3b) were monetised as well. See Table 5.3.

Table 5.3 The costs associated with the remediation have been quantified and monetised.

	Costs	VE TFM	VE MVUT	D&D
		MSEK		
C1	Performance costs of measures			
C12	Costs for investigation and framing of measures	0	0	0
C1b	Costs for purchasing of concessions	0	0	0
C1c	Costs associated with default returns due to locked-up capital	0	0	0
C1d	Costs for performing the measure	24.878	24.878	12.060
C1e	Cost for conducting and performing a control program	1.344	1.344	1.344
C1f	Project risks	0	0	0
C2	Negative effects on health due to measure			
C2a	Increased health risks due to measure on the site	0	0	0
C2b	Increased health risks due to transports associated with measures	0	0	0
C2c	Increased health risks at depositing site	0	0	0
C3	Negative effects on eco-system services/goods due to measure			
C3a	Reduced access to eco-system services/goods on site	0	0	0
C3b	Reduced access to eco-system services/goods off-site	0.113	0.113	0.113
C3c	Reduced access to eco-system services/goods at the depositing site	0	0	0

The two different benefits increased land value (B1a) and increased possibilities for recreation within the site (B3ba) have not been possible to monetise. However, these benefits are considered to have positive monetary values. Increased access to other eco-system services and goods (B3bc) is considered beneficial in terms of both saved trees and less negative impact on Saltsjön. The benefit of the trees was monetised using two different methods, both resulting in relatively large values. On the contrary, the benefit considering Saltsjön could not be monetised, although this benefit is also considered to have a positive monetary value. Both posts in reduced health risks (B3a) could be monetised. All quantified benefits are presented in Table 5.4.

Table 5.4 The benefits associated with the remediation have been quantified and monetised. Some benefits were not possible to monetise but are greater than zero, these are indicated by >0.

	Benefits	VE TFM	VE MVUT	D&D
		MSEK		
B1	Increased land value			
B1a	Increased land value	> 0	> 0	> 0
B1b	Increased land value at surrounding real estates	0	0	0
B2	Net impact on market-priced services/goods			
B2a	Increased possibility for more profitable production of services/goods			
B2aa	Production with lower costs, better quality and higher returns	0	0	0
B2ab	Less business restrictions	0	0	0
B2ac	Increased business trust	0	0	0
B2ad	Less legal responsibility	0	0	0
B2ae	Better working environment	0	0	0
B3	Net impact on non-market-priced services/goods			
B3a	Reduced health risks			
B3aa	Reduced acute health risks	0.117	0.117	0.117
B3ab	Reduced non-acute health risks	0.702	0.702	0.702
B3b	Increased access to eco-system services/goods			
B3ba	Increased possibilities for recreation within the site	> 0	> 0	> 0
B3bb	Increased possibilities for recreation in the surrounding area	0	0	0
B3bc	Increased access to other eco-system services/goods			
	TFM	9.112		
	MVUT		5.602	
	Saltsjön	> 0	> 0	> 0

5.4 Calculations

The VE NPV including TFM is higher than the VE NPV including MVUT; however, both NPVs took negative values. Considering D&D, the sum of the costs is about half the size in comparison with the VE alternative. On the contrary, the sum of the D&D benefits is considerably lower than for the VE benefits due to the lack of the benefit from the saved trees. Furthermore, the NPV of the D&D alternative is higher than for both the VE NPVs, separately. However, the D&D NPV is also negative. The NPV calculations are summarised in Table 5.5.

Table 5.5 All costs and benefits for the two different remediation alternatives are summarised and presented in the table. The monetary values are presented in MSEK. The sum for both costs and benefits has been summarised for each alternative, whereas the NPV is presented for each alternative, respectively.

Monetised costs		VE TFM	VE MVUT	D&D
		MSEK		
C1d	Performing the measure	24.878	24.878	12.060
C1e	Conducting and performing a control program	1.344	1.344	1.344
C3b	Reduced access to eco-system services/goods off-site	0.113	0.113	0.113
Sum		26.336	26.336	13.517
Monetised benefits		VE TFM	VE MVUT	D&D
		MSEK		
B3aa	Reduced acute health risks	0.117	0.117	0.117
B3ab	Reduced non-acute health risks	0.702	0.702	0.702
B3bc	Increased access to other eco-system services/goods			
	TFM	9.112		
	MVUT		5.602	
Sum		9.931	6.421	0.820
NPV		-16.404	-19.914	-12.697

The three different benefits increased land value (B1a), increased possibilities for recreation within the site (B3ba), and increased access to other eco-system services and goods (B3bc) were not possible to monetise. However, they are all greater than zero, see Table 5.6.

Table 5.6 Three non-monetised benefits.

Non-monetised benefits		
B1a	Increased land value	> 0
B3ba	Increased possibilities for recreation within the site	> 0
B3bc	Increased access to other eco-system services/goods (Saltsjön)	> 0

5.5 Sensitivity analysis

Altogether six uncertain variables were identified for the cost valuations and eight uncertain variables were identified within the benefit valuations. Some of these uncertain variables are included in more than one valuation, whereas others are just used for one particular valuation. Moreover, some of these variables are just included in one remediation alternative, whereas some are included in both. For both VE cases five different cost variables, and seven different benefit variables, were identified. For the D&D alternative all uncertain cost variables, and four of the uncertain benefit variables, were identified. All uncertain variables part of the tree appraisal does of course include more than one assumption per variable, whereas all other variables only contain one assumption each. All identified uncertain variables and their distributions are presented in Table 5.7 - 5.8.

Table 5.7 The uncertain variables identified within the cost valuations. GS is short for Green Space. Statistical distributions are presented for each variable, respectively. S within a parenthesis means that the triangular distribution is skewed. The log-normal distribution has a mean value and a standard deviation.

Uncertain variable	Unit	Distribution	Min	Likeliest	Max
SITA costs assigned to GS	%	Triangular	5	7.5	10
Total costs for all of Beckholmen	MSEK	Triangular (S)	134.762	134.762	148.238
Tons transported to/from Beckholmen	Tons	Triangular	69,809	73,483	77,157
Proportion of total tons assigned to GS	%	Triangular	9	10	11
Load per truck	Tons	Triangular (S)	9	10	12.5
Project management	MSEK	Log-normal	Mean 0.4 & Std.dev. 0.03		

*Table 5.8 The uncertain variables identified within the benefit valuations. GS is short for Green Space. The unit of each variable is presented, where * means unit less. For the variables assigned with triangular distributions min/likeliest/max-values are presented. S within a parenthesis means that the triangular distribution is skewed. For the discrete uniform distributed variables all values are as likely to occur. EV means estimated value.*

Uncertain variable	Unit	Distribution	Min	Likeliest	Max
Probability to die from cancer	%	Triangular	30	40	50
Duration of exposure	Years	Triangular (S)	5	20	60
Contribution in LR	%	Triangular	-10	EV	10
Tree perimeter	cm	Triangular	-10	EV	10
MVUT damages	*	Discrete uniform	EV & EV +/- 1		
Factors in CR	*	Discrete uniform	EV & EV +/- 1		
Children between 5-7 visiting/day	Children	Discrete uniform	0, 1, 2, 3, 4		
Number of people living at the GS	People	Discrete uniform	4, 5, 6, 7, 8		

The 95% NPV uncertainty interval of VE TFM ranges within -17.880 and -16.153 MSEK. Four of the identified uncertain variables affect the uncertainty interval significantly. The duration of exposure for those living at the green space, from reduced non-acute health risks, has a contribution of 41.9% to the total variance. Moreover, SITA costs assigned to green space, from performing the measure, stands for another 21.1%. The number of people living at the green space, from reduced non-acute health risks, affects the results with 11.3%, whereas the number of children between 5-7 years visiting the green space per day, from reduced acute health risks, has an impact of 4.7%. The statistical distribution of NPV VE TFM is shown in Figure 5.1.

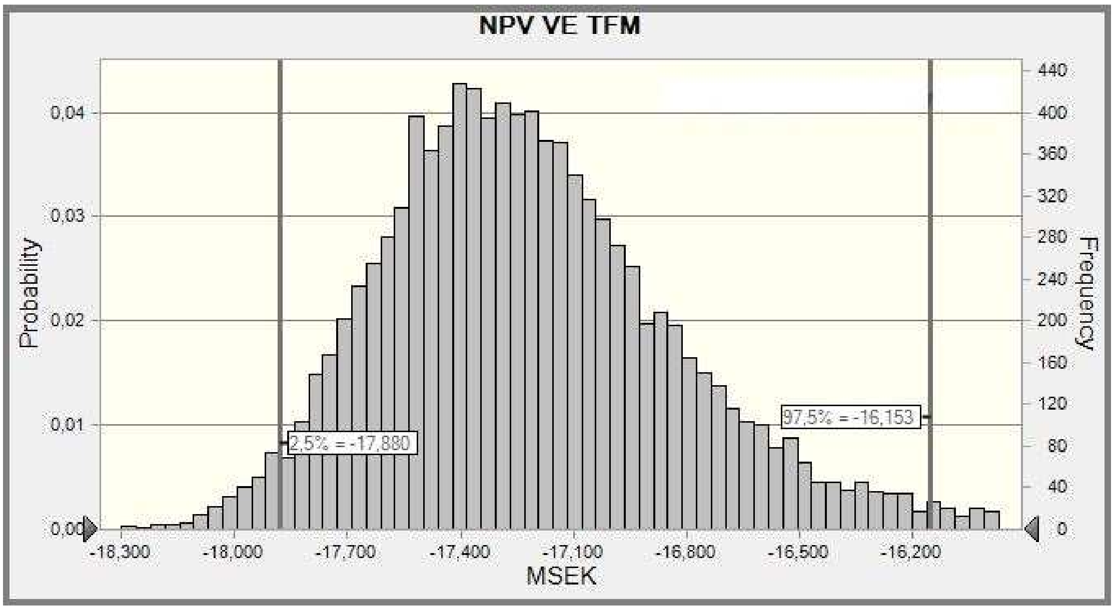

Figure 5.1 Statistical distribution of NPV for VE TFM. The field between the two vertical lines represents the 95% uncertainty interval of the NPV.

The VE MVUT has a 95% NPV uncertainty interval between -20.888 and -19.238 MSEK. The four uncertain variables affecting VE TFM also contribute substantial uncertainty in this case, however with different proportions. The duration of exposure for those living at the green space has a contribution of 47.4% to the total variance. SITA costs assigned to green space contribute another 25.2%. The number of people living at the green space contributes 12.9% to the total variance, whereas the number of children between 5-7 years visiting the green space per day has an impact of 5.6%. The statistical distribution of NPV VE MVUT is presented in Figure 5.2.

The D&D alternative has a 95% NPV uncertainty interval which range within -14.791 and -11.784 MSEK. The uncertainty variable called proportion of total tons assigned to green space, which affects costs for performing the measure, and reduced access to eco-systems off-site, contributes with 59.9% to the total variance of the NPV. The total costs for all of Beckholmen, from costs for performing the measure, have an impact of 21.6%. Duration of exposure, from reduced non-acute health risks, contribute another 11.9% to the total variance of the NPV. The number of children between 5-7 years visiting the green space per day, from reduced acute health risks, contributes with 2.8% to the total variance. The statistical distribution of NPV D&D is shown in Figure 5.3.

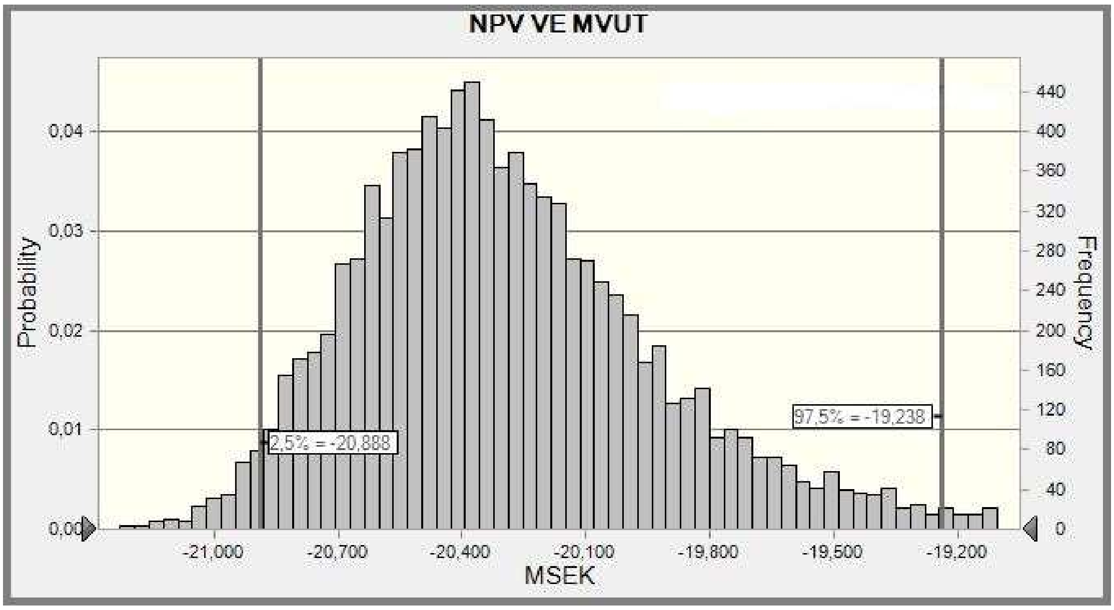

Figure 5.2 *Statistical distribution of NPV for VE MVUT. The field between the two vertical lines represents the 95% uncertainty interval of the NPV.*

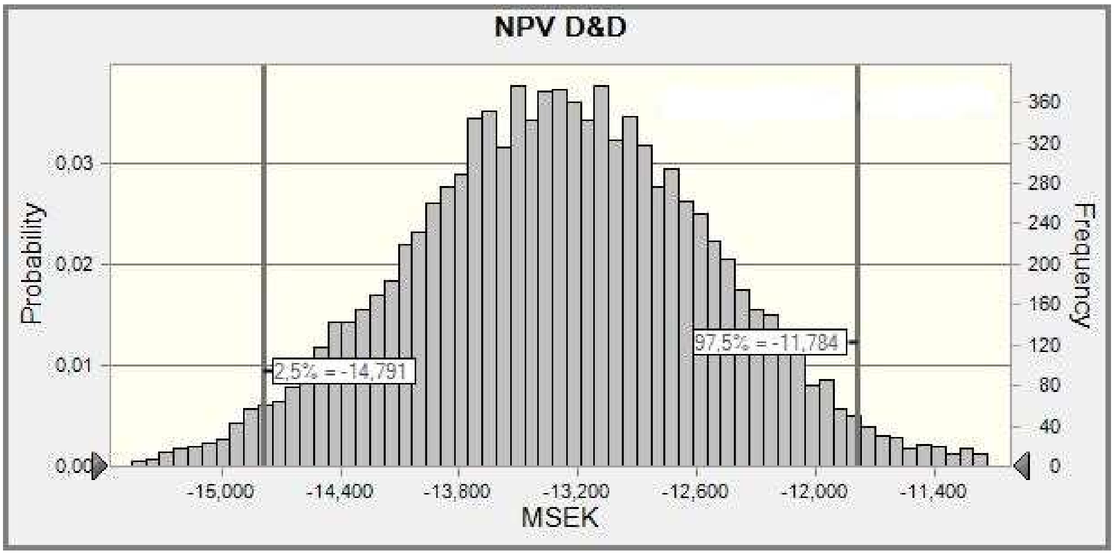

Figure 5.3 *Statistical distribution of NPV for D&D. The field between the two vertical lines represents the 95% uncertainty interval of the NPV.*

In Figure 5.4 an overlay chart of the NPV distributions is shown. The probability that NPV VE TFM will exceed NPV D&D, or be less than NPV VE MVUT, is significantly low considering what is included in the MCS. Consequently, the probability that NPV VE MVUT will exceed NPV D&D is non-existent for this case.

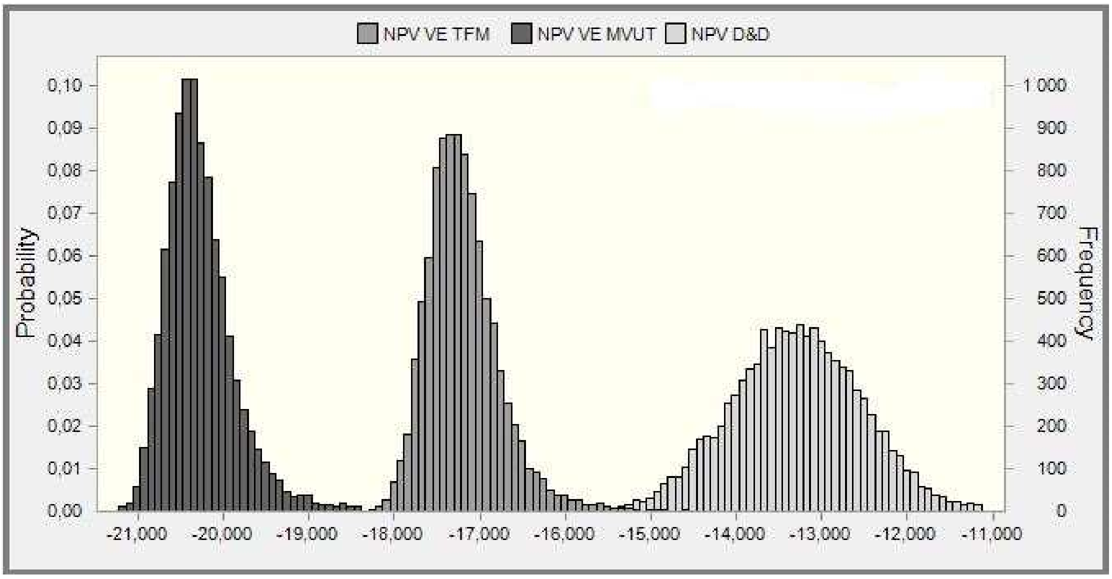

Figure 5.4 *An overlay chart showing the statistical distributions of the NPVs for the remediation alternatives VE and D&D. The unit on the horizontal axis is MSEK.*

For both remediation alternatives the lower boundaries of the uncertainty intervals are higher using the lower discount rates. For instance, the difference between the minimum values considering 4% and 0% is 0.545 MSEK for VE TFM, whereas the same value is 0.681 MSEK for D&D. Considering the upper boundaries of the uncertainty intervals, applying the lower discount rates, the differences in these values are larger compared to the lower boundaries. The VE MVUT increases with 2.974 MSEK using a discount rate of 0% instead of 4%, whereas the same value for D&D is 2.634 MSEK. However, it should be noted that the uncertainty intervals are extended when a discount rate of 0% is used instead of 4%. Considering VE TFM and VE MVUT, both cases exhibit a wider range, the former with 2.432 MSEK, and the latter with 2.460 MSEK. Further, the range of D&D is extended by 1.953 MSEK. See Table 5.9 for figures considering the different discount rates.

Table 5.9 *95% uncertainty intervals, including mean values and range, for both remediation alternatives, with the additional discount rates 1.4% and 0.0%. The values from discount rate 4.0% are included as well for a more transparent comparison. All values are presented in MSEK.*

Remediation alternative	*r* (%)	Min	Mean	Max	Range
VE TFM	4.0	-17.880	-16.404	-16.153	1.727
	1.4	-17.628	-15.821	-14.874	2.754
	0.0	-17.335	-15.038	-13.176	4.159
VE MVUT	4.0	-20.888	-19.914	-19.238	1.650
	1.4	-20.648	-19.331	-17.593	3.055
	0.0	-20.374	-18.548	-16.264	4.110
D&D	4.0	-14.791	-12.697	-11.784	3.007
	1.4	-14.451	-12.114	-10.272	4.179
	0.0	-14.110	-11.331	-9.150	4.960

6 Discussion and Analysis

6.1 Uncertainty

Considering the VE alternative the uncertain variable that contributes to the NPV uncertainty the most is duration of exposure for those living at the green space. Moreover, this variable is only affecting the benefit reduced non-acute health risks (B3ab). It stands for 72.9% of the total variance of the statistical distribution of this benefit. Consequently, this distribution has a relatively large 95% uncertainty interval of 1.391 MSEK, see Appendix D. Thus, this assumption must be considered to be the most important regarding the VE alternative. A drawback likely contributing to the large uncertainty is the fact that this assumption has not been based on any literature. In retrospect, due to its great impact, the overall uncertainty for the VE alternative could probably have been reduced evaluating this assumption, and more specifically its distribution. Except the uncertain variable duration of exposure, the benefit B3ab is associated with two other uncertainties as well. The upper boundary of this benefit, which is located at 97.5%, is more than 100% above the mean value, which must be considered to correspond to a relatively large uncertainty. In addition to this, many assumptions and uncertainties, which were not possible to assign as uncertainties in the MCS, have been part of the calculations of the B3ab. This is consistent with the statement that estimating the magnitudes of health effects often requires a lot of guesswork (Driesen, 2006).

Regarding the cost valuation of performing the measure (C1d) considering the VE alternative, two uncertain variables have been included in the MCS. These uncertain variables are SITA costs assigned to the green space, and project management. Apart from these, another uncertainty difficult to include in the simulation exists as well. Altogether 48 different documents regarding performance costs invoiced by NCC, concerning all of Beckholmen, were provided by Sweco. From this, the costs belonging to the green space were singled out, which was difficult for certain bills. Due to this it would have been preferable to assign the NCC costs as an uncertain variable, but it was considered too difficult to identify an appropriate distribution. If this would have been conducted, the 95% uncertainty interval of C1d for the VE alternative would surely be wider. In turn, this would affect the final NPV distributions of the remediation alternatives.

The NPV D&D distribution rests upon the assumption about the proportion of total tons assigned to the green space, which by far is the most sensitive assumption for the NPV D&D. This assumption affects both the uncertain cost valuations associated with the NPV D&D. However, in absolute figures it affects the costs for performing the measure (C1d) significantly more than the reduced access to eco-system services and goods off-site (C3b). The 95% uncertainty interval for the C1d is 2.632 MSEK, of which 70.7% depends on the uncertainty of the proportion of total tons assigned to the green space. The statistical distribution of the C1d is exhibited in Appendix D. Consequently, as mentioned in Chapter 4, the assumption of 10% was made by Egelstig. It was, however, difficult to estimate the level of uncertainty in this assumption. Due to this, a relatively low maximum value of 11% was chosen for the triangular distribution. In retrospect, perhaps this maximum value should have been higher, although, it must be considered difficult to determine what is right or wrong for this case. Also, it should be noted that the lower boundary of the 95% uncertainty interval for NPV D&D is more than twice as far from the mean value as the value of the upper boundary.

6.2 Reduced health risks

Considering the reduced acute health risks (B3aa), a measure taken due to practical reasons was to use all sample values of arsenic. For a child to avoid involuntary ingestion it is only the upper 0.5 metre of soil remediation that contributes to the reduced risk benefit (Liljelind et al., 2008). More or less 50% of the total number of samples was within this depth. If this would have been taken into account it would probably have affected the results, however, it is difficult to tell to what extent, and in what direction.

The valuation of the benefit from the reduced non-acute health risks (B3ab) consists of even more additional uncertainties than the calculations of the benefit from reduced acute health risks (B3aa). The software SADA required both depth and coordinates for all samples, but due to practical reasons simplifications were made for both these factors. Especially the simplification about all depths being set to zero most likely affect the results because this brings all contaminants closer to people, which probably increases the risk. Furthermore, it was possible to choose from different sub-categories of both lead and PAH-H in the implemented toxilogical database in SADA. These choices were based on uncertain assumptions due to lack of information. Additionally, only the contaminants considered most important by Sweco were taken into account; that is, lead and PAH-H. Rosén et al. (2008) include arsenic in one of their case studies. However, it has not been evaluated if neither arsenic nor any other additional contaminants ought to have been included in the calculations.

From the results it can be concluded that if a lower discount rate is used a larger monetary benefit is achieved from the reduced health risks (B3a). Hence, the size of this additional benefit if using 0% as discount rate is 1.302 MSEK for the reduced non-acute health risk (B3ab), whereas the extra benefit from reduced acute health risks (B3aa) is insignificant. In the literature, discount rates above 4% are not mentioned, on the other hand, it is recommended to examine lower discount rates. From this, it can be assumed that using 4%, as in this thesis, contributes with a minimum benefit considering with respect to the selection of discount rate. Hanley et al. (1997) stress that effort should be put on determining time horizons for which benefits should be discounted. Rosén et al. (2008) suggest in their examples the usage of 10 years for the B3aa, and 70 years for the B3ab. They further present the effect on the results for the B3ab of using the time horizons 350 and 700 years, respectively. Although, it is not mentioned when these time horizons are preferable. As an example, 700 years enlarges the result 10 times if using a 0% discount rate, which is the most extreme case. Thus, if both a 0% discount rate, and a time horizon of 700 years is applied for the valuation of the B3ab, a mean benefit value of 19.478 MSEK will be achieved. It is further possible to calculate the time horizons, for which the reduced health risks become large enough to result in positive final NPVs of the remediation alternatives, if all other costs and benefits are held constant. Then stakeholders can collectively decide if the time horizons are acceptable or not. This illustrates the importance of stakeholders collectively defining appropriate time horizons and discount rates.

6.3 Tree appraisal

The mean value of the NPV in the TFM valuation is 9.112 MSEK, whereas the mean value of the overall NPV VE TFM is -16.404 MSEK. Thus, the TFM valuation must be considered to contribute to the overall NPV VE TFM to a relatively large extent. In the sensitivity analysis no uncertain variables associated with the tree appraisal were represented among the most sensitive. Watson (2001) states that the variation of TFM appraisal often reaches values of 100 to 200%. It is further suggested by Watson (2002) that this variation probably is due to the large subjective evaluation of tree attributes by the appraiser. As mentioned in Chapter 4, the TFM appraisal was made by a tree consultant. Moreover, it was his first TFM appraisal ever conducted. Considering this, perhaps it would have been motivated to define the total TFM value as an uncertain variable, instead of assigning the primary data as uncertain assumptions, which was made for this thesis. Possibly this should have been conducted with minimum and maximum values reaching as much as 100 to 200%. This measure would certainly have given a much wider 95% uncertainty interval for the NPV VE TFM; thus, adding more uncertainty. Additionally, Watson (2002) suggests that the TFM appraises very low values in comparison with other formula methods. From this suggestion, it could be asked if the overall NPV VE TFM should be higher. On the contrary, Chadwick (1975) argues that values for very large trees often are unrealistically high. At the green space several trees must be considered to be large trees. From this, it could on the contrary be questioned if the overall NPV VE TFM is too high. As suggested by Rosén et al. (2008) valuation becomes more complicated if products and services are not subject to business at a market, which is the case for most of the trees. As a conclusion, this statement by Rosén et al. (2008) can be considered accurate considering the tree appraisal.

The remediation alternative VE including MVUT only differs in one value in comparison with VE TFM; that is, the value of the trees. Moreover, these two cases have more or less the same uncertainty interval. Both the TFM and the MVUT method estimate the present market value of the tree. As mentioned in Chapter 4, the former method includes how physical characteristics of the appraised tree are likely to be enjoyed or experienced. Meanwhile, the MVUT method only appraises the market value, excluding aesthetics. Therefore, it is likely that the extra value from the TFM is about the value of the aesthetics. When developing the MVUT method it was highly prioritised to create a method which did not overestimate the value of a tree (Östberg et al., 2012). Judging from this, it is likely that the value of the trees at least not is below the value appraised by the MVUT method. Östberg[20] argues that many professional tree appraisers use many different methods for the same set of trees, and finally, they use the mean value of all methods. Thus, another option would have been to use the mean value of both the TFM and the MVUT appraisals.

It is important to stress that the benefit from the trees not have been discounted. Thus, this is an additional value not taken into account. This value would have been included in the results if a formula method estimating the age of trees had been used. However, as suggested by Stjernberg (2011), this is not an easy practice. Due to the tree consultant's lack of experience estimating the age of trees it was decided to use a formula method not including this task. Therefore, the TFM was used, which does not take age into consideration. If the 23 trees would have been appraised again, for

[20] Johan Östberg (PhD Student, Swedish Agricultural University) discussing with the author on the 15th of September 2012.

example next year, they would have been larger, and since the appraised value partly is a function of the perimeter, the market value would have been higher. Then, this extra value must be discounted somehow. On the other hand, if the condition rating of the trees would have been lower, the market value could possibly be lower although their larger size. According to Kelman (1981) there are good reasons to oppose efforts to put monetary values on unpriced costs and benefits. Founded on this proposal it was decided not to discuss the size of this additional value. Thus, it must be considered defensible to conclude that this value is existent, and most likely above zero.

6.4 Non-monetised benefits

Three different benefits have not been monetised in the case study, however, these benefits are all considered to have positive monetary values.

Increased land value (B1a) has not been monetised. Correspondingly, Rosén et al. (2008) argue that the B1a often is problematic to express in monetary terms. In Rosén et al. (2008) the B1a has been calculated for two different case studies. In the first case study a value estimated by the owner of the remediated land was used. In the second case study, the land value at the property was considered to be non-existent before the remediation, because it was not possible to make use of the land. After the remediation, depending on if the land was to be used for housing or industrial purposes, a value was estimated. The approach to ask the land owner about the increased land value was considered an option. Unfortunately the National Property Board Sweden has not appraised the B1a themselves. Due to the regulations governing the land within the National City Park, the green space will be used for the same purposes after the remediation as before. Thus, the method which was used in the second case study by Rosén et al. (2008) was also inappropriate for this thesis. Although the present purpose of the green space is to continue using it as before, there is an option for this land to be used for other purposes in the future. Thus, this option can be considered to have a value. As mentioned in Section 3.1, the green space is located in the city centre of Stockholm. Due to its central location the land can be assumed to be relatively attractive regarding housing or different business opportunities. The increased land value equals all discounted monetary benefits the land owner gain as a result of the remediation. As an example, the National Property Board Sweden has an option, which is dependent on governmental regulations, to lease the land to any business in the future. For this case the benefit to be discounted is rent. To conclude, it must be reasonable to assume that the B1a include optional future monetary benefits reaching several millions of SEK. However, it is unclear at which point in time these potential benefits could become realised. If they become realised after a long period of time, the NPV of this benefit is small due to the effect of the discount rate.

Increased possibilities for recreation within the site (B3ba) is another benefit that has not been monetised. Rosén et al. (2008) have not monetised the B3ba in their two case studies either. They mention three types of main categories of valuing studies available for monetising environmental improvement such as recreation possibilities. However, these studies are considered very time consuming, often including questionnaire studies, and were considered beyond the scope of this thesis. Another option mentioned by Rosén et al. (2008) is to make a value transfer analysis, which means generalising results from a similar valuing study already made, and by this, make an estimation about the recreation value. This option was evaluated. Nevertheless, it was not possible to find any similar valuing studies in the database recommended by Rosén et al. (2008). As mentioned in Section 3.1.1, the trees were assumed not to have any market value before the remediation, but still they must be assumed to have had a recreational value. This is because it was not possible to see that these trees were contaminated. However, Stål (1998) argues that the life length of trees is extended due to VE, which in the long-term contributes to better recreation possibilities in the future. In parallel there might have been an additional value before the remediation due to the presence of more trees, although most of these extra trees were in bad condition. As mentioned in Section 3.1, the green space is supposed to serve as a shorter walking trail for the public after the remediation. Due to this purpose, marketing measures for the walking trail will probably be taken to attract more people, and more people equal a higher recreation value. The number of additional people who will use the green space as recreation area is difficult to estimate, however, Djurgården must be considered as the main recreation area in Stockholm. It is difficult to estimate a value of the B3ba, but it is certainly above zero. Further, the value is likely to be larger for the VE alternative in comparison with the D&D alternative due to the presence of large trees in the former case. If it is significantly larger, it could affect the ranking between the remediation alternatives. In order to change the ranking between the VE TFM case and D&D alternative then the B3ba value of the VE TFM has to reach a value that is 3.707 MSEK larger than the same value for the D&D alternative. Comparing the VE MVUT case and the D&D alternative this value has to equal 7.217 MSEK. The valuing studies from the database mentioned above were observed from a holistic perspective. Considering a relatively long time horizon it must be reasonable to assume this value to be at least larger than 3.707 MSEK, but perhaps not above 7.217 MSEK; thus, possibly affecting the ranking between the VE and the D&D alternatives depending on which tree valuation method is applied.

Beside the benefit from the trees, increased access to other eco-system services and goods (B3bc) have been concluded to also include the benefit from a less contaminated Saltsjön. Consequently, this benefit has not been monetised. The benefit must be considered to be a long-term benefit mainly affecting the sediment close to Beckholmen. The size of the benefit is very difficult to estimate, yet a cleaner Saltsjön was one of the main purposes with the remediation. To judge from this, the value of the B3bc, considering Saltsjön, can presumably be expected to be relatively large in order to reach a positive NPV.

For the VE TFM to reach a positive NPV the non-monetised benefits have to add up to a value larger than 16.404 MSEK, whereas this value for the VE MVUT case is 19.914 MSEK. Considering the D&D alternative this value has to reach 12.697 MSEK. Based on the above discussion it is considered to be reasonable to assume that the non-monetised benefits add up to values larger than the figures mentioned above for both the VE cases and the D&D alternative, respectively.

6.5 Additional uncertainties

From what have been discussed so far it can be concluded that the conducted CBA includes many additional uncertainties that have not been taken into account in the MCS. Further, the additional underlying uncertainty most likely contributes to a relatively larger degree of uncertainty than what the statistical NPV distributions exhibit. To judge from this, perhaps not too much value should be put in the final NPVs of the remediation alternatives; thus, no conclusions about which remediation alternative is better in comparison with the other, but also in comparison with the reference alternative, should be drawn. It should further be remembered that when conducting an environmental CBA, a certain decision might be right even though its monetised benefits do not outweigh its monetised costs (Kelman, 1981). Moreover, it should also be noted that Driesen (2006) argue that CBA disfavours health and environmental protection. Due to the fact that health and environmental protection partly reasoned the decision to grant funds for the remediation this statement should also be kept in mind trying to conclude what would have been the better option. Consequently, the conducted case study did not contribute to prioritise between the remediation alternatives. On the other hand, the study structured the problem in an easy and comprehensive way. In accordance with this proposal it was concluded by Hanley et al. (1993) that CBA is a useful contribution to the decision-making process but that it is not sufficient as the single criterion.

6.6 Monte Carlo simulation

Some researchers argue that MCS is a poor technique (Elishakoff, 2003). This proposal must be considered to be opposed by the conducted case study. The calculations of the CBA brought very precise figures. Next, when the MCS was completed another perspective was revealed. Thus, in line with Burgman (2005), the MCS provided another possibility to justify a decision. If the MCS would not have been conducted, straight forward conclusions would probably have been based on unambiguous figures, however, this was opposed by the MCS which broadened the perspective on the decision.

6.7 Selection of reference alternative

The chosen reference alternative is not the only possible option; it could have been defined differently. The 23 trees that were still standing after the VE could have been defined as included in the reference alternative; that is, not assigning the saved trees as a benefit using VE. Instead applying D&D would give a cost for loss of trees. This approach would give only one case for the VE alternative, and two cases for the D&D alternative. The latter cases are D&D TFM and D&D MVUT. The actual differences this reference alternative would contribute with, in comparison with the reference alternative defined in the case study, only consider the trees. The only benefit possible to quantify for each of the alternatives would be the reduced health risks, whereas both the D&D cases would get an extra cost for loss of trees. The mean NPV VE would take a value of -25.517 MSEK. Consequently, the NPV of the D&D TFM case would be -21.810 MSEK, and the NPV of the D&D MVUT case would equal -18.300 MSEK. In terms of NPV, the VE alternative is still inferior to the D&D alternative, but a lower NPV of the trees gives a higher total NPV. This means that the lower valuation of the MVUT is preferable to the valuation using TFM. This was mainly the reason why this reference alternative was not used. However, it should be noticed that the reference alternative could be defined in many ways, and that this may affect the results.

6.8 Distributional analysis

From a distributional point of view, it was observed that the Swedish tax payers bore the financial costs due to the origin of funds, which was the Swedish EPA. The costs of the transport emission can probably be assumed to be distributed worldwide in terms of climate change. On the contrary, benefits have been distributed amongst several groups of people. The property owner and its tenants can probably be pointed out as main beneficiaries. The property owner benefits in terms of increased land value. The tenants benefit mainly from the reduced health risks, but also from the increased recreational possibilities from living in a cleaner environment where effort is put on cultural values. Also visitors benefit from the reduced health risks. From a recreational point of view it is mainly the people living in Stockholm who must be considered as the main beneficiary. Furthermore, the city of Stockholm has been beneficial in terms of a healthier Saltsjön.

7 Conclusion

This thesis attempts to test and evaluate the CBA method developed by Rosén et al. (2008). The working process and the results obtained clearly indicate that the CBA method is an easy and user friendly decision tool for prioritising between remediation alternatives. However, the CBA method requires a lot of data. Thus, detailed and extensive knowledge about the project is required, which on the other hand is necessary to obtain results comprehensive enough to be able to use the CBA method as a decision tool.

Considering the case study, the uncertainty shown by the Monte Carlo simulation is relatively insignificant. On the other hand, it can be concluded that additional underlying uncertainties not included in the uncertainty analysis, most likely contribute to a larger degree of uncertainty than what the statistical NPV distributions exhibit. The additional uncertainties mainly originate from the benefit valuations. For example, the benefit from the reduced non-acute health risks can reach values approximately 27 times greater than the calculated NPV, which in turn depends on the preferences of the stakeholders. Further, the benefit from saving the trees is not unlikely to vary as much as 200%. Finally, three benefits have not been monetised; increased land value, increased possibilities for recreation within the site, and reduced leakage to Lake Saltsjön. The size of these benefits is uncertain, which makes it difficult to predict whether the NPV is positive or negative. However, despite the large uncertainties, it is still possible to produce a likely ranking between the remediation alternatives. Thus, the uncertainty of the result of the CBA is relatively high, but still it is concluded certain enough for the CBA method to work as a decision tool prioritising between the remediation alternatives.

This thesis further aims to contribute to the existing literature on the performance of remediation methodologies by determining whether or not VE has been beneficial at the green space. It is concluded that the NPV of the VE is probable to be positive, which in turn indicate that the remediation methodology has been beneficial in comparison to not taking any measures at all. The NPV of the D&D alternative is also likely to be positive; however the NPV of the VE alternative is expected to be greater.

Finally, the findings from this thesis have contributed to the literature by identifying costs and benefits associated with VE, and by describing the relative size and range of its values.

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Appendix A Costs

Table A.1 All costs associated with the remediation alternative VE at the green space. PM means project management, which has been performed by Sweco. Also, costs for conducting and performing a control program are included. All figures are presented in MSEK.

Costs for performing the measure					Control program
Binsell AB	NCC AB	VIÖS AB	SITA	PM	Sweco
0.688	0.313	0.162	0.647	0.400	0.013
0.180	0.068	0.045	0.095		0.363
0.874	0.044	0.083	0.002		0.096
0.582	0.040	0.033	0.108		0.008
0.933	0.089	0.008	0.088		0.048
0.408	0.016	0.090	0.043		0.174
1.365	0.069	0.041	0053		0.163
1.506	0.180	0.011	0.078		0.091
1.838			0.026		0.115
2.869			0.011		0.021
1.563			0.001		0.002
0.778			0.031		0.001
1.245			0.063		0.092
0.648					0.086
1.113					0.070
1.394					0.002
3.955					
Total monetary costs					
24.878					1.344

Table A.2 All data applied for the calculations considering the costs associated with transport emissions. All calculated figures are presented as well. Total costs are presented in MSEK.

Data		Calculations	
Tons transported to/from Beckholmen	73,483	Number of round-trips to deposit	735
Proportion of total tons to/from green space	0.1	Total number of kilometres	70,544
Tons transported to/from the green space	7,348	Total amount of liters diesel	28,217
Number of kilometres to deposit	48	Total kilos of NO_X-emissions	141
Diesel/kilometre and truck	0.4	Total kilos of CO_2-emissions	70,544
NO_X released in kilos per liter of diesel	0.005		
CO_2 released in kilos per liter of diesel	2.5		
Costs in SEK per kilo NO_X	49		
Costs in SEK per kilo CO_2	1.5		
Load per truck in tons	10		
Total monetary costs		0.113	

Appendix B Health risks

Table B.1 All figures associated with the reduced acute health risks calculations.

C_{AE}	
C_{AE} (mg/kilo)	3000
Ln C_{AE}	0.4771
Before remediation	
Ln mean value	0.8615
Ln Std.dev.	0.3659
Probability of exceeding C_{AE}	0.8533
After remediation	
Ln mean value	0.2928
Ln Std.dev.	0.3659
Probability of exceeding C_{AE}	0.3072
Probabilities	
Reduction of probability of exceeding C_{AE}	0.5460
Probability a child will eat soil per year	0.0006
Probability a child will eat soil with arsenic above C_{AE} before	0.0005
Probability a child will soil with eat arsenic above C_{AE} after	0.0002
Monetary benefit (MSEK)	
Benefit from reduction per year	0.013
Total discounted monetary benefit	0.117

Table B.2 All figures associated with the reduced non-acute health risks calculations.

	Lead	PAH-H
Non-acute health risk level before remediation	0.0000160	0.0074000
Non-acute health risk level after remediation	0.0000042	0.0017000
Monetary benefit per year (MSEK)	0.0000595	0.0287280
Total discounted monetary benefit (MSEK)	0.702	

Appendix C Tree appraisal

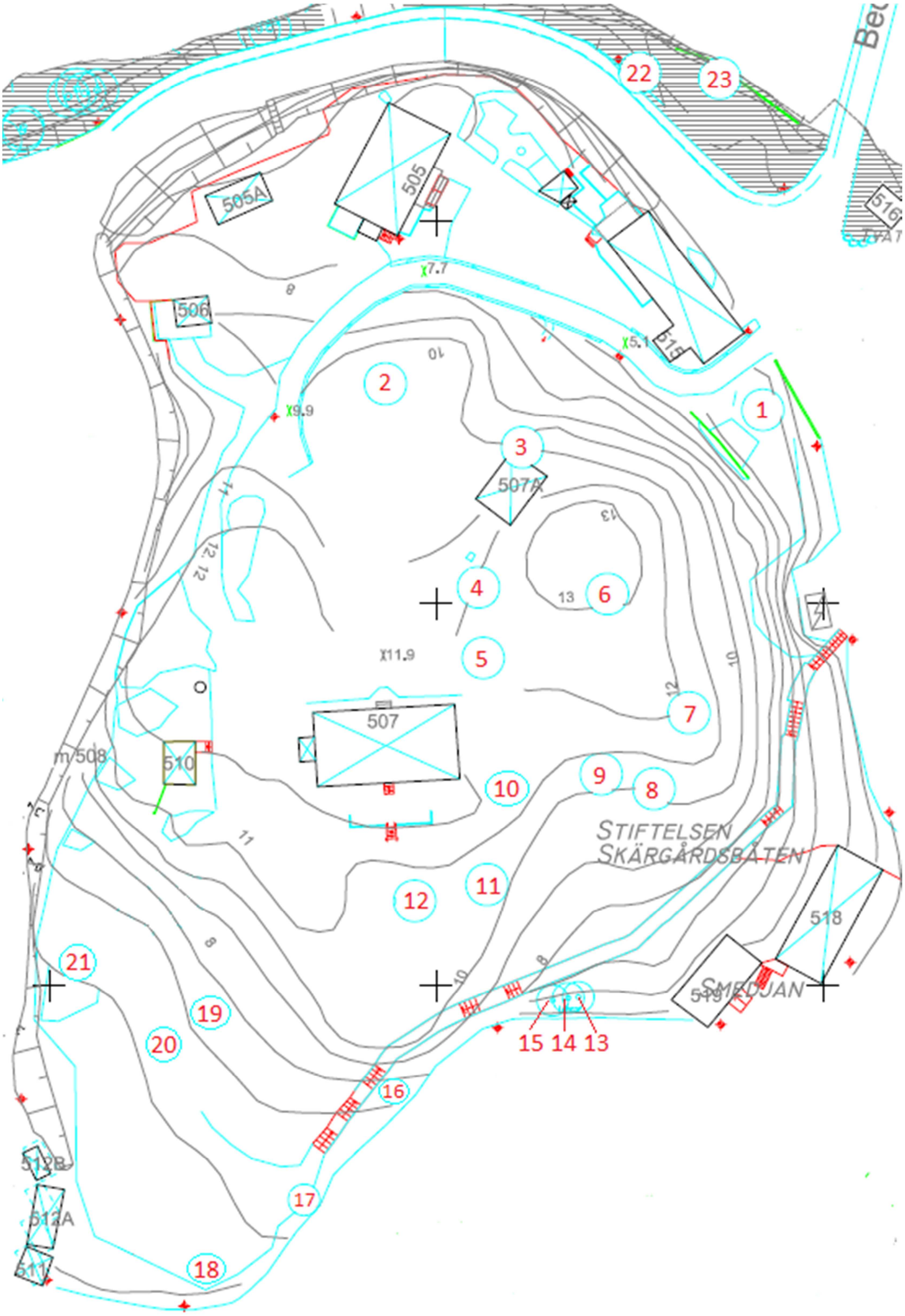

Figure C.1 *Map provided by Sweco showing the green space at Beckholmen. All amenity trees inventoried have been assigned with figures ranging from 1-23 and have then been deployed at the map. The species of each tree is presented in Table C.1.*

Table C.1 Primary data collected at Beckholmen considering species and perimeter for both TFM and MVUT, damages for MVUT, and location rating for TFM. Perimeter is presented in centimetres. LR equals Location Rating, S is Site, C is Contribution, and P stands for Placement.

Tree	Species (English/Latin)	LR			Perimeter	Damages MVUT		
		S	C	P		Roots	Trunk	Crown
1	Whitebeam / Sorbus aria	1	0.5	1	120	2	2	3
2	Maple / Acer platanoides	1	0.5	1	173	1	2	1
3	Maple / Acer platanoides	1	0.4	1	126	2	3	2
4	Maple / Acer platanoides	1	0.4	1	283	3	3	4
5	Lime-tree / Tilia cordata	1	1	1	251	2	2	2
6	Higher ash / Fraxinus excelsior	1	0.5	1	89	2	2	2
7	Lime-tree / Tilia cordata	1	1	1	128	2	2	1
8	Lime-tree / Tilia cordata	1	1	1	251	3	2	1
9	Lime-tree / Tilia cordata	1	1	1	314	1	2	1
10	Oak-tree / Quercus robur	1	1	1	142	1	3	1
11	Maple / Acer platanoides	1	1	1	298	2	3	1
12	Lime-tree / Tilia cordata	1	1	1	314	2	3	1
13	Maple / Acer platanoides	1	0.75	1	97	2	3	1
14	Maple / Acer platanoides	1	0.75	1	120	2	3	1
15	Maple / Acer platanoides	1	0.75	1	110	1	1	1
16	Oak-tree / Quercus robur	1	0.75	1	22	1	1	1
17	Oak-tree / Quercus robur	1	0.8	1	54	1	1	1
18	Oak-tree / Quercus robur	1	0.8	1	39	1	2	2
19	Maple / Acer platanoides	1	0.5	1	60	1	2	2
20	Maple / Acer platanoides	1	0.5	1	57	1	2	2
21	Oak-tree / Quercus robur	1	0.8	1	46	1	1	1
22	Maple / Acer platanoides	1	0.9	1	204	3	4	2
23	Maple / Acer platanoides	1	0.9	1	129	1	3	2

Table C.2 *Primary data collected at Beckholmen considering CR for the TFM calculation. All figures range between 1-4. SB&T equals Scaffold branches and twigs. F&B stands for Foliage and/or buds.*

	Roots		Trunk		Scaffold Branches		SB&T	F&B
Tree	Structure	Health	Structure	Health	Structure	Health	Health	Health
1	4	3	3	3	3	3	3	2
2	3	3	3	4	3	3	3	3
3	2	3	2	3	2	3	3	3
4	3	2	3	3	3	2	2	2
5	4	3	3	3	3	4	4	4
6	3	3	4	3	3	3	3	3
7	4	4	3	3	3	3	3	3
8	4	4	3	3	4	3	4	4
9	4	4	2	3	3	4	4	4
10	4	4	4	4	4	4	3	4
11	4	4	2	4	2	4	4	4
12	4	4	3	3	3	4	4	4
13	2	3	2	3	2	4	4	4
14	2	3	3	3	3	4	4	4
15	2	3	3	3	3	4	4	4
16	4	4	3	4	4	4	4	4
17	4	4	4	4	3	4	4	4
18	4	4	4	4	3	4	4	4
19	4	4	3	3	3	3	4	4
20	4	4	3	3	3	3	4	4
21	4	4	3	3	3	3	4	4
22	2	3	3	2	3	3	3	3
23	3	4	3	3	3	3	4	4

Table C.3 *Secondary data from 6 different nursery gardens. The nursery garden numbers are shown in Table C.4. The data was collected and provided by Johan Östberg at the Swedish Agricultural University. Data of importance for this thesis was later sorted out. All figures are price/area for a tree with the area 13 cm^2. The unit is SEK/cm^2. The data was used to calculate BP_{13} in the MVUT calculations. * means no data available.*

	Nursery garden number					
Tree	1	2	3	4	5	6
Maple / Acer platanoides	152	155	108	127	126	145
Whitebeam / Sorbus aria	188	190	183	171	167	126
Oak-tree / Quercus robur	169	173	167	156	171	155
Lime-tree / Tilia cordata	152	155	119	127	123	71
Higher ash / Fraxinus excelsior	152	155	119	*	*	82

Table C.4 Secondary data from 6 different nursery gardens used for the TFM calculation. The nursery gardens are numbered as follows: (1) Lorenz von Ehren; (2) Bruns; (3) Flyinge; (4) Splendor Plant; (5) Tönnersjö's nursery garden; and (6) Hallberg's nursery garden. The secondary data was collcted and provided by Johan Östberg at the Swedish Agricultural University. Data of importance for this thesis was later sorted out. The data was used to calculate RC and BP. TA_r was the same at all nursery gardens. Grey field means no data available. Price (P) is presented in SEK, area (A) is presented in cm^2, and price/area (P/A) is presented in SEK/cm^2.

Tree		Nursery garden number					
		1	2	1	2	1	2
Maple	P	58,063	58,992	158,395	158,859	191,56	189,981
	A	241	241	719	719	963	963
	P/A	241	245	220	221	199	197
Whitebeam	P	15,700	15,700				
	A	58	58				
	P/A	270	270				
Higher ash	P	108,879	109,622				
	A	448	448				
	P/A	243	245				
Lime-tree	P	195,183					
	A	963					
	P/A	203					
Oak-tree	P	5,593	5,713	5,390	4,935	5,200	4,990
	A	29	29	29	29	29	29
	P/A	195	199	188	172	181	174
	P	26,291	29,264	36,881	37,160	43,199	54,347
	A	109	109	147	147	176	176
	P/A	241	268	251	252	246	309
	P	221,102	222,031				
	A	963	963				
	P/A	230	230				
		Nursery garden number					
		1	2	3	4	5	6
	P	5,593	5,713	5,390	4,935	5,200	4,990
	A	29	29	29	29	29	29
	P/A	195	199	188	172	181	174

Table C.5 Calculated data for TFM. RC is shown in SEK. TA_r and TA_a are presented in cm^2. BP in presented SEK/cm^2. Basic value and appraised value are exhibited in MSEK. SR, CR, and LR are all presented in %.

Tree	RC	BP	TAr	TAa	Basic Value	SR	CR	LR	Appraised value
1	15,700	270	58	1146	0.310	100	75	83	0.193
2	190,771	198	963	2383	0.472	100	78	83	0.307
3	190,771	198	963	1264	0.250	100	66	80	0.131
4	190,771	198	963	6377	1.263	100	63	80	0.631
5	195,183	203	963	5016	1.018	100	88	100	0.891
6	109,250	244	448	631	0.154	100	78	83	0.100
7	195,183	203	963	1304	0.264	100	81	100	0.215
8	195,183	203	963	5016	1.018	100	91	100	0.923
9	195,183	203	963	7850	1.593	100	88	100	1.394
10	221,567	230	963	1605	0.369	100	97	100	0.358
11	190,771	198	963	7070	1.400	100	88	100	1.225
12	195,183	203	963	7850	1.593	100	91	100	1.444
13	158,627	220.5	719	749	0.165	100	75	92	0.114
14	190,771	198	963	1146	0.227	100	81	92	0.169
15	190,771	198	963	963	0.191	100	81	92	0.142
16	5,303	187.5	29	39	0.007	100	97	92	0.006
17	48,773	277	176	232	0.064	100	97	93	0.058
18	27,777	254.5	109	121	0.031	100	97	93	0.028
19	58,527	243	241	287	0.070	100	88	83	0.051
20	58,527	243	241	259	0.063	100	88	83	0.046
21	37,021	277.5	147	168	0.043	100	88	93	0.035
22	190,771	198	963	3313	0.656	100	69	97	0.436
23	190,771	198	963	1325	0.262	100	84	97	0.214
									9.112

Table C.6 Calculated data for MVUT. Basic values are presented in SEK, whereas appraised values are all shown in MSEK. TA_a is presented in cm^2. BP_{13} is exhibited in SEK/cm^2. RE_{dv} is presented in %. D_{tot} and V are both unit less.

Tree	TA_a	BP_{13}	Basic value	D_{tot}	V	RE_{dv}	Appraised value
1	1146	171	196,051	8	0.75	69	0.135
2	2375	136	322,949	11	0.78	88	0.285
3	1256	136	170,816	8	0.66	66	0.113
4	6359	136	864,756	5	0.63	47	0.405
5	5024	124	622,976	9	0.88	78	0.487
6	631	126	79,462	9	0.78	76	0.060
7	1304	124	161,753	10	0.81	83	0.134
8	5024	124	622,976	9	0.91	79	0.492
9	7850	124	973,400	11	0.88	91	0.882
10	1605	165	264,893	10	0.97	87	0.230
11	7085	136	963,509	9	0.88	78	0.753
12	7850	124	973,400	9	0.91	79	0.768
13	749	136	101,881	9	0.75	75	0.076
14	1146	136	155,924	9	0.81	77	0.119
15	963	136	131,019	12	0.81	95	0.125
16	39	165	6,358	12	0.97	99	0.006
17	232	165	38,307	12	0.97	99	0.038
18	121	165	19,981	10	0.97	87	0.017
19	287	136	38,981	10	0.88	84	0.033
20	259	136	35,180	10	0.88	84	0.030
21	168	165	27,798	12	0.88	97	0.027
22	3317	136	451,061	6	0.69	55	0.247
23	1325	136	180,189	9	0.84	77	0.139
							5.602

Appendix D Distributions from the Monte Carlo simulation

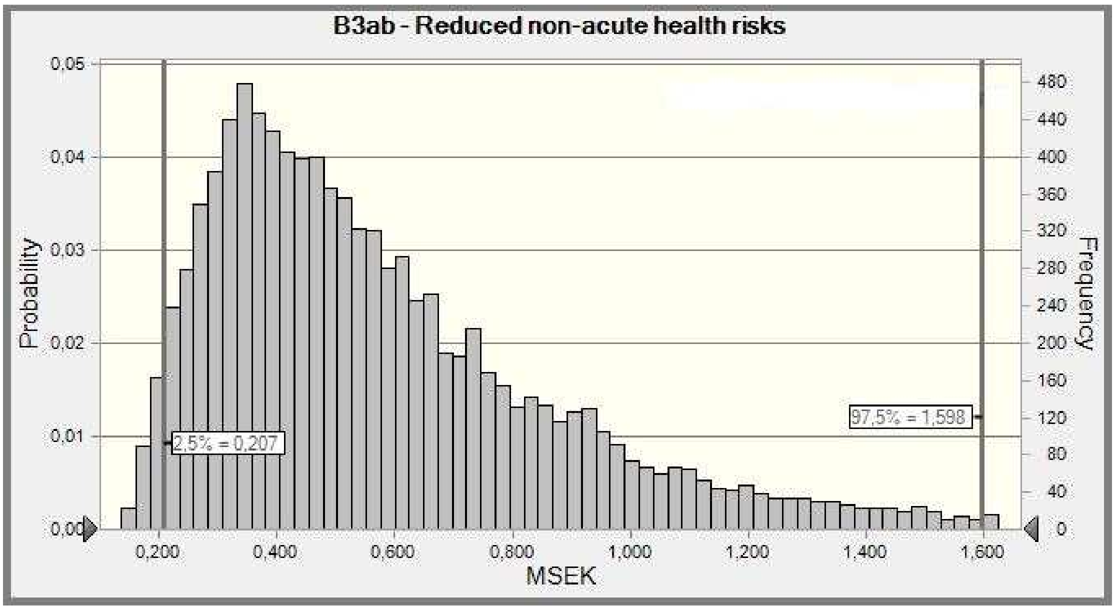

Figure D.1 *Statistical distribution of the NPV for reduced non-acute health risks. The field between the two vertical lines represents the 95% uncertainty interval of the NPV.*

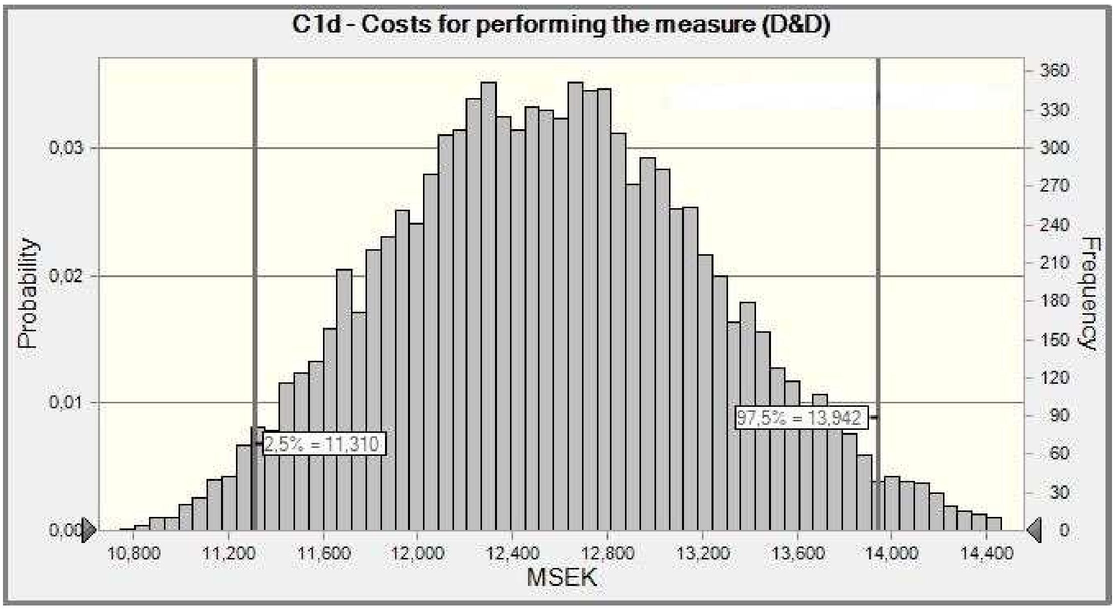

Figure D.2 *Statistical distribution of the NPV for costs for performing the measure for D&D. The field between the two vertical lines represents the 95% uncertainty interval of the NPV.*