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# THE REC DECISION SUPPORT SYSTEM FOR COMPARING SOIL REMEDIATION ALTERNATIVES

## Phase 2: A methodology based on Risk reduction, Environmental merit and Costs


E. Beinat (Institute for Environmental Studies)
M.A. van Drunen (Institute for Environmental Studies)
R. Janssen (Institute for Environmental Studies)
M.H. Nijboer (TAUW Milieu bv)
J.G.M. Koolenbrander (TAUW Milieu bv)
J.P. Okx (TAUW Milieu bv)
A.R. Schütte (Berenschot Osborne)



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Het beslissingsondersteunende systeem RMK voor het beoordelen van varianten voor bodemsanering Fase 2: Een methodiek gebaseerd op Risicoreductie, Milieuverdienste en Kosten

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**Auteur(s)**
E. Beinat
M.A. van Drunen
R. Janssen
M.H. Nijboer
J.G.M. Koolenbrander
J.P. Okx
A.R. Schütte

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**Uitvoerende organisatie(s) (Consortium)**
Berenschot Osborne (A.R. Schütte, +31-30-2942741)
Instituut voor milieuvraagstukken (IVM), Vrije Universiteit Amsterdam (E. Beinat, +31-20-4449555)
Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer (S. Boekhold, +31-70-3394311)
NITG-TNO (I.L. Ritsema, +31-15-2697199)
Gemeentelijk Havenbedrijf Rotterdam (C.E.H.M. Buijs, +31-10-4896911)
Provincie Gelderland (J.W. Kamerman, +31-26-3598854)
Schelwald-Van der Kley Milieu-advies en -training (A.J.M. Schelwald-Van der Kley, +31-180-315654)
Shell International Oil Products B.V. (G. Beuming, +31-70-3776047)
TAUW Milieu bv (J.P. Okx, +31-570-699429)
TNO-MEP (H. Leenaers, +31-55-5493537)

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**Uitgever**
CUR/NOBIS, Gouda

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**Samenvatting**
RMK (Risicoreductie, Milieuverdienste en Kosten) is een methodiek voor het objectief beoordelen van verschillende bodemsaneringsalternatieven op hun gevolgen voor het milieu, de risico's voor mensen en ecosystemen en op hun kosten. Aan de hand van gegevens uit het saneringsonderzoek berekent RMK indices voor Risicoreductie, Milieuverdienste en Kosten. Deze indices helpen de beslissers over saneringsalternatieven doordat ze de grote hoeveelheid beschikbare gegevens beheersbaar maken. Bovendien wordt het besluitvormingsproces inzichtelijker.

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TAUW Milieu bv
(J.P. Okx, +31-570-699429)

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**Author(s)**
E. Beinat
M.A. van Drunen
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M.H. Nijboer
J.G.M. Koolenbrander
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A.R. Schütte

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**Excecutive organisation(s) (Consortium)**
Berenschot Osborne (A.R. Schütte, +31-30-2942741)
Institute for Environmental Studies (IVM), Vrije Universiteit Amsterdam (E. Beinat, +31-20-4449555)
Ministry of Housing, Physical planning and Environment (VROM) (S. Boekhold, +31-70-3394311)
NITG-TNO (I.L. Ritsema, +31-15-2697199)
Port of Rotterdam (C.E.H.M. Buijs, +31-10-4896911)
Province of Gelderland (J.W. Kamerman, +31-26-3598854)
Schelwald-Van der Kley Milieu-advies en -training (A.J.M. Schelwald-Van der Kley, +31-180-315654)
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**Abstract**
REC is a Decision Support System for the analysis and evaluation of possible clean-up strategies for a contaminated site. The aim of REC is to support the choice of the most effective and efficient strategy for soil remediation for the site concerned. REC is the acronym of Risk reduction, Environmental merit and Costs, which are the three perspectives used in the system. The REC system simplifies the decision process, streamlines the multiple factors involved in clean-up management and allows the user to focus on few, clear and strategic issues increasing the understanding of the decision and its effectiveness.

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# PREFACE

Many have contributed to the development of the REC methodology. Firstly, I wish to mention the authors of this report. Jan Koolenbrander and Rob Theelen (TAUW Milieu) contributed to the 'R'; Euro Beinat, Michiel van Drunen and Ron Janssen (Institute for Environmental Studies, Vrije Universiteit Amsterdam) took care of the 'E', and Alexander Schütte (Berenschot Osborne) devoted himself to the 'C'. I wish to thank also those who assisted these authors. Henk Leenaers and René Korenromp from TNO-MEP and Elze-Lia Visser-Westerweele from TAUW Milieu contributed to the development of a number of essential elements of the REC methodology. Furthermore, without the assistance rendered by Lida Schelwald-van der Kley, we would have received far fewer responses and would not have been able to anticipate many questions received from the field. Arjen Michels, Ipo Ritsema and Koos Uil (NITG-TNO) developed the tool with which a number of cases could be assessed using the methodology. Finally, I wish to thank Harry Vermeulen (NOBIS) and Bram de Borst (TAUW Milieu) for having chaired the many advisory meetings and meetings of the steering committee.

This document could never have been drafted without the efforts made by the first REC team led by Annemieke Nijhof (TAUW Milieu) and those made by the members of our steering committee. Cees Buijs (Port of Rotterdam), Ger Beuming (Shell International Oil Products), Harry Vermeulen (NOBIS), Jan-Willem Kamerman (Province of Gelderland) and Sandra Boekhold (Ministry of VROM) asked us many difficult questions, but we are confident that this has resulted in a better product. Lastly, I wish to thank the members of the advisory committee and all those who were interviewed for the Costs and the Environmental Merit parts.

March 1998

## CONTENTS

# SAMENVATTING

## Het beslissingsondersteunende systeem RMK voor het beoordelen van varianten voor bodemsanering

*Achtergrond*

Van biologische in situ bodemreinigingstechnieken wordt verwacht dat ze bijdragen aan een significante reductie van kosten, vooral als ze grootschalig en extensief worden ingezet. Bovendien zijn de negatieve milieu-effecten van biologische in situ technieken relatief gering, vooral omdat de grond niet hoeft te worden afgegraven. Er was tot op heden echter geen goede methodiek voor het objectief beoordelen van verschillende bodemsaneringsalternatieven op hun gevolgen voor het milieu, de risico's voor mensen en ecosystemen en op hun kosten. Het NOBIS-onderzoeksproject Risicoreductie, Milieuverdienste en Kosten (RMK) heeft als doelstelling daarin te voorzien.

Aan de hand van gegevens uit het saneringsonderzoek berekent RMK indices voor Risicoreductie, Milieuverdienste en Kosten. Deze indices, die voor elk alternatief de belangrijkste gevolgen van saneringsoperaties beschrijven, helpen de beslissers over saneringsalternatieven doordat ze de grote hoeveelheid beschikbare gegevens beheersbaar maken. Bovendien wordt het besluitvormingsproces inzichtelijker.

*Risicoreductie*

Risico's van bodemverontreiniging worden in Nederland beoordeeld op basis van de mogelijke blootstelling in relatie tot het humaan en ecotoxicologische maximale toelaatbare risiconiveau. Binnen Risicoreductie is gekozen om blootstelling als uitgangspunt te nemen. Hiervoor is het noodzakelijk om te kijken welke objecten geselecteerd worden voor de berekening van Risicoreductie. Aan de hand van resultaten uit speciale risicobeoordelingsprogramma's, zoals CSOIL of HESP wordt het verschil in blootstelling voor en na de sanering vastgesteld.

*Milieuverdienste*

Bij het onderdeel Milieuverdienste wordt als het ware geprobeerd door de ogen van 'Moeder Aarde' te kijken naar de effecten van verontreinigde bodems en de saneringsactiviteiten. In feite is het onderdeel Milieuverdienste een vereenvoudigde levenscyclusanalyse (LCA) die is toegesneden op bodemsanering en de uit het saneringsonderzoek beschikbare gegevens, en die bovendien geen milieu-effecten meetelt die ook al bij Risicoreductie worden meegenomen.

*Kosten*

Het onderdeel Kosten binnen RMK bekijkt de sanering vooral vanuit het belang van de opdrachtgever voor een saneringsoperatie. De opdrachtgever zoekt naar de kosteneffectiefste maatregel. In de RMK-methodiek worden de kosten van saneringsvarianten zodanig berekend dat de kosten per jaar, vanaf de aanvang van de sanering, inzichtelijk zijn. In de RMK-methodiek zijn Kosten gedefinieerd als alle kosten die vanaf het beslismoment gedurende het vervolg van de sanering zullen worden gemaakt.

## SUMMARY

**The REC decision support system for comparing soil remediation alternatives**


*What's REC?*
REC is a Decision Support System for the analysis and evaluation of possible clean-up strategies for a contaminated site. The aim of REC is to support the choice of the most effective and efficient strategy for soil remediation for the site concerned. REC is the acronym of Risk reduction, Environmental merit and Costs, which are the three perspectives used in the system. With REC, the user can measure the results of clean-up in terms of:

*Risk Reduction*. The degree to which a remedial action reduces the risks for humans, ecosystems and other targets on the site. High risk reduction indicates that the residual risks after remediation are low.

*Environmental Merit*. The degree to which a remedial action achieves a positive environmental balance. Operations prevent the spreading of contamination and increase the stocks of clean soil and groundwater. However, they also use up resources, like energy, water or space, and may pollute other media, like air or water. Environmental merit states the balance between environmental benefits and costs. High scores indicate that a limited use of natural resources and a limited pollution transfer are necessary for achieving a good environmental output.

*Costs*. The total costs necessary for the clean-up of the site. Costs include preparation, operation, maintenance and monitoring costs at all phases of the operation. Low costs indicate that the operation is very efficient in achieving a given risk reduction and a given environmental merit score.

With REC its is possible to seek for an optimal balance between Risk reduction, Environmental merit and costs, and to target the most effective and efficient clean-up alternative, that is:

- An option with high Risk reduction;
- An option with high Environmental merit;
- An option with reasonable Costs.

*Why REC?*
Soil remediation has often focused on a single perspective: reducing concentrations below a given standards in the shortest possible time, so that a high soil quality can be restored. If standards are high enough, then the soil after remediation can be used for any purpose without restrictions. Although this is a very desirable outcome, experience has shown that this objective is difficult to achieve. Cost constraints and technical limitations make it difficult to restore a pristine soil in all situations. Clean-up management is first of all a matter of balancing out environmental achievements against reasonable costs. However, there is more in it than this.

Different clean-up operations have different costs and benefits. Experience has shown that this holds for financial aspects as well as for environmental aspects. Soil remediation aims, first of all, at reducing risks for people, ecosystems and other targets directly affected by soil contamination. Reducing risks is always a positive environmental outcome, which is felt particularly at the local level. However, remediation also has effects beyond the local scale. On the one hand, clean-up prevents the spread of contamination and restores a stock of clean soil and clean groundwater. On the other hand, operations usually require the use of resources (such as energy and clean water) and may lead to a transfer of contamination to other compartments (due to

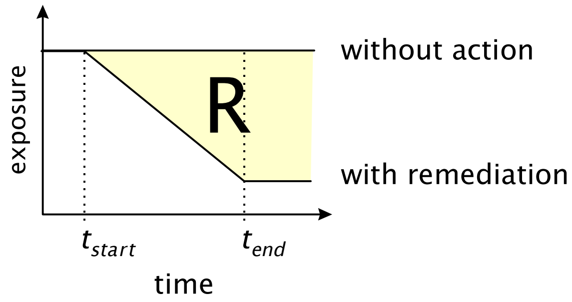
air or water emissions). These effects are felt at the regional or even global level, but contribute to the full picture of the costs and benefits of the operations.

Clean-up operations, therefore, are a matter of balancing out a full range of environmental and financial costs and benefits. An effective decision support for soil remediation has to account for all these aspects and provide evidence of the full implications of remedial strategies.

| Benefits | Costs |
|---|---|
| Risk reduction for people, ecosystems and other targets (local benefits) | Financial costs of the operations |
| Prevent spreading of pollution, restore stock of clean soil and groundwater (regional or global benefits) | Use of resources (energy, space) and pollution transfer (air and water emissions) (regional or global benefits) |

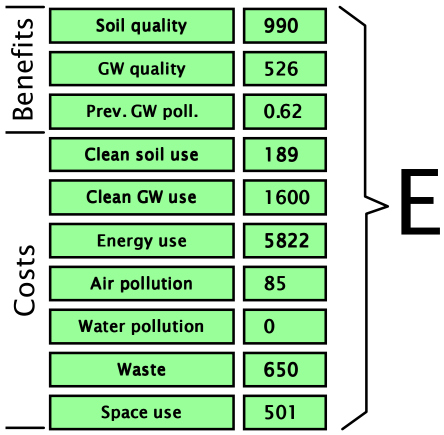
*How does REC work?*
Costs and benefits, all together, determine whether a remedial strategy is a feasible, effective and efficient solution. REC extends the traditional single perspective evaluation and focuses on the full balance sheet of remedial operations by evaluating the Risk reduction, Environmental merit and Costs of operations.

*Risk reduction* considers the exposure to humans, ecosystems and other targets and how it changes as a result of clean-up. The time profile of exposure is compared to that in absence of remediation (the do-nothing option). The difference  provides the extent of risk reduction.



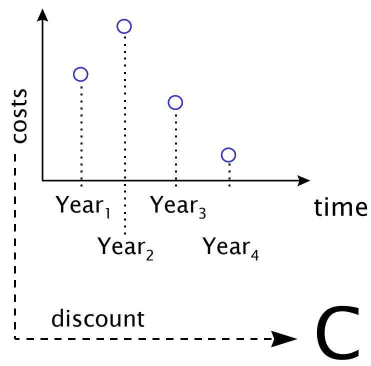

Risk reduction takes the time dimension into account. Choosing when to start operation, or choosing a time consuming option like bio-remediation, may have distinct advantages. However, it may also imply that risks decrease slowly. This is accounted for in the REC risk reduction model.

*Environmental merit* is an index that combines a list of environmental costs and benefits of soil remediation. Each aspect in the list has been weighted by a panel of experts to capture its importance in the environmental balance. If the resulting index is positive, then, all considered, the operations have a positive environmental balance.




Environmental merit highlights clean-up strategies which do not put a particular burden on environmental resources. Intensive techniques, which can be very effective to reduce risks, may correspond to low environmental merit scores. They achieve risk reduction either by an intensive use of resources (like energy, space, clean water etc.) or with significant side effects (like air or water pollution).

*Costs* are estimated for the full time span of the operation, and expressed on a yearly basis. They include the initial costs, the operational, replacement and overhead costs. Costs are discounted with a fixed discount rate to account for the time value of money. The result is a net-present cost figure for each cleaning up alternative.

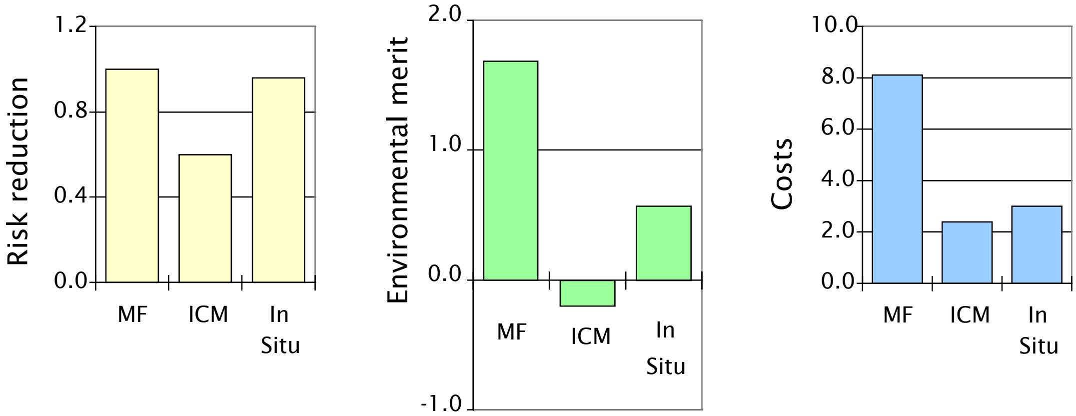



Costs in REC are based on best estimates for expected costs, but also on a safety margin which depend on the uncertainty in the cost estimates. This margin is optimally selected at a level which prevents real costs to exceed the estimated costs.

In addition to the methodology described in this report, spreadsheets have been developed for calculating the indices for R, E and C.

*The REC output*
The output of REC is a set of three indices for each clean-up alternative: the Risk reduction, the Environmental merit and the Costs. Together, these indices summarise the overall performances of each option.

The figure on the next page shows an example of the REC results for three remedial options for a contaminated site. The MF option (multifunctional option: soil excavation and groundwater extraction) provides high risk reduction and environmental merit at high costs. The ICM option (Isolation and Control Management) shows a significantly inferior risk reduction and a negative environmental merit balance, but is the cheapest option. The In Situ option (biological remediation) provides high risk reduction, intermediate environmental merit performances at rather low costs.




On this basis, and depending on the context in which remediation takes place, the user can tailor the decision strategy balancing out effectiveness and efficiency. In this specific case, possible decision strategies are:

- Focus on effectiveness: select the most effective option provided the budget available is sufficiently high (the MF option);
- Focus on costs: select the cheapest solution provided some significant risk reduction is achieved (the ICM option);
- Focus on efficiency: select the solution which gives the best ratio between risk reduction, environmental merit and costs (the In Situ option).

*Advantages of REC*

The REC system has four main advantages:

- It allows a systematic analysis of the pros and cons of decision options highlighting their strengths and weaknesses.
- It introduces a structure for the evaluation which simplifies the decision process and streamlines the multiple factors involved in clean-up management.
- It allows the user to focus on few, clear and strategic issues increasing the understanding of the decision and its effectiveness.
- It favours communication between decision actors by offering evidence on the advantages and disadvantages of the possible choices in a simple, concise and direct way.

*How to read this report*

This report contains a full description of REC, including the aims of REC, the methodology used to calculate the REC indices and the various components of the R, E and C models. The report, besides this summary, contains three main parts. They are meant to be read sequentially: each part adds information to the previous one. The core of the report is included in Part 1, which contains the explanation of the methodology. To clarify all concepts, an example is used along the text. This example, step-by-step, illustrates the meaning of REC in practice and shows the typical results of the methodology.

| Parts of the REC report | Content | Reader |
|---|---|---|
| Summary | The main ideas behind REC and their relevance for remediation management.<br>Management content: ✓✓<br>Methodology: ✓<br>Analytical parts: -<br>Background: - | A reader interested in the key issues without their technicalities. |
| 1. Methodology | How to construct the R, E and C indices. Explanation of each step by means of an application.<br>Management content: ✓<br>Methodology: ✓✓✓<br>Analytical parts: ✓<br>Background: - | A reader interested in understanding all steps of REC without all details of REC components. |
| 2. Technical specifications | A detailed analysis of the assumptions, technicalities, data requirements and analytical content of the R, E and C models.<br>Management content: -<br>Methodology: ✓✓<br>Analytical content: ✓✓✓<br>Background: ✓ | A reader interested in all parts of REC, including the assumptions behind the models and the analytical calculations. |
| 3. Appendices | A collection of background information on the REC system<br>Management content: -<br>Methodology: -<br>Analytical parts: -<br>Background: ✓✓✓ | A reader interested in a full exploration of REC. |

# PART 1: THE REC METHODOLOGY

CHAPTER 1

# REC: METHODOLOGY

## 1.1 The REC decision-support methodology

REC is a Decision Support System (DSS). A DSS is meant to [Janssen, 1992]:

- help individuals or groups make decisions;
- support rather than replace them;
- raise the effectiveness of the decision-making process.
- provide a structure for the evaluation in order to simplify the analysis and the synthesis of large amounts of information.

Decision Support Systems are used in many fields and for several different purposes. REC is particularly suitable for the comparison of alternative clean-up strategies for a single contaminated site. Given a contaminated site, the aim of REC is that of supporting the selection of the most effective and efficient remedial alternative.

The REC methodology provides information about three aspects: Risk reduction, Environmental merit, and Costs. These three indices are calculated for each remedial alternative and are the basis for the comparison. The role played by the REC methodology as a decision-support system is shown in Figure 1.

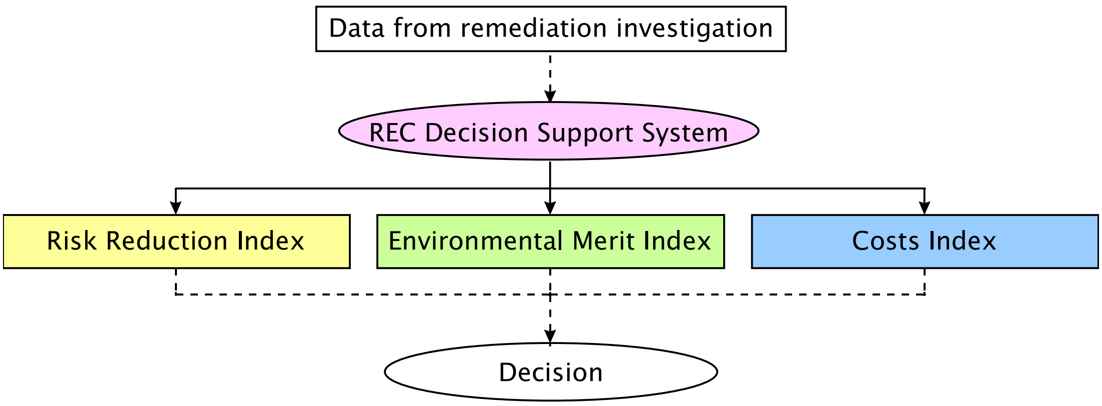



Fig. 1. Diagram of the role played by the REC methodology during the decision-making process.

## 1.2 The decision context: actors and interests

The REC methodology is not an independently operating system that can replace experts or decision makers. Instead, it supports the decision-making process by arranging information and presenting it in an orderly fashion. This helps the decision makers understand the issues at stake and allows a clear analysis of the trade-offs which are necessary for making a decision. Clean-up operations are not carried out in a vacuum, but rather involve a number of actors which affect, and are affected by, the decision. Figure 2 shows the main actors usually involved in a remediation project. Those located in the centre of the network usually have the strongest influence on the selection of a remedial alternative.

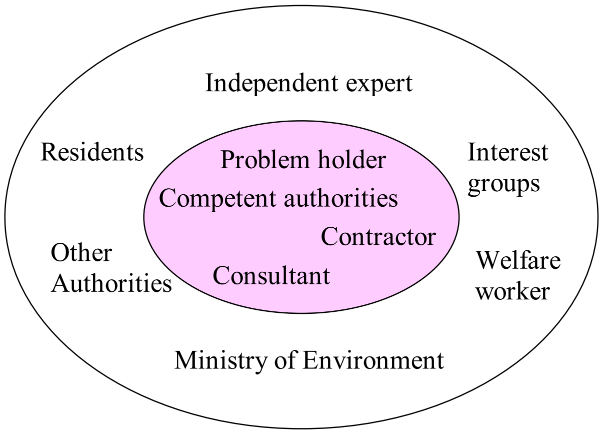



Fig. 2. The network of actors involved in the selection of a remedial alternative [Kolkman, 1997].

The interests of different actors partly coincide and partly may be different. Table 1 illustrates possible interests for the main actors in the decision process for soil remediation.

Table 1. Indication of the interests of various actors.

| Actors | Interests |
|---|---|
| Problem holder | cost effectiveness |
| | functionality of soil |
| | efficient decision-making |
| Authorities | multifunctionality of soil |
| | minimisation of the remaining environment load |
| | consistent policy |
| | efficient decision-making |
| Consultants | looking after the interests of the client (problem holder or competent authority) |
| | efficient decision-making |
| Third parties, residents | risk reduction |
| | minimal limitations of use |
| | minimal nuisance |
| | efficient decision-making |
| Contractor | looking after the interests of the client |
| | efficient decision-making |

Efficient decision-making is important to all actors involved. The creation of a (as far as possible) univocal picture of the main decision criteria - Risk reduction, Environmental merit and Costs - may result in better weighing of interests by the various actors involved and therefore in a more efficient decision-making process. It is evident that not all specific interests can be represented in a general methodology. The REC system provides information on three key issues, but does not replace the decision makers. The final decision will always include some subjective judgement and site-specific evaluations, which will depend on the context of the decision and on the actors which are involved.

The reason behind the selection of Risk reduction, Environmental merit and Costs has been briefly explained in the previous Chapter. These three aspects are meant to help the specification, analysis and evaluation of the main items in the balance sheets of soil remediation.

Table 2. Overview of the main items in the balance sheet of soil remediation. The aspects in the yellow cells are accounted for in Risk reduction; those in the green cells in Environmental merit and those in the blue cells in Costs.

| | **Benefits** | **Costs** |
|---|---|---|
| Costs or benefits felt especially at the site (local relevance) | Reduces risks for humans<br><br>Reduces risks for ecosystems<br>Reduces risks for other targets at the site | Nuisance at the site (noise, vibrations, etc.) |
| Costs and benefits felt at the regional or global scale | Increases the stock of clean soil<br><br>Increases the stock of clean groundwater<br>Prevents spread of contamination | Use up scarce resources<br><br>Transfer contamination to other media<br>Modification of soil texture and organic matter content |
| | | Financial costs to carry out the remediation |

As can be seen from Table 2, REC does not include all aspects which may be of relevance for soil remediation. Local nuisance, for instance, is not included in the present version of REC. The reason is that, although an important aspect, this is likely to be ranked after R, E and C. As a first approximation, it can be considered as a side aspect which enters the evaluation after R, E and C are accounted for. Aspects like this one, however, may be of relevance when the decision based on REC is made (cf. Chapter 5). The justification for the selection of which aspects to be included in REC is given Chapter 7 for Risk reduction and in Chapter 8 for Environmental merit.
The fundamental objectives of a soil remediation are those of maximising the benefits of the remediation and of minimising its costs. These objectives can be achieved in a number of ways, depending on the clean-up strategy used. However, the path that links the contaminated site, the soil remediation operations, the consequences of remediation and their relationship with the fundamental objectives of remediation is shown in Figure 3.

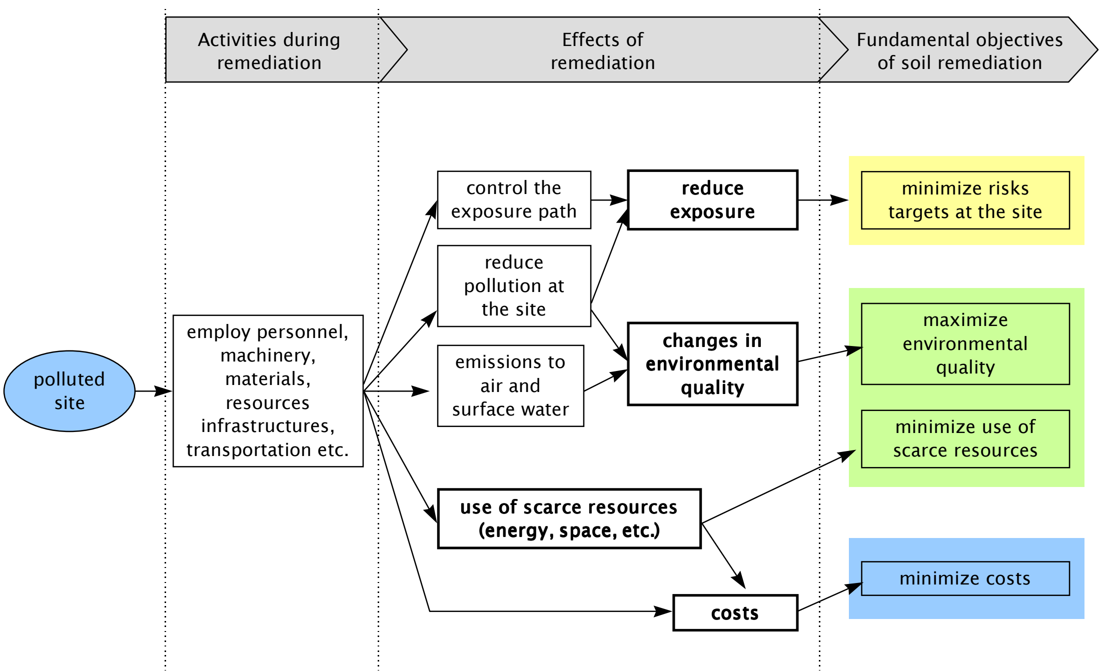



Fig. 3. The viewpoints of taken by R, E and C.

This figures shows, in a very simple fashion, the various activities which take place during remediation, their effects and their links with the objectives to be achieved. The thick-bordered boxes indicate which specific aspects are included in the R, E and C models. For instance, risk minimisation is the effects of reduced exposure. This, in turn, can be achieved by reducing the contamination at the site or by controlling the exposure path (e.g. by isolation). In any case, and as it will be explained below, what we measure in REC are the changes in exposure, which will serve as an indication of risk reductions.

## 1.3 **Risk reduction**

Risk reduction focuses on the local consequences of a soil remediation project at the site concerned. Risks are the result of all forms of exposure to the soil contamination for a range of possible targets, like the people living in the vicinity of the contaminated site, the workers involved in the execution of the remediation, the ecosystems in the area affected and, possibly, also other objects, like pipelines or monuments.

Risk reduction is often the main motive behind a remediation project. If a certain remedial alternative results in insufficient risk reduction (e.g. the concentration of a contaminant remains above the an accepted threshold value[1] after termination of the remediation project), this alternative is dropped irrespective of other considerations (that is, of its performances on environmental merit and costs).

Risk reduction takes a local viewpoint. It focuses on all consequences of a soil remediation project at the site itself. More specifically, Risk reduction relates to the direct effects of the contamination as a result of exposure to objects present at the site (cf. Figure 3). The risks estimated in REC depend both on the level of contamination, on the exposure paths and on the presence of targets. This implies that if there are no targets at the site, the risk level is zero whatever the level of contamination. The effect of this definition of risk is that remediation would become unnecessary if no targets are present. However, this would disregard the fact that even in such a case soil remediation would increase the quality of the soil stock and thus allow the use of this soil in the future (both for human activities and for ecosystem life). In a more global perspective, this is a clear benefit for the environment, which occurs with or without risk reduction. This type of aspects are included in Environmental merit model.

## 1.4 **Environmental merit**

Environmental merit focuses, on the *potential* environmental effects of the contamination or of the remedial operation and on the other environmental consequences which are not included in the risk framework.

Remediations prevent the spread of contamination and increase the stock of clean soil and groundwater. But clean-up operations also use up resources, like energy, water or space, and may involve operations which result into a transfer of contamination to other media, for instance through air emissions or emissions to surface water. All together, these aspects determine the quality of the operations from the environmental perspective.

Environmental merit assesses a remediation project from the viewpoint of *general interest*, whereas risk reduction focuses on local interests. Environmental merit includes both the positive environmental outcomes of the remediation, which are an increase of the stock of clean soil and

[1] E.g. the intervention value in the Netherlands.

clean groundwater, but also the fact that this is usually obtained at some environmental costs, like the use of scarce resources or the pollution of other environments.

Environmental merit is derived by making an integrated assessment of these non-local, not-object-related environmental consequences. In principle, all relevant environmental effects caused by the contaminated soil are taken into consideration, except those covered by risk reduction (i.e. local, object-related effects).

The environmental merit achieved consists of the difference between the initial situation and the final result of the remediation project. Hence, a clean-up operation leads to a positive environmental balance if the environmental benefits outweigh the environmental costs.

The environmental consequences of clean-up are assessed based on the results of a life cycle inventory (see Appendix A). Such an inventory focuses on the contaminated soil, the contaminated groundwater, and the remediation process. Not only primary effects (e.g. electricity consumption by pumps and the consumption of groundwater) are included but also secondary ones, for example, sulphur dioxide emissions by power stations and the electricity consumption by the pumps of wastewater treatment plants, if the wastewater is discharged into the sewage system.

Tertiary effects (e.g. energy required for the construction or repair of pumps present at the site) are left out of consideration for practical reasons and because the expected effects would be relatively limited.

### 1.5 **Costs**

Possibly the most easily recognisable perspective in REC is that of costs. The REC criterion of costs assesses a remediation project based on the interest that the problem holder has in this project. This always is that of selecting the most cost-effective solution. In REC, all costs incurred from the moment of decision until the end of the remediation project are considered. These include the costs incurred:

- during the preparatory phase;
- for onetime investments;
- for replacing equipment;
- for the actions to be carried out;
- because of loss of capital and production.

Since cost estimates are uncertain and since costs may be incurred at different moments, the costs of an alternative is obtained by discounting its annual costs and by including safety factors which account for the uncertainty in the cost estimates.

This section sketches the example case which is used throughout this report to illustrate the REC methodology in practice. It is based on an existing case in the Netherlands, which has been simplified for illustration purposes.

The source of the contamination in this case is a former dry-cleaning company. Chlorinated solvents were encountered in both the groundwater and soil. In addition, the site was found to be contaminated with oil and heavy metals of unclear origin. The soil at the site is heavily contaminated above the intervention value. In the phreatic and deeper groundwater, concentrations of chlorinated solvents above the intervention value were encountered. This is shown in Figure 4. Table 3 shows the concentrations of all contaminants for each section.

Table 3. Contamination situation per section.

| Section (extent in $m^3$) | Groundwater (µg/l) | Soil (mg/kg) |
|---|---|---|
| 1. 120 $m^3$ | - | 1,000 mg/kg mineral oil |
| 2. 1,500 $m^3$ | - | 100 mg/kg tetrachloroethylene |
| 3. 1,750 $m^3$ | 3,000 µg/l cis-1,2-dichloroethylene | 25 mg/kg tetrachloroethylene |
| 4. 1,000 $m^3$ | 2000 µg/l cis-1,2-dichloroethylene | - |
| 5. 140,000 $m^3$ | 200 µg/l cis-1,2-dichloroethylene | - |
| 6. 4,000 $m^3$ | 1000 µg/l cis-1,2-dichloroethylene | 50 mg/kg tetrachloroethylene |
| 7. 30,000 $m^3$ | 100 µg/l cis-1,2-dichloroethylene | - |
| 8. 500 $m^3$ | - | 250 mg/kg zinc; 300 mg/kg lead |

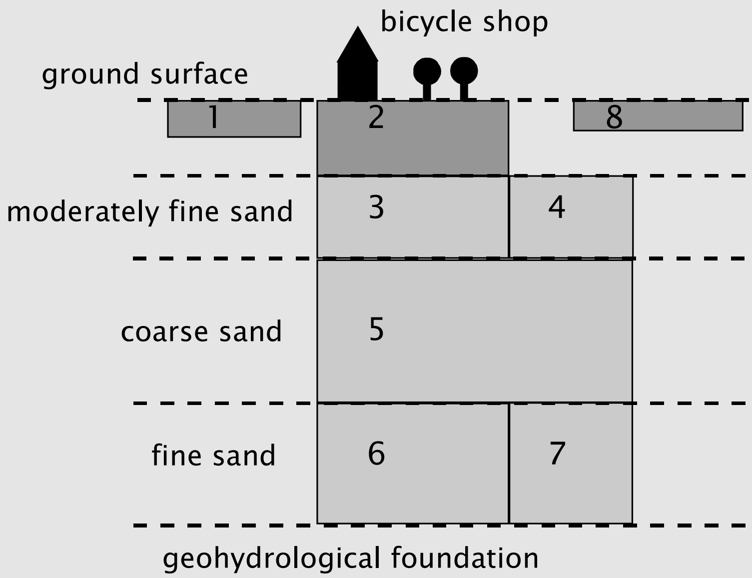



Fig. 4. Diagram of the contamination situation.

Three remedial alternatives were designed, namely:

| | |
|---|---|
| Alternative I (*MF*) | A multifunctional alternative to be carried out by wet excavation, in which also the groundwater within and outside the site's borders would be remediated. |
| Alternative II (*ICM*) | An alternative for containing the entire soil contamination within and outside the site's borders. At the site, the shallow groundwater would be remediated down to the risk limit. |
| Alternative III (*In Situ*) | An in situ alternative comprising partial excavation and complete groundwater remediation. |

In the following chapters, both the calculations necessary for the REC indices and the use of REC for supporting the choice between these three alternatives will be described.

CHAPTER 2

# RISK REDUCTION

## 2.1 The framework for Risk reduction

This chapter describes a methodology for assessing the Risk reduction for soil remediation alternatives. These days, remedial actions are more and more risk driven [ASTM, 1995; CONCAWE, 1997]. Risk modelling aims at assessing the risks for humans, ecosystems and physical objects due to exposure to soil contamination. The use of such physico-chemical models as CSOIL [Van den Berg, 1991 and 1993; Van den Berg and Denneman, 1993], HESP [ECETOC, 1990] and CLEA [Ferguson and Denner, 1993] for human exposure assessment is widespread. Models for ecosystem exposure assessment are available [e.g. Van Straalen and Denneman, 1989], but their use is limited.

The framework of Risk reduction is related to the Dutch legislation. In the Netherlands, risks posed by soil contamination are assessed based on possible exposure in relation to a human or ecotoxicological limit value. In the assessment of exposure, only exposure related to soil contamination is taken into consideration; possible exposure to other sources (e.g. a production process, food, other pollution sources) is not considered.

Risks of soil contamination are assessed based on possible exposure in relation to a human or ecotoxicological maximum tolerable risk level. This approach deviates from the general concept of risks as it focuses on exposure instead of focusing on the chance of an adverse effect (which is the more traditional definition of risk). The term 'exposure reduction', therefore, would be preferable over the term 'risk reduction', which is however used in REC.

The Risk reduction model requires, first of all, the identification of the targets at the site. The following are the main ones selected in REC:

- the people who live and work at the affected site;
- the ecosystem at the affected site;
- other objects at risk.

This list results from interviews with soil experts and corresponds to the set of targets usually considered in the practice of soil remediation. However, there is a general consensus among soil experts that the most relevant risks to be considered are those related to those living or working at the affected site. The remaining aspects, generally speaking, play a less important role in the assessment of the overall risks.

The experts interviewed concluded that remedial workers do not need to be necessarily included in the risk assessment. Since legislation on working conditions must be respected during the remedial operations, specific measures aimed at lessening the exposure of such workers hardly contribute to the total risk reduction. As a consequence, it was decided to include remedial workers only as an option of REC.

Based on these considerations, a preferential sequence for estimating risks was derived, as shown in Figure 5. On the basis of this figure, the following considerations can be made:

- The sequence includes an implicit rating of importance: first human risks, then ecosystem risks and after that risks to other objects.

- If there are only slight differences (say less than 10 %) between the risk reduction of different alternatives, proceeding along the scheme and introducing other aspects may serve to increase the discriminating power of the system, that is to highlight differences between alternatives.
- On the other hand, if there is sufficient confidence that some objects will not contribute to the picture of risk reduction, they may be left out altogether.

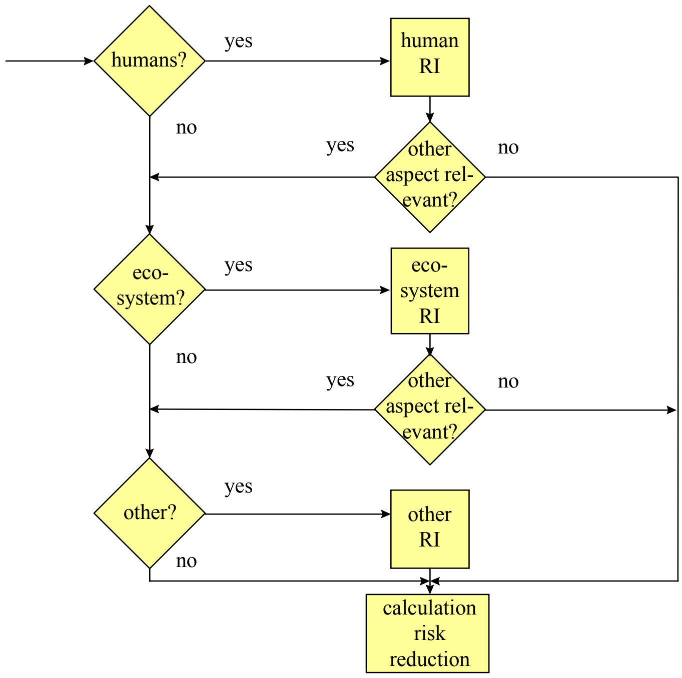



Fig. 5. Procedure for the assessment of risk reduction.

In short, when calculating risk reduction the selection of the number of aspects depends on the local situation. This approach corresponds with the definition of risk reduction: the prevention of local adverse effects on the objects or ecosystem located in the immediate vicinity of the contamination.

Once objects and targets are specified, the REC methodology bases the risks estimates on a 'Risk Index' (*RI*). This index is the ratio between the exposure and the toxicological limit value linked to a target. For soil contamination, the limit values are:

- for human health, the Tolerable Daily Intake (TDI);
- for ecosystems, the 50 % Hazard Concentration (HC50);
- for other objects, a concentration to which a specific effect can be linked.

The Risk Index (*RI*) can be calculated based on little detailed information by using fixed exposure parameters and physicochemical models that predict the behaviour of substances in the environment. In this way, future situations can also be predicted. Hence, the use of exposure models for assessing risk reduction in REC was the only useful alternative.

To assess (human) risk reduction as part of the REC methodology, physicochemical exposure models (e.g. HESP, CLEA, UMS or CSOIL) are used. To determine the degree of risk reduction, one exposure model needs to be selected, otherwise alternatives cannot be compared. It is less important which model is selected, because the REC methodology is meant to assess alternatives only in relation to each other. Consequently, it is not very important that such models are, for instance, conservative and not site-specific.

Ecotoxicological risk reduction is assessed by employing a generic assessment method. Such a method is based on the principle that if all species present in an ecosystem are protected, the ecosystem as a whole will also be protected. In the Netherlands, this principle was elaborated in the form of protection levels based on the number of potentially present species exposed above the NOEC (No Observed Effect Concentration). The HC50 is used as a limit value to assess soil contamination.

Because the REC methodology assesses remedial alternatives on site-specific aspects per project and per case of contamination, the results of such an assessment can be used only locally. Transferability of results, in this framework, is limited.

## 2.2 Quantification of Risk reduction

This section makes operational the assessment of individual aspects of Risk reduction. Risk for alternative $i$ ($r_i$) is computed as follows:

$$r_i = X_i \times t$$

where:

- $X_i$ is the standardised total exposure of alternative $i$;
- $t$ is the time.

Exposure to contaminants can be assessed by using the following expression for the standardised total exposure ($X$):

$$X = RI \times n$$

where:

- $RI$ is the Risk Index, defined as exposure divided by a toxicological threshold (i.e. $RI$ is the exposure/threshold value);
- $n$ is the number of exposure units (for human health these are the number of dwellings, workshops, recreational facilties etc. (see Section 7.1 for details); for ecosystems, $n$ depends on the area affected by contamination).

For the calculation of the normalised exposure for humans, the Total Daily Intake (TDI) is used as the toxicological threshold value, whereas for ecosystems the concentration where 50 % of the species are at risk (HC50) is the adequate threshold. If the Risk Index for humans is one, the level equals the Maximum Tolerable Risk (MTR). If the Risk Index for the ecosystem equals one, 50 % of the species is expected to be affected. Once the normalised exposure is determined for all relevant objects, the total normalised exposure can be calculated by simply adding the different normalised exposures. Thus, in REC, the exposures of the relevant targets are not weighted and have the same importance.
The calculation of the risk should be repeated for all the targets indicated in Figure 5. Risk reduction is then defined as:

$$R = Risk\ reduction = r_0 - r_i$$

where:

- $r_0$ is the risk when no measures have been taken;
- $r_i$ is the total risk as a result of remedial alternative $i$.

This results in the following formula for risk reduction for alternative *i*:

$$R = \frac{r_0 - r_i}{t_{tot}}$$

In cases where exposure also takes place during remedial action, time is being subdivided in time before the remedial action $t_{before}$, time during remedial action $t_{during}$, and time after remedial action $t_{after}$ (see Figure 6). The reason why the time before the remediation is considered is that some techniques have an immediate impact, while others show a delayed effect. Hence:

$$r_i = r_{i,before} + r_{i,during} + r_{i,after}$$

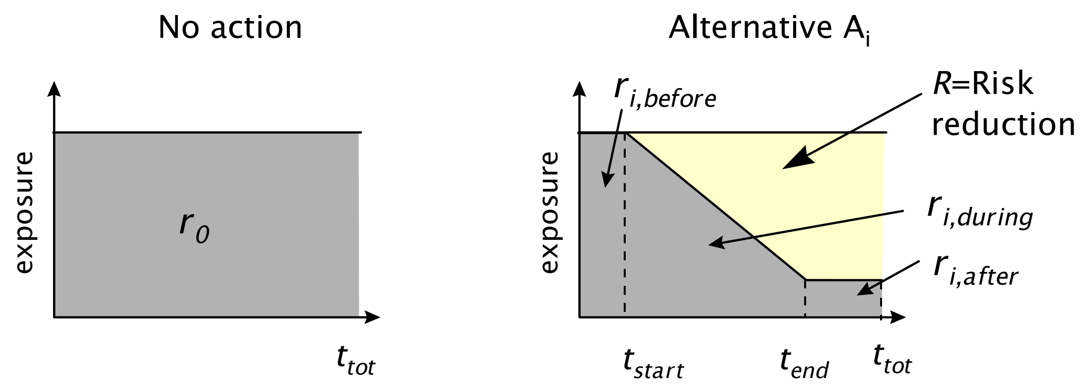



Fig. 6. Example of calculation of risk reduction for alternative $A_i$.

The alternative with the highest final score will result in the highest Risk reduction *R*. An example for calculating the risk reduction is given below.

**Computing Risk reduction for the example case**

The main exposure scenarios were selected. Since a dwelling and a shop are situated on the site these scenarios are living and working. Ecological and other risks are not decisive, because the site covers only a very small area. The number of humans exposed was chosen to be 1, since this number is the same for all alternatives (see Section 7.1). Finally, for all three alternatives, the duration of the various phases of the remediation project were determined. With these inputs CSOIL calculations yielded the results summarised in Table 4.

Table 4. CSOIL results for the calculation of Risk reduction.

| Alternatives | zero (doing nothing) | MF alternative | ICM alternative | In Situ alternative |
|---|---|---|---|---|
| Exposure scenarios (total risk): | | | | |
| - Shop | 149 | 2.5 | 59 | 7.4 |
| - Dwelling | 1,131 | 18.8 | 452 | 56.4 |
| Total risk | 1,280 | 21.3 | 512 | 64 |
| Risk reduction | 0 | 1,259 | 768 | 1,216 |

For the MF alternative and In Situ alternative, the Risk reduction is comparable; the difference is the result of the duration of the remediation project rather than the final concentrations attained.

## 2.3 Some comments on Risk reduction

To quantify exposure, a Risk Index can be calculated based on little detailed information by using fixed exposure parameters and the existing physicochemical models that predict the behaviour of substances in the environment. Because models enable the prediction of future situations, risk reduction can be assessed only by using these models. For example, exposure models like CSOIL are the most suitable for assessing the risk reduction. These models are conservative - they are based on worst scenario assumptions - and not very site-specific. However, this has no significant effect on the result, because the REC methodology compares alternatives only in relation to each other.

The operationalisation of the assessment of risk reduction for the users of a site can be simplified by assessing the risk based on lifelong exposure and by subdividing the site into relevant sections. Additionally, the method can be drastically simplified by using scenarios (for dwellings, factories, natural areas etc.) with a formalised number of users.

A specific assessment of ecosystem risks can be made operational by making a generic assessment using the ETX method (see Section 7.2), which is simple and provides sufficient power of discernment.

A risk assessment based on the probability that a serious hazard will occur can be made within the same conceptual framework as that used for the assessment of risks of exposure posed to humans and the ecosystem. In addition to the risk of incidents, other objects and risks can be assessed. For example, the operationalisation of the calculation of the exposure of remedial workers can be assessed by using such models as SOILDIG. However, because occupational health regulations impose exposure limits, this criterion provides little additional information. Therefore, an assessment of the exposure of remedial workers will only in exceptional cases yield different results for the various remedial alternatives. However, if necessary, an assessment of such risks can supplement the system, so that the desired power of discernment can be attained.

In the REC methodology, standardisation for various substances occurs by using the risk index (*RI*): the ratio between exposure and the toxicological limit value.

The R in REC is based on a simple and straightforward model. Nevertheless, it provides sufficient information to distinguish between alternatives and highlight their differences in terms of risk reduction.

CHAPTER 3

# ENVIRONMENTAL MERIT

## 3.1 The framework for Environmental merit

This chapter details the methodology developed for calculating the Environmental merit index. As shown in Figure 3, Environmental merit accounts for several aspects simultaneously. Unlike risks and costs, Environmental merit is designed to aggregate several types of environmental costs and benefits into an index, which shows the overall environmental balance of a soil remediation (beyond the indications provided by Risk reduction).

The aspects which are included in Environmental merit are based on the indications of a Life Cycle Analysis (LCA) carried out for soil remediation (cf. Appendix A) and on interviews with soil experts [cf. CUR/NOBIS, 1996]. Table 5 shows the final list used in E for REC. A detailed description of the rationale behind each aspect in the list is provided in Chapter 8, where also the steps necessary to compute these quantities are illustrated.

Since a number of different aspects are involved in the determination of the Environment merit performance of an alternative, the need for weighing the contribution of each aspect is evident. A panel of environmental experts has been interviewed for this purpose and their weights have been used for computing the E of REC.

Table 5. Aspects of Environmental merit in the REC methodology.

| REC aspects | Perspectives |
|---|---|
| **Positive aspects** | |
| clean soil as a result of remediation | maximise the stock of clean soil |
| clean groundwater as a result of remediation | maximise the stock of clean groundwater |
| prevention of future groundwater contamination | prevent (spreading of) groundwater contamination |
| **Negative aspects** | |
| clean soil use | minimise depletion of clean soil |
| clean groundwater use | minimise depletion of clean groundwater |
| energy consumption | minimise depletion of energy sources |
| surface water pollution | minimise eutrophication, non-local ecotoxicity |
| air pollution | minimise greenhouse effect, acidification, smog formation, eutrophication |
| final waste | minimise non-local aquatic and terrestrial ecotoxicity, space use. |
| space use by remediation project | reduce adverse effects of economic activities carried out elsewhere |

## 3.2 Quantification of Environmental merit

The simplest way to explain the functioning of the Environmental merit index is through an analogy with temperature measurement. To measure the temperature of an object, for instance, two elements are needed: a *temperature scale* and a *measurement operation.* The scale provides the interpretation of temperature (high, low, etc.), while the measurement operation is the method by which a temperature is associated to an object. The linear temperature scale is specified when two end points are known. The Celsius scale, for instance, is completely specified by defining the 0 °C point (which corresponds to the freezing temperature) and the 100 °C point (which corresponds to the boiling temperature). However, there are other possible choices, which lead for instance to the Fahrenheit scale or to the Kelvin scale. The measurement operation, which associates a temperature to an object, is very simple in this case. It simply requires to put the object and the thermometer close to each other.

The Environmental merit model works exactly in the same way. To specify the Environmental merit of an option it is necessary to define an environmental merit scale and then an operation which associates a merit score to each clean-up alternative. Unlike in the temperature case, fixing the scale and measuring environmental merit requires some more complex operations. The reason is that measuring temperature means evaluating a single variable, while environmental merit depends on several variables (energy use, soil quality increase, air emissions, etc.). Intuitively, this implies some sort of weighting scheme between scales defined for each variable taken separately. In spite of this complication, the principle remains exactly the same.

The E index (Environmental merit index) is computed with the so-called *value functions method* [Beinat, 1997] which comprises 6 steps:

1. Quantification of all aspects included under environmental merit. The results are organised in the so-called performance table.
2. Selection of two reference or anchor points for each aspect (these play the role of the 0 and 100 levels in the temperature scale).
3. Assessment of a value function for each aspect.
4. Conversion of the performance table into standardised scores by means of the value functions.
5. Assessment of the weight of each aspect.
6. Calculation of the weighted sum of the standardised scores. This results in the E index.

Figure 7 shows the results of steps 1 to 4 for the aspect 'Clean soil as a result of the remediation'. The performance of an alternative with respect to each aspect can be ranked on a thermometer-like scale. The scores for the other aspects can be visualised in the same way. The steps 5 and 6 are needed to add up all these scores in order to obtain the full Environmental merit index.

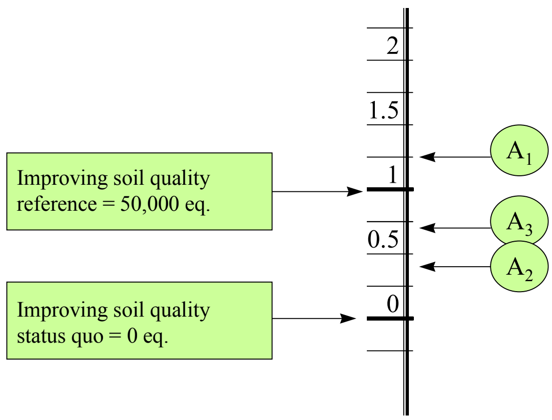



Fig. 7. Thermometer' scale for one of the aspects in Environmental merit. All alternatives ($A_1$, $A_2$, and $A_3$) can be placed on a scale which is determined by two reference points (0 and 50,000 equivalents in this case).

**Step 1** (quantification of all aspects) is detailed in the Sections 8.2 and 8.3. In this step, all ten environmental aspects are operationalised and quantified. The result is a *performance table* (see Table 6), which shows the scores for each aspect for all alternatives considered. The methodology employed in the other steps are elaborated below.

Table 6. Performance table for three remedial alternatives in the example case: MF, ICM and In Situ.

| **Positive aspects** | unit | MF | ICM | In Situ |
|---|---|---|---|---|
| clean soil as a result of remediation | (×1,000) $G_{eq}$ | 990 | 0 | 378 |
| clean groundwater as a result of remediation | (×1,000) $W_{eq}$ | 526 | 227 | 527 |
| prevention of groundwater contamination | (×1,000) $T_{eq}$ | 0.62 | 0.62 | 0.62 |
| **Negative aspects** | | | | |
| loss of soil | $m^3$ | 189 | 0 | 25 |
| loss of groundwater | (×1,000) $m^3$ | 1,600 | 1,344 | 1,800 |
| energy consumption | GJ | 5,822 | 2,091 | 3,141 |
| air emissions | pop. eq. | 85 | 31 | 46 |
| emissions into surface water | (×1,000) $O_{eq}$ | 0 | 0 | 0 |
| final waste | $m^3$ | 650 | 0 | 25 |
| space use | $m^2$.year | 501 | 900 | 300 |

**Step 2: Assessment of anchor points**

Anchor points serve as reference points for the assessment of the evaluation functions. For REC, the following two anchor points were chosen:

1. Zero is equal to leaving the situation unchanged. In this status quo, neither costs nor benefits will result from an operation, simply because no remedial operation is carried out. This does not mean, however, that the situation is desirable, because the REC methodology is applied after it is found that a remediation project should be carried out. Moreover, future groundwater contamination is not prevented.
2. A reference performance level. This value is determined for each aspect based on current remediation practice and is therefore related to the currently employed techniques. The reference performance level corresponds with an artificial, 'average' remediation project. See Appendix B.

The reference case is what a group of soil remediation experts considered to be an 'average' soil remediation case in current soil remediation practice. The status quo and the reference profiles are shown in Table 7. The definition of the reference score and the assumptions on which it is based are discussed in Appendix B.

Table 7. Status-quo values and reference levels for all aspects. The volume of contaminated soil for the reference case is 5,000 $m^3$, and that of contaminated groundwater is 20,000 $m^3$. The measurement units are explained in Section 8.2.

| **Positive aspects** | unit | Status quo | Reference |
|---|---|---|---|
| clean soil as a result of remediation | (×1,000) $G_{eq}$ | 0 | 50 |
| clean groundwater as a result of remediation | (×1,000) $W_{eq}$ | 0 | 800 |
| prevention of groundwater contamination | (×1,000) $T_{eq}$ | 0 | 800 |
| **Negative aspects** | | | |
| loss of soil | $m^3$ | 0 | 460 |
| loss of groundwater | (×1,000) $m^3$ | 0 | 1,600 |
| energy consumption | GJ | 0 | 4,100 |
| air emissions | pop. eq. | 0 | 60 |
| emissions into surface water | (×1,000) $O_{eq}$ | 0 | 700 |
| final waste | $m^3$ | 0 | 300 |
| space use | $m^2$×year | 0 | 3,000 |

**Step 3. Value function assessment**
In order to compare aspects, they need to be standardised first. This is done based on the anchor points established in step 2. In Figure 8, two examples of the functions used for standardisation are shown. These functions are called *value functions* and in this application are all linear functions. The assumption of linearity can be justified as follows. For each aspect, the change made by a single remediation project on a global scale would be marginal. For example, the quantity of soil released during a remediation project is only a minute fraction of the total soil supply available. In other words, we are dealing with a few drops in the sea: the effect of adding two drops is twice as high as that of adding one, etc. This leads to the linearity assumption.

The situation would of course be much different if, for example, the groundwater consumption would be of the same order of magnitude as the entire groundwater supply available in the region concerned (see Section 8.1). In that case, the evaluation function would not be linear and should take into account that, after a certain point, groundwater consumption would approach a severe depletion of the available stock.

The standardised functions were constructed in such a manner that:

1. Positive aspects always have a value above 0. Scores higher than 1 indicate that the performance is better than the reference level, and scores between 0 and 1 lie between the status quo and the reference level.
2. Negative aspects always have a value below 0. Scores between 0 and -1 lie between the status quo (= 0) and the reference level (= -1). Lower than -1 means that a contribution to environmental merit is more negative than that associated with the reference level.

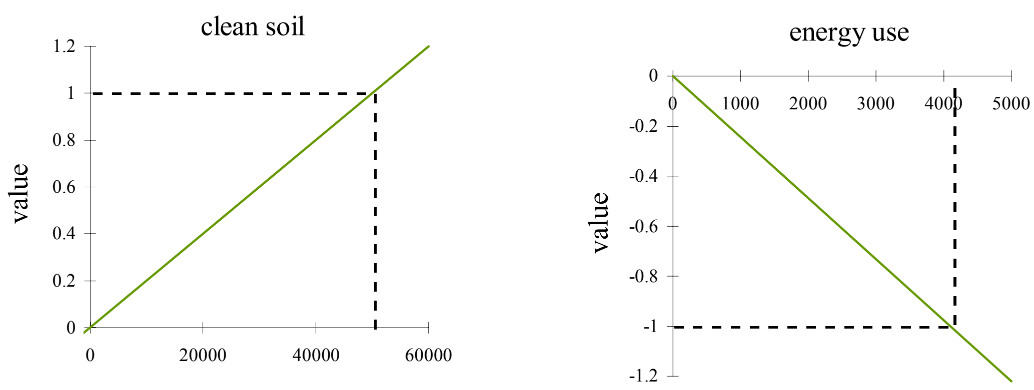



Fig. 8. Examples of the (linear) evaluation functions.

**Step 4. Conversion of scores given in the performance table into standardised scores**
Using the value functions, each score given in the performance table (see Table 6) is converted into a standardised score as shown in Figure 8. This results in a normalised performance table (see Table 8).

Table 8. Normalised performance table for the example case. As an example, the score 19.80 of the alternative MF on the aspect 'clean soil as a result of remediation' means that the total amount of clean soil produced by MF is 19.80 times that produced by the reference case.

| **Positive aspects** | unit | MF | ICM | In Situ |
|---|---|---|---|---|
| clean soil as a result of remediation | (×1,000) $G_{eq}$ | 19.80 | 0 | 7.55 |
| clean groundwater as a result of remediation | (×1,000) $W_{eq}$ | 0.66 | 0.28 | 0.66 |
| prevention of groundwater contamination | (×1,000) $T_{eq}$ | 0.001 | 0.001 | 0.001 |
| **Negative aspects** | | | | |
| loss of soil | $m^3$ | -0.41 | 0 | -0.05 |
| loss of groundwater | (×1,000) $m^3$ | -1.0 | -0.84 | -1.13 |
| energy consumption | GJ | -1.42 | -0.51 | -0.77 |
| air emissions | pop. eq. | -1.42 | -0.51 | -0.77 |
| emissions into surface water | (×1,000) $O_{eq}$ | 0 | 0 | 0 |
| final waste | $m^3$ | -2.17 | 0 | -0.08 |
| space use | $m^2$.year | -0.17 | -0.30 | -0.10 |

A brief analysis shows:

1. MF and In Situ score high especially for clean soil;
2. ICM does not result in loss of soil;
3. The three alternatives do not result in surface water pollution;
4. Relatively little final waste is produced as a result of alternatives ICM and In Situ.

**Step 5. Assessing the weights**

To establish the weights for each aspect, eight environmental or soil experts were interviewed according to a *swing pairwise comparison method* [Beinat, 1997]. As expressed in its name, this method compares aspects in pairs. Systematic comparison of all aspects enables the calculation of weights, if the comparisons are sufficiently consistent.

The questions posed to the interviewed experts were always twofold. The first part of each question concerned preference, the second part the degree of preference. We always asked them to answer the questions from an environmental viewpoint, meaning that costs and risks had to be left out of consideration. For each question, the comparison started with the status quo. For example:

> *Would you prefer to prevent the loss of 460 $m^3$ of soil or to prevent 300 $m^3$ of final waste being formed ?*

If the expert preferred to prevent the loss of 460 $m^3$ of soil, he was asked:

> *If the quantity of final waste prevented from being formed were multiplied by x, would you still prefer to prevent the loss of 460 $m^3$ of soil?*

This question was repeated until for *x* a value was established at which the chosen option was no longer preferred. The value of *x* is the relative weight for these two aspects. In principle, this is an exact method, but in practice the value of *x* is always rather uncertain. To increase its reliability, each aspect was compared with all other aspects, which results into a surplus of information.

By checking the coherence of all answers and averaging out inconsistencies, the reliability of the values for *x* can be strongly raised.

It is very important that the assessment of weights apply to the aspects *in connection with the values given in the reference case*. For example, the weight for energy consumption is not a universal weight of energy, but the relative weight of 4,100 GJ compared to the levels of all other aspects in the reference case.

Table 9 gives the weights established by the experts and the average weight for each aspect. It is evident that the weights are different for different experts. This variability is dealt with in Section 8.4. In Section 8.5 it is argued that, for the time being, it is plausible to use the geometrical average of all experts to obtain the environmental merit index.

Table 9. The weights established by experts 1-8.

| Expert | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | mean |
|---|---|---|---|---|---|---|---|---|---|
| clean soil as a result of remediation | 0.05 | 0.29 | 0.09 | 0.08 | 0.04 | 0.18 | 0.12 | 0.03 | 0.11 |
| clean groundwater | 0.06 | 0.07 | 0.16 | 0.14 | 0.11 | 0.06 | 0.02 | 0.07 | 0.08 |
| prevention of groundwater contamination | 0.13 | 0.06 | 0.26 | 0.33 | 0.30 | 0.06 | 0.08 | 0.26 | 0.19 |
| loss of soil | 0.18 | 0.20 | 0.07 | 0.05 | 0.04 | 0.06 | 0.10 | 0.03 | 0.09 |
| loss of groundwater | 0.18 | 0.11 | 0.10 | 0.22 | 0.32 | 0.18 | 0.15 | 0.23 | 0.19 |
| energy consumption | 0.12 | 0.08 | 0.00 | 0.01 | 0.01 | 0.01 | 0.19 | 0.08 | 0.06 |
| air emissions | 0.11 | 0.07 | 0.04 | 0.01 | 0.02 | 0.04 | 0.04 | 0.07 | 0.05 |
| emissions into surface water | 0.12 | 0.06 | 0.17 | 0.09 | 0.11 | 0.16 | 0.07 | 0.13 | 0.11 |
| final waste | 0.03 | 0.04 | 0.06 | 0.06 | 0.05 | 0.12 | 0.13 | 0.10 | 0.07 |
| space use | 0.02 | 0.00 | 0.05 | 0.01 | 0.00 | 0.13 | 0.10 | 0.01 | 0.04 |

**Step 6. Calculation of the total Environmental merit score**

The E index for each alternative is calculated based on the weighted sum of the standardised scores:

$$E(A_i) = \sum_{j=1}^{10} w_j N(x_{ij}) \quad 1$$

where:

- $A_i$ is the $i^{th}$ alternative;
- $x_{ij}$ is the performance of alternative $A_i$ regarding aspect *j*;
- *N(x)* is the standardised performance of alternative $A_i$ regarding aspect *j*;
- $w_j$ is the weight of aspect *j.*

Table 10 shows the environmental merit score for the three alternatives of the example case. The weights used are the average weights established by the eight experts in the panel.

Table 10. Total score for the alternatives in the example case ($w_jN(x_{ij})$). The weights used are the average weights established by all eight experts.

| Positive aspects | weight | MF | ICM | In Situ |
|---|---|---|---|---|
| clean soil as a result of remediation | 0.11 | 2.18 | 0 | 0.83 |
| clean groundwater as a result of remediation | 0.08 | 0.06 | 0.02 | 0.06 |
| prevention of groundwater contamination | 0.19 | 0.00 | 0.00 | 0.00 |
| **Negative aspects** | | | | |
| loss of soil | 0.09 | -0.04 | 0 | 0.00 |
| loss of groundwater | 0.19 | -0.19 | -0.16 | -0.21 |
| energy consumption | 0.06 | -0.09 | -0.03 | -0.05 |
| air emissions | 0.05 | -0.07 | -0.03 | -0.04 |
| emissions into surface water | 0.11 | 0 | 0 | 0 |
| final waste | 0.07 | -0.16 | 0 | -0.01 |
| space use | 0.04 | -0.01 | -0.01 | 0.00 |
| **M-index (sum)** | | 1.68 | -0.20 | 0.57 |

In the example case, the multifunctional alternative (MF) has the highest score for environmental merit based on the set of weights selected. This is mainly because of the high quantity of treated soil. The In Situ alternative would consume less energy, produce less waste and emit less air pollution, but would result in too little clean soil to compete with the MF alternative. From the viewpoint of environmental merit, the ICM alternative would result in a negative contribution, that is it offers very limited benefits but shows significant costs (especially in terms of loss of groundwater).

### 3.3 Some comments on Environmental merit

This chapter explained and justified the methodology for calculating the environmental merit index. Although a very simple methodology, it has proven very effective in highlighting the pros and cons of remedial alternatives in a simple and direct way. There are several open issues, however.

The sensitivity for the weights - which are different for different experts - and the uncertainty linked to the inputs used in Environmental merit require special attention. Yet, it was found that in the example case and in four other cases for which Environmental merit was first tested, the sequence of the possible alternatives regarding the environmental merit index is rather stable. This means that, based on the individual set of weights of each expert, in nearly all cases *the same* alternative comes out best for Environmental merit, independent of the differences in the weights sets. Therefore, the average of the weights established by the experts was chosen as the preferential value for calculating the environmental merit index.

The weights are a critical point in Environmental merit. They should represent at a policy perspective on the quality of the environment which is independent of the specific interests of a single remediation project. For this purpose, the experts interviewed in REC included responsible of environmental policy at the level of the Netherlands Ministry of Environment, at the level of the Dutch Provinces and of large city councils.

Since the experts were interviewed on the basis of a reference case, not directly linked to a real clean-up situation, it was of interest to verify if the opinions of public authorities coincided with the opinion of environmental experts employed by private companies. For this purpose, experts from large Dutch multinationals were also interviewed. The results, fortunately, do not show any particular correlation. That is, there no such a thing as a patterns of responses from the private sector and a pattern of responses from the public sector.

What emerged, instead, was a pattern of responses which depended on regional differentiation. Since each experts was free to choose the reference environmental conditions for the assessment (for instance, areas where groundwater was scarce, or urban areas where space was scarce and so on), the results show quite a coherent set of responses which depend on the perspective chosen. For instance, experts who focused on areas where groundwater is a relevant issue provided similar weights and tended to form a natural cluster of responses. The implication is that, the interviewed carried out in REC so far should be improved by first highlighting a set of reference environmental conditions and then by systematically interviewing experts on the basis of these conditions.

CHAPTER 4

# COSTS

## 4.1 The framework for Costs

When a soil contamination needs to be cleaned up, a number of remedial alternatives are designed, and the total expected costs per alternative needs to be estimated. These costs are an important factor in the final selection of a alternative. Costs are incurred at all stages of the remediation and range from design costs, to recurring costs, such as maintenance and reparations, overheads etc. The objectives of the costs model in REC are:

1. To develop a cost classification and a cost estimation system which includes all costs at all stages of the remediation;
2. To design a cost weighing scheme which allows the inclusion of the time value of money and of uncertainties in the cost estimates.

The cost classification system of REC is largely based on the costs classification system of the Soil Protection Guidelines [1997] in the Netherlands. Other classification schemes are available for the same purpose, but the one chosen satisfies the REC requirements to the largest extent. The choice of this scheme was based on several aspects. As a first step, a number of preconditions were formulated which an adequate cost classification system for REC should meet (see Chapter 9). Next, a number of existing classification methods were compared with these preconditions. A specific REC classification system would have been developed only if none of the existing classification systems had been found suitable. Fortunately, the Soil Protection Guideline agreed for the most part with the preconditions formulated. This system was then adapted as far as some details are concerned.

### 4.1.1 *Classification system of the Soil Protection Guidelines*

The Dutch Soil Protection Guidelines contain a survey of costs items (*Overzicht kostenposten*) which could be used as a standard cost classification method for REC purposes. Most consultant firms apply specifications based on this table, even though the problem holder usually does not demand the use of this system. Following the above guidelines, however, has also the advantage that most (Dutch) users are familiar with the classification system, facilitating understanding and acceptation of this part of the REC methodology.

The system distinguishes the following cost categories:

A. Initial costs — The Guidelines define initial costs as those costs not included in the recurring costs or costs of replacement or repair. It concerns mainly expenses to be incurred before and during the initial phase of a remediation project.

B. Recurring or operational costs — Recurring costs comprise the costs to be incurred during a remediation project (excluding costs of replacement), which means that they comprise such operational costs as maintenance costs, costs of the renting of installations, and costs of energy consumption.

C. Costs of replacement — Costs of replacement are those costs that have to be incurred after some time in order to replace entire (or large parts of) installations or facilities.

| | |
|---|---|
| D. Overheads | Overheads are the sum of the operating and general costs, profit, and the risk surcharge to be paid to the contractor. The total contracting costs comprise the costs of facility maintenance and the initial costs (excluding project preparation, processing costs, management, environmental supervision, and secondary costs). |
| E. Other costs | Other costs comprise only the payment of compensation to third parties. |

For each item, a non-exhaustive description is given of actions that may fall under it. A summary of the table is included in Appendix C

#### 4.1.2 *The REC classification scheme*

The following classification scheme is based on the Guideline specifications and includes some adaptations (the items are explained in more detail in Chapter 9).

| Cost category | Cost items |
|---|---|
| A. Initial costs | A.1. Project preparation<br>A.2. Preparatory work<br>A.3. Demolition<br>A.4. Costs of land redevelopment<br>A.5. Ground work<br>A.6. Costs of processing<br>A.7. Withdrawal and treatment plant<br>A.7a. Withdrawal installation for groundwater remediation<br>A.7b. Withdrawal installation for in situ remediation<br>A.7c. Treatment installation<br>A.8. Screening constructions<br>A.9. Monitoring system<br>A.10. Management and environmental supervision<br>A.11. Secondary costs |
| B. Recurring or operational costs | B.1. Facility maintenance<br>B.2. Secondary costs<br>B.3. Aftercare |
| C. Costs of replacement | C.1. Screening constructions<br>C.2. Withdrawal and treatment installation |
| D. Overheads | |
| E. Other costs | E.1. Compensation<br>E.2. Loss of capital and production |

### 4.2 **Quantification of Costs**

Uncertainties are always present in cost estimates and different alternatives show different uncertainty levels. Taking them into account is a precondition for obtaining reliable and robust cost estimates, and for correct evaluations. A model which allows to quantify the accuracy of the cost estimate made for each alternative was therefore developed. In addition, the time value of money should be taken into account, which allows the comparison of costs incurred at different times during the remediation. The conditions under which the weighing model is developed are explained in detail in Chapter 9.

**Uncertainty about costs**

Many factors are responsible for uncertainty in costs estimates. Examples include:

- the volume of contaminated soil;
- the degree to which the soil is contaminated;
- the accuracy of the geohydrological model used to describe soil features;
- the effectiveness of the remediation technology applied.

Regarding uncertainties in cost estimates, a distinction can be made between so-called *normal* uncertainties and *uncertain events.* These categories can be dealt with differently.

Normal uncertainties are uncertainties in the estimation of quantities, costs, and the duration of the remediation project. For example, if contaminated soil should be excavated, it is often uncertain how much should be excavated and then treated or dumped. The costs of processing the (not exactly known) quantity of soil to be excavated may greatly vary. It is, however, certain that excavation and treatment costs will have to be incurred.

Uncertain events may strongly affect the costs of the entire project, but this is not always likely to happen. Contrary to normal uncertainties, a special event will therefore not necessarily occur. For example, (in a hypothetical case) an in situ remediation project carried out for several years does not yield the desired result. This implies that the soil still needs to be excavated afterwards, modifying the costs of the operations radically (the quantitative effect of an uncertain event may in turn be composed of normal uncertainties).

At present, the REC methodology takes into account only normal uncertainties. Items of the classification system that are highly sensitive to uncertainties and may result in relatively great differences between the estimated and actual costs are:

A.5. Ground work (because of uncertainty about the quantity of soil);
A.6. Processing costs (because of uncertainty about the quantity of soil and the processing rate);
B.1. The maintenance of facilities (because of uncertainty about the duration of the remediation project).

However, it is relatively easy to quantify uncertainties by employing the method detailed in the following section. This means that for all relevant items the uncertainty about their costs can be included in the weighing scheme.

**Quantification of uncertainties**

The uncertainty about the costs of a remedial alternative can be presented as an expectation of the costs with a standard deviation. If the distribution of probability of the costs is known, the expected costs and their variance are easily calculated. In the simplest case, when the distribution is the most common normal distribution, this is shown in Figure 9.

In this simple case, it is easy to account for uncertainty. For instance, if we want to be sure that the real costs will have only a limited probability of being exceeded we can introduce a safety factor *k.* The estimated costs will then be:

$$c = ec + k\,\sigma$$

When $k = 1$, the estimated costs will have only 16 % probability of being exceeded by the real costs. Other values of $k$ will lead to higher or lower degrees of confidence in the cost estimates.

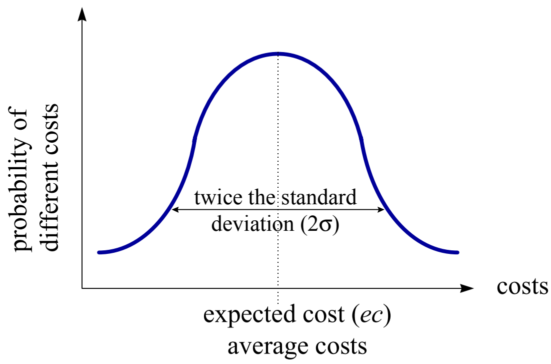



Fig. 9. Expected costs and their variance for a normal distribution of costs.

An important problem in the case of remediation investigations is that insufficient data are available to calculate these two parameters accurately and reliably. However, for the quantification of normal uncertainties, the triangular probability density function can be used. This method is highly suitable for the analysis of situations with a limited number of data. In this case the probability distribution of costs is determined by a most probable value (W), a lowest value (L) and a highest value (H). The lowest value (L) is the cost estimate applying if everything turns out better than expected. The highest value (H) is the cost estimate applying if everything turns out worse than expected. In this way, the lower limit (L) and upper limit (H) of the estimate are fixed. The probability density can be represented as a triangle with a surface area of 1. From this distribution an expectation and a standard deviation can be calculated following the procedure described in Chapter 9, assuming that all cost items are independent of each other (cf. Figure 10).

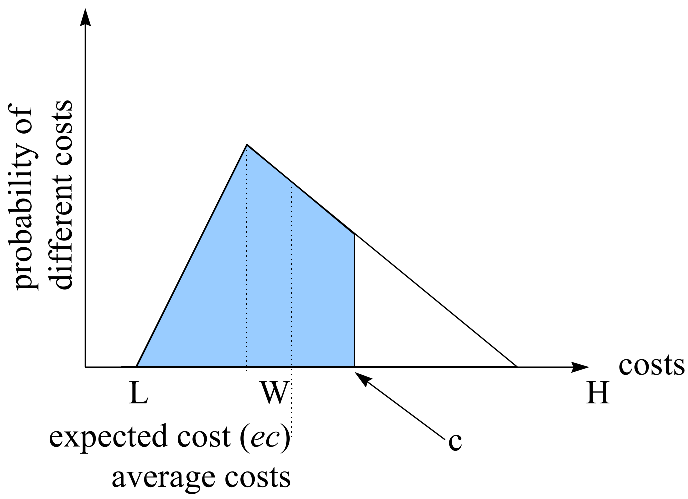



Fig. 10. Expected costs and their variance for a normal distribution of costs.

To guarantee that the real costs do not exceed the expected costs, again the variance of the costs estimates can be used. Since cost estimates are assumed to be included between the L and H value, the variance provides an indication of the uncertainty within these levels. The costs of each item to be included in REC, therefore, can be based on the expected costs and on a safety factor based on the variance of costs estimates. This will produce a cost higher that the expected one, but with a lower probability of being exceeded in practice.

As shown in Figure 10, the cost estimate can be computed as done before for the normal distribution. That is:

$$c = ec + k\,\sigma$$

In this case, i.e., with a triangular distribution, when $k = 1$, the estimated costs will have about 20 % probability of being exceeded by the real costs. However, if the total costs are the sum of many cost items, each one represented by a triangular distribution of probability, the total distribution approaches a normal distribution, and the analysis made for the normal distribution becomes valid again.

This approach assumes that all cost items are independent, which inevitably leads to an approximation. For example, the assumption is that there is no correlation between costs of demolition and costs of soil processing. However, there is probably a correlation between ground work and processing costs, because regarding both items there is an uncertainty about the total amount of contaminated soil. This type of correlation could be considered by using simulation models to compute costs. However, simulation models require specific techniques and software tools which are not widespread and not always available in practice. Therefore, this version of REC uses the 'analytical' method given above.

**Time-value of money**
Cost are incurred at different stages of the remediation. Therefore, the full picture of costs requires to plot costs on the time axis. Different alternatives usually show different time plots of costs. In some cases cost will be concentrated in the first period of the operations; in other cases costs will be spread almost throughout the entire period during which all remediation activities are carried out. Since the value of money changes in time, to compare the costs of different alternatives it is necessary to transform all costs into comparable quantities. The most common approach is that of computing the costs of each alternative as its Net Present Value (NPV). The NPV is an hypothetical cost which has to be incurred at the beginning of the operations and once for all. The NPV and the real stream of costs of a remediation alternative are, from the point of view of the problem holder, equivalent. Clearly, this involves some sort of interest rate, since the same sum of money now and in the future has a different value.

Therefore, to take into account the time-value of money, all costs are discounted and transformed into costs to be incurred at the beginning of the operations. These estimates are then comparable. Details of the calculation of the NPV can be found in Section 9.2.1.

The C part of REC is based on the following list of steps repeated for each alternatives:

1. For the costs of each item specified in the classification system, the lowest (L), most probable (W) and highest values (H) are estimated.
2. For the recurring costs and costs of replacement, estimates are located on the time axis. In the case of a phased remediation project, the initial costs for each phase are also plotted on the time axis.
3. All costs are discounted, so that they correspond to the value of money at the moment of decision.
4. The average and the standard deviation of the total estimate are determined using the method detailed above. This produces the Expected Costs of alternative $A_i$ ($EC_i$) and its standard deviation ($\sigma_i$).

As explained before, the cost estimate is based on Expected Costs and standard deviation. The following score is then calculated for each alternative and represents the *C* estimate in REC:

$$C_i = EC_i + k\,\sigma_i$$

where:

- $C_i$ is the estimated cost of alternative $A_i$;
- $k$ is a function of the required confidence;
- $\sigma$ is the standard deviation of the expected costs.

For example, let us assume that the expectation of the estimate equals 10 million and the standard deviation 2 million. Then, there is a probability of 16 % that a score of 10 + 2 = 12 million ($k$ = 1!) will be exceeded (assuming a normal distribution of costs).

Of all alternatives, the alternative with the lowest score is of course preferable. The classification system was applied to all three alternatives. Based on a discount rate of 5 % and $k$ = 1 (a margin of error of 16 %), this yields the following results for the three alternatives (see Table 11):

Table 11. Results regarding the cost aspect of the example case.

| | MF alternative | ICM alternative | In Situ alternative |
|---|---|---|---|
| Average discounted costs (in Dfl. 1000.=) | 7,600 | 2,000 | 2,600 |
| Standard deviation (in Dfl. 1000.=) | 400 | 200 | 300 |
| **Total** | 8,000 | 2,200 | 2,900 |

## 4.3 Some comments on Costs

The table Survey of Cost Items given in the Soil Protection Guideline can be used as part of the REC methodology to classify costs. To be able to take into account loss of capital and production when weighing the various alternatives, a separate item for this should be added to the classification system given in the Guidelines.

In addition to the main subdivision into initial costs, maintenance costs and costs of replacement, the classification system given in the Guidelines includes a number of secondary items. If a cost estimate is made in conformity with this classification system, it is relatively easy to derive other relevant subdivisions. Examples of such subdivisions are: costs of execution versus other costs; remediation costs versus other costs; and a subdivision showing who incurred which costs (consultant/contractor/own company).

Finally, the classification system given in the Guidelines has the advantage that the users in the Netherlands are experienced in using it.
The weighing model satisfies the requirement that both the time value of money and the uncertainty about costs can be included in the weighing of remedial alternatives. The decision maker can weigh time costs (i.e. weigh between investment and recurring costs) by means of the discount rate, and control the risk of wrong cost estimates by means of factor *k*.

However, the determination of low and high estimates for each cost item is to some degree subjective. This makes questionable the principle that it must be possible to univocally determine the costs within certain margins. On the other hand, the accuracy of the expected costs depends to a high degree on the knowledge and experience of the person formulating the remediation investigation. The process also involves a certain amount of subjectivity.

CHAPTER 5

# DECISION-MAKING WITH REC

## 5.1 Assessment based on R, E and C indices

While the above chapters discussed the method developed for calculating the R, E and C indices, this chapter examines the possibilities for selecting a certain set of remedial alternatives based on REC results. It can therefore help incorporate REC into the decision-making process. It should be noted that there is no fixed approach in this regard; the approach followed depends on the decision context and the actors involved.

The selection of a remedial alternative is a multiobjective problem. Ideally, the alternative selected is that which maximises Risk reduction and Environmental merit and minimises Costs. However, in practice such an alternative is rare, and therefore the final selection is usually based on weighing the advantages and disadvantages of each remedial alternative.

The REC methodology yields the information required for such a weighing. The indices for R, E and C:

- Indicate the main consequences of remedial operations in a simple, direct manner;
- Introduce a structure to the decision-making process;
- Clarify the situation for the decision-makers and therefore make it easier for them to decide.

Figure 11 show a typical example of the output of the R, E and C models, again referred to the example case.

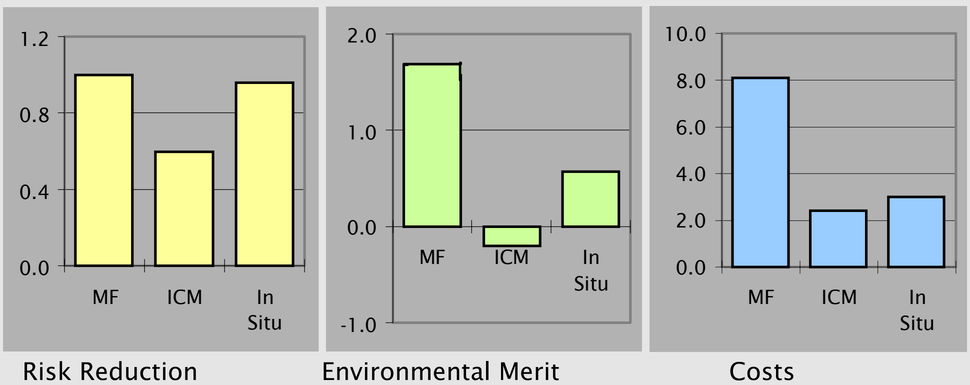



Fig. 11. The indices for R, E (both dimensionless) and C (in millions of guilders) in the example case.

In this example, the indices for Risk reduction show that in this respect the multifunctional alternative (MF) has the highest score, followed by the In Situ alternative and then the ICM alternative, which clearly has a lower score. The MF alternative has the highest score too for Environmental merit, whereas the In Situ alternative has a much lower score in this respect, and the ICM alternative has even a negative score, which means that the environmental merit score for the ICM alternative is lower than the status quo.

In summary, in this example the MF alternative is the best option as regards Risk reduction and Environmental merit. However, the costs of this alternative are higher than those of the other two alternatives: the In Situ alternative is less expensive and the ICM alternative is cheapest. These considerations are summarised in Table 12.

Table 12. Qualitative description of the final results of applying the REC methodology to the example case.

| | Risk reduction | Environmental merit | Costs |
|---|---|---|---|
| MF | Best result, a considerable risk reduction | Best result, much better than the status quo | Highest costs, approximately three times as expensive as the other alternatives |
| ICM | Worst results, but still a reasonable risk reduction | Worst result, worse than the status quo (doing nothing) | Cheapest alternative: a quarter of the costs of the MF alternative, and 10% less expensive than the In Situ alternative |
| In Situ | Second score, hardly worse than the MF alternative | Second best score, between MF and ICM, but much better than the status quo. | Second best score, much cheaper than the MF alternative and only slightly more expensive than the ICM alternative |

With regard to the example case, it remains to be seen which alternative is most suitable, because suitability depends on many issues. However, three considerations are especially important for understanding the role played by the REC methodology in the decision-making process, namely:

1. The degree to which the REC methodology covers the various relevant interests. For example, for certain decisions it may be important to include (in addition to the REC results) complaints received from local residents about noise nuisance. As a result, certain alternatives may become preferable over others.
2. The decision rule applied and therefore the relative importance of R, E and C. Examples of such decision rules are:
   - Select the alternative that results in the highest Risk reduction and Environmental merit and is cheaper than 10 million guilders. The MF alternative would then be selected.
   - Select the alternative that reduces the risks as efficiently as possible, i.e. the alternative with the highest possible ratio between Risk reduction and Costs, provided that the Environmental merit index is positive. The In Situ alternative would then be selected.
   - Select the cheapest alternative resulting in a considerable Risk reduction, irrespective of the value of the Environmental merit index. The ICM alternative would then be selected.
   - Select the alternative with the highest weighted sum for the three indices (Costs would then be ranked as negative). In the case of equal weights and suitable normalisation, the MF alternative would be selected.
3. The degree to which the assessment is the result of a formal analysis (e.g. the above decision rules) or a compromise reached after consultations held between the main actors involved in the decision process (e.g. the site owners and the authorities).

These considerations imply that the final quality of the remedial alternative in a certain decision context is a function of the R, E and C indices as well as other factors not associated with the REC methodology. This function may either be determined explicitly or will implicitly play a role in the consultations held between actors.

In formula:

$$Q(A_i) = f(R_i\,,\, E_i\,,\, C_i\,,\, Other\ factors)$$

where:

| | |
|---|---|
| $Q(A_i)$ | is the quality of alternative $A_i$; |
| $R_i$ | is the index for this alternative, |
| $E_i$ | is the E index for this alternative; |
| $C_i$ | is the C index for this alternative; |
| $f$ | is the decision rule applied implicitly or explicitly. |

## 5.2 Using REC to support the desicion

Based on the above, various approaches can be followed to take a decision based on REC results. These approaches are categorised in Table 13.

Table 13. The use of REC indices in the decision-making process.

| | The REC indices are is adequate for taking the decision | Other factors play a role in the decision-making process |
|---|---|---|
| The decision rule is explicitly known as a function of R, E and C | **Case (1)** The alternatives are assessed based on the decision rule and then arranged from suitable to unsuitable. | **Case (2)** The alternatives are assessed based on the decision rule and then ranked from suitable to unsuitable. The decision rule may comprise additional factors (e.g. noise nuisance), or such factors may play a role as additional information next to the REC results. |
| The decision rule is not made explicit | **Case (3)** The assessment of the alternatives is based on the REC results, but the advantages and disadvantages of these alternatives are discussed between the decision-making parties during consultations. The decision is the result of negotiation and bargaining between decision players. | **Case (4)** The assessment of the alternatives is based on the REC results and other factors, but the advantages and disadvantages of these alternatives are discussed between the decision-making parties during consultations. The decision is the result of negotiation and bargaining between decision players. |

In practice, these four cases will, of course, be less different from each other than Table 13 seems to indicate. For example, sometimes part of the decision rule is made explicit (e.g. the maximisation of the cost-effectiveness regarding risk reduction), while other factors play a role during the consultations (e.g. environmental merit). The selection of a proper approach can be made easier based on the following considerations:

*Case (1)*
In this case, the REC results are adequate for describing the consequences of a remediation project, and there is a clear wish to make the decision as open and explicit as possible.

As explained above, various decision rules may be used. The selection depends mainly on the decision context. For example, if the indices for R, E and C are regarded as independent indicators for the quality of the alternatives, it would be suitable to use the weighted sum between R, E and C. The indices for R, E and C would then have to be standardised to a scale so that they can be compared, and subsequently weights would have to be established.

The decision rule would then look like:

$$REC_i = W_R R_i + W_E E_i + W_C C_i$$

where:

$W_R$, $W_E$ and $W_C$ are the weights belonging to standardised R, E and C indices for alternative $A_i$.

Table 14 and Figure 12 show possible results for three different sets of weights. These weights belong to the REC values normalised on the basis of the highest value.

Table 14. Example of three sets of weights for R, E and C, and, for each set, the alternative with the highest total score.

| Example of sets of weights | $W_R$ | $W_E$ | $W_C$ | best alternative |
|---|---|---|---|---|
| (a) | 0.33 | 0.33 | 0.33 | MF |
| (b) | 0.20 | 0.30 | 0.50 | In Situ |
| (c) | 0.10 | 0 | 0.90 | ICM |

Table 14 contains the figures for the example case which correspond to Figure 12. In set (b), the In Situ alternative has the highest score, especially because here costs have a relatively high weight. The ICM alternative comes out best only if costs have an extremely high weight (set c).

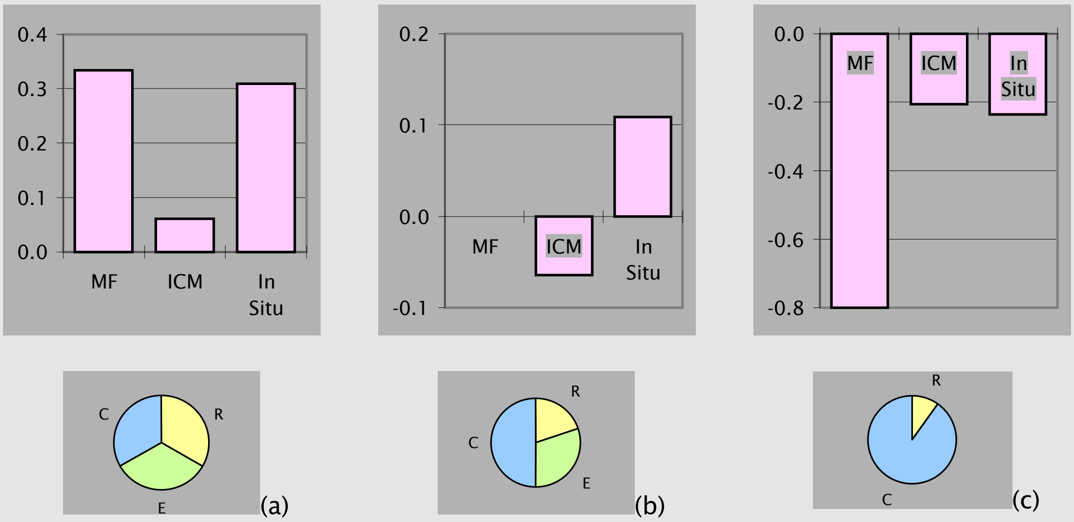



Fig. 12. Illustration of the 'formal' approach (1) for using REC during a decision process. The calculated Total index depends on the explicitly chosen sets of weights.

In this specific example, the differences between MF and In Situ for the weight set (a), and the differences between ICM and In Situ for the weight set (c) are very small. An uncertainty analysis could reveal whether these differences are significant.

*Case (2)*

Here the situation is similar to that associated with Case (1). The reason for following this approach will also be based on the wish to make the decision-making process as transparent as possible. If other factors beyond R, E and C are important for the decision they can be treated in a similar fashion and be explicitly included in the decision rule. However, the decision can be reached also by first considering the REC indications and then adding considerations based on additional factors. In the case of the set of weights (c) in the above example (see Figure 12), the In Situ alternative may be preferred over the ICM alternative based on local circumstances (because, for example, the former would cause less noise nuisance).

*Case (3)*
There may be good reasons for not using explicit decision rules, but to leave the decision-making to the consultation process which takes place between the actors. R, E and C supply the most important information, and the final decision is taken after the consultations. Typical situations in which it would not be desirable, or necessary, to use explicit decision rules are:

- The alternatives would yield greatly varying results for R, E and C: one or two clearly emerge from the full set. A formal assessment would then be unnecessary and the decision may simply focus on the choice between the few alternatives which dominate the others.
- The actors involved in the decision-making process approach the decision from different angles. It would then be hard to reach agreement about a univocal decision rule, and it would be more practical to directly commence consultations about the selection to be made.
- The actors greatly differ in opinion, and the situation would become even worse if a decision rule had to be chosen. Keeping the decision rule implicit leaves more room for consultations aimed at reaching a compromise.

*Case (4)*
This approach is highly similar to Case (3). The only difference is that additional factors play a role. The comments made as regards approach (3) apply here too. However, the consultation process would be more complicated due to the larger number of factors. On the other hand, more room can be left for consultations, for example by proposing that compensating measures be taken.

CHAPTER 6

# DISCUSSION AND CONCLUSIONS

## 6.1 Some lessons from the practical applications

The main element determining whether the REC methodology will be successful is whether it will be accepted in practice. To gain a deeper insight into this acceptation and the quality of the methodology, practical tests were carried out [Nijboer and Visser-Westerweele, 1997a-c].

Their results show that the methodology has a high validity, testability, clarity, reproducibility and power of discernment. Moreover, the methodology was found to be feasible and useful for consultants. The results also show that REC is a suitable decision-support system for the assessment of soil remediation alternatives. Case studies have shown that REC can be applied to many different situations and that it is a highly flexible methodology. This is clearly a positive outcome and demonstrates the practical usefulness of REC.

However, there are some considerations to be kept in mind when using REC. Although it has proven to be a flexible and widely applicable methodology, this does not mean that REC is a universal tool for all cases of soil remediation. In some, highly specific cases, other factors may play a role which is more important than the REC indices. The use of this methodology, therefore, requires knowledge of the remediation practice and the user of REC must be capable of distinguishing a special case from a general one, so that proper use of the REC methodology is guaranteed.

In general, the REC indices provide evidence on the most important effects of soil remediation. However, since the methodology considers only these aspects, its use may result in an underestimation of other criteria, such as disturbance, or noise hindrance. When criteria other than risk reduction, environmental merit and costs are considered very important for the selection of a remedial alternative, the system will have to be adapted in order to remain a decision-support system.

It is extremely problematic to develop a standard formula for taking decisions based on REC results. Although decisions are likely to be based on some form of synthesis between risk reduction, environmental merit and costs, the type of analysis to be employed depends very much on the decision context. Different actors (problem holder, competent authority, residents, etc.) hold different views and interests. This decision context may prescribe that certain decision rules be followed, for instance a rule that emphasises environmental performances in spite of the costs involved. However, in other contexts another approach may be more suitable. The contribution of REC does not reside in the automatisation of the decision, but rather on the ability to structure and organise information and to focus on few relevant issues. In this, the REC methodology may contribute to a common interest of all interested parties and to improve the effectiveness and efficiency of the decision.

During practical tests, it was always found that the results of the system were in line with the expectations of the experts which were involved in the remediation. This is an important conclusion. A Decision Support System is never supposed to impose a solution which is not perceived as valid or feasible by those using it. A DSS should bring about understanding and should serve to make the users more confident in the decision. If there is a strong, persistent and systematic disagreement between the indications of a DSS and the expectations of those using it, then the assumptions on which the DSS is built and those of the user do not coincide. In such a case the decision process may be further complicated instead of being made simpler and more effective.

## 6.2 Some comments on the development of REC

The choices made during the development of the REC methodology depended on the requirement that it must be possible to apply the methodology based on data obtained from a remediation investigation, as much as possible. The assumption was that a methodology that would require additional site investigations would have been rejected by the users for practical reasons. Additionally, an attempt was made to use as much as possible of the evaluation tools already available from the various disciplines related to R, E and C. This resulted in unbalanced starting-points: generally, large amounts of information are available about costs, while limited evidence is available about the aspects in Environmental merit.

When elaborating the criteria of R, E and C, the state of the art in the various fields was taken into account, with a special attention to the direct transferability of the developments to the everyday practice. This also means that the methodology requires maintenance, and that it should be updated to follow both the scientific developments and the evolution of the soil remediation practice.

To develop the risk reduction model it was decided to use exposure scenarios to characterise the site. This means that, first, various exposure scenarios applicable to the site concerned are considered and, second, the exposure is calculated within the scenario conditions. This can be done best by means of physicochemical exposure models, especially because future situations need to be assessed.

During the development of the Environmental merit model, the selection of aspects was an especially difficult step. Partly in order to maintain a clear distinction between Environmental merit and Risk reduction, it was decided to employ a method other than a life cycle analysis (LCA), although the various inputs and outputs of the remediation process can be listed in a similar way. This approach resulted in a method for calculating the environmental merit index that is better geared to the remedial practice and can be clearly distinguished from that employed for calculating the Risk reduction index. In addition, this method includes positive aspects, contrary to a 'normal' LCA, and integrates the various aspects of Environmental merit. All this results in better possibilities for supporting the decision-making process compared to the use of an LCA.

To integrate the various aspects in Environmental merit, several experts were interviewed. Although this did not yield univocal results, a sensitivity analysis showed that this is not problematic. Although weights are dependent on the perspective of who assesses them, the variability detected in the panel of experts interviewed shows that this does prevent a clear decision strategy. In the cases analysed, different expert weights lead to the indication of the same best alternative, reducing substantially the potential effect of uncertainty.

When developing a method for assessing costs, the following two elements are important: a standardised classification system, and a weighing model. The classification system developed conforms to that of the Soil Protection Guidelines, which was found to be useful after some adaptations. During the development of a weighing model, it was decided to include uncertainties about various cost items by introducing three values (an expected, highest and lowest value) for various costs and possible different duration. Developments occurring over time (e.g. development of technology) are not taken into account.

## 6.3 Future developments and recommendations for the use of REC

REC outputs are only as good as the quality of the input which feed the system. Acceptance of the methodology may rapidly deteriorate if results are obtained and decisions are made on the basis of poor quality inputs. Although this is not REC's flaw, ensuring that the methodology is properly applied and that the inputs are coherent, tested and suitable for REC is a highly sensitive issue. Providing guidelines for data collection and data quality control will be one of the tasks for ensuring a proper REC use.

All pieces of information used in REC are uncertain, and uncertainty may jeopardise the results of an evaluation. This can be prevented by introducing sensitivity and uncertainty analyses. In the present version of REC, uncertainties are systematically included only for Costs. The reason is simply that a simple and effective way for estimating the extent and effect of costs uncertainty could be used. However, uncertainties may also be important in relation to R and E, and they should be included in the assessment of these criteria. The effect of such uncertainties can, in principle, be calculated using well known sensitivity analysis techniques [cf. Janssen and Van Herwijnen, 1994]. These calculations are based on specific algorithms and require ad hoc software tools. Since these tools are not generally available, and few of them are applicable to a spreadsheet environment, a decision was made to include them only as a option. As a result, almost all the emphasis of REC for R and E is put on figures which are calculated on the basis of uncertain input. It is important to stress that although sensitivity analysis is not included as a default part of REC, carrying out a sensitivity and uncertainly analysis for R and E in particular is a prerequisite for making robust evaluations.

Related to this last point, before the REC methodology can be fully applied in practice and receive a full market recognition, it needs to be supplemented with software. In this, it is important to take into account the results of the definition study on computerisation and experiences gained in practice. In addition, the creation of a helpdesk function for methodological and technical support seems to be important, especially during the initial phase of the commercial distribution of the system.

To keep the REC methodology up to date and to provide a quality control for the use of the system, it is advisable to create a structure for this purpose. This structure would, in the first place, include experts and other actors which can provide continuous updates on the developments occurring in the field of soil remediation.

Finally, it is advisable to develop the REC also into another direction. REC, as it has been considered up to this point, is a decision support to decide among existing options. REC could also be used a s a design tool, that is as a tool that promotes the development of innovative, high-quality remedial options. This possibility could be explored by reversing the path that takes from basic information to the three R, E and C indices. This development, altough extremely interesting, is still to be fully explored.

# PART 2: THE TECHNICAL MANUAL

CHAPTER 7

# RISK REDUCTION MODEL

## 7.1 Derivation of the standardised exposure of humans

To assess the exposure of humans within the system as a result of soil contamination, *X* (standardised exposure) is expressed as follows:

$$X = RI \times n$$

where:

*RI* is the exposure as a result of soil contamination/TDI;
*n* is the number of human exposure units.

If a subdivision into adults and children were made, it would result in many additional pieces of information, which would not provide a very high power of discernment. The system was simplified by basing it on lifetime average exposure. This makes the system simpler and has the following advantages:

- there is no need to collect data on the present nature, features and characteristics of the users of the site;
- the changes over time in the number and type of users of the site (for instance, because dwellers move away or simply because of changes in the age distribution) does not have to be estimated.

In addition to using lifetime average exposure, we propose to calculate risk indices for relevant sections of the site. For such sections a standard type of land use can be chosen based on the exposure scenarios given in the Urgency System of the Dutch Soil Protection guideline:

- dwelling houses with a kitchen garden;
- dwelling houses with a garden;
- dwelling houses without a garden;
- factories, workshops or offices;
- recreational facilities;
- green areas;
- social and cultural facilities;
- roads.

For each type of land use, the relevant concentration is derived and a risk index (*RI*) is calculated based on a standard exposure scenario. To ensure that the aspect results in a sufficient power of discernment, this scenario should be geared to the local situation as far as possible.

Because standard exposure scenarios, lifetime average exposure and a relevant concentration are used, risk reduction is not assessed based on individual objects but on 'exposure units', such as a factory building or dwelling houses with gardens. A risk index is calculated for each exposure unit by deriving a relevant input concentration for the unit. The actual number of objects (humans) present (*n*) does not have to be determined. This simplification is substantiated in the same way that a lifetime average exposure is substantiated (the users of the exposure units can be described less accurately, and there may be uncertainties about the changes over time in the number of users). However, there are specific cases in which using the parameter *n* may result in a simplification (e.g. a homogeneous contamination in a residential area comprising ten houses where the remedial alternative includes the demolition of three houses; in this case, the risk reductions occurring before and after the remediation project can be determined and then multiplied by ten and seven, respectively). In the case of remediation projects involving clearly different exposure units (e.g. a factory building accommodating 100 employees, and a dwelling house with 4 occupants at one contaminated site, where the alternatives have different effects on the exposure of the users), the parameter *n* can also be necessary in order to gain an insight into the differences in risk reduction between the various alternatives. In such cases, the user of the system may decide to use this parameter after all.

The above method for the derivation of risk reduction fits in with the Urgency System and can simply be employed after a few supplementary actions have been carried out. To prevent the power of discernment from being lowered as a result of such simplifications, we advise having the risk reduction assessed by a specialist.

## 7.2 Derivation of the standardised exposure of ecosystems

To assess the exposure of an ecosystem as a result of soil contamination, *X* is expressed as:

$$X = RI \times n$$

where:

- $RI$ is the percentage of unprotected species/50;
- $n$ is the affected area/critical test area.

There is no methodology available for the assessment of the actual risks posed to an ecosystem. The practical cases were therefore assessed using a somewhat simplified, generic 'ETX method' based on the Urgency System.

The ETX method determines the potential percentage of unprotected species exposed to a concentration above the NOEC. In this standardised ETX function, the percentage of unprotected species is plotted against concentration. This percentage is standardised by the used limit value of 50 %.

In addition to the number of unprotected species, the accessibility of an area is relevant to the assessment of the exposure of an ecosystem. In a totally accessible area (e.g. a nature reserve), there will be a great variety of species per $m^2$, whereas in less easily accessible areas (e.g. built-on areas) there will be a lower number of species per $m^2$. The number of exposed species can be determined by standardising the area affected by the soil contamination based on critical surface areas derived from the Urgency System: 50 $m^2$ for nature reserves, 5,000 $m^2$ for rural areas, and 500,000 $m^2$ for an urban or industrial area.

## 7.3 Exposure of (or risk posed to) other objects

If a soil remediation project does not result in a significant risk reduction for local residents or the ecosystem, it may be decided to carry out a supplementary assessment of different risks or of risks of exposure to other objects. During the REC project, this aspect was elaborated only for remedial workers, because other objects were not included in the assessment of practical cases. Other objects may be assessed by determining the exposure of such objects and using a limit value for this exposure in order to standardise it. As part of such a risk assessment, other risks could be assessed based on the same conceptual framework. An example of this can be found in Koolenbrander [1997].

To assess the exposure of remedial workers as a result of soil contamination, $X$ is expressed as:

$$X = RI \times n$$

where:

$RI$ is the exposure/MAC value;
$n$ is the number of remedial workers.

The exposure of remedial workers can be assessed using such models as SOILDIG. However, regulations for occupational hygiene impose exposure limits: if an action value related to the MAC value is exceeded, safety measures should be taken. The intention of such measures is to reduce the exposure as far as possible. As a result, the maximum exposure will not exceed certain action values. In general, 0.3 and 0.5 times the MAC value are used as action values.

CHAPTER 8

# ENVIRONMENTAL MERIT MODEL

## 8.1 Objectives of Environmental merit

The objectives for the selection, operationalisation, standardisation and weighing of the aspects of environmental merit in the REC methodology were:

- to substantiate the method in a scientific way that provides insight;
- to achieve acceptation of the method as a whole by future users (authorities, consultants, companies dealing with contaminated soils and remedial options);
- to have the REC methodology incorporated into other systems, especially to have it clearly positioned in relation to risk reduction;
- to make the methodology user-friendly, i.e. during a remediation investigation, the required input data should in principle be available;
- to include the highest possible number of aspects relevant to environmental merit;
- to ensure that these aspects can be operationalised within a short period of time;
- to ensure that weighing factors can be determined in a manner that is acceptable and clear to future users;
- to ensure that weighing factors can be determined as objectively as possible.

These objectives were translated into the following questions:

- What aspects should be selected in order to calculate environmental merit?
- Have the most important processes been considered for the calculation of environmental merit?
- What data are required in order to calculate a score for a certain aspect?
- Are these data available/can they be easily obtained?
- How are scores for environmental aspects calculated?
- Are the assessment functions linear?
- How are the reference points for each aspect constructed?
- What does the function between these reference points look like?
- What are the representative reference scores for the various aspects?
- What are the weights for the various aspects?

Environmental merit is calculated by aggregating a number of expected environmental consequences of remediation. During the first phase of the REC project [CUR/NOBIS, 1996], the environmental consequences to be included in relation to environmental merit were selected mainly based on practical experience. To investigate the completeness and consistency of the selections made and to change them if necessary, a comparison was made with the environmental consequences of a remediation project as detailed in a life cycle assessment (LCA). The results of the LCA are given in Appendix B. Appendix B evaluates both the REC methodology employed for the calculation of environmental merit and the LCA method employed for assessing soil remediation projects. It concludes that the REC methodology is more suitable for calculating the environmental merit index than the LCA method, provided that the former is adapted in certain respects compared to the version developed during the first phase of the REC project.

The following sections discuss the quantification of the Environmental merit aspects. The REC methodology includes positive environmental aspects of soil remediation and negative aspects:

**Positive aspects:**

1. improvement of soil quality;
2. improvement of groundwater quality;
3. prevention of future groundwater contamination.

**Negative aspects:**

1. clean soil use;
2. clean groundwater use;
3. energy consumption;
4. surface water pollution;
5. air pollution;
6. final waste;
7. space use by remediation project.

Both soil and groundwater are important motivators for a remedial operation. They should be considered under the heading of environmental merit, because a remedial operation thus contributes to the recovery of environmental quality. Because clean soil and groundwater are often used when contaminated soil and groundwater are remediated, this should be included in the negative aspects.

The inclusion of energy is highly relevant from the viewpoint of both environmental merit and the LCA. The rather high energy consumption by wastewater treatment plants will from now on be included in the calculation of energy consumption, if wastewater is discharged into the sewage system.

Air emissions will also be included in environmental merit, because they clearly affect air quality, as appears from, among other things, LCA results.

During a soil remediation project, emissions into surface water may be high and result in a significant deterioration of environmental quality. Although such a deterioration had not occurred in the case where an LCA was carried out (because the wastewater was discharged into the sewage system), it is important to include this aspect.

The LCA results show that taking final waste into account may be important when considering the environment load caused by a remedial project. An LCA distinguishes between final and hazardous waste. Regarding environmental merit, however, this distinction was not made in order to limit the number of aspects.

If excavated soil is reused, this is expressed in a lower score for loss of soil and in a lower amount of final waste produced compared to the dumping of soil.

The fact that space is used during remedial actions is important for environmental merit, because space is a scarce commodity, which conceptually is comparable to fossil fuels and groundwater. In general, soils to be remediated consist of land that is often suitable for industrial or other economic activities. As a result of a remedial operation, such activities have to carried out at other locations. However, a remedial operation can also have a positive effect on the available space: space may become available for a certain purpose. However, it is assumed that alternatives do not differ in this regard, because each alternative would make the site suitable for the desired purpose.

The cleaner the soil is after remediation, the more degrees of freedom arise for physical planning in the area involved. E.g. extremely clean soil can be used for agriculture, housing and for industry, while moderately clean soil can only be used for industrial activities. Although very clean soil has advantages with respect to future spatial options, this is not an environmental merit but a merit for physical planning policy. Thus this aspect is not taken into account in Environmental merit.

The quality of soil depends not only on the chemicals contained in it. Two important aspects that are a measure of soil quality and so far have not been taken into consideration are soil texture and the role played by soil in the ecosystem. The soil texture is determined by, among other things, particle size distribution (percentages of clay, sand, etc.) and organic matter content. As a result of certain remedial operations, these quantities may drastically change, which is considered unfavourable from the viewpoint of environmental merit, because a change usually negatively affects the existing ecosystem. Increasingly more attention is being paid to the ecological functions of soil. For example, Tenner et al. [1997] deal extensively with this. Unfortunately, it seems to be practically impossible to obtain quantitative data on soil texture and ecological functions at the stage at which REC plays a role, namely during the preliminary investigation of a remediation project.

The amount of drinking water utilised during remedial operations is usually negligible. The evaporation of volatile substances is also negligible as far as environmental merit is concerned, because usually relatively low quantities are involved and have measurable effects only locally (i.e. evaporation results in local risk reduction). Therefore, these aspects were not included.

Certain remedial methods are very noisy and can therefore cause much nuisance. However, this is a local effect of easily discernible objects. Therefore, noise load is an aspect of risk reduction. However, it is not included in the assessment of risk reduction, because during such an assessment only exposure as a result of soil contamination is considered.

There are two aspects in which regional differences may play a role, namely space use and groundwater consumption. Regarding both aspects, the degree of scarcity depends on the location where the remediation project is carried out. For example, in the Randstad (the urban agglomeration in western Holland) space is more scarce than in eastern Groningen (an area in the north of the country, characterised by a low population density).

Regional differences in scarcity also came up during interviews, and the relative shortage of groundwater was clearly expressed in the weighing factors established by a number of experts. Sometimes 10 - 50 % of all groundwater in an area is used for remedial actions, which may result in desiccation. In such a case, this has consequences for the evaluation function: it will no longer be linear.

Special conditions not explicitly included in the REC methodology (e.g. harm to special nature reserves, noise, odours, the evaporation of e.g. CFCs during a remediation project) will play a role in the assessment in addition to the R, E and C indices. They are part of the 'other factors', as explained in Section 5.2.

## 8.2 Calculation of environmental benefits: positive aspects

The establishment of soil quality improvement under the heading of environmental merit should meet two important preconditions:

1. It should be taken into account that contaminated soils generally contain different (categories) of contaminants.
2. In the assessment of environmental merit, it is not the final concentration of a contaminant that should be considered (contrary to the assessment of risk reduction, because in that case the exposure of objects is considered and limit values are used), but improvement of the soil quality compared to the initial situation.

The solutions found to meet these preconditions are explained below. Each chemical has specific (eco)toxicological effects: for example, 100 mg/kg mercury in soil is far more harmful than 100 mg/kg mineral oil. The Soil Protection Guidelines [1997, see Section A 2.2] contain factors used to standardise contaminant concentrations. These guidelines distinguish intervention values and target values.

Intervention values are based on both human toxicological and ecotoxicological effects. The former are established based on maximum tolerable risk levels; for non-carcinogenic substances, these correspond with the TDI (tolerable daily intake), in which it is assumed that all possible exposure routes are present. The latter are quantified in the form of those content values in soil at which 50 % of the (potentially) present species may suffer negative effects. To establish intervention values, the values for human toxicity and ecotoxicity were integrated.

Target values are generally based on environmental policy objectives, such as drinking water standards and surface water standards. However, target values for heavy metals, arsenic and fluorine are based on field data obtained from rural areas subjected to a relatively low load. For a number of substances (e.g. aromatic compounds and certain chlorinated hydrocarbons), the target values are equal to the detection limit.

For standardisation, *in principle* it does not matter very much what value is chosen, provided it meets the following conditions:

1. It must be available;
2. It must have the same meaning for each class of contaminants;
3. A multiple of this value must have more or less the same meaning for each class of contaminants.

Soil quality can be raised to one of three levels:

- the target value;
- the intervention value;
- a combination of both.

Target values do not meet criteria 2 and 3 above. However, concentrations below the corresponding target values can be considered harmless from an environmental viewpoint. The intervention value seems to be most suitable for standardisation. However, it has a disadvantage in that it is directly associated with risk reduction. Therefore, two combinations were investigated that largely meet the above criteria and yet are not associated with risk reduction.

The first combination is the *t* value or *interim value*. This concentration is located exactly between the target and intervention value. The Soil Protection Guidelines state that this *t* value needs to be further investigated.

$$t_j = \frac{i_j + s_j}{2}$$

where:

$i_j$ is the intervention value of substance *j*;
$s_j$ is the target value of substance *j* in mg/m$^3$.

The second combination is similar to the *t* value, but it is a corrected value based on the *s* value:

$$\underline{t}_j = \frac{i_j + s_j}{2} - s_j$$

where:

$\underline{t}_j$ is the corrected *t* value;
$i_j$ is the intervention value of substance *j*;
$s_j$ is the target value of substance *j* in mg/m$^3$.

For the REC methodology, it was decided to use the *t* value for standardisation, especially because its formula is simpler. Correction based on the *s* value occurs by disregarding concentrations below the target value.

For most substances, the target value is one or more orders of magnitude lower than the intervention value. Their *t* value is approximately half their intervention value (see Table 15). However, this is not true for heavy metals, which occur also naturally in soil. Their target values are based on concentrations occurring in virgin areas. This should therefore be expressed in the *t* value.

Table 15. Examples of some target, interim and intervention values for soil contamination [Soil Protection Guidelines, 1997].

| **substance** | target value *s* (mg/kg) | *t* value (mg/kg) | $\underline{t}$ (mg/kg) | intervention value *i* (mg/kg) |
|---|---|---|---|---|
| oil | 50 | 2,525 | 2,475 | 5,000 |
| tetrachloroethylene | 0.01 | 2.005 | 1.995 | 4 |
| PAH | 1 | 20.5 | 19.5 | 40 |
| mercury | 0.3 | 5.15 | 4.85 | 10 |
| arsenic | 29 | 42 | 13 | 55 |

This standardisation is based on the assumption that the deterioration of environmental quality is linear to the concentrations of the substances. This is shown in the following graph[2] (see Figure 13).

[2] The target and intervention values will probably be adapted in the future and be based on e.g. the bioavailability of the substances concerned. It will then be simple to adapt the standardisation system of environmental merit to it.

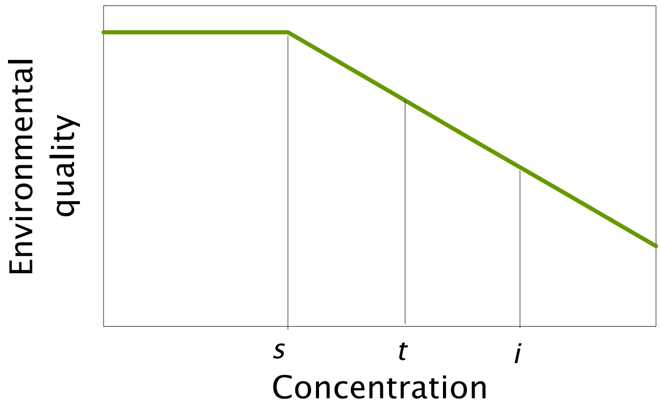



Fig. 13. Environmental quality is assumed to deteriorate linearly as a function of concentration. No deterioration of environmental quality occurs below the target value.

### 8.2.1 *Load approach*

The concentrations of the various contaminants can be summed up after being standardised based on the interim value. Next the *load* of the contaminants can be calculated. For each contaminant, the load equals its concentration (as far as it exceeds the target value) times the soil volume.

In Figure 14, this is indicated for an imaginary remediation project. The light green line drawn up to $C_{max,b}$ indicates the volumes measured before the remediation project, and the dark green line indicates those measured after it. In this example, the volume of soil with contaminant concentration *C* decreases linearly to an increasing concentration. The maximum concentration measured before the remediation project is $C_{max,b}$ and the one measured after the remediation project $C_{max,e}$. The loads[3] before and after the project equal the surface areas below the lines. Therefore, the degree of success of a remediation project can be expressed as the dark green surface area in Figure 14.

### 8.2.2 *Calculation of improvement in soil quality*

Improvement in soil quality can be expressed in a formula as follows:

$$G_{eq} = \sum_j \int_{c=s_j}^{c_{max}} \left( \frac{V_{b,j}(c) - V_{e,j}(c)}{N_j} \right) dc \quad 2$$

where:

- $G_{eq}$ is the improvement in soil quality expressed in soil quality equivalents;
- $j$ is the contaminant $j$;
- $V$ is the volume of soil with concentration $C_j$ in $m^3$;
- $c_j$ is the concentration of contaminant $j$ in $mg/m^3$;
- $s_j$ is the target value for contaminant $j$ in $mg/m^3$;
- $e$ is the final value;
- $b$ is the initial value;
- max is the maximum value;
- $N_j$ is the standard value for contaminant $j$ (= $t$ value).

[3] The actual load also contains volumes with concentrations below the target value.

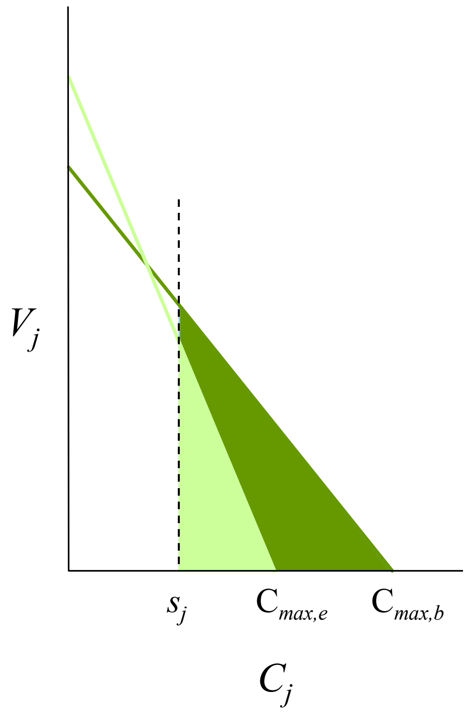



Fig. 14. Imaginary volumes $V_j$ before and after a remediation project as a function of concentration $C$. The load equals the surface area below the line.

Thus, this equation can be used to calculate the load resulting from a certain contaminant $j$, as far as its concentration exceeds target value $s_j$. Next, the difference between the initial and final situation (the improvement in environmental quality) is determined, and this is subdivided by $t$ in order to determine the number of soil equivalents in $m^3$. Finally, the contributions made by all contaminants $j$ are summed up[4].

### 8.2.3 *Improvement in groundwater quality*

Improvement in groundwater quality is calculated in a similar fashion:

$$W_{eq} = \sum_j \int_{c=s_j^w}^{c_{\max}} \left( \frac{V_{b,j}^w(c) - V_{e,j}^w(c)}{N_j} \right) dc \quad 3$$

where:

- $W_{eq}$ is the improvement in groundwater quality expressed in groundwater equivalents;
- $j$ is the contaminant $j$;
- $V$ is the volume of water with concentration $C_j$ in $m^3$;
- $c$ is the concentration of contaminant $j$ in $mg/m^3$;
- $w$ is the water;
- $e$ is the final value;
- $b$ is the initial value;
- $N_j$ is the standard value for substance $j$ (= interim value for contaminant $j$ in $mg/m^3$).

This formula is based on considerations similar to those on which the formula for improvement in soil quality is based.

4 Soil quality equivalents are determined by summation rather than integration, if only volumes for discrete concentrations are known.

### 8.2.4 *Prevention of future groundwater contamination*

When soil is remediated, future contamination of the groundwater is prevented by cleaning or removing the contaminated soil. This can be expressed in equivalents for the prevention of future groundwater contamination.

$$T_{eq} = \sum_j \int_{c=s_j^w}^{c_{max}} \left( \frac{V^w_{b,pot,j}(c) - V^w_{e,pot,j}(c)}{N_j} \right) dc \quad 4$$

where:

- $T_{eq}$ are the equivalents for the prevention of future groundwater contamination;
- *j* is the contaminant *j*;
- *V* is the volume of water with concentration $C_j$ in $m^3$;
- *c* is the concentration of contaminant *j* in $mg/m^3$;
- *b* is the initial situation;
- *w* is the water;
- *pot* is the final value;
- max is the maximum value;
- $N_j$ is the standard value for contaminant *j* (= interim value for contaminant *j* in $mg/m^3$).

Thus, $T_{eq}$ expresses the decrease of the groundwater volume units threatened by contamination in the future. $V^w_{pot,j}(c)$ can usually not easily be calculated analytically, but most consultants have models suitable for estimating its value.

## 8.3 **Calculation of environmental costs: negative aspects**

In the REC methodology, the following negative environmental aspects are considered: loss of soil, loss of groundwater, energy consumption, air pollution, space use, final waste, and emissions into surface water.

### 8.3.1 *Soil loss*

Because certain remedial techniques result in loss of soil, the total supply of soil will decrease. Because soil is a scarce commodity, this loss is a negative aspect in environmental merit. Soil quality does not play a role in this, because this is already taken into account under the positive aspect of improvement of soil quality. Consequently, regarding the aspect of loss of soil the same weight will be assigned to one $m^3$ of contaminated soil as to one $m^3$ of clean soil, because the contaminant will usually comprise only a very small fraction of the total volume.

Figure 15 shows that the cleaning of contaminated soil usually results in loss of volume. This loss is (over)compensated for by using soil from another location. However, soil is also 'created' by treating contaminated soil, so that it can be reused. Because during the cleaning process loss occurs (e.g. during extraction or thermal treatment), the net environmental result is loss of soil at the location from where the fill is taken minus the amount of soil becoming available for reuse (possibly at the location where it was excavated). In formula:

$$\text{Soil Loss} = V_{fill} - V_{reuse}$$

where:

- $V_{fill}$ is the volume of the soil obtained from elsewhere;
- $V_{reuse}$ is the volume of the reused soil originating from the remediated site.

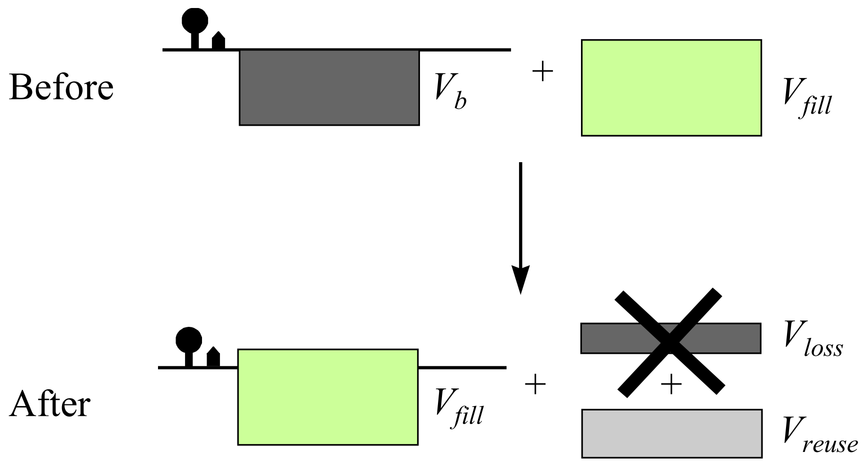



Fig. 15. Because a remediation project usually results in a loss of volume ($V_{loss}$), the soil is supplemented with soil obtained from elsewhere ($V_{fill}$). The net loss equals $V_{fill}$-$V_{reuse}$.

### 8.3.2 *Loss of groundwater*

Groundwater is a scarce commodity. During many remediation projects, both clean and contaminated groundwater are pumped up. Ideally, only contaminated groundwater is pumped up, which is then treated and infiltrated. Then, the groundwater loss equals zero. In formula the loss of groundwater is:

$$\text{Groundwater Loss} = V_{withdrawn} - V_{infilt}$$

where:

$V_{wthdrawn}$ is the volume of withdrawn groundwater in $m^3$;
$V_{infilt}$ is the volume of infiltrated groundwater in $m^3$.

### 8.3.3 *Energy consumption*

Energy is a scarce resource. To calculate energy consumption, the main energy-consuming processes occurring during a soil remediation project are considered. This choice is partly based on the LCA approach. The unit used is the Joule. Energy consumption by wastewater treatment plants is included, if the wastewater is discharged into the sewage system. To give some reference points: in the Netherlands, the average annual energy consumption per capita is approximately 250 GJ. The annual average consumption per household is approximately 80 GJ (1 GJ = $10^9$ J).

### 8.3.4 *Air emissions*

Because no target values for air exist, it is not possible to follow an approach similar to that followed for soil and groundwater. Nevertheless, the LCA results show that emissions as a result of energy consumption have strong environmental effects.

For environmental merit, air emissions are calculated based on energy consumption. Other air emissions (e.g. the evaporation of volatile substances from soil) can usually be disregarded from the viewpoint of environmental merit. Air emissions are proportional to energy consumption. However, this does not mean that the aspects are of equal importance: the impact as a result of gases causing acidification, eutrophication and the greenhouse effect may be higher than that resulting from the depletion of fossil fuels, or vice versa.

The factor used for converting energy consumption into air emissions depends of course on the state of the art. If, for example, in the future far more electricity is generated from sustainable resources (sun, wind, wood), the factor will have to be adapted.

Table 16 to Table 18 show air emissions as a function of the consumption of electricity and of diesel. The factors given express the contributions of $CO_2$, $NO_x$ and $SO_2$ to acidification, the greenhouse effect and eutrophication. The values thus calculated are the contributions of these gases to acidification, the greenhouse effect and eutrophication, standardised on the basis of $SO_2$, $CO_2$ and phosphorus (P), respectively. For example, 1 kg of $NO_x$ contributes 0.7 kg to acidification expressed in $SO_2$ equivalents and 0.13 kg to eutrophication expressed in P equivalents.

The emission of $CO_2$ is of course much higher than that of $SO_2$ and $NO_x$. Values are therefore standardised based on the annual emissions per capita in the Netherlands (population equivalents). In formula:

$$\text{Air Emission [pop. eq.]} = \mathit{0.0219} \times \text{power consumption [GJ]} + \mathit{0.0074} \times \text{diesel consumption [GJ]}$$

Table 16. Calculation of air emission based on energy consumption for electricity and diesel.

| | contribution | $CO_2$ | $NO_x$ | $SO_2$ |
|---|---|---|---|---|
| Air emissions as a result of electricity consumption (kg/MJ) [1] | | | | |
| - carbon | 48.50 % | 0.1231 | 0.000243 | 0.000229 |
| - gas | 44.08 % | 0.0611 | 0.000109 | 0 |
| - oil | 0.31 % | 0.0006 | 0.000001 | 0.000004 |
| - nuclear | 7.11 % | 0 | 0 | 0 |
| Total | 100.00 % | 0.1848 | 0.000353 | 0.000233 |
| Air emissions as a result of diesel consumption (kg/MJ) [1] | | | | |
| Total | | 0.0770 | 0.000048 | 0.000085 |

[1] [Lim and Lindeijer, 1994; pp. 28-29]

Table 17. Conversion factors for calculating air emissions from the energy use.

| factor[1] | $CO_2$ | $NO_x$ | $SO_2$ |
|---|---|---|---|
| acidification ($SO_2$) | 0 | 0.7 | 1 |
| greenhouse effect ($CO_2$) | 1 | 0 | 0 |
| eutrophication (P) | 0 | 0.13 | 0 |

[1] [Heijungs, 1992; p. 88 and following]

Table 18. Emission per capita and resulting conversion factors for calculating air emissions from the energy use.

| | emission per capita | | conversion factors | |
|---|---|---|---|---|
| | (tonnes)[1] | | *Electricity* | *Diesel* |
| acidification($SO_2$) | 0.067 | | 0.0072 | 0.0017 |
| greenhouse effect ($CO_2$) | 14.3 | | 0.0129 | 0.0053 |
| eutrophication (P) | 0.025 | | 0.0018 | 0.0002 |
| | | Total: | 0.0219 | 0.0074 |

[1] [Korenromp, 1997]

### 8.3.5 *Emissions into surface water*

The arithmetic method used is similar to that used for soil and groundwater, except that for surface water there are no intervention values, only target and limit values. The limit value for surface water is a medium-term policy objective and is usually located between the target value and the MTR (maximum tolerable risk level) for the ecosystem (see Table 19). The MTR concentration is that concentration at which 95 % of the (potentially) present species are not at risk of death. The target value is at the Negligible Risk level [Evaluation Memorandum on Water, 1994]. The limit value was used as a standardisation unit. In formula:

$$O_{eq} = \sum_j \int_{c^w = s_j^w}^{c_{\max}^w} \frac{V_{opp,j}}{g_j^w} dc \quad 5$$

where:

- $O_{eq}$ are the emissions into surface water in surface water equivalents;
- $j$ is the contaminant $j$;
- $V_{opp,j}$ is the volume of the water discharged into surface water with concentration $c$ during the total duration of the remediation project;
- $c$ is the contaminant concentration;
- $s_j$ is the target value (for surface water) for contaminant $j$;
- $g_j$ is the limit value (for surface water) for contaminant $j$.

Table 19. Limit values for surface water for a number of substances [Evaluation Memorandum on Water, 1994].

| substance | limit value for surface water (μg/l) |
|---|---|
| trichloroethylene | 2 |
| PAH (median) | 0.014 |
| mercury | 0.03 |
| arsenic | 10 |

### 8.3.6 *Final waste*

The LCA results show that final waste is an important element when considering the impact of a soil remediation project on the environment. This is included under the heading environmental merit in terms of $m^3$. This waste includes removed contaminated soil, unless it is reused.

### 8.3.7 *Space use*

Space use as a result of remedial actions is important for environmental merit, because space is a scarce commodity. Space use is defined here as the amount of space in $m^2$ that as a result of remedial actions cannot be used for other purposes times the duration of this space use in years. Therefore, the unit of space use is $m^2 \times$ years.

## 8.4 **A closer look at the weights**

In Section 3.2 we discussed the procedure for obtaining the weights for the environmental merit aspects. Of course, not all experts gave the same weight for all aspects. In this section we discuss the implications of the differences and similarities between the sets of weights.

Table 20 shows to what extent the experts and 'coalitions' of experts agreed with each other. This agreement was calculated using the Friedman test, a non-parametric test that only considers the order of the values given (in this case, the weights). The Friedman test enables calculation of *the degree of agreement* [see Rees, 1987[, which ranges from 0 (no agreement) to 1 (full agreement). It is also possible to check whether the degree of agreement differs significantly from a random order, because especially in the case of small number of experts a random order makes it likely that there will be rather a high agreement.

The analysis results show that, although the eight experts were not very much in agreement with each other (the degree of agreement is 0.37), this value is sufficiently high to conclude that the established weights differ significantly from a random series. Furthermore, two coalitions were identified that agreed to a significant extent based on a qualitative analysis of their weights: four expects who assigned high weights to the improvement of the (future) groundwater quality and loss of groundwater, and five experts who are in government service. The data do *not* show that the environmental view of the experts employed in industry differs from that of experts in government service: the degree of agreement between the experts employed in industry is not significant.

Table 20. Results of the statistical analysis of the degree of agreement between the experts.

| | experts | degree | *n* | significant (95 %) |
|---|---|---|---|---|
| all | 1, 2, 3, 4, 5, 6, 7, 8 | 0,37 | 8 | yes |
| government | 2, 3, 4, 5, 6 | 0.53 | 5 | yes |
| industry | 1, 7, 8 | 0.49 | 3 | no |
| groundwater | 3, 4, 5, 8 | 0.84 | 4 | yes |
| soil | 1, 2, 7 | 0.52 | 3 | no |

Figure 16 and Figure 17 show the sets of weights for those experts who considered groundwater highly important and those who considered soil highly important. There was much agreement especially in the former group. Table 21 gives the numerical values for the average weights for both groups.

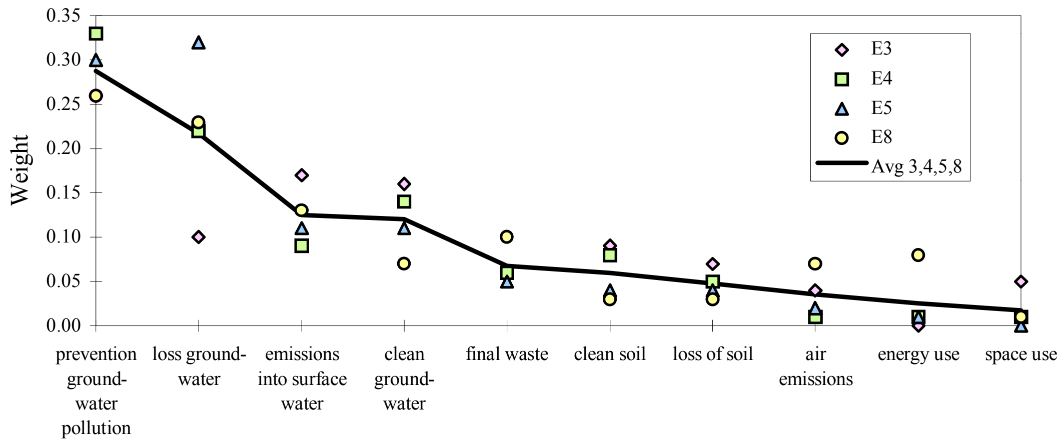



Fig. 16. Sets of weights for those experts who considered groundwater highly important, including their average (line).

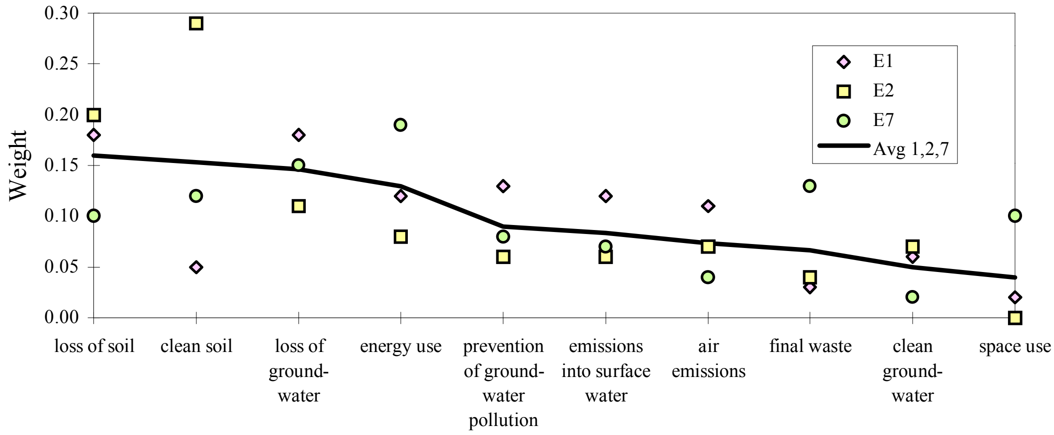



Fig. 17. Set of weights for those experts who considered soil highly important, including their average (line).

Table 21. Average weight for all experts (mean), for those experts focused on groundwater (3, 4, 5, 8), and for those experts focused on soil (1, 2, 7). The weights refer to the quantities of the Status quo and the Reference case.

| | mean | 3, 4, 5, 8 | 1, 2, 7 |
|---|---|---|---|
| clean soil as a result of remediation | 0.11 | 0.06 | 0.15 |
| clean groundwater as a result of remediation | 0.08 | 0.12 | 0.05 |
| prevention of groundwater contamination | 0.19 | 0.29 | 0.09 |
| loss of soil | 0.09 | 0.05 | 0.16 |
| loss of groundwater | 0.19 | 0.22 | 0.15 |
| energy consumption | 0.06 | 0.03 | 0.13 |
| air emissions | 0.05 | 0.04 | 0.07 |
| emissions into surface water | 0.11 | 0.12 | 0.08 |
| final waste | 0.07 | 0.07 | 0.07 |
| space use | 0.04 | 0.02 | 0.04 |

## 8.5 Sensitivity analysis

A sensitivity analysis is carried out to test the stability of model results as a function of the variations in the input data of the model. In principle, there are two analysis methods. The *direct analysis method* considers the consequences of a change in input data for the model results, whereas the *indirect analysis method* considers to what extent the input data can be changed without resulting in a change in the model results. An example of this is the ranking of two alternatives. The direct analysis method requires the availability of input data (for example, confidence intervals).

Regarding environmental merit, two types of sensitivity were investigated:

- that related to the scores per aspect;
- that related to the weights established by the experts.

The following questions were therefore posed:

1. What effect has a change in scores per aspect on the sequence of remedial alternatives?
2. What effect has a change in weights on the sequence of remedial alternatives?

3. To what extent can scores per aspect be changed without causing a change in the sequence of remedial alternatives?
4. To what extent can weights be changed without causing a change in the sequence of remedial alternatives?

There are many methods for executing a sensitivity analysis. However, most cannot be executed with a normal spreadsheet program, such as Microsoft Excel. For example, there are methods that take into account correlation between aspects and that model uncertainty about both weights and scores. More information on this can be found in (e.g.) Rios Insua [1990] and Van Herwijnen et al. [1995]. A very suitable computer program for uncertainty analysis is DEFINITE [Janssen and Van Herwijnen, 1994]. To enable also users of the REC methodology to simply carry out a sensitivity analysis, we decided to present here only a method that can be easily employed using a spreadsheet program.

For the analysis of uncertainty about scores, we added uncertainty margins to the scores and calculated the corresponding minimum and maximum values for the environmental merit index. Figure 18 shows the consequences if the scores for each aspect have an uncertainty margin of 50 %. In this case, the score for the MF alternative and that for the In Situ alternative turn out to overlap. ICM shows the lowest scores in all cases. To ensure that the In Situ alternative comes out best for environmental merit the positive aspects all should score lower, and that the negative aspects all should score higher. Using DEFINITE, it was calculated that even at an uncertainty margin of 100 % there is a probability of 93 % that the MF alternative will come out best for environmental merit.

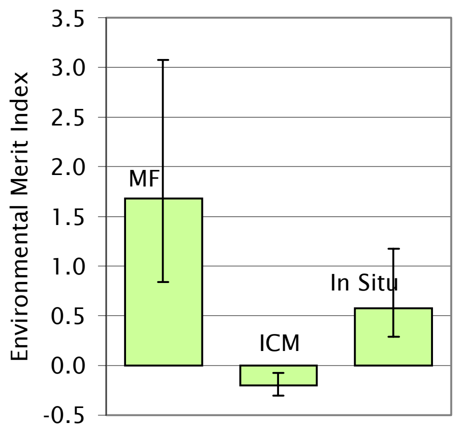



Fig. 18. Values for the environmental merit index for the example case and the uncertainty margins, if there is an uncertainty of 50 % for the score of each aspect.

It is more difficult to calculate the uncertainty about weights, because weights are standardised on 1. This means that, if the weight for aspect 1 must increase, the weights for aspects 2 - 10 must decrease. However, because the weights were established by a panel of experts, the variation between the experts can be used to determine the minimum and maximum values for the weights. This variation is shown in Figure 19.

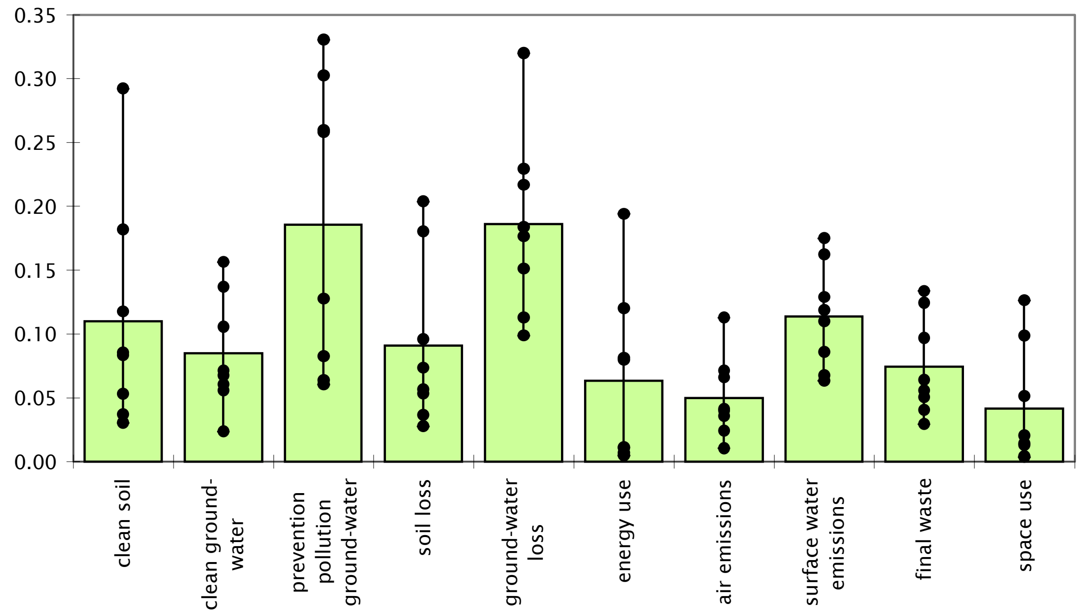



Fig. 19. Average weights (bars) including range and the weights established by the experts (circles).

To determine the sensitivity for the weights, the sequence of the possible remedial alternatives was examined. The following procedure was followed:

1. Determine the minimum weight for aspect 1 (0.03);
2. Calculate the average weights for the other aspects;
3. Standardise the new set of weights again based on 1;
4. Determine which alternative has the highest score for the Environmental merit index based on this new set of weights;
5. Repeat steps 1 to 4 for aspects 2 to 9;
6. Repeat steps 1 to 5 with the *maximum* weight.

This results in a table showing the alternative that has the highest score and belongs to the minimum and maximum values for each weight that corresponds with a certain aspect. In the example case, such a table shows that for all sets of weights examined the multifunctional alternative has the highest score for environmental merit. This is because this alternative has a high score for the remediation of the layer located far below the ground surface. It is also due to the method employed: only one weight is changed at a time.

Using DEFINITE, it was calculated that the weight for clean soil as a result of remediation should be lower than 0.005 to displace the MF alternative at the top.

However, this stability of the value of weights is not unique for the example case. In both the example case and four existing remedial situations, it was found that, based on the set of weights established by each separate expert, in nearly all cases the same alternative still came out best for environmental merit.

Therefore, we propose taking the average of the weights as the preferential value for the calculation of the environmental merit index. Next, the sensitivity can be calculated based on the minimum and maximum values. These values are given in Table 22.

Table 22. The average, minimum and maximum values of the weights for the determination of the environmental merit index.

| | mean | min | max |
|---|---|---|---|
| clean soil as a result of remediation | 0.11 | 0.03 | 0.29 |
| clean groundwater as a result of remediation | 0.08 | 0.02 | 0.16 |
| prevention of groundwater contamination | 0.19 | 0.06 | 0.33 |
| loss of soil | 0.09 | 0.03 | 0.20 |
| loss of groundwater | 0.19 | 0.10 | 0.32 |
| energy consumption | 0.06 | 0.00 | 0.19 |
| air emissions | 0.05 | 0.01 | 0.11 |
| emissions into surface water | 0.11 | 0.06 | 0.17 |
| final waste | 0.07 | 0.03 | 0.13 |
| space use | 0.04 | 0.00 | 0.13 |

CHAPTER 9

# THE COSTS MODEL

## 9.1 Classification of Costs

The cost classification system to be used should satisfy the preconditions of completeness, univocalness and clarity. Completeness means that all costs related to the remediation project to be carried out should be included in the estimate. To properly compare alternatives and remediation projects, all costs to be incurred should be classified under a univocal common denominator. The more or less automatic assessment of various alternatives also requires a certain degree of univocalness. Finally, the classification system should provide both the consultant and the decision maker with sufficient insight. The preconditions of univocalness and clarity are important too for being able to check an estimate for completeness.

Several existing classification system were evaluated to assess their suitability as a basis for the REC classification system. The following, in particular, were investigated:

1. NEN standards;
2. RAW[5] specifications system;
3. Classification system of the Soil Protection Guidelines.

A full description of the pros and cons of each of these systems can be found in Appendix D. A final choice has been made to use the classification system of the Soil Protection Guidelines with some minor modifications.

## 9.2 Weighing model

The weighing model should meet the following preconditions:

1. The parameters to be entered should be available from a remediation investigation or it should be easy to determine them.
2. The model should be in line with the cost classification system.
3. It should be possible to univocally determine the parameters to be entered within a certain range.
4. The model should be practical.
5. The model should provide insight to laymen.
6. The model should express the time value of money.
7. The model should express the uncertainty about the amount of the costs.
8. It should be possible to use the model within a standard spreadsheet program.
9. Regarding the estimation of total costs, the model does not specify who will cover which costs of the remediation project. Changes in the value of land, possibilities for financing and such like are also left out of consideration

**Uncertainty about costs**
Many uncertain factors associated with the remediation investigation phase should be considered.

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[5] RAW = *Rationalisatie en Automatisering in de Wegenbouw* (Rationalisation and Automation in Road Construction)

Examples of such factors are:

- the volume of contaminated soil;
- the degree to which the soil is contaminated;
- conversion from the quantity of soil to weight;
- the accuracy of the geohydrological model used;
- the velocity at which the contamination moves;
- the duration of the remediation project;
- the effectiveness of the remediation technology applied;
- the moment when the remediation project will be commenced;
- the costs of soil processing.

All the above factors can have an adverse effect on the accuracy of the cost estimate.

**Quantification of uncertainties**
As explained before, for each item of a cost estimate, a most probable value (W), a lowest value (L) and a highest value (H) are estimated. The lowest value is the cost estimate applying if everything turns out better than expected, and the highest value is the cost estimate applying if everything turns out worse than expected. In this way, the lower limit (L) and upper limit (H) of the estimate are fixed. The probability density can be represented as a triangle with a surface area of 1.

A number of cost items the probability density function of which is characterised by a triangle distribution can be easiest combined into a total estimate with an expectation and a standard deviation as follows.

1. For each cost item, the average of L, W and H is calculated.
2. For each cost item, the variance is calculated using the following formula:

$$\sigma^2 = \frac{1}{18} \times \left(H^2 + L^2 + V^2 - LV - LH - HV\right)$$

3. The expectation is the sum of all averages calculated under point 1.
4. Assuming that all cost items are independent of each other, the standard deviation can be calculated as the root of the sum of all variances. In the case of complete independence, the standard deviation of the total estimate is the sum of all standard deviations found.

### 9.2.1 *REC discounting process*

The time value of money can be explained most clearly as follows. If one could choose between receiving Dfl. 100,- now or receiving it in a year’s time, one would of course prefer the first alternative, even if one did not actually need it until the following year, because moneys received now carry interest. Reasoned the other way around, we would not need the full amount now, if we needed it only in a year’s time.

Therefore, time value is related to interest. Interest is what is received as a reward for making money available, or what is sacrificed in return for moneys received. The process of assigning future receipts and expenditures to one moment is called discounting.

What cash value has Dfl. 100.- now if you will receive it in one year and the interest rate is 10 %? The answer is 100/1.10 = Dfl. 90.90. In formulas:

$$PV(1) = \frac{CF}{(1 + i)}$$

where *PV* is the current (present) value of the amount *CF* (cash flow) received in a year time. A single amount to be received after several (*n*) years is computed as:

$$PV(n) = \frac{CF}{(1 + i)^n}$$

If the same amount *CF* is received every year for multiple years, then the total cash value/future value of the series of payments is equal to the sum of their cash values divided by their future values. In formulas:

$$PV(n) = CF \times \frac{1 - (1 + i)^{-n}}{i}$$

If different sums are received at the end of several periods, then also the individual amounts appear in the formula:

$$NPV = \sum_{t=1}^{n} \frac{CF(t)}{(1 + i)^t}$$

where *NPV* is called the Net Present value of the sums *CF* received at time *t* for *n* years.

### 9.2.2 *Magnitude of the discount rate*

The discount rate is a measure of the time value of money. However, the magnitude of this rate depends to a major degree on the probability that certain ingoing or outgoing money flows will be realised in the future.

Comparatively certain money flows (e.g. the proceeds received from government bonds) can be discounted at a lower value than the expected returns from an investment in stocks and shares of a one-year-old software company. According to this line of thought, each project (including each remedial alternative) has an individual discount rate that depends on the probability that certain receipts or expenditures will be realised.

For companies, the discount rate depends on the market. Depending on the company’s risk profile (including its financing structure), certain returns are required in the form of interest on loan capital and an increase in dividend/value (to be expressed in percent) for/of its own capital. The combination of both types of return (weighted average cost of capital) can be used as a measure of the discount rate.

Only if a company wishes to realise a project with a risk profile similar to that of the company itself may the discount rate be calculated from the presently required capital returns be used.

The financial/economic disciplines have developed some (rather impractical) methods for establishing the 'correct' discount rate. To assess proposals for investment, companies therefore generally use, for the sake of simplicity, a fixed, normative discount rate, possibly including a risk surcharge.

A completely different matter is whether or not inflation should be taken into account. Inflation affects the final decision only if the receipts and expenditures as well as the discount rate used take inflation into account or omit this[6]. In this report, it is assumed that the calculation of remedial costs does not take into account the expected inflation. As a result, the items given are automatically expressed in the cash values of a certain reference year. A discount rate not corrected based on inflation is therefore required for the discounting of future expenditures.

In REC, it is desirable (although theoretically incorrect) that for each remediation investigation a fixed, univocal discount rate be used in the cost weighing model, both to make the model more acceptable to future users and because there is no useful alternative.

To ensure that the cost estimates of different remediation investigations are comparable, the discount rate would have to be established completely independently of the project concerned. However, it is especially a wish of companies to be able to use the internally used discount rate when selecting the 'best' remedial alternative.

We propose to use a 'default' discount rate in the cost weighing model of the REC methodology. This rate may be based on one of the general interest rates, such as those used for promissory notes or the legal rate of interest. In addition, the model should be adapted in such a way that a second analysis can be carried out using a discount rate introduced by the user.

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[6] The relationship between percentages of real interest ($r$), nominal interest ($n$) and inflation ($i$) is as follows: $(1 + n) = (1 + i) \times (1 + r)$. Because the same changes occur in the numerator and denominator, the result will be the same.

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# PART 3: APPENDICES

APPENDIX A

# ENVIRONMENTAL MERIT IN RELATION TO LIFE CYCLE ANALYSIS

This appendix details the results of a life cycle analysis (LCA) carried out as part of a soil remediation project, and discusses what elements of the LCA methodology can be used in the REC methodology. This discussion is based on the fact that the LCA method is scientifically well-substantiated and that its 'from cradle to grave' approach takes into consideration all known environmental effects.

We detail here the LCA methodology and discuss the results of an LCA carried out during four actual alternatives for an existing soil remediation projects. Furthermore, weighing methods are discussed that can be used in combination with LCAs. In Section 5.2, it is explained why it was decided to employ the methodology developed during the REC project rather than the LCA methodology, based on the REC aims. However, during the second phase of the REC project, the REC methodology for calculating the environmental merit score was adapted in certain respects.

**LCA combined with weighing methods**

This section deals with two methods that are being developed and are suitable for the integration of LCA themes: the *'distance-to-target'* method, and the *panel* method. However, we first sketch the LCA method itself.

**General characteristics of an LCA**

This section outlines the procedures followed during the execution of an LCA. For a more exact description, please refer to Heijungs [1992].

An LCA details the effects of a social need or *function* (in LCA terminology) on the environment as accurately as possible within the limits of the field of study determined in advance. In the case of contaminated soils, the function of the process studied is the remediation of certain quantities of soil and groundwater. An important element of an LCA is the functional unit; in the case of soil remediation, this could be the treatment of 1 $m^3$ of soil until the desired concentration is attained. Usually, the production process is studied 'from cradle to grave', and based on the results of this study the environmental effects are taken into account. Thus, the first step of an LCA is the determination of the aim, field of study, and functional unit.

The second step consist of the listing of all process inputs and outputs, or the *Life Cycle Inventory* (LCI). This part of an LCA was standardised by the establishment of an ISO standard (ISO 14040).

The third step consists of classification and characterisation, that is, the expression of the LCI results in environmental themes. An LCA considers the potential environmental effects of the life cycle of a certain product or process. These effects may be related to the consumption of scarce commodities and/or to environmental quality. An LCA expresses environmental effects in such environmental themes as acidification, the greenhouse effect, depletion of raw materials, and ecotoxicity. Consequently, an LCA does not consider their social or ecological consequences, such as harm caused to forests or health effects created on humans.

In the case of soil remediation, there are also positive environmental effects, because contaminants are removed from soil and groundwater. Such effects can be included in an LCA; however, they are then assigned a negative score. Problems encountered in the application of such 'subtraction' methods are that it is often hard to establish the system boundaries, and that the environmental quality of soil and groundwater and their potential effects cannot be easily assessed and quantified.

Finally, the LCA results need to be evaluated before they can be used to support the decision-making process. However, LCA results are usually presented per theme rather than being integrated. Often standardisation is carried out based on the total score for a theme for the Netherlands or Europe as a whole, and sometimes it is done based on the highest score calculated for the alternatives considered. The evaluation step is elaborated upon in the next section.

**The distance-to-target weighing method**

To carry out the last LCA step (the evaluation), environmental themes need to be compared, because a product or service can be considered 'better for the environment' only if it has a higher score than another product or service for all themes. This, however, will usually not be the case. Such themes can be weighed using the *distance-to-target* method [Corten et al., 1994].

First, the environmental themes are standardised based on the total score calculated for an area or on a certain number of inhabitants. Next, weighing occurs by determining the distance from the target. In this, the *target* is the sustainable environmental quality. Values for this can be found in, among others, *Zorgen voor Morgen* (Concern for Tomorrow) [1991]. The *distance* is the relative distance from this sustainable level. This relative distance is the weighing factor used to multiply the standardised environmental theme. Next, the weighted environmental themes are summed up to obtain a figure in which the environmental effects are integrated.

For example, 10 acidification units per functional unit are emitted to manufacture a product. In the whole country (the field of study), 1,000 units are emitted. However, the target is 500. This means that the contribution to the integrated environmental value is:

$$\frac{10}{1000} \times \frac{1000}{500} = 0.02$$

In practice, sustainability levels cannot be established objectively, because they comprise not only scientific data but also social standards and values[7]. However, if they had been established objectively, all environmental levels would have had the same weight, because in this method the weight depends only on the distance from the sustainability level. Yet, for example, human ecotoxicity may be considered more important than the greenhouse effect. Corten et al. [1994] managed to establish targets only for the greenhouse effect, depletion of the ozone layer, dispersal, acidification, eutrophication, and smog.

**The panel weighing method**

One of the alternatives to the distance-to-target method is the panel method. In this, weighing factors are established based on an assessment made by a panel of experts. There are various possibilities for the phrasing of the question, panel composition, steering, and method of consensus creation. Depending on the phrasing of the question, the quality or accuracy of the answers may be high. A high accuracy can thus be attained, although it would be hard to establish to what degree. In the Netherlands, so far little experience has been gained with the panel method for weighing LCA themes. Assessments made by experts were also used during the phase of the REC project described in this report.

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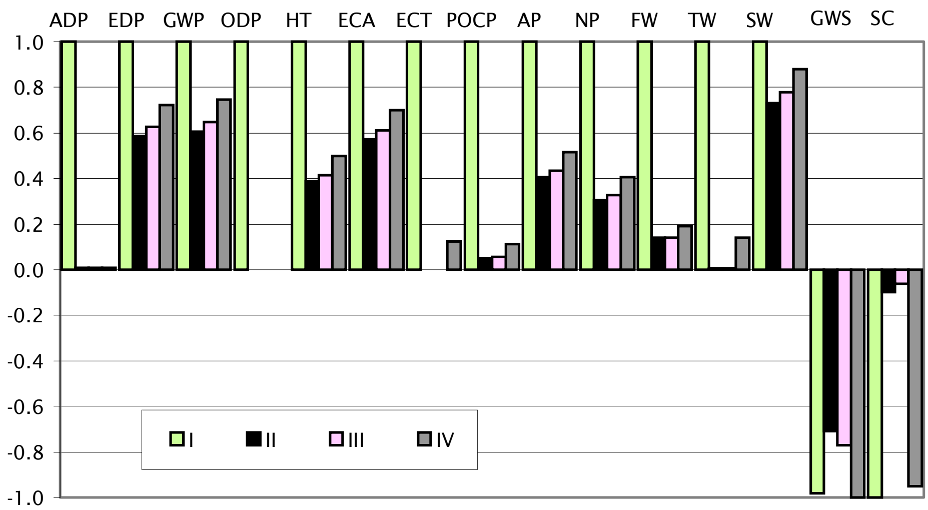
[7] The definition of 'sustainability' may also be based on more than only scientific data.

**Case study - LCA**
Korenromp [1997] contains all results of the LCA carried out regarding four remedial alternatives for soil contaminated with chlorinated hydrocarbons (this case is different from the example case detailed in this report). These remedial alternatives were:

- Alternative I: a multifunctional alternative to be carried out by wet excavation, in which additionally the groundwater within and outside the site's borders would be remediated.
- Alternative II: a containment alternative, including groundwater remediation outside the site's borders. At the site, first the shallow groundwater would be remediated to the risk limit, and then containment would occur.
- Alternative III: an alternative involving containment of the entire soil contamination within and outside the site’s borders. At the site, the shallow groundwater would be remediated to the risk limit.
- Alternative IV: an in situ alternative including partial excavation, in which additionally the groundwater at the site would be fully remediated.

The LCA themes were not mutually weighed; they were standardised based on the annual emission per Dutch citizen, i.e. divided by the average emission per inhabitant. Two additional elements were included in the LCA: removal of the contamination in the soil, and groundwater consumption. These elements are usually not considered during an LCA, because no standard procedure is available for this purpose. For all other elements, the standard LCA environmental effects were included, sometimes after these elements had been slightly adapted.

Figure A1 shows the LCA scores calculated for the four alternatives. Each score was divided by the score of the alternative with the highest value (in the case of negative scores, with the lowest value).




Legend: ADP = abiotic depletion potential, EDP = energy depletion potential, GWP = global warming potential, ODP = ozone depletion potential, HT = human toxicity, ECA = ecotoxicity aquatic, ECT = ecotoxicity terrestrial, POCP = photochemical ozone creation potential, AP = acidification potential, NP = nitrification potential, FW = final waste, TW = toxic waste, SW = special waste, GWS = groundwater stock, SC = soil contamination.

Fig. A1. LCA profiles standardised on the basis of the maximum score for the four remedial alternatives [Korenromp, 1997].

The case study examined showed that the LCA score depends on four more or less independent parameters: depletion of fossil fuels, final waste, hazardous waste, and groundwater consumption. Furthermore, it was found that environmental merit (as defined during the first phase of the REC project) should be supplemented as regards the following important aspect. The energy consumed by the wastewater treatment plant should be taken into account, if during the remediation project the wastewater is discharged into the sewage system, because the installations concerned consume a lot of electricity. However, the drinking water consumption is negligible from an environmental viewpoint, as is the evaporation of volatile substances in view of the relatively low quantities involved.

Because the executed LCA does not integrate environmental effects, it is not possible to univocally indicate the most environmentally-friendly remedial alternative based on the LCA data. However, in the case study examined (see Figure A1), the multifunctional excavation alternative (I) has the lowest score for nearly all LCA themes. The other three alternatives were not clearly distinguishable: their relative scores heavily depend on the weights assigned to the LCA themes.

For example, the containment alternative that includes groundwater remediation (II) would result in the lowest energy consumption, which means that the air emissions (greenhouse gases, smog formation, acidification) would be lowest. However, the amount of clean groundwater (GWS) released during the remediation project would be lowest, and the decrease in contamination in the soil would rank second. Thus, it depends on the weights assigned to the themes whether this alternative would rank first, second or third.

**Case study - Environmental merit**

Although an LCA and the environmental merit method use the same input data, the results of these methods are not directly comparable. This is due to the nature of these methods. Based on the weights established by nearly all experts (see Chapter 8), the alternative involving partial excavation and in situ remediation (IV) is the best option from the viewpoint of environmental merit. The multifunctional alternative involving excavation (I) and the alternative involving containment and groundwater remediation (II) rank second and third, respectively.

The score for environmental merit depends mainly on energy consumption, air emissions, and improvement of soil and groundwater quality. Because air emissions are calculated based on energy consumption, the following three elements of environmental merit are decisive: improvement of soil quality, improvement of groundwater quality, and energy consumption.

**Discussion: Environmental merit and LCAs**

*Scientific foundation of the methodology*

LCAs are scientifically well substantiated and accepted, and all parts of the LCA method have internationally been standardised. This is, however, not true for the weighing methods (the distance-to-target method and the panel method). The distance-to-target method has the following disadvantages: it is often hard to establish the targets, and if the targets can be established objectively, the themes have the same weight. This is because a weight depends only on the distance from the target. The authors are not aware of the existence of any methods for the establishment of targets for soil and groundwater quality or related environmental themes. So far little experience has been gained with the panel method combined with LCAs.

Regarding Environmental merit, the selection of aspects is based on questions asked by people working in the field of soil remediation, which means that it is not standardised, contrary to the situation with LCAs. The aggregation of aspects of environmental merit is based on a clear theoretical foundation [Beinat, 1997]. Weights are established by interviewing experts. Although it is hard to determine the accuracy of weights, the method used to establish weights comprises many cross-checks, which guarantees carefulness. Moreover, the method is easily understandable to the user. Although the same approach can be followed in the case of the LCA panel method, this method has a disadvantage in that experts consider it often very hard to weigh environmental themes, because they have little feeling for the magnitude of the figures used (for example, how bad is one unit of terrestrial ecotoxicity?). In the environmental merit method, this problem is solved by using a more or less real remediation situation as a reference.

The weights do not seem to be objective (contrary to the procedure developed for establishing them), but the same applies to the determination of *targets* as part of the distance-to-target method. It is also hard to define the term 'sustainability' in a non-normative manner.

*Acceptation by soil experts*
Dutch soil experts seem to differ in opinion about the usability of LCAs for the assessment of remedial processes, because LCAs supply only information about environmental effects. The REC methodology was developed especially for the (integral) assessment of soil remediation options, and during the development phase it was tested several times in the field. It is a method for taking decisions aimed not only at environmental merit, but also at risk reduction and the costs of remediation projects.

Environmental merit makes it also possible to adapt weights to specific circumstances; for example, when a contaminated site is located in an area sensitive to drought. However, the standard weights should reflect the priorities of the Dutch soil policy.

*Definition of system boundaries*
In LCAs, the field is exactly defined during the first step. Regarding the REC methodology, this report does so too for environmental merit (see Section 1.4).

*Difference from risk reduction*
Environmental merit is defined in such a manner that it can be clearly distinguished from risk reduction. This is necessary, because most soil remediation projects are carried out especially to achieve risk reduction.

Because LCAs are not designed as decision-support tools for soil remediation, they do not clearly distinguish between environmental merit and risk reduction. For example, terrestrial ecotoxicity comes (partly) under risk reduction, because it is a local effect with a clearly discernible exposed object. It may in principle be possible to distinguish such effects in an LCA.

*Availability of the method*
Because of the specific approach followed as regards environmental merit, the REC methodology is readily available. However, specific methods for the application of LCAs should be further developed in order to assess especially improvement of groundwater and soil quality. If it is planned to apply the distance-to-target method, many targets still have to be established, which would take a lot of time and effort in the form of research.

*Conclusion*
Based on the above discussion, it can be concluded that the REC methodology is more suitable for the determination of environmental merit than the LCA method, provided that a few elements are adapted compared to the first phase of the REC project. For the sake of completeness, the similarities and differences between the assessment methods are diagrammed in Figure A2.

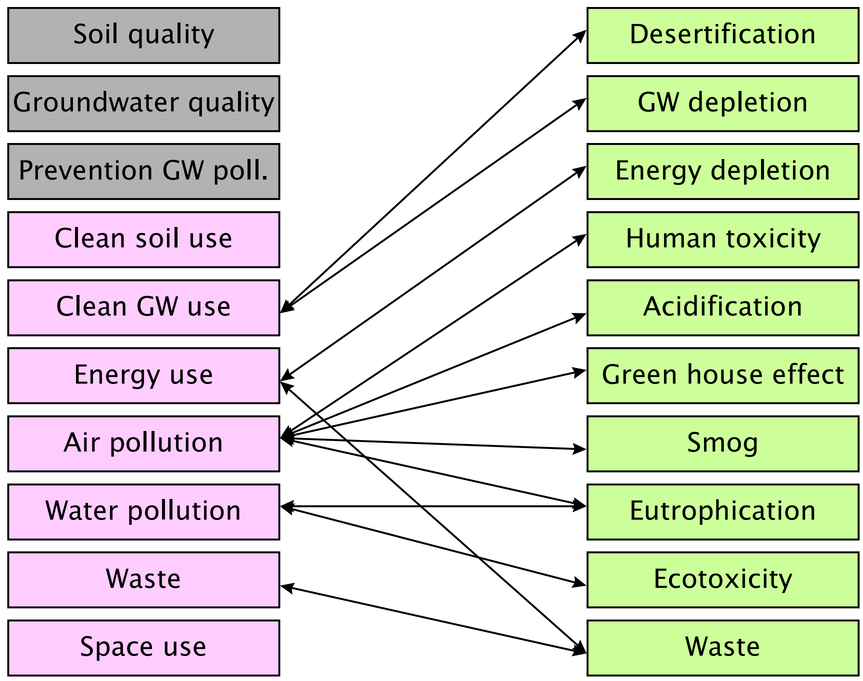



Fig. A2. Differences and similarities between environmental merit and LCAs.

APPENDIX B

# CONSTRUCTION OF THE REFERENCE CASE

The reference case is an 'average' soil remediation case formulated by a group of soil remediation experts from TAUW Milieu in Deventer, the Netherlands, based on current soil remediation practice. The initial situation is represented in Table B1. The volume of contaminated soil amounts to 5,000 $m^3$, that of contaminated groundwater to 20,000 $m^3$. The situation is sketched in Figure B1.

The quantity of contaminated groundwater was estimated based on the following consideration: it was assumed that in 50 % of all remediation cases the groundwater is contaminated (by aromatics and/or mineral oil in 90 % of these cases, and by CHCs (chlorinated solvents) for the rest.

Table B1. Standards and contaminant concentrations in the soil, groundwater and surface water in the reference case. *s* = target value, *t* = interim value, and *g* = limit value.

| Contamination | Soil | | Groundwater | | Surface water |
|---|---|---|---|---|---|
| *Standards* | *s* (mg/kg) | *t* (mg/kg) | *s* (μg/l) | *t* (μg/l) | *g* (μg/l) |
| oil | 50 | 2525 | 50 | 325 | 120 |
| chlorinated solvents[1)] | 0.007 | 11.2 | 0.010 | 87.4 | 0.8 |
| heavy metals[2)] | 60 | 174 | 18 | 106 | 12 |
| PAH[3)] | 1.0 | 20.5 | 0.002 | 0.1385 | 0.014 |
| | before | after | before | after | emission |
| *Concentrations* | (mg/kg) | (mg/kg) | (μg/l) | (μg/l) | (μg/l) |
| oil | 15,000 | 9,000 | 1,500 | 900 | 100 |
| chlorinated solvents | 4.8 | 2.9 | 60 | 36 | 0.1 |
| heavy metals | 3,000 | 1,800 | 0 | 0 | 0 |
| PAH | 900 | 540 | 12.6 | 7.6 | 0.03 |
| *Conc. based on t values* | (*t*) | (*t*) | (*t*) | (*t*) | (*g*) |
| oil | 5.9 | 3.6 | 4.6 | 2.8 | 0.83 |
| chlorinated solvents | 0.43 | 0.26 | 0.69 | 0.41 | 0.13 |
| heavy metals | 17.2 | 10.3 | 0 | 0 | 0 |
| PAH | 43.9 | 26.3 | 91.6 | 55.0 | 2.1 |
| *Volumes* | ($m^3$) | ($m^3$) | ($m^3$) | ($m^3$) | ($m^3$) |
| oil | 1,000 | 650 | 20,000 | 20,000 | 240,000 |
| chlorinated solvents | 600 | 550 | id. | id. | id. |
| heavy metals | 1,700 | 1650 | id. | id. | id. |
| PAH | 1,700 | 1,650 | id. | id. | id. |

1) 60 % tetrachloroethylene; 30 % trichloroethylene; 5 % chlorobenzenes; 5 % chlorophenols.
2) For heavy metals, the average was taken for all metals mentioned in the Guidelines.
3) For groundwater, the median values for all PAHs were taken.

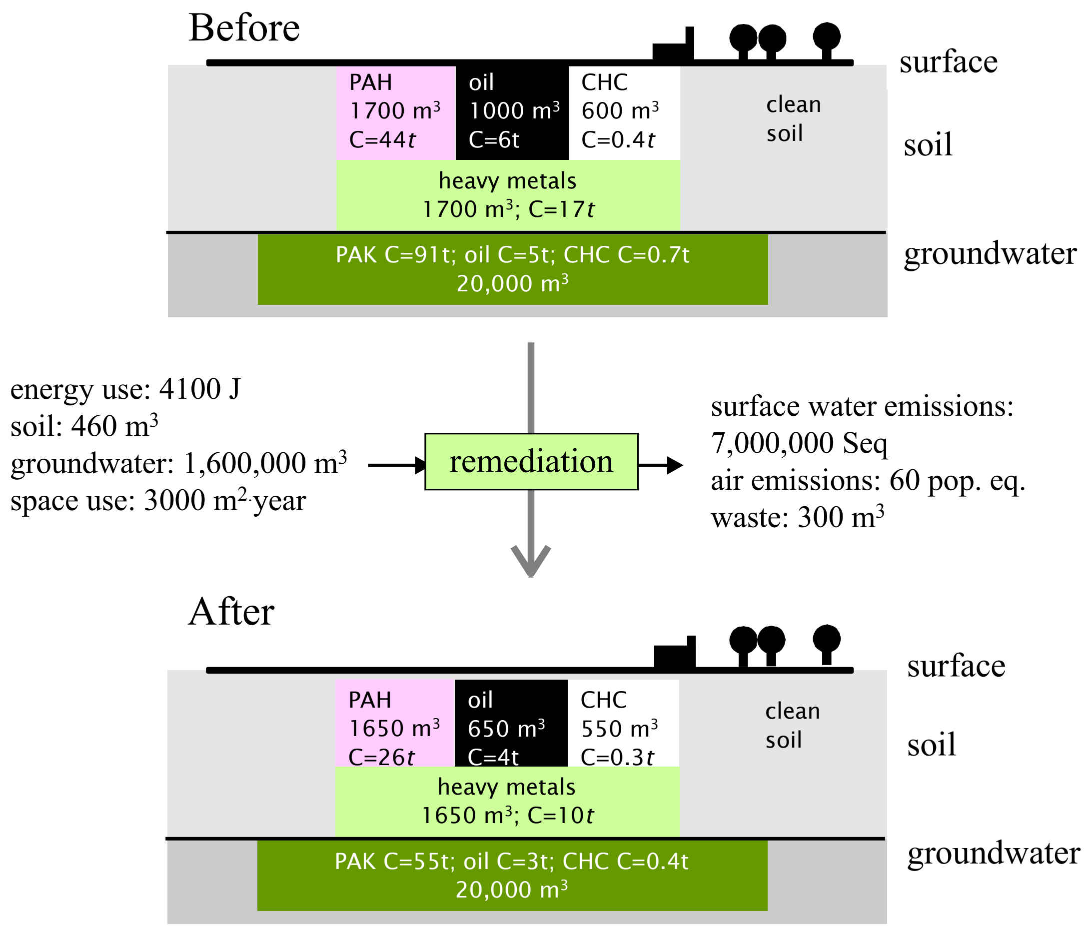



Fig. B1. Illustration of the reference case. The initial situation is depicted at the top, the final situation at the bottom, and the remediation technique in the centre.

**Positive aspects**

It was estimated that 40 % of the soil and groundwater contamination was removed. The future groundwater contamination was estimated based on the current soil contamination. Converted to soil and water equivalents, the environmental merit of the reference case is:

| | before | after | difference |
|---|---|---|---|
| $G_{eq}$ | 110,000 | 60,000 | 50,000 |
| $W_{eq}$ | 1,900,000 | 1,100,000 | 800,000 |
| $T_{eq}$ | 2,100,000 | 1,300,000 | 800,000 |

**Negative aspects**

*Loss of soil*

In about 40 % of the cases, the total amount is treated. This comes down to $0.4 \times 5{,}000\ m^3 = 2{,}000\ m^3$. In this, the following treatment categories may be distinguished:

| Technique | % | soil ($m^3$) | loss ($m^3$) |
|---|---|---|---|
| In Situ: | 5 % | 100 | 0 |
| Extractive: | 30 % | 600 | 30 |
| Thermal: | 45 % | 900 | 30 |
| Dumping of waste: | 10 % | 200 | 200 |
| Reuse of soil: | 10 % | 200 | 200 |

Therefore, the total loss of soil is 460 $m^3$.

*Loss of groundwater*

In about 40 % of the cases, the groundwater is remediated. In this, the contaminated groundwater is flushed six times. In the other cases, containment occurs at a flow rate of 10 $m^3$/h for 30 years. 2 % of this total is infiltrated. Therefore, the total loss is:

$$0.98 \times \left(0.6 \cdot 10 \cdot 24 \cdot 365 \cdot 30 + 0.4 \cdot 6 \cdot 20{,}000\right) = 1.6 \cdot 10^6 \mathrm{m}^3$$

*Energy consumption*

The following activities consume energy:

- Contaminated soil must be excavated and then transported over an average distance of 80 km;
- New soil must be transported over an average distance of 25 km;
- Most of the techniques employed consume energy;
- 80 % of the total contaminated amount of groundwater is treated;
- 83 % of the treated groundwater is discharged into the sewage system;
- 2 % of the treated groundwater is infiltrated.

The total (4,100 GJ: 2,500 GJ of electricity, and 1,600 GJ of diesel) equals 16 times the energy consumed annually by an average Dutch citizen (including that consumed on his behalf by industry, agriculture, etc.) and 51 times the energy consumed annually by an average household (6.4 million in the Netherlands).

*Air emissions*

The resultant air emissions are calculated from the energy consumption: 4,100 GJ. This energy consumption is related to the air emissions, which in turn are related to acidification, the greenhouse effect and eutrophication.

*Emissions into surface water*

15 % of the total average withdrawn volume (1,600,000 $m^3$) is discharged into surface water. This is expected to result in an average concentration of 10 × *s*. Here, '*s*' is the target value for surface water. Three types of substances are discharged (see Table B2). The total emission is 745,000 $O_{eq}$.

Table B2. Calculation of emissions into surface water.

| Contaminant | Concentration | Volume | $O_{eq}$ |
|---|---|---|---|
| | (µg/l) | ($m^3$) | ($m^3$) |
| oil | 100 | 240,000 | 200,000 |
| chlorinated solvents | 0.10 | 240,000 | 31,000 |
| PAH | 0.03 | 240,000 | 514,000 |
| Total: | | | 745,000 |

*Final waste*

The results of soil treatment show the total amount of final waste. However, extraction doubles the amount of waste compared to loss of soil, because as a result of extraction the waste fraction will include water. This leads to a total amount of waste of 60 + 30 + 200 = 290 $m^3$.

*Space use*

The space use was estimated as follows: the total volume is 5,000 $m^3$; assuming a depth of 5 m, the surface area is 1,000 $m^2$. In the case of an average remediation project, it is then estimated that 10 % of the surface area (100 $m^2$ or 10 x 10 m) will be occupied for 30 years (taking the maximum duration into account). This equals 3,000 $m^2$/year.

*The reference situation*

For the purpose of the interviews with experts, the reference values were rounded off. The values used are given in Table B3.

Table B3. The aspects used during the second phase of the REC project, and the accompanying reference level.

| Aspect | Reference level |
|---|---|
| **Positive aspects** | |
| Improvement of soil quality | 50,000 $S_{eq}$ |
| Improvement of groundwater quality | 800,000 $W_{eq}$ |
| Prevention of future contamination | 800,000 $T_{eq}$ |
| **Negative aspects** | |
| Loss of soil | 460 $m^3$ |
| Loss of groundwater | 1,600,000 $m^3$ |
| Energy consumption | 4,100 GJ |
| Air emissions | 60 pop.eq. |
| Emissions into surface water | 700,000 $O_{eq}$ |
| Final waste | 300 $m^3$ |
| Space use | 3,000 $m^2$/year |

APPENDIX C

# ADAPTED SUMMARY OF COSTS FROM THE SOIL PROTECTION GUIDELINES

## A. Initial costs

A.1. Project preparation
- execution of a further investigation and a remediation investigation;
- drafting of a remediation plan;
- specifications;
- scenario.

A.2. Preparatory work
- clearing/preparation of the site:
- removal of vegetation;
- installation and removal of sheds, removal of pavements, installation of temporary pavements;
- temporary safety measures (fence/washing area);
- breaking up the ground;
- pipes and cables from public utilities:
- adaptation/supporting/moving;
- maintenance;
- constructional facilities:
- maintenance of infrastructural facilities;
- foundations;
- sheet-pile walls;
- auxiliary constructions;
- facilities for occupational hygiene and safety during execution.

A.3. Demolition
- aboveground buildings;
- foundations, floors, wells, etc.;
- pavements;
- processing of released materials (as far as they are not contaminated).

A.4. Costs of land redevelopment
- repair of infrastructural facilities (road/site pavements, sewage system, utility facilities, green areas).

A.5. Ground work (including ground work for the purpose of sediment remediation)
- excavation (soil, contaminated foundations, rubble, etc.);
- drainage for the purpose of ground work;
- separation of batches/fractions;
- transport;
- temporary storage in makeshift depots at the site;
- supply, processing and compaction of clean fill;
- dehydration of sludge;
- sediment remediation (removal, dehydration and transport).

A.6. Processing costs
- dumping of soil;
- treatment of soil;
- treatment of sludge;
- reuse of soil;
- temporary storage.

A.7. Drainage and treatment installations

A.7a. Drainage installation for groundwater remediation
- installation and removal of a drainage system, including pipes and pumps;
- installation of drains;
- installation of monitoring wells and such like.

A.7b. Drainage installation for in situ remediation
- installation and removal of a drainage system, including pipes and pumps;
- installation of drains;
- installation of monitoring wells and such like.

A.7c. Treatment installation
- installation and removal of treatment installation, including pipes and pumps.

A.8. Screening constructions (prevention of spreading if ICM is applied and temporary safety measures taken)
- digging of a ditch for the installation of a sheet-pile wall (the moving and processing of soil: A.5/A.6);
- installation of a sheet-pile wall;
- application of a horizontal sealing layer (at the top and bottom).

A.9. Monitoring system
- installation of flow meters;
- installation of monitoring wells and sampling filters or drains;
- installation of gauge rods;
- execution of site assessment and zero measurements.

A.10. Management and environmental supervision
- management;
- environmental supervision;
- costs of analysis;
- drafting an assessment report;
- costs of equipment.

A.11. Secondary costs
- licences (fees, levies);
- insurances.

**B. Recuring costs**

B.1. Maintenance of facilities
- maintenance:
- drainage system;
- treatment plant.
- costs of energy:

- drainage;
- treatment.
- maintenance of aboveground constructions and facilities;
- maintenance of groundwater control system:
- purging and possible replacement of control drains;
- flushing and possible replacement of monitoring wells.

B.2. Secondary costs
- licences (fees, pollution tax);
- insurances.

B.3. Aftercare (concerning both ICM measures and temporary safety measures)
- quantitative measurements:
- flow measurements;
- geohydrological observations and evaluation;
- settlement measurements, and evaluation.
- quality measurements:
- sampling;
- analysis;
- evaluation.
- general coaching and supervision.
- scenario to be followed should facilities break down.

**C. Costs of replacement (concerning both ICM and temporary safety measures)**

C.1. Screening constructions
- replacement of sheet-pile walls;
- application of a horizontal sealing layer;
- recording equipment.

C.2. Drainage and treatment installations
- drainage system, including pipes and pumps;
- treatment installation;
- peripherals (recording, regulation and switch boxes).

**D. Overheads**

- costs of execution;
- general costs, profit, and the risk surcharge to be paid to the contractor, excluding the costs of the processing of released soil, groundwater and waste.

**E. Other costs**

E.1. Compensation to be paid to third parties for damage caused by the remediation project.

E.2. Loss of capital and production as a result of the remediation project.

APPENDIX D

# CLASSIFICATION SYSTEMS FOR COSTS: AN ANALYSIS OF EXISTING SYSTEMS

**NEN standards**

The Netherlands Normalisatie Instituut (NNI, Dutch Standardisation Institute) has issued many standards, which are accepted as univocal standards by the relevant parties on the market. NEN standards (NEN = Nederlandse norm, Dutch standard) of relevance for REC are standards 2631 and 2632. NEN 2631 details the concepts related to and the subdivision of investment costs for buildings, and NEN 2632 contains information on the operating costs of buildings.

Investment costs are subdivided into: costs of soil, and construction, design and secondary costs. Operating costs are subdivided into fixed costs, energy costs, maintenance costs, administrative management costs, and specific operating costs. Both subdivisions are apparently aimed at civil and utility construction.

So far no standard has been formulated or is in preparation for costs incurred in the field of civil engineering, in general, or soil remediation projects in particular. Nor have relevant standards been formulated on a European (CEN) or international (ISO) level.

NEN standards 2631 and 2632 are suitable for use during soil remediation projects only after drastic adaptation. As a result of the many adaptations required for reasonable applicability, the main advantage of the use of NENs - their generally accepted and established standardisation - would be nullified. The above two NEN standards do not meet any the three preconditions formulated in Chapter 9.

**RAW specifications system**

The importance of a more or less standardised subdivision of cost items during the specifications phase has long been recognised. For civil and utility construction projects as well as for projects in the civil engineering sector, standards have been developed that detail the concepts related to and the subdivision of the various items of specifications. Based on these standards, tables of costs and standards have been drafted that give an impression of the unit costs of materials and labour for the various cost items.

The STABU specifications system has been developed for civil and utility construction, and the RAW specifications system for civil engineering. For soil remediation specifications, the RAW specifications system is usually applied. This system was developed by CROW (Centre for Regulation and Research in the fields of Civil Engineering and Traffic Technology).

In the RAW specifications system, desired results are subdivided into a number of working categories. Such a category is a collection of actions commonly carried out in the civil engineering sector. Because a working category may comprise several types of work, categories are subdivided into secondary working categories, each of which in turn is subdivided into several serially numbered categories, the lowest level at which a result can be detailed by the RAW specifications system.

Here is an example:

| | | |
|---|---|---|
| Working category | 22. | Ground work |
| Secondary working category | 22.01 | Soil excavation |
| Serial number | 22.01.01 | Excavation of soil from a watercourse |

In specifications, the sequence of working categories is not fixed. The person drafting specifications is free in how he or she subdivides chapters, and he or she may use various (secondary) working categories within chapters (cost items). For example, the working category 24 'Techniques with or without the use of trenches' may include the freely chosen entry numbers 32 'Sewage system' and 33 'Road drainage'.

This shows that the RAW specifications system is far less standardised than the STABU one (system for utility construction). The latter prescribes the subdivision of specifications; for example, Chapter 22 of a set of STABU specifications always concerns brickwork. Furthermore, the chapter subdivision of STABU specifications has a more or less logical structure: the construction process is detailed chronologically, contrary to RAW specifications in which the working categories are not arranged according to a logical structure.

The use of a specifications system for cost classification during a remediation investigation has a disadvantage in that such a system is highly detailed. Moreover, possible costs incurred during the planning phases preceding the specifications phase are, of course, not taken into account. Operating costs that may have to be incurred during the execution of in situ and ICM alternatives are also left out of consideration. Both types of costs should play a role in REC weighing.

Based on the above, it can be concluded that the RAW specifications system is not suitable as a standard cost classification method for REC purposes. Adaptations made in the system to make it suitable would be too drastic.

**Classification system of the Soil Protection Guidelines**
The Soil Protection Guidelines [1997] contain a table entitled *Overzicht kostenposten* (Survey of cost items), which can be used as a standard cost classification method for REC purposes. Most consultant firms subdivide specifications based on this table, even though the problem holder usually does not demand the use of this system. Following the above guidelines has an advantage in that most users are familiar with the accompanying classification system; it would therefore promote understanding and acceptation of this part of the REC methodology.

**A. Initial costs**
The Guidelines define initial costs as those costs not included in the recurring costs or costs of replacement or repair. It concerns mainly non-recurring expenses to be incurred before and during the initial phase of a remediation project.

**B. Recurring costs**
Recurring costs comprise the costs to be incurred during a remediation project (excluding costs of replacement), which means that they comprise such operational costs as maintenance costs, costs of the renting of installations, and costs of energy consumption.

**C. Costs of replacement**
Costs of replacement are understood to mean those costs that have to be incurred after some time in order to replace entire (or large parts of) installations and or facilities.

**D. Overheads**
Overheads are the sum of the operating and general costs, profit, and the risk surcharge to be paid to the contractor. The total contracting costs comprise the costs of facility maintenance and the initial costs (excluding project preparation, processing costs, management, environmental supervision, and secondary costs).

**E. Other costs**
Other costs comprise only the payment of compensation to third parties.
The classification system given in the Guidelines more or less satisfies the preconditions defined in the previous section. However, they could be improved in certain respects, and some comments should be made about them.

1. *In situ remediation projects*
There is no separate cost item for in situ remediation projects, and in situ costs are not explicitly mentioned anywhere in the Guidelines. Only by elimination can it be made plausible that such costs can be placed in category A.7: Installation for drainage and treatment.

During the REC project, it was decided to include a separate item for in situ costs. However, in situ remediation projects distinguish themselves only from other projects as regards the withdrawal of soil vapour or groundwater. The treatment installation used can in certain (partial in situ) cases can also be used for the application of other remedial techniques. The costs of a treatment installation should therefore be placed in a separate category, as should those incurred for the withdrawal of groundwater for the purpose of groundwater treatment.

For the time being, item A.7 will be subdivided into:

A.7a: Withdrawal during groundwater remediation;
A.7b: Withdrawal during in situ remediation;
A.7c: Treatment installation.

2.*Drainage versus withdrawal (cost item A.7)*
The term 'drainage' is normally used only for the (temporary) removal of groundwater so that an open cut can be made, whereas the term 'withdrawal' is associated with the treatment of groundwater or soil vapour. This distinction is not clearly made in the classification.

We propose categorising costs associated with drainage under item A.5: Ground work. Drainage in the above sense will always be associated with the excavation of contaminated soil. The withdrawal of groundwater for the purpose of groundwater treatment can continue to be classified under item A.7. Because costs of soil vapour withdrawal are typical in situ costs, they fall under item A.7b.

3. *Sediment remediation*
During a remediation project, it may be necessary to (partly) remediate sediment. The associated costs are not included in any category.
We propose adding sludge treatment to the examples given under item A.6, and adding Sediment remediation (removal, dehydration and transport) to those mentioned under item A.5.3.

4. *Loss of capital and production*
The category Other costs of the classification system given in the Guidelines takes into account only compensation to be paid to third parties.

Erroneously, this system disregards situations in which a remediation project or alternative would result in loss of capital for the owner of the site to be cleaned up. Additionally, the owner's operations may be impeded by a remediation project, which would result in loss of production.

In the selection of a certain remedial alternative, possible loss of own capital or production is especially an important aspect for companies. However, an assessment of such a loss differs greatly in character from an estimation of the other costs of a remediation project. Therefore, the company concerned will have to inform the designer of the remediation investigation of these costs, possibly with the assistance of a consultant knowledgeable in this field.

For REC purposes, under the item Other costs item 'E.2. Loss of capital and production' was added to item 'E.1. Compensation to be paid to third parties'.

5. *Non-exhaustive list*
The fact that the Guidelines include a non-exhaustive list of actions that may be part of a certain cost item makes it hard to apply the completeness test to a cost estimate.

However, the 18 sub-items given help the consultant making a cost estimate ensure that all cost-entailing actions are sufficiently covered. The risk that a consultant will nonetheless omit to include an important cost item in the estimate is considered low.

6. *Conformity with items used in specifications*
Because the classification system given in the Guidelines does not require a cost estimate to be highly detailed, such an estimate will usually not be in conformity with the items used in specifications. This makes it hard to compare a cost estimate with the actual costs mentioned in specifications, based on items.

However, the fact that it is hard to compare estimated costs with costs mentioned in specifications and, later, with the costs incurred during the phase of execution is partly due to other factors. For example, only in a limited number of cases will a alternative designed during a remediation investigation be carried out fully according to its original design.

The classification system given in the Guidelines does not make it easier than any other classification method to fulfil the general REC requirement that it should be possible to evaluate the estimated costs in a later phase.

7. *Easily understandable to industry*
The government and industry weigh certain alternatives based on costs from different backgrounds and by employing different methods (see also comment 2). To properly assess the alternatives presented as a result of a remediation investigation, it is desirable that the classification method to be selected should fit in with the decision maker's perception of the environment. Therefore, we wanted the estimates to be easily understandable to industry.

The distinction between initial costs, recurring costs and costs of replacement will appeal to industry. In this way, it is made clear that a certain remedial alternative should be considered a project with a certain duration rather than a non-recurring cost item.

The classification system given in the Guidelines classifies costs mainly based on certain actions. Information about to whom which payments should be made (e.g. contracting costs, consultant costs) cannot easily be derived from it. However, another subdivision can be easily made by combining some items given in this system. This subdivision process can be computerised by using a spreadsheet program.

8. *Basis for general estimates*
It is important to be able to make a general cost estimate for remedial alternatives (e.g. in situ treatment costs are approximately Dfl. 200 - 300/$m^3$), based on a collection of a large number of data.

Before such an estimate can be made, it should be known which costs can and which cannot be regarded as actual remedial costs. For example, costs of processing and ground work can be regarded as direct remedial costs, but this does not apply to costs of demolition or land redevelopment. Once this distinction has been made, it can be determined whether the various items can be separately classified based on the classification system given in the Guidelines.

For the time being, the Guidelines seem to a large extent to fulfil the demand for a subdivision into generic remedial costs and site-specific costs.