CHALMERS

Choosing sustainable remediation alternatives at contaminated sites

Application and Evaluation of a Multi-Criteria Analysis method

Master of Science Thesis in the Master’s Programme Geo and Water Engineering

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Remediation at Hexion, Mölndal. 2011-06-13. Photo: Åsa Landström.

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ABSTRACT

One of the goals in the Swedish environmental policy is that the most severe contaminated sites shall be remediated by year 2050. The approach for choosing remediation method is depending on a large number of aspects; cost, type of contaminant, soil behaviour and time horizon, to mention a few. The by far most common and experienced method in Sweden is excavation and transport to landfill. This might however not always be the most sustainable remediation alternative. At Chalmers University, Gothenburg, a technical approach to create a decision support tool for this purpose has been developed, "*Multikriterieanalys för hållbar efterbehandling, metodutveckling och exempel på tillämpning".* This is a Multi-Criteria Analysis (MCA) that takes three dimensions into account; ecological, socio-cultural and economic, in order to find the most sustainable remediation alternative. This Master's thesis aims to evaluate this specific tool by applying it on a practical case; the former industrial area Hexion in Mölndal. Four different remediation alternatives, combinations of excavation and on-site treatment, were evaluated against a null-alternative. Furthermore, relevant project risks for the site-owner at Hexion was identified and it is suggested how these project risks can be incorporated into the MCA-tool. The result from the case study shows that the most sustainable remediation alternative implies excavation according to site-specific guideline values and sieving prior to transport to landfill. It is suggested that negative impact on health due to measure and the use of natural resources can be compensated by positive impacts on other criteria and a beneficial economic outcome. It can be concluded that the tool is comprehensive, fulfills its aim and gives a good overview of the impact from each suggested remediation alternative. There is a risk of double counting due to linguistic misunderstanding and confusion concerning how specific criteria in the MCA shall be assessed. Project risks connected to Hexion were identified by means of interviews and literature study of a previous project at BT Kemi where a project matrix was developed. This matrix was modified to suit the conditions at Hexion. These project risks can be monetized and included in the economic dimension of the MCA. To develop the MCA-tool further, it is recommended to produce an Excel work sheet where all calculations for the three dimensions together with uncertainty and sensitivity analyses can be performed.

Key words: Decision support tool, multi-criteria analysis, cost-benefit analysis, contaminated sites, project risks, Hexion.

Val av hållbar efterbehandling på förorenade markområden
Tillämpning och utvärdering av en multikriterieanalys

Examensarbete inom Geo and Water Engineering
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SAMMANFATTNING

Ett av Sveriges miljömål är att de förorenade markområden där störst risk föreligger ska vara efterbehandlade till år 2050. Valet av efterbehandlingsmetod beror av ett stort antal aspekter såsom kostnad, typ av förorening, jordart och tidsplan, för att nämna ett fåtal. Den överlägset vanligaste och mest beprövade efterbehandlingen i Sverige är grävsanering, vilket dock inte alltid är den mest hållbara metoden. Vid Chalmers tekniska högskola, Göteborg, har ett forskningsprojekt pågått för att utveckla ett verktyg för beslutsstöd för att hitta hållbara efterbehandlingsmetoder, *”Multikriterieanalys för hållbar efterbehandling, metodutveckling och exempel på tillämpning”*. Denna multikriterieanalys beaktar tre dimensioner: ekologisk, socialkulturell samt ekonomisk. Detta examensarbete syftar till att utvärdera verktyget genom att tillämpa det på ett konkret fall, det tidigare industriområdet Hexion i Mölndal. Fyra olika efterbehandlingsalternativ, alla kombinationer av grävsanering och on site-behandling, utvärderades mot ett nollalternativ. Utöver detta har relevanta projektrisker för markägaren identifierats och det föreslås hur dessa risker kan inkluderas i verktyget.

Resultatet av fallstudien visar att det mest hållbara alternativet av de analyserade efterbehandlingsmetoderna innebär utgrävning baserad på platsspecifika riktvärden och siktning på platsen innan förorenad jord transporteras till deponi. Hållbarheten är dock svag på grund av de negativa effekterna på hälsa med avseende på åtgärdens utförande samt användningen av naturresurser. Det föreslås att detta kan kompenseras av positiva effekter på andra kriterier samt en gynnsam ekonomisk dimension. Det kan konstateras att verktyget är omfattande, uppfyller sitt syfte och ger en bra översikt av effekterna av de föreslagna efterbehandlingsalternativen. Verktyget är dock tidskrävande och kräver mycket indata. Det finns viss risk för dubbelräkning p.g.a. språkliga missförstånd och det råder osäkerhet hur vissa av kriterierna i verktyget skall bedömas. Projektrisker knutna till Hexion identifierades med hjälp av intervjuer och en litteraturstudie av ett tidigare projekt på BT Kemi där en projekt-matris utvecklades. Denna matris justerades för att passa de förhållanden som råder på Hexion. Dessa projektrisker omvandlas till monetära värden och därmed inkluderas i den ekonomiska dimensionen av verktyget. För att ytterligare utveckla multikriterieverktyget rekommenderas att ett program i Excel utvecklas där alla beräkningar för de tre dimensionerna tillsammans med osäkerhetsbedömningar och känslighetsanalyser kan utföras.

Nyckelord: Beslutsstöd, multikriterieanalys, kostnadsnyttoanalys, förorenad mark, projektrisker, Hexion.

Contents

Preface and acknowledgements

In this Master's thesis a case study and method evaluation of a Multi-Criteria Analysis for comparing sustainable remediation alternatives at contaminated sites has been performed. The Master's thesis work has been carried out within the Department of Civil and Environmental Engineering at Chalmers University of Technology, Sweden. The work took place during spring 2011 and is a part of a research group concerning risk investigation and soil treatment, FRIST Competence Centre.

We wish to thank our supervisors Professor Lars Rosén and Assistant Professor Jenny Norrman for your continuous support and interest of our work. We also wish to thank Malin Norin at NCC Construction for providing us with valuable information and opinions to the case study. We also like to express our sincere gratitude to all those who have contributed with worthwhile information by means of interviews and study visits. Also thanks to Petra Brinkhoff and Andreas Lindhe at the division of GeoEngineering for always answering our questions.

Finally, we would like to thank our friends and families for your never ending encouragement!

Gothenburg, June 2011

Åsa Landström Ann-Sofie Östlund

1 Introduction

This chapter briefly presents the contemporary goals concerning contaminated sites in Sweden. The aim of this Master's thesis, delimitations and methodology, as well as reading instructions are also described.

1.1 Background

The overall main of the Swedish environmental policy, formed in 1999, is "*to hand over an environment to the next generation where the largest and most severe environmental problems are solved, without causing further health- and environmental problem outside the Swedish boarder*" (NV, 2010a). This policy includes 16 objectives, one of them is, "*A Non-toxic Environment*" (Kemikalieinspektionen, 2009). Furthermore, this objective is divided into 9 sub objectives where the 6:th and 7:th concern contaminated sites. The 7:th sub objective states that, all contaminated sites within risk class 1, according to the risk classification system (MIFO), should be remediated until year 2050 (NV, 2010b). This risk classification system categorizes all contaminated sites in Sweden into four different risk classes. Class 1 sites are expected to pose the highest risk to humans and the environment thus in greatest need of remediation actions. In June 2010 the environmental policy for Sweden was redeveloped and the goal "*A Non-toxic Environment*" was revised. One of the decisions was then to speed up the process of prioritizing contaminated sites in order to meet the goal of "*A Non-toxic Environment*" until year 2050 (Sveriges Riksdag, 2009).

Remediation at contaminated sites can be done in numerous ways and when choosing method there are several aspects to take into consideration; e.g. cost, type of contaminants and time duration. It is desirable to find the most sustainable method in regard to economy, the environment and social aspects. Currently, the most common remediation action in Sweden is to excavate and transport the contaminated soil for off-site treatment and/or disposal. There are several reasons for this; it is a quick, well-tested and relatively cheap method that can remove all types of contaminants. However, transport to landfill is not always the most sustainable remediation alternative[1].

Holdbacks in the prioritizing process and in the choice of sustainable remediation methods have partly been due to the lack of easy, informative and user friendly decision making tools. At Chalmers University in Gothenburg a tool based on multi-criteria analyses for choosing proper remediation alternative has been developed. The report by Rosén et al. (2009) describes the methodology and is published as a report in the Sustainable Remediation Programme by the Swedish Environmental Protection Agency, Naturvårdsverket.

1.2 Aim

The aim of this Master's thesis is to test and evaluate the decision support tool developed by Rosén et al. (2009) based on Multi-Criteria Analysis (MCA) for finding

[1] Yvonne Ohlsson, Environmental Chemist, Technical. Dr. at the Swedish Geotechnical Institute (SGI), FRIST Workshop, Chalmers University 2011-01-20.

and ranking sustainable remediation alternatives at contaminated sites and to identify relevant project risks for the site-owner as well as suggest how to incorporate these into the MCA-tool.

The tool is tested by means of a case study and evaluated according to the following criteria:

- Does the tool fulfil its aim? Is the tool comprehensive enough?
- Applicability and user friendliness with questions like: Difficulties in finding relevant input data? Is the tool time consuming?
- How well does the tool fulfil the three dimensions of ecological, economic and socio-cultural aspects for achieving sustainability?

1.3 Method

The MCA-tool has been applied in a case study of the contaminated site Trädgården 1:124, also called Hexion. Four different remediation alternatives were compared to a null-alternative for the site. At present (spring 2011), the site is in the process of being remediated by the site-owner NCC. For the case study of Hexion a full MCA has been performed. Most input parameters are based on real estimations from the present remediation project at Hexion. However, some input parameters had to be estimated by expert judgments.

The economic dimension of the MCA is evaluated by performing a Cost-Benefit Analysis (CBA) for the different remediation alternatives. For this, the method described in the report "*Kostnads-nyttoanalys som verktyg för prioritering av efterbehandlingsinsatser"* (Rosén et al, 2008) was applied.

The different remediation alternatives have been chosen and developed together with Malin Norin at NCC and supervisor Jenny Norrman, Chalmers. Field visits to Hexion have been carried out to get a clear and more detailed picture of the site-specific conditions, the remediation process and the surroundings at the site.

Interviews with people experienced in remediation projects were performed to evaluate project risks and to obtain input data to the CBA and the MCA. On behalf of the site-owner NCC, several pre-investigations have been carried out at the site. These reports have been an important source of information for the case study. Health risks were calculated in the software *Spatial Analysis and Decision Assistance* (SADA, 2007). The CO_2-emissions are calculated by Almqvist et al. (2011) in a bachelor thesis using the Excel-tool VHGFM.

Uncertainty and sensitivity analysis for the CBA was performed using Monte Carlo simulations with an Excel add-in, Crystal Ball (Oracle, 2010). Sensitivity analysis of the ecological and socio-cultural dimension was performed by a method described in Burgman (2005).

1.4 Delimitation

This Master's thesis includes one case study. The number of remediation alternatives is limited to four, in addition to the null-alternative. In the process of the remediation project some limitations have been set; the MCA performed for this case study does not include the purchase of the property, demolition of the factory or removal of surrounding vegetation. Further, planning of residences, green areas, roads, lightening and parking lots have not been included in the MCA. Thus, MCA and project risk identification for Hexion merely handles the soil remediation alternatives, where the planning before and the remediation action itself are included.

Most scoring of the criteria in the MCA was done by the authors. To score the socio-cultural key criterion S1, *justice and acceptance*, three experts have been interviewed. These were Petra Brinkhoff, Environmental Consult at NCC and PhD-student at Chalmers, Uffe Schultz, Environmental Engineer at the County Authorities in Gothenburg and Thomas Holm, Civil Engineer at SWECO.

1.5 Disposition

This Master's thesis begins with a brief explanation of definitions and objectives concerning site remediation together with a description of the first selection of remediation methods, Chapter 2. Some theoretical background to the decision making process and a description of the MCA-tool, where working process, dimensions of sustainability, uncertainty and sensitivity analyses as well as project risks are explained are found in the next chapter, Chapter 3.

Chapter 4 concerns the case study Hexion and industrial history, geology, hydrogeology and the contamination situation at the site is described. Next are descriptions and explanations of the remediation alternatives and the null-alternative, Chapter 5. Explanations of the MCA performed for the case study at Hexion are provided, including the three dimensions of sustainability, uncertainty and sensitivity analyses and results of the MCA for Hexion, Chapter 6. The study on how to identify and incorporate project risks into the MCA can also be found in Chapter 6.

A discussion of the performance of the MCA as well as the results from the MCA for the case study is given in Chapter 7. The evaluation of the MCA-tool is also performed and discussed, as well as the incorporation of project risks in the MCA-tool. Conclusions from the Hexion case study and the evaluation of the MCA-tool ends this Master's thesis, Chapter 8, together with recommendations to further improve the MCA-tool.

2 Remediation at contaminated sites

This chapter presents some important definitions concerning contaminated sites and how risks are managed within a remediation project. It is also described how to make a first choice of suitable remediation methods for a contaminated site.

2.1 Pathways and exposure

Contaminants at a site can origin from many different scores, e.g. landfills, industrial activities or petrol filling stations. The individuals that will be affected by the contaminants are called receptors and can be people living or working at the site, or children playing. The way contaminants travel from source to receptor is called pathway and can appear in different ways. A risk will be present if the chain from source to receptor is unbroken and if there will be a negative effect at the receptor. The exposure to humans can occur through dermal contact, intake of soil, vegetables and water as well as inhalation of vapours and dust, all seen in Figure 2.1. The exposure also depends on the period of time in which humans reside on the site. A residential area implies higher exposure for humans than a recreational area.

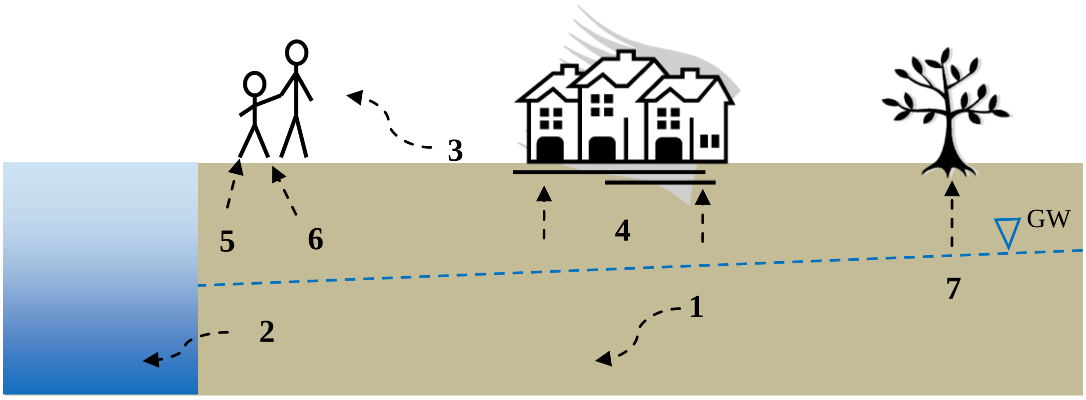


Figure 2.1. The arrows represent ways of dissipation and exposure of contaminants at a contaminated site. 1) Advection – contaminant moves with the groundwater. 2) Spreading by ground water to surface water e.g. to a river. 3) Inhalation of dust. 4) Inhalation of vapours (indoors). 5) Dermal contact. 6) Oral intake of soil. 7) Uptake by plants.

However, the total risk at a specific site depends on more than exposure pathways to humans. The properties of the contaminant(s), such as toxicity and mobility also affect the risk, as well as the level of concentration.

2.2 Remediation objective

At a remediation project there are objectives to fulfil; one might for example be to prepare the site for residences by reducing the amount of contaminants. However, there are guideline values for the highest allowed concentrations of pollutants. In Sweden, two methods are used for finding these values; generic guidelines and site specific guidelines. These guideline values are compared to the concentrations measured on the site, to control whether the objective is fulfilled or not.

2.2.1 Generic guideline values

The Swedish Environmental Protection Agency (Naturvårdsverket) has developed generic guideline values for contaminated sites. These values are calculated in a model based on four protection objects (NV, 2009):

- People located in the area
- Soil environment in the area
- Groundwater
- Surface water

For each protection object a guideline value is calculated; health risks, protection of the soil environment and the protection of groundwater and surface water. The lowest of these guideline values becomes the generic guideline value. Depending on type of land use, the guideline values differs.

On sensitive land (KM), all groups of people including children, can reside permanently on the site. This puts high demands on the contaminant situation. Example of KM is residential areas. On less sensitive land (MKM), exposed groups are at the site during working hours and children for shorter periods, i.e. guideline values are less strict than for KM. Examples of MKM are office and industrial areas.

2.2.2 Site specific guideline values

Sometimes the land use and exposure situation do not match the general cases, KM and MKM. In these cases, site specific guideline values might need to be calculated where the circumstances on the specific site are taken into account. The same model as for the generic guideline values can be used, but with corrections to reflect the situation on the specific site (NV, 2009). Site specific guideline values are in general less strict than the generic guideline values, this can be due to that one or more pathways of exposure to humans have been removed.

Further division can be done in cases where part of the soil is contaminated to an extent that it is classified as hazardous waste (FA). The basis for this classification is described in the EC directive 91/689/EEC of 12 December 1991. Human activity is not to recommend at these places, restrictions are required and the site needs to be carefully remediated.

2.3 First selection of remediation method

When starting to analyse what type of remediation method to choose, a first qualitative judgment is required. It is crucial to have a good and varied knowledge of the conditions at the contaminated site, in excess of pathways and remediation objectives, as seen in Section 2.1 and 2.2. Additional knowledge is required about e.g. the type of soil, the groundwater behaviour, as well as distribution and toxicity of present contaminants. Furthermore, the time horizon of the remediation project is significant to consider when doing the first selection of sustainable remediation methods. Table 2.1 shows questions for reflection and their impact on the first selection of possible remediation methods.

Table 2.1 Questions for reflection in an early stage of the process of choosing a reasonable remediation method and some comments on what is needed to be considered. Based on NV, 1998.

	Questions to reflect on	Comments
Site specific	Type of soil	Soil type indicates the contaminants' possibility to spread to nearby areas and groundwater.
	Groundwater behaviour	If the contaminants are in contact with the groundwater more remediation and control will be needed.
Contaminant specific	Most common contaminants	Soil and groundwater samples will show type of contaminants and their levels. The toxicity of the contaminants is also essential. This information is important for choosing a remediation method that is effective. Different techniques are developed to defeat different types of contaminants like e.g. fuels and metals.
	Behaviour, on-going and future distribution of the contaminants	Mobility is a good indicator of how well the contaminants will bind to soil particles. High mobility means a low K_d-value, see Table 4.1. If the mobility is low (high K_d-value) it is possible to assume that the contaminants will bind to small soil particles and then a treatment like physical separation is to prefer (FRTR, n.d.). The on-going and future spreading of contaminants gives boundary conditions to the remediation method.
	Volume of contaminated soil, location, width and depth	Large amounts of contaminated soil can be a time consuming and expensive. It is hard to reach contaminated soil on great depths.
Project specific	Remediation actions	Is the method possible to perform at the site depending on the amount of soil, terrain and project risks? Is it effective enough?
	Time horizon	The time a method takes into account can differ a lot. It is often favourable for the site-owner to have a short remediation process.
	Future land use	What future land use that is planned for the site will govern which levels of remediation that is needed at the site.

3 Presentation of the MCA-tool

This chapter presents an overview of the decision making process with focus on contaminated sites and a general description of an MCA. The structure and the working process of the MCA-tool by Rosén et al. (2009) are explained. The three dimensions included in the tool and the concept of project risks is described, as well as methods for uncertainty and sensitivity analysis.

3.1 General description of decision making

A decision making process always starts with a problem, e.g. a contaminated site that is in need of remediation. The next step is to identify some different decision alternatives, e.g. remediation alternative that can reduce the risks at the site. Based on Figure 3.1, the following step is to analyse and evaluate the identified alternatives. Here, the possible impacts of the different alternatives are analysed (Keeney, 1982). Two commonly used decision support tools are Cost-Benefit Analysis (CBA) and Multi-Criteria Analysis (MCA). These tools can support the decision making process and provide transparency, but it is important to note that these tools can act only as support to the final decision.

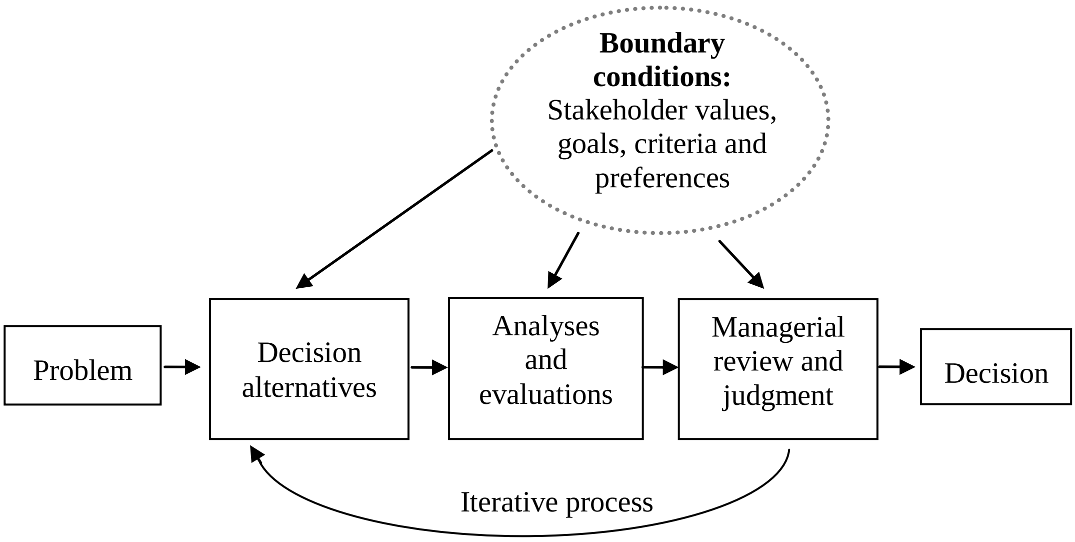


Figure 3.1 Overview of decision making process based on Aven (2003).

The boundary conditions seen in Figure 3.1 can be defined by the decision makers but also by experts and environmentalist or by other politicians (Aven, 2003). If there is more than one decision maker, different goals and political agendas can affect the choosing of a particular action alternative. Their personal attitude towards real risk versus perceived risk can also colour their preferences. Real risk is objective and based on evidence, when on the other hand, perceived risk is subjective, emotional and irrational (Burgman, 2005).

The participants in a decision making process are not merely the decision makers and the experts; the process can also involve problem-owners and stakeholders who can ensure public support and acceptance (after Perhac, 1998; Burgman, 2005). It might be valuable to have a facilitator involved who can guide the different stakeholders through discussions (Keeney, 1982).

The decision making process is an iterative process and the discussions and analyses can be repeated if an action alternative or decision preference is changed. This makes it possible for the process to end up in a well thought-out decision.

An MCA is a decision support tool used by the decision makers when facing a complex problem. The result of the analysis gives a structure to the problem and works as a base for further discussion in order to find the most convenient course of action. As the name suggests, MCA identifies multiple criteria against which the alternatives can be evaluated and then compared to each other. The basic process of MCA is described by Burgman (2005); first, criteria are established and classified in groups and subgroups. Criteria may have monetary or nonmonetary values. Thereafter weights and scores are assigned to all criteria to show how they interrelate, i.e. how important they are in the final rating. This is a step involving a lot of subjectivity, wherefore it should be executed e.g. by a group of experts whose opinions are summed up. Having this done, each alternative/course of action, is tested against all criteria and can then be compared to one another. Analyses shall always be tested by a sensitivity analysis in order to find how the final results reply to changes in the input parameters. By doing this, one can find out which steps or criteria that are most crucial for the final result.

In environmental management projects, an aim for the decision makers can be to find the most sustainable course of action. A common definition of sustainability is "*to meet present needs without compromising with future generation's ability to meet their own needs*" according to The Brundtland Commission (1987). This is often defined as fulfilling three dimensions; economic, socio-cultural and ecological, seen in Figure 3.2.

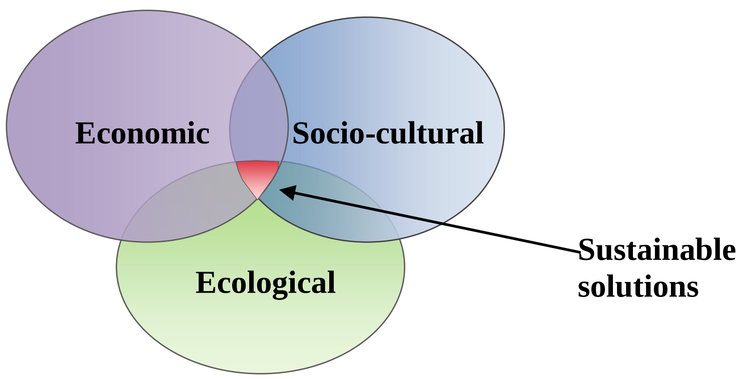
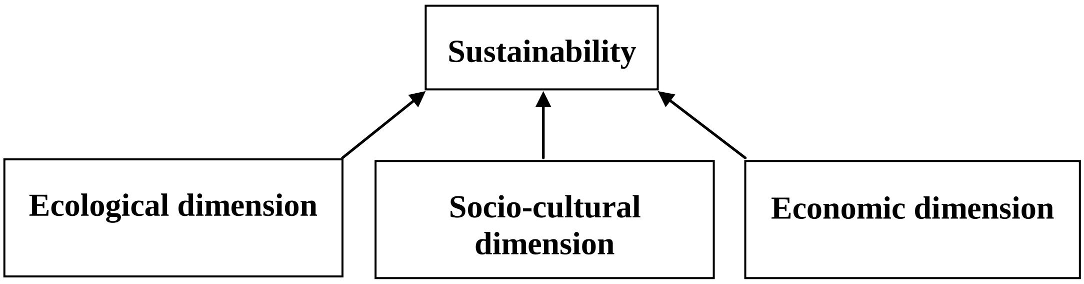


Figure 3.2. The three dimensions resulting in sustainability based on NV (2011a).

3.2 Theoretical description of the MCA-tool

The MCA-tool presented in *"Multikriterieanalys för hållbar efterbehandling, metodutveckling och exempel på tillämpning"* aims to identify sustainable remediation alternatives for contaminated sites and make a ranking for prioritizing among the alternatives, according to Rosén et al. (2009). Sustainability is assessed through the ecological, economic and socio-cultural dimensions, which are defined by a number of criteria, see Figure 3.3. The sustainability can either be strong, where there are no negative effects on any of the criteria, or, if this is not possible to fulfil, weak. Weak sustainability means that negative effects on some criteria are accepted if they can be compensated by positive effects on other criteria, i.e. the net effect is positive.



Key criteria: - Ground - Surface water - Ground water - Air - Sediment - Use of natural resources	Key criteria: - Health (contaminants) - Health (measure) - Cultural environment - Recreation - Land use on-site - Land use off-site - Justice and acceptance	Key criterion: -Socio-economic profitability

Figure 3.3. The three dimensions of sustainability and the suggested key criteria from Rosén et al. (2009).

Depending on the desired degree of specificity, there are several different methods to choose from when doing an MCA. The MCA-tool evaluated in this Master's thesis uses two of them in combination; *linear additive method* and *non-compensatory method*. The linear additive method is frequently applied. It uses scores to describe how well each alternative perform on the different criteria and weights to show the importance of each criteria in the final rating (Belton & Stewart, 2002), see Eq. 3.1.

$$Value(x) = \sum_{i=1}^{n} W_i(x) \times C_i(x) \qquad (3.1)$$

$Value(x)$ = Final value for alternative *x*

$W_i(x)$ = Weight of criterion *i* for alternative *x*

$C_i(x)$ = Score of criterion *i* for alternative *x*

Each criterion in the ecological and the socio-cultural dimension are given scores between -2 to +2. The scale is going from probably negative effect to probably positive effect, as seen below.

Probably negative effect = -2

Possible negative effect = -1

Negligible or non-existent effect = 0

Possible positive effect = +1

Probably positive effect = +2

All dimensions are weighted equally. Also the key criteria in the ecological and socio-cultural dimension are weighted as equals. This is true for the general case, but the tool can include weighting of the dimensions and/or key criteria on decision makers request (Rosén et al., 2009). All scores C for each dimension is summarized and put together in a total index for each alternative (i=1…N). The ecological dimension is calculated according to Eq. 3.2, taking into account the scores of each environmental criterion, e=1...E (Rosén et al., 2009).

$$H_{E,i} = \sum_{e=1}^{E} C_{e,i} \tag{3.2}$$

The socio-cultural dimension is summarized in a similar way, taking into account the scores of each socio-cultural criterion, s=1...S, see Eq 3.3 (Rosén et al., 2009).

$$\mathrm{H_{S,i}} = \sum_{\mathrm{s}=1}^{\mathrm{S}} \mathrm{C_{s,i}} \tag{3.3}$$

The economic dimension is expressed according to Eq. 3.4 where Φ is the net present value in a cost benefit analysis (Rosén et al., 2009). See also section 3.6.

$$H_{\Phi,i} = \Phi_{\mathrm{i}} \tag{3.4}$$

When the final value of each alternative is calculated, each dimension is normalized, see Eq. 3.5.

$$H_i = \frac{\left(\frac{H_{E,i}}{Max\ [Max\ (H_{E,1..N});|Min\ (H_{E,1..N})|]} + \frac{H_{S,i}}{Max\ [Max\ (H_{S,1..N});|Min\ (H_{S,1..N})|]} + \frac{H_{\Phi,i}}{Max\ [Max\ (H_{\Phi,1..N});|Min\ (H_{\Phi,1..N})|]}\right)}{3} \tag{3.5}$$

In the tool, the non-compensatory method is applied when no compensation between the criteria is accepted, i.e. a negative score on the criterion cannot be compensated by a very positive score on another criterion. This is primarily a method to sort out the alternatives that has a strong sustainability.

3.3 Working process

An overview of the working process is given in Figure 3.4. First, a number of reasonable alternatives for remediation are identified. This includes identifying the null-alternative, which will serve as reference for all other alternatives. Many aspects are taken into consideration when identifying the alternatives, e.g. location, type and behaviour of the contaminants, exposure situation now and for future land use. More information about this first cull is found in Chapter 2.

Step two is to score each criterion in the ecological and socio-cultural dimensions. To aid in the assessment are matrixes with relevant key questions to consider and examples of scenarios for the various awarding of points.

Step three is to take the economic dimension into account by performing a CBA, which is a way of comparing the total positive impacts with the total negative in monetary terms. This process is further described in Section 3.6. Then the alternatives are compared to each other and ranked in terms of sustainability, by calculating the sustainability index, H_i, see Eq. 3.5 (Rosén et al., 2009).

A negative sustainability index indicates that sustainability is not achieved. If a sustainability index is positive and no negative effect exists, the sustainability is considered strong wherefore the alternatives can be ranked and the MCA is fulfilled. If however, an alternative has negative impact on any criterion, the sustainability is weak. If this cannot be accepted the process must be iterated from step 1. For the cases where weak sustainability is accepted and no measures are found whom provide strong sustainability for any of the alternatives, the process continue by finding criteria to control the weak sustainability.

If one or more of the alternatives fulfil the new criteria the alternatives are possible to rank and the MCA is fulfilled. If not, the process must be iterated from step 1. A schematic figure of the MCA process can be seen in Figure 3.4.

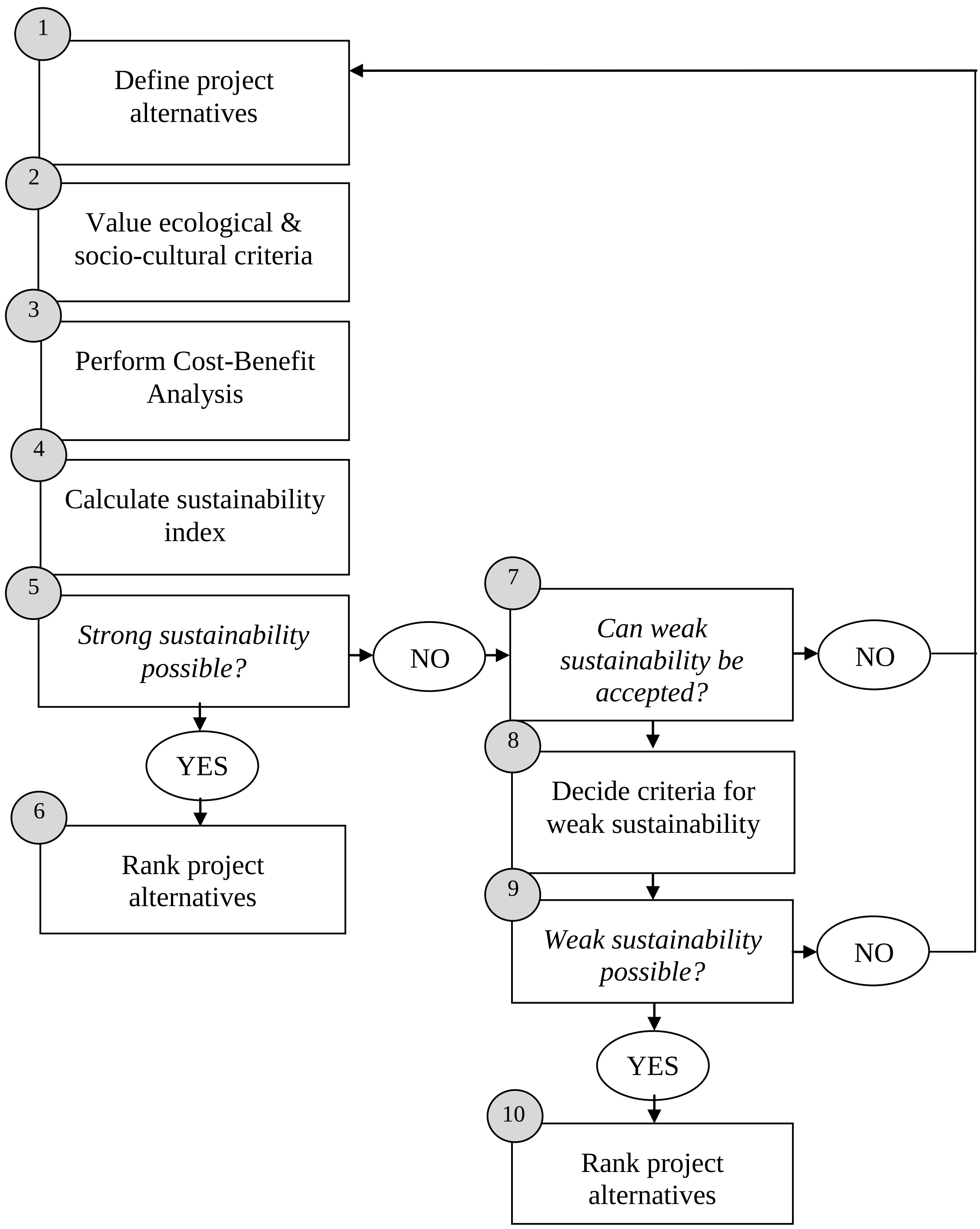


Figure 3.4. Flow chart for the MCA process (Rosén et al., 2009).

3.4 Ecological dimension

Key criteria in the ecological dimension are selected on the basis of the ecosystem's media; air, surface water, sediment, groundwater and soil (Rosén et al., 2009). These criteria are scored based on how the ecological function is affected. In addition to these five criteria, consumption of natural resources is included, which considers consumption of finite natural resources, e.g. exploitation of new lands for landfill, usage of natural gravel and the consumption of fossil fuel.

The assessment of these six key criteria is made with the help of supporting matrixes with key questions to consider. But as remediation projects may differ from case to case, complementary criteria might be required. The following is a brief description of the six key criteria and how they should be assessed.

- *Air.* The criterion air includes emissions and impacts on air caused by the remediation alternative; comprising greenhouse gases, acidifying and eutrophying substances (Rosén et al., 2009).

- *Surface water.* This criterion evaluates the impact on surface water properties; flow, flow velocity, water level and chemical quality (Rosén et al., 2009).

- *Sediment.* In this criterion, the first thing to consider is to examine how important the sediment is from an ecological perspective. When this is established, it should be considered how remediation alternatives affect sediment quality or function (Rosén et al., 2009).

- *Groundwater.* In this criterion it is examined how groundwater quality is affected by the remediation alternative. Factors like how and how fast the contaminant(s) spread, as well as the impact on organisms exposed or taking advantage of groundwater, are of importance (Rosén et al., 2009).

- *Soil.* For this criterion, the significance of the soil from an ecological perspective should be assessed first. Secondly it is examined how the function in the ground, in terms of ecology, changes as a result of remediation alternative (Rosén et al., 2009).

- *Consumption of natural resources.* In this criterion it is assessed how natural resources are affected by the remediation alternative. Examples of natural resources are; surface and groundwater for water supply, the use of sand and gravel, the use of fossil fuels by e.g. transport and excavation work (Rosén et al., 2009).

3.5 Socio-cultural dimension

In the socio-cultural dimension values which cannot be monetized are handled, e.g. perceived risk and anxiety. The dimension includes the following criteria: justice and acceptance, health for people living nearby, cultural environment, access to recreational areas and land use. As for the ecological dimension, there are matrixes with key questions to support the assessment. The following is a brief description of the criteria and how they should be assessed.

- *Justice and acceptance.* This criterion includes third party people, i.e. not those who are directly involved in the project's execution. An assessment should be made whether one or more groups in society benefit from or disadvantage of the remediation alternative, now or in the future (Rosén et al., 2009).

- *Health.* Health includes two criteria; the first "health with respect to the site's contaminants", addresses the health risks connected with the contaminants on the site affected by the remediation. The other criterion concerning health is "Health with respect to the remediation action's execution" concerns for example risks to workers at the workplace and how they are exposed to contaminants and the risk of transport accidents (Rosén et al., 2009).

- *Cultural environment.* Here it should be assessed whether a cultural environment benefit from or disadvantages of the remediation alternative. A cultural environment can be solitary objects or buildings as well as environments telling something about historical times (Rosén et al., 2009).

- *Recreation and outdoor activities.* There is often a change in land use on the site after a remediation; this criterion considers whether there is a change in possibilities for outdoor life and/or recreation in the area as a result of the action (Rosén et al., 2009).

- *Land use off-site.* This criterion includes all other influences on the area outside the site. It can for example concern jobs or housing (Rosén et al., 2009).

- *Land use on-site.* The last criterion handles future land use on the site and how it is affected by remediation (Rosén et al., 2009).

3.6 Economic dimension

The economic dimension is handled with a CBA, which is a way of comparing the total positive impact (benefits) of a project with the total negative impact (costs). The goal is to assess the socio-economical profitability. This is possible by putting monetary values on all or most of these impacts[2]. All costs and benefits are calculated and summarized to a net present value and a discount rate is used to convert future incomes and costs into a present value. The analysis can be done ex-ante which means

[2] Gerda Kinell, Analyst, lecture notes from the course: Risk Control in Engineering (BOM125) Chalmers University 2011-02-17.

doing the CBA before the project is implemented or ex-post when the project already has been carried out (Rosén et al, 2008).

In 2008, Rosén et al. described the use of a CBA for prioritizing amongst remediation alternatives. The purpose is to compare the benefits and costs of a number of remediation alternatives with a null-alternative. The method is shortly described below and schematically seen in Figure 3.5.

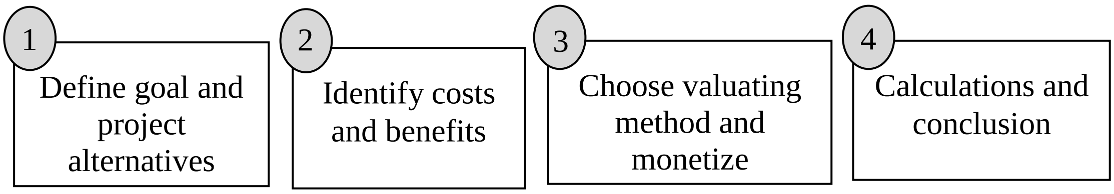


Figure 3.5. Flow chart for the cost-benefit analysis according to Rosén et al., (2008).

To begin with, it is important to have well-defined goals and project alternatives, including the null-alternative or reference alternative. The next step is to find all costs and benefits related to the different alternatives. To facilitate and rationalize this process, suggestion on benefits and costs typically connected to remediation actions are listed in Rosén et al (2008). The benefits have three main categories: *increased land value, net impact on market-priced services and goods* and *net impact on non-market-priced services and goods*. The main categories for costs are the following: *cost for performing the measure, negative effect on health due to the measure* and *negative effects on ecosystem services and goods*.

When reaching step 3, the challenging task of quantifying the costs and benefits begins; especially services and goods that are not traded on a market are difficult to monetize. Two examples of methods for doing this are; *the contingent valuation method*, where people are asked how much they are willing to pay for a certain scenario and *the hedonic pricing method* that use the connection between a good/service and its characteristics to calculate the monetary value (Rosén et al, 2008).

In the last stage, the monetized values of all benefits/costs are summarized and the Net Present Value (NPV) is calculated according to Eq. 3.6 where:

$$NPV_i = \sum_{t=1}^{T} \frac{1}{(1+r)^t} * (B_{it} - C_{it}) = \Phi_\mathrm{i} \qquad (3.6)$$

$T =$ Time horizon [years]

$r =$ Discount rate

$B =$ Benefits [SEK]

$C =$ Costs [SEK]

The result of the NPV_i is interpreted as follows (Rosén et al., 2008):

$NPV_i < 0$ Indicates a negative socio-economic profitability.

$NPV_i > 0$ Indicates a positive socio-economic profitability.

3.7 Project risks in the MCA-tool

Project risks are included in the MCA-tool through the CBA, where the project risks, concerning risks for delays and risks for work related accidents, are monetized and included in the costs (Rosén et al., 2008).

A project risk is an unintended event in a project that may lead to an increased cost or benefit to the site-owner. Risk is generally defined as the probability of an unwanted event to occur weighed with the consequences if it does occur, e.g. by multiplying the probability with the consequence. All projects have some sort of uncertainty and the bigger the input or cost, the greater becomes the reason to lower the uncertainty in the project, i.e. the probability for an unwanted event to occur.

Generally, the uncertainties are associated with; estimates, design and logistics, objective and priorities, and relationship between project parties (Chapman & Ward, 2009). Variability in estimates includes project parameters like time frame, quality and cost. In design and logistics there might be uncertainty in specification of job assignment. All parties need to understand their role in the project but also how they are related to the objective. Also the connection and communication between the different parties is important. To sum up, good project management results in good uncertainty management.

The project risks can be divided into the work phases of the project; preparation/planning, implementation and follow up.

3.8 Uncertainty and sensitivity analyses

It is recommend in the MCA-tool to perform a sensitivity analysis, but it is not specified what method to use (Rosén et al., 2009). In the CBA, it is suggested to make a sensitivity analysis for the discount rate and also investigate the reliability of the other input data. Rosén et al. (2008) suggest that this can be done either with a statistic simulation or with a more simple method.

Uncertainty and/or sensitivity analysis is a way to explore the uncertainties in the model. This is important, especially for models that involve input parameters that can vary from typical to extreme scenarios (Burgman, 2005). An often used approach to explore uncertainties and sensitivities in environmental risk assessments are by Monte Carlo analyses.

A Monte Carlo analysis operates with random variables and if an input parameter in a model is uncertain it requires a statistical distribution. After applying a proper statistical distribution the Monte Carlo simulation starts by running the model over and over again to estimate the likelihood of different outcomes of the model (Burgman, 2005). This is schematically described in Figure 3.6. With the Excel add-in Crystal Ball, the simulation can be performed 10 000 times. Some useful results from a Monte Carlo simulation are e.g. what input parameters that affect the outcome the most (are most sensitive) and the uncertainty in both input parameters and in the outcome of the model. According to Burgman (2005), this provides a possibility to justify decisions. Moreover, a Monte Carlo simulation gives indication about which parameters that need further investigations in order to be estimated right.

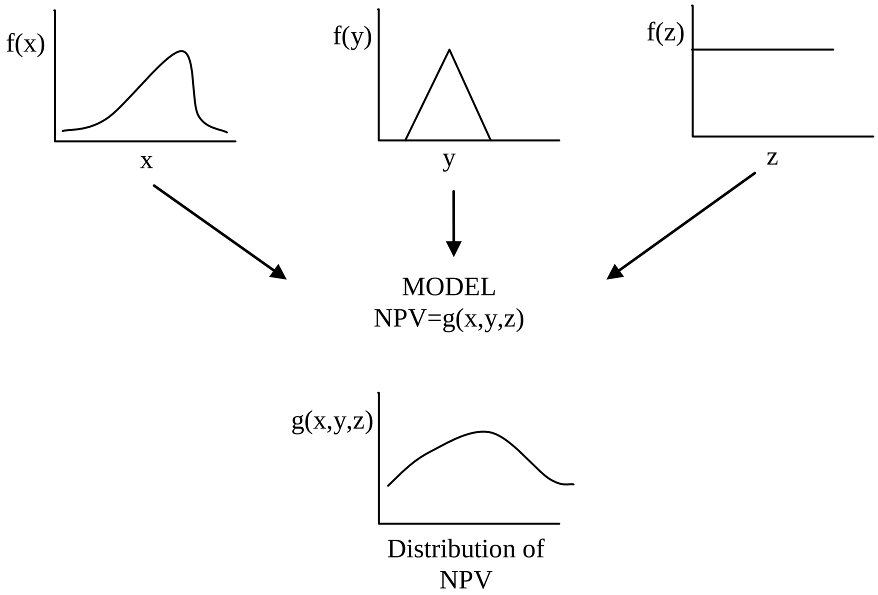


Figure 3.6. A schematic description of a model and the use of Monte Carlo simulation (after Suter, 1993; Burgman 2005). The input parameter; x, y, z and their distributions are after modelling resulting in e.g. a NPV. The Monte Carlo simulation makes the distribution of the NPV (the result from the model) possible to analyse.

To perform an uncertainty and sensitivity analysis for the economic dimension in the MCA a Monte Carlo simulation using the software Crystal Ball is appropriate. The most interesting simulations are the ones made for the calculated NPV's. Results of interest from the distribution of the NPV are:

- $P(NPV_i > 0)$, i.e. how high is the probability that the NPV is positive.
- The 95% confidence interval (CI), i.e. an interval which the NPV will be within with a probability of 95%.
- Mean value μ of the NPV.
- Standard deviation s, a measure of dispersion based on deviations from the mean.

Two statistical distributions are used for the input parameters in the CBA performed in this Master's thesis. These are the uniform and the triangular distributions.

The **uniform distribution** is a model for independent random variation, see Figure 3.7 for the shape. This distribution is often used when the uncertainty is unknown, when equiprobable appears (Burgman, 2005). It is used in this Master's thesis e.g. on the input parameter; *people involved in car accident* where it is known how many and how few that can be involved in a car accident but there is no information available on the most probable number of people involved.

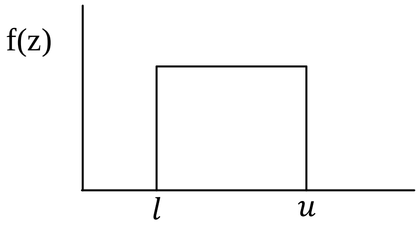


Figure 3.7. Uniform probability distribution.

The mean value μ, and the standard deviation s, is calculated according to Eq. 3.7 and 3.8 based on Burgman (2005).

$$\mu = \frac{l+u}{2} \tag{3.7}$$

$$s = \sqrt{\frac{(u-l)^2}{12}} \tag{3.8}$$

$l =$ Lower boundary value

$u =$ Upper boundary value

According to Burgman (2005) the **triangular distribution** has a lower and upper boundary and a most likely value of a parameter, see Figure 3.8 for the shape. This is a distribution suitable for expert judgment and when no other distribution is possible to use. It is used in this Master's thesis e.g. on the input parameter, *amount excavated soil,* for which a most likely value is known, but this value might differ and there is a limited knowledge of how much. This distribution can result in biases for skewed data and often too large weights are given to the tails (Burgman, 2005).

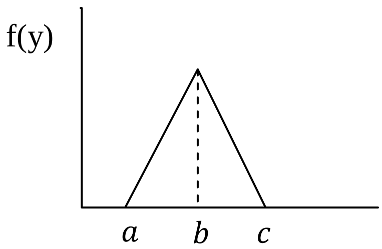


Figure 3.8. Triangular probability distribution.

The mean value μ, and the standard deviation s, is calculated according to Eq. 3.9 and 3.10 based on Burgman (2005).

$$\mu = \frac{a+b+c}{3} \tag{3.9}$$

$$s = \sqrt{\frac{a^2+b^2+c^2-ab-ac-bc}{18}} \tag{3.10}$$

$a =$ Lower boundary value

$b =$ Best estimate of the parameter (mode)

$c =$ Upper boundary value

However, for the ecological and socio-cultural dimensions, a Monte Carlo simulation with Crystal Ball was not performed. This is due to that there are no numerical input parameters used in these models, merely scoring is performed. The scoring can instead be analysed through a sensitivity analysis discussed in Burgman (2005). This analysis examines according to Burgman (2005), "*what change that can be expected of the outcome if a parameter is changed by a small amount in the region of the best estimate*". The analysis also shows how sensitive a model is to different expert views and judgment when scoring the criteria in the ecological and socio-cultural dimension. The sensitivity analysis is performed by Eq. 3.11.

$$s_p = \frac{\Delta V / V}{\Delta P / P} \tag{3.11}$$

$s_p =$ Sensitivity

$V =$ Output variable

$P =$ Parameter

$\Delta V =$ A small change in the output variable

$\Delta P =$ A small change in the parameter

The result of the sensitivity analysis is interpreted as follows:

$s_p \geq 1$	Indicates that the output is sensitive to parameter P.
$s_p \sim 0$	Indicates that parameter P has little influence on the output variable V.

4 Case study, Hexion

This chapter presents general information about industrial history, future land use, geology, hydrogeology and the contamination situation at the case study site Trädgården 1:124, referred to as Hexion.

4.1 General information

A case study of the site Trädgården 1:124, often referred to as Hexion, has been performed. The property, with an area of 35 000 m^2, was acquired in 2007 by NCC. Before that, the last company to operate on the site was Hexion Speciality Chemicals. Due to the former industrial activities, the site is now heavily polluted. NCC intends to remediation the site and to turn it into a residential area. The site is interesting as a case study because it is located in a well-developed area and is an on-going remediation project.

Hexion is situated in the old centre of Mölndal, south of Gothenburg. A railroad, Boråsbanan, marks the northern border of the site, in the west there is a small forest area and Kvarnbygatan lies south of the site. In the east along Mölndalsån, an area is situated with some old industrial buildings, cafés and museums. The topography is varied, sloping heavily from north to south with 32 meter difference in ground level at most. See Figure 4.1 for an overview.

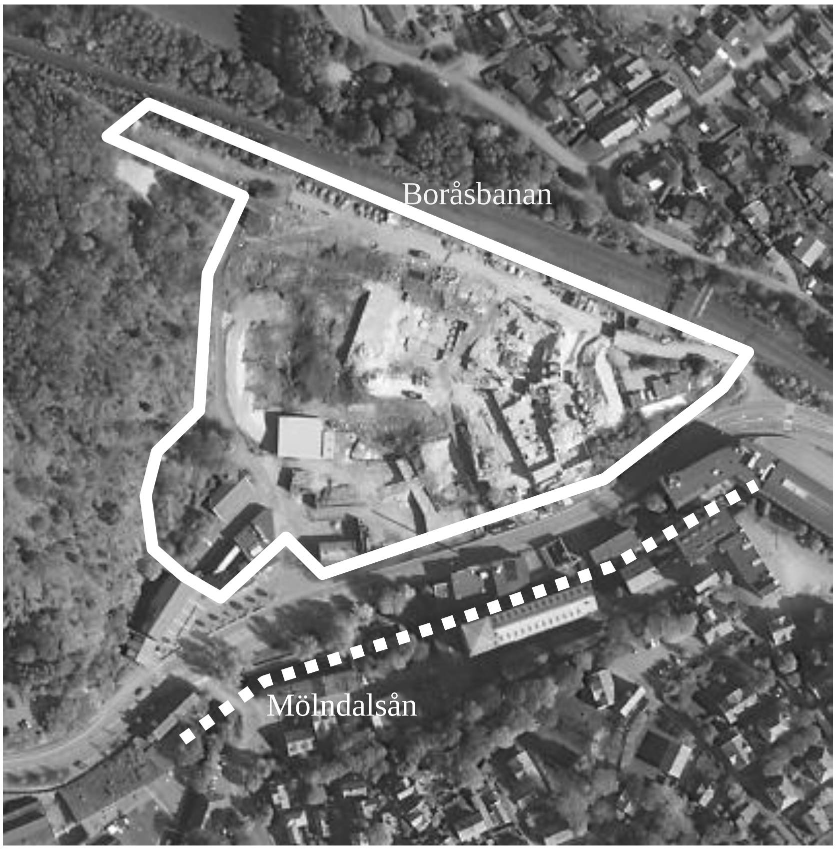


Figure 4.1. Aerial photo over Trädgården 1:124, Hexion. The white line marks the border of the site and the dotted line marks Mölndalsån. © Lantmäteriet Gävle 2011. Medgivande I 2011/007.

The site has a long history of industrial activities which starts around 1900. The chemical production started at the site in the 1940's and in 1979 it was sold to Soab AB which produced binding agents. Hexion Speciality Chemicals was the latest company to operate on the site from year 2005 to 2007 (NCC Teknik, 2007). At that time, there were, in addition to industrial buildings, also cisterns, hardstand area and parking surfaces situated on the site. For an overview of the area as it looked before demolition, see Figure 4.1.

In 2007, the property was purchased by NCC, whose intent is to exploit the property. Residences are planned for most of the area, but also parking lots which will be situated next to the railway. Some shops and a marketplace are planned in the southern parts. A green area will be created in the steepest part of the slope. An overview of the planned future land use can be seen in Figure 4.2 (SWECO, 2009a).

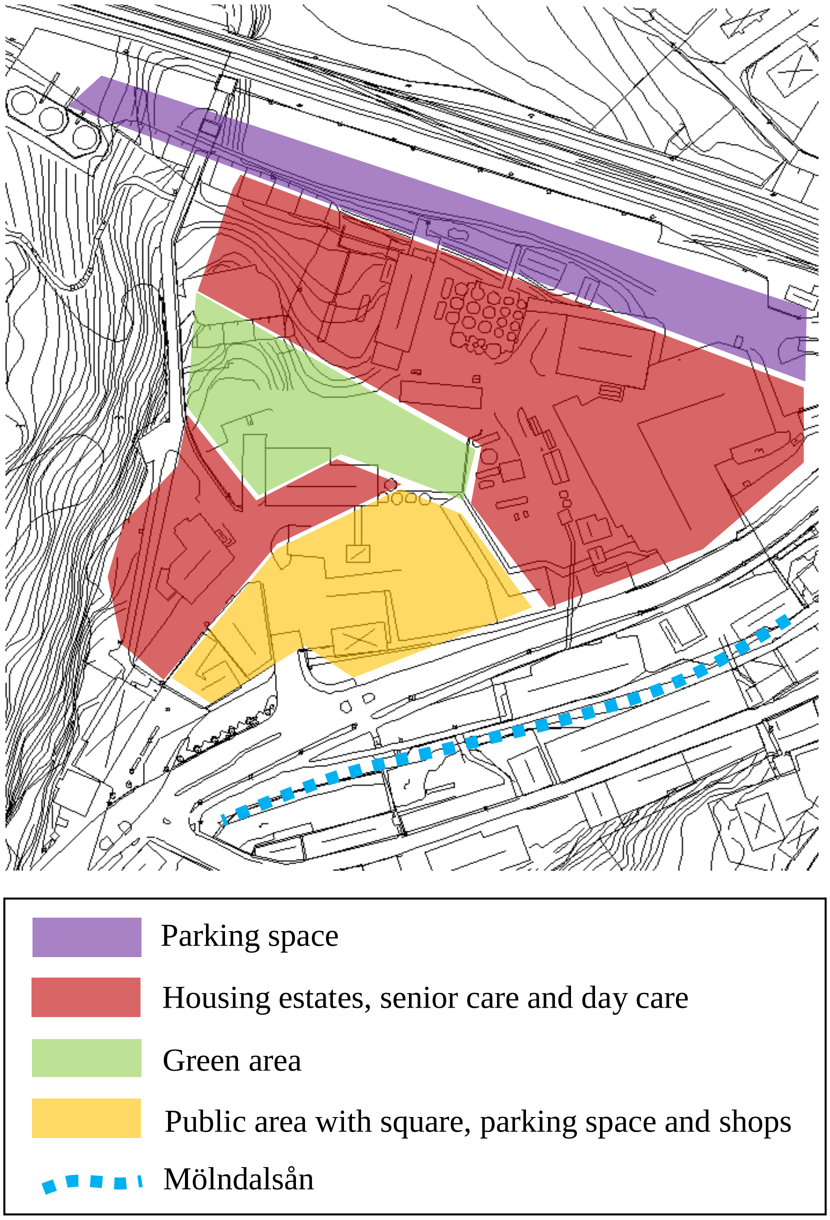


Figure 4.2. Overview of the future land use at Hexion, based on information from SWECO (2009a).

4.2 Geology and hydrogeology

Hexion is situated in an area with Gothenburg till. This type of till has a complex composition with varying fraction distribution, from sand and gravel to till with lenses of finer grains (Adrielsson & Fredén, 1987). At Hexion, the depth of the soil is generally 5-15 meter with till closest to the bedrock, followed upwards by sand, gravel and silt (SWECO, 2009a). Lenses of clay can be found at random depths. On top of the natural fractions there are large amounts of filling materials due to the long history of industrial activity. The filling mostly consists of sand, gravel, bricks and asphalt (NCC Teknik, 2010). See Figure 4.3 for a conceptual ground model.

The ground water flows 2-10 meters beneath the ground level in a north-southerly direction and is not in contact with any drinking water supply. In the steep slope, the ground water is artesian, forming a small spring. The ground water is in contact with the small river Mölndalsån, which runs southeast of the site. The river has been restored after many years of pollution and its protection value is today considered to be very high (SWECO, 2009a). Contaminants cannot accumulate in the sediments in Mölndalsån due to the high flows in the river (SWECO, 2009a). According to the action plan made by SWECO (2009b), the large depth to the ground water levels in the downstream area near Mölndalsån will result in a limited transport of contaminants from groundwater to surface water.

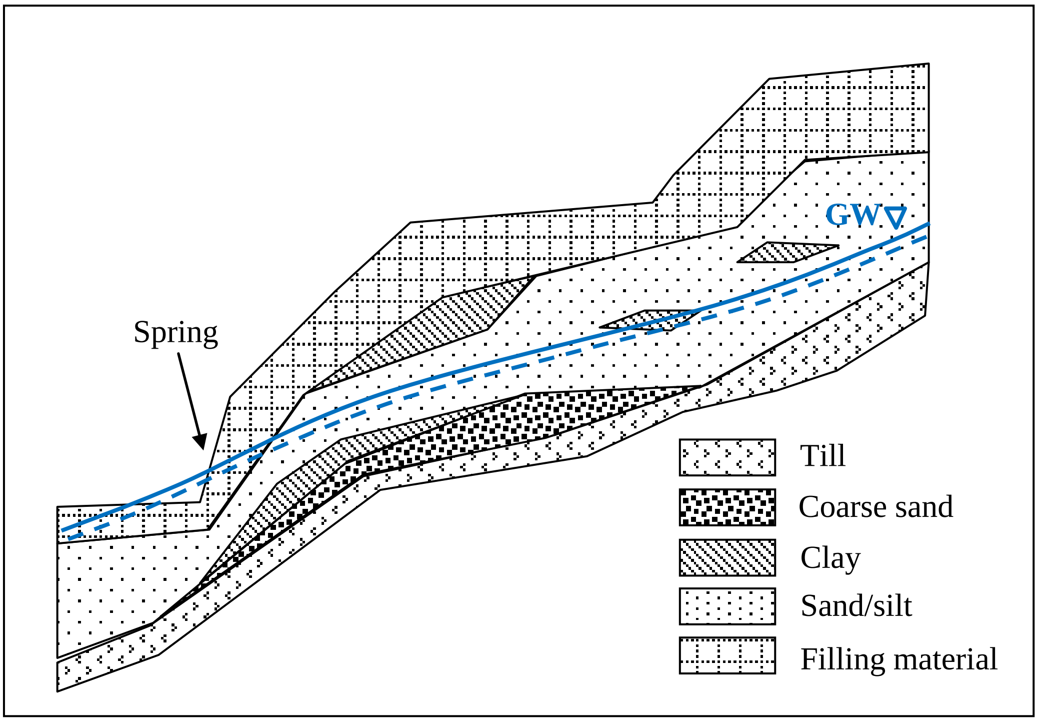


Figure 4.3. Conceptual ground model of the geology and hydrogeology at Hexion, based on information from SWECO (2009a).

4.3 Contaminants

The most common contaminants in the soil at Hexion according to the in-depth risk assessment made by SWECO (2009a) are shown in Table 4.1. The table also shows an important property of the contaminants, their mobility. Contaminants with a high K_d-value e.g. PAH-H and aliphatic hydrocarbon >C16-C35 are very stable and will not move in the ground without any physical support from the surrounding. Lead can also be considered as relatively stable. Contaminants with a high mobility, (low K_d-value) are PAH-L, PAH-M, xylene, aromatic hydrocarbon C8-C10 and C10-C16.

Table 4.1. The most common contaminants at Hexion (SWECO, 2009a). Different mobility for the contaminants were found in the SRP model from Trafikverket (former Banverket), 2007. Some mobility were also found at Toxnet, 2009a, Toxnet, 2005 and Toxnet, 2009b.

Contaminant	Mobility, K_d-value
Polycyclic aromatic hydrocarbons, PAH-L	100
Polycyclic aromatic hydrocarbons, PAH-M	100
Polycyclic aromatic hydrocarbons, PAH-H	15 000
Bis(2-ethylhexyl) phthalates, DEHP	10 000
Aliphatic hydrocarbon, >C8-C10	640
Aliphatic hydrocarbon, >C10-C12	5 000
Aliphatic hydrocarbon, >C12-C16	100 000
Aliphatic hydrocarbon, >C16-C35	2 000 000
Aromatic hydrocarbon, C8-C10	5
Aromatic hydrocarbon, C10-C16	50
Ethyl benzene	520
Xylene	39-365
Lead	1 000

Soil samples investigated by SWECO and NCC has shown that large areas within the property is almost unaffected by the previous industrial activities, but that very high concentrations of different contaminants have been found in confined areas. These heavily polluted areas and their main contaminants are shown in Figure 4.4. The surface soil down to 4 meters contains a large part of the contaminants, with some exception. For example, DEHP has the highest concentrations at depths greater than 6 meters.

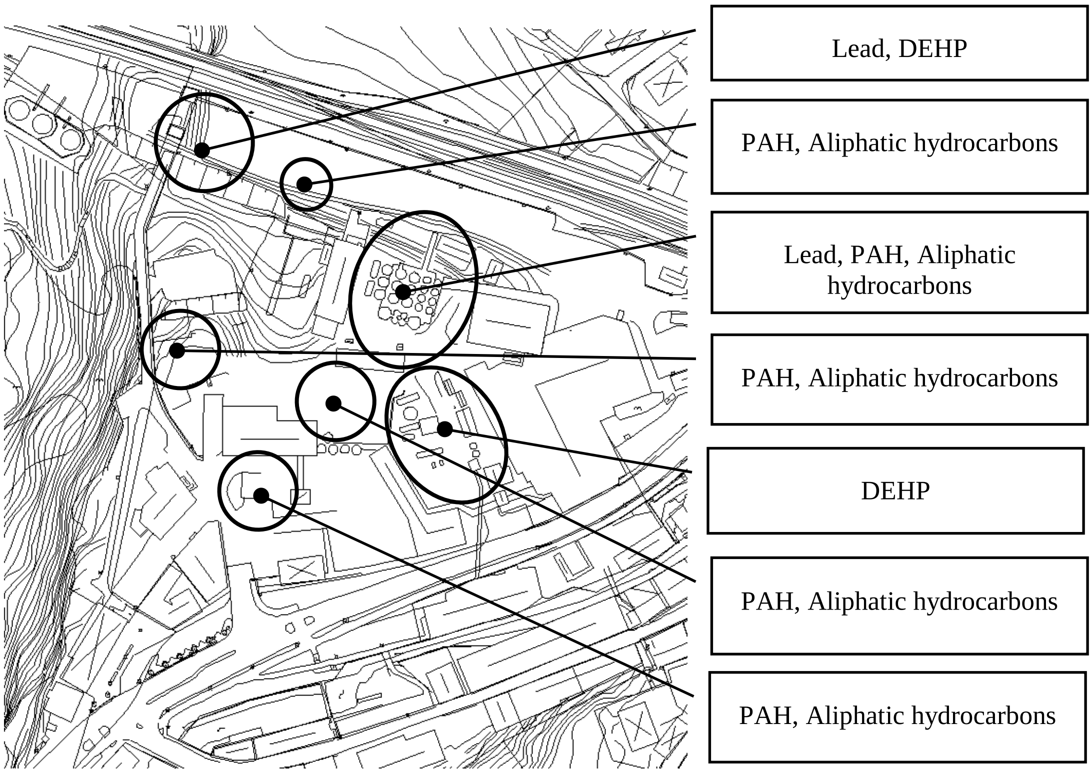


Figure 4.4. Location of the most severe polluted parts of the site and their main contaminant, based on information from SWECO (2009b).

Sampling data from SWECO (2009a) show limited effect on the ground water. All samples analysed for metals showed values lower than the generic guideline values. As for PAH, aromatics, xylene and benzenes, all sample except two showed very low concentrations. One sample showed concentrations of PAH, aromatics and benzenes, denoted as “serious” or “very serious” compared to generic guideline values (SWECO, 2009a). Another sample showed increased concentrations of PAH, xylene and benzenes.

5 Remediation alternatives, case study

This chapter describes and explains the evaluated remediation alternatives and the null-alternative considered in the case study for Hexion.

5.1 Null-alternative

A null-alternative is needed to be able to compare the different remediation alternatives and their achievements to one and the same action, the null-alternative. This alternative implicates what would happen at the site if no action at all were taken, i.e. if everything continued as before.

For Hexion this implies:

- The chemical factory continues their productions of chemicals, such as binding agents for colours and no action to minimize or reduce contaminants are performed at the site.
- The factory will have approximately 30 employees (www.121.nu, 2007).
- There are limitations for unauthorized people to enter the site and the area is enclosed by fences.
- There are restrictions for the employees on how to handle chemicals in the factory but these restrictions are only made to avoid jeopardizing the employees' health when working.

The goal to fulfil in choosing a reasonable null-alternative is that, it is the most likely outcome if nothing else is planned for the site. If the last active company at the site were disused and NCC did not purchase the site, the area probably would have activities like earlier, with industrial purposes.

Another scenario would be that the site forms an attractive area for residential purposes and that the site was re-built for residences without any soil remediation. However, this is not allowed according to Swedish legislation and has therefore not been considered as a possible null-alternative.

5.2 Remediation strategies

The remediation alternatives were chosen in cooperation with Malin Norin, NCC and Jenny Norrman, Chalmers. Alternative 1 and 2 are presented and evaluated in SWECO (2009b), where alternative 2 was recommended.

All four remediation alternatives are combinations of excavation and one or more of the following; transport to landfill, physical separation and soil wash.

Other remediation techniques like biodegradation, soil vapour extraction and incineration that might have been useful for remediation at Hexion was eliminated. Biodegradation was not chosen because the method is not effective enough on lead compounds and it is too time consuming. Soil vapour extraction would have been effective on PAH's, xylene, ethyl benzene, aliphatic- and aromatic hydrocarbon but fine fractions, like clay and silt combined with a groundwater level close to the ground surface could cause problems with this technique. Incineration could have been effective enough on many of the contaminants but the technique is too energy consuming. These conclusions are based on Table 2.1 and FRTR (n.d.).

The performance of the remediation will come in two steps; first excavation of the worst contaminated areas at the site, see Figure 4.4, then further excavation as the exploitation work progresses[3]. The excavation in step one is based on sample-taking in soil and groundwater, as for step two, environmental control will be made during ground work and it is likely that this will imply further need for removal of soil. The considered landfill areas Kikåstippen in Mölndal and Heljestorp in Vänersborg can be seen in Figure 5.1. For transport distances to the two areas, see Table 5.1.

Figure 5.1. Transports of contaminated soil from Hexion in Mölndal will go by E6 and E45 to Heljestorp in Vänersborg and from Hexion to Kikåstippen in Mölndal. The quarry in Hisings-Kärra providing new refilling material is also marked in the map. © Lantmäteriet Gävle 2011. Medgivande I 2011/007.

[3]Malin Norin, Technical. Dr. NCC Construction, study visit at Hexion 2011-05-12.

Table 5.1. Distances to landfill and their possibilities to handle soil with different contamination levels (SWECO, 2009b).

Contamination level	Landfill area	Distance from Hexion [km]
KM-MKM	Kikåstippen, Mölndal	2
>MKM-FA	Ragnsells, Heljestorp Vänersborg	100
>FA	Ragnsells, Heljestorp Vänersborg	100

Excavation in remediation alternative 3 and 4 are based on the site-specific guideline values also seen for alternative 2. Moreover, the landfill areas are the same as in alternative 1 and 2. In addition to excavation, alternative 3 and 4 also includes on-site treatment.

Refilling material is required in all four remediation alternatives to restore the ground surface after excavation. It can be assumed that 50% of the total excavated soil needs to be replaced[4]. The need may then differ for the remediation alternatives according to how large amount of soil that will be excavated. New refilling material is assumed to be bought and transported by lorry, taking approximately 37 ton/transport, from a quarry owned by NCC Roads in Hisings-Kärra, Gothenburg[5], for location see Figure 5.1. The refilling is a combination of crushed stones, gravel and other filling material common for ground constructions.

Surface water is collected and treated by a cleaning process performed at the site before it is lead to the waste water treatment plant in Gothenburg. The main task of this cleaning process is to separate oil products from the surface water[4].

5.2.1 Remediation alternative 1

Remediation alternative 1 suggests disposal of all soil with a contamination level exceeding the generic guideline values stated by Naturvårdsverket: KM for estates and green areas and MKM for office- and traffic areas. These limits are applied for all depths of the ground. The soil is excavated and transported to a landfill and no further treatment of the excavated soil will be performed. Figure 5.2 displays the amounts of removed soil, contamination level and measure after excavation, based on SWECO (2009b).

[4] Malin Norin, Technical. Dr. NCC Construction, study visit at Hexion 2011-03-11.
[5] Elaine Andersson, NCC Roads, mail contact 2011-05-06.

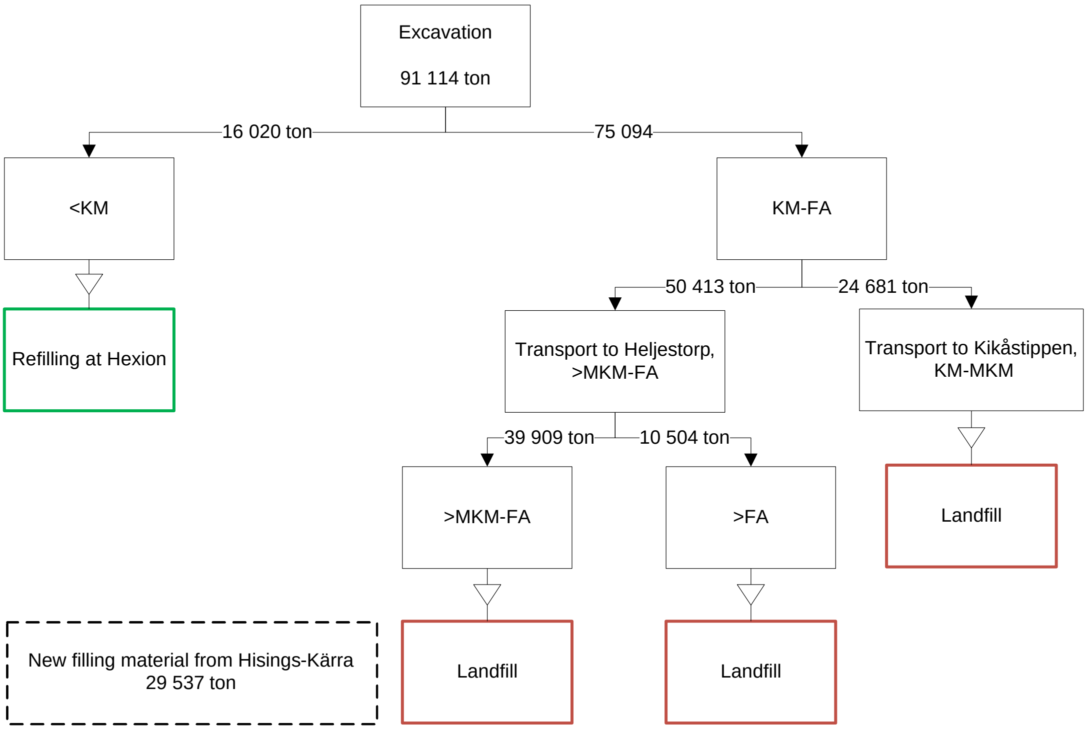


Figure 5.2. Overview of the remediation process in alternative 1.

The excavation is divided into 2 different depths, 0-4 meter and 4-8 meter. The contamination level on different depths can be seen in Table 5.2. It is clear that the most contaminated soil is found in the surface layer.

Table 5.2. Total amount of removed soil in alternative 1 at depths of 0-4 and 4-8 m. The values are based on the action plan for Hexion (SWECO, 2009b).

Contamination level*	0-4 m [ton]	4-8 m [ton]	Measure
<KM	12 420	3 600	Refilling at the site
KM-MKM	21 260	3 421	Landfill
>MKM-FA	31 040	8 869	Landfill
>FA	7 740	2 764	Landfill
	∑ 72 460	∑ 18 654	

*According to Naturvårdsverket

5.2.2 Remediation alternative 2

In remediation alternative 2, the amount of soil being excavated is based on the site specific guideline values defined by SWECO (2009b). The design pollutants are lead and DEHP according to SWECO (2009b). For soils at a depth >2 m, the content of contaminants may not exceed 25% of the restrictions for FA (SWECO, 2009b).

Figure 5.3 shows the different amount of excavated soil, contamination levels and measure after excavation.

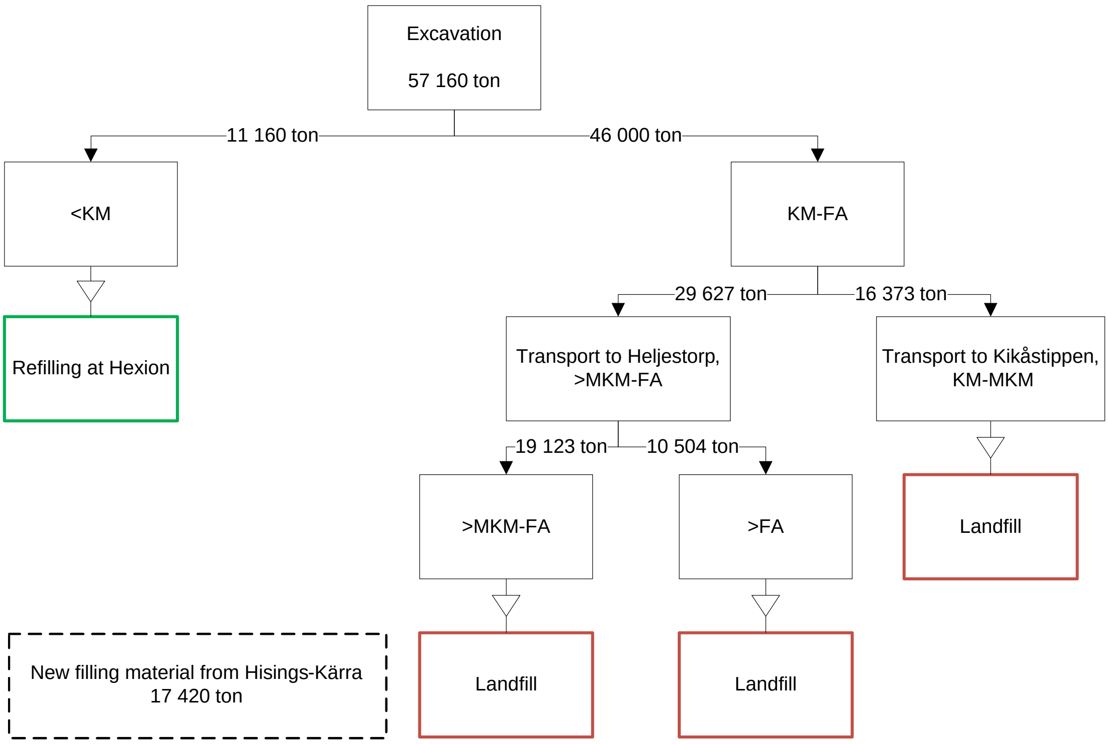


Figure 5.3. Overview of the remediation process in alternative 2.

Table 5.3 displays the amounts of removed soil at different depths according to SWECO (2009b). It can be seen that as for remediation alternative 1 the most contaminated soil it situated in the surface layer.

Table 5.3 Total amount of removed soil in alternative 2 at depths of 0-4 and 4-8 m. The values are based on the action plan for Hexion (SWECO, 2009b).

Contamination level*	0-4 m [ton]	4-8 m [ton]	Measure
<KM	7 560	3 600	Refilling at the site
KM-MKM	16 373	0	Landfill
>MKM-FA	15 243	3 880	Landfill
>FA	7 187	3 317	Landfill
	∑ 46 363	∑ 10 797	

*According to Naturvårdsverket

5.2.3 Remediation alternative 3

In remediation alternative 3, the excavation of soil will be performed as in alternative 2, i.e. on the basis of site specific guideline values. However, the contaminated masses are sieved before transport to landfill or refilling at the site. The sieving is done in two steps; first the larger fractions (>40 mm) are separated in a rotating trammel screen as seen in Figure 5.4. The remaining fractions (0-40 mm) proceed into a star screen in which the smallest fractions (<10 mm) are sorted out and transported to landfill,[6] see Figure 5.4. Stones and gravel with fraction size larger than 40 mm can be considered as clean and are therefore possible to reuse as filling material in the constructing process at the site (NCC Teknik, 2010). All grains with a size between 10-40 mm will be analyzed, classified and transported to proper landfill. The capacity of the sieving process is approximately 300 ton/day[6].

Figure 5.4. Overview of the sieving process at Hexion. Trammel screen to the right and star screen to the left. Photo: Åsa Landström.

From calculations seen in Appendix A it can be stated that 15% of the contaminated soil has a grain size >40 mm and can thus be considered clean. An overview of the processes for alternative 3 can be seen in Figure 5.5.

[6] Jonas Wiberg, Local manager at Hexion, NCC Construction, study visit 2011-05-17.

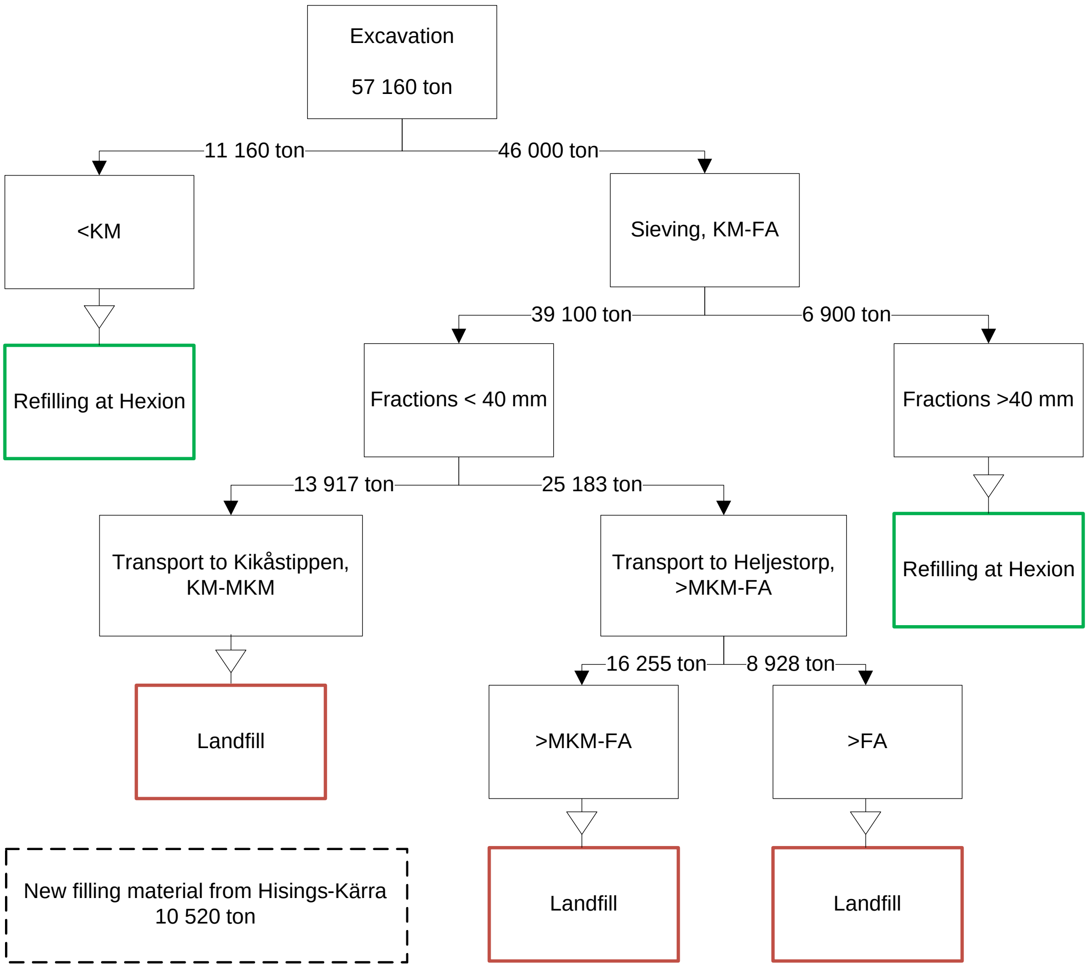


Figure 5.5. Overview of the remediation process in alternative 3. The soil masses are based on excavation according to alternative 2 in combination with sieving, see Appendix A.

5.2.4 Remediation alternative 4

In remediation alternative 4 the excavation is done according to remediation alternative 2 followed by sieving as in alternative 3. Additional treatment is a soil washing process done on-site.

Soil washing cannot be done for particles smaller than 0.6 mm; these fractions will be washed out and transported to landfill[7]. Since the contaminants are accumulated in the sludge it is assumed that all waste from soil with a contamination level corresponding to sensitive land, KM-MKM, is transported to Heljestorp for landfill as well as soil with contamination level >MKM-FA. The cleaning water is transported together with the soil to Heljestorp[7]. The stones and gravel classified as clean (larger than 40 mm) and the soil of mid-sizes fractions i.e. 0.6-40 mm will be washed and are thereafter

[7]Per-Arne Fjälling, Responsible for contaminated soil, Ragnsells Gothenburg, study visit at Heljestorp 2011-02-12.

suitable as refilling material. 35% of the total is washable material according to calculations seen in Appendix A. For an overview of the processes, see Figure 5.6.

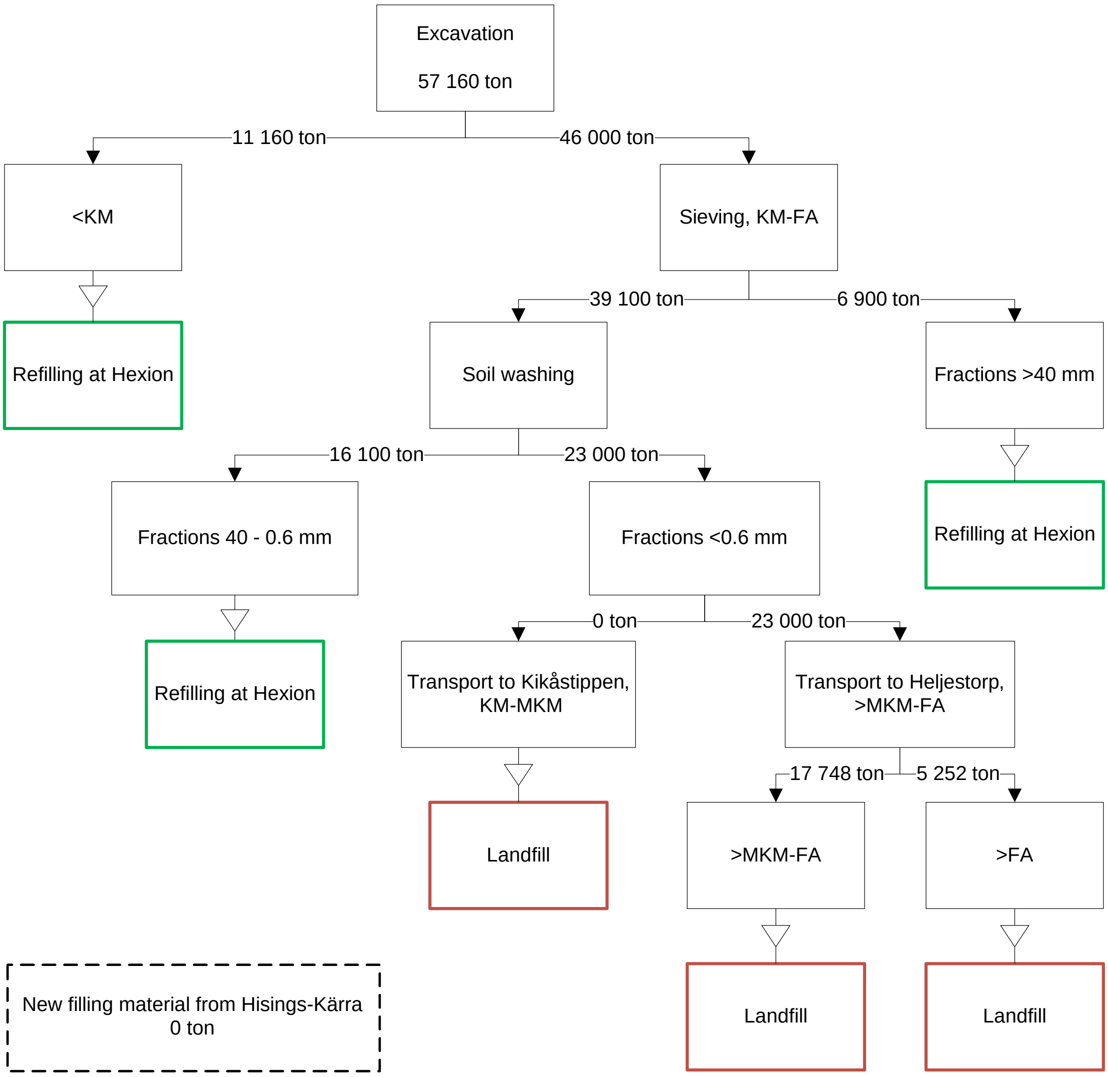


Figure 5.6. Overview of the remediation process in alternative 4. The soil masses are based on excavation according to alternative 2 in combination with sieving and soil washing as seen in Appendix A.

Total amount of soil possible to reuse as refilling material at Hexion according to alternative 4 is approximately 34 160 ton, which corresponds to 60% of the excavated masses. This makes it unnecessary to buy new refilling material from Hisings-Kärra with this remediation alternative.

6 MCA, case study

This chapter presents the performance and the results from the MCA for the case study at Hexion. Assessments of the ecological, socio-cultural and economic dimensions are explained. The chapter ends with uncertainty and sensitivity analyses and a short summary of the most important results.

6.1 Ecological dimension

The scoring of the different key criteria for the ecological dimension was done by expert judgement from the authors based on material provided by NCC and SWECO. The grounds for the scoring are motivated for each criterion. Scoring was based on the key questions for each key criterion described in Appendix A in Rosén et al. (2009). For the scores of the key criteria, see Table 6.1.

Soil (E1): The ecosystem at the site has been heavily disturbed by many years of industrial activity and has therefore small environmental values worth to preserve. However, remediation will improve the physical situation due to decreased amount of contaminants. The positive effect is presumed to be possible, not probable, even for remediation alternative 1, where more contaminated soil is excavated than in the other alternatives. This due to the fact that the site is going to be exploited for residential purposes that will continue to disturb the ground. For alternative 4, the possible positive effect claims that no contaminated water from the soil washing process is released to the ground.

Surface water (E2): Water from the site reaches the recipient Mölndalsån, which has a very high protective value (SWECO, 2009a). During excavation, contaminants may be released and travel with ground- or surface water to the recipient. However, the intent is to collect and treat this water. There might have been previous leakages from the industry causing contaminants to reach Mölndalsån. Although the river is small the flow velocity and by that the dilution is high.

Air (E3): In the null-alternative there are industrial activities on the site, goods are transported by train and lorries and there are also air emissions from the industry. During remediation, there will be transports with lorries due to excavation on the site and transport to landfill. For alternative 3 and 4, the number of transports will be reduced compared to alternative 1 and 2 since more of the soil can be used for refilling. However, both the sieving and washing machines are running on diesel. The negative effects will occur on regional and local ecosystems.

Sediments (E4): No sediments are affected on the site. If the contaminants will reach Mölndalsån, the high velocity will stop sedimentation from taking place.

Ground water (E5): It is possible that the ground water on the site will have a reduced quality due to the excavation process that might mix the soil and release contaminants into the groundwater. Samples taken before remediation have shown low contamination levels in the ground water (SWECO, 2009a). The ground water is not in contact with any drinking water supply. Alternative 1 leads to an excavation on greater depths which can be a risk for the groundwater. On the other hand, more contaminated soil will be removed, which lowers the risk for releases of contaminants in the future to the groundwater.

Consumption of natural resources (E6): There are no identified natural resources on the site. Non-renewable natural resources in the form of oil and gravel will be consumed. Alternative 1 demands more refilling material than alternative 2 and 3 whilst alternative 4 demands no new filling material. More fuel is consumed in alternative 1 than for other alternatives because of the many transports.

Table 6.1. Scores for the key criteria in the ecological dimension.

Alternative	E1	E2	E3	E4	E5	E6
1	+1	0	0	0	0	-2
2	+1	0	+1	0	0	-1
3	+1	0	+1	0	0	-1
4	+1	0	+1	0	0	0

6.2 Socio-cultural dimension

Grounds for the scoring of the socio-cultural dimension can be found below. These grounds are as for the ecological dimension, based on key questions for each key criterion found in Appendix A in Rosén et al. (2009) and performed by expert judgment by the authors. All scores can be seen in Table 6.2.

For the criterion, **justice and acceptance (S1)**, three persons with different roles in remediation projects and especially involved in the remediation of Hexion were interviewed. They were; Uffe Schultz, Environmental Engineer at the County Authorities 2011-05-11, Thomas Holm, Civil Engineer at SWECO, 2011-05-30 and Petra Brinkhoff, Environmental Consult at NCC and industrial PhD-student at Chalmers, 2011-05-06. They were asked to grade the criterion with assistance of the topical matrix with supporting key questions. They were also supported by descriptions of the results for the different remediation alternatives found in this case study.

Justice and acceptance (S1): In common for all three interviewed persons was that they wanted positive scores for all four remediation alternatives. A major reason for this is that the industry was disliked by the public and there is generally a large acceptance for remediation of old, contaminated industries. The effects of the remediation will also be positive to future generations. According to Schultz, it is a good thing for the acceptance to excavate and transport the soil to a landfill because in that way, the public can directly see that the contaminated soil is being removed.

All three also agreed upon that transports to and from the site are more disturbing than the excavation process. Whether the sieving and washing will interfere with people living close to the area is depending on the execution. Holm pointed out that the impact on residents in the vicinity is affected less if these processes are controlled to minimize spread of dust and noise. Brinkhoff believes that detailed information to the public is required to give a positive feeling for the sieving and washing alternatives.

Which groups that might be disfavoured of a remediation differ slightly among the interviewed persons. Schultz and Holm believes that residents near landfills will not disfavour since they already should have an acceptance of that type of activities. Holm believes, however, that there is a group that can disadvantage of transports, i.e. people living along the transport routes. Likewise Brinkhoff, he also mentions the workers in the factory as a group to consider and that they will be disfavoured since they lose their job. More detailed description of the interviewee's scoring and motivation can be seen in Appendix B.

Health (contaminants) (S2): The concentrations of contaminants will be reduced and no new contamination will be added, which on the other hand might not been the case in the null-alternative. After remediation, more people will be exposed to the site than before. However, to the neighbours the remediation will only bring benefits. All remediation alternatives will lower the concentrations of contaminants but the exposure situation for humans will however increase. Despite this, the health risks for humans might be decreased.

Health (measure) (S3): A monetized aspect of this criterion can be found in the CBA, such as workers being exposed to contaminants and traffic accidents caused by transports. The focus when scoring this criterion is therefore on dust and noise. Alternative 3 and 4 which include sieving might cause dust in the surroundings whilst alternative 1 and 2 demands more transport of soil, thus more noise. It is assumed that the transports of soil to landfill in alternative 1 and 2 are covered so no dust will spread and therefore, the scoring are higher than for alternative 3 and 4.

Cultural environment (S4): A historical industrial building along Mölndalsån will be preserved, but on the other hand, there is no information saying that the building would be threatened in the null-alternative. Moreover, the view in the surrounding area is improved.

Recreation (S5): In the null-alternative there are no possibilities for recreation or outdoor activities at the site. After the remediation, the public will get possibilities to enjoy the new green area and public square at the site.

Land use off-site (S6): During the time remediation is performed no other area will be restricted than the site itself. Trains can pass and traffic can run as before.

Land use on-site (S7): The site will be used for the intended residential purpose, which would not have been possible without remediation.

Table 6.2. Scores for the key criteria in the socio-cultural dimension.

Alternative	S1	S2	S3	S4	S5	S6	S7
1	+1	0	-1	+1	+1	0	+2
2	+1	0	-1	+1	+1	0	+2
3	+1	0	-2	+1	+1	0	+2
4	+2	0	-2	+1	+1	0	+2

6.3 Economic dimension

The CBA performed for Hexion is based on the difference between the null-alternative and the different remediation alternatives according to the method described in Section 3.6. Only the effects of the most crucial contaminants at the site according to SWECO (2009b), ethyl benzene, DEHP, PAH-H and lead are taken into consideration in the CBA.

6.3.1 Identification of costs and benefits

The costs and benefits have been identified and valuated depending on the expected importance. For Hexion, all possible benefits and their importance are gathered in Table 6.3.

The main benefit of a remediation at Hexion is probably *the increased land value of the property,* B1a, since the site is converted from an industrial to a residential area. B2ab-B2ad are included since it can be assumed that an increase of the land value for Hexion due to remediation insistently will lead to fewer restrictions for the site, better trust and less juridical responsibility. There are some properties in the near surrounding of Hexion and it is likely that the *land value for surrounding properties*, B1b will be affected by the remediation of the site. After measure, no production will take place on the site, why B2aa is assumed to be of no importance. Other important benefits are *the reduced health risks*, B3a acute and non-acute, as well *as increased possibilities for recreation within the site*, B3ba when the area is opened up for the public.

Table 6.3. Identification of benefits for remediation alternatives at Hexion, where "X" answer to great importance, "(X)" answer to some importance and "0" implicate no importance.

	Monetary benefit (B)	**Importance** "X", "(X)", "0"
B1.	***Increased land value***	
B1a.	Increased land value for the site	X
B1b.	Increased land value for surrounding properties	(X)
B2.	***Net impact on market-priced services and goods***	
B2a.	Possibility for more profitable service or good production	
B2aa.	Production with lower cost, higher quality and better rate of return	0
B2ab.	Fewer restrictions for the activity	X
B2ac.	Better trust for the activity	X
B2ad.	Less juridical responsibility	(X)
B2ae.	Better working environment	(X)
B3.	***Net impact on non-market-priced services and 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 and goods	
B3ba.	Increased possibilities for recreation within the site	X
B3bb.	Increased possibilities for recreation in surrounding area	(X)
B3bc.	Increased access to other eco-system services and goods	(X)

As for the cost, C1a and C1b have no values since they are included in C1e, *cost for conducting and performing control-program*. *Default rate of return from capital locked up by the measure*, C1c, is relevant since remediation projects will result in big investments. *Cost of performing the measure*, C1d is of great importance, as well as C1e. The *project risks*, C1f will last during the time for remediation, year 3-5 and is also of large importance in this CBA. *Negative effects on health due to measure,* C2 includes both *increased health risks due to measure on the site,* C2a and *increased health risks due to transports caused by measure,* C2b which are equally important in the analysis. However, *increased health risk at the landfill area,* C2c, can be assumed to only be of some importance due to that a landfill is a controlled and restricted area.

The *negative effects on ecosystem services and goods due to measure*, C3 gives only that C3b, *reduced access to ecosystem services and goods off-site*, is of great importance. This is due to the large amount of emissions that can be assumed from transports of material from and to the site. The *reduced access to eco-system services and goods in landfill area,* C3c, can have some importance but it can be assumed that the area is restricted for landfill. All possible costs of the project at Hexion and their importance are gathered in Table 6.4.

Table 6.4. Identification of costs for remediation alternatives at Hexion, where "X" answer to great importance, "(X)" answer to some importance and "0" implicate no importance.

	Monetary cost (C)	Importance "X", "(X)", "0"
C1.	***Cost for performing the measure***	
C1a.	Costs for investigation- and framing of measures	(X)
C1b.	Costs for purchasing of concessions	(X)
C1c.	Cost, default rate of return from capital locked up by the measure	X
C1d.	Cost for performing the measure	X
C1e.	Cost for conducting and performing control-program	X
C1f.	Project risks	X
C2.	***Negative effects on health due to measure***	
C2a.	Increased health risks due to measure on the site	X
C2b.	Increased health risks due to transports caused by measure	X
C2c.	Increased health risks at the landfill area	(X)
C3.	***Negative effects on ecosystem services and goods due to measure***	
C3a.	Reduced access to eco-system services and goods on the site	0
C3b.	Reduced access to eco-system services and goods off-site	X
C3c.	Reduced access to eco-system services and goods in landfill area	(X)

6.3.2 Time plan

The time plan for the remediation project at Hexion starts in 2007, i.e. the year when NCC bought the property; see Appendix C for an overview of the time plan. Investigation and framing of measures where then done during 2007-2009 and the remediation is planned to be finished during the period 2009-2011, in the time plan called year 3-5[8]. To investigate the possible long-term health risks, a time period of 1-350 years was chosen, which correspond to five generations (Rosén et al., 2008). Increased health risks due to the measure on the site and due to transports caused by the measure are of importance during year 3-5.

Default rate of return from capital locked up by the measure stretches over a period of 3 year, i.e. the time for which NCC is planning to perform the remediation at the site.

6.3.3 Quantification of costs and benefits

Before the costs and benefits are entered in the calculation of the NPV, they need to obtain monetary values, i.e. be quantified. This section explains what type of methods and information that were used for the quantifications. All quantified costs and benefits for each remediation alternative are listed in Appendix D.

[8] Lars-Göran Petersson, Head of department, NCC Boende Region West, interview 2011-03-03.

6.3.3.1 Increased land value (B1)

Increased land value for the site, B1a has a value equal to the difference in land value between an industrial land of Hexion's size and a residential area with 300 apartments. These data were provided during a meeting with Lars-Göran Petersson, Head of department, NCC Boende Region West, 2011-03-03.

Increased land value for surrounding properties, B1b was estimated by comparing the equity in value on an average lot nearby Hexion with lots near an area in Gothenburg where there earlier have been remediation activities. The lots used for the comparison are situated near Eriksberg at Hisingen which is a formal shipbuilding yard where remediation and construction for residences started in 2005-2006 (Skoog, 2005). The comparison is made for the years 2006-2009. Lots in Sweden are divided into specific value areas and all such areas have a standard size of a lot in m^2, this information is obtained from the Swedish Tax Agency. More detailed information about these calculations can be found in Appendix E.

The hedonic pricing method is often used to compare variations in housing prices which reflect the value of a local environmental change; this is an alternative method which was not applied at Hexion. The hedonic pricing method studies selling prices (often during one year) in the area, property characteristics that can affect selling prices like lot size, size of rooms, property taxes, crime rates, and distances to work etc. When all data are collected it is fitted together to a statistical function measuring the portion of the property price that is due to each characteristics (Ecosystem Valuation, n.d.). This is a method demanding large number of data and is therefore too time consuming for this Master's thesis but could however have given a more accurate result.

6.3.3.2 Market-priced services and goods (B2)

The posts B2, are included in *increased land value for the site* B1a, and have therefore no value to avoid double counting in the CBA, see Rosén et al (2008).

6.3.3.3 Non market-priced services and goods (B3)

The calculations of *reduced acute health risk*, B3aa, was calculated in accordance to Appendix B in Rosén et al. (2008). A reference concentration of acute effects from the most crucial acute toxicity contaminant is compared to data from samples taken at the site. Probability of exceeding the reference concentration can then be calculated.

Ethyl benzene was selected for calculations of acute health risk. Ethyl benzene has an available acute toxicity level, which can lead to "*immediately danger to health or life"* according to Toxnet (2005). DEHP and PAH were not chosen due to their low acute health risks to humans (Department of Health and Ageing NICNAS, 2010 & Toxnet, 2004). Lead seems to have an acute health risk but there is no appropriate acute-toxicity levels available for this pollutant (U.S. EPA, 2000). For more details on the acute health risk calculations, see Appendix F.

Reduced non-acute health risk, B3ab, where handled by calculating the non-acute health risk for the null-alternative and compare these results with the generic target risk for KM. The software, SADA (2007) was used for the risk calculation. Only the most crucial contaminants at Hexion; lead, DEHP and PAH-H, where analysed (SWECO, 2009b). In SADA, these contaminants were represented by:

- Lead: Lead-205
- PAH-H: Benzo(a)pyrene
- DEHP: Bis-(2ethylhexyl)phthalate

PAH-H is a carcinogenic substance, the -H specify a high molecular weight and this type of PAH is very toxic to human according to Trafikverket (former Banverket), (2007). Different substances that are classed as PAH-H are; benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene and indeno(123cd)pyrene according to NV (2011b). Benzo(a)pyrene is well documented and hence selected to represent PAH-H in SADA. The behaviour of benzo(a)pyrene and the health effects are documented for some human exposure cases but mostly from animal experiments (U.S. Department of Health and Human Services, 1995). Lead-205 was chosen to represent lead in SADA. See Appendix G for the calculations.

Increased possibilities for recreation within the site, B3ba, and *increased possibilities for recreation in surrounding area*, B3bb are difficult to monetize. However, these benefits should not be negligible and hence be considered in the final judgment of the result of the MCA, by means of the socio-cultural dimension.

6.3.3.4 Cost for performing the measure (C1)

Costs for investigation and framing of measures, C1a and *costs for purchasing of concessions*, C1b have no value in themselves, since they, according to SWECO (2009b) can be included in C1e.

Default rate of return from capital locked up by the measure, C1c is calculated on the basis of C1d, *cost for performing the measure* which is the capital locked up by the measure at the site. This sum is thus specific to each alternative. Rate of return is the Swedish prime rate from the 16th February 2011. Appendix H shows more of this calculation.

Cost for performing the measure, C1d, includes costs for performing the remediation method, purchasing new refilling material and transports of contaminated soil to landfills. The different remediation alternatives have some activities in common which generates costs. These are; building temporary roads, excavations, transports of contaminated soil, fees at the landfills and (excluding alternative 4) cost for new refilling material. Alternative 3 and 4 also include costs for sieving and in alternative 4, soil washing is added. The latter costs are according to a tender made by SoilTech in 2009.

Cost for conducting and performing investigation and control-programs, C1e as well as *cost for project risks*, C1f, are according to SWECO (2009b). See Appendix H for more information about costs for performing the measures.

6.3.3.5 Negative effect on health due to measure (C2)

Negative effects on human health due to the remediation project includes health risk from excavation and cleaning processes, the transports of the soil as well as increased health risk at the landfill area. *Increased health risk due to measure on the site*, C2a, is divided into two parts that are summarized; first the health risk associated with exposure to contaminants during the excavation, and second, the risk for work related to accidents on the site. The health risk is calculated in SADA based on the amount of soil that needs to be excavated in order to fulfil the target risk values. Default scenario parameter is used, except for the adult exposure duration and exposure frequency. It is estimated that 10 persons work with the excavation during 3 year and that they work 200 days/year. The analysis in SADA was done for the same contaminants as for *reduced non-acute health risk*, B3ab, i.e. lead-205, benzo(a)pyrene and bis-(2ethylhexyl)phthalate.

The calculations of work related accidents are based on data from the Swedish Work Environment Authority, showing statistics of work related accidents during a period of 12 months. The accident cost of a person getting slightly injured is according to SIKA (2009). See Appendix I for calculations.

Accidents connected to transports of the contaminated soil and new refilling material is included in *increased health risks due to transports caused by measure,* C2b. If an accident happens, the costs, including injuries and remediation, might be considerable. Information about the value of severe injuries from a traffic accident is accessed in SIKA (2009).

The estimated number of transports/day from the site with contaminated soil is 6[9]. It is supposed the transports will go on 200 days/year, during 3 years. The contaminated soil will be transported by a lorry with a trailer to Kikåstippen and Heljestorp, containing totally 30 ton contaminated soil[10]. Based on this information risk calculations were carried out, as seen in Appendix J. The cost for remediation after an accident with contaminated soil is calculated based on the same costs as for excavation of the surface soil at Hexion.

Calculations of costs in case of a traffic accident involving refilling material which is transported by lorries from a quarry at Hisingen, Gothenburg can be seen in Appendix K. These transports are however shorter than and not as many as the transports concerning the contaminated soil.

The increased health risk at the landfill, C2c, is not possible to estimate in an exact monetary value. However, is assumed to be present but difficult to estimate.

6.3.3.6 Negative effects on ecosystem due to measure (C3)

The negative effects on ecosystem services and goods due to the remediation project are not negligible. There are no *eco-system services and goods on the site,* C3a of importance but the cost from CO_2-emissions are calculated as a *reduced access to eco-system services and goods off site*, C3b. The amount of CO_2-emissions from the different alternatives can be seen in Appendix L. The calculations are made in a bachelor thesis by Almqvist et al. (2011). The costs for CO_2-emissions are according to SIKA (2009). See Appendix L for complete calculations.

The cost *reduced access to services and goods in landfill area*, C3c is not possible to estimate but cannot however be put to 0.

[9] Jonas Wiberg, Local manager at Hexion NCC Construction, study visit 2011-05-17.
[10] Allan Olsson, VD Nao Entreprenad AB, phone call 2011-03-29.

6.4 Incorporation of project risks

To find and incorporate relevant project risks into the MCA-tool a report made by Rosén & Wikström (2005) on project risks and safety matter at BT Kemi was used as a basis. The report includes a matrix which was modified, see Appendix M. The authors have listed different kinds of possible project risks, the probability for the events to occur and the consequences. The consequences are anticipated in terms of; damage to person, economic consequence and/or environmental damage. Probability and consequences are estimated and given a number, 1-5, where 1 = very low/small and 5 = very high/catastrophic.

Roughly, a division into three main work phases is done; preparation, implementation and follow-up. Included in these phases are groups and sub-groups of project risks, see Table 6.5. The work phase follow-up has been excluded in the example Hexion since the site-owner NCC intends to sell the land after completion[11].

[11] Lars-Göran Petersson, Head of department, NCC Boende Region West, interview 2011-03-03.

Table 6.5. The three work phases and their groups of project risks that are relevant for Hexion, adapted from Rosén & Wikström (2005). Project risk groups in brackets have been excluded since they are irrelevant for Hexion.

Work phase	Project risk
Preparation	Enquiry material Procurement Risk reduction and risk evaluation Authorization Environmental control (Drainage) Sectoral planning Construction work Electrical installations Working environment Factors outside consultancy mission
Implementation	Delimitation of working area All tasks All activities where machines and/or vehicles are used Excavation, loading and transport Management of contaminated water Temporary landfill (Management of chemical products) Waste management Electrical installation Waste water treatment plant All contract work Sampling Material supply Recovery for planned land use Usefulness of action to Mölndal's society
(Follow-up)	

Some project risks in preparation and implementation have been excluded since they are not relevant or included in other parts of the MCA. Parts that are not relevant for Hexion are e.g. drainage, since the groundwater table does not need to be lowered, as well as recovery for planned land use since this parts is excluded according to the delimitations of this Master's thesis. To avoid double counting, all project risks connected to health risks for workers due to exposure to contaminants have been omitted because these risks are calculated in SADA and handled in the CBA, under *cost for negative effects on health due to measure C2a-b*. Moreover, some parts of the list include events that are handled in the socio-cultural criteria, e.g. lack of information to public which is mentioned in criterion S1; *justice and acceptance*. Health threatening events that afflicts third part is handled in the criterion S3; *health risk due to measure*. These project risks are therefore left out.

6.4.1 Project risk matrix, case study

All project risks are defined by their probability and consequences, as seen in Appendix M. When they are identified and estimated they can be placed into an ALARP-matrix, according to Rosén & Wikström (2005), see Figure 6.1**Fel! Hittar inte referenskälla.**. ALARP is shortening for *As Low As Reasonable Practicable* and is a system for defining acceptable risks (Burgman, 2005). The probability of the unwanted event to occur is on the vertical axis and the consequence on the horizontal axis. The green area represents acceptable risks, the orange area is the ALARP-region, meaning the risks should be reduced if it is practicable and the benefit exceeds the cost. Project risks in the red region cannot be accepted unless certain circumstances.

Probability		1	2	3	4	5
Very high	**5**					
High	**4**	1	3	2	1	
Moderate	**3**		11	10	6	
Low	**2**		22	25	21	1
Very low	**1**	1	3	6	5	

Consequence		**1** Very small	**2** Small	**3** Moderate	**4** High	**5** Catastrophic
	Damage to person	None or slight	Traversal injury	Permanent and serious	Occasional decease	More decease
	Economic consequences	<1 kSEK	1-100 kSEK	100 kSEK - 1 MSEK	1-10 MSEK	>10 MSEK
	Environmental damage	None or slight	Moderate spreading, non-permanent	Large spread, non-permanent	Very large spread or permanent	Very large spread and permanent

Figure 6.1. Number of project risks in each region of the ALARP-matrix for the case study Hexion. As seen, most project risks are located in the ALARP-region (orange area).

A total of 118 project risks were identified and estimated for Hexion. The number of project risks in each part of the ALARP-matrix is indicated with a number, see Figure 6.1. Most project risks are situated in the ALARP-region and indicate that these shall be investigated further. However, one project risk, *incorrect assessment of various substances distribution* is defined as unacceptable. This is due to long, not always well-documented duration of industrial history on the site together with complex soil conditions and confined time and resources for sample taking. This risk can lead to major economic consequences, remediation alternative changes or extensions, causing delays and increased costs.

Project risks can be valued in monetary terms and incorporated in the CBA under *project risks, C1f*. For the case study of Hexion it is set to 5 MSEK without any investigations of probable project risks, see Appendix H.

To conclude, the matrix contain many project risks, but the most severe at Hexion are connected to the probability of incorrect assessment of distribution and properties of contaminations as well as physical properties of the soil. Other severe project risks in the preparation phase are related to lack of communication; between site-owner and contractor and between site-owner and authorities.

In the implementation phase the project risks are work related accidents, especially in poor weather and working in darkness. During winter, freezing of water work can cause severe environmental damages. Also dust is a problem when spreading to the nearby road causing slippery lanes and/or contaminating treated soil. If the benefit for the society of Mölndal becomes lower than expected, the economic situation will disadvantage due to less establishment of people and activities on and nearby Hexion.

6.4.2 Interviews, case study

From interview with Jonas Wiberg, local manager at Hexion, 2011-05-17 one project risk was added to the matrix seen in Appendix M under *dust, by wind*: S10, which deals with personal injuries due to dust with clay particles causing slippery lanes at the nearby steep road Kvarnbygatan, southeast of the site. Overall, accidents on the site are important project risks according to Wiberg. One other critical project risk is if an electric power failure occurs and the waste water cleaning process will be disturbed, leading to overflow of contaminated surface water.

According to Per-Arne Fjälling, Responsible for contaminated soil at Ragnsells, 2011-02-21 an important project risk at Hexion is the risk for ground water intrusion which can make the excavation and sieving process more expensive.

According to Thomas Holm, Civil Engineer at SWECO, 2011-05-30 important project risks are the conjuncture and that e.g. the construction project should be performed exactly at right time to benefit the site-owner. This is a view that Petra Brinkhoff Environmental Consult, 2011-05-06 share with him. Holm also pointed out the importance of certainty in pre-studies from the preparation phase. Uncertainty in the spread of contaminants can be problematic, for example how deep the contaminants reaches. This risk was also pointed out as important by Brinkhoff. Furthermore, Holm emphasized that it shall be no doubt whether the site is clean enough after remediation. The fact that the planning of the housing is not fulfilled when the remediation starts can also lead to delays and other project risks. According to Brinkhoff, delays in the project are a severe project risk for the site-owner.

Uffe Schultz, Environmental Engineer at the County Authorities, 2011-05-11, pointed out the importance of continuous communication with the County Authorities through the project to avoid delays and lower confidence for the project and by that increased cost. At Hexion important project risks are connected to the excavation, were contaminants can be spread by dust and surface water. The fact that it is easy to mix up “clean” soil with contaminated soil due to that it is hard to take enough samples on the soil can also be considered as a project risk according to Schultz. This was also mentioned by Fjälling, who also was concerned about the risk for transporting contaminated soil to the wrong landfill area.

6.5 Results of the MCA

Results from the MCA for Hexion can be seen in Table 6.6. Alternative 1 has a negative sustainability index, indicating that this alternatives does lead towards sustainable development; this is hence not a suitable alternative at Hexion. It can be concluded that remediation alternative 2-4 will have a weak sustainability. It must therefore be determined whether weak sustainability is possible to accept; otherwise the alternatives must be modified and the analysis be iterated. Since suggested remediation alternatives for Hexion, excavation and transports to landfill are the by far most common methods in Sweden today, these also are the most likely. Therefore, weak sustainability could be accepted for this analysis.

Next step is to suggest criteria for weak sustainability, i.e. if the negative scores can be compensated by positive scores or not. Alternative 2 has negative scores on *use of natural resources* and *health due to measure*. This might be possible to compensate with the fact that the sum of each of the three dimensions are positive. Alternative 3 has negative scores on the same criteria as alternative 2 but slightly lower sustainability index. The negative scores might be compensated by all three dimensions being positive, it is also the most economically profitable alternative. From the uncertainty analysis it was concluded that the probability for a positive NPV is 100%. Alternative 4 has negative scores on the economic dimension and the criterion *health due to measure*. This might be possible to compensate by the high score of the ecological dimension.

The current site-owner NCC took a risk when starting the Hexion-project and economic profitability is crucial when determining if the project will be beneficial or not. A negative value on the economic dimension can therefore be impossible to compensate for. However, it is up to responsible decision makers to decide which criteria for weak sustainability they can accept.

If NCC decides not to accept negative dimensions, all alternative with a negative economic dimension does not fulfil the criterion for weak sustainability. However, the calculated value of the economic dimension seen in Table 6.6 is a point value and it might be more accurate to look at the distribution of the NPV from the Monte Carlo simulation, see Appendix N. From this it can be notified that alternative 2 has 1% probability for a positive NPV, while alternative 3 on the other hand has 99% probability of NPV being positive. Alternative 4 has 42% probability of having a positive NPV. For further information about the uncertainty analysis, see Section 6.6.2.

Alternative 2 does not under any circumstances fulfil the criterion for weak sustainability. If the decision makers can accept 58% probability of having a negative NPV, remediation alternative 4, with its high sustainability index will have the highest rank. If this however cannot be accepted, only remediation alternative 3 remains and will be the recommended remediation alternative.

Table 6.6. Results of the MCA. $\boldsymbol{\Phi_i}$ is the estimated NPV for discount rate 4%, without Monte Carlo simulations.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Ecological dimension				
Ground	1	1	1	1
Surface water	0	0	0	0
Air	0	1	1	1
Sediments	0	0	0	0
Ground water	0	0	0	0
Use of natural resources	-2	-1	-1	0
H_E	-1	1	1	2
Socio-cultural dimension				
Justice and acceptance	1	1	1	2
Health (contaminants)	0	0	0	0
Health (measure)	-1	-1	-2	-2
Cultural environment	1	1	1	1
Recreation	1	1	1	1
Land use off-site	0	0	0	0
Land use on-site	2	2	2	2
H_S	4	4	3	4
Economic dimension, Φ_i	-9.703	5.643	5.983	-0.037
Sustainability index, H	-0.17	0.69	0.62	0.67
Strong sustainability?	NO	NO	NO	NO

6.6 Uncertainty and sensitivity analysis

For the ecological and socio-cultural dimension a sensitivity analysis according to Burgman (2005) was performed to investigate the sensitivity of the scoring, i.e. how large impact a change in the scoring leads to. For the economic dimension, an uncertainty and sensitivity analysis was performed by Monte Carlo simulations to evaluate calculated NPV's.

6.6.1 Ecological and socio-cultural dimension

The sensitivity analysis according to Burgman (2005) was done by changing the scoring of the key criteria in the ecological and socio-cultural dimension with +/-1 score. Only one key criterion at the time was changed. The investigated results were changes in the sustainability index due to the varied scores. Moreover, the s_p-values were calculated. Unfortunately, this was impossible for many of the alternatives since the score was set to 0 and deviation with zero is not valid, see Eq. 3.11. Due to this, only the changes in sustainability index were considered in the sensitivity analysis. The results are shown in Figure 6.2-6.5. Not shown in the figures are that changes in score in one alternative can affect the sustainability index for other alternatives. Scores that are varied in a positive direction for the alternative which has the highest summarized score in either ecological or socio-cultural dimension will lower the sustainability index for remaining alternatives. Alternative 4 has the highest score in the ecological dimension, and alternative 1, 2 and 4 have the highest score in the socio-cultural dimension.

In general, changes in sustainability index show that the ecological key criteria are more sensitive than the socio-cultural. This is partly depending on the scoring and partly on the fact that there are only six criteria in the ecological dimension compared to seven in the socio-cultural. The most interesting result is whether an alternative can become either weak or strong depending on changes in the scores.

Remediation alternative 2-4, which have default values similar to each other, can by a change in the scoring of one criterion in either two dimensions cause changes in the ranking order. Alternative 1 is the least favourable alternative since it is not sustainable despite positive changes in the scoring. The fact that sustainability index for alternative 4 does not change much is due to the alternative's high summarized scores in the ecological and socio-cultural dimensions.

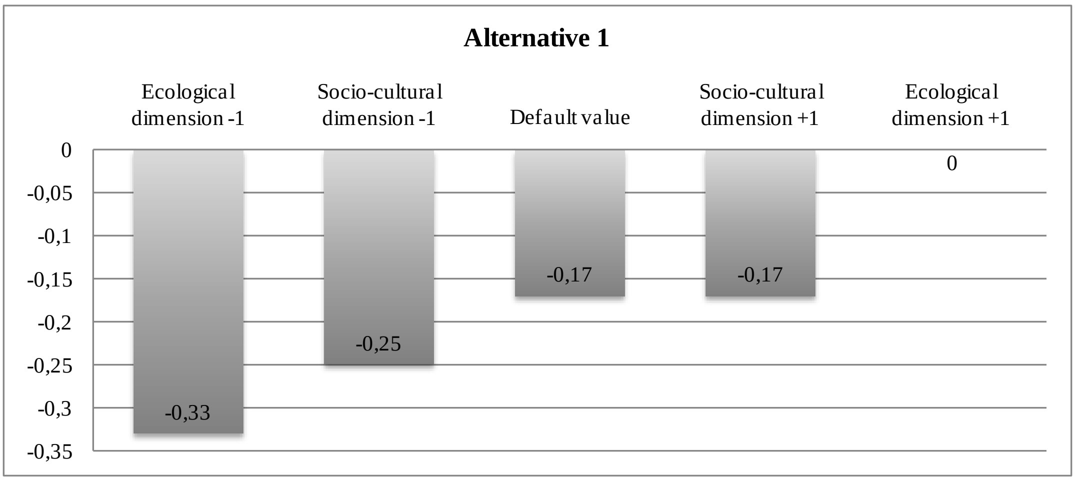


Figure 6.2. Change in sustainability index H_i for alternative 1 due to modified scores in one criterion in either socio-cultural or ecological dimension.

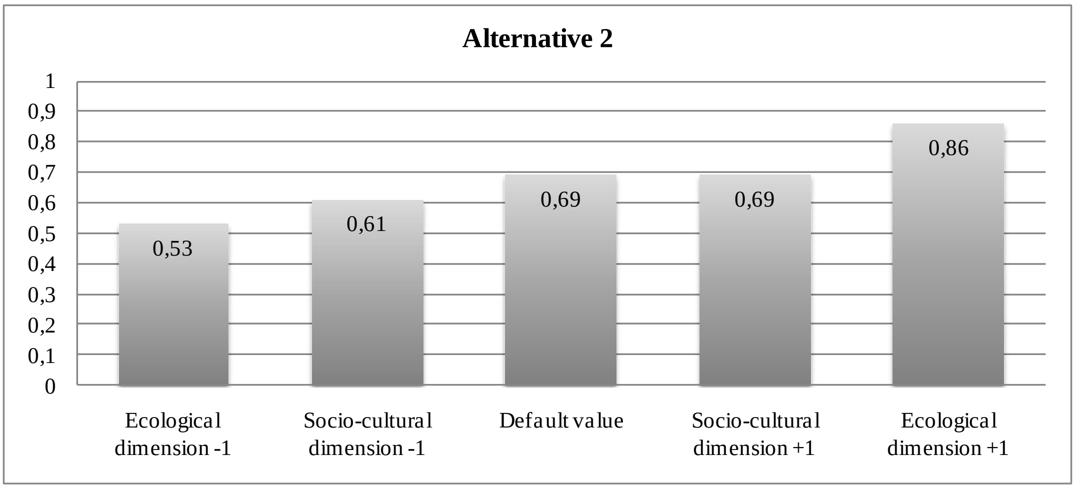


Figure 6.3. Change in sustainability index H_i for alternative 2 due to modified scores in one criterion in either socio-cultural or ecological dimension.

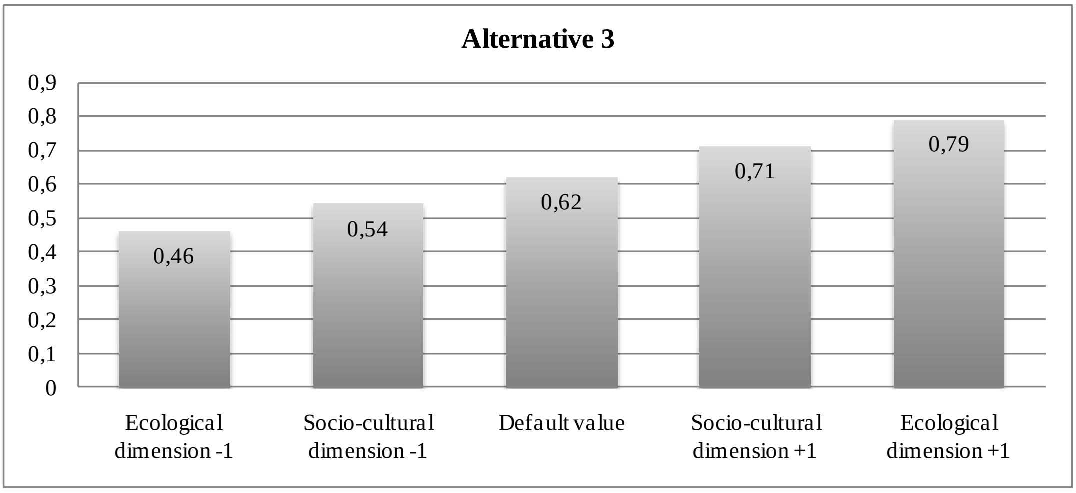


Figure 6.4. Change in sustainability index H_i for alternative 3 due to modified scores in one criterion in either socio-cultural or ecological dimension.

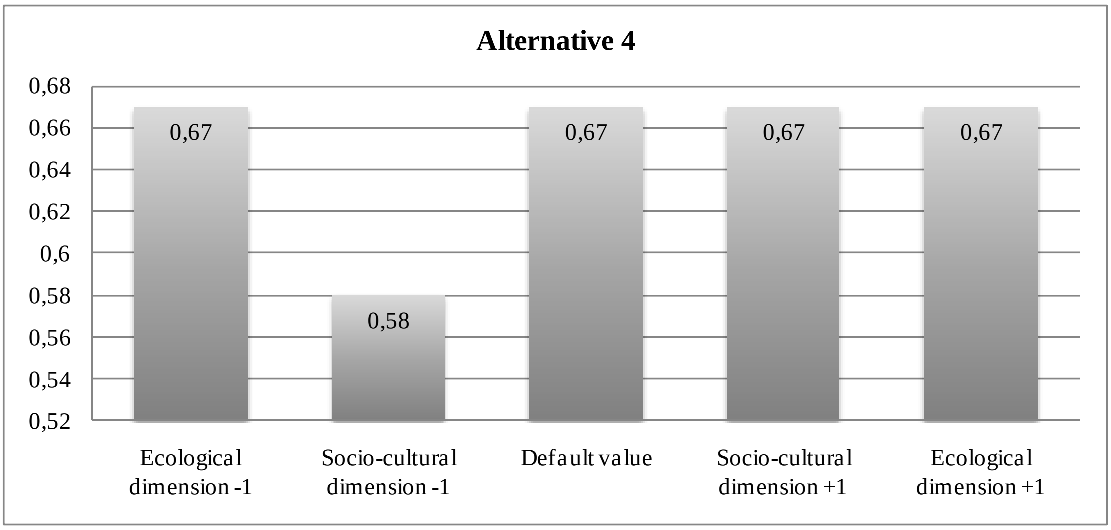


Figure 6.5. Change in sustainability index H_i for alternative 4 due to modified scores in one criterion in either socio-cultural or ecological dimension.

6.6.2 Economic dimension

The uncertainty and sensitivity analysis of the calculated NPVs is made through Monte Carlo simulation, for all uncertainty parameters and their distributions, see Appendix O.

The simulation is done for all four remediation alternatives and with three different discount rates. In addition to the discount rate 4% recommended by Naturvårdsverket, 0% and 1.4% was tested. These rates are suggested in Rosén et al. (2009) to be used in the uncertainty analysis.

It is less interesting to look at higher interest rates since the time perspective is so long, 350 years. All costs emerge during the first five years and are not affected much by changes in the discount rate. The benefit from reduced health risk, which remains during 350 years, however, is strongly influenced by the changes in the discount rate. A high interest rate makes costs influence the NPV more than the benefits, relatively seen.

Result from varied discount rate that is being evaluated, without Monte Carlo simulation:

- Change in NPV [MSEK]

Results from Monte Carlo simulations and varied discount rate that are being evaluated:

- P(NPV>0)
- 95% Confidence interval (CI)
- Mean value, μ
- Standard deviation, s

See Appendix N for a presentation of all results mentioned above.

From observed changes in NPV when the discount rate is varied the following conclusion is made; a lower discount rate gives a higher NPV. This is particularly important in alternative 4 where a discount rate of 4% gives a negative NPV, while a discount rate of 1.4 or 0% gives a positive NPV. The economic dimension being positive or negative makes a big difference in the calculation of the sustainability index. However, the inter-relation between the remediation alternatives is not affected by a change in the discount rate.

From the Monte Carlo simulation, one can see that the difference in results is similar for all alternatives. The reason for this is that same distributions for the input parameters were used. When studying the changes in standard deviation and confidence intervals one can conclude that the dissipation in the results increase as the discount rate is being reduced.

An essential issue to reach sustainability is that the economic dimension has a positive value. This is investigated by evaluating whether the NPV is positive or not, it is desirable that the probability of NPV>0 is as high as possible. From the Monte Carlo simulations it is found that the remediation alternative with the highest probability of a positive NPV is alternative 3, with a near 100% probability for all discount rates that were tested. Alternative 4, which includes sieving and soil washing, has a high probability for NPV being positive for the two lower discount rates; however, when using the recommended rate of 4%, the probability is only 41%. See Figure 6.6 for the distributions of NPV for all four alternatives using the recommended discount rate 4%.

Least beneficial is alternative 1, with just a few percentage probability of receiving a positive NPV, regardless of discount rate. Slightly better is alternative 2, only for the lower discount rates though.

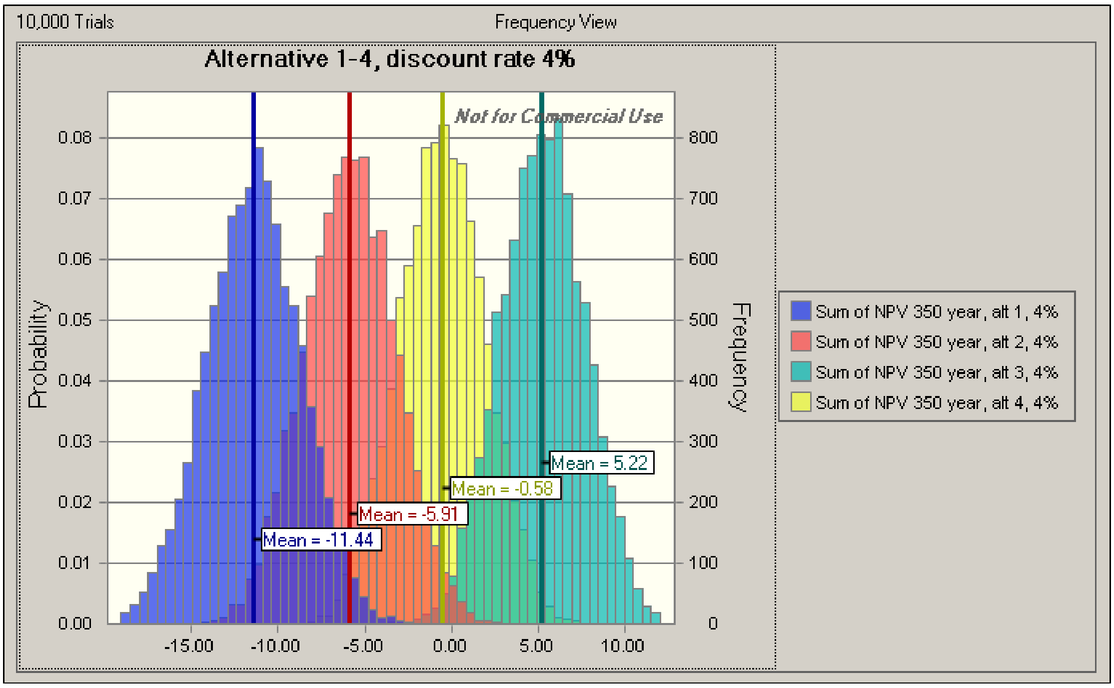


Figure 6.6. Result of Monte Carlo simulation of the NPV.

The sensitivity analysis performed by the Monte Carlo simulation shows that common to all alternatives is that the variance in *increased land value for the site*, B1a has the biggest influence, approximately 51-64% on the variance of the forecasted NPV. This is hence the most important assumption in the model. If more information about the increased land value was known, this assumption could be given a more narrow distribution and by that reduce the dissipation of the forecasted NPV. The second most sensitive parameter was also common to all alternatives, *cost for performing measure*, C1d, which accounts for 16-19% of the variance. This due to its complexity of many different input parameters with uncertainty distributions like e.g. amount of contaminated soil, number of transports of contaminated soil and the need of refilling material. Third most sensitive parameter differs for the four remediation alternatives. For alternative 1-2 the amount of excavated soil in need for landfill was the third most sensitive parameter, while for alternative 3-4 it was *project risks*, C1f. However, cost for project risks does also for alternative 1-2 have a sensitive value close to the one for alternative 3-4, approximately 4-5%.

7 Discussion

This chapter discusses the results from the case study of Hexion and how the MCA-tool was implemented. Furthermore, the MCA-tool and incorporation of project risks are evaluated with respect to the aim of this Master's thesis.

7.1 Case study

Remediation of the investigated case study site, Hexion is a challenging task for the site-owner due to the site's complex soil structure, its fluctuating ground water condition and the dramatic topography at the site. All this generates a large number of risks associated with the project and it is essential to investigate possible and sustainable remediation alternatives closely. For this, it is proper to use a decision support tool, as comprehensive as the MCA-tool used in this Master's thesis.

7.1.1 Ecological and socio-cultural dimension

The assessment of the ecological criteria was overall hindered by the limited information of the null-alternative. For example, very little was known about previous air pollution due to transports to and from the site. It was difficult to make a fair assessment on the key criteria a*ir* and *use of natural resources*. However, knowledge about the number of transports for the different remediation alternatives made it possible to make a comparison between the alternatives for the key criterion *air*. For the same reason, *use of natural resources* was hard to estimate. None was known about e.g. type of source of energy in the factory, number of transports per day, type of vehicle and fuel use. From this, it is clear that a well stated and defined null-alternative have a big impact on the final result.

Also, the ecological key criteria have a long-term approach whilst the remediation process at Hexion only will last during three years. Because of this, it is relevant to compare the null-alternative with the final result, i.e. residences and public areas. It is difficult though to find a balance between the short time remediation which is on-going and the future use of land. To mention the key criteria a*ir* again: pollution connected to the remediation will occur during a shorter time period but the factory had polluted the air during many years. What level of pollution to air that will take place at Hexion in the future is hard to estimate.

For the key criterion *cultural environment* in the socio-cultural dimension, excavation had not been a good method if the ground under and around a cultural building had been polluted. Then an in-situ method had received a higher score.

For the key criterion *justice and acceptance*, the assessments of the three experts were based on various grounds since the interpretation can diverge, e.g. which groups in the society to include when scoring. The judgment might have been facilitated if the groups that could be affected by the remediation alternative were identified prior to the judgments. It is important to identify stakeholders, to find which groups/individuals that are affected by the measures on the site. If their needs and wishes are known and understood, it will be easier to fulfil sustainability and find groups that may disadvantage from the alternative. Stakeholders to include can be; neighbours (residence), local business/industry, site-owners, citizens groups, general public, local government like the County Authorities and federal government like

Naturvårdsverket. When the stakeholders are identified, communication is important, e.g. with the public, and use it as input in the decision making process.

The formulation of possible or probable positive effect "*It is possibly/probably that no group in society will disadvantage*" obstruct the interpretation. Overall experience is that the remediation would have a positive effect and produce positive effects for several groups in society; however, if one group would be disadvantaged, the criterion should have a negative score according to the formulation.

7.1.2 Economic dimension

The quantification of costs and benefits for the remediation project at Hexion was time consuming and for some posts not possible at all. *Increased land value for the site*, B1a is the largest benefit at Hexion and estimated by interview with the site-owner NCC. How well this value corresponds to the real value can be discussed. This value is uncertain since it is difficult to predict how well the site-owner will manage to clean and sell estates at the site. This can also be seen in the sensitivity analysis made for the CBA. It is clear that all four remediation alternatives have this post as the most sensitive. When considering the *increased land value for surrounding properties*, B1b, there are uncertainties in both the way of finding monetary values as well as in the actual value. The uncertainty in the property value is large due to that Eriksberg is situated in Gothenburg and close to Göta Älv River which can be assumed to give a higher property value than for an area in Mölndal. However, the living area at Hexion in Mölndal will have other benefits like the closeness to nature, the lake Stensjön and Mölndalsån with the old mill area. The fact that the specific value areas also include properties in the surroundings that would not be affected at all by the remediation projects gives another uncertainty to this calculation. However, it is reasonable to believe that there will be a benefit to the nearby properties due to the remediation at the site.

To be able to calculate the *reduced health risks* at the site, crucial contaminants must be selected. Depending on which ones that are selected the result may differ. For the *reduced acute health risk,* B3aa ethyl benzene was chosen due to the fact that this contaminant seems to be most studied. It was also possible to find an acute toxicity level for humans, which also made this contaminant suitable to use in the study. It should be pointed out that the possibility to get relevant information about different contaminants and their behaviour in the nature is very limited. The most studies of toxic effects are made for animals and not for humans. The fact that no acute health risk is present at Hexion is not fully true. However, the result depends on which type of contaminant that is used in the study and the firm detecting level of ethyl benzene.

The *reduced non-acute health risk,* B3ab is also dependent on which contaminants that are chosen. It should be noted that the contaminants selected in SADA are stable contaminants. More volatile contaminants like e.g. PAH-L could have been more interesting to investigate. These are however not as carcinogenic as PAH-H. The benefit due to risk reduction is relatively small due to so few people working on the site in the null-alternative and much more people living at the site afterwards. The risk after measure is set to the target risk for sensitive land but it is likely that the mean concentration is lower than that after remediation, which would result in a higher benefit.

When considering costs, the largest part is the *cost for performing the measure*, C1d which is divided into several parts that can differ both in range and value for the different remediation alternatives. For all alternatives, the costs differ depending on differences in amount of soil to excavate (both depth and contamination dependent), number of transports, need for new refilling material and the performance of the remediation alternatives. Some costs, like costs for temporary roads, are common for all four alternatives. These uncertainties are however handled by Monte Carlo simulations and from the sensitivity analysis it can be concluded that C1d is the second largest post of sensitivity, for all four remediation alternatives.

The negative effects on humans due to the remediation are calculated by *increased health risk due to measure on the site*, C2a and C2b, *increased health risk due to transports caused by measure*. In C2a the main cost comes from work related accidents due to that the risk for accidents on the site is larger than the risk for exposure of harmful levels of contaminants. The risk connected to contaminants, calculated in SADA, might have increased if more volatile contaminants were selected. Important uncertainties in the calculated cost for C2b are the estimated working days, possible number of people involved in road accident and number of transports per day. The large difference in amount of soil in need of transport to landfills and from quarries makes remediation alternative 1 more expensive than e.g. alternative 4. Concerning C2b, it should also be pointed out that if an accident with the contaminated soil will happen in a water protection area, e.g. Lärjeholm, north of Gothenburg, the contaminants can be transported to the nearby drinking water supply. However, the risk for the contaminated soil to reach the drinking water intake is lower than for example when a liquid is released. The mobility of the soil is low and the clean up after an accident will occur almost immediately afterwards.

The cost for *eco-system services and goods off-site*, C3b is calculated on basis of a bachelor thesis made at Chalmers 2011. The amount of soil calculated in that report is not exactly the same as in this Master's thesis which can lead to that the CO_2-emissions may differ.

From the sensitivity analysis performed on the CBA, indications of which posts to investigate more carefully before performing a CBA are given. For Hexion, these posts are: *increased land value for the site*, *cost for performing the measure* as well as *project risks,* which is the third most sensitive parameter.

The NPV is calculated for a time period of 350 years, but the result does not differ much if the time period instead had been 10 years. This is due to the low benefit from reduced non-acute health risk and level of the discount rate. The recommended discount rate of 4% limits the impact on the NPV from events that occur in a distant future. It is possible that a hyperbolic discount rate, which is descending with time, would give the most accurate result; this is also discussed in Rosén et al. (2008). Such a rate would have a big impact on events close in time and smaller effect on events occurring in the future.

From a distributional point of view it can be concluded that there are three groups in the society that pays and/or earns from a remediation project; the public, the site-owner and the individuals. It can be seen from the CBA for Hexion that both the largest benefit (*increased land value for the site, B1a*) and cost (*costs for performing the measure, C1*) will be for the site-owner. Moreover, the second largest benefit will be generated to the individuals owing properties in the surroundings (*increased land value for surrounding properties*). The second largest costs will be for the society due to the CO_2-emissions calculated in *eco-system services and goods off-site.* Furthermore, *increased health risk due to measure on the site* is a relatively large cost that affects single individuals and the society as a whole.

7.1.3 Result of case study

When reflecting on the final result from the MCA for Hexion it seems like only one remediation alternative, number 3, is possible to recommend. This is however depending on which criteria for weak sustainability that the site-owner and other decision makers can agree upon. If they can accept a high uncertainty for economical profitability and can see benefits in other criteria from the ecological and socio-cultural dimension then remediation alternative 4 can be recommended. It seem reasonable that remediation alternative 3 and 4 should be the most sustainable due to the lower number of transports and the possibility for reuse of material at the site. The prime step to improve these alternatives is to rise the score for key criterion *health due to measure*. This can be done by reducing noise and spreading of dust by shielding the specific area for sieving and washing processes.

The uncertainty in the input parameters used in the MCA for Hexion is in general large, often due to the difficulty in finding relevant data. An important uncertainty is the amount of soil that is possible to wash and sieve. This data is based on a rough estimation based on ocular investigations and by a literature study of the complex composition of the Gothenburg till.

It can always be discussed if the remediation methods are effective enough and if the pre-investigations have detected and mapped all contaminants at the site. These are however project risks that are common for most remediation projects.

Overall, the result from the case study is interesting and could have been a support for the site-owner NCC at a earlier stage, when they investigated possible remediation alternatives for Hexion.

7.2 Evaluation of the MCA-tool

The MCA is a useful and comprehensive tool to identify and highlight interest that might otherwise have been missed in the decision making process. The economic dimension is always of importance to make it possible to implement with a remediation project. The ecological dimension must be considered in order to get approval from the County Administrative Board. Dissatisfaction from the public is desirable to avoid since it might cause bad publicity. The MCA highlight these factors together with others that might otherwise have been left out. Decision makers therefore receive more comprehensive information to base their decision upon, which also is the aim with the MCA.

The reliability of some of the key criteria in the socio-cultural and ecologic dimensions is rather weak since they were scored on vague basis. However, the assessments of key criteria in the case study were mainly based on literature studies. The result would be more trustworthy if the assessment were done by people involved in the project and with more experience. Some expressions and key questions are hard to interpret and by that, the subjectivity of the judgment increases.

The criteria for sustainability are fulfilled in the MCA which includes all three dimensions in a structured and detailed way. None of the dimensions are prioritized ahead of another. If an alternative has a weak sustainability, it is easy to see what criteria that have negative scores and by that identify criteria which might be necessary to compensate for. The comprehension of the tool however, may well be expanded on project risks in the CBA, see section 9.3 for further discussion.

It is essential to have a comprehensive investigation of the contaminated area to make a fair assessment of the criteria. Information about the contamination situation, ground conditions, surroundings etc. is necessary, otherwise the result might point in an untrue direction. It is important to remember that the method elucidate strengths and weaknesses connected to different remediation alternatives, but the alternative with the highest sustainability index is not necessary the best alternative. As the sensitivity analysis of the ecological and socio-cultural dimensions in the case study showed; a small adjustment in the scores can change the ranking of alternatives completely. If no further criterion is added, there is one less key criteria in the ecological dimension compared to the socio-cultural dimension. That makes scoring of the ecological criteria slightly more sensitive to the sustainability index.

The sensitivity analysis performed in the case study on the ecological and socio-cultural dimensions is inconvenient since calculations are done by hand in Excel. To improve the application handiness of the tool, should all steps of the MCA be included into an Excel-file and a sort of program be created. Monte Carlo simulation with respresentation of uncertainties of scores by discrete probability distributions may be a possible approach to perform a more detailed uncertainty analysis of the MCA-results. Also the use of SADA for risk calculations should be recommended. Unfortunately there are limitations in the SADA program since only one contaminant at the time can be analysed which makes the process time consuming.

There can be some linguistic problems when performing the MCA. An example of this can be seen by experience from interviews concerning the key questions in the criterion *justice and acceptance.* These questions were perceived as diffuse and the need of a clearly defined null-alternative is of great importance to compare the situation before and after remediation. There is a risk for misinterpretation of different expressions like e.g. "*viable ecosystem* (livskraftigt ekosystem)". Most key criteria have such expressions and many key questions that are easy to misinterpret what is of importance when scoring. This should be adjusted by more clear and less comprehensive wording combined with a more structured layout of the key criteria. This can be done by e.g. introducing subheadings to criteria *justice and acceptance* and *health due to measure*. Moreover, there is a minor risk for double counting and confusion when scoring the socio-cultural and ecological dimension concerning traffic accidents and transports as these are also monetary valued in the CBA. Although other aspects are taken into account, the scoring and the CBA are based on the same input data.

7.3 Incorporation of project risks in the MCA

When identifying project risks for a remediation project it is suitable to use a matrix like the one made by Rosén & Wikström (2005). However, the large amount of potential project risks makes the risk identification time consuming. Furthermore, the way of roughly calculating uncertainties and risk costs very rough by the

ALARP-matrix and gives no clear picture of the risk costs, only indications. To be able to use this matrix in its right manner, a better and more structured way for calculating the risk cost of each project risk have to be developed.

In the methodology for the CBA, it is unclear that the post *project risks,* C1f, only concerns risks connected to the site-owner. This can be confusing and lead to double counting, e.g. in *cost for negative effects on health due to measure,* C2a-b. In this thesis, the post C2a-b includes both risks for work related accidents and exposure on the site, as well as risks related to transports. It is however a bit unclear who is responsible to take the cost for the consequences if a work related accident occur. If it is the site-owner, this risk should be included in the post *project risks*.

In the socio-cultural dimension under key criterion *justice and acceptance* and *health due to measure,* project risks like public acceptance, anxiety from the public and the risk for noise and dust are included. These key criteria can lead to double counting if the user does consider these project risks from a non-monetizing point of view. Moreover, it is necessary to point out that project risks like anxiety, is very difficult to value in money and a project risk like this needs to be handled by scoring.

By means of interviews, the most severe project risks were identified. The opinion differed somewhat depending on which step of a remediation project the interviewed person were part of. This makes it hard to say that all persons involved in a remediation project will agree upon the project risks pointed out according to the matrix used. This makes risk communication important and if possible, involved stakeholders should be a part of the identifications of project risks.

Relevant project risks should be discussed together with the public and other stakeholders through a session were possible project risks are explained and clearly defined. When the public is well informed about both the positive and negative aspects of a remediation project they can be more patient and understanding to future disturbances.

When it is possible to put a monetary value on the project risks it gives a clearer picture of what level of risk the site-owner is taking when considering a remediation project. Therefore, a recommendation is to further develop the MCA by making a combination of the risk matrix with possible project risks, the ALARP-matrix and a better defined risk cost calculation to end up with a cost for project risks to include in the CBA. To avoid double counting, the post *project risks* in the CBA should be rephrased to clarify that it only concerns project risks for the site-owner. The CBA performed in this Master's thesis shows that it is possible to find monetary values on e.g. work related accidents and traffic accidents. A further suggestion is also to limit the number of project risks by only calculating risk costs for those in the ALARP-region or higher (the most severe). This will lower the number of project risks to analyse and make the risk calculations less time consuming.

8 Conclusion and recommendations

This chapter concludes the results from the case study and the evaluation of the MCA-tool. Furthermore, recommendations to improve the tool are presented.

A case study was performed for the preindustrial site Hexion in which four different remediation alternatives were compared to a null-alternative. This was done to be able to evaluate the specific decision support tool discussed in this Master's thesis. The main difficulties with the work were to find exact and accurate information about the null-alternative scenario and input data to the CBA. It turned out that remediation alternative 3, i.e. excavation, sieving and transport to landfill, was the most sustainable remediation alternative. However, strong sustainability was not achieved for any of the alternatives.

Remediation alternative 3 had negative scores on the following key criteria; *use of natural resources*, in the ecological dimension and *health due to measure*, in the socio-cultural dimension. It is suggested that these key criteria can be compensated by a very high probability for receiving a positive NPV, in the economic dimension. The stable positive value in the economic dimension of alternative 3 makes it a preferable strategy. Also, preventive actions to avoid spreading of dust and noise can increase the scoring for the key criterion *health due to measure* to a positive or neutral value. If however the decision makers can tolerate a lower probability of receiving a positive NPV, alternative 4 is preferable since it has higher scores in both the ecological and socio-cultural dimension, compared to alternative 3.

The MCA-tool is comprehensive and fulfils its aim of identifying sustainable remediation alternatives. The result gives a good overview of the impact from each suggested remediation alternative. However, the tool requires a lot of input data, especially for the economic dimension, which is time consuming. There is a risk for double counting due to linguistic misunderstandings. One example is health connected to the measure, which is included both in the economic and socio-cultural dimension. Another example is key criteria *justice and acceptance* and *health due to measure* in the socio-cultural dimension where the many and varying key questions makes it difficult to define a score. Therefore, these key criteria should be structured in a more detailed way, e.g. by giving them subheadings. Sensitivity analysis of the ecological and socio-cultural dimensions is somewhat problematic to execute since there is no software available for this purpose.

A project risk matrix, together with the ALARP-method can be suitable to monetize and include project risks into the CBA. Not all project risks are possible to monetize, and are therefore not convenient to include in the CBA. These are instead handled in the socio-cultural dimension by key criteria *justice and acceptance* and *health due to measure*.

Finally, to develop the MCA-tool further, it is recommended to produce an Excel work sheet where all calculations for the three dimensions together with uncertainty and sensitivity analyses can be performed. Some linguistic difficulties should also be sorted out, as well as a further developed project risk approach, including a project risk matrix.

9 References

Adrielsson, P. & Fredén, C. (1987). *Description to the quaternary map, Marstrand SO/Göteborg SV.* Part, Ae No: 72. Stockholm: Liber Distribution.

Almqvist, P., Johansson, J., König, L., Lindvert, D., (2011). *Greenhouse gas emissions from remediation of contaminated sites. An evaluation of the tool WHGFM through a case study on the Hexion estate.* Bachelor Thesis. Chalmers University. Gothenburg: Chalmers.

Aven, T. (2003). *Foundations of risk analysis, a knowledge and decision-oriented perspective.* University of Stavanger, Norway.

Belton V. & Stewart T. (2002). *Multiple Criteria Decision Analysis: An Integrated Approach.* Kluwer Academic, Dodrecht.

Burgman, M. (2005). *Risks and decisions for conservation and environmental management*. Cambridge: Cambridge University Press.

Burgman, M. (2005). *Risks and decisions for conservation and environmental management*. After; Perhac, R. M. (1998). Comparative risk assessment: where does the public fit in? *Science, Technology, and Human Values* **23**, 221-41.

Burgman, M. (2005). *Risks and decisions for conservation and environmental management.* After; Suter, G. W. (1993). *Ecological Risk Assessment*. Boca Raton, Florida: Lewis. 1995.

Chapman, C. & Ward, S. (2009). *Project Risk Management – Processes, Techniques and Insights (2nd edition).* John Wiley & Sons. (2009-06-30)

Department of Health and Ageing NICNAS. (2010). [Electronic] *NICNAS Existing Chemicals Information Sheet – Diethylhexyl phthalate*. Available at: <http://www.nicnas.gov.au/Publications/Information_Sheets/Existing_Chemical_Information_Sheets/ECIS_DEHP_PDF.pdf> [2011-03-23].

Ecosystem Valuation. (n.d.). [Electronic] *Hedonic Pricing Method*. Available at: <http://www.ecosystemvaluation.org/hedonic_pricing.htm#summ> [2011-06-03].

FRTR. (n.d.). *Ex Situ Physical/Chemical Treatment (assuming excavation), Soil Washing.* Remediation Technologies Screening Matrix and Reference Gudie, Ver. 4.0. Available at: <http://www.frtr.gov/matrix2/section4/4-19.html> [2011-05-23].

Keeney, R.L. (1982). Decision Analysis: An Overview. *Operations Research* **30**, 803-38.

Kemikalieinspektionen. (2009). [Electronic] *Bakgrund till miljökvalitetsmålet.* Available at: <http://www.kemi.se/templates/Page____2877.aspx> [2011-02-14].

NCC Teknik. (2007). *Översiktlig miljöteknisk markundersökning*. NCC Construction Sverige AB. No: 7024603.

NCC Teknik. (2010). *Saneringsanmälan för Trädgården 1:124*. NCC Teknik. December 2010.

NV. (1998). *Vägledning för miljötekniska markundersökningar. Del 1: Strategi.* Report no: 4310. September 1998.

NV. (2009). *Riktvärden för förorenad mark. Modellbeskrivning och vägledning.* Report no: 5976. September 2009.

NV. (2010a). [Electronic] *Miljömål, Generationsmålet*. Available at: <http://miljomal.se/Generationsmalet/> [2011-02-14].

NV. (2010b). [Electronic] *Miljökvalitetsmål för förorenade områden.* Available at: <http://www.naturvardsverket.se/sv/Verksamheter-med-miljopaverkan/Efterbehandling-av-fororenade-omraden/Miljokvalitetsmal-for-fororenade-omraden/> [2011-02-14].

NV. (2011a). [Electronic] *Hållbar utveckling*. Available at: <http://www.naturvardsverket.se/sv/Start/Sveriges-miljomal/Ett-hallbart-samhalle/Hallbar-utveckling/> [2011-05-23].

NV. (2011b). [Electronic] *Urval av ämnen och ämnesgrupper samt förklarningar*. Available at: <http://www.naturvardsverket.se/sv/Start/Verksamheter-med-miljopaverkan/Fororenade-omraden/Att-utreda-och-efterbehandla-fororenade-omraden/Riktvarden-for-fororenad-mark/Tabell-over-generella-riktvarden/Urval-av-amnen-och-amnesgrupper/> [2011-03-11].

Oracle. (2010). [Electronic] *Oracle Crystal Ball.* Software version: 11.1.2. Available at: <http://www.oracle.com/us/industries/education-and-research/046915.html>

Rosén, L. & Wikström, N. (2005). *BT Kemi. Efterbehandling Skede: Förberedelser Metodik för riskhantering, riskidentifiering och riskbedömning i förberedelseskedet.* SWECO VIAK AB. (2005-10-25)

Rosén, L., Back, P-E., Soutukorva, Å., Söderqvist, T., Brodd, P., Grahn, L. (2008). *Kostnads-nyttoanalys som verktyg för prioritering av efterbehandlingsinsatser, metodutveckling och exempel på tillämpning.* Naturvårdsverket Report no: 5836. June 2008.

Rosén, L., Back, P-E., Soutukorva, Å., Söderqvist, T., Brodd, P., Grahn, L. (2009). *Multikriterieanalys (MKA) för hållbar efterbehandling av förorenade områden, metodutveckling och exempel på tillämpning.* Naturvårdsverket Report no: 5891. Februari 2009.

SADA. (2007). [Electronic] *Spatial Analysis and Decision Assistance, SADA.* Software version: 5.0. The University of Tennessee, Knoxville. Available at: <http://www.tiem.utk.edu/~sada/download.shtml>

SIKA. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4.* Statens institut för kommunikationsanalys. March 2009.

Skoog, G. (2005). [Electronic] 2000 nya lägenheter byggs i västra Eriksberg. *Göteborgs Posten*, 3 juni. Available at: <http://www.gp.se/bostad/1.19289-2-000-nya-lagenheter-byggs-i-vastra-eriksberg> [2011-03-23].

Sveriges Riksdag. (2009). [Electronic] *Miljö och jordbruksutskottet 2009/10:MJU25, Svenska miljömål*. Available at: <http://www.riksdagen.se/webbnav/?nid=3322&rm=2009/10&bet=MJU25> [2011-02-14].

SWECO. (2009a). *Fastigheten Trädgården 1:124, Kvarnbyparken; Mölndal. Fördjupad riskbedömning inklusive beräkning av platsspecifika riktvärden*. Gothenburg. (2009-04-15)

SWECO. (2009b). *Fastigheten Trädgården 1:124, Hexionområdet, Mölndal. Åtgärdsutredning inklusive förslag till övergripande och mätbara åtgärdsmål.* Gothenburg. (2009-05-25)

The Brundtland Commission. (1987). [Electronic] *Our Common Future, From One Earth to One World.* UN documents. Available at: <http://www.un-documents.net/ocf-ov.htm#III.4.6> [2011-05-23].

Toxnet. (2004). [Electronic] Hazardous Substances Data Bank, HSDB. Available at: <http://toxnet.nlm.nih.gov > Search: *PAH.* [2011-03-23].

Toxnet. (2005). [Electronic] Hazardous Substances Data Bank, HSDB. Available at: <http://toxnet.nlm.nih.gov> Search: *Ethyl benzene.* [2011-03-22].

Toxnet. (2009a). [Electronic] Hazardous Substances Data Bank, HSDB. Available at: <http://toxnet.nlm.nih.gov> Search: *DEHP* or *Bis(2-ethylhexyl)phthalate.* [2011-02-03].

Toxnet. (2009b). [Electronic] Hazardous Substances Data Bank, HSDB. Available at: <http://toxnet.nlm.nih.gov> Search: *Xylene.* [2011-02-03].

Trafikverket (former Banverket). (2007). *Förorenade områden - System för Riskklassificering och Prioritering (SRP).* Banverkets Standard BVS 585:82.

U.S. Department of Health and Human Services. (1995). [Electronic] *Toxical profile for Polycyclic aromatic hydrocarbons.* Available at: <http://www.atsdr.cdc.gov/ToxProfiles/tp69.pdf> [2011-03-23].

U.S. EPA. (2000). [Electronic] *Lead Compounds.* Available at: <http://www.epa.gov/ttnatw01/hlthef/lead.html> [2011-03-23].

www.121.nu. (2007). [Electronic] Search: *Hexion Chemicals Sweden AB.* Available at: <www.121.nu> [2011-03-23].

Appendices

Appendix A
Fraction distribution

There are no investigations made on the fraction size distribution at Hexion. The site lies in an area with the soil type Gothenburg till (Adrielsson & Fredén, 1987). However, from ocular observations made by NCC at the site, it is clear that most soil consists of fillings, why it is unsuitable trying to find a fraction size distribution curve for the till. The ocular observations are described in NCC Teknik (2007). These observations have in this master thesis been divided into different sections and subsections, see Figure A.1 below.

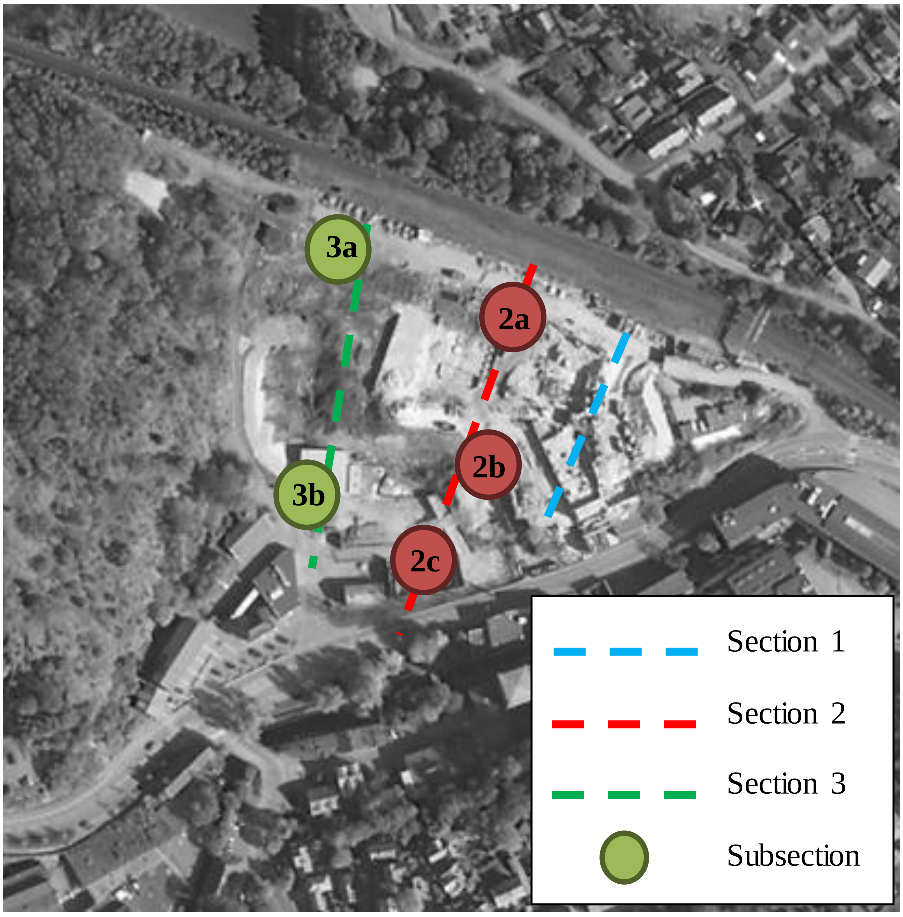


Figure A.1. Map showing sections and subsections dividing the ocular observations. © Lantmäteriet Gävle 2011. Medgivande I 2011/007.

The fraction sizes of interest:

<0.6 mm	Grains smaller than 0.6 mm cannot be washed[1].
0.6-40 mm	Grains in the size 0.6-40 mm can be washed and then used for refilling[1].

[1] Per-Arne Fjälling, Responsible for contaminated soil, Ragnsells Gothenburg, study visit 2011-02-12.

>40 mm	Grains larger than 40 mm are considered clean and suitable for refilling (NCC Teknik, 2010).

It is assumed that asphalt has a fraction size of >40 mm and can be used for refilling in 90% of the cases. On the base of the observations made by NCC and the usage of a grain size table, fraction sizes and percentage distribution was estimated, see below.

Depth	Ocular observation	Fraction size
Section 1:	Excavation down to 1 m	
0-1 m	Asphalt, filling of gravel and sand	25% >40 mm 75% 0.6-6 mm
(1-2 m)	Sand ending in silty clay	<0.6 mm
(>2 m)	Bedrock and concrete	-
Section 2:		
Subsection 2a:	Excavation 0-3 m	
0-1 m	Asphalt, filling of gravelly sand	25% >40 mm 75% 0.6-2 mm
1-3 m	Sand with lenses of clay	<0.6 mm
(3-6 m)	Sandy till (one borehole)	50% <0.6 mm 50% 0.6-40 mm
Subsection 2b:	Excavation >4 m, maximum 8 m	
0-1 m	Asphalt, filling of sand and clay	25% >40 mm 30% <0.6 mm 45% 0.6-40 mm
1-8 m	Silty clay with some sand layers	10% 0.6-40 mm
Subsection 2c:	Excavation 0-1 m	
0-1 m	Asphalt, filling of gravelly sand	25% >40 mm 75% 0.6-2 mm
(1-3 m)	Sand with lenses of clay	<0.6 mm
Section 3:		
Section 3a:	Excavation >4 m, maximum 8 m	
0-1.5 m	Filling of bricks and gravelly sand with stones	50% 0.6-40 mm 50% >40 mm
1.5-4 m	Filling of sand	0.6-40 mm
4-6 m	Sandy till and silty sand	75% <0.6 mm 25% 0.6-40 mm
>6	Probably clay	<0.6 mm
Section 3b:	Excavation 0-3 m	
0-0.5 m	Asphalt	>40 mm
0.5-1 m	Filling of large stones	>40 mm
1-1.5 m	Filling of sand, gravel and stones	75% 0.6-40 mm 25% >40 mm
1.5-2 m	Concrete	>40 mm
2-3 m	Filling of sand, gravel and stones	75% 0.6-40 mm 25% >40 mm

Calculations (Total soil depth that is investigated is approximately 24 m)

Percentage of soil, <0.6 mm:

$$2 + 0.3 * 1 + 0.9 * 7 + 0.75 * 2 + 2 = 12.1 \text{ m}$$

$$\frac{12.1}{24} = 50\%$$

Percentage of soil, 0.6-40 mm:

$$0.75 * 1 + 0.75 * 1 + 0.45 * 1 + 0.1 * 7 + 0.75 * 1 + 0.5 * 1.5 + 2.5 + 0.25 * 2 + 0.75 * 0.5 + 0.75 * 1 = 8.3 \text{ m}$$

$$\frac{8.3}{24} = 35\%$$

Percentage of soil, >40 mm:

$$0.25 * 1 * 0.9 + 0.25 * 1 * 0.9 + 0.25 * 1 * 0.9 + 0.25 * 1 * 0.9 + 0.5 * 1.5 + 0.5 * 0.9 + 0.5 + 0.25 * 0.5 + 0.5 + 0.25 * 1 = 3.5 \text{ m}$$

$$\frac{3.5}{24} = 15\%$$

The calculations of amount of soil that can be used for refilling after the sieving process in alternative 3 can be seen in Table A.1. The values of amount contaminated soil are based on SWECO (2009b) and the same as for remediation alternative 2.

Table A.1. Calculations of contaminated masses, i.e. >KM, that will be included in the sieving process according to alternative 3.

Contamination level*	Soil to reuse after sieving [ton]	Soil to landfill at Kikåstippen [ton]	Soil to landfill at Heljestorp [ton]
KM-MKM	$16373 * 0.15 = 2\,455$	$16\,373 - 2\,456 = 13\,917$	-
>MKM-FA	$19123 * 0.15 = 2\,868$	-	$19\,123 - 2\,868 = 16\,255$
>FA	$10504 * 0.15 = 1\,576$	-	$10\,504 - 1\,576 = 8\,928$
	$\sum 6\,900$	$\sum 13\,917$	$\sum 25\,183$

* According to Naturvårdsverket

In remediation alternative 4 the reusable material is a combination of sieved and washed soil, for calculations see Table A.2. The arrow in the table means that contaminants have accumulated in the soil washing process. Then this soil is in need of transport to Heljestorp due to higher concentration of contaminants than allowed at Kikåstippen.

Table A.2. Calculations of the contaminated masses, i.e. >KM, that will be included in the sieving and soil washing process according to alternative 4.

Contamination level*	Soil to reuse after sieving [ton]	Soil to reuse after washing [ton]	Soil to landfill at Kikåstippen [ton]	Soil to landfill at Heljestorp [ton]
KM-MKM	$16\,373 * 0.15 = 2\,456$	$16\,373 * 0.35 = 5\,731$	$16\,373 - 2\,456 - 5\,731 = 8\,186$ →	$8\,186$
>MKM-FA	$19\,123 * 0.15 = 2\,868$	$19\,123 * 0.35 = 6\,693$	-	$19\,123 - 2\,868 - 6\,693 = 9\,562$
>FA	$10\,504 * 0.15 = 1\,576$	$10\,504 * 0.35 = 3\,676$	-	$10\,504 - 1\,576 - 3\,676 = 5\,252$
	$\sum 6\,900$	$\sum 16\,100$	$\sum 0$	$\sum 23\,000$

*According to Naturvårdsverket

References

Adrielsson, P. & Fredén, C. (1987). *Description to the quaternary map, Marstrand SO/Göteborg SV*. Part, Ae No: 72. Stockholm: Liber Distribution.

NCC Teknik. (2007). *Översiktlig miljöteknisk markundersökning - Appendix 3*. NCC Construction Sverige AB. No: 7024603.

NCC Teknik. (2010). *Saneringsanmälan för Trädgården 1:124*. NCC Teknik. December 2010.

Appendix B

Socio-cultural key criterion: *Justice and acceptance*, S1

Scoring and motivations from the three interviewed experts on the key criterion, *justice and acceptance* can be seen in Figure B.1 for each remediation alternative from 1-4.

1	2	3	4
+1 "It will be a positive change but the load of traffic is negative."	+2 "As for alt. 1, a positive change, however the lower amount of traffic is good."	+1 "With careful information about the processes it seem to be positive but the load of traffic is negative."	+2 "With careful information about the processes it seems to be positive and the low amount of transports and no transports of refilling material is good."
+1 "The fact that the soil is removed from the site make neighbours feel secure. More transports are acceptable during a shorter time."	+1 "As in alt. 1 the excavation will give a feeling of careful and well-done remediation when excavation and physical removal is involved."	+1 "As in alt 1 and 2 a remediation is very positive. The method will not affect the view of the remediation, rather the fact that something is done at the site."	+2 "As in alt. 1-3 a remediation is positive. However, the lower amount of transports will make it better compared to the other alternatives."
+1 "It is clear that the people living close to the site today will be most affected by a remediation. The large amount of transports and excavations is negative."	+1 "Can be considered as more acceptable than alt. 1, due to lower amount of transports."	+2 "The score on this alt. depends on how well the method will be performed. If the sieving process is secured by screens so that no dust and noise will disturb neighbours."	+2 "As for alt. 3, with the lower amount of transports this is the best alternative."

Figure B.1. Overview of the discussions made on the criterion justice and acceptance. The motivations are made by Petra Brinkhoff 2011-05-06, Uffe Schultz 2011-05-11 and Thomas Holm 2011-05-30, in descending order.

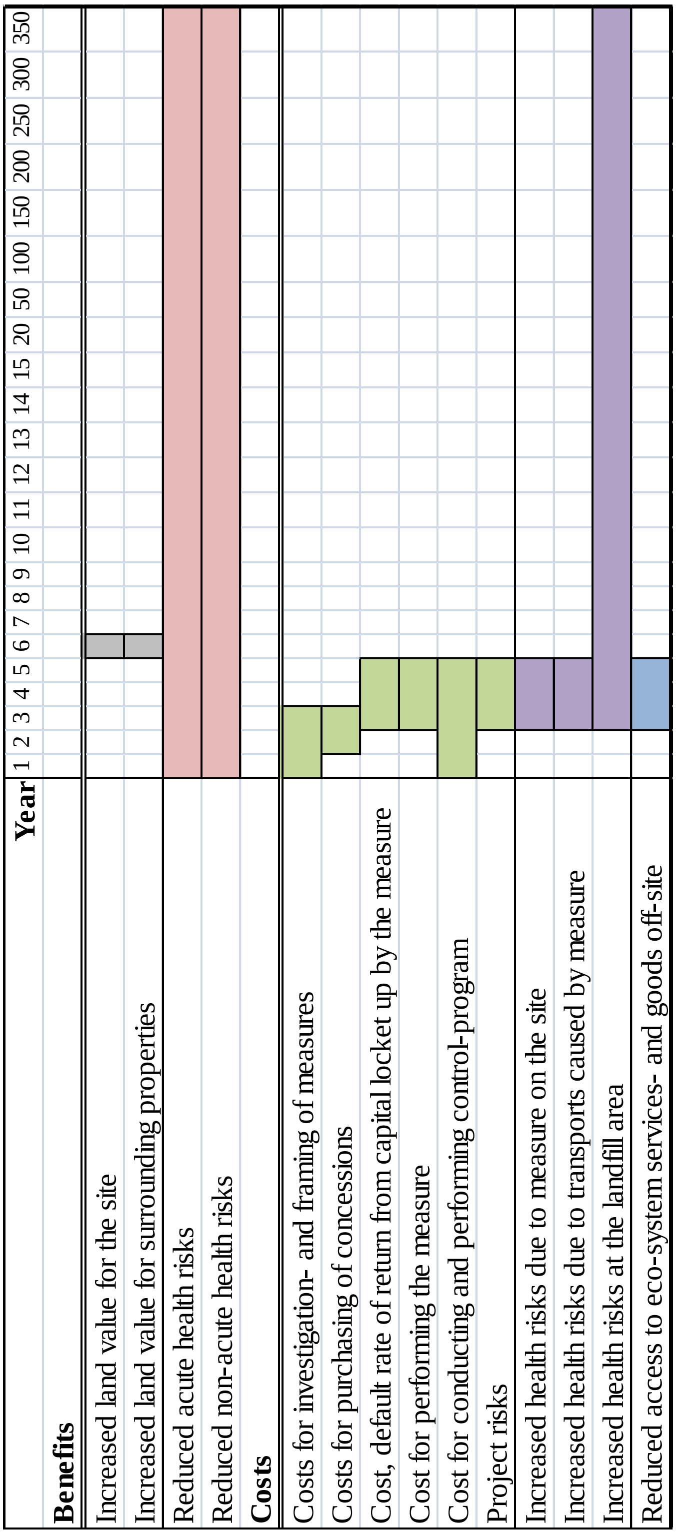
To calculate an aggregated score for *justice and acceptance* the mean value of the scores from the three interviewed persons were calculated, see Table B.1.

Table B.1. Final scores for justice and acceptance.

Alternative	Aggregated score
1	+1
2	+1
3	+1
4	+2

Appendix C

Time plan, remediation at Hexion



Appendix D
Results from CBA, case study

Alternative 1: removal and transport of soil for landfill according to Naturvårdsverket

Sum of NPV, 350 years	-9,703 MSEK

	Monetary benefit (B)	Importance ("X", "(X)", "0")	Time period (year)	MSEK
B1.	***Increased land value***			
B1a.	Increased land value for the site	X	6 (1)	60
B1b.	Increased land value for surrounding properties	(X)	6 (1)	0,09
B2.	***Net impact on market-priced services and goods***			
B2a.	Possibility for more profitable service and good production			
B2aa.	Production with lower cost, higher quality and better rate of return	0		
B2ab.	Fewer restrictions for the activity	X		
B2ac.	Better trust for the activity	X		
B2ad.	Less juridical responsibility	(X)		
B2ae.	Better working environment	(X)		
B3.	***Net impact on non-market-priced services and goods***			
B3a.	Reduced health risks			
B3aa.	Reduced acute health risks	X	1-350	0
B3ab.	Reduced non-acute health risks	X	1-350 (five generations)	4,67E-04
B3b.	Increased access to eco-system services- and goods			
B3ba.	Increased possibilties for recreation within the site	X		>0
B3bb.	Increased possibilities for recreation in surrounding area	(X)		>0
B3bc.	Increased access to other eco-system services- and goods	(X)		n.i.

	Monetary cost (C)	Importance ("X", "(X)", "0")	Time period (year)	MSEK
C1.	**Cost *for performing the measure***			
C1a.	Costs for investigation- and framing of measures	(X)	1-3	
C1b.	Costs for purchasing of concessions	(X)	2-3	
C1c.	Cost, default rate of return from capital freezed by the measure	X	3-5	0,43
C1d.	Cost for performing the measure	X	3-5	14,22
C1e.	Cost for conducting and performing control-program	X	1-5	2,00
C1f.	Project risks	X	3-5	1,67
C2.	***Negative effect on health due to measure***			
C2a.	Increased health risks due to measure on the site	X	3-5	0,29
C2b.	Increased health risks due to transports caused by measure	X	3-5	0,26
C2c.	Increased health risks at the landfill area	(X)	3-353 (five generations)	>0
C3.	***Negative effects on ecosystem services and goods due to measure***			
C3a.	Reduced access to eco-system services and goods on the site	0		
C3b.	Reduced access to eco-system services and goods off site	X	3-5	0,69
C3c.	Reduced access to eco-system services and goods in landfill area	(X)		n.i.

	No value to avoid double counting
	Information not necessary
n.i.	No information available

Figure D.1. Results from CBA, alternative 1.

Alternative 2: removal and transport of soil for landfill according to site-specific gudieline values

Sum of NPV, 350 years	5,643 MSEK

	Monetary benefit (B)	**Importance ("X", "(X)", "0")**	**Time period (year)**	**MSEK**
B1.	***Increased land value***			
B1a.	Increased land value for the site	X	6 (1)	60,00
B1b.	Increased land value for surrounding properties	(X)	6 (1)	0,09
B2.	***Net impact on market-priced services and goods***			
B2a.	Possibility for more profitable service and goods production			
B2aa.	Production with lower cost, higher quality and better rate of return	0		
B2ab.	Fewer restrictions for the activity	X		
B2ac.	Better trust for the activity	X		
B2ad.	Less juridical responsibility	(X)		
B2ae.	Better working environment	(X)		
B3.	***Net impact on non-market-priced services and goods***			
B3a.	Reduced health risks			
B3aa.	Reduced acute health risks	X	1-350	0
B3ab.	Reduced non-acute health risks	X	1-350 (five generations)	4,67E-04
B3b.	Increased access to eco-system services and goods			
B3ba.	Increased possibilties for recreation within the site	X		>0
B3bb.	Increased possibilities for recreation in surrounding area	(X)		>0
B3bc.	Increased access to other eco-system services and goods	(X)		n.i.

	Monetary cost (C)	**Importance ("X", "(X)", "0")**	**Time period (year)**	**MSEK**
C1.	**Cost *for performing the measure***			
C1a.	Costs for investigation- and framing of measures	(X)	1-3	
C1b.	Costs for purchasing of concessions	(X)	2-3	
C1c.	Cost, default rate of return from capital freezed by the measure	X	3-5	0,27
C1d.	Cost for performing the measure	X	3-5	8,94
C1e.	Cost for conducting and performing control-program	X	1-5	2
C1f.	Project risks	X	3-5	1,67
C2.	***Negative effect on health due to measure***			
C2a.	Increased health risks due to measure on the site	X	3-5	0,29
C2b.	Increased health risks due to transports caused by measure	X	3-5	0,15
C2c.	Increased health risks at the landfill area	(X)	3-353 (five generations)	>0
C3.	***Negative effects on ecosystem services and goods due to measure***			
C3a.	Reduced access to eco-system services and goods on the site	0		
C3b.	Reduced access to eco-system services and goods off site	X	3-5	0,44
C3c.	Reduced access to eco-system services and goods in landfill area	(X)		n.i.

	No value to avoid double counting
	Information not necessary
n.i.	No information available

Figure D.2. Results from CBA, alternative 2.

Alternative 3: Sieving

Sum of NPV, 350 years	5,983 MSEK

	Monetary benefit (B)	Importance ("X", "(X)", "0")	Time period (year)	MSEK
B1.	***Increased land value***			
B1a.	Increased land value for the site	X	6 (1)	60
B1b.	Increased land value for surrounding properties	(X)	6 (1)	0,09
B2.	***Net impact on market-priced services and goods***			
B2a.	Possibility for more profitable services and goods production			
B2aa.	Production with lower cost, higher quality and better rate of return	0		
B2ab.	Fewer restrictions for the activity	X		
B2ac.	Better trust for the activity	X		
B2ad.	Less juridical responsibility	(X)		
B2ae.	Better working environment	(X)		
B3.	***Net impact on non-market-priced services and goods***			
B3a.	Reduced health risks			
B3aa.	Reduced acute health risks	X	1-350	0
B3ab.	Reduced non-acute health risks	X	1-350 (five generations)	4,67E-04
B3b.	Increased access to eco-system services and goods			
B3ba.	Increased possibilties for recreation within the site	X		>0
B3bb.	Increased possibilities for recreation in surrounding area	(X)		>0
B3bc.	Increased access to other eco-system services and goods	(X)		n.i.

	Monetary cost (C)	Importance ("X", "(X)", "0")	Time period (year)	MSEK
C1.	**Cost *for performing the measure***			
C1a.	Costs for investigation and framing of measures	(X)	1-3	
C1b.	Costs for purchasing of concessions	(X)	2-3	
C1c.	Cost, default rate of return from capital freezed by the measure	X	3-5	0,27
C1d.	Cost for performing the measure	X	3-5	8,86
C1e.	Cost for conducting and performing control-program	X	1-5	2,00
C1f.	Project risks	X	3-5	1,67
C2.	***Negative effect on health due to measure***			
C2a.	Increased health risks due to measure on the site	X	3-5	0,29
C2b.	Increased health risks due to transports caused by measure	X	3-5	0,13
C2c.	Increased health risks at the landfill area	(X)	3-353 (five generations)	>0
C3.	***Negative effects on ecosystem services and goods due to measure***			
C3a.	Reduced access to eco-system services and goods on the site	0		
C3b.	Reduced access to eco-system services and goods off site	X	3-5	0,41
C3c.	Reduced access to eco-system services and goods in landfill area	(X)		n.i.

	No value to avoid double counting
	Information not necessary
n.i.	No information available

Figure D.3. Results from CBA, alternative 3.

Alternative 4: Sieving and soil wash

Sum of NPV, 350 years	-0,037 MSEK

	Monetary benefit (B)	**Importance ("X", "(X)", "0")**	**Time period (year)**	**MSEK**
B1.	***Increased land value***			
B1a.	Increased land value for the site	X	6 (1)	60
B1b.	Increased land value for surrounding properties	(X)	6 (1)	0,09
B2.	***Net impact on market-priced services and goods***			
B2a.	Possibility for more profitable good- or service production			
B2aa.	Production with lower cost, higher quality and better rate of return	0		
B2ab.	Fewer restrictions for the activity	X		
B2ac.	Better trust for the activity	X		
B2ad.	Less juridical responsibility	(X)		
B2ae.	Better working environment	(X)		
B3.	***Net impact on non-market-priced services and goods***			
B3a.	Reduced health risks			
B3aa.	Reduced acute health risks	X	1-350	0
B3ab.	Reduced non-acute health risks	X	1-350 (five generations)	4,67E-04
B3b.	Increased access to eco-system services and goods			
B3ba.	Increased possibilties for recreation within the site	X		>0
B3bb.	Increased possibilities for recreation in surrounding area	(X)		>0
B3bc.	Increased access to other eco-system services and goods	(X)		n.i.

	Monetary cost (C)	**Importance ("X", "(X)", "0")**	**Time period (year)**	**MSEK**
C1.	**Cost *for performing the measure***			
C1a.	Costs for investigation and framing of measures	(X)	1-3	
C1b.	Costs for purchasing of concessions	(X)	2-3	
C1c.	Cost, default rate of return from kapital freezed by the measure	X	3-5	0,34
C1d.	Cost for performing the measure	X	3-5	11,11
C1e.	Cost for conducting and performing control-program	X	1-5	2,00
C1f.	Project risks	X	3-5	1,67
C2.	***Negative effect on health due to measure***			
C2a.	Increased health risks due to measure on the site	X	3-5	0,29
C2b.	Increased health risks due to transports caused by measure	X	3-5	0,10
C2c.	Increased health risks at the landfill area	(X)	3-353 (five generations)	>0
C3.	***Negative effects on ecosystem services and goods due to measure***			
C3a.	Reduced access to eco-system services and goods on the site	0		
C3b.	Reduced access to eco-system services and goods off site	X	3-5	0,39
C3c.	Reduced access to eco-system services and goods in landfill area	(X)		n.i.

(light grey)	No value to avoid double counting
(dark grey)	Information not necessary
n.i.	No information available

Figure D.4. Results from CBA, alternative 4.

Appendix E

Increased land value for surrounding properties

Lots in Sweden are divided into specific value areas and all such areas have a standard size. In the area where Hexion is situated (center part of Mölndal) a normal lot has the standard size 800 m^2, the property value can be seen in table E.1 (Skatteverket, 2006 & Skatteverket, 2009).

Eriksberg is situated on Hisingen in Gothenburg and a normal lot in the value area of Sannegården, Kyrkbyn near the remediate site had a standard size of 600 m^2 (Skatteverket, 2006 & Skatteverket, 2009). For property values, see Table E.1.

Table E.1. Property values and calculations of change in property values (Skatteverket, 2006 & Skatteverket, 2009).

Area	Year	Property value (SEK)	Change in value/m^2 (SEK/m^2)
Sannegården, Kyrkbyn	2006	550 000	-
	2009	900 000	$350\,000/600 = 583$
Center part of Mölndal	2006	800 000	-
	2009	1 200 000	$400\,000/800 = 500$

According to Table E.1 it can be assumed that a remediation can result in a property value increase of:

$583 - 500 = 83$ SEK/m^2 in 3 years.

The increased property value (only due to remediation) for nearby properties to Hexion (in center part of Mölndal) is then:

$83 * 800/3 = 22\,133$ SEK/year for a lot of standard size

Assumed number of lots effected of a remediation ≈ 4

Annual benefit from increased land value for surrounding properties

$4 * 22\,133 = 88\,532$ SEK

References

Skatteverket. (2006). [Electronic] *Värdeområden för småhus 2006-2008, förenklad fastighetstaxering 2006.* Search: *Sannegården Kyrkbyn, Center part of Mölndal.* Available at: <http://www.skatteverket.se/4.1a098b721295c544e1f800029085.html> [2011-05-24].

Skatteverket. (2009). [Electronic] *Värdeområden för småhus 2009-2011, förenklad fastighetstaxering 2009.* Search: *Sannegården Kyrkbyn, Center part of Mölndal.* Available at: <http://www.skatteverket.se/4.18e1b10334ebe8bc80002123.html> [2011-05-24].

Appendix F
Health risk, acute toxicity

For calculations of the acute toxicity at Hexion, appendix B in Rosén et al. (2008) was consulted. The reference concentration for acute effects, C_{AE}, can be calculated according to Eq. F.1.

$$C_{AE} = \frac{ARV * m_{child}}{m_{soil\ intake}} \tag{F.1}$$

$ARV =$ Acute toxicity level of the most crucial contaminant at the site [mg/kg body weight]

$m_{child} =$ Weight of a child [kg]

$m_{soil\ intake} =$ Amount of soil intake [g]

Input parameters, ethyl benzene

The acute toxicity level of ethyl benzene is 800 mg/kg (Toxnet, 2005). The body weight of a child is assumed to be higher than the assumption made by NV (2009) for the reason that a child needs to be approximately 5-6 years old to be able to enter the area alone. The amount of soil intake for a child at a random place on the site is according to the standard values from NV (2009).

$ARV = 800$ mg/kg (Toxnet, 2005)

$m_{child} = 20$ kg

$m_{soil\ intake} = 5$ g

Calculation

$$C_{AE} = \frac{800 * 20}{5 * 10^{-3}} = 3\ 200\ 000\ \text{mg/kg}$$

To consider the probability of having a higher concentration of ethyl benzene at Hexion than C_{AE}, the different sample results for ethyl benzene were plotted in a lognormal distribution plot. Lognormal distribution was chosen since it fitted the data best, see Figure F.1. The calculations was done in an Excel sheet and based on Norrman et al. (2009).

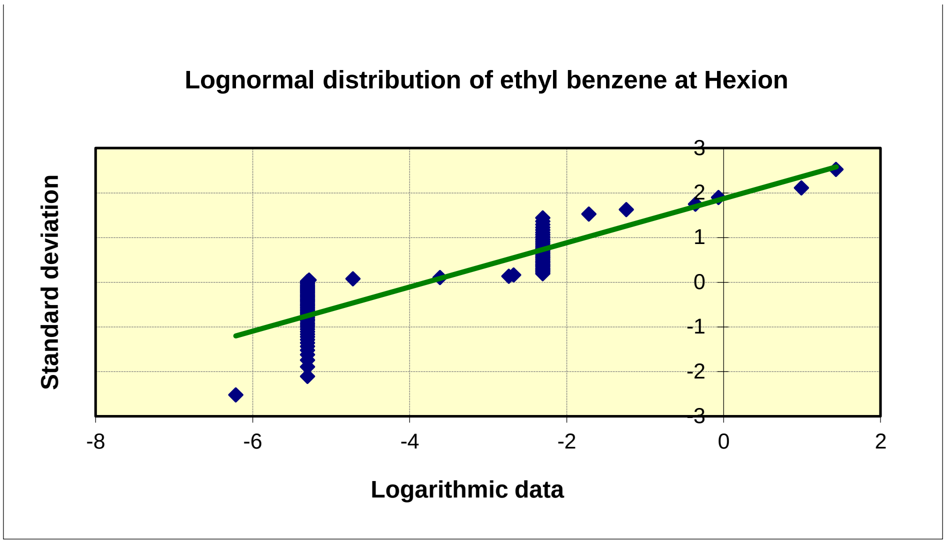


Figure F.1. Lognormal data of sample results of ethyl benzene at Hexion.

The input data gave a curve which has a very high amount of sample data at a specific level e.g. 0.005 mg/kg. This is due to that the detection level is at this level (NCC, 2007). The calculation showed that **0% of the site exceeded the reference concentration.**

References

NCC. (2007). *Översiktlig miljöteknisk markundersökning, Hexion Mölndal -Appendix 6.* No: 7024603. NCC Construction Sverige AB. October 2007.

Norrman, J., Purucker, T., Back, P-E., Engelke, F., Stewart, R. (2009). *Metodik för statistisk utvärdering av miljötekniska utvärderingar i jord.* Report no: 5932. Naturvårdsverket. July 2009.

NV. (2009). *Riktvärden för förorenad mark. Modellbeskrivning och vägledning.* Report no: 5976. Naturvårdsverket. September 2009.

Rosén, L., Back, P-E., Soutukorva, Å., Söderqvist, T., Brodd, P., Grahn, L. (2008). *Kostnads-nyttoanalys som verktyg för prioritering av efterbehandlingsinsatser, metodutveckling och exempel på tillämpning.* Naturvårdsverket Report no:5836. June 2008.

Toxnet. (2005). [Electronic] *Hazardous Substances Data Bank, HSDB.* Available at: <http://toxnet.nlm.nih.gov> Search: Ethyl benzene. [2011-03-22].

Appendix G
Health risk, non-acute toxicity

The most crucial contaminants were analyzed in SADA in terms of concentration, exposure and toxicological parameters. Some modifications of the default settings in SADA had to be performed to fulfill the needs of this case study.

Excluded exposure parameters were: intake of vegetable, beef and dairy since no farming or vegetable gardening would take place in the null-alternative. The scenario parameters were adjusted to fit Naturvårdsverket's standard for less sensitive land (MKM), see Table G.1. The soil depth that was analyzed was 0-2 m since neither the workers nor the residents will be in contact with the deeper layers of the soil.

The non-acute health risk was calculated for all three contaminants on the base of the UCL95 for the mean value of two sub-areas, see Figure G.1. Area A represent the area that is most contaminated at Hexion and area B represent an area that is less contaminated according to SWECO (2009). Area A is estimated to cover 40% of the total area and area B is estimated to cover the remaining 60% of the area.

The total health risk at the site for the two subareas was calculated according to Eq. G.1.

$$Risk_{tot} = Risk_{area\ A} + Risk_{area\ B} \tag{G.1}$$

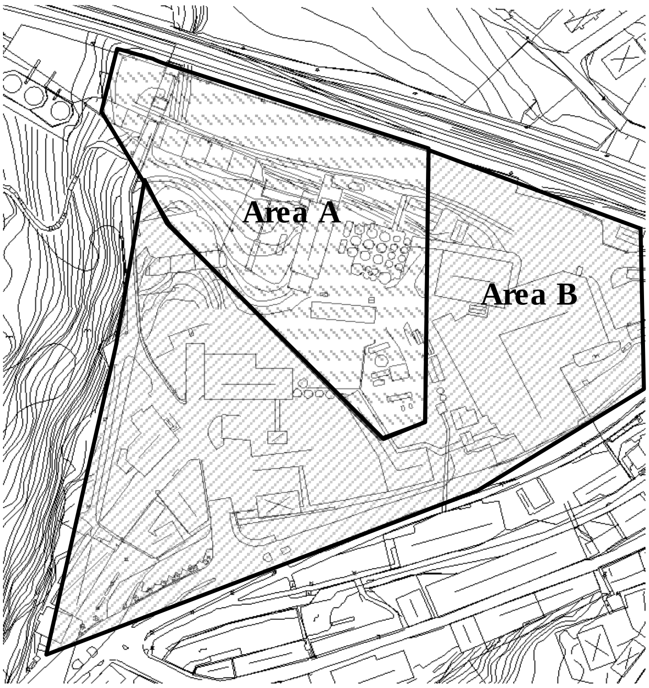


Figure G.1. Subareas used in SADA to calculate non-acute health risk and health risk due to measure on the site.

Exposure parameters used in SADA are adjusted according to Naturvårdsverket's scenario parameters (NV, 2009b) and can be seen in Table G.1.

Table G.1. Exposure parameters set in SADA. Parameter in bold text are adjusted according to Naturvårdsverket, default option in SADA are within parenthesis.

Parameters	Industrial site	Units
Exposure frequency	**200** (250)	days/year
Adult exposure duration	**59** (25)	years
Child exposure duration	0	years
Adult soil ingestion rate	**20** (100)	mg/day
Child soil ingestion rate	**80** (0)	mg/day
Fraction ingested	1	-
Inhalation rate	20	m^3/day
Adult surface area	0,3	m^2/day
Adherence factor	1	mg/cm^2
Body weight (Adult)	70	kg
Body weight (Child)	15	kg
Lifetime	**80** (70)	years

The risk levels calculated in SADA for less sensitive land, seen in Table G.2. (null-alternative) was compared to the risk levels after measure (alternative 1-4). The risk level after measure (R_1) was put equal to the target risk levels for carcinogens. The target risk corresponds to one extra person out of 100 000 person getting cancer during a lifetime (NV, 2009a).

$$R_1 = 10^{-5}$$

Table G.2. Risk levels (R_0) for the null-alternative calculated in SADA for less sensitive land and for each crucial contaminant at Hexion. The fact that area A is smaller than Area B has been considered when summarizing the risk levels.

Contaminant	Risk level, area A	Risk level, area B	Total risk level null-alternative
DEHP carcinogen	(1-0.6)*5.00*10^{-5}	0.6*1.50*10^{-5}	$R_{0, DEHP}$ = 3.15*10^{-5}
Lead	(1-0.6)*9.50*10^{-8}	0.6*9.80*10^{-8}	$R_{0, Lead}$ = 1.55*10^{-7}
PAH-H	(1-0.6)*6.10*10^{-5}	0.6*1.10*10^{-5}	$R_{0, PAH-H}$ = 4.76*10^{-5}

The annual benefit from reduction of non-acute health risk is calculated according to Eq. G.2 for each crucial contaminant separately.

$$B_{non-acute\ risk} = \left(\frac{R_0 \times n}{t} - \frac{R_1 \times n}{t}\right) \times VSL * 2 * P_{mortality} \qquad \text{(G.2)}$$

t = Adult exposure duration in null-alternative [years]

n = Number of people active on the site in the null-alternative

VSL = Value of a statisctial life [SEK]

$P_{mortality}$ = Mortality due to cancer

Input parameters

It is supposed that the health risk is reduced for as many people that work on the site in the null-alternative. The value of a statistical life in a traffic accident is 21 MSEK (SIKA Rapport, 2009). However, according to Rosén et al. (2009) it is recommended to double this value to make it more suitable for benefits due to reduced health risk at contaminated sites.

Moreover, the probability to actually die of cancer has been considered. Bladder cancer, which can affect people working in paint industry, has a mortality of 37% for men during a period of 10 year (Cancerfonden, 2009).

$t = 59$ years

$n = 30$

$VSL = 21$ MSEK

$P_{mortality} = 37\%$

Calculations

Annual benefit from risk reduction of DEHP:

$$B_{non-acute\,risk,DEHP} = \left(\frac{(3.15\times10^{-5})\times30}{59} - \frac{(1\times10^{-5})\times30}{59}\right)\times 21000000 * 2 * 0{,}37 = 170\text{ SEK}$$

Annual benefit from risk reduction of PAH-H:

$$B_{non-acute\,risk,PAH-H} = \left(\frac{(4.76\times10^{-5})\times30}{59} - \frac{(1\times10^{-5})\times30}{59}\right)\times 21000000 * 2 * 0{,}37 = 297\text{ SEK}$$

There is no benefit from risk reduction of lead since $R_{0,\ lead} < R_{1,\ lead}$.

The total annual benefit from reduction of non-acute health risks

The benefits from decreased concentrations of the two contaminants can be summarized, because they are completely independent of each other and do not correlate[2].

$170 + 297 = 467$ SEK

References

Cancerfonden. (2009). *Populärvetenskapliga fakta om cancer*. Cancer i siffror 2009. Socialstyrelsen, 2009.

NV. (2009a). *Riktvärden för förorenad mark. Modellbeskrivning och vägledning.* Report no: 5976. September 2009.

NV. (2009b). *Riskvärdering vid val av åtgärdsstrategi.* Report no: 5537. April 2006.

Rosén, L., Back, P-E., Soutukorva, Å., Söderqvist, T., Brodd, P., Grahn, L. (2009). *Multikriterieanalys (MKA) för hållbar efterbehandling av förorenade områden, metodutveckling och exempel på tillämpning.* Naturvårdsverket report no: 5891. Februari 2009.

SIKA Rapport. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4*. Statens institut för kommunikationsanalys. March 2009.

SWECO. (2009). *Fastigheten Trädgården 1:124, Hexionområdet, Mölndal. Åtgärdsutredning inklusive förslag till övergripande och mätbara åtgärdsmål - Appendix 2b*. Gothenburg. (2009-05-25)

[2] Lars Rosén, Professor at Chalmers University, 2011-04-26.

Appendix H

Cost for performing the measures

Input data in this appendix were used to calculate, *cost for performing the measure,* C1 in the CBA for the case study, Hexion.

C1c, *default rate of return from capital locked up by the measure*

C1c is calculated on the basis that C1d, *Cost for performing the measure*, is the capital locked to the measure. This sum is thus specific to each alternative. The rate of return is the Swedish prime rate from the 16th February 2011; 1.5%. C1c is calculated according to Equation H.1.

$$C1c_i = C1d_i * \left(r^{(n-1)}\right) - C1d_i \qquad \text{(H.1)}$$

$C1c_i$ = Annual default rate of return, alternative *i*

$C1d_i$ = Cost for performing measure, alternative *i*

n = Time period [years]

r = Discount rate

C1d, *cost for performing the measure*

C1d is calculated using following costs:

- Temporary roads: 400 000 SEK (SWECO, 2009).
- Transport to landfill and landfill fee, Kikåstippen, Mölndal: 70 SEK/ton (SWECO, 2009).
- Transport to landfill and landfill fee, Heljestorp, Vänersborg: 350 SEK/ton at a contaminated level of MKM-FA (SWECO, 2009).
- Transport to landfill and landfill fee, Heljestorp, Vänersborg: 550 SEK/ton at contaminated level >FA[3].
- Excavation: 0-4 m 165 SEK/ton, 4-8 m 330 SEK/ton (SWECO, 2009).
- Refilling material from Hisings-Kärra: 91 SEK/ton[4].
- Sieving process is approximately 16 000 SEK/day including transports on the site. Based on a capacity of 300 ton/day, this gives a sieving cost of 53 SEK/ton[5].
- Soil washing: Establishment 280 000 SEK, unestablishment 110 000 SEK and a process cost of 235 SEK/ton washed soil (SoilTech, 2009).

[3] Per-Arne Fjälling, Responsible for contaminated soil, Ragnsells Gothenburg, study visit 2011-02-12.
[4] Elaine Andersson, NCC Roads, mail contact 2011-05-06.
[5] Jonas Wiberg, Local manager at Hexion, NCC Construction, study visit 2011-05-17.

C1e*, cost for conducting and performing control-program*

The costs for conducting, performing controls-program, investigations and risk assessments is set to 10 MSEK (SWECO, 2009).

C1f*, project risks*

Project risk is estimated to a cost of 5 MSEK (SWECO, 2009).

References

SoilTech. (2009). *Tender from SoilTech to Malin Norin at NCC, Teknik*. Stockholm. (2009-06-12)

SWECO. (2009). *Fastigheten Trädgården 1:124, Hexionområdet, Mölndal. Åtgärdsutredning inklusive förslag till övergripande och mätbara åtgärdsmål.* Gothenburg. (2009-05-25)

Appendix I

Health risk, measure on the site

To calculate the health risk for the staff at the site during remediation measures Eq. I.1 was used.

$$C_{health\ risk\ due\ to\ measure} = \frac{(VSL \times n \times \sum Risk)}{t} \qquad \text{Eq. (I.1)}$$

$VSL =$ Value of a statistical life [SEK]

$n =$ Estimated number of workers at the excavation at Hexion

$t =$ Adult exposure duration [years]

The risk is due to the fact that workers are exposed to pollutants during work but also the risk for accidents at the site.

Input parameters and calculations

Table I.1 shows calculated risk levels in SADA due to the excavation at Hexion. In SADA the area was divided into two sub areas, A and B, also seen in Appendix G. The adult exposure duration is changed to be 3 years (the time during which the remediation takes place) and the exposure frequency was raised to 200 working days/year.

Table I.1. Risk levels ($\sum \boldsymbol{Risk}$) due to excavation on the site calculated in SADA. The fact that area A is smaller than area B has been considered.

Contaminant	Area	Risk calculated in SADA
PAH-H	A B	$(1-0.6)*5.8*10^{-6}$ $0.6*1.0*10^{-6}$
		$\sum 2.92*10^{-6}$
Lead	A B	$(1-0.6)*3.6*10^{-6}$ $0.6*1.1*10^{-7}$
		$\sum 1.51*10^{-6}$
DEHP carcinogen	A B	$(1-0.6)*3.5*10^{-8}$ $0.6*3.7*10^{-8}$
		$\sum 3.62*10^{-8}$

VSL = 21 MSEK (SIKA Rapport, 2009).

n = 10

t = 3 years

The annual cost is calculated according to the Eq. I.1 for the most crucial contaminants at Hexion.

PAH-H:

$$C_{health\,risk\,due\,to\,measure,\ \mathrm{PAH-H}} = \frac{21000000 \times 10 \times (2.92 * 10^{-6})}{3} = 204\ SEK$$

DEHP:

$$C_{health\ risk\ due\ to\ measure,\ DEHP} = \frac{21000000 \times 10 \times (3.62 * 10^{-8})}{3} = 3\ SEK$$

Lead:

$$C_{health\ risk\ due\ to\ measure,\ lead} = \frac{21000000 \times 10 \times (1.51 * 10^{-6})}{3} = 106\ SEK$$

The number of building- and construction workers that suffered from pain due to a work related accident during a period of 12 months is 4.9% (Arbetsmiljöverket, 2010). 10 people working with the excavation at Hexion during 3 years gives the following number of workers that will suffer from a work related accident:

$$10 \times 0.049 \times 3 = 1.47$$

According to SIKA, the accident value for a person getting slightly injured in a traffic accident is 199 000 SEK (SIKA Rapport, 2009). This value is assumed to be suitable when calculating the expected cost for work related accidents.

$$C_{work\ related\ accident} = 199\ 000 \times 1.47 = 292\ 530\ SEK$$

Total annual risk cost from health risks due to measure on the site

$$204 + 3 + 106 + 292\ 530 = 292\ 843\ SEK$$

References

Arbetsmiljöverket. (2010). *Arbetsorsakade besvär 2010. Arbetsmiljöstatistik Rapport 2010:4.* Sveriges officiella statistik. September 2010

SIKA Rapport. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4.* Statens institut för kommunikationsanalys. March 2009

Appendix J

Probability for traffic accident with contaminated soil

The annual probability (P_0) for accidents on road with heavy vehicle loaded with hazardous goods, in our case, contaminated soil is calculated according to Eq. J.1 (Vägverket & Räddningsverket, 1998):

$$P_0 = N * Q * L * 365 * F * 10^{-6} \quad \text{(J.1)}$$

$N =$ Mean number of transports with heavy vehicle per day

$Q =$ Number of accidents/million transport kilometers

$L =$ Road length [km]

$F =$ Number of veichles per accidents [1.8 in urban areas, 1.5 in rural areas]

The transports of contaminated soil will go from Hexion in Mölndal to either Heljestorp in Vänersborg or Kikåstippen, Mölndal. This appendix includes risk calculations for route A, Hexion to Heljestorp and B, Hexion to Kikåstippen.

$Number\ of\ transports\ from\ Hexion =$ 6 transports/day[6]

Input parameters, route A

Route A, from Hexion to Heljestorp is divided into three sections. The first section (no 1) is 73 km highway, 90 km/h and then a section (no 2) of 11 km four-lane road, 70 km/h. Finally reaching Heljestorp there is a section (no 3) of 5 km four-lane road, 90 km/h (Eniro, 2011).

$People\ per\ car =$ 1.5 (Assumed number involved in traffic accident).

$L =$ Differs for every section according to Table J.1.

$Q =$ Differs for every section according to Table J.1 and table 3-1 in Vägverket & Räddningsverket (1998).

$F =$ 1.5 (Rural area)

[6] Jonas Wiberg, Local manager at Hexion NCC Construction, study visit 2011-05-17.

Table J.1. Differences between the road sections in route A. P_0 is calculated for each road section.

Road section	L [km]	Q	F
No 1	73	0.32	1.5
No 2	11	0.6	1.5
No 3	5	0.4	1.5

Input parameters, route B

Route B, from Hexion to Kikåstippen, is a 2 km long road in an urban area with a speed limit of 50 km/h. Other parameters are as following:

$L = 2$ km

$Q = 1.2$ (Table 3-1 in Vägverket & Räddningsverket, 1998)

$F = 1.8$ (Urban area)

Calculations of annual risk cost

It is assumed that the number of people involved in an accident is the same in route A and B. The involved persons will get severe damages and the cost will then be 4 147 000 SEK/person (SIKA Rapport, 2009).

The risk cost of concern also includes possible remediation on and beside the road due to the leakage of soil in case of an accident. Cost to remediate can be compared to the cost for excavation of surface soil at Hexion (165 SEK/ton) but the amount is assumed to be approximately 30 ton, one lorry with trailer.

Annual risk cost in case of an accident (rural area), route A, see Eq. J.4.

$$P_0 * (30 * 165 + 4\,147\,000 * 1.5 * 1.5) \tag{J.4}$$

Annual risk cost in case of an accident (urban area), route B, see Eq. J.5.

$$P_0 * (30 * 165 + 4\,147\,000 * 1.5 * 1.8) \tag{J.5}$$

The results from the risk calculations can be seen below in Table J.2. It is clear that a larger amount of soil, like in e.g. alternative 1, generates greater risk costs.

Table J.2. Results from risk calculations for route 1 and 2 for the different alternatives.

Alternative	Annual risk cost [SEK]
1	240 868
2	142 472
3	121 065
4	99 911

References

Eniro. (2011). [Electronic] Eniro – maps. Available at: <http://kartor.eniro.se/> *Measuring function*. [2011-04-14].

SIKA Rapport. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4*. Statens institut för kommunikationsanalys. March 2009.

Vägverket & Räddningsverket. (1998). *Förorening av vattentäkt vid vägtrafikolycka - hantering av risker vid petroleumutsläpp.* Vägverket publication: 98:064.

Appendix K
Probability for traffic accident with refilling material

The annual probability (P_0) involving accidents on road with heavy vehicle, in this case loaded with refilling material, is calculated according to Eq. K.1 (Vägverket & Räddningsverket, 1998):

$$P_0 = N * Q * L * 365 * F * 10^{-6} \tag{K.1}$$

N = Mean number of transports with heavy vehicle per day

Q = Number of accidents/million transport kilometers

L = Road length [km]

F = Number of vehicles per accidents [1.8 in urban areas, 1.5 in rural areas]

The transports of refilling material will go from Hisings-Kärra, Gothenburg to Hexion, Mölndal.

$Number\ of\ transports\ to\ Hexion =$ 6 transports/day[7]

Input parameters

From Hisings-Kärra to Mölndal there is a transport section of 14 km, four-lane road, 90 km/h (Eniro, 2011).

$People\ per\ car =$ 1.5 (Assumed number involved in traffic accident)

$L =$ 14 km

$Q =$ 0.4 (Table 3-1 in Vägverket & Räddningsverket, 1998)

$F =$ 1.5 (Rural area)

Calculations of annual risk cost

It is assumed that the persons involved in accidents will suffer severe damages and the corresponding cost is 4 147 000 SEK/person (SIKA Rapport, 2009). Also, the risk cost of concern will include possible excavation actions on and beside the road due to the spreading of material in case of an accident. This cost can be compared to the cost for excavation of surface soil at Hexion (165 SEK/ton) but the amount is assumed to be approximately 37 ton.

[7] Jonas Wiberg, Local manager at Hexion NCC Construction, study visit 2011-05-17.

Annual risk cost in case of an accident in rural area, see Eq. K.4:

$$P_0 * (37 * 165 + 4\,147\,000 * 1.5 * 1.5) \quad \text{(K.4)}$$

The results from the risk calculation can be seen in Table K.1. It is clear that a larger amount of soil, like in e.g. alternative 1, generates greater risk costs.

Table K.1. Annual probability for traffic accident with refilling material to Hexion and risk cost for each remediation alternative. In alternative 4 there is no need for refilling material, therefore no probability for accident and risk cost.

Alternative	P_0 [%]	Annual risk cost [SEK]
1	0.20	19 043
2	0.12	11 231
3	0.072	6 784
4	-	-

References

Eniro. (2011). [Electronic] Eniro – maps. Available at: <http://kartor.eniro.se/> *Measuring function*. [2011-05-03].

SIKA Rapport. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4*. Statens institut för kommunikationsanalys. March 2009.

Vägverket & Räddningsverket. (1998). *Förorening av vattentäkt vid vägtrafikolycka - hantering av risker vid petroleumutsläpp*. Vägverket publication: 98:064.

Appendix L
CO_2-emissions

Under the post C3, *negative effects on ecosystem due to measure* in the CBA, C3b, *reduced access to eco-system services and goods off-site* is calculated based on the amount of CO_2-emissions from the remediation project at Hexion found by Almqvist et al. (2011), see Table L.1. According to SIKA Rapport (2009) the price for CO_2-emissions from a larger project should be put to 3.50 SEK/kg = 3500 SEK/ton.

Table L.1. Amount of CO_2-emissions from the different remediation alternatives and total risk costs for Hexion.

Alternative	CO_2-emission [ton]	Costs [SEK]
1	590	688 000
2	376	439 000
3	352	411 000
4	332	387 000

References

Almqvist, P., Johansson, J., König, L., Lindvert, D. (2011). *Greenhouse gas emissions from remediation of contaminated sites. An evaluation of the tool WHGFM through a case study on the Hexion estate.* Bachelor Thesis. Chalmers University. Gothenburg.

SIKA Rapport. (2009). *Värden och metoder för transportsektorns samhällsekonomiska analyser – ASEK 4.* Statens institut för kommunikationsanalys. March 2009.

Appendix M
Project risk matrix

Table M.1. Project risks in the preparation stage, based on Rosén & Wikström (2005).

	Date:	Modified by:						
Project risks	20110505	Ann-Sofie Östlund, Åsa Landström	Hexion					
Activity	**Occurrence**	**Risk event**	**How do the risk occur?**	**Main consequence**	**Risk estimation**			**Measures to reduce the risk**
					Probability	**Consequence**	**Risk (P*C)**	
A1. Enquiry material	Enquiry material for the contractor	A11. Incorrect formulation of requirements specification.	Important items are ignored, unnecessary requirements.	Economic impact (invalid basis for procurement would result in delay and/or increased costs).	**2**	**4**	**8**	Carefully thought out specifications based on experiences from similar remediation project.
	Characterization of the distribution of pollutions	A12. Incorrect assessment of various substances (pollutants) distribution.	Incompletely knowledge of contaminant spreading due to samples which is not representative of the current contaminated situation, with respect to heterogeneity, type of sampling and basis of analyzed substances.	Delay with economic impact and/or increased costs (extended scope of remediation which leads to delays, replacement of the remediation alternative and/or the operation target cannot be reached), environmental damage.	**4**	**4**	**16**	Careful analysis of the number, type and location of test points to characterize pollutant distribution. Geophysical surveys. Analysis of uncertainties. Thorough documentation.
	Characterization of pollution type and properties	A13. Incorrect assessment of the properties.	Oversight of the knowledge-base, the properties of the substances are not known (characteristics associated with treatment methods, both in-situ and ex-situ).	Delay with economic impact and/or increased costs (extended scope of remediation which leads to delays, replacement of the remediation alternative and/or the operation target cannot be reached), environmental damage.	**2**	**4**	**8**	Rigorous analysis of the experiences and literature around the current pollution types properties. Analysis of uncertainties. Thorough documentation.
	Characterization of soil material properties	A14. Incorrect assessment of soil physical and chemical properties.	Surveys are not sufficiently comprehensive or representative to describe soil material properties with respect to heterogeneity, soil layers or the earth's composition.	Delay with economic impact and/or increased costs (extended scope of remediation which leads to delays, replacement of the remediation alternative and/or the operation target cannot be reached), environmental damage.	**3**	**4**	**12**	Careful analysis to guarantee the physical and chemical properties. Analysis of uncertainties. Thorough documentation.
	Provision of test materials	A15. Contractor receives non-representative samples.	Sample taking is not representative of the area, with respect to the soil layers, heterogeneity and pollution distribution.	Delay with economic impact and/or increased costs (extended scope of remediation which leads to delays, replacement of the remediation alternative and/or the operation target cannot be reached), environmental damage.	**3**	**3**	**9**	The selection is preceded by a careful analysis of soil material and its variability in the area in order to analyze the amount of material that should be provided in order to achieve good representativeness. Thorough documentation.
	Description of the technical requirements and obstruction	A16. Preconditions of remediation alternative implementation is not sufficiently investigated.	Key factors on technical factors such as transport conditions, proximity to rail way or landfill will be overlooked.	Delay with economic consequences, increased remediation costs, increased transportation costs.	**1**	**2**	**2**	Careful examination of the technical conditions and obstacles in the area. Consultation with the Municipal Planning Department, technical administration, Trafikverket which have detailed information. Thorough documentation.
	Other						**0**	
A2. Procurement	Assessment and selection of the remediation method	A21. Incorrect design of remediation method.	The technology is not suitable to the type of pollution and/or the geological/hydrogeological conditions.	Delay with economic impact and/or increased costs (extended scope of remediation which leads to delays, replacement of the remediation alternative and/or the operation target cannot be reached), environmental damage.	**2**	**4**	**8**	Careful screening and critical viewing of the proposed remediation method. Use of reviewers with experience from the different methods. Thorough documentation.
	Assessment and selection of contractor	A22. Inadequate knowledge/capability of the contractor selected for implementation phase.	The contractor have misjudged his ability to cope with the mission.	Delay with economic consequences, legal problems, new procurement.	**2**	**3**	**6**	Careful consideration of the contractor's past experience and references. Consider the size of the company.
	Formation of contract	A23. Ambiguity is written into the contract that leave room for different interpretations of the contract.	Contract wording unclear and/or ignores important parts in the works.	Delay with economic impact and/or increase, legal dispute.	**2**	**2**	**4**	The contract is circulated for review by experienced project managers and clients.
	Basis of evaluation criteria	A24. Incorrectly selected criteria for procurement.	Lack of insight into which properties should be demanded of the contractor.	Economic impact, environmental damage, personal injury.	**2**	**3**	**6**	Criteria is communicated and circulated to the experienced project managers and customers of this type of contracts.
	other						**0**	
A3. Risk reduction and risk evaluation	Assessment of risk reduction from proposed measures	A31. Risk reduction of the measure not adequate.	The capacity is overestimated by the tenderer, at the same time as this are not detected by the originator.	Environmental damage, injuries (health effects, concerns).	**2**	**4**	**8**	Careful examination of the proposed methods ability to achieve the objectives of risk levels.
	Valuation of risk reduction against other factors	A32. The measure's effectiveness is not sufficient.	Environmental and health risk levels and/or other factors, such as implementation costs, not properly described to provide a true and fair view of the effectiveness (the benefit of the measure compared to its cost).	Economic impact from long processing time or large processing costs.	**2**	**3**	**6**	Careful analysis of whether the risk reduction achieved by the method is proportional to the cost and implementation time.
	Other						**0**	

Table M.1. continued..

B. Authorization	Permit application	B1. Incorrect format of the permit application.	Deficiencies in application depending on lack of consultation and communication, oversight of important aspects.	Delay with economic impact and/or increased costs.	**1**	**4**	**4**	Frequent contacts with authorities to avoid mistakes.
		B2. Appeals of the application.	Deficiencies in application depending on lack of consultation and communication, oversight of important aspects, disagreements with other stakeholders.	Delay with economic impact and/or increased costs.	**3**	**4**	**12**	Frequent contacts with authorities to avoid mistakes. Close contact with the public to avoid misunderstandings and keep the public informed.
	Negotiation	B3. Authority does not accept the remediation alternative selected.	Dissenting opinion about method of the County Administrative Board.	Delay with economic impact and/or increased costs.	**3**	**4**	**12**	Frequent contacts with authorities to avoid mistakes.
	Notification to the authority	B4. Notification is not received by the authority.	The notification is handed in too late.	Delay with economic impact and/or increased costs (legal alternatives, bad reputation).	**2**	**4**	**8**	Frequent contacts with authorities to avoid mistakes.
	Other						**0**	
C. Environmental control	Development of environmental control programs	C1. Incorrect design of environmental control.	Environmental control program is not properly designed, for example measurements, position in space and time, analysis method, accounting method.	Environmental damage (contamination left behind is not detected).	**3**	**2**	**6**	Rigorous analysis of the design of control program with demands on remnants pollutants diffusion and distribution patterns in both time and space. In addition, careful analysis of the measurement and analysis methods. Thorough documentation.
	Other						**0**	
D. Sectorial planning	Area plan	D1. Plan proposal cannot be implemented due to conflict with plan conditions.	Inadequate consultation on questions to the plan proposal.	Economic impact (other uses than planned)	**2**	**3**	**6**	Thorough consultation with the municipality and other stakeholders.
		D2. Plan proposal cannot be implemented due to conflict with the action objectives.	Remediation alternative does not reach the goals.	Economic impact (other uses than planned)	**2**	**4**	**8**	Careful adjustment of the land area planning to reach the operation target-important with clear communication with requesters.
		D3. Plan proposal offers the possibility for accidents on the railway tracks.	The area is set so that the people staying there may enter the adjacent railway tracks.	Personal injuries	**2**	**4**	**8**	The chance of being hit are addressed with a proper fence, particularly important if one considers ball games in the area.
		D4. Plan proposal offers the possibility to contact with power lines by rail.	Area is designed so that people who are staying may come into contact with the rail traffic control system, for example by Dragon flight.	Personal injuries	**2**	**4**	**8**	Warning signs or planting of trees.
	Other						**0**	
E. Construction work	Design of pump station	E1. Insufficient capacity of pump station.	Flawed investigation.	Economic impact (new pump station must be built).	**2**	**4**	**8**	Careful dimensioning of the needs. Thorough documentation.
	Design of water and sewage plant	E2. Insufficient capacity of the water and sewage plant.	Flawed investigation.	Economic impact (new plant must be completed).	**2**	**4**	**8**	Careful dimensioning of the needs. Thorough documentation.
	Selecting a contractor	E3. Inadequate knowledge/capability of the contractor that shall carry out the construction work.	The contractor have misjudged his ability to cope with the mission.	Delay with economic impact and/or price increase, legal problems.	**2**	**3**	**6**	Careful consideration of the contractor's past experience and references. Consider the size of the company.
	Execution	E4. Technical problems of buildings and constructions.	Failure of technical installations.	Delay with economic impact and/or price increase.	**3**	**2**	**6**	Detailed description and design of the control of installed systems. Preparedness for repairs.
	Control	E5. Mistakes in constructions are not found.	Incorrect method of control.	Delay with economic impact and/or price increase.	**3**	**2**	**6**	Careful consideration of the need for control. Documentation of the design of the control.
	Permits	E6. No permits for the construction.	Installation can not be handled within the existing permission, new permission must be sought.	Delay with economic impact and/or price increase (new application).	**3**	**3**	**9**	Dimensioning and design of the facility should as far as possible take into account the current state.
	Other						**0**	

Table M.1. continued..

F1. Insufficient capacity of electrical installations.	Flawed investigation.	Delay and/or price increase.	**1**	**2**	**2**	Careful dimensioning of the needs. Thorough documentation.
F2. Inadequate knowledge/capability of the contractor shall carry out electrical installations.	The contractor have misjudged his ability to cope with the mission.	Delay with economic impact and/or price increase, legal problems.	**1**	**3**	**3**	Careful consideration of the contractor's past experience and references. Consider the size of the company.
F3. Technical problems of electrical installations.	Failure of technical installations.	Delay with economic impact and/or price increase.	**1**	**2**	**2**	Detailed description and design of the control of installed systems. Preparedness for repairs.
F4. Mistakes in the electrical installations are not found.	Incorrect method of control.	Delay with economic impact and/or price increase.	**1**	**1**	**1**	Careful consideration of the need for control. Careful documentation of the design of the control.
F5. Consent is not given for electrical installations.	Installation can not be handled within the existing permission, new permission must be sought.	Delay with economic impact and/or price increase (new application).	**1**	**3**	**3**	Dimensioning and design of the facility should as far as possible take into account the current state.
					0	
AM1. Define coordinating responsibility according to the Swedish Working Environment Law.	Coordinating responsibility not clear.	Economic impact (legal issues).	**2**	**4**	**8**	Determine coordinating responsibility according to the Swedish law before procurement.
AM2. Identify possible harmful substances.	All harmful substances have not been detected.	Personal injuries (impact on workers' health).	**2**	**3**	**6**	Established routines for how harmful substances are handled in the project shall be submitted and tracked. Project management will ensure that the substances are evaluated correctly and accept them before use. Supervision is carried out by security rounds.
AM3. Protective equipment deficiencies are not being used.	Protective equipment is not available, is incorrect, incomplete or incorrectly used.	Personal injuries (injuries on workers ' health).	**2**	**4**	**8**	Established routines for protective how equipment shall be submitted and tracked. Supervision is carried out by security rounds.
AM4. Precautions and conditions in order to interrupt the work shall be determined.	Precautions are not taken, the decision-making period to cancel the work is not established.	Personal injuries (impact on workers' health).	**2**	**4**	**8**	Procedures established for when the work may be interrupted by precaution shall exist and be followed. Also describes how reporting takes place, and that a new work permit shall be granted before restarting.
AM5. Health and safety plan.	Plan not established.	Personal injuries (impact on workers' health).	**2**	**4**	**8**	All operations in the contract work shall be described in a method description that includes a working environment/health and safety plan. Method description shall be approved by the project team before the start permission.
AM6. Field staff have shortcomings in knowledge of conditions.	Mission briefing with field staff not implemented.	Personal injuries (impact on workers ' health).	**2**	**4**	**8**	Routine for information/education/communication shall be provided and used. Mission briefing with all field staff, shall be executed prior to the initial state is given.
AM7. Client and the responsible coordinator does not ensures that the necessary protective measures are taken.	Client and responsible coordinators are ill-informed about the necessary protective measures.	Personal injuries (impact on workers ' health).	**1**	**4**	**4**	Routine for information/education/communication shall be provided and used. Client and responsible coordinator shall be informed of the necessary protective measures.
					0	
G1. Selection of key people.	The working group does not have sufficient competence.	Delay with economic implications (also possibly that the operation target cannot be reached).	**1**	**4**	**4**	Broad search of key people. Thorough assessment of the experience gained from similar projects.
G2. Project participants are receiving incorrect or incomplete information.	Deficiencies in communication approach and scope.	Delay with economic consequences (key points overlooked and revision becomes defective).	**3**	**4**	**12**	Clear procedures for the communication within the project group. Project management in that regard must be very active and make clear demands on the project's participants.

Table M.2. Project risks in the implementation stage, based on Rosén & Wikström (2005).

	Date:	Modified by:						
Project risks	20110505	Ann-Sofie Östlund, Åsa Landström	Hexion					
Activity	**Occurrence**	**Risk event**	**How do the risk occur?**	**Main consequence**	**Risk estimation**			**Measures to reduce the risk**
					Probability	**Consequence**	**Risk (P*C)**	
Delimitation of working area	Entrance and exit	H1. Lack of control of where employees are situated in the event of an accident or emergency.	System for entrance and exit is lacking. Notification obligation is not established or is not accompanied.	Personal injuries (obstruct rescue work in the event of an accident or emergency.)	**3**	**3**	**9**	Entrance system.
	Intrusion	H2. Unauthorized person intruding the area.	Lack of guarding and/or delimiting of the work area.	Personal injury (unauthorized person).	**2**	**4**	**8**	Monitoring procedures and systems, alarms.
		H3. Sabotage or destruction of machinery, equipment and materials.	Lack of guarding and/or delimiting of the work area.	Economic consequences and injuries (delay, bad publicity).	**2**	**2**	**4**	Monitoring procedures and systems, alarms.
	Personal protective equipment.	Deficiencies in the use of personal protective equipment.	H4. Personal protective equipment is not available or is invalid.	Personal injuries (workers).	**2**	**3**	**6**	Safety training and information.
			H5. Lack of skills on how to use personal protective equipment.	Personal injuries (workers).	**2**	**2**	**4**	
	Emergency preparedness.	H6. Emergency care can not be carried out by employees.	Lack of training/information in first aid.	Personal injuries (workers and third parties).	**2**	**4**	**8**	Safety training and information.
		H7. Deficiencies in the use or design of gas alarms.	Identification of possible gaseous substances is incomplete, information about the use of gas detector has not been given.	Personal injuries (workers and third parties).	**1**	**3**	**3**	
		H8. Exposure or injury can not be handled as desirable.	Necessary equipment and materials for first aid is not available.	Personal injuries (workers and third parties).	**2**	**4**	**8**	
		H9. Fire can not be handled as desirable.	Fire-extinguishing equipment is not available.	Personal injuries (workers and third parties).	**2**	**3**	**6**	
All tasks	All tasks	Fire	Mechanical breakdown, sparks, self-heating, smoking, fire.	I1. Economic consequences (damage to machinery and equipment).	**2**	**3**	**6**	Maintenance, and preparedness for fire fighting.
				I2. Personal injuries (workers).		**4**	**8**	
				I3. Personal injuries (third man).		**3**	**6**	
				I4. Environmental damage (emission from extinguish fire and other chemical substances (e.g. fuel, oil)).		**3**	**6**	
				I5. Financial impact (cost of delay and new equipment or repair).		**3**	**6**	
	Work in darkness or in poor weather.	Collision, fall	Poor vision, poor lighting.	I6. Personal injury, death.	**3**	**4**	**12**	Enlightened working area, separated walking and vehicle routes, markings or securing of level differences.
	Work in the street and road area.	Collision	Accident	I7. Personal injury, death.	**1**	**4**	**4**	Separate roads for vehicles and pedestrians, speed limits, speed barrier, signs.
	Set-up of machinery	Oil spills	Leakage from machinery.	I8. Environmental damage.	**3**	**2**	**6**	
	Establishment of worksite accommodation.	Poor placement	Lack of procurement, information, communication.	I9. Economic impact (delay).	**2**	**2**	**4**	
	Safety training and information.	People working in the area lack security expertise.	Responsible managers/staff are not informed upon arrival to the workplace about applicable local workplace rules. There are gaps in security training and information.	I10. Personal injury, damage to the environment.	**1**	**3**	**3**	Safety training and information.
	Construction management and supervision.	Approval of implementation plan.		I11. Personal injury, damage to the environment.	**2**	**3**	**6**	
	Execution of control programs (environment, health and safety, risk).	Bad design		I12. Personal injury, damage to the environment.	**2**	**3**	**6**	
	Reporting and follow-up	Incidents are repeated until they finally lead to accident or illness.	Incidents are not reported or followed-up.	I13. Personal injury, damage to the environment.	**2**	**3**	**6**	
		Personnel are exposed to high concentrations of harmful substances despite discovery.	Reporting to the UL, requester and/or coordination officer serves are not fulfilled.	I14. Personal injury.	**2**	**3**	**6**	

Table M.2. continued..

All activities where machines and/or vehicles are used	All the moments in which machines and/or vehicles are used.	Mechanical breakdown.	Misuse, overload, poor service and maintenance.	S1. Cost of delay and new equipment or repair	**2**	**2**	**4**	Maintenance of machinery and equipment. Degree of readiness to quickly be able to obtain new equipment.
				S2. Contaminate releases to land or water		**2**	**4**	Maintenance and readiness for management of releases to land and water.
		Vehicle or machine accident.	Collision between vehicles, vehicles or machinery, vehicles running over pedestrians.	S3. Economic consequences (damage to machinery and equipment)	**2**	**3**	**6**	
				S5. Personal injury (third man)		**4**	**8**	
				S6. Environmental damage (the emission of chemical substances, such as fuel, oil)		**2**	**4**	
		Noise	The use of large construction vehicles.	S7. Harmful levels of noise for workers	**3**	**3**	**9**	
Excavation, loading and transport	Excavation, loading and transport.	Liberation of gas, odor.	Making pollutions free by excavation.	S8. Economic impact (delay, stopping of the work and/or bad publicity).	**3**	**3**	**9**	Open shaft surfaces and storage are covered with e.g. fiber cloth. Transport surfaces are kept clean. Excavation are performed in tents. Transport surfaces binds so they do not brush up. Excavator and/or loading machine operator shall ensure that excavating and loading is performed in a manner so that it do not brush up. Surfaces for storage and separation must be covered with asphalt. Transport of soil outside the working area is covered.
		Dust	By wind	S9. Environmental damage (pure or treated surfaces become contaminated).	**3**	**2**	**6**	Machine driver skill and behaviour affects how much it will brush up.
				S10. Personal injuries (dust with clay particels causing slippery lanes at the nearby, steep road)	**3**	**4**	**12**	
				S11. Economic impact (delay, stopping of the work and/or bad publicity).	**3**	**3**	**9**	
			At excavation	S12. Environmental damage (pure or treated surfaces become contaminated).	**4**	**2**	**8**	Manual working should be avoided.
				S13. Economic impact (delay, stopping of the work and/or bad publicity).		**2**	**8**	The transport vehicles shall be equipped with air conditioning. The vehicle shall be so equipped that the driver can perform all their duties from the driving position.
			When moving working machines	S14. Environmental damage (pure or treated surfaces become contaminated).	**2**	**2**	**4**	
				S15. Economic impact (delay, stopping of the work and/or bad publicity).		**3**	**6**	The transport vehicles shall be equipped with air conditioning.
			Sorting the soil	S16. Environmental damage (pure or treated surfaces become contaminated).	**4**	**3**	**12**	To minimize the brush up from the sieving must: Long conveyors be covered. The falling height for the fine fractions should be as low as possible. Manual work should be avoided. Staff change their footwear and work clothes before they go and eat or go home for the day. When working in contaminated soil, gloves should be used.

Table. M.2. continued..

		Spread by water	By rain	S17. Economic impact (surface water run into the excavation).	**3**	**2**	**6**	
				S18. Environmental damage and/or economic impact (rain water flowing from contaminated surfaces to already processed and approved surfaces).		**3**	**9**	Prevent surface water from leaking into the excavation. For example, by ditches.
				S19. Economic impact (rain water increases the cost of treatment in particular for fine fractions due to weight gain).		**2**	**6**	Constructe shaft bottom so that the clean and polluted surface water are kept separate.
				S20. Environmental damage, contaminated material is spread with transport vehicles and machines.		**2**	**6**	Cover up of storage. Consider cancelling works with excavation, sorting when large floods are expected. Hold routes free from pollution. Cleaning of machines and vehicles at the exit from the area (for example at a separate area with drainage to waste water treatment plant).
			At treatment of surface and groundwater.	S21. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**3**	**6**	Transports of contaminated soil outside the work area is performed with cover.
			Pollutions which is dissolved in water are transported with the pumping water and can contaminate the nearby river or unauthorized levels are released to the waste water treatment plant.	S22. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**4**	All surface water must go through a purification plant for control of water pollution level so it is below the specified allowed level.
			The water work is too small.	S23. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**4**	Constructe large smooth magazine.
			Water work got too small inflow.	S24. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**4**	Benefit of time at malfunctions in sewage treatment plant, power outage.
			Water work goes periodic due to too small inflow.	S25. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**4**	The treatment plant can go with an even flow for long periods. This prevents stops due to biomass in the filter.
			Water may leak from the pumping tubes.	S26. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**8**	During the warm season, it is expected that a certain amount of water in countervailing magazine evaporates.
			Downtime in pumping during non working hours.	S27. Environmental damage and/or delay-spread of pollution to rivers.	**2**	**2**	**4**	Never pump directly into the excavation. Organize some form of protection around the pump, so that the pump do not pulls solid particles.
			Freezing of water works (e.g. filter) or hoses with reduced treatment as a result.	S28. Environmental damage and/or delay-spread of pollution to rivers.	**4**	**3**	**12**	Verify that pipes and pipe connectors are tight. Protect pipes at intersections of routes or in road area. If pumping must be done during non working hours, some form of supervision needs to be is arranged. Insulation and heating cable on exposed pipes, fittings, fixtures. If the plant must go in the winter, have the space heated. Insulation and heating cable on exposed pipes, fittings, fixtures.
			At shafts under the ground water surface in silty materials.	S29. Environmental damage (contamination spreads by water in the shafts and when excavation).	**2**	**2**	**4**	Shafts shall be carried out in dryness to the greatest extent possible.
		High water content in the masses.	At the beginning of the shafts before the water surface has been lowered.	S30. Economic impact (rising costs for disposal of masses).	**4**	**2**	**8**	Water treatment. Shaft in dryness. The masses on a waste disposal area is drained before they are transported to the disposal/treatment. If Ts-content changes from 50% to 70% reduces the weight from 1.4 tons to 1 tons for the same amount of soil to be transported, deposited/treated.
		Wet weather when excavation is performed.	Heavy or prolonged rain.	S31. Increased costs for transport.	**2**	**3**	**6**	Can be profitable to stop working in adverse weather conditions.
		Landslides	The movement of machinery and vehicles in the work area.	S32. Environmental damage and/or retardation, dozers and truck wheels spreads pollutions when traveling.	**3**	**3**	**9**	Transportation routes are built with fiber cloth and 30 cm crushed stones.
		Unexpected discovery of reservoirs, pipes etc. in the soil.	Incomplete knowledge about soil conditions.	S33. Financial impact (cost of delay (waiting on information) and disposal of found materials).	**3**	**3**	**9**	Managing release shall be requested before excavation starts.
		Overload on vehicles.	Lack of routines, carelessness.	S34. Economic consequences (increased wear on the road network at overload).	**2**	**4**	**8**	Weighing
		Too little cargo on vehicles.	Lack of routines, carelessness.	S35. Economic impact (For little cargo make bad transport economics).	**2**	**2**	**4**	Weighing

Table. M.2. continued..

Management of contaminated water	Collection, treatment and transport of contaminated water.	Releases to land or water	All contaminated water is not collected.	T1. Environmental damage and/or delay.	**3**	**3**	**9**	Regular supervision, maintenance and sampling of surface water at the site.
			Processing equipment leaks, have insufficient capacity or used incorrectly.	T2. Environmental damage and/or delay.	**2**	**3**		Regular supervision, maintenance and sampling of surface water at the site.
			Leakage in pipes, valves, connectors, etc.	T3. Environmental damage and/or delay.	**2**	**3**	**6**	Regular supervision, maintenance and sampling of surface water at the site.
Temporary landfill	Temporary landfill	Leakage of pollutants.	Lack of design of temporary landfill.	T4. Environmental damage.	**1**	**3**	**3**	Temporary landfills must be approved before usage.
Waste management	Management of construction waste.	Malfunctioning or defective sorting.	Non-existent or inadequate opportunities to separation, bad marking, lack of education/information.	T5. Environmental damage, economic implications (legal penalties).	**3**	**2**	**6**	
	Management of household waste.	Malfunctioning or defective sorting.		T6. Environmental damage, economic impacts (household waste from the project on the environment seems to be more negative than necessary, legal penalties).	**4**	**1**	**4**	
	Management of hazardous waste.	Malfunctioning or defective sorting.		T7. Environmental damage, personal injuries, financial implications (legal penalties).	**2**	**2**	**4**	
Electrical installation	T8. Feeding				**2**	**2**	**4**	
	T9. Load				**2**	**2**	**4**	
	T10. Safety fuse				**2**	**2**	**4**	
Waste water treatment plant	T11. Wastewater and oil separator		Too low dimensioning	Environmental damage	**2**	**2**	**4**	
	T12. Vehicle washing		Too low dimensioning	Environmental damage	**2**	**2**	**4**	
	T13. Cleaning of clothing and equipment.	Bad cleaning of contaminated equipment, materials.	Cleaning difficult or impossible		**3**	**2**	**6**	
	T14. Hygiene and cleaning	Deficiencies in hygiene, cleaning and handling of contaminated materials and equipment.	Inadequate information, poorly designed work, service and maintenance of premises.	Poor well-being, disease, contaminated soil removed from the area.	**3**	**2**	**6**	
All contract work	Engagement of subcontractors.	Determined requirements for environmental, health and safety are not met.	T15. Lack of writing		**2**	**3**	**6**	
			T16. Lack of education and/or information.		**2**	**3**	**6**	
Sampling	T17. Sampling of contaminated soil and water.	Exposure to contaminated soil and		Personal injury (hazard)	**2**	**3**	**6**	
	T18. Work at drilling wagon or similar.	Risk for clamping and punches, noise, burning.		Personal injury (death)	**1**	**4**	**4**	
Recovery for planned land use	T19. The construction of fence/fencing against rail way.				**1**	**3**	**3**	
Usefulness of action to Mölndals society	T20. Communication about that the environmental damage from Hexion now finally is fixed.	Measures provides limited benefits to Mölndal.	Poor communication, bad reputation being underestimated.	Economic impact (lower property prices, less establishment of people and activities).	**2**	**5**	**10**	

References

Rosén, L. & Wikström, N. (2005). *BT Kemi. Efterbehandling Skede: Förberedelser. Metodik för riskhantering, riskidentifiering och riskbedömning i förberedelseskedet*. SWECO VIAK AB. (2005-10-25).

Appendix N

Result from uncertainty analysis, CBA

Table N.1. NPV for different discount rates, no Monte Carlo simulation.

	Discount rate 0%	Discount rate 1.4%	Discount rate 4%
Alternative 1	-5.72	-7.39	-9.70
Alternative 2	12.16	9.55	5.64
Alternative 3	12.56	9.92	5.98
Alternative 4	5.54	3.28	-0.04

Table N.2. Monte Carlo simulation of NPV, alternative 1.

	Discount rate 0%	Discount rate 1.4%	Discount rate 4%
P (NPV>0)	0.7	0.0	0.0
95% CI	(-14.06, -1.54)	(-15.22, -3.52)	(-16.68, -6.32)
Mean	-7.69	-9.26	-11.4
Standard deviation	3.25	3.04	2.69

Table N.3. Monte Carlo simulation of NPV, alternative 2.

	Discount rate 0%	Discount rate 1.4%	Discount rate 4%
P (NPV>0)	34.1	14.4	1.0
95% CI	(-7.39, 4.80)	(-8.91, 2.50)	(-10.95, -0.87)
Mean	-1.33	-3.24	-5.91
Standard deviation	3.16	2.95	2.61

Table N.4. Monte Carlo simulation of NPV, alternative 3.

	Discount rate 0%	Discount rate 1.4%	Discount rate 4%
P (NPV>0)	100.0	100.0	98.7
95% CI	(5.91, 17.38)	(3.71, 14.41)	(0.47, 9.90)
Mean	11.63	9.04	5.22
Standard deviation	2.97	2.77	2.44

Table N.5. Monte Carlo simulation of NPV, alternative 4.

	Discount rate 0%	Discount rate 1.4%	Discount rate 4%
P (NPV>0)	94.9	83.0	41.0
95% CI	(-0.97, 10.91)	(-2.80, 8.27)	(-5.42, 4.35)
Mean	4.95	2.71	-0.58
Standard deviation	3.04	2.84	2.51

Appendix O
Distributions in Monte Carlo simulation

The likeliest values are equal to the ones calculated before the simulation. The min and max values for the triangular distributions of most cases were calculated according to this system; 0.9*likeliest/likeliest/1.1*likeliest.

The rate used when calculated default rate of return is 0.5-6% with the likeliest being 1.5%, which is the rate used in Sweden today (Sveriges Riksbank, 2011).

Table O.1. Distributions common for all four alternatives.

Assumption	Unit	Distribution	Min/likeliest/max (triangular) Min/max (uniform)
Cost for remediation			
Temporary roads	SEK	Triangular	360 000/400 000/440 000
Excavation 0-4 m	SEK/ton	Triangular (skew)	149/165/200
Excavation 4-8 m	SEK/ton	Triangular	297/330/363
Control program and investigations	SEK	Triangular	9 000 000/10 000 000/11 000 000
Project risks	SEK	Triangular	4 000 000/5 000 000/6 000 000
Landfill KM-MKM, Kikåstippen	SEK/ton	Triangular	63/70/77
Landfill MKM-FA, Heljestorp	SEK/ton	Triangular	315/350/385
Landfill >FA, Heljestorp	SEK/ton	Triangular	495/550/605
CO_2 equivalent	SEK/ton	Triangular	1 350/1 500/1 650
Cost new refilling material	SEK/ton	Uniform	91.0/141.0
Probability for traffic accident, landfill			
Length of road section No 1, Heljestorp	km	Triangular	65.7/73.0/80.3
Length of road section No 2, Heljestorp	km	Triangular	9.9/11.0/12.1
Length of road section No 3, Heljestorp	km	Triangular	4.5/5.0/5.5

Road length, Kikåstippen	km	Triangular	1.8/2.0/2.2
No of people involved in accident	-	Uniform	1.0/5.0
Probability for traffic accident, refilling material			
Road length	km	Triangular	12.6/14.0/15.4
No of people involved in accident	-	Uniform	1.0/5.0
Increased land value for surrounding properties			
No of surrounding properties	-	Uniform	3/20
Property value	SEK	Triangular	18 000/22 133/26 000
Other costs and benefits			
Increased land value for the site	MSEK	Triangular	54/60/66
Annual cost for conducting and performing control program	MSEK	Triangular	1.5/2.0/2.5
Annual cost for project risks	MSEK	Triangular	1.2/1.7/2.2

Table O.2. Distributions valid for alternative 1.

Assumption	Unit	Distribution	Min/likeliest/max (triangular)
Cost for remediation			
Excavation 0-4 m	ton	Triangular	65 214/72 460/79 706
Excavation 4-8 m	ton	Triangular	16 789/18 654 20 519
Landfill KM-MKM, Kikåstippen	ton	Triangular	22 212/24 680/27 148
Landfill MKM-FA, Heljestorp	ton	Triangular	35 918/39 909/43 900

Landfill >FA, Heljestorp	ton	Triangular	9 454/10 504/11 554
Emission of CO_2	ton	Triangular	516/590/667
Soil usable for refilling	ton	Triangular	14 418/16 020/17 622

Table O.3. Distributions valid for alternative 2.

Assumption	Unit	Distribution	Min/likeliest/max
Cost for remediation			
Excavation 0-4 m	ton	Triangular	41 727/46 363/50 999
Excavation 4-8 m	ton	Triangular	9 717/10 797/11 877
Landfill KM-MKM, Kikåstippen	ton	Triangular	14 736/16 373 /18 010
Landfill MKM-FA, Heljestorp	ton	Triangular	17 211/19 123/21 035
Landfill >FA, Heljestorp	ton	Triangular	9 454/10 504/11 554
Emission of CO_2	ton	Triangular	322/376/435
Soil reusable for refilling	ton	Triangular	10 044/11 160/12 276

Table O.4. Distributions valid for alternative 3.

Assumption	Unit	Distribution	Min/likeliest/max
Cost for remediation			
Excavation 0-4 m	ton	Triangular	41 727/46 363/50 999
Excavation 4-8 m	ton	Triangular	9 717/10 797/11 877
Landfill KM-MKM, Kikåstippen	ton	Triangular	12 510/13 900/15 290
Landfill MKM-FA, Heljestorp	ton	Triangular	14 580/16 200/17 820
Landfill >FA, Heljestorp	ton	Triangular	8 010/8 900/9 790
Emission of CO_2	ton	Triangular	303/352/400
Soil reusable for refilling	ton	Triangular	16 252/18 058/19 864

Capacity, sieving	ton/day	Triangular	240.0/300.0/360.0
Soil being sieved	ton	Triangular	41 400/46 000/50 600

Table O.5. Distributions valid for alternative 4.

Assumption	Unit	Distribution	Min/likeliest/max
Cost for remediation			
Excavation 0-4 m	ton	Triangular	41 727/46 363/50 999
Excavation 4-8 m	ton	Triangular	9 717/10 797/11 877
Landfill KM-MKM, Kikåstippen	ton	Triangular	0/0/0
Landfill MKM-FA, Heljestorp	ton	Triangular	15 973/17 748/19 523
Landfill >FA, Heljestorp	ton	Triangular	4 727/5 252/5 777
Emission of CO_2	ton	Triangular	288/332/377
Capacity, sieving	ton/day	Triangular	240.0/300.0/360.0
Soil being sieved	ton	Triangular	41 400/46 000/50 600
Establishment soil wash	SEK	Triangular	252 000/280 000/308 000
Unestablishment soil wash	SEK	Triangular	99 000/110 000/121 000
Cost washing	SEK/ton	Triangular	211.5/235.0/258.5
Soil being washed	ton	Triangular	35 184/39 097/43 002

References

Sveriges Riksbank. (2011). [Electronic] Räntor & valutor. Available at: <http://www.riksbank.se/templates/Page.aspx?id=8912> *Reporäntan, tabell.* [2011-04-14]